LIGHTING BEST PRACTICES SERIES
Developed by the
California Lighting Technology Center, UC Davis

2019

DAYLIGHT HARVESTING
FOR COMMERCIAL BUILDINGS

How to meet and exceed
California's Building Energy Efficiency Standards

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Nonresidential: What's New in the 2019 Title 24, Part 6 Code
Residential: What's New in the 2019 Title 24, Part 6 Code
What's New in the Title 20 Code

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CONTENTS

1 INTRODUCTION

Daylighting Benefits 6

Daylight Harvesting Objectives and Challenges 8

Daylighting Regulations 8

About This Guide 9

2 CALIFORNIA ENERGY CODE

The Compliance Process 12

Energy Code Requirements for Daylighting Controls 14

3 DAYLIGHTING CONSIDERATIONS IN BUILDING DESIGN

CITY PLANNING AND ARCHITECTURAL DESIGN

Site Selection 18

Building Massing and Fenestration Orientation 25

Glazing and Shading Systems 33

INTERIOR AND LIGHTING DESIGN

Reflectance of Interior Surfaces 49

Arrangement of Furniture 51

Electric Lighting 52

4 CONSTRUCTION, COMMISSIONING AND ACCEPTANCE TESTING

Construction 66

Commissioning 66

Acceptance Testing 68

5 IN CLOSING

Daylighting and Energy Efficiency 74

California Green Building Standards 75

Daylight Management 76

APPENDIX

Glossary 79

Compliance Resources 82

CHAPTER 1

INTRODUCTION

Daylight and fire were the main sources of illumination before the invention of electric lighting. Earth's living organisms evolved under these two main sources of light. Human biology is intimately linked to solar energy not only for vision, but also for biological functions, especially those that follow the day-night cycle, referred to as 'circadian rhythms.'

Advances in technologies have resulted in highly controlled indoor environments, independent of both daily and seasonal variations in outdoor environmental conditions such as light, temperature and humidity.

In response to the energy crises of the 1970s, access to daylight and outdoor views was greatly reduced, as windows were identified as the most inefficient building envelope component, considering both heating and cooling loads. At the time, energy efficiency measures were focused on reducing window size and even eliminating them entirely, in some extreme cases. Some office and school spaces were designed to operate without any daylight apertures, resulting in negative impacts on the well-being of occupants.

Today, we have a much better understanding of daylighting benefits, including psychological, physiological, biological and energy benefits.

HOW TO READ THE INFORMATION BLOCKS THROUGHOUT THIS DOCUMENT

Throughout this document, there are three different types of information blocks to supplement the main text.

The information blocks in red, like this one, are intended to provide relevant additional context to the topic(s) discussed on the same page. The information blocks in blue provide information about relevant Energy Code requirements. The denoted figures provide a visual reference to help explain the topic discussed.

FENESTRATION

The term "fenestration" refers to all glazed apertures in the building envelope that bring daylight in interior spaces. The term comes from the Latin word "fenestra," which means "window, opening for light."

Example of red information block

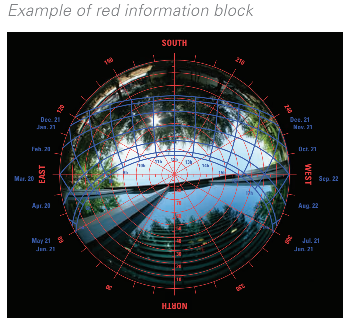


FIGURE X

Example of figure

ENERGY CODE

Energy Code, Section 140.3(a)5A

WINDOW AREA

In the prescriptive path to compliance for the building envelope, the total window area may not exceed one of the following: 1) six times the length of the display perimeter or 2) 40% of the gross wall area encompassing all conditioned spaces for the building. Additionally, the west-facing window area may not exceed 40% of the west-facing gross wall area.

The maximum allowed window area is determined by whichever is greater between:

$$A_M = 6 \times L \text{ or } A_M = 0.4 \times A_W$$

- A_M = Maximum allowed window area for a building
- **L** = Length of the display perimeter, where a display perimeter is the length of an exterior wall that immediately abuts a public sidewalk, such as retail display window
- A_W = Gross exterior wall area

As a practical matter, window area is generally taken from the rough opening dimensions.

Example of blue information block

DAYLIGHTING BENEFITS

DAYLIGHT VS. DAYLIGHTING

Daylight is radiation emitted by the sun, including the radiation scattering effects of the atmosphere. Daylighting is the practice of utilizing daylight in buildings to provide view and illumination.

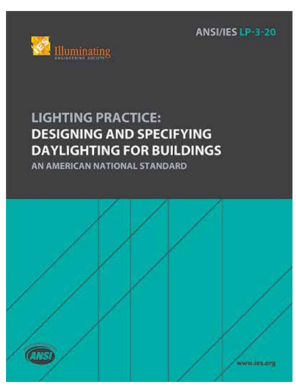
The most important benefit of daylight apertures, such as windows and skylights, is the connection to the outdoors, which provides information about the time of the day, weather conditions and outdoor activities — all of which are critical for our psychological well-being.

As human vision has evolved under daylight (**FIGURE 1**) during the day and fire-light during the night, biologically, it is best to use these light sources or light sources that mimic their spectral power distribution. This is the main reason that daylight and incandescent light are considered standards for color fidelity metrics and necessary for maintaining healthy circadian rhythms during daytime and nighttime. The daily variation of daylight intensity and spectral composition is critical to our health, as it adjusts our biological clock and related functions, such as alertness, hormone levels and body temperature (**FIGURE 2**).

FENESTRATION

The term "fenestration" refers to all glazed apertures in the building envelope that bring daylight in interior spaces. The term comes from the Latin word "fenestra," which means "window, opening for light."

Utilizing daylight for ambient and task lighting can also have significant energy benefits through reduction of electric lighting and associated HVAC loads. Daylighting in commercial buildings can reduce lighting electricity use by as much as 38%[1], but it also presents complex challenges. Realization of these energy benefits requires lighting controls that adjust electric lighting based on available daylight. Moreover, effects on HVAC loads significantly depend on a building's geographic location and fenestration orientation.



THE IES' LIGHTING PRACTICE: DESIGNING AND SPECIFYING DAYLIGHTING FOR BUILDINGS (LP-3-20)

The Illuminated Engineering Society (IES) developed a guide to provide up-to-date solutions for addressing the challenges of daylighting while maximizing its benefits.

[1] *Williams, Alison, et al. A meta-analysis of energy savings from lighting controls in commercial buildings. No. LBNL-5095E. Ernest Orlando Lawrence Berkeley National Laboratory, Berkeley, CA (UC), 2011.*

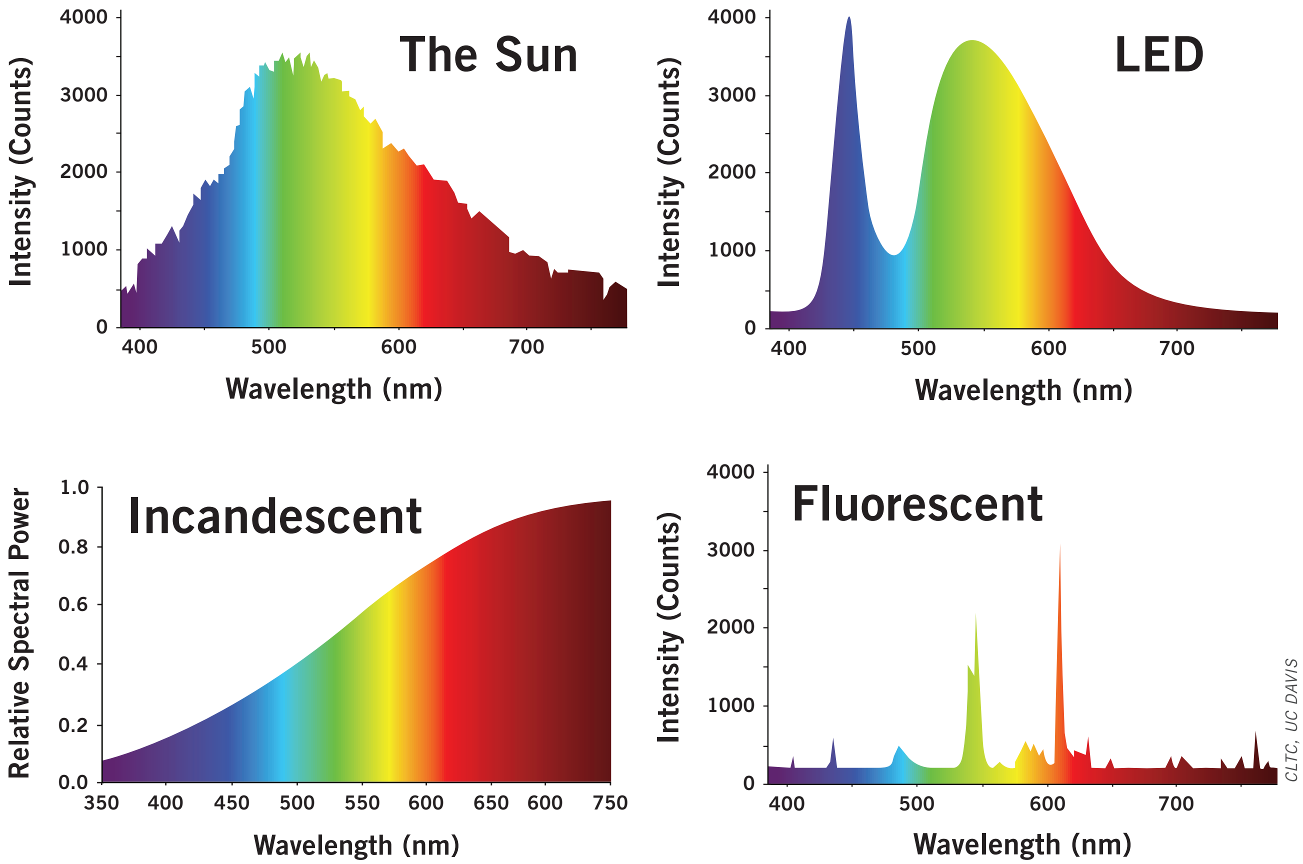


FIGURE 1 *Spectral power distribution refers to "the radiant power emitted by a light source over a range of specified wavelength," typically the visible range (approximately 360 to 830 nm).*

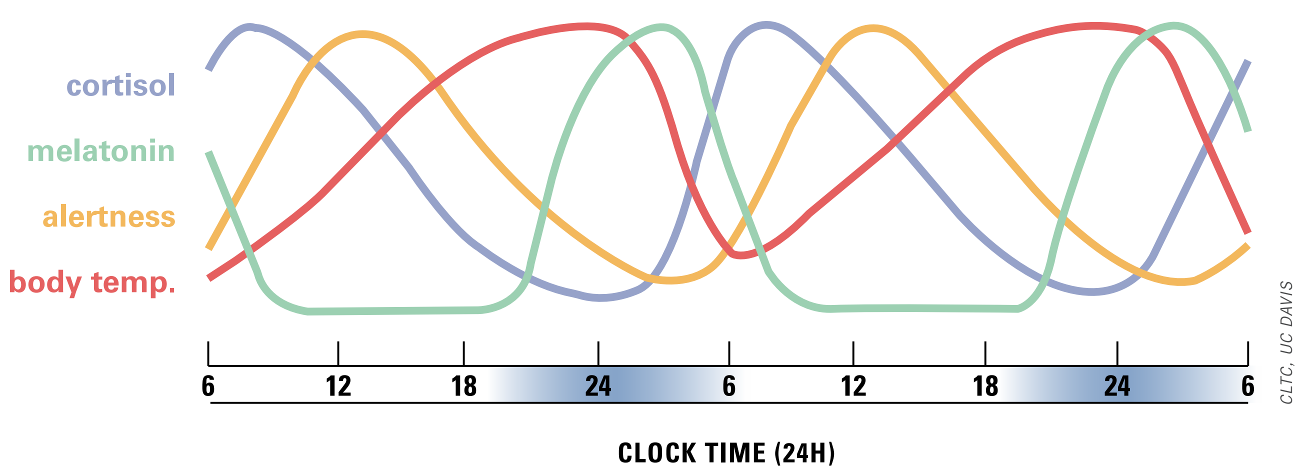


FIGURE 2 *Circadian rhythms showing the variation of cortisol, melatonin, alertness and body temperature over two 24-hour periods.*

LAWRENCE BERKELEY NATIONAL LABORATORY—RADIANCE SIMULATION

FIGURE 3 *Glare from direct solar radiation.*

LAWRENCE BERKELEY NATIONAL LABORATORY—RADIANCE SIMULATION

FIGURE 4 *Glare from veiling reflections off a computer monitor, that compete with the brightness of the screen, producing visual discomfort.*

FIGURE 5 *Interior surfaces seen against fenestration may appear as silhouettes due to high contrast between their low brightness and the very bright outdoor surfaces.*

DAYLIGHT HARVESTING OBJECTIVES AND CHALLENGES

Daylighting design includes several, often competing, objectives. Considering comfort and energy performance, daylighting design aims to provide view to the outdoors and illumination that allows for reduction of electric lighting without producing glare. During cooling periods, daylighting design aims to do this without producing excessive solar heat gain through direct solar penetration.

Even though daylight is excellent for vision, it can also produce visual discomfort through glare from direct solar radiation (**FIGURE 3**), veiling reflections (**FIGURE 4**) and high contrast of interior and exterior surfaces, or the 'silhouette effect' (**FIGURE 5**).

Realizing the energy benefits of daylighting is also challenging, mainly because it requires automated electric lighting and daylight management controls.

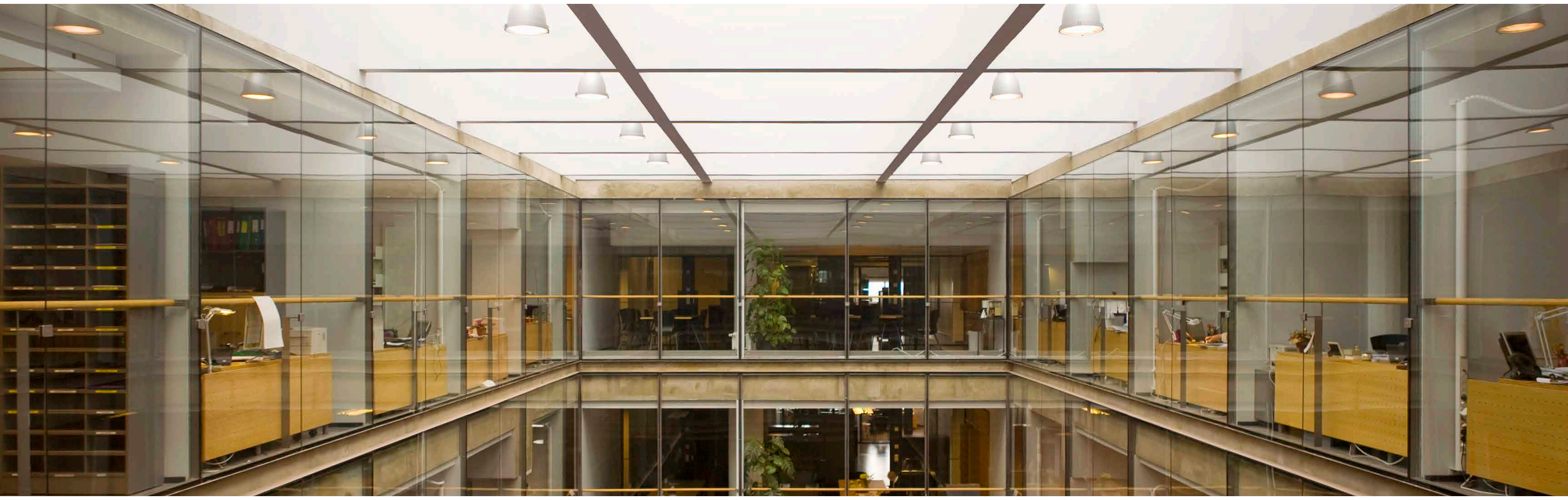
The key challenge for effective daylight harvesting is that it involves decisions made by different decision makers at different stages of the building life-cycle:

1. **City planning** — site selection
2. **Architectural design** — building massing, space dimensions, fenestration location, orientation, size, glazing and exterior shading
3. **Interior design** — geometry and reflectance of interior surfaces, including furniture and its layout, interior shading systems and window treatments
4. **Electric lighting design** — layout of light sources and controls to manage their output based on available daylight
5. **Building Construction** — implementation of design decisions
6. **Building Commissioning** — verification of design decisions and calibration of electric lighting and daylight management control systems
7. **Building Operation** — automated and manual operation of lighting and daylight management systems

Each discipline inherits the decisions made by the preceding discipline, which can greatly affect later decisions and the full potential of daylighting benefits.

DAYLIGHTING REGULATIONS

To capitalize on the potential for energy efficiency and peak electricity demand reduction, California and many other states are adopting increasingly stricter daylight-related requirements as part of their building energy efficiency standards.



California set an ambitious goal of decarbonizing buildings and reducing greenhouse gas emissions, with a target of 40% below 1990 levels by 2030. To reach this objective, new construction projects must combine highly efficient building systems and distributed renewable energy generation.

Meeting the Energy Code is a good start, but new buildings must go beyond these requirements to meet this bold goal.

ABOUT THIS GUIDE

This daylight harvesting guide includes a description of California's Title 24, Part 6 Building Energy Efficiency Standards (Energy Code), as well as design guidelines that can help make decisions to meet and exceed the Energy Code's performance goals. Regulations and design guidelines are organized along seven building-related disciplines that affect daylight performance.

Some of the daylight-related building standards address fenestration requirements and some address electric lighting and control requirements, especially photosensor-based controls, which adjust the output of the electric lighting system based on available daylight.

Additional savings are possible through use of today's control and communication technologies, which are not yet incorporated into the Energy Code nor heavily adopted into recommended practices. Such emerging approaches are included in this guide to assist readers achieve persistent energy savings while improving comfort and well-being.

APPLICATION GUIDES FROM ENERGY CODE ACE

Energy Code Ace provides several application guides, organized along seven building-related disciplines, to help lighting professionals understand the Energy Code as it pertains to their projects.

Application guides are offered for the following topics:

- *Nonresidential Envelope and Solar-ready Areas*
- *Nonresidential Lighting and Electrical Power Distribution*
- *Nonresidential HVAC and Plumbing*
- *Process Equipment and Systems*
- *Residential Envelope and Solar*
- *Residential Lighting*
- *Residential HVAC and Plumbing*

These application guides are available to download at **energycodeace.com/resources**.

EnergyCodeAce™

CHAPTER 2

CALIFORNIA ENERGY CODE

The Energy Code defines mandatory and prescriptive requirements for new buildings and major retrofits of existing buildings.

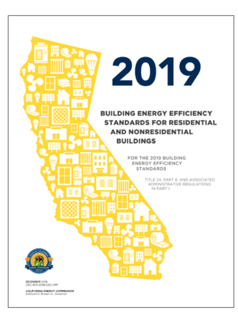
The Energy Code regulates many aspects of the built environment, including general construction, building commissioning and system acceptance testing. The Energy Code is updated on a three-year cycle. The current Energy Code was adopted in 2019 and went into effect on January 1, 2020.

MAJOR CHANGES FROM THE 2016 ENERGY CODE AND DAYLIGHT HARVESTING FOR COMMERCIAL BUILDINGS GUIDE

This document serves as an update from our 2016 edition of Daylight Harvesting for Commercial Buildings to reflect changes in the 2019 Energy Code cycle.

Major changes to the 2019 Energy Code relevant to daylight harvesting include:

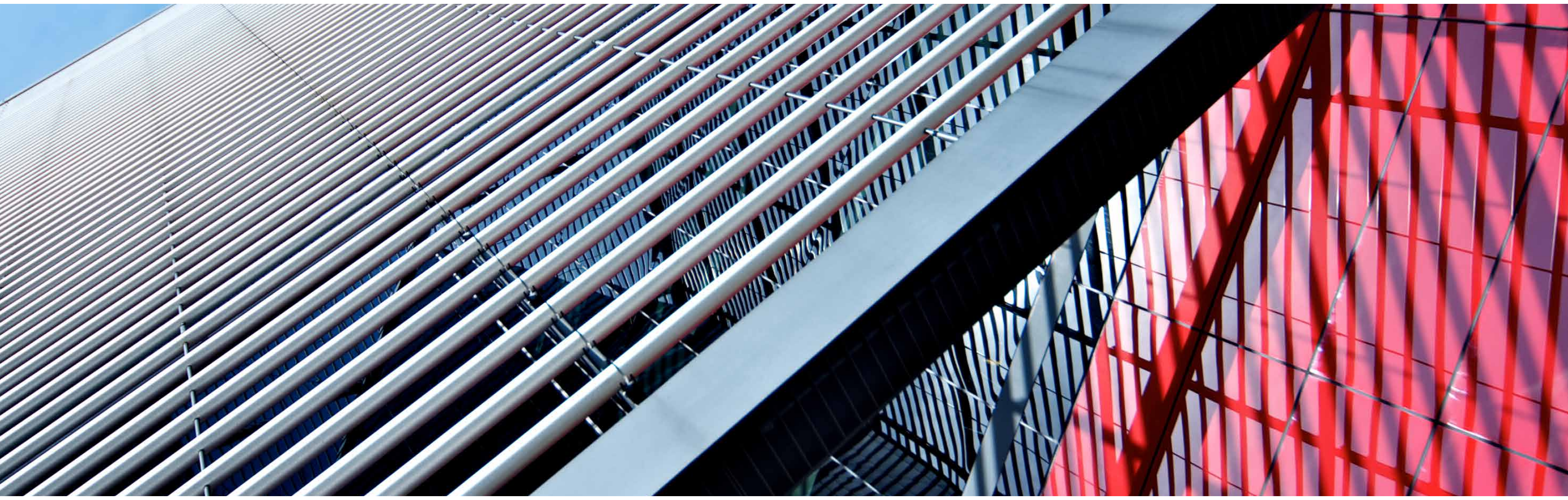
- *Device control requirements have been moved from the Appliance Efficiency Regulations to* **Section 110.9 of the Energy Code***.*
- *New power adjustment factors (PAFs) have been added to encourage the use of clerestory fenestration, horizontal slats and light shelves. These PAFs may also be combined with the existing Daylight Dimming plus OFF Control credit.*
- *Automatic daylighting control language has been restructured and clarified, combining language for parking garages and indoor-only applications.*
- *Explicit direction is now included requiring separate controls for luminaires in each daylit zone type: skylit, primary sidelit and secondary sidelit.*
- *Automatic daylighting control exceptions have been added for (1) areas under skylights where direct sunlight is blocked for more than 1,500 daytime hours per year between the hours of 8 A.M. and 4 P.M. and (2) areas adjacent to vertical glazing below an exterior overhang that meets specific sizing requirements in* **Exception 2 to Section 130.1(d)***.*
- *A new section* **(Section 130.1(f))** *on how mandatory controls, including automatic daylighting controls, should operate within a system has been added.*
- *Alterations with proposed lighting power greater than 80 percent of the allowed lighting power are required to adhere to the automatic daylighting control requirements defined in* **Section 130.1(d)***. A third option is available for alteration projects in small buildings or tenant spaces that include 'one-for-one luminaire alterations' to more than 50 luminaires (see* **Page 58** *of this guide for more details).*
- *Updates to fenestration and ventilation thresholds.*



CALIFORNIA'S ENERGY CODE

California's Energy Code has saved Californians billions in reduced electricity bills since 1977.

To view the standard online, visit **www.energy.ca.gov/programs-and-topics/programs/building-energy-efficiency-standards/2019-building-energy-efficiency**.



THE COMPLIANCE PROCESS

The Energy Code requires the following process for all new construction, additions and alterations of existing buildings where a permit is issued.

STEP 1: COMPLY WITH APPLICABLE MANDATORY MEASURES

All nonresidential buildings must be designed and built to comply with the applicable mandatory measures of the Energy Code using devices that adhere to the Appliance Efficiency Regulations. Mandatory measures are the basic set of requirements that apply to all buildings. For example, lighting controls are mandatory measures.

STEP 2: COMPLY WITH APPLICABLE PRESCRIPTIVE OR PERFORMANCE MEASURES

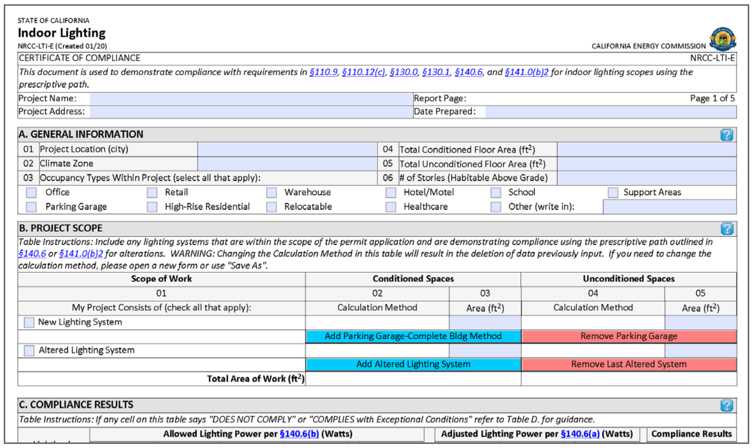
In addition to meeting the mandatory requirements for your project, commercial buildings and common areas of hotel, motel and multifamily buildings must adhere to the applicable prescriptive or performance measures.

Prescriptive Approach: The prescriptive approach allows builders to comply by using methods known to be efficient. This approach does not require software — rather, it is completed in a checklist format using the Certificates of Compliance.

Performance Approach: The performance approach allows builders freedom of design so long as the building achieves the same overall efficiency as an equivalent building using the prescriptive option, all the while meeting all applicable mandatory measures. This approach requires using software approved by the Energy Commission and is best suited for use by experienced professionals familiar with the Energy Code. This method allows for energy trade-offs between building systems. For example, under the performance approach, use of highly efficient lighting can allow for a larger portion of the energy budget to be allocated to heating and cooling loads.

STEP 3: VERIFY COMPLIANCE

After choosing a compliance method, calculate the proposed energy use of the building or spaces within the building. This value should not exceed the allowed energy budgets specified in the Energy Code. If the design does not comply, then it will have to be revised.



STATE OF CALIFORNIA
Indoor Lighting
NRCC-LTI-E (Created 01/20)
CALIFORNIA ENERGY COMMISSION

CERTIFICATE OF COMPLIANCE NRCC-LTI-E

This document is used to demonstrate compliance with requirements in §110.9, §110.12(c), §130.0, §130.1, §140.6, and §141.0(b)2 for indoor lighting scopes using the prescriptive path.

Project Name:		Report Page:	Page 1 of 5
Project Address:		Date Prepared:	

A. GENERAL INFORMATION

01	Project Location (city)		04	Total Conditioned Floor Area (ft^2)	
02	Climate Zone		05	Total Unconditioned Floor Area (ft^2)	
03	Occupancy Types Within Project (select all that apply):		06	# of Stories (Habitable Above Grade)	

☐ Office	☐ Retail	☐ Warehouse	☐ Hotel/Motel	☐ School	☐ Support Areas
☐ Parking Garage	☐ High-Rise Residential	☐ Relocatable	☐ Healthcare	☐ Other (write in):	

B. PROJECT SCOPE

Table Instructions: Include any lighting systems that are within the scope of the permit application and are demonstrating compliance using the prescriptive path outlined in §140.6 or §141.0(b)2 for alterations. WARNING: Changing the Calculation Method in this table will result in the deletion of data previously input. If you need to change the calculation method, please open a new form or use "Save As".

Scope of Work	Conditioned Spaces		Unconditioned Spaces	
01	02	03	04	05
My Project Consists of (check all that apply):	Calculation Method	Area (ft^2)	Calculation Method	Area (ft^2)
☐ New Lighting System				
	Add Parking Garage-Complete Bldg Method		Remove Parking Garage	
☐ Altered Lighting System				
	Add Altered Lighting System		Remove Last Altered System	
Total Area of Work (ft^2)				

C. COMPLIANCE RESULTS

Table Instructions: If any cell on this table says "DOES NOT COMPLY" or "COMPLIES with Exceptional Conditions" refer to Table D. for guidance.

	Allowed Lighting Power per §140.6(b) (Watts)	Adjusted Lighting Power per §140.6(a) (Watts)	Compliance Results

NONRESIDENTIAL LIGHTING COMPLIANCE FORMS

As part of the Energy Code compliance process, the design team must prepare and submit documents to verify compliance (see Step 4).

The Energy Commission has made these compliance documents, or examples of these documents, available at **energycodeace.com/NonresidentialForms/2019**.

STEP 4: PREPARE AND SUBMIT PLANS

Once the Energy Code requirements have been met, the design team compiles the building plans and Certificates of Compliance. Plans and compliance forms are submitted to the appropriate enforcement agency, together with a building permit application.

STEP 5: PASS PLAN REVIEW AND RECEIVE PERMIT

A building department plans examiner must check that the building design satisfies the Energy Code requirements and that the submitted documentation contains all information to be verified during field inspection. A building permit is issued after plans are reviewed for compliance and approved.

STEP 6: COMPLETE CONSTRUCTION

The installation team must follow the approved plans and specifications during construction. Certificates of Installation must be completed and signed by licensed individuals to certify that the lighting installed for the project corresponds with the lighting proposed on the Certificates of Compliance.

STEP 7: COMMISSION BUILDING SYSTEMS

After construction is complete, the contractor or the design team must properly commission, or bring into working condition, the building and its systems. They must also advise the building owners and operators of their responsibilities regarding compliance with Energy Code. They must provide information and training to the building owner on how to maintain and operate the building systems.

STEP 8: PASS ACCEPTANCE TESTING

The Energy Code requires that Certified Lighting Controls Acceptance Test Technicians (CLCATT) review and test newly installed building systems to ensure the controls and connected loads operate as required by the Energy Code.

STEP 9: PASS FINAL INSPECTION

The building department field inspector(s) must verify that the building construction follows the plans and specifications that were approved when the building permit was issued. Once final inspection is complete, the Certificate of Occupancy is issued.

STEP 10: PROVIDE DOCUMENTATION TO BUILDING OWNERS

Upon occupancy, the building owner must receive copies of the energy compliance documents from the installation team, including Certificates of Acceptance, along with instructions for operation and maintenance.

ENERGY CODE REQUIREMENTS FOR DAYLIGHTING CONTROLS

Specific to electric lighting controls for daylight harvesting, automatic daylight controls and photo controls are defined by the Energy Commission, as transcribed in the sidebar, and regulated under **Section 110.9(b)2** of the Energy Code.

Controls that provide automatic daylighting functionality must:

- Automatically return to its most recent time delay settings within 60 minutes of the last received input when left in calibration mode
- Have a set point control that easily distinguishes settings to within 10% of full-scale or maximum adjustment
- Provide a linear response within 5% accuracy over the range of illuminance measured by the light sensor
- Be capable of being calibrated in a manner that the person initiating the calibration is remote from the sensor during calibration to avoid influencing calibration accuracy
    - For example, by having a light sensor that is physically separated from where the calibration adjustments are made

AUTOMATIC DAYLIGHT CONTROLS

Automatic Daylight Control is defined by the Energy Code as a control that uses "one or more photosensors to detect changes in daylight illumination and then automatically adjusts the luminous flux of the electric lighting system in response."

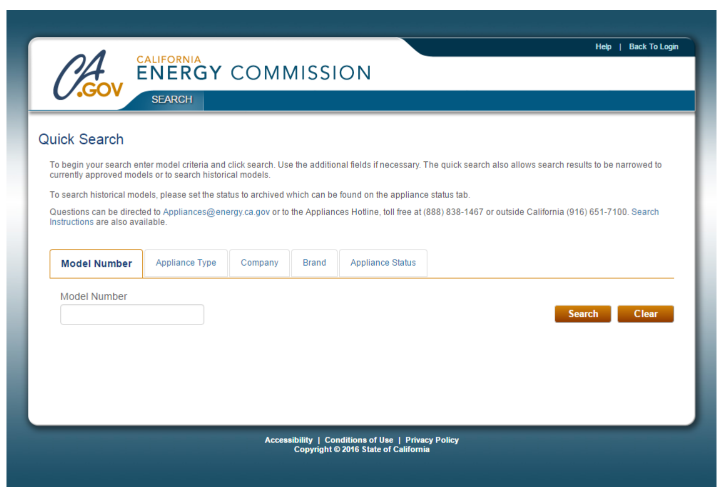
PHOTO CONTROLS

Photo Control is defined by the Energy Code as a control that "automatically turns lights ON and OFF, or automatically adjusts lighting levels, in response to the amount of daylight that is available. A photo control may also be one component of a field assembled lighting system, the component having the capability to provide a signal proportional to the amount of daylight to a lighting control system to dim or brighten the electric lights in response."

MODERNIZED APPLIANCE EFFICIENCY DATABASE SYSTEM (MAEDBS)

www.energy.ca.gov/rules-and-regulations/appliance-efficiency-regulations-title-20/appliance-regulations-certification

This online database of products certified by the Energy Commission has a Quick Search function allowing users to search by product type, brand or model name.



CHAPTER 3

DAYLIGHTING CONSIDERATIONS IN BUILDING DESIGN

Daylight harvesting considerations span the whole building life cycle, from the selection of the building site, to the architectural and interior and lighting design, to building construction, commissioning and operation. Every decision affecting daylighting becomes context for the following decision.

The main objectives in daylighting design are:

- providing a view to the outdoors
- providing enough daylight to support all or part of the required illumination for the tasks performed in the space during daytime
- avoiding visual or thermal discomfort
- minimizing electric lighting and HVAC requirements

This chapter addresses city planning, architectural, interior and lighting design decisions.

CITY PLANNING AND ARCHITECTURAL DESIGN

Design decisions related to daylighting include site selection, building massing and orientation of spaces, fenestration design and associated glazing and shading systems.

ENERGY CODE | Nonresidential Compliance Manual, Section 2.1

ENERGY CODE

Primary responsibility for compliance and enforcement rests with the local enforcement agency, typically associated with a city or county government. A building permit must be obtained from the local jurisdiction before construction of:

- A nonresidential building
- Significant alterations to existing lighting systems
- An outdoor lighting system
- Signage
- Additions to existing buildings

The core compliance process has two steps:

1. Meet all applicable mandatory requirements, which define the following:
   - Required controls that must be installed
   - Minimum lighting system functionality
2. Utilize the prescriptive or performance approach to ensure the minimum level of performance for the building is met.

CONTINUED ON PAGE 21

SITE SELECTION

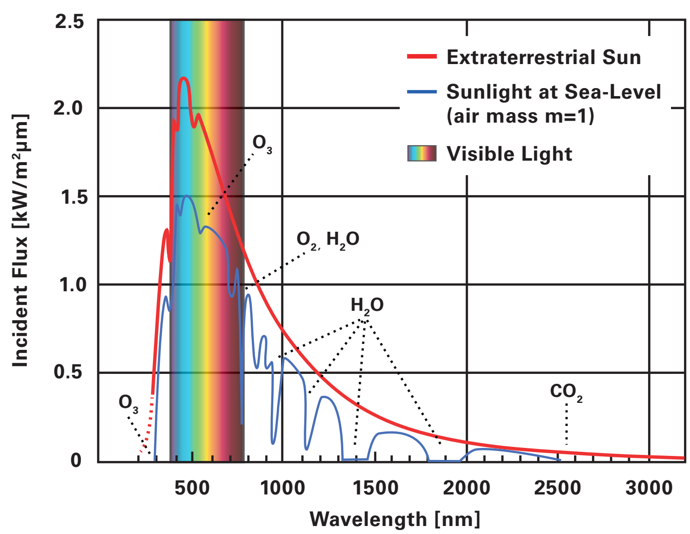
GUIDELINES

Site selection is very important for daylight performance and has a strong effect on what will be possible in the architectural design. Site selection defines the context for design decisions related to daylight harvesting. Additionally, site selection dictates sun paths, climatic conditions, external obstructions and the Energy Code requirements.

THE NATURE OF DAYLIGHT

Sunlight is electromagnetic radiation with a spectrum composed of about 5% Ultra Violet (UV) radiation (below 400 nanometers), about 43% visible radiation (from 400 nanometers to 700 nanometers) and about 55% Infrared radiation (IR) (above 700 nanometers). The spectral power distribution of sunlight is altered significantly by the atmosphere, as different gases and particles interact with different wavelengths of the solar radiation (**FIGURE 6**). As the solar radiation enters the atmosphere, it encounters air molecules that scatter the wavelengths that correspond to blue light, making the sky appear blue. When sunlight is scattered by cloud water droplets, all of the solar spectrum is scattered, making clouds appear white and turning grey as the water droplets become larger (**FIGURE 7**).

Spectral Distribution of Sunlight and Molecular Absorption



REPRODUCED BY CLTC, UC DAVIS ORIG. SOURCE: CLEAR—COMFORTABLE LOW ENERGY ARCHITECTURE

FIGURE 6 *The spectral power distribution of daylight above the atmosphere and at sea level.*

REPRODUCED BY CLTC, UC DAVIS, ORIG. SOURCE UNKNOWN

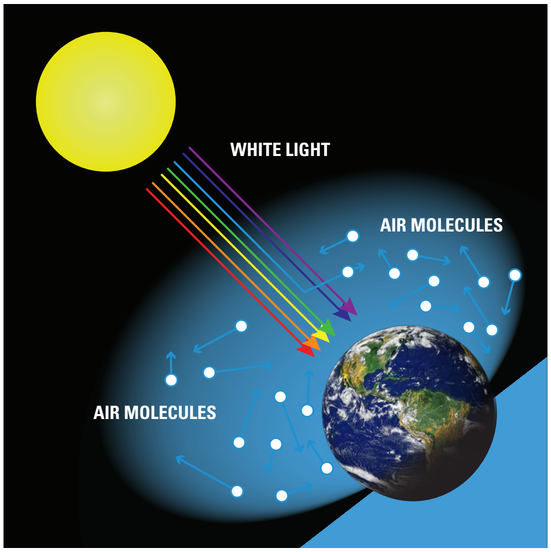


FIGURE 7 *LEFT: The air molecules of the atmosphere scatter the blue part of the solar spectrum, making the sky appear blue. RIGHT: Water droplets scatter the whole solar spectrum, making clouds appear white and turn grey as water droplets become larger and reduce the transmitted sunlight.*

REPRODUCED BY CLTC, UC DAVIS
ORIG. SOURCE: DEPT. OF GEOGRAPHY AT PENN STATE

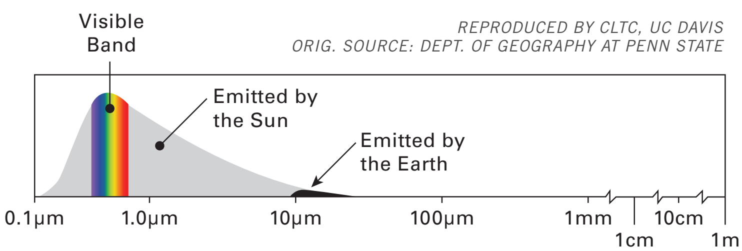


FIGURE 8 *LEFT: The spectral power distribution of solar radiation and the distinction between near and far IR radiation. The lower the temperature of an object, the longer the wavelength of the IR radiation it emits. The wavelengths of radiation emitted by the earth are more than an order of magnitude larger than the wavelengths emitted by the sun.*

The spectral power distribution of the visible spectrum arriving on the Earth surface changes dramatically, depending on the position of the sun in the sky and the atmospheric conditions.

The IR portion of solar radiation comprises more than half of the solar energy at sea level. While not visible, IR radiation is felt as heat and has a strong impact on HVAC loads, with potential to reduce heating loads and increase cooling loads. The key challenge in daylighting is balancing light and heat to prevent glare and reduce HVAC loads.

When solar radiation is incident on a surface, a fraction of it is reflected and the rest is absorbed, elevating the surface temperature, and then reemitted in the long-wavelength IR (thermal or far IR) which has much longer wavelengths than the short-wavelength IR (near IR) (**FIGURE 8**). The difference between near and far IR is important because the first can be transmitted through the atmosphere and through glass while the latter cannot. This is the cause of the "greenhouse" effect trapping of solar energy transmitted through glass or the atmosphere, causing "local" and global warming, respectively.

REACH CODES
State law allows local jurisdictions to adopt and enforce standards that are more stringent than the Energy Code, through an approval process with the Energy Commission. These local ordinances, sometimes called "reach codes," are available to view at **localenergycodes.com**.

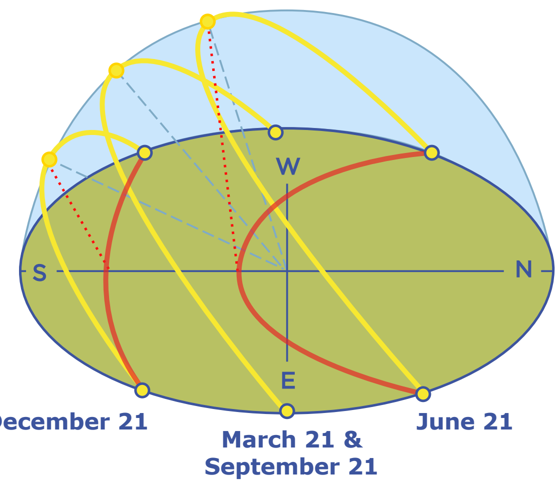
CUSTOMIZED SUN PATH DIAGRAMS

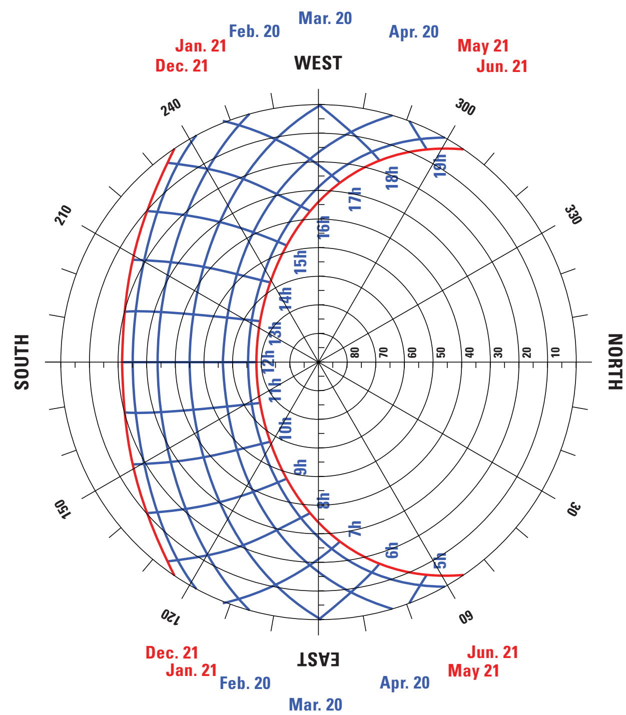
The sun paths used in this guide were created by the University of Oregon's Solar Radiation Monitoring Laboratory. Customized sun path diagrams can be produced by a free online tool developed by the University of Oregon's Solar Radiation Monitoring Laboratory: **solardat.uoregon.edu/PolarSunChartProgram.php**.

SUN PATHS

The sun is the main source of daylight. Its apparent movement through the sky, referred to as "sun paths," is critical for architectural and interior design decisions (**FIGURE 9**).

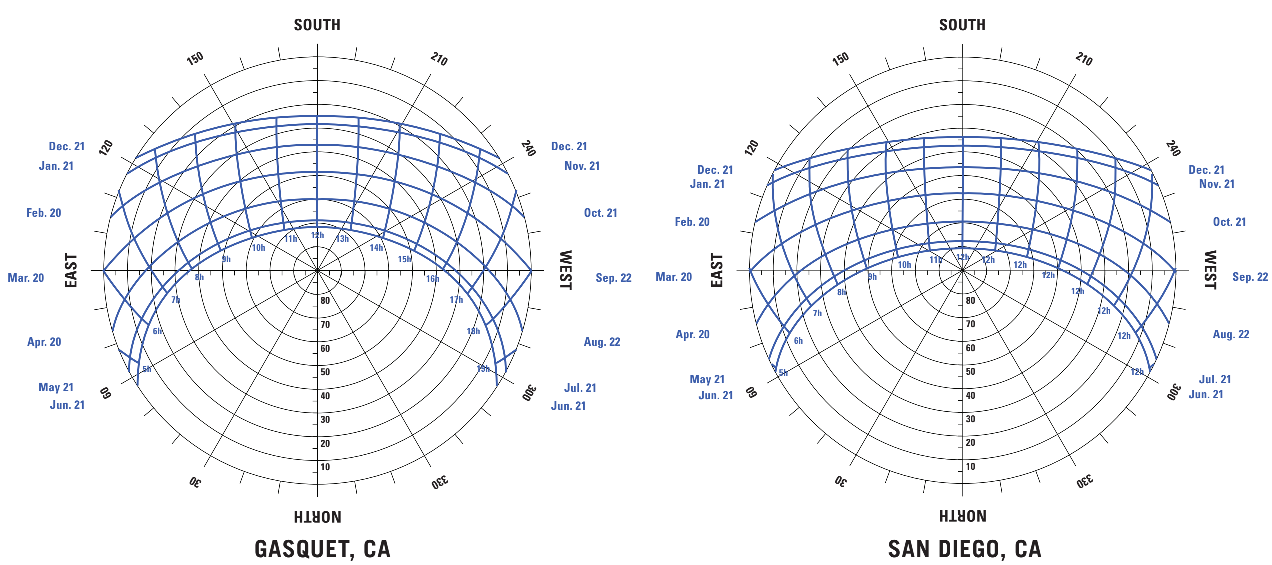
Sun paths vary by geographic latitude, which is the angular distance from the equator. Sun paths do not vary significantly across California latitudes (**FIGURE 10**).





KONSTANTINOS PAPAMICHAEL
ORIG. SOURCE: © UNIVERSITY OF OREGON SRML

FIGURE 9 *LEFT: Schematic drawing of sun paths for mid-north-latitude locations. Sunrise and sunset orientations vary significantly throughout the year, along with the length of the sun paths and their highest position on the sky. RIGHT: Sun paths diagram showing the projection of sun paths on a horizontal surface. Sun path diagrams are most useful in daylighting design, as they show the sun positions for the whole year and allow for quick and easy evaluation of effects on different surfaces, such as building facades with different orientations.*



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ORIG. SOURCE: © UNIVERSITY OF OREGON SRML

FIGURE 10 *Sun paths for locations at the northern (Gasquet) and southern (San Diego) California borders.*

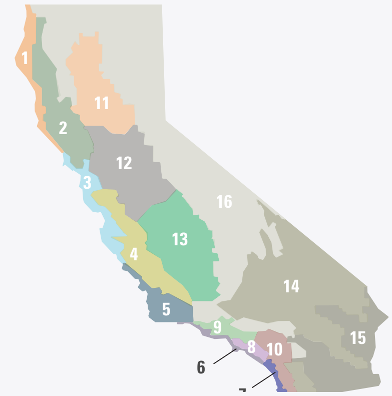
CLIMATIC CONDITIONS

Locations with the same latitude have identical sun paths, but may have very different climatic conditions. Climatic conditions have a strong impact on sky conditions and HVAC loads, both of which greatly affect daylight performance and are important in daylighting design decisions. Review of climatic conditions is the first daylight consideration in architectural design. The most important climate characteristics for daylighting are: 1) sky conditions (**FIGURE 11**) and 2) outdoor daylight illuminance on horizontal and vertical surfaces from both direct solar radiation from the sun and diffuse radiation from the sky (**FIGURE 12**).

Climate data are being collected for a large number of cities in the United States by the National Climatic Data Center (NCDC), under the National Oceanic and Atmospheric Administration (NOAA) (**ncdc.noaa.gov/cdo-web)**. Climate data have been used for a long time in the hourly simulation of the energy performance of buildings and have also been introduced in annual daylighting simulations for the computation of annual daylight performance metrics, such as the Daylight Autonomy and the Spatial Daylight Autonomy.

ENERGY CODE

CALIFORNIA CLIMATE ZONES



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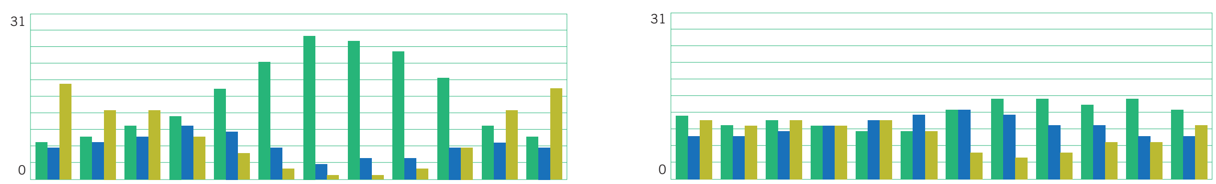
DAYLIGHT AUTONOMY AND SPATIAL DAYLIGHT AUTONOMY
Daylight autonomy refers to the percent of occupied time that daylight alone meets design work place illuminance at a particular point in space. Spatial daylight autonomy refers to the percent of space that meets or exceeds a specific daylight autonomy.



SACRAMENTO, CA

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Clear	7	8	10	12	17	22	27	26	24	19	10	8
Partly Cloudy	6	7	8	10	9	6	3	4	4	6	7	6
Cloudy	18	13	13	8	5	2	1	1	2	6	13	17

SAN DIEGO, CA

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Clear	12	10	11	10	9	9	13	15	15	14	15	13
Partly Cloudy	8	8	9	10	11	12	13	12	10	10	8	8
Cloudy	11	10	11	10	11	9	5	4	5	7	7	10

FIGURE 11 *Cloud cover data for Sacramento and San Diego by month, from data collected over 30 years of empirical measurements through 1995.*

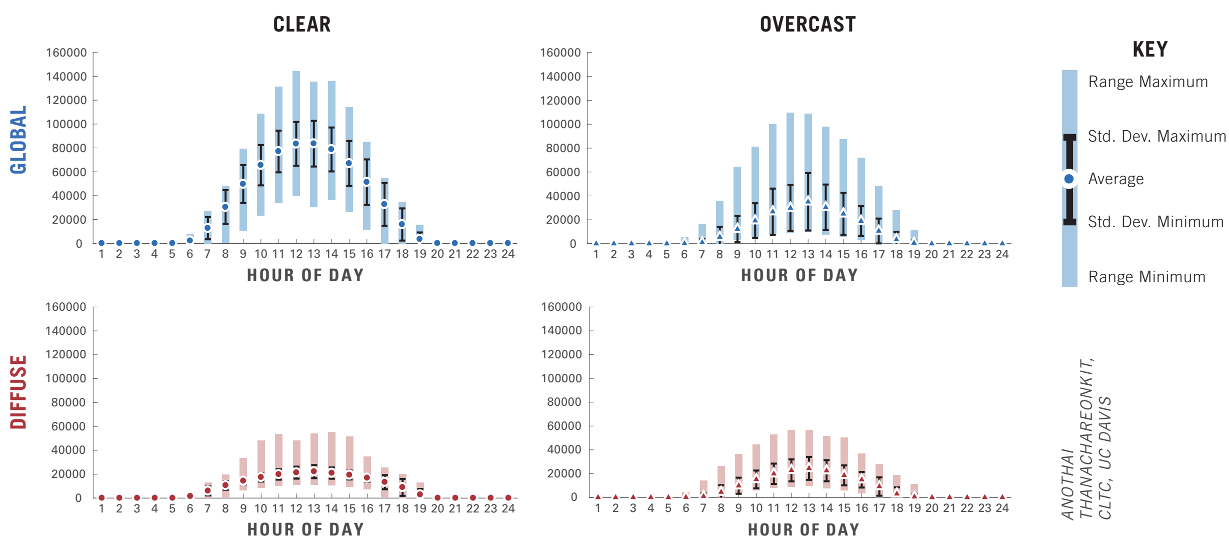


FIGURE 12 *Average hourly horizontal daylight illuminance for Sacramento, California, from global (sun and sky) and diffuse (sky only) radiation under clear and overcast sky conditions. The data show average values for each hour, along with standard deviation, minima and maxima. Overcast sky conditions from global radiation result in higher illuminance values than clear sky conditions from diffuse radiation.*

ENERGY CODE

Energy Code, Section 140.3(c)

In Climate Zones 2 through 15, conditioned and unconditioned enclosed spaces that are greater than 5,000 ft^2 and that are directly under a roof with ceiling heights greater than 15 feet must meet the following requirements:

- A combined total of at least 75% of the floor area, as determined using building floor plans, must be within one or more of the following:
  - Primary Sidelit Daylit Zone in accordance with **Section 130.1(d)**, or
  - The total floor area in the space within a horizontal distance of 0.7 times the average ceiling height from the edge of rough opening of skylights.
- All Skylit Daylit Zones and Primary Sidelit Daylit Zones must be shown on building plans.
- General lighting in daylit zones must be controlled in accordance with **Section 130.1(d)**.
- The total skylight area is at least 3% of the total floor area in the space within a horizontal distance of 0.7 times the average ceiling height from the edge of rough opening of skylights; or the product of the total skylight area and the average skylight visible transmittance is no less than 1.5% of the total floor area in the space within a horizontal distance of 0.7 times the average ceiling height from the edge of rough opening of skylights.
- All skylights shall have a glazing material or diffuser that has a measured haze value greater than 90%, tested according to **ASTM D1003** (notwithstanding its scope) or another test method approved by the Energy Commission.
- Skylights for conditioned and unconditioned spaces shall have an area-weighted average Visible Transmittance (VT) no less than the applicable value specified in **Section 140.3(a)6D**.

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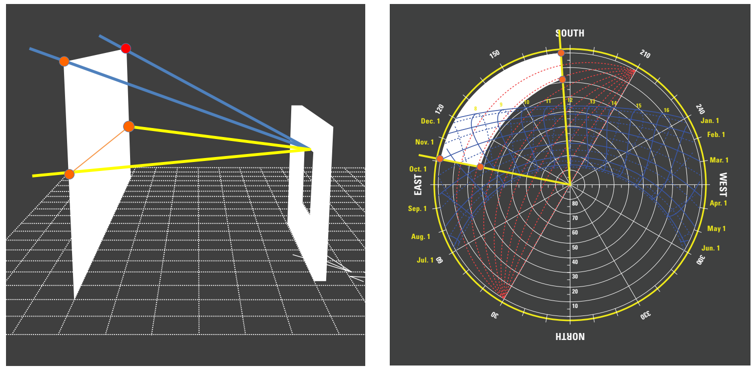


ORIG. SOURCE: "SOLAR TOOL" SOFTWARE, ANDREW MARSH
KONSTANTINOS PAPAMICHAEL

FIGURE 13 *Determination of the shadow mask of an external obstruction for the midpoint of the window head. The blue lines are the sun paths for Sacramento, California. The white area is the shadow mask for the center point of the window head, as shown in the left drawing of the figure. The sun is blocked by the external obstruction for the times that the sun paths overlap with the full shadow mask of the external obstruction. The red lines are profile angles in 10-degree increments from 0 (horizon) to 90 (sky zenith), which define the projection of straight lines (e.g., the top edge of the external obstruction), which has a profile angle of about 21 degrees from the horizon.*

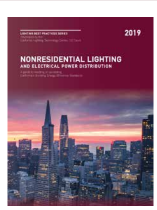
EXTERNAL OBSTRUCTIONS

Understanding the effects of the size and location of external obstructions, such as neighboring buildings and landscaping, is also critical for daylight design. External obstructions may block direct sunlight from reaching daylight apertures or reflect direct sunlight towards them.

SHADOW MASKS

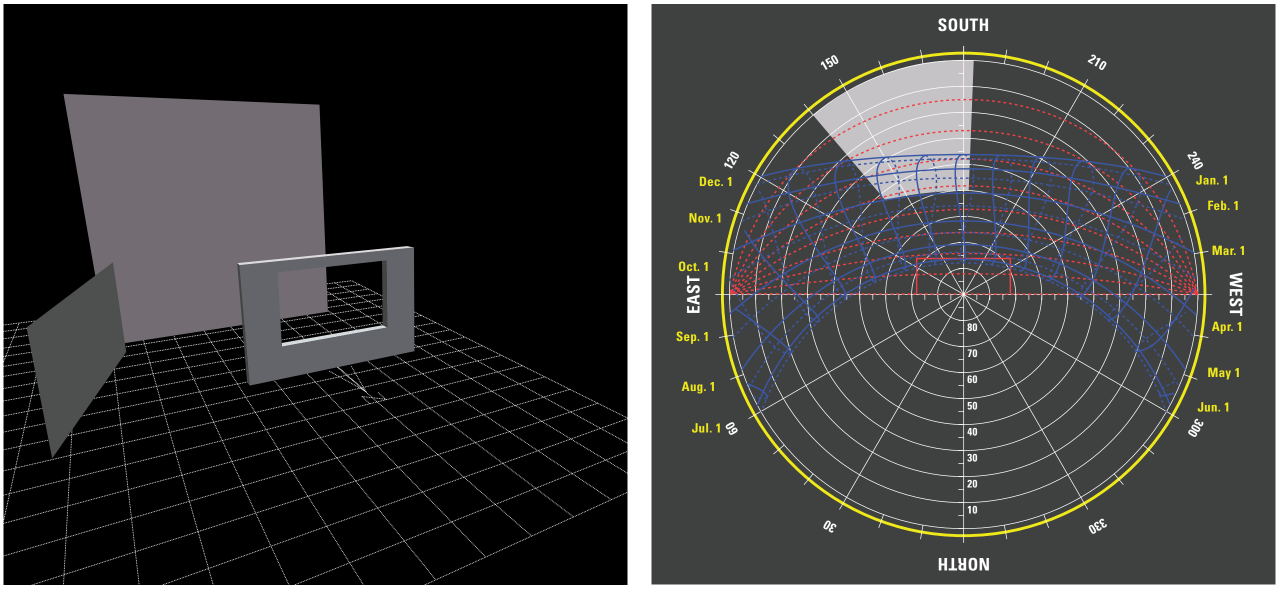
The shading effect of external obstructions can be effectively determined and visualized by drawing shadow masks of external obstructions on sun path diagrams. Shadow masks define the area of the sky that is blocked by an obstruction when viewed from a particular point, usually the middle point of window heads (**FIGURE 13**).

Full shadow masks show the area of the sky that is blocked for all points of a fenestration aperture. Full shadow masks are determined by the intersection of the shadow masks of key fenestration points (**FIGURE 14**). Center Point shadow masks are for the center point of the window (**FIGURE 15**). Percent shadow masks show the percent of the window area that is blocked by a sky element and are usually determined through specialized software applications (**FIGURE 16**).



DAYLIT ZONES

The Energy Code defines how to determine the size and location of your daylit zones. Visit ***page 56*** *of this guide or the* ***Nonresidential Lighting and Electrical Power Distribution Guide*** *for details.*



KONSTANTINOS PAPAMICHAEL
ORIG. SOURCE: "SOLAR TOOL" SOFTWARE, ANDREW MARSH

FIGURE 14 *A full shadow mask for a daylight aperture, determined as the intersection of individual shadow masks for the left and right edges of the window head. Only the taller obstruction produces a full shadow mask, as the shorter cannot block the sky for the high aperture areas.*

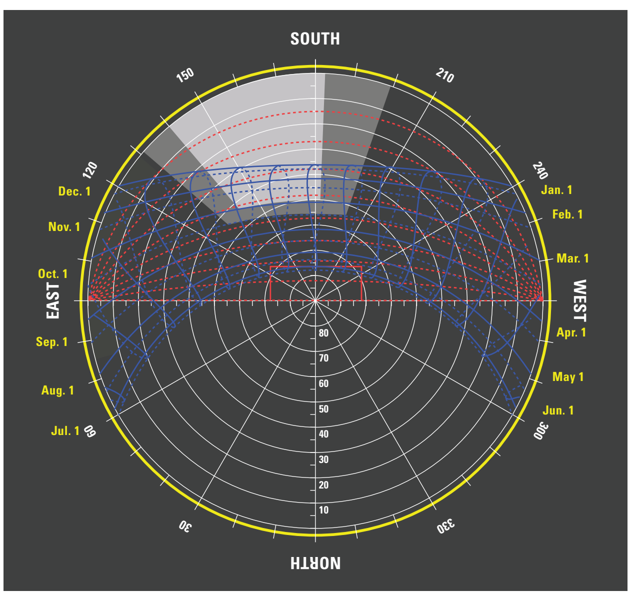
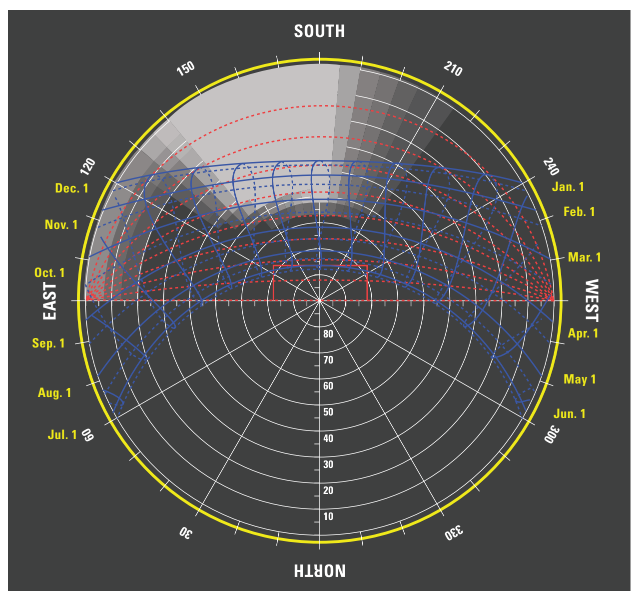


FIGURE 15 *Full and center point shadow masks for a daylight aperture.*



KONSTANTINOS PAPAMICHAEL
ORIG. SOURCE: "SOLAR TOOL" SOFTWARE, ANDREW MARSH

FIGURE 16 *Percent shadow mask showing the percent of the daylight aperture that is being blocked.*

ENERGY CODE

Energy Code, Section 140.3(c)

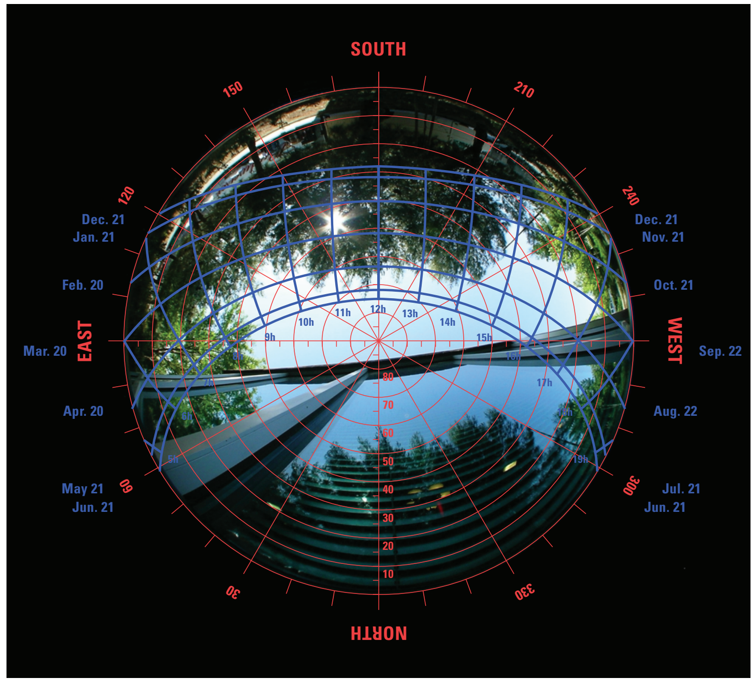
EXCEPTIONS: SECTION 140.3(c)

The following spaces are exceptions of the requirements in **Section 140.3(c)**:

- Auditoriums, churches, movie theaters, museums and refrigerated warehouses
- In buildings with unfinished interiors, future enclosed spaces for which there are plans to have:
  - A floor area of less than or equal to 5,000 ft^2; or
  - Ceiling heights of less than or equal to 15 feet. This exception shall not be used for S-1 or S-2 (storage), or for F-1 or F-2 (factory) occupancies.
- Enclosed spaces having a designed general lighting system with a lighting power density less than 0.5 watts per ft^2
- Enclosed spaces where it is documented that permanent architectural features of the building, existing structures or natural objects block direct beam sunlight on at least half of the roof over the enclosed space for more than 1,500 daytime hours per year between 8 A.M. and 4 P.M.

SKETCHUP PLUGINS

Shadow masks can be determined using CAD tools, like the SketchUp software program. Additional plug-ins for SketchUp designed to help you meet and exceed the Energy Code are available at **extensions.sketchup.com**.



KONSTANTINOS PAPAMICHAEL ORIG. SOURCE: © UNIVERSITY OF OREGON SRML

FIGURE 17 *Shadow mask produced with a fish-eye photograph of the sky from a point close to the mid-point of a window sill, with superimposed sun path diagrams that show which time of the year the sun will be reaching the midpoint of the window sill (the camera location).*

Shadow masks can be determined manually using architectural drawings, various CAD tools and through fish-eye photographs facing the sky. Superimposing sun path diagrams with shadow masks using the same hemispherical projection show the times of the year that the external obstructions would be blocking the sun for a particular point (**FIGURE 17**).

REFLECTED SUNLIGHT

External obstructions can reflect sunlight towards daylight apertures. Depending on the magnitude and type of the surface reflectance of external obstructions, the reflected sunlight can be very intense. Reflected sunlight from surfaces with high specular reflectance, such as the façade of glass buildings, has the same — and sometimes worse — effect as direct sunlight (**FIGURE 18**).

PHOTO: (CAR) LAURA LEAN, CITY AM (BUILDING) AFP. 20 FENCHURCH ST., LONDON, U.K.

FIGURE 18 *External obstructions can redirect sunlight through reflection, reaching areas that otherwise would be in the shadow. This photograph shows the heat effects of reflected sunlight being concentrated through reflection off a high reflectance curved facade. The concentrated reflected sunlight deformed a car mirror.*

BUILDING MASSING AND FENESTRATION ORIENTATION

GUIDELINES

Building massing and arrangement of spaces are the most important daylighting decisions, as they define the total building area of the building that will be adjacent to daylight apertures and also the orientation of the different spaces that will be benefiting from daylighting (**FIGURE 19** and **FIGURE 20**). Building massing also defines shadow effects of the building shape on its own fenestration. Orientation of building spaces initiates the consideration of architectural shading systems, such as external horizontal and vertical elements for different façade orientations and individual spaces.

ENERGY CODE

The Energy Code is accompanied by a Compliance Manual published by the Energy Commission. The Compliance Manual contains design guidance and provides examples for specific requirements included in the Energy Code. Portions of this section include information contained in the Compliance Manual to fully explain the Energy Code requirements.

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ENERGY CODE

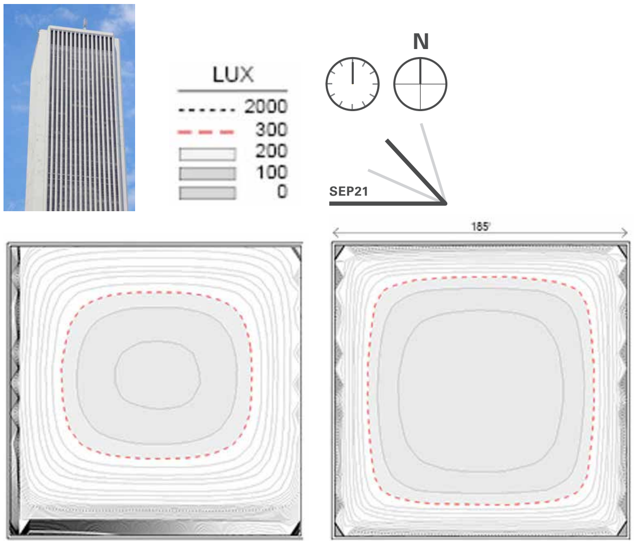


FIGURE 19 *Rectangular foot-print building with large core area, resulting in 55% and 25% of floor space being adequately illuminated by daylight under sunny and overcast conditions, respectively, on September 21 at noon.*

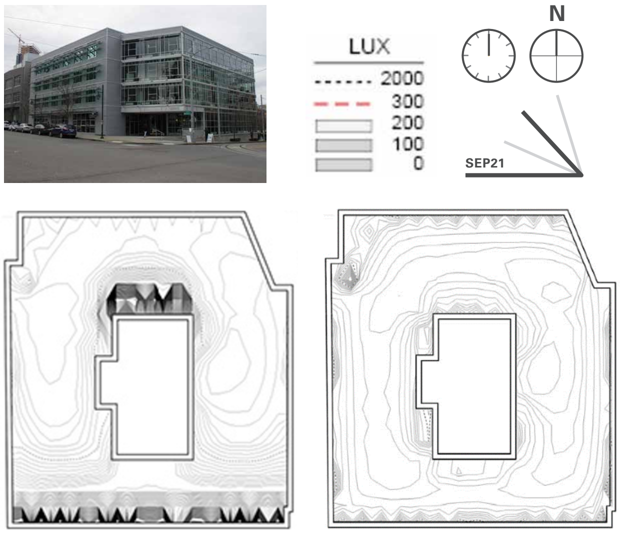
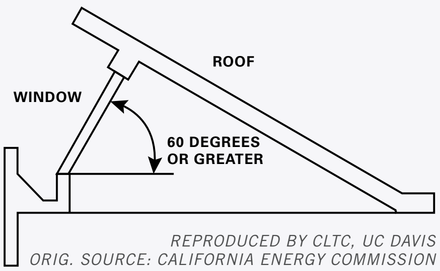


FIGURE 20 *Rectangular foot-print building with atrium, resulting in 100% and 90% of floor space being adequately illuminated by daylight under sunny and overcast conditions, respectively, on September 21 at noon.*

ENERGY CODE

Nonresidential Compliance Manual, Section 3.2.1

The Energy Code differentiates windows from skylights based on glazing slope, with skylights having a glazing slope less than 60 degrees from horizontal and windows having a glazing slope of 60 degrees or greater from horizontal (**FIGURE 21**).



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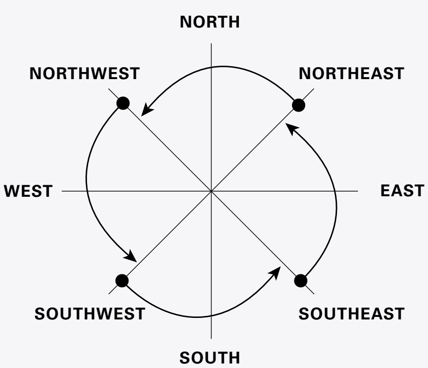
ORIG. SOURCE: CALIFORNIA ENERGY COMMISSION

FIGURE 21 *Schematic drawing showing the Energy Code definition for windows.*

Nonresidential Compliance Manual, Section 3.3.3.1A

WINDOW ORIENTATION

Windows at any orientation within 45 degrees of true north, east, south or west will be assigned to that orientation. **FIGURE 22** demonstrates how window surface orientations are determined and what to do if the window surface is oriented exactly at 45 degrees off a cardinal orientation. For example, an east-facing window surface cannot face exactly northeast, but it can face exactly southeast. If the window surface were facing exactly northeast, it would be considered north-facing.



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ORIG. SOURCE: CALIFORNIA ENERGY COMMISSION

FIGURE 22 *Determination of a window surface orientation if the surface is oriented exactly 45 degrees off a cardinal orientation.*

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FENESTRATION ORIENTATION

Fenestration orientation is very important because it defines the incident direct solar radiation through the year and the related need for exterior and interior shading devices. By observing the sun paths across California, it becomes evident that different fenestration orientations have very different relationships to the sun paths.

NORTH ORIENTATION

North-facing fenestration in California is exposed to direct sunlight only during the early morning and late evening hours of the summer (**FIGURE 23**).

North-facing apertures can be large and need minimal to no shading from direct sun penetration. North apertures provide consistent daylight illumination in interior spaces for most of the year, with diffuse daylight from the sky, making them most suitable for work environments.

SOUTH ORIENTATION

South-facing fenestration is exposed to direct sunlight throughout the year (**FIGURE 24**). This is true for the whole day during the period from the fall equinox through the spring equinox. During the period from the spring equinox through the fall equinox, the exposure to the sun is reduced to late morning and early afternoon hours, with minimal exposure during the summer solstice. All sun positions and exposure durations are centered around solar noon.

The incident angle of the sun on a vertical fenestration during solar noon (true south orientation) is much larger during the summer, with its maximum on summer solstice, and much lower during the winter, with its minimum on winter solstice.

EAST AND WEST ORIENTATIONS

East and west fenestration orientations are symmetrical in terms of sun paths, with east orientation being exposed to direct sunlight during the morning hours and the west orientation being exposed during afternoon hours (**FIGURE 25**). While the sun paths are the same, the west orientation is considered worst in terms of thermal comfort and solar heat gain because during the afternoon hours, thermal (and cooling) loads reach their peak during the day.

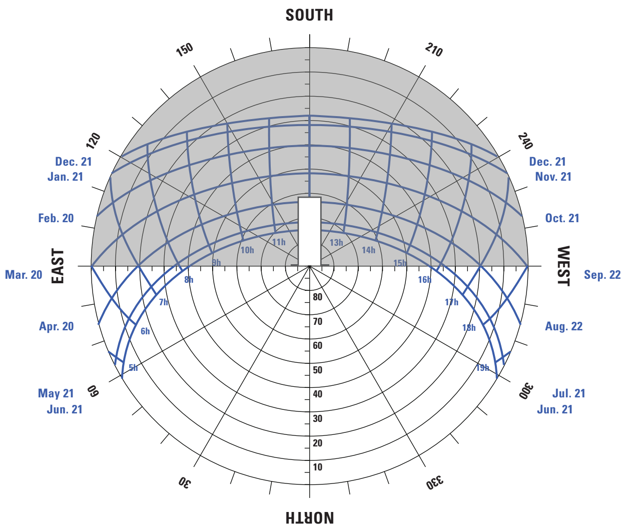


FIGURE 23 *North-facing apertures in California will be affected by direct solar radiation only during the early morning and late evening of the summer season.*

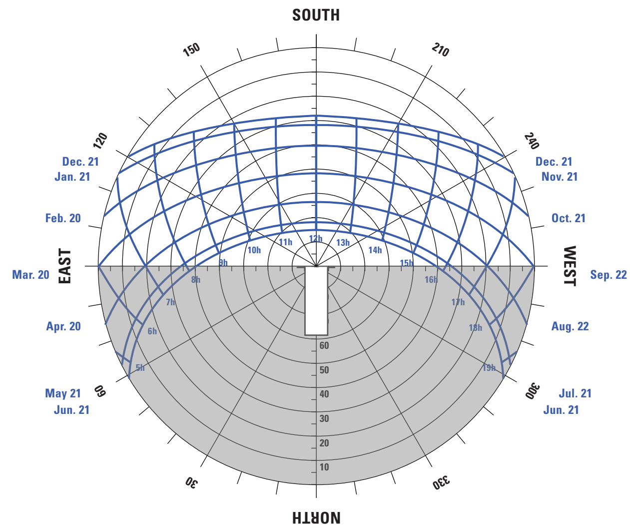


FIGURE 24 *South-facing apertures in California are exposed to direct sun throughout the day during the fall-winter-spring periods. The winter sun directions are from very low solar altitude angles and can produce significant flare. The sun exposure during the summer occurs only during the middle of the day and from very high solar altitude angles, resulting in high incident angles on vertical apertures.*

KONSTANTINOS PAPAMICHAEL
ORIG. SOURCE: © UNIVERSITY OF OREGON SRML

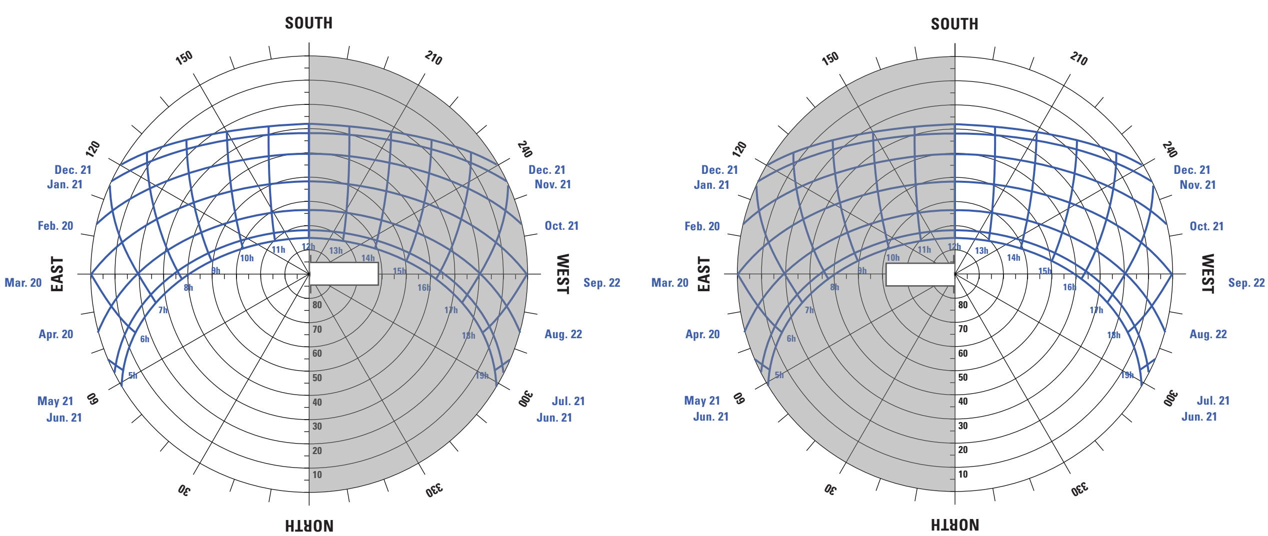


FIGURE 25 *East- and West-facing apertures in California will be exposed to direct solar radiation only during the morning and afternoon hours, respectively, throughout the year. Direct solar radiation is incident at very small incident angles for both orientations during the beginning and the end of the day, respectively.*

KONSTANTINOS PAPAMICHAEL
ORIG. SOURCE: © UNIVERSITY OF OREGON SRML

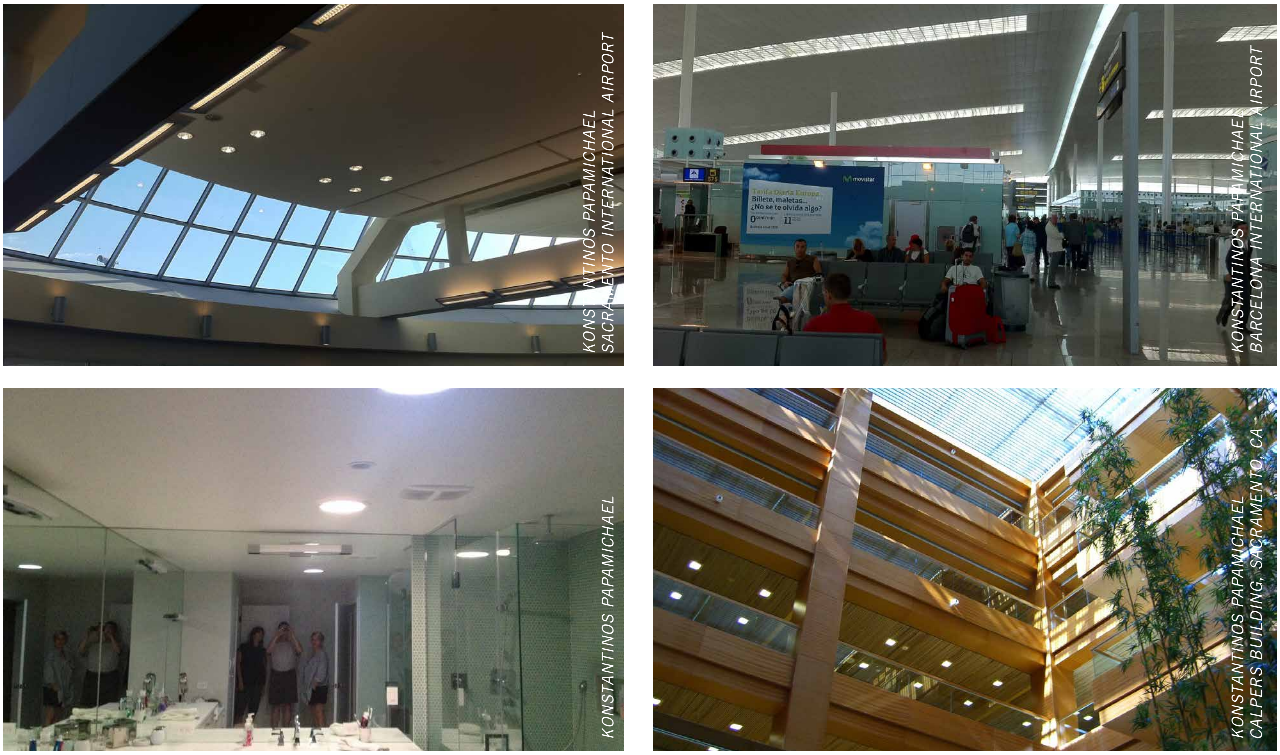


FIGURE 26 *Photographs of different daylighting systems, showing clerestory and vertical windows (top left), skylights and clerestory windows (top right), tubular daylighting devices bringing sunlight through the ceiling (bottom left) and an atrium providing daylight to the space below and the adjacent spaces on each floor (bottom right).*

ENERGY CODE

Energy Code, Section 140.3(a)5A

WINDOW AREA

In the prescriptive path to compliance for the building envelope, the total window area may not exceed one of the following: 1) six times the length of the display perimeter or 2) 40% of the gross wall area encompassing all conditioned spaces for the building. Additionally, the west-facing window area may not exceed 40% of the west-facing gross wall area.

The maximum allowed window area is determined by whichever is greater between:

$$A_M = 6 \times L \text{ or } A_M = 0.4 \times A_W$$

- A_M = Maximum allowed window area for a building
- **L** = Length of the display perimeter, where a display perimeter is the length of an exterior wall that immediately abuts a public sidewalk, such as retail display window
- A_W = Gross exterior wall area

As a practical matter, window area is generally taken from the rough opening dimensions.

BUILDING FENESTRATION

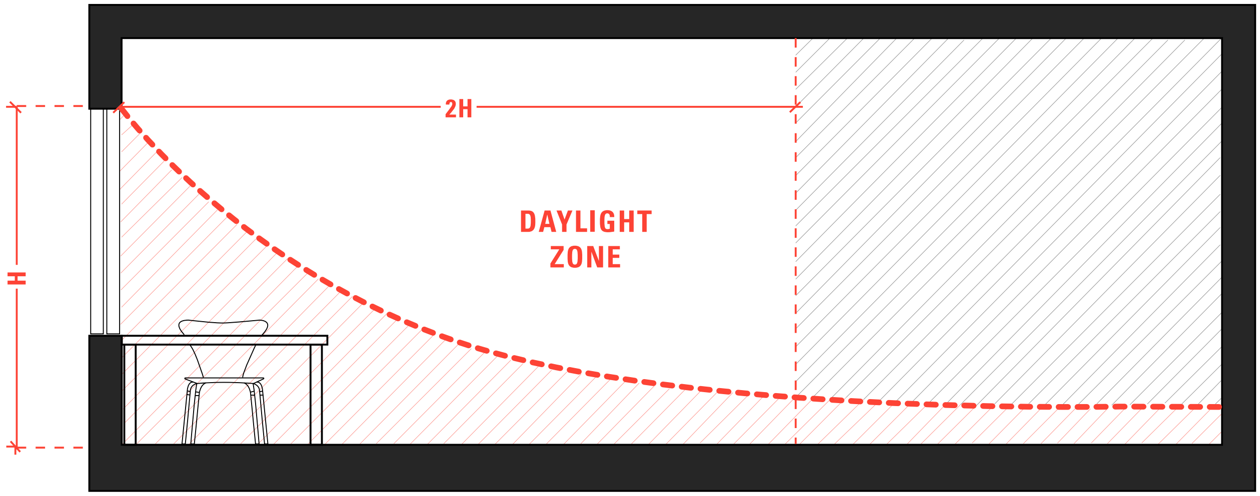
The building fenestration can include a variety of daylight apertures, bringing daylight from side walls, through windows and clerestories, and from the roof, through skylights, atria and tubular daylighting devices (**FIGURE 26**).

WINDOWS

Windows are the most common daylight apertures, with potential to illuminate interior spaces at depths of two window-head heights. While the main function of skylights is to introduce daylight into architectural spaces, the main function of windows is to provide view and connection to the outdoors.

The daylight distribution through windows is very uneven, with comparatively very high levels next to the window that drop significantly as you move away from the window (**FIGURE 27**).

To balance electric lighting savings through daylight harvesting and associated thermal loads, window area should usually be between about 30% and 50% of the window wall area. This percent varies by application, depending on various factors such as location, window orientation, glazing transmittance and space proportions (**FIGURE 28**).



REPRODUCED BY CLTC, UC DAVIS, ORIG. SOURCE: MATTHEW TANTERI

FIGURE 27 *Schematic diagram showing the daylight work-plane illuminance levels across the depth of a space with a window. The daylight levels close to the window are very high and drop significantly with distance from the window. Daylight through windows can provide daylight illumination at distances of up to two window head-heights from the window.*

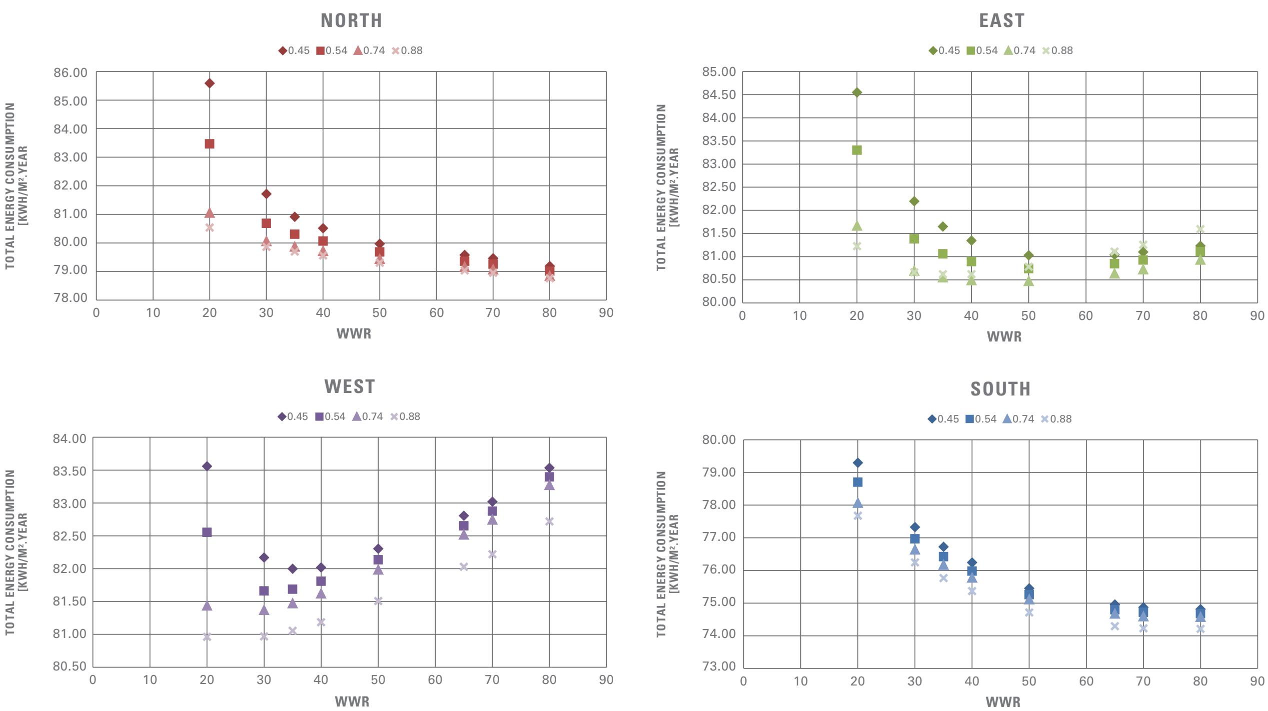
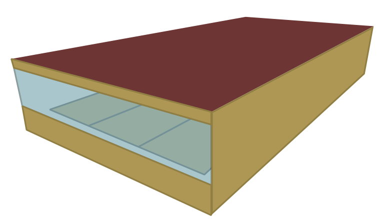


FIGURE 28 *Simulation results for total energy consumption as a function of window-to-wall ratio for different glass transmittance values in Sacramento, California.*



TOTAL ENERGY CONSUMPTION -SACRAMENTO-

SIMULATIONS & PLOTS: RAPHAELA DE FONSECA, CLTC, UC DAVIS

POWER ADJUSTMENT FACTORS FOR CLERESTORY FENESTRATION

Power adjustment factors (PAFs) provide flexibility when developing a lighting design, effectively allowing projects to reduce their reported lighting power use. PAFs incentivize the use of additional, specific lighting controls and daylighting strategies. These strategies allow for light levels to be increased when needed and automatically reduced to meet energy savings goals.

Starting with the 2019 Energy Code cycle, projects may gain a 5% lighting power adjustment credit for implementing clerestory fenestration.

For more information about PAFs, refer to the **Nonresidential Guide** *or to the* **Power Adjustment Factor subsection** *later in this guide.*

CLERESTORIES

Clerestories, also known as daylight monitors, are identical to windows but bring daylight in spaces from top areas of walls and also from walls that are above roofs.

Clerestories introduce daylight deeper into spaces than windows, as they occupy areas of walls higher than windows. They can also provide connection to the outdoors in the way that skylights do by providing a view of the sky if the glazing material has specular transmittance. As the primary objective of clerestories is daylight penetration rather than view, they often incorporate glazing with diffuse transmittance or shading devices to avoid glare from direct solar penetration.

Clerestories are often used instead of skylights when they are mounted in walls above roofs, such as in saw-tooth roof applications. Their performance, however, is much more affected by orientation thank skylights, as they bring light from the side walls of spaces.

For the best daylight uniformity, clerestories in saw-tooth roof applications should be spaced at distances of about 2.5 times the ceiling height of the space. (**FIGURE 29**).

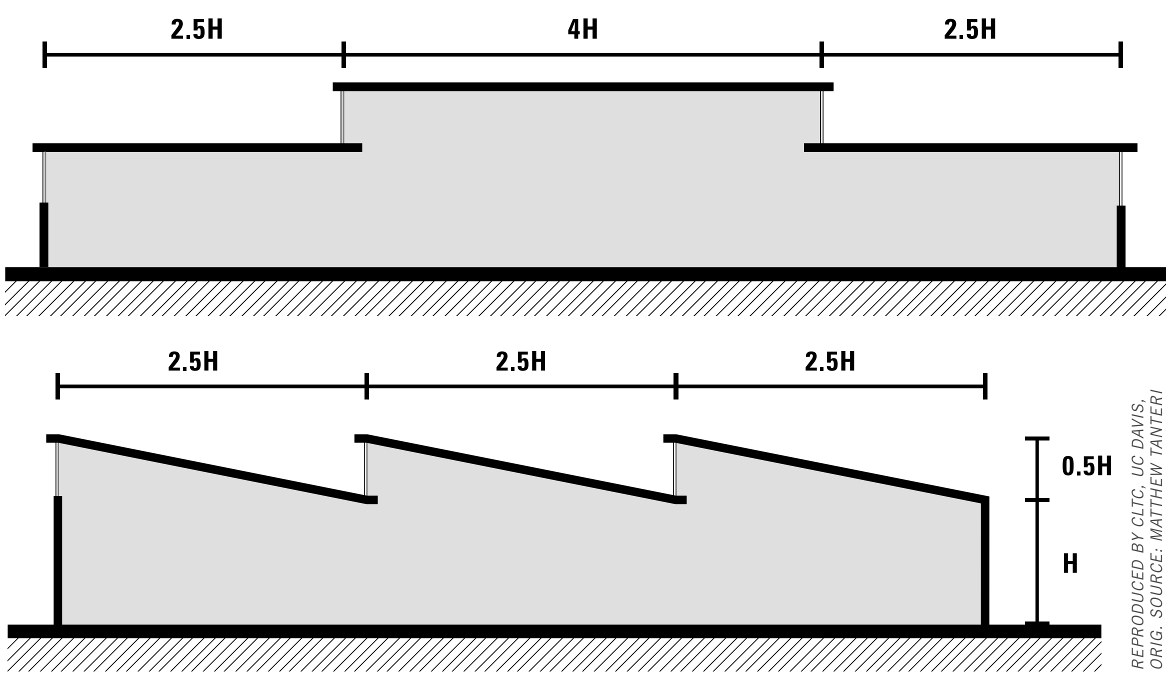


FIGURE 29 *Schematic drawings showing rule-of-thumb for spacing clerestories.*

SKYLIGHTS

Single-story buildings and top floors of multistory buildings can be illuminated by daylight very effectively and efficiently using skylights (**FIGURE 30**). The primary function of skylights is to introduce daylight in architectural spaces. They can also provide a view of the sky if the glazing material has specular transmittance. However, skylights usually incorporate glazing with diffuse transmittance to avoid glare from direct solar penetration. Diffuse glazing materials prevent view to the outdoors but provide some degree of connection in terms of sky conditions and time of day.

To balance electric lighting savings through daylight harvesting and associated thermal loads (convective/conductive heat loss/gain and solar heat gain), the skylight area should be between 3–8% of the floor area. This percent varies by application, depending on various factors, such as location and glazing transmittance. For uniform daylight distribution, skylights should be spaced at distances of about 1.5 times the ceiling height of the space. Skylights at the perimeter of the space should be at a distance of about one-half ceiling height from the perimeter (**FIGURE 31**).

Skylights in commercial applications are usually installed on horizontal roofs but can also be installed on sloped roofs. Horizontal skylights are exposed to direct solar radiation throughout clear sky days. When installed on sloped roofs, the times and intensity of incident solar radiation varies by latitude and orientation. As sun paths are very similar across California, orientation becomes the primary factor that affects performance in terms of exposure to direct solar radiation for sloped skylights.

ATRIA

Atria are equivalent to closed courtyards in buildings with more than one story, covered with glazing material for protection from the elements. In addition to providing daylight in the closed courtyard, atria also provide daylight to interior spaces with windows and clerestories facing the atrium (**FIGURE 32**).

TUBULAR DAYLIGHTING DEVICES (TDD)

Tubular daylighting devices (TDDs) bring daylight to interior spaces through ceiling apertures. They use metallic tubes with very high reflectance materials that reach the building roof and specialized optics to capture daylight from the sun and the sky. The metallic tubes can include corner elements that allow TDDs to be installed around obstacles between the ceiling and the roof (**FIGURE 33**).

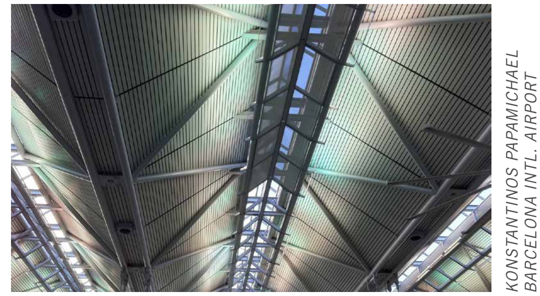


FIGURE 30 *Linear skylights with sloped glazing.*

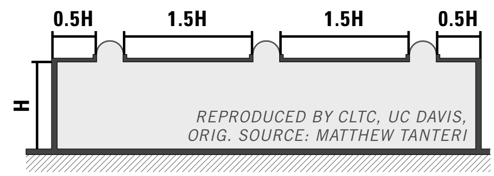


FIGURE 31 *Schematic drawing showing rule-of-thumb spacing for skylight applications.*

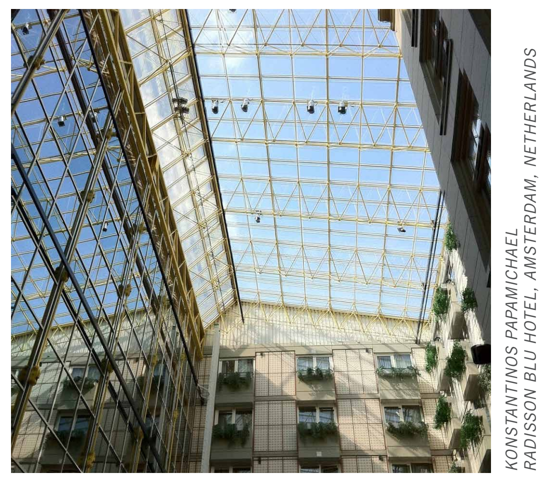


FIGURE 32 *Atrium in multi-story building providing daylight to the yard below and the spaces adjacent to the atrium.*

FIGURE 33 *Tubular daylighting devices bringing daylighting through the roof.*

FENESTRATION DESIGN

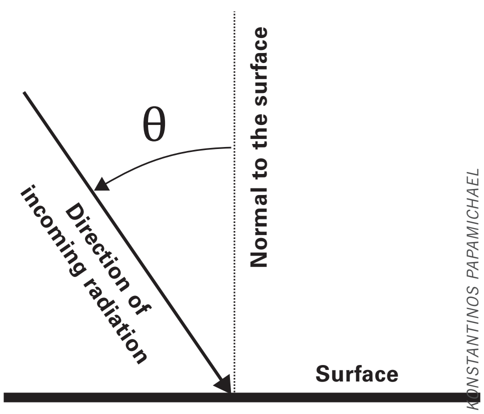
The main objective in fenestration design is to maximize as many benefits — illumination, view and circadian health — and minimize negative performance effects, such as glare and increased HVAC loads, especially for cooling. The main challenge is to thoughtfully consider the annual variation of daylight levels, sun paths and cloud conditions at the building location and also the outdoor terrain, neighboring buildings and vegetation for each daylight aperture.

NATURAL VENTILATION AND COOLING
Building fenestration can include venting mechanisms to support natural ventilation and cooling, which can be very effective in California, where the outdoor temperature during night time is much lower than the temperature during day time.

Fenestration design starts with architectural design decisions in terms of arranging the spaces of the building and the daylight apertures of each space. Effective decisions on placement, size and shape of daylight apertures require simultaneous consideration of glazing and shading decisions, which is the focus of this section.

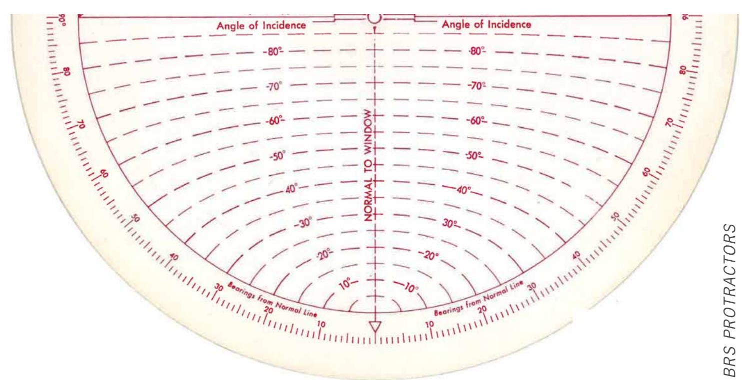
Fenestration design decisions are greatly affected by the local sun paths, which dictate the incident angle (**FIGURE 34** and **FIGURE 35**) of direct solar radiation through the year, along with the orientation of daylight apertures. The smaller the incident angle, the more challenging that the shading from direct solar radiation becomes, as blocking small incident angles significantly compromises view.

An emerging strategy for window design is separation of the daylight aperture in two separate apertures: one below human height, intended for view, and the other above human height, intended for providing daylight to reduce electric lighting and HVAC requirements. Each of the two daylight apertures is treated differently in terms of glazing and shading and they are usually separated by an exterior or interior light shelf, which provides shade from high solar altitudes for the lower view aperture while reflecting direct and diffuse sunlight and from the upper daylight aperture towards the ceiling for deeper daylight penetration.



KONSTANTINOS PAPAMICHAEL

FIGURE 34 *The incident angle of radiation on a surface is the angle of the direction of incoming radiation from the normal direction to the surface. It varies from 0 (coincident to the normal direction) to 90 degrees.*



BRS PROTRACTORS

FIGURE 35 *Incident angle iso-contours for a vertical surface. Usually used as overlay on sun path diagrams to quickly estimate solar incident angles on vertical surfaces.*

GLAZING AND SHADING SYSTEMS

GUIDELINES

Glazing and shading systems are most important for effective daylighting in terms of comfort and energy performance. Daylight apertures affect multiple performance aspects beyond illumination and energy, such as view, privacy and safety. Glazing and shading systems come in a wide range of options that address different combinations of such performance aspects.

KEY PROPERTIES OF GLAZING AND SHADING SYSTEMS

The most important properties of glazing and shading systems relevant to comfort and energy efficiency are their thermal and solar-optical properties, especially the U-value (U-factor), the Visible Light Transmittance (VT) and the Solar Heat Gain Coefficient (SHGC).

GLASS VS. GLAZING

Glass is an inorganic transparent material composed of silica (sand), soda (sodium carbonate), lime (calcium carbonate) and small quantities of alumina, boric or magnesia oxides. Glazing is the combination of glass and plastic panes in a window, door or skylight.

MANUFACTURED VS. SITE-BUILT VS. FIELD-FABRICATED FENESTRATION PRODUCTS

Manufactured fenestration is a product constructed of materials which are factory cut or otherwise factory formed with the specific intention of being used to fabricate a fenestration product.

Site-built fenestration is a product designed to be field glazed or field assembled using specific factory-cut or otherwise factory-formed framing and glazing units, manufactured with the intention of being assembled at the construction site. These include storefront systems, curtain walls and atrium roof systems.

Field-fabricated fenestration is a product whose frame is made at the construction site of standard dimensional lumber or other materials that were not previously cut, or otherwise formed with the specific intention of being used to fabricate a fenestration product. Field-fabricated does not include site-built fenestration.

ENERGY CODE

Energy Code, Section 110.6

ENERGY CODE

The Energy Code includes mandatory requirements for the building envelope and lighting systems that are directly related to daylight harvesting.

BUILDING ENVELOPE

There are three types of fenestration products: manufactured, field-fabricated and site-built. All fenestration products must meet specific requirements for key solar, optical and thermal performance parameters. For manufactured and site-built products, air leakage, U-factor, solar heat gain coefficient (SHGC), visible transmittance (VT), labeling and acceptance criteria are specified by the Energy Code in **Section 110.6(a)**. Field-fabricated products must meet **Section 110.6(b)**, which addresses U-factor, solar heat gain coefficient, visible transmittance and caulking, sealing and weatherstripping. There are no air infiltration, labeling or certification (other than NRCC-ENV-05) requirements for field-fabricated products.

AIR LEAKAGES

Air infiltration rates must not exceed 0.3 cfm/ft^2 for windows and nonresidential single doors (swinging and sliding) and 1.0 cfm/ft^2 for nonresidential double doors (swinging).

CONTINUED ON PAGE 34

ENERGY CODE

Energy Code, Section 110.6(a)

U-FACTOR

The fenestration product and exterior glazed door U-factor shall be rated in accordance with **NFRC 100**[1], or use the applicable U-factor set forth in **Table 110.6-A** of the Energy Code presented on **page 36** of this guide.

EXCEPTIONS TO SECTION 110.6(a)2

- If the fenestration product is a skylight or a vertical site-built fenestration product in a building covered by the nonresidential standards with less than 200 ft² of site-built fenestration, the default U-factor may be calculated as set forth in **Reference Nonresidential Appendix NA6** and provided on page 36.
- If the fenestration product is an alteration consisting of any area replacement of glass in a skylight product or in a vertical site-built fenestration product, in a building covered by the nonresidential standards, the U-factor may be calculated as set forth in **Reference Nonresidential Appendix NA6** and provided on page 36.

Nonresidential Appendix, Section 6.2

U-FACTOR CALCULATION METHOD

$$U_T = C_1 + (C_2 \times U_C)$$

- U_T = U-factor of the fenestration, including glass and frame
- C_1 = Coefficient selected from **Table NA6-6**
- C_2 = Coefficient selected from **Table NA6-6**
- U_C = Center of glass U-factor calculated in accordance with **NFRC 100 Section 4.5.3.1**[1]

[1] *National Fenestration Rating Council. Procedure for Determining Fenestration Product. ANSI/NFRC 100. 2017.*

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SPECTRAL SOLAR-OPTICAL PROPERTIES

Solar-optical properties represent the aggregated effect of spectral properties (i.e., the transmittance, reflectance and absorptance across the solar and visible parts of the spectrum).

U-FACTOR

The U-factor is a metric of the rate of heat transfer through the glazing or shading system due to temperature differences on either side of the fenestration assembly, expressed in terms of power per area per temperature difference (W/m² · K in the metric system and BTU/hr · °F · ft² in the imperial system).

U-factors are used to characterize glazing and shading systems, as well their combination and the entire fenestration assembly, including frames. The lower the U-factor, the greater the resistance to heat flow.

U-factors are normally given for NFRC/ASHRAE winter conditions of 0°F (18°C) outdoor temperature, 70°F (21°C) indoor temperature, 15 mph wind and no solar load.

SOLAR-OPTICAL PROPERTIES

The solar-optical properties of glazing and shading systems describe their interaction with the solar and visible parts of the electromagnetic radiation, respectively.

Incident radiation on glazing and shading systems is partly reflected, partly absorbed and partly transmitted, depending on their material and thickness. These three fractions of the incident radiation are the transmittance (T), reflectance (R) and absorptance (A) properties of the glazing and/or shading system, which have different values for the visible and solar spectra (**FIGURE 36**).

The key parameters for visual performance are the Visible Transmittance and Reflectance, while the key parameters for thermal performance are the Solar Transmittance and Absorptance.

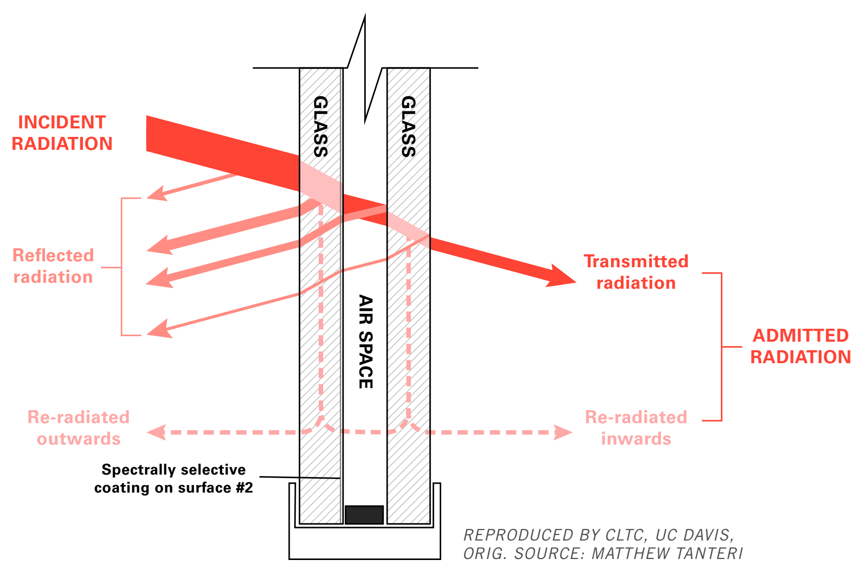


FIGURE 36 *Schematic drawing showing the transmitted, reflected and absorbed fractions of the incident solar radiation.*

TABLE 1. Typical values for Visible Light Transmittance (VT), Solar Heat Gain Coefficient (SHGC), and Light-to-Solar Gain (LSG) ratio for different glazing types

Glazing Type	Glazing Tint	VT (%)	SHGC (%)	LSG
Standard Low-E	Clear	79	70	1.13
	Grey	40	45	0.89
	Bronze	48	50	0.96
	Blue-Green	60	39	1.54
Reflective Low-E	Reflective Grey	15	27	0.56
	Reflective Bronze	19	30	0.63
Spectrally Selective Low-E	Low Iron Green	64	27	2.37
	Green	49	28	1.75
Skylight Low-E Double with Argon Fill	Clear	53	32	1.66
	White	38	30	1.27
Skylight Triple	White	45	58	0.78

SOLAR HEAT GAIN COEFFICIENT (SHGC)

The absorbed solar radiation increases the temperature of the glazing and/or shading system, resulting in increased emitted radiation in the long-IR region of the spectrum.

Part of emitted radiation flows towards the outdoors (outward flowing fraction) and partly towards the interior space (inwards flowing fraction). The combination of the solar transmittance and the inwards flowing fraction of the absorbed solar radiation is referred to as solar heat gain (**FIGURE 36**).

The solar heat gain coefficient (SHGC) is defined as the fraction of the incident solar radiation that is transmitted through the glazing and/or shading assembly. It is expressed as a number between 0 and 1 and can refer to the glazing material alone or the entire fenestration system.

The lower the SHGC of a glazing or fenestration system, the less solar heat it transmits and the greater its shading ability.

LIGHT-TO-SOLAR-GAIN RATIO (LSG)

The light-to-solar-gain ratio (also known as Coolness Index) is a derivative metric, computed by dividing the VT by SHGC, that indicates the ability of the glazing or fenestration system to provide daylight without excessive solar heat gain. The higher its value, the better the performance of the glazing during cooling periods (**TABLE 1**).

ENERGY CODE

Energy Code, Section 110.6(a)

SOLAR HEAT GAIN COEFFICIENT (SHGC)

The fenestration product's SHGC shall be rated in accordance with **NFRC 200**[2], or use the applicable SHGC set forth in **Table 110.6-B**.

EXCEPTIONS TO SECTION 110.6(a)3

- If the fenestration product is a skylight or a vertical site-built fenestration product in a building covered by the nonresidential standards with less than 200 ft^2 of site-built fenestration, the SHGC may be calculated as set forth in **Reference Nonresidential Appendix NA6**.
- If the fenestration product in a nonresidential building is an alteration consisting of any area replacement of glass in a skylight product or in a vertical site-built fenestration product, the SHGC may be calculated as set forth in **Reference Nonresidential Appendix NA6**.

Nonresidential Appendix, Section 6.3

SHGC CALCULATION METHOD

$$SHGC_T = 0.08 + (0.86 \times SHGC_C)$$

- **$SHGC_T$** = SHGC of the fenestration, including glass and frame
- **$SHGC_C$** = Center of glass SHGC calculated in accordance with **NFRC 200 Section 4.5.1.1**

[2] *National Fenestration Rating Council. Procedure for Determining Fenestration Product Solar Heat Gain Coefficient and Visible Transmittance at Normal Incident. ANSI/NFRC 200. 2017.*

CONTINUED ON PAGE 38

ENERGY CODE

Nonresidential Appendix, Section 6.2

Table NA6-6: Coefficients for U-Factor Computation (presented on page 34)

Product Type	Frame Type	C_1	C_2
Site-Built Vertical Fenestration	Metal	0.311	0.872
	Metal Thermal Break	0.202	0.867
	Non-Metal	0.202	0.867
Skylights with a Curb	Metal	0.711	1.065
	Metal Thermal Break	0.437	1.229
	Non-Metal	0.437	1.229
Skylights with no Curb (Deck Mounted)	Metal	0.310	0.878
	Metal Thermal Break	0.195	0.882
	Non-Metal	0.310	0.878

Energy Code, Section 110.6

Table 110.6-A: Energy Commission-Defined Fenestration Product U-Factor

Frame Type	Product Type	U-Factor		
		Single Pane [3, 4]	Double Pane [1, 3, 4]	Glass Block [2, 3]
Metal	Operable	1.28	0.79	0.87
	Fixed	1.19	0.71	0.72
	Greenhouse or Garden Window	2.26	1.40	N/A
	Glazed Doors	1.25	0.77	N/A
	Skylights	1.98	1.30	N/A
Metal, Thermal Break	Operable	N/A	0.66	N/A
	Fixed	N/A	0.55	N/A
	Greenhouse or Garden Window	N/A	1.12	N/A
	Glazed Doors	N/A	0.59	N/A
	Skylight	N/A	1.11	N/A
Non-Metal	Operable	0.99	0.58	0.60
	Fixed	1.04	0.55	0.57
	Greenhouse or Garden Window	1.94	1.06	N/A
	Glazed Doors	0.99	0.53	N/A
	Skylight	1.47	0.84	N/A

[1] For all dual-glazed fenestration products, adjust the listed U-factors as follows:

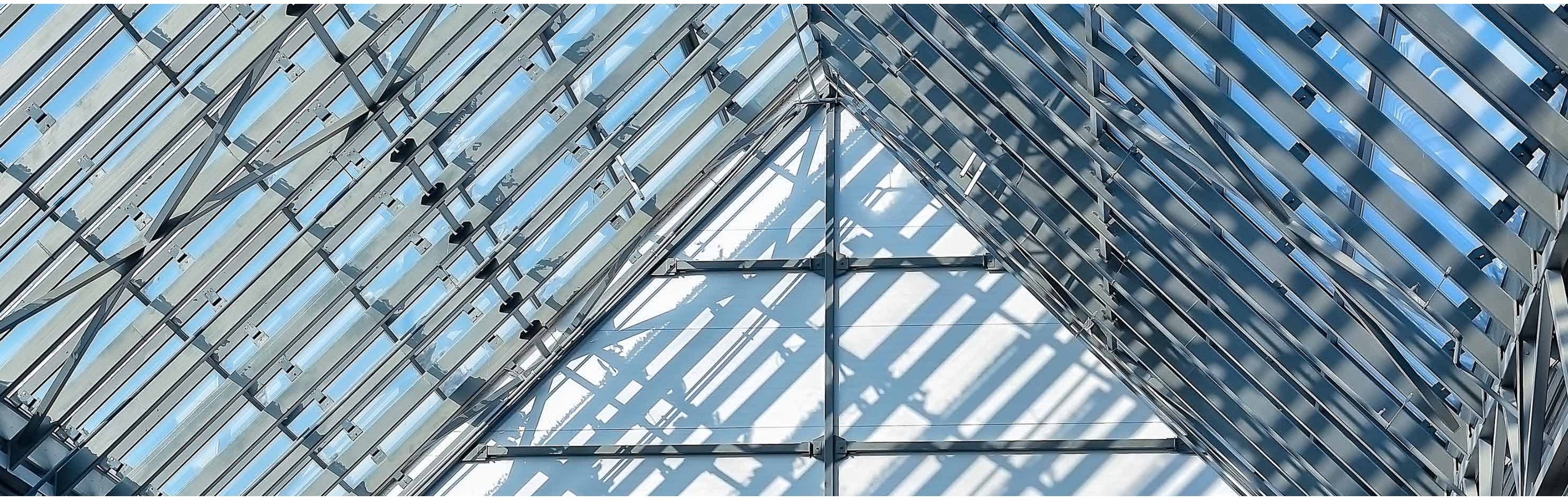
a. Add 0.05 for products with dividers between panes if spacer is less than 7/16 inch wide.

b. Add 0.05 to any product with true divided lite (dividers through the panes).

[2] Translucent or transparent panels shall use glass block values when not rated by NFRC 100.

[3] Visible Transmittance (VT) shall be calculated by using Reference Nonresidential Appendix NA6.

[4] Windows with window film applied that is not rated by NFRC 100 shall use the values from this table.



ENERGY CODE

Energy Code, Section 110.6

Table 110.6-B: Energy Commission-Defined Solar Heat Gain Coefficient (SHGC)

Frame Type	Product	Glazing	Fenestration Product SHGC		
			Single Pane [2, 3]	Double Pane [2, 3]	Glass Block [1, 2]
Metal	Operable	Clear	0.80	0.70	0.70
	Fixed	Clear	0.83	0.73	0.73
	Operable	Tinted	0.67	0.59	N/A
	Fixed	Tinted	0.68	0.60	N/A
Metal, Thermal Break	Operable	Clear	N/A	0.63	N/A
	Fixed	Clear	N/A	0.69	N/A
	Operable	Tinted	N/A	0.53	N/A
	Fixed	Tinted	N/A	0.57	N/A
Non-Metal	Operable	Clear	0.74	0.65	0.70
	Fixed	Clear	0.76	0.67	0.67
	Operable	Tinted	0.60	0.53	N/A
	Fixed	Tinted	0.63	0.55	N/A

[1] Translucent or transparent panels shall use glass block values when not rated by NFRC 200.
[2] Visible Transmittance (VT) shall be calculated by using Reference Nonresidential Appendix NA6.
[3] Windows with window film applied that is not rated by NFRC 200 shall use the values from this table.

RELATIVE SOLAR HEAT GAIN COEFFICIENT (RSHGC)
Relative Solar Heat Gain Coefficient (RSHGC) is the ratio of solar heat gain through a fenestration product (corrected for external shading) to the incident solar radiation. Solar heat gain includes directly transmitted solar heat and absorbed solar radiation, which is then re-radiated, conducted or convected into the space.

ENERGY CODE

Energy Code, Section 140.3(a)

The Energy Code allows exceptions for the SHGC in select applications.

EXCEPTIONS TO SECTION 140.3(a)5C

An area-weighted average Relative Solar Heat Gain Coefficient (RSHGC) of 0.56 or less shall be used for windows that are in the first story of exterior walls that form a display perimeter and for which the Energy Code restricts the use of overhangs to shade the windows.

For vertical windows containing chromogenic type glazing, the lower-rated labeled RSHGC shall be used with automatic controls to modulate the amount of heat flow into the space in multiple steps in response to daylight levels or solar intensity, chromogenic glazing shall be considered separately from other glazing and area-weighted averaging with other glazing that is not chromogenic shall not be permitted.

CONTINUED ON PAGE 39

SOLAR-OPTICAL PROPERTIES AND INCIDENT ANGLE OF RADIATION

As the incident angle of radiation increases from 0 degrees (normal to the surface) to 90 degrees (parallel to the surface), the incident radiation per unit area decreases by the cosine of the incident angle **(Lambert's Cosine Law)** (**FIGURE 37**).

Lambert's Cosine Law: $E_\theta = E * \cos(\theta)$

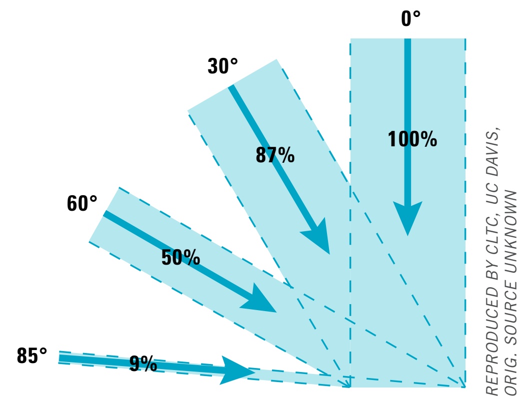


FIGURE 37 *The incident radiation per unit area decreases by the cosine of the incident angle.*

The incident angle of radiation on glazing also affects the solar-optical properties with significant decrease in transmittance and corresponding increase in reflectance as the incident angle exceeds 70 degrees (**FIGURE 38**).

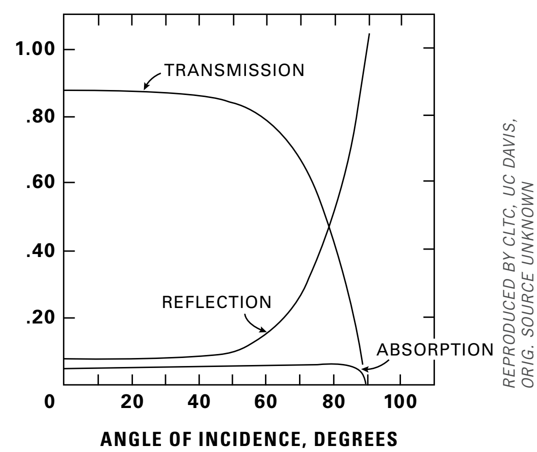


FIGURE 38 *Single-pane clear glass optical and solar properties as functions of incident angle on the glass surface.*

The single angle effect on solar optical properties can be significant for different fenestration orientations. Compared to south-facing vertical clerestory windows, horizontal skylights in California transmit more solar radiation during the summer and less during the winter (**FIGURE 39**).

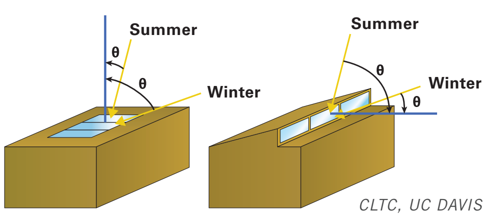


FIGURE 39 *South-facing clerestories receive more radiation per unit area during the winter than during the summer, while horizontal skylights receive more during the summer and less during the winter.*

GLASS AND GLAZING TYPES

CLEAR GLASS

Clear glass is the most common material used in fenestration assemblies. Glass is a material with unique physical structure that combines the random atomic arrangement of liquid, which is "frozen" in place so that it is a solid and permanent substance. The ASTM defines glass as "an inorganic product of fusion, which has cooled to a rigid condition without crystallizing."

Clear glass has very high visible light transmittance and solar heat gain coefficient. It is transparent and impervious to common elements and many harsh chemicals and liquids, with exceptional resistance to abrasions and surface scratches. It is used as the basis for many different types of glazing systems that also include different coatings and special films.

TINTED GLASS

Tinted glass is colored glass, produced by incorporating a mineral mixture, and comes in a wide variety of colors (**FIGURE 40**). Compared to clear glass, tinted glass has lower light transmittance and lower solar heat gain coefficient but the same U-factor.

Tinted glass is used for aesthetic and solar shading purposes. While lower solar heat gain coefficient values are beneficial for reducing associated cooling loads, lower visible light transmittance limits the benefits from electric lighting savings.

Depending on the tint color, tinted glass may affect the spectrum of the transmitted daylight and thus, the color rendering of outdoor and indoor surfaces (**FIGURE 41**). Green and blue tints have higher transmittance than bronze and gray tints. Gray tints have the least spectral effects, preserving good color rendering.

ENERGY CODE

Energy Code, Section 110.6

VISIBLE TRANSMITTANCE (VT)

The glazing's VT shall be rated in accordance with **NFRC 200** or **ASTM E972**. For tubular daylighting devices, VT shall be rated using **NFRC 203**[3].

EXCEPTIONS TO SECTION 110.6(a)4

1. If the fenestration product is a skylight or a vertical site-built fenestration product in a building covered by the nonresidential standards with less than 200 ft^2 of site-built fenestration, the VT may be calculated as set forth in **Reference Nonresidential Appendix NA6**.

[3] *National Fenestration Rating Council. Procedure for Determining Visible Transmittance of Tubular Daylighting Devices. ANSI/NFRC 203. 2017.*

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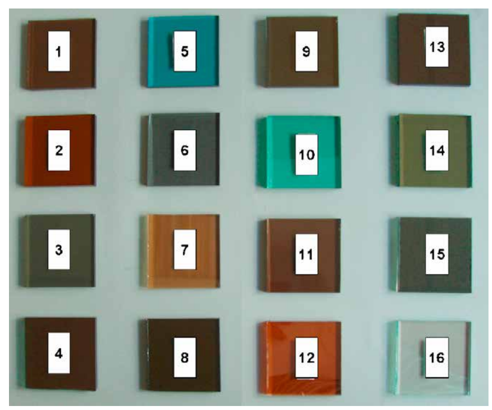

PHOTO: L. DOULOS[A], A. TSANGRASSOULIS[B], F.V. TOPALIS[A]
A. NATIONAL TECHNICAL UNIVERSITY OF ATHENS
B. UNIVERSITY OF THESSALY

FIGURE 40 *Photograph of samples of commonly used tinted glass.*

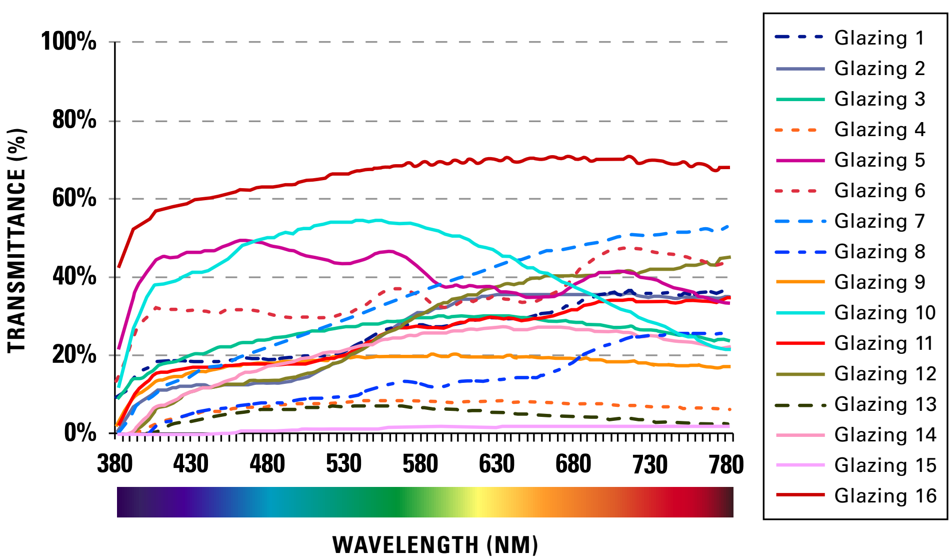

DIAGRAM: L. DOULOS[A], A. TSANGRASSOULIS[B], F.V. TOPALIS[A]
A. NATIONAL TECHNICAL UNIVERSITY OF ATHENS
B. UNIVERSITY OF THESSALY

FIGURE 41 *Spectral transmittance of the glazing samples shown in Figure 39.*


ISTOCK


ISTOCK

FIGURE 42 *Reflective glazings prevent view of interiors from the outside during the day, as the reflected radiation is significantly higher than that transmitted from the interior light levels. However, they allow a clear view of interiors during the night when the electric lights are on. The opposite is true for an outdoor view from the inside of the space.*

ENERGY CODE

2. If the fenestration product is an alteration consisting of any area, replacement of glass in a skylight product or in a vertical site-built fenestration product in a building covered by the nonresidential standards, the VT may be calculated as set forth in **Reference Nonresidential Appendix NA6** and provided below.

Nonresidential Appendix, Section 6.4

VISIBLE TRANSMITTANCE CALCULATION METHOD

$$VT_T = VT_F \times VT_C$$

- VT_T = Total performance of the fenestration, including glass and frame
- VT_F = 0.53 for projecting windows, such as casement and awning windows
- VT_F = 0.67 for operable or sliding windows
- VT_F = 0.77 for fixed or non-operable windows
- VT_F = 0.88 for curtain wall or storefront, site-built and manufactured non-curb mounted skylights
- VT_F = 1.0 for curb-mounted manufactured skylights
- VT_C = Center of glass VT is calculated in accordance with **NFRC 200 Section 4.5.1.1** or **NFRC 202**[4] for Translucent Products or **NFRC 203** for Tubular Daylighting Devices and Hybrid Tubular Daylighting Devices or **ASTM E972**

Examples of typical commercial products are provided in **TABLE 1**.

[4] *National Fenestration Rating Council. Procedure for Determining Translucent Fenestration Product Visible Transmittance at Normal Incidence. ANSI/NFRC 202. 2017.*

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REFLECTIVE GLASS

Reflective glass is produced by applying a highly reflective metallic coating to the glass surface. This coating can reduce the SHGC and VT either moderately or dramatically, depending on the thickness of the coating.

The reflective coating acts like a mirror on the side with the higher light levels, while allowing view from the side with a lower light level. This effectively supports occupant view and privacy during the day but compromises both during the night (**FIGURE 42**).

The higher the reflectance, the lower the visible transmittance and the potential for electric lighting savings.

LOW-EMISSIVITY COATINGS AND FILMS

Low-emissivity (Low-E) coatings and films are microscopically thin, virtually invisible, metal oxide layers in glazing assemblies, aimed at reducing primarily the U-factor by suppressing radiative heat flow. Typically, low-E coatings are transparent to visible and short-wave infrared radiation and reflective of long-wave infrared radiation.

Originally used in residential applications to prevent heat losses during the winter, low-E coatings are now standard in most glazing systems, as they also can reduce heat gains during the summer, which is most beneficial for both residential and commercial applications.

Because of their sensitivity to humidity and scratching, low-E coatings are usually applied to the inner surfaces of double- or triple-pane glazing systems, dramatically reducing U-factor and SHGC while maintaining high VT.

Low-E coatings also reflect UV light, which protects interior objects' color from fading.

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ORIG. SOURCE: PPG ARCHITECTURAL GLASS BINDER

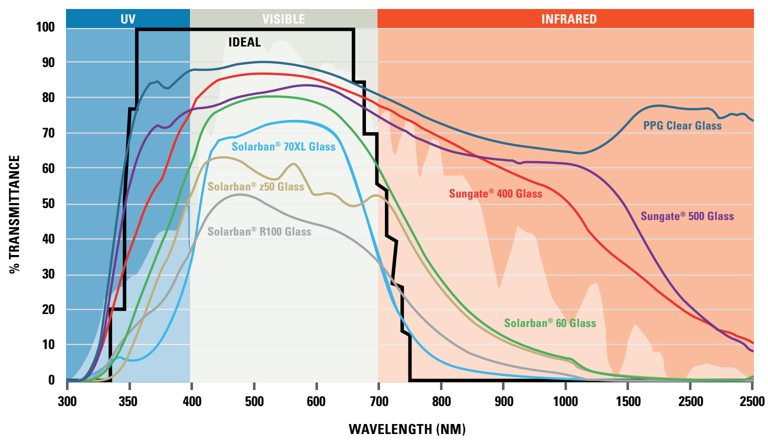

FIGURE 43 *Spectral transmittance of clear glass and various spectrally selective glazings.*

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ORIG. SOURCE: PPG ARCHITECTURAL GLASS BINDER

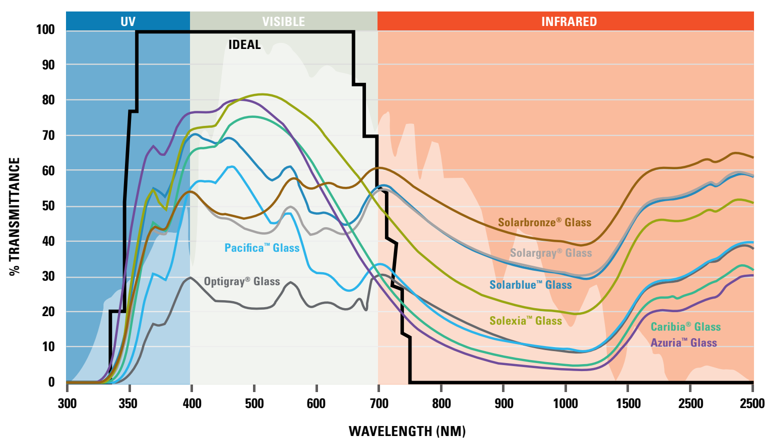

FIGURE 44 *Spectral transmittance of tinted glass and various spectrally selective glazings.*

SPECTRALLY SELECTIVE GLAZINGS

Spectrally selective glazings are coated or tinted glazings that are transparent to some wavelengths of electromagnetic radiation and reflective to others. Typical spectrally selective coatings aim at transmitting visible light while reducing short- and long-wave infrared radiation (**FIGURE 43** and **FIGURE 44**).

Spectrally selective glazings offer the highest LSG values and the best performance for commercial applications, as they can contribute to significant reduction in electric lighting with minimal cooling penalty.

ENERGY CODE

Energy Code, Section 110.6

LABELING

Fenestration products and exterior doors are required to include two labels: one temporary, for use during the inspection, and one permanent label.

- Have a temporary label **(Section 10-111(a)1)**, which shall not be removed before inspection by the enforcement agency.
- Have a permanent label or a label certificate **(Section 10-111(a)2)** if the product is rated using NFRC procedures (**FIGURE 45**).

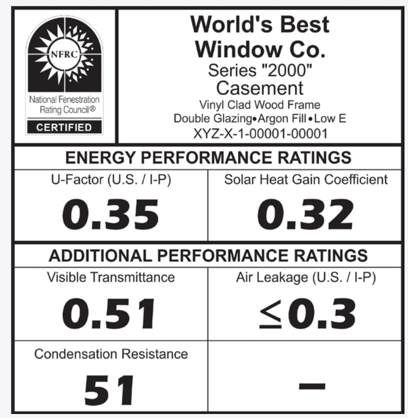

FIGURE 45 *An example label for windows from the National Fenestration Rating Council (NFRC). The NFRC label compares energy performance ratings from U-Factor, Solar Heat Gain Coefficient, Visible Transmittance and Air Leakage.*

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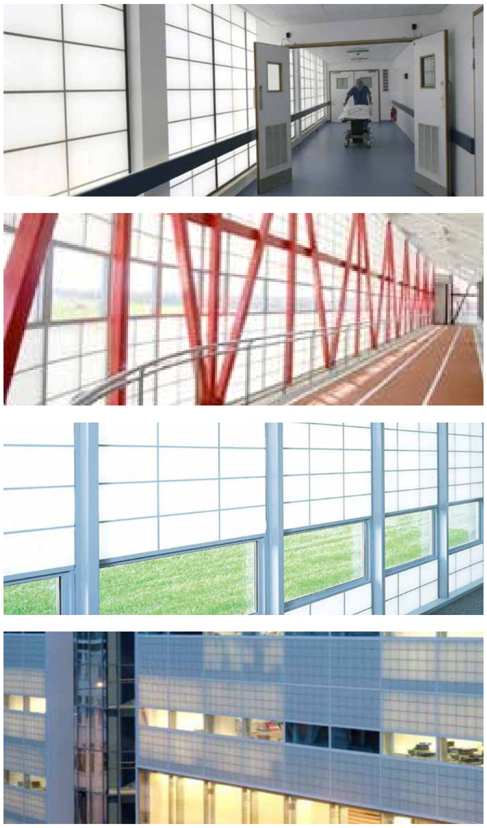


PHOTOS: KALWALL

FIGURE 46 *Photographs of translucent glazing installations.*

ENERGY CODE

Energy Code, Section 140.3(a)

The Energy Code allows exceptions for the U-factor of chromogenic products, such as electrochromic glazing.

EXCEPTIONS TO SECTION 140.3(a)5B

For vertical windows containing chromogenic type glazing:

1. The lower-rated labeled U-factor shall be used with automatic controls to modulate the amount of heat flow into the space in multiple steps in response to daylight levels or solar intensity.
2. Chromogenic glazing shall be considered separately from other glazing.
3. Area-weighted averaging with other glazing that is not chromogenic shall not be permitted.

CONTINUED ON PAGE 48

TRANSLUCENT GLAZINGS

Translucent glazings, also called diffuse glazings, aim at utilizing the direct solar radiation for indoor illumination by reducing intensity and diffusing the sun light through low, diffuse reflectance. Due to their diffuse transmittance, these glazings do not allow view to the outdoors. They are usually used in skylight and clerestory applications as well as window applications above and below eye level (**FIGURE 46**).

Translucent glazings are excellent in eliminating glare from direct solar penetration and also in providing excellent daylight indoors in terms of intensity and color rendering. As they are equivalent to area light sources, they help eliminate shadows, making them excellent for work and sport environments.

DYNAMIC GLAZINGS

Dynamic glazings, also called chromogenic glazings, include layers that can change their solar optical properties either passively or actively, through dynamic tinting glazing layers. The most common passive technologies include photochromic and thermochromic glazings, which change their solar and visible transmittance based on incident UV radiation and temperature, respectively. The most common active technology is electrochromic glazings, which change their solar and visible transmittance on demand. In all cases, the change in solar optical properties is realized through tinting.

PHOTOCHROMIC GLAZINGS

Photochromic glazing is commonly used in eye glasses as transition lenses but are not used in building applications because they can only be produced economically in small sizes.

THERMOCHROMIC GLAZINGS

Thermochromic glazings contain materials that absorb solar heat, which increases their temperature and reduces their solar and visible transmittance, based on the temperature of the glazing.

Thermochromic glazings have recently entered the buildings market and have the potential to increase comfort and reduce cooling loads.

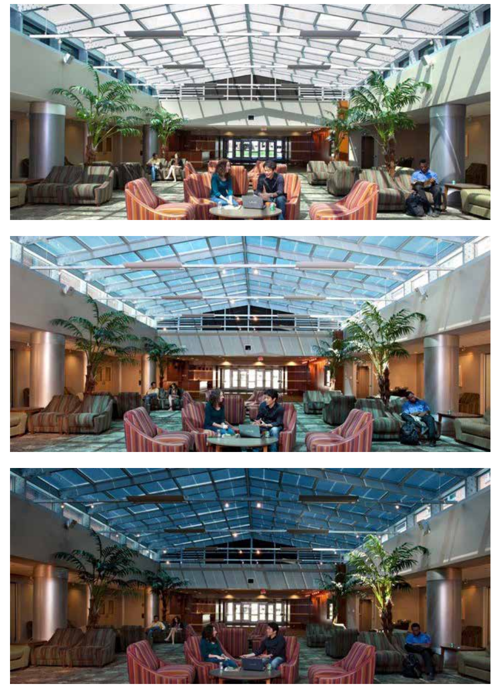
Depending on materials used, some commercial offerings change faster than others, but in all cases, transition speed is dependent on the glass temperature.

Manufacturer-specific design determines if the product has continuous tinting or two tint levels where the change is triggered by a temperature set point. Two-tint windows typically take 5 to 20 minutes to change tint in normal use.

ELECTROCHROMIC GLAZINGS

Active technologies include electrochromic glazings, which change their solar and visible transmittance on demand, through application of voltage between two transparent layers that enclose a very thin film stack of ceramic metal oxide coatings and three electrochromic layers (**FIGURE 47**).

Today's electrochromic glazings support four pre-defined tint levels, including fully-tinted and non-tinted states. The corresponding VT and SHGC values of the four different states are approximately 2%, 6%, 21% and 62% for VT, and 0.09, 0.11, 0.17 and 0.47 for SHGC. Electrochromic glazings are operated manually or automatically to improve comfort and energy efficiency with minimal effects on view, taking between 5 and 10 minutes to switch from one tint level to the next.



PHOTOS: SAGE GLASS BALL STATE UNIVERSITY, MUNCIE, INDIANA

FIGURE 47 *Photographs of atrium with electrochromic glazing at high (top), medium (middle) and low (bottom) transmittance states.*

LIGHT-REDIRECTING GLAZINGS

Light-redirecting glazings include optical microstructures that change the direction of incoming radiation. Their main objective is to redirect direct solar radiation towards the ceiling, reducing the potential for direct sun glare and increasing daylight levels further away from windows through reflection of redirected sunlight off the ceiling of the space (**FIGURE 48** and **FIGURE 49**). While these technologies work very well when the sun is within a certain range of incoming directions, their performance is compromised for sun directions outside of the effective range.

PHOTOS: SERRAGLAZE

FIGURE 48 *Photograph of space with light redirecting film installed at the upper area of one window pane, showing the sun shape on the ceiling from the redirection of direct solar radiation.*

SINGLE, DOUBLE AND TRIPLE GLAZING SYSTEMS

One approach to increasing the U-factor of fenestration systems is the use of two or three glass panes (double- and triple-pane, respectively), separated by spacers for improved insulation. The volume between glass panes is usually hermetically sealed and may be vacuum or include inert non-toxic, clear gases such as argon or krypton, which further increase insulating value. On average, each pane of glass reduces the U-value by 50%, effectively doubling the insulating value.

PHOTOS: SERRAGLAZE

FIGURE 49 *Photograph of light redirecting microstructure installed on a window, showing the direct and redirected patterns on the transmitted radiation on the side wall of the space.*

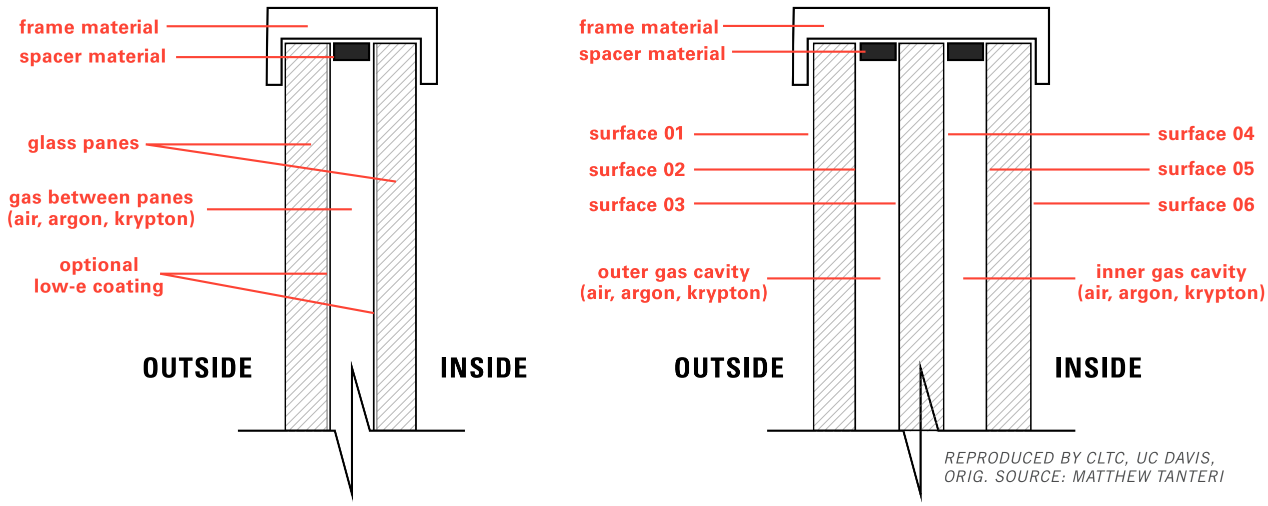


FIGURE 50 *Schematic drawings of double and triple glazing systems.*

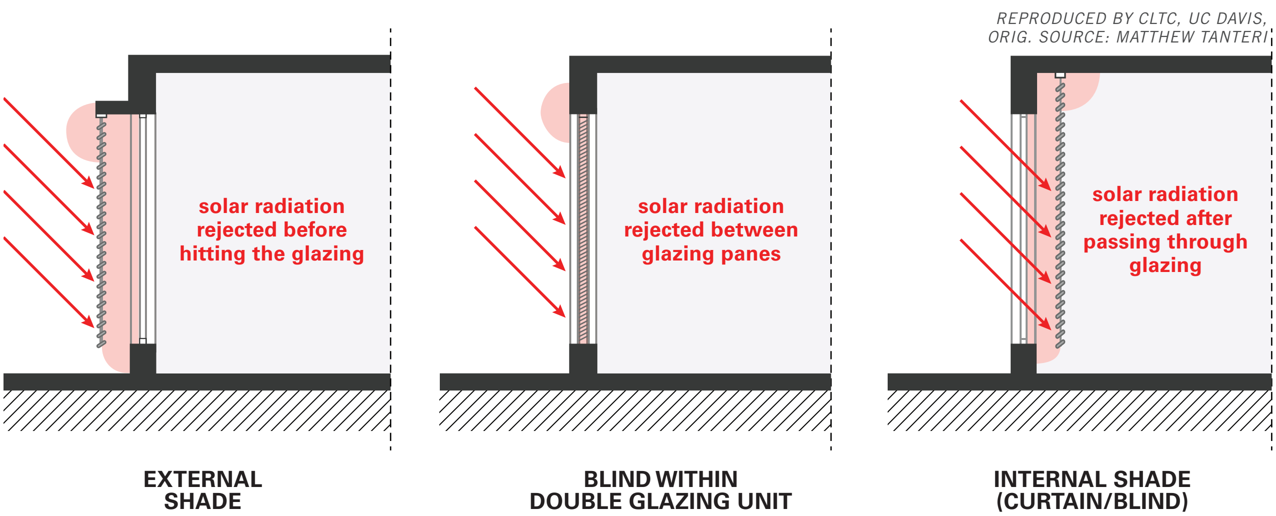


FIGURE 51 *Schematic drawing showing the effect of a shading device placed on the exterior of the glazing system (left), between glazing panes (center) and on the interior of the glazing system (right).*

The glass or glazing panes in double- and triple-pane glazing systems can be of any glass type and include a number of low-E or other coatings in the interior surfaces of the glass or glazing panes (**FIGURE 50**).

SHADING STRATEGIES AND TECHNOLOGIES

The goal of shading systems is protection from direct solar radiation to mitigate glare and solar heat gain. Direct solar radiation can be blocked, using opaque shading elements, or reduced in intensity, using transparent or translucent materials of different visible and solar transmittance, including glazings, fabrics and plastics.

Shading elements can be horizontal or vertical. Horizontal shading elements are best at mitigating direct solar radiation from high solar altitudes, while vertical shading elements are best at mitigating direct solar radiation from low solar angles. Horizontal and vertical shading systems can also be combined to mitigate direct solar radiation from a wider range of incoming directions.

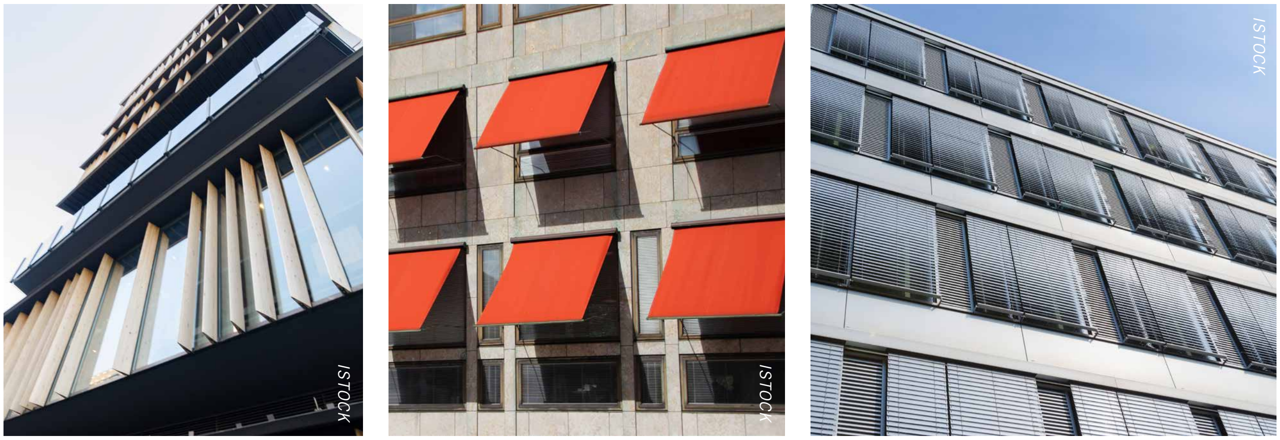


FIGURE 52 *Photographs of building facades with exterior shading systems.*

EXTERIOR AND INTERIOR SHADING SYSTEMS

Depending on their position relative to the glazing assembly of the fenestration, shading systems are classified into exterior, between glass panes and interior systems (**FIGURE 51**).

EXTERIOR SHADING SYSTEMS

Exterior systems are the most effective in reducing solar heat gain as they block or reduce the solar radiation before it passes through the glazing. If solar radiation passes through the glazing assembly of the fenestration system, it is absorbed by interior surfaces and then re-emitted in the long-infrared spectrum, which cannot penetrate the glazing assembly and results in increased thermal loads.

Exterior shading systems include horizontal and vertical shading elements, such as overhangs, light shelves, horizontal and vertical louvers, metal screens and awnings. They can be opaque, transparent or translucent (**FIGURE 52**).

Horizontal shading systems are best for high solar altitude angles, while vertical shading systems are best for low solar altitude angles (**FIGURE 53** and **FIGURE 54**). In both cases, the important characteristic is their profile angle, which is the highest angle that they can block on a plane normal to the shading elements. This is a function of width of the shading elements and distance between two consecutive elements (**FIGURE 55**).

While exterior shading systems are better in terms of shading effectiveness than interior systems, they are usually more expensive as they require material and construction processes that can withstand weather conditions.

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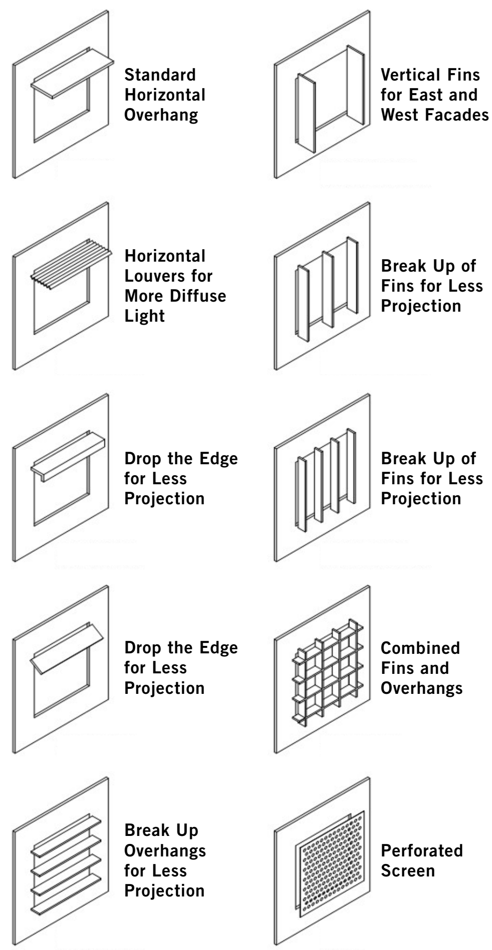

FIGURE 53 *Schematic drawings of horizontal and vertical exterior shading devices.*

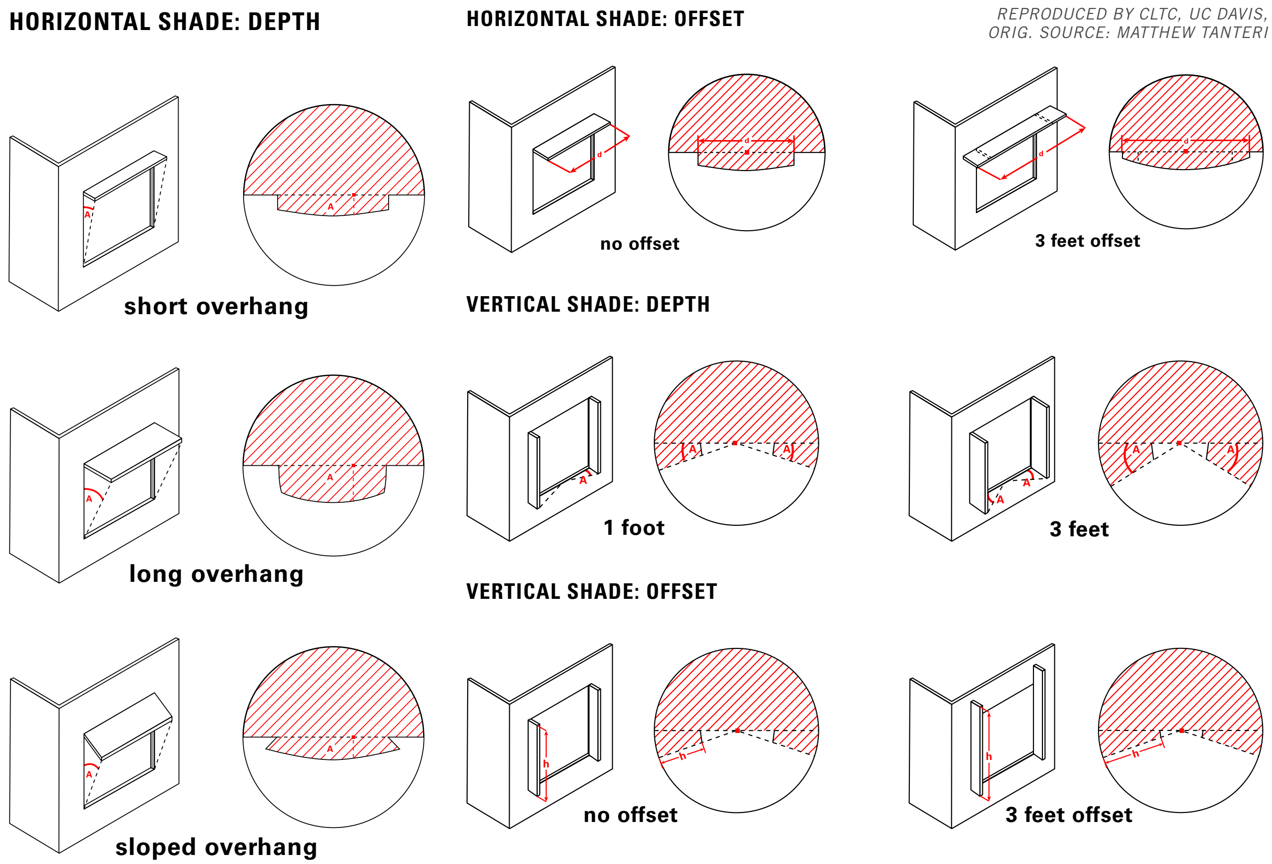

FIGURE 54 *Shadow masks of exterior overhangs and vertical fins.*

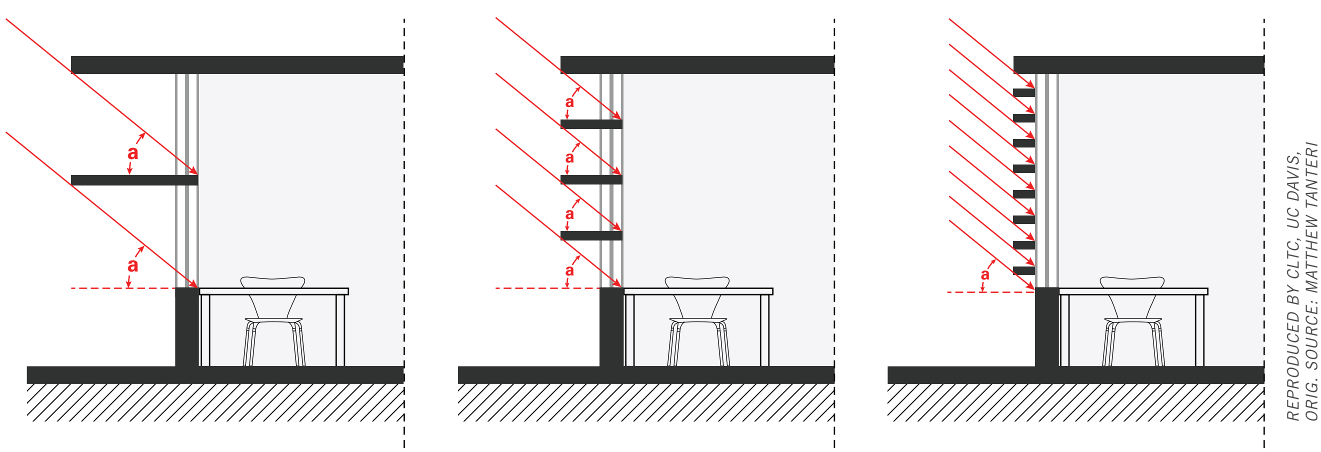

FIGURE 55 *The same cut-off angle of solar radiation can be achieved with different combinations of the width of the shading elements and the distance between two consecutive elements.*

INTERIOR SHADING SYSTEMS

Interior shading systems intercept the solar radiation after it has passed through the glazing assembly, reflecting part of it and absorbing or transmitting the rest. Dark-colored interior shading absorbs most of the transmitted solar radiation, contributing to thermal loads. Light-colored interior shading reflects most of the transmitted solar radiation, maintaining the spectral composition by reflecting it through the glass to the outdoors.

Interior shading systems are not as effective in shading compared to exterior systems, but they are significantly lower in cost, especially considering life-cycle cost that includes maintenance.

Interior systems include horizontal and vertical shading elements, such as interior light shelves, Venetian blinds, vertical louvers (**FIGURE 56**) and rolling shades made from a very large variety of opaque, transparent or woven materials (**FIGURE 57**).

BETWEEN GLASS PANES SHADING SYSTEMS

Shading systems installed between glazings combine the advantages of exterior and interior shading systems. They include shading systems that can fit in the cavities between glazing panes, such as blinds, louvers and rolling films and shades (**FIGURE 58**).

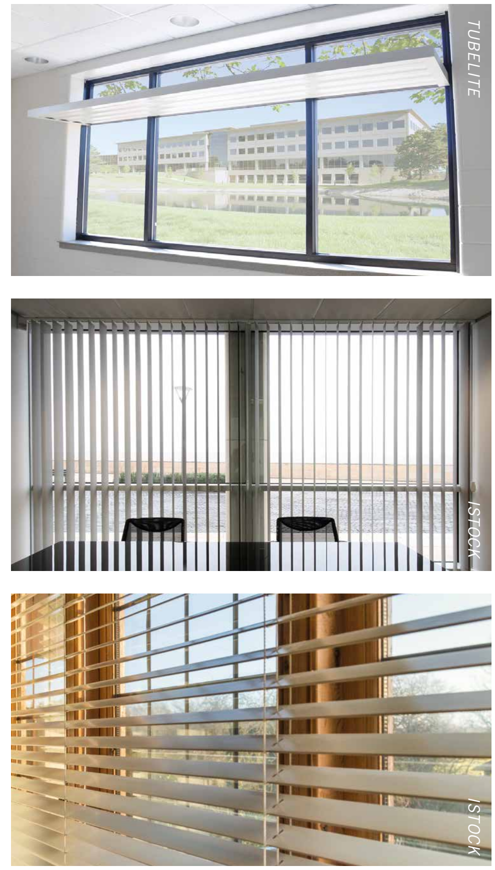

FIGURE 56 *Photographs of an interior light shelf and interior shading systems with horizontal and vertical elements.*

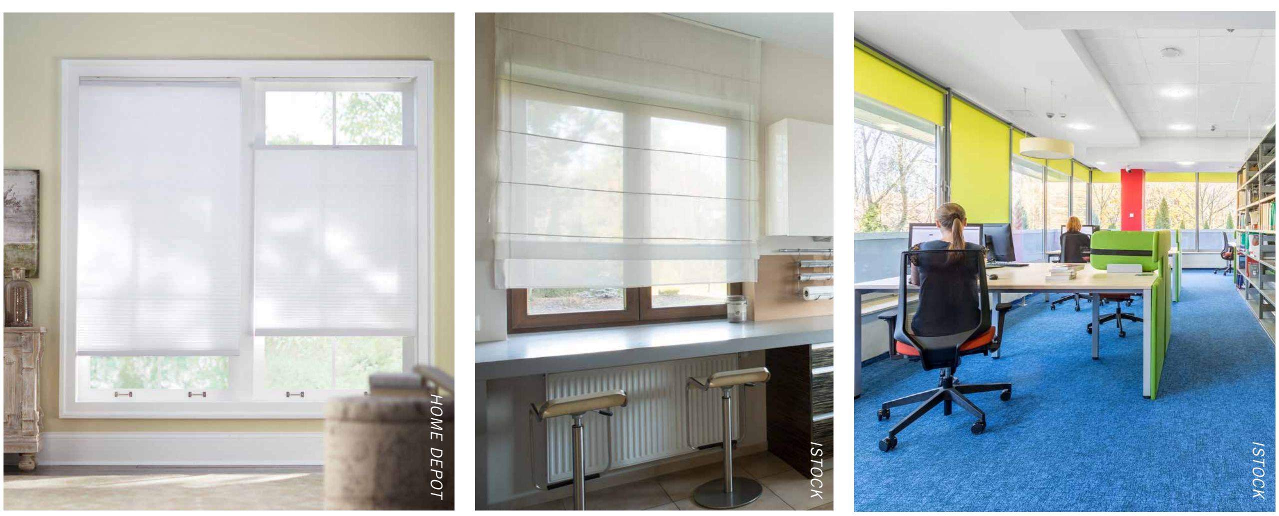

FIGURE 57 *Interior pull-down/up shades come in a wide variety of materials in terms of visible and solar transmittance and reflectance.*

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FIGURE 58 *Photograph of shading systems between glazing panes.*

ENERGY CODE

Energy Code, Section 120.1

REQUIREMENTS FOR VENTILATION

Outside air must be provided for ventilation for all enclosed conditioned spaces in a building, other than refrigerated warehouses and other spaces or buildings that are not normally used for human occupancy and work.

Operable windows and skylights can provide natural ventilation to a space. Spaces or portions of spaces to be naturally ventilated shall be permanently open to operable wall openings directly to the outdoors. The operable area shall be not less than 4% of the net occupiable floor area. Where openings are covered with louvers or otherwise obstructed, the openable area shall be based on the net free unobstructed area through the opening. Where interior rooms, or portions of rooms, without direct openings to the outdoors are ventilated through adjoining rooms, the opening between rooms shall be permanently unobstructed and have a free area of not less than 8% of the area of the interior room or less than 25 ft^2.

The means to open the required operable opening shall be readily accessible to building occupants whenever the space is occupied. Controls shall be designed to coordinate operation of the natural and mechanical ventilation systems.

STATIC VS. DYNAMIC SHADING SYSTEMS

Shading systems can be static, permanently mounted horizontal and vertical shading elements, which are designed to block or mitigate solar radiation from specific incoming directions. Shading systems can also be dynamic, or operable, supporting adjustment of horizontal and vertical elements in ways that can be effective for a variety of incoming directions of solar radiation.

MANUAL VS. AUTOMATED SHADING SYSTEMS

The operation of dynamic shading systems can be manual or motorized and can either be left to occupants or be automated based on environmental conditions.

Automated shading systems are most effective, as they continuously adjust to maintain best possible performance in terms of comfort and energy efficiency. Automated operation can be based on a single criterion, such as potential for glare, or a combination of criteria, such as potential for glare, maximization of view and reduction of cooling loads. Optimization of automated operation for comfort and energy efficiency requires information about occupancy, indoor and outdoor light levels and the state of the electric lighting and HVAC system in order to achieve desirable adjustments in visible light transmittance and solar heat gain coefficient.

POWER ADJUSTMENT FACTORS

Power adjustment factors (PAFs) provide flexibility when developing a lighting design, effectively allowing projects to reduce their reported lighting power use. PAFs incentivize the use of additional, specific lighting controls and daylighting strategies. These strategies allow for light levels to be increased when needed and automatically reduced to meet energy savings goals.

Three new PAFs have been added to the Energy Code to encourage the use of clerestory fenestration, horizontal slats and light shelves. Now, projects may gain a 5% lighting power adjustment credit for implementing clerestory fenestration or horizontal slats, and a 10% lighting power adjustment credit for implementing light shelves. Luminaires that are in a daylit zone adjacent to these devices are eligible for the credit.

Additionally, these credits may be combined with the credit for ‘Daylight Dimming plus OFF Control.’ The light shelf and clerestory fenestration credits may also be combined if used in the same space.

INTERIOR AND LIGHTING DESIGN

Interior and lighting design are most important in realizing energy savings by adjusting electric lighting based on available daylight. Interior design is also very important in maintaining luminous comfort. The key interior design parameters that affect daylight performance are the reflectance of interior surfaces and the arrangement of furniture. The key lighting design parameters are the layout of luminaires and the design and implementation of the lighting control system that adjusts electric lighting based on available daylight.

REFLECTANCE OF INTERIOR SURFACES

The reflectance of interior surfaces, including furniture, is very important for daylighting performance. Even the best architectural and fenestration designs can fail if the interior surfaces do not contribute towards maintaining the daylight transmitted through fenestration.

There are two key surface reflectance properties that are critical to daylighting performance: color and texture. The lighter the color of interior surfaces, the more daylight that reflects, keeping it alive in the space. The darker the color, the less the reflected daylight, and the lower the overall daylight levels and the brightness of interior surfaces. The rougher the texture of interior surfaces, the larger the spread of reflected light off the surface in all directions. The shinier the texture, the more concentrated the reflected light, and the higher the potential to produce glare conditions, especially through reflection of direct sunlight.

Daylight levels and brightness of interior surfaces is the result of all inter-reflections of light among all interior surfaces. Some interior surfaces cannot receive direct light from the sun or the sky, such as the ceiling, the window wall and the areas of the side walls above window head height. These areas can only receive daylight reflected off exterior surfaces and the rest of the interior surfaces (**FIGURE 59** and **FIGURE 60**). This makes the reflectance of the floor, the side walls and the furniture important for directing daylight to the surfaces that cannot receive daylight directly. The higher the reflectance of the floor and the side walls, the more the daylight that will be reflected towards the ceiling and front wall. The higher the reflectance of the ceiling and the front wall, the more daylight will be inter-reflected, keeping it alive to contribute to illumination needs (**FIGURE 61**).

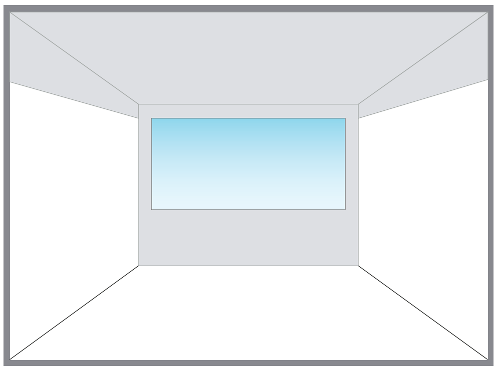

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FIGURE 59 *The ceiling, window wall and areas of the side walls above window head height cannot receive direct daylight from the sun or the sky.*

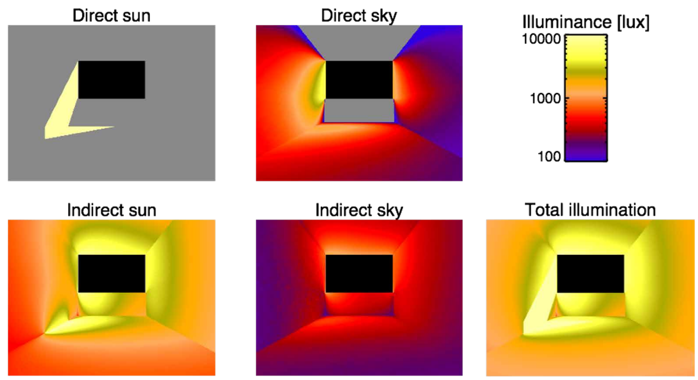

DIAGRAM: JOHN MARDALJEVIC, INSTITUTE OF ENERGY AND SUSTAINABLE DEVELOPMENT, DE MONTFORT UNIVERSITY

FIGURE 60 *Daylight simulation results showing the contribution of the direct and reflected sun and sky components on the brightness of interior surfaces.*

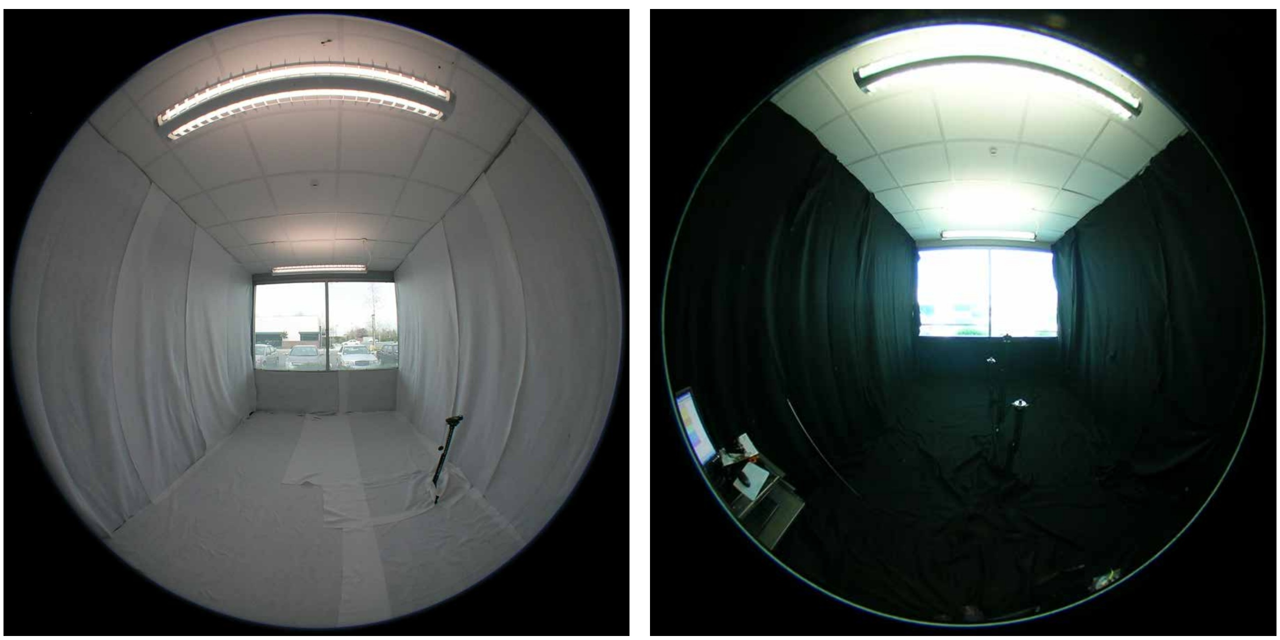

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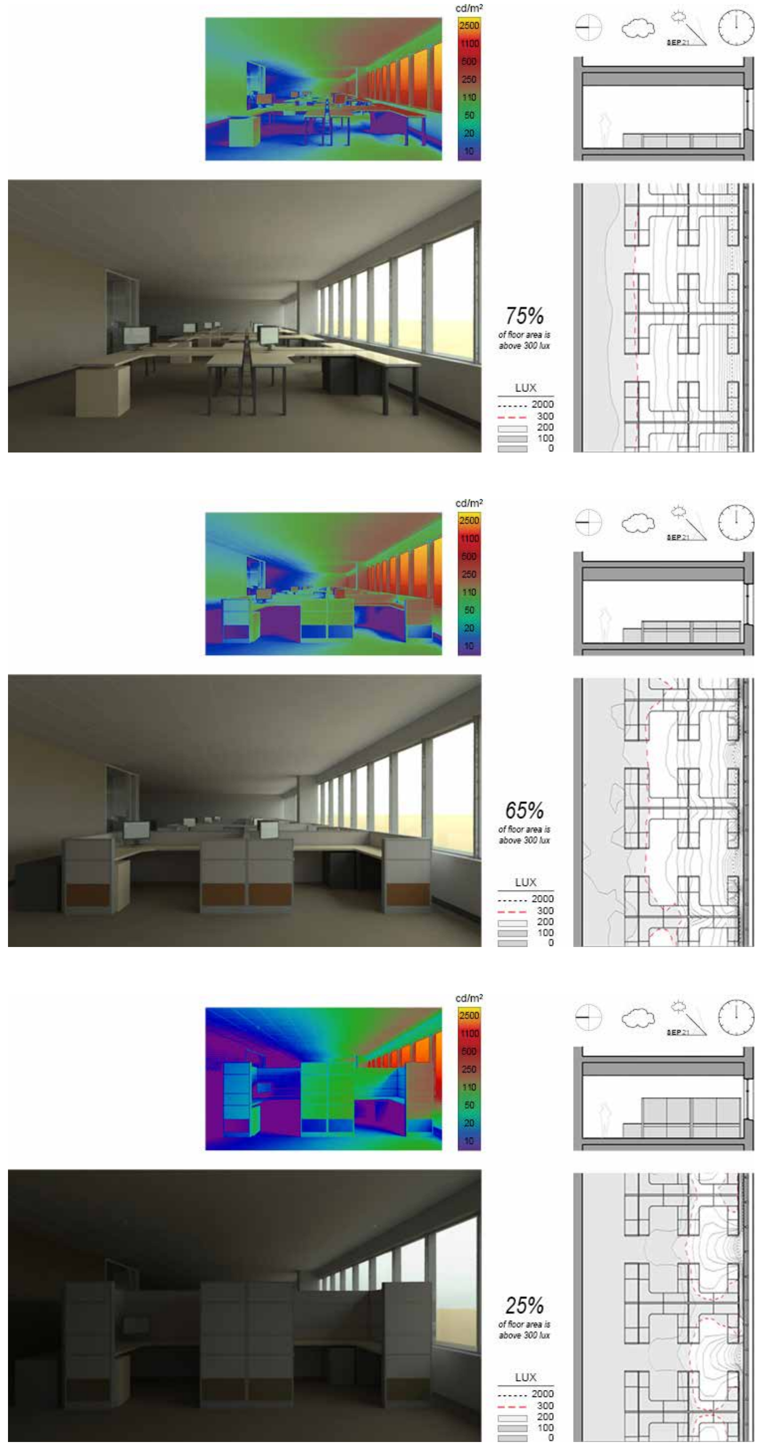
FIGURE 61 *Photographs of the same space with white cloth (left) and black cloth (right) on the floor and side walls. The work plane illuminance from the electric lighting meets the minimum requirements for office spaces in both cases. The luminous environments are dramatically different, demonstrating the need for consideration of luminance (objective brightness) distributions in addition to meeting illuminance standards for effective daylight performance.*

ARRANGEMENT OF FURNITURE

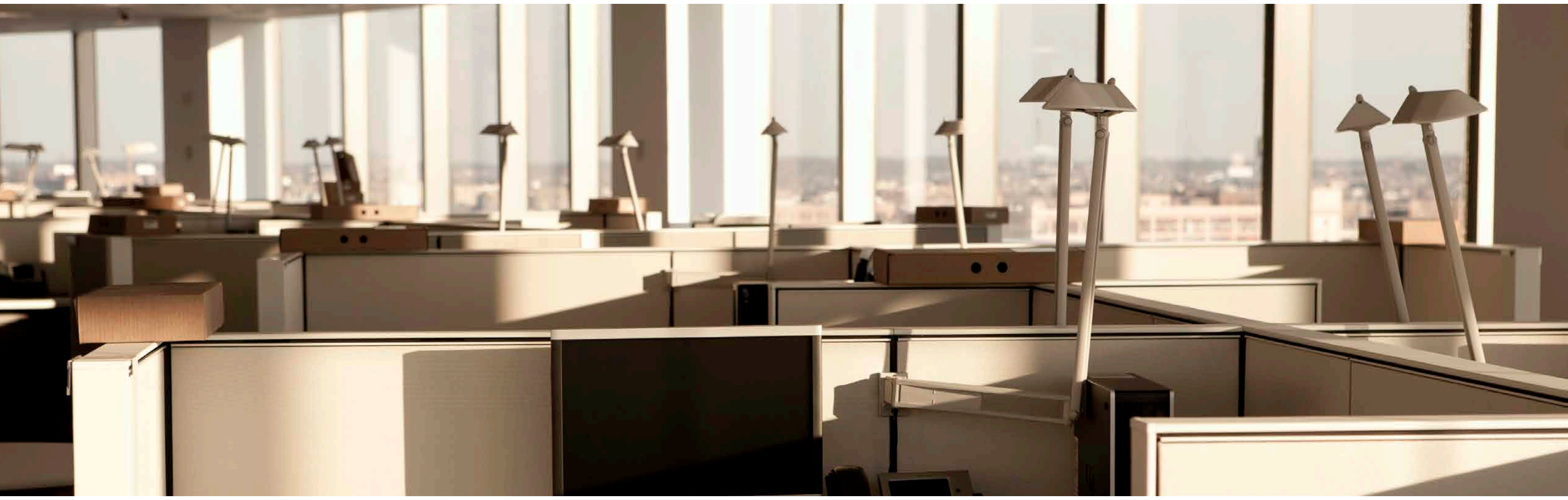
In addition to the reflectance of their surfaces, furniture can significantly affect daylight performance by its geometry and placement, especially in spaces illuminated by windows.

The lower the height of the furniture, the deeper the daylight penetration in the space. If high vertical elements, such as partitions, are required, they should be oriented perpendicular to the window wall to allow direct daylight to penetrate deeper into the space. Higher partitions can effectively perform if they include light transmitting materials, which can have diffuse transmittance to maintain visual privacy while propagating daylight through the space (**FIGURE 62**).



DAYLIGHTING PATTERN GUIDE, NEW BUILDINGS INSTITUTE

FIGURE 62 *Series of computer-simulated renderings showing the effect of furniture on daylight performance under overcast skies.*



ELECTRIC LIGHTING

ENERGY CODE

Energy Code, Section 130.1

The Energy Code includes mandatory and prescriptive requirements for electric lighting.

MANDATORY REQUIREMENTS

Mandatory requirements define the controls that must be installed in new construction projects. Five mandatory lighting control strategies are required by the Energy Code, including automated controls for daylight harvesting **(Section 130.1(d))**.

1. **Manual Area Controls:** Manual controls that control lighting in each area separately. **(130.1(a))**
2. **Multi-level Controls:** Allow occupants to choose the appropriate light level for each area, or "dimmability." **(130.1(b))**
3. **Shut-OFF Controls:** Automatically shut OFF lighting or reduce light levels when illumination is not needed. **(130.1(c))**
4. **Automatic Daylighting Controls:** Adjust electric lighting in response to the presence of daylight. **(130.1(d))**
5. **Demand Responsive Controls:** Receive and automatically respond to demand response (DR) signals. **(130.1(e))**
6. **Control Interactions:** Each lighting control installed to comply with **Section 130.1** shall permit or incorporate the functions of the other lighting controls required by this Section. **(130.1(f))**

CONTINUED ON PAGE 54

GUIDELINES

This section of the daylighting guidelines is focused on electric lighting design considerations that are directly related to daylight harvesting. For extensive information on electric lighting design, please see the publication titled **"Nonresidential Lighting and Electrical Power Distribution—A Guide to Meeting or Exceeding California's 2019 Building Energy Efficiency Standards."**

AMBIENT AND TASK LIGHTING

Interior lighting design usually includes consideration of different layers of light that address different lighting needs, such as ambient lighting, task lighting, accent or display lighting and decorative or ornamental lighting. Daylight harvesting is usually focused on work-space ambient and task lighting layers, which have been traditionally combined and provided by ceiling-mounted recessed and pendant luminaires.

The task-ambient strategy for increased lighting energy efficiency is based on the separation of the ambient and task lighting layers, using ceiling-mounted luminaires to provide ambient lighting and providing task lighting at workstations. This strategy is very effective in saving energy, as task lighting at the workstation can provide better illumination in terms of intensity and direction at a fraction of the power of providing task lighting throughout the space with ceiling-mounted luminaires. In such cases, daylight harvesting is addressing only the ambient illumination, which can be completely replaced by daylighting during most daytime work periods in daylit spaces.

The IES-recommended task illuminance range for most work space environments, such as office and school spaces, is from 30 to 50 footcandles (fc), depending on task size and contrast. Ambient light levels are much lower and can be entirely covered by daylighting during most daytime hours.

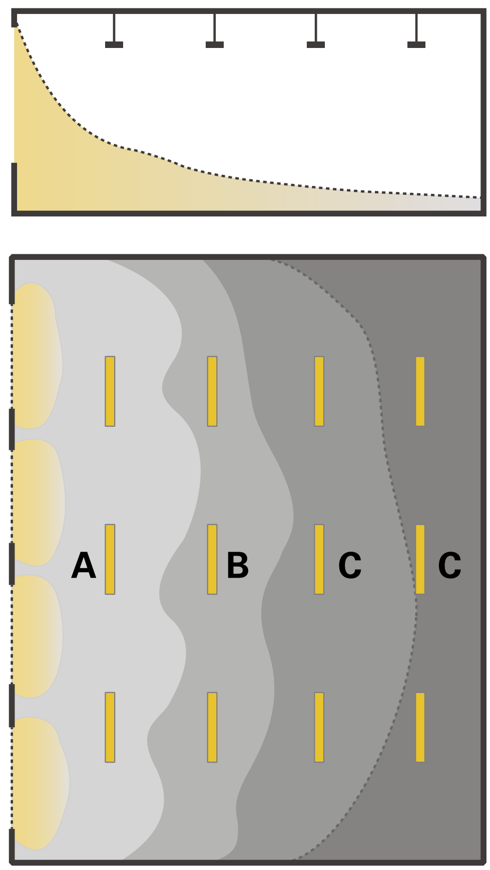
Daylight harvesting is most effective in areas under skylights and close to windows and clerestories, where it often can satisfy most of the ambient and task lighting requirements. Skylights can provide adequate illumination in the areas directly below them and surrounding floor area, depending on ceiling height, skylight well and glazing. Window and clerestories can provide significant illumination to replace ambient and most task lighting needs in the areas adjacent to them, up to a distance of two window or clerestory head-heights.

LUMINAIRE PLACEMENT

The arrangement and grouping of luminaires for the purposes of controlling them for daylight harvesting are very important, as they have a significant effect on realizing potential savings from the strategy. In skylight applications, luminaires are usually mounted between skylights and controlled in groups defined by lighting needs, rather than proximity to skylights, as daylight levels usually are relatively uniform across skylit areas. In window and clerestory applications, luminaires are typically laid out in individually controlled groups parallel to window walls, as daylight levels drop significantly by distance from windows and clerestories (**FIGURE 63** and **FIGURE 64**).

FIGURE 63 *Photograph of an open office showing electric lighting luminaires laid out in groups parallel to the window wall and controlled individually to different dimming levels based on their distance from the window walls.*

THE LIGHTING LIBRARY FROM IES
The IES-recommended task illuminance range for most work space environments, such as office and school spaces, is from 30 to 50 footcandles (fc), depending on task size and contrast.



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ORIGINAL SOURCE UNKNOWN

FIGURE 64 *Schematic drawing showing layout of electric lighting luminaires parallel to the window wall and organized in three groups that are controlled individually to effectively account for available daylight levels, which drop significantly as the distance from the window wall is increasing.*

ENERGY CODE

Energy Code, Section 130.1

PRESCRIPTIVE AND PERFORMANCE APPROACHES

The prescriptive approach defines the lighting power requirements. The Energy Code offers multiple compliance paths for electric lighting systems: Complete Building Method, Area Category Method and Tailored Method. The performance approach is based on whole building design using software approved by the Energy Commission.

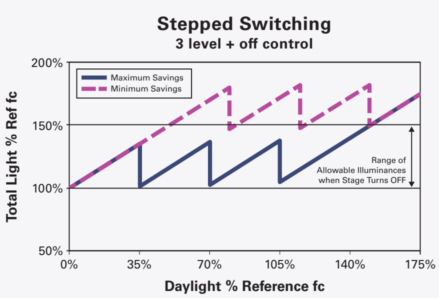
For more information about the prescriptive and performance approaches, refer to **"Nonresidential Lighting and Electrical Power Distribution—A Guide to Meeting or Exceeding California's 2019 Building Energy Efficiency Standards."**

ELECTRIC LIGHTING CONTROLS FOR DAYLIGHT HARVESTING

The Energy Code requires electric lighting controls enabling daylight harvesting to be installed in skylit and primary daylit zones (defined on the next page) where there is at least:

- 120 watts of electric lighting being used for general illumination
- 24 ft^2 of glazing

When the electric lighting controls detect that daylight illuminance equals at least 150% of the designed illuminance from the electric lighting when measured at the task plane, the general lighting power in that daylit zone must be reduced by at least 65% of full power.



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ORIG. SOURCE: CALIFORNIA ENERGY COMMISSION

FIGURE 65 *Example of stepped switching automatic daylighting controls showing the daylit and electric lighting contribution to total footcandles in the y-axis and the daylight contribution only in the x-axis.*

CONTINUED ON PAGE 55

LIGHTING CONTROLS FOR DAYLIGHT HARVESTING

Lighting controls for daylight harvesting refer to control output of electric lighting based on available daylight.

CONTROLLING THE OUTPUT OF ELECTRIC LIGHTING

Controlling electric lighting output in work spaces used to be challenging and expensive with fluorescent and high-intensity discharge light sources that could not be dimmed easily or switched quickly. Even if they were dimmable, they were inefficient at turning on at low intensity. The new LED light sources have resolved this issue, as they can be dimmed very effectively from OFF through full output. Traditionally, electric lighting control strategies included ON/OFF switching, stepped switching, stepped dimming and continuous dimming.

ON/OFF AND STEPPED SWITCHING

ON/OFF switching refers to turning all electric lighting ON and OFF, while stepped switching refers to turning OFF only specific luminaires or specific lamps within luminaires. There are two main disadvantages of ON/OFF and stepped switching controls. The first disadvantage is the relatively large change in overall light levels, which is immediately perceived during electric lighting reduction, especially with ON/OFF controls and stepped switching with one or two large steps between ON and OFF. The second disadvantage is the change in the illuminance distribution across the space that results from turning OFF individual luminaires or individual lamps within each luminaire.

STEPPED AND CONTINUOUS DIMMING

Stepped dimming refers to adjusting all electric lighting output in steps, which is similar to stepped switching but now controlling the output of all electric lighting luminaires in the same way, maintaining relative illuminance distributions in a space. The perceived change in illumination levels depends on the number of steps between full and minimum output of electric lighting. Continuous dimming is the equivalent of stepped dimming with at least ten steps between full output and OFF states.

Some ON/OFF and stepped switching-dimming approaches also use a ramping function to gradually adjust light output from one step to the next. Spreading the ramping function over long periods of time makes it hard to perceive electric light output changes, as it provides time for the human vision to adjust to the changing light levels.

With the advent of solid-state lighting (SSL), most of the traditional electric lighting challenges have been resolved, as SSL can be easily dimmed across the whole range of its output. Considering the fact that SSL has become today's baseline technology for work-space lighting, these guidelines focus on continuous dimming controls.

SWITCH-TO-OFF VS. DIM-TO-LOW

Traditionally, fluorescent lamps were not turned completely OFF, even during times that daylight exceeded required light levels, because it was difficult to effectively turn them back ON at low light levels. Rather, they were dimmed to the lowest level they could reach without flickering. Today's SSL light sources can be effectively dimmed up and down across their whole output range and can easily support switch-to-OFF operation to maximize energy savings. However, building occupants that are not familiar or aware of daylight harvesting controls often get confused when electric lights are turned OFF automatically and either call the facility manager to report a malfunction or override the system by turning electric lights ON manually, eliminating electric lighting savings. Unless occupants are educated and aware of electric lighting controls for daylight harvesting, it may be best to dim-to-low, rather than to switch-to-OFF, to avoid confusion and potential elimination of lighting savings.

DETERMINING AVAILABLE DAYLIGHT

Determining available daylight has been and still is a key challenge in controlling electric lighting as part of a daylight harvesting strategy. Traditionally, there have been two main strategies to determine daylight levels: time and photosensing.

ASTRONOMICAL TIME CLOCKS

Astronomical time clocks are ordinary clocks that also include information about sunrise and sunset times for the building location. They are very easy and economical to use for switching or dimming electric lights at specified times. Set points are based on sunrise and sunset times, which change through the year.

The main disadvantage of time-based controls is the lack of information about sky conditions, including cloud coverage and external obstructions, which can greatly affect daylight penetration through building apertures. The solution to this shortcoming is the addition of a photosensor to help determine sky conditions.

ENERGY CODE

Energy Code, Section 130.1

DAYLIT ZONES

Daylit zones are determined according to methods defined in the Energy Code.

Daylit zones are areas within a building where daylight harvesting is possible due to their close proximity to daylight apertures. There are three types of daylit zones: Primary Sidelit Daylit Zone, Secondary Sidelit Daylit Zone and Skylit Daylit Zone.

- **Primary Sidelit Daylit Zone:** Daylit area directly adjacent to one or more windows
- **Secondary Sidelit Daylit Zone:** Daylit area not directly adjacent to a window that still receives some daylight through its proximity to the window
- **Skylit Daylit Zone:** Daylit area illuminated by one or more skylight

Daylit zones must be marked on building floor plans.

Daylit zones must have daylighting controls. Daylighting control sensors must be located so that they are not readily accessible to unauthorized personnel. Additionally, for spaces required to install multilevel controls under **Section 130.1(b)**, the automatic daylighting controls should adjust lighting via continuous dimming or the number of control steps provided by the multilevel controls. Combined illuminance, from daylight and electric light, should not be less than the designed illuminance from controlled lighting when no daylight is available. For areas other than parking garages, controls must reduce lighting power by at least 65% when daylight illuminance is greater than 150% of the design illuminance. A power adjustment factor (PAF) of 10% can be applied to the luminaires in skylit daylit zones or primary sidelit daylit zones where the electric lighting is commissioned to turn OFF completely.

The prescriptive compliance approach for a space requires that mandatory automatic daylighting controls also apply to general lighting luminaires that are located at least 50% in a secondary sidelit daylit zone.

CONTINUED ON PAGE 56

ENERGY CODE

Energy Code, Section 130.1

DETERMINING DAYLIT ZONES

All skylit daylit zones and primary sidelit daylit zones must be shown on building plans. Secondary sidelit daylit zones must also be shown on the plans when complying with prescriptive requirements for automatic daylighting controls in secondary sidelit daylit zones. The easiest way to determine the size of daylit zones is examining building plans.

CALCULATING A SKYLIT DAYLIT ZONE

1. **Define the shape of the skylight.** A skylit daylit zone takes the shape of the skylight it is produced from. For example, a rectangular skylight produces a rectangular daylight zone while a circular skylight produces a circular zone.
2. **Determine the average ceiling height (CH) surrounding the skylight.** The ceiling height is the vertical distance from the finished floor level to the ceiling.
3. **Multiply the CH by 0.7**.
4. **Add the value determined in Step 3 in all directions around the skylight** (starting at the edges of the opening).
5. Subtract any area blocked from receiving daylight by a permanent obstruction taller than half the distance from the floor to the bottom of the skylight.

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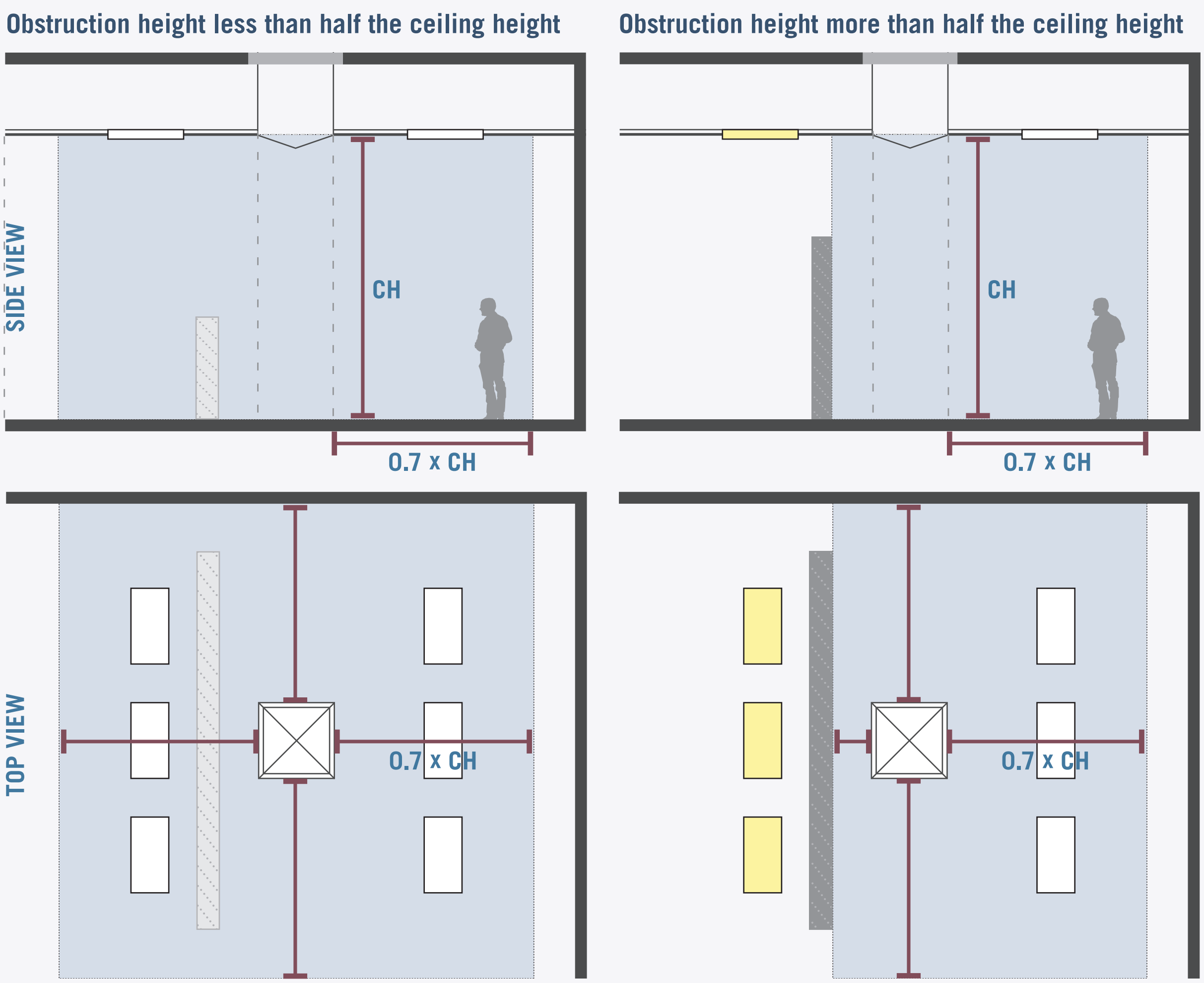

FIGURE 66 *Example electric lighting and daylighting design used to show how to calculate a skylit zone with varying obstruction heights.*

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ENERGY CODE

Energy Code, Section 130.1

CALCULATING A PRIMARY SIDELIT DAYLIT ZONE

1. **Determine the window head height for each window.** The window head height (WHH) is the vertical distance from the finished floor level to the top of the glazing.
2. **Determine the depth of the zone.** The zone depth is one window head height into the area adjacent to the window.
3. **Calculate the width of the zone.** The zone width is the window's width added to half the window head height on each side of the window.
4. Subtract any area blocked from receiving daylight by a permanent obstruction that is six feet or taller. Modular furniture is not considered a permanent obstruction.

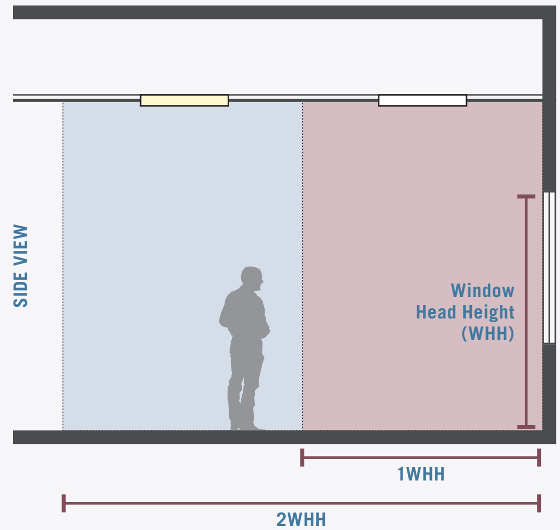

FIGURE 67 *Example electric lighting and daylighting design used to show how to calculate a primary sidelit zone.*

CALCULATING A SECONDARY SIDELIT DAYLIT ZONE

A secondary sidelit daylit zone extends one additional window head height beyond the primary sidelit daylit zone(s) adjacent to it.

1. Add one additional window head height to the depth of the primary sidelit daylit zone to determine the depth of the secondary sidelit daylit zone. The width of the secondary sidelit daylit zone is the same as the width of the primary sidelit daylit zone.
2. Subtract any area that is blocked from receiving daylight by a permanent obstruction that is 6 feet or taller. Modular furniture is not considered a permanent obstruction.

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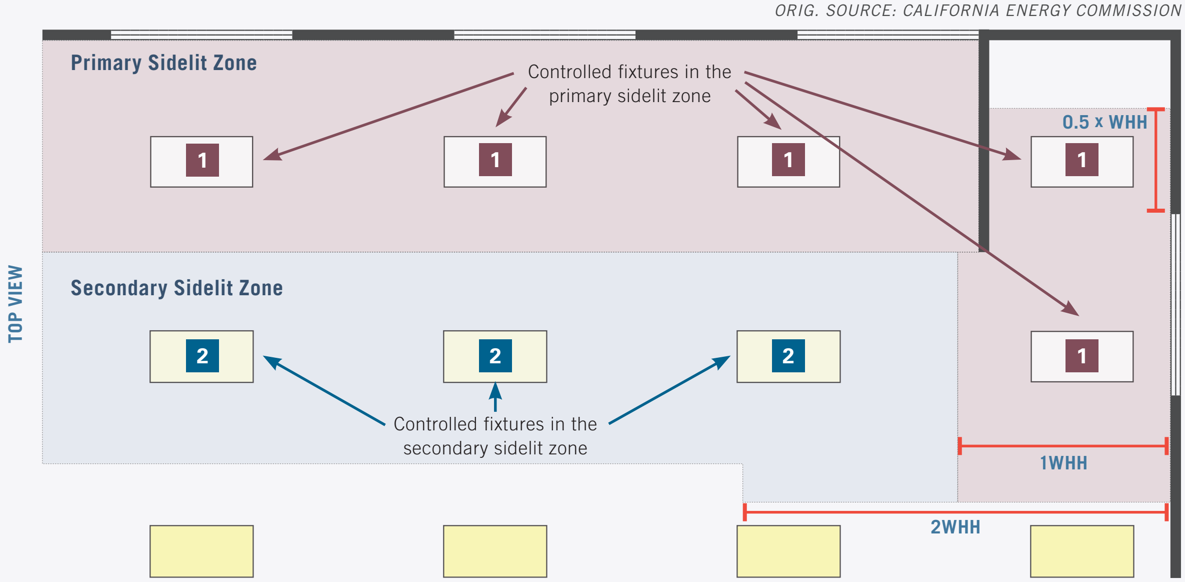

FIGURE 68 *Example electric lighting and daylighting design used to show how to calculate a primary and secondary sidelit zone with a permanent obstruction that is 6 feet.*

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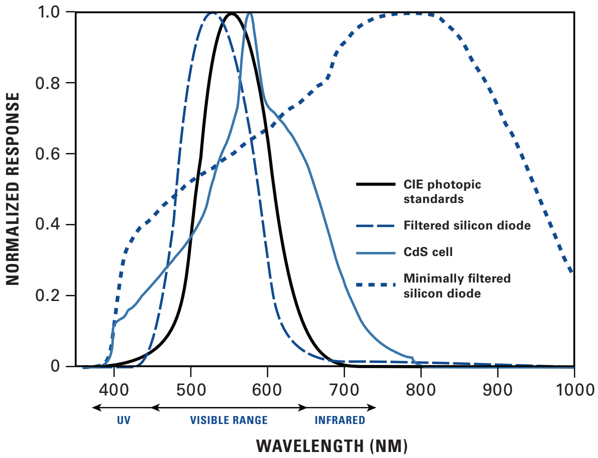

FIGURE 69 *Spectral sensitivity of different light sensing technologies, along with the human Photopic sensitivity standard. Photosensors that deviate from the Photopic sensitivity, such as those that use a minimally filtered silicon diode, can be unreliable, as their signal is affected by non-visible radiation.*

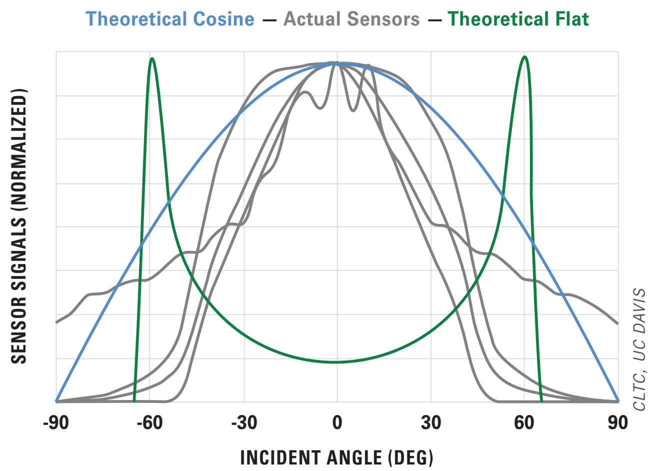

FIGURE 70 *Directional sensitivity of various commercially available photosensors, along with a cosine response, where the sensitivity drops by the cosine of the incident angle, and a "flat" response, which is a computed sensitivity aimed at producing the same signal from all incoming directions within a confined field of view (FOV).*

ENERGY STANDARDS

ALTERATIONS

Alterations with proposed lighting power greater than 80 percent of the allowed lighting power are required to adhere to the automatic daylighting control requirements defined in **Section 130.1(d)**.

Alterations with proposed lighting power that is 80 percent or less of the allowed lighting power do not need to meet the automatic daylighting control requirements defined in **Section 130.1(d)**.

A third option is available for alteration projects in small buildings or tenant spaces (5,000 ft^2 or less) that include 'one-for-one luminaire alterations' to more than 50 luminaires. For this alteration scenario, existing luminaires can be retrofit with new luminaires or component modifications that achieve at least 40% power reductions over pre-alteration luminaires. Projects utilizing this option do not need to meet the automatic daylighting control requirements defined in **Section 130.1(d)**.

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PHOTOSENSING

Photosensing refers to using one or more photosensors to determine available daylight. While it sounds straightforward, it is in fact, very challenging and even today, the challenge has not been entirely resolved. The main components of photosensor-based controls are one or more photosensors and a logic controller, which receives the signal(s) of the photosensor(s) as input and sends a signal to the power controller of the electric lighting as output. Power controllers include the dimming ballast for fluorescent and HID sources and dimming drivers for SSL sources.

Photosensors can vary significantly in terms of spectral and directional sensitivity, both of which are most important for effective sensing of available daylight. The spectral power sensitivity depends on the light sensing technology of the photosensor and ideally should match human Photopic sensitivity (**FIGURE 69**). The directional sensitivity depends on the optical elements of the photosensor that direct the incident light towards the light sensitive element (**FIGURE 70**).

Traditionally, there have been two main photosensing strategies: open- and closed-loop sensing.

OPEN-LOOP SENSING

In open-loop sensing, the signal of the photosensor used to determine daylight levels is not affected by the electric lighting being controlled. Open-loop photosensing has been traditionally implemented with photosensors placed either outdoors, aimed towards the sky, or indoors, aimed towards windows or skylights with their field of view (FOV) limited to outdoor surfaces through the windows or skylights (**FIGURE 71**). Open loop sensing usually requires photosensors with extensive range to capture the high outdoor daylight levels, which vary dramatically from 1 fc at the beginning and the end of the day, to more than 10,000 fc under mid-day clear sky conditions. The main disadvantage of open-loop sensing is that it does not reflect indoor daylight levels and often results in over-dimming, as outdoor daylight levels usually increase very rapidly to high levels, making it hard to map on the relatively small range of low levels indoor by both electric and daylight.

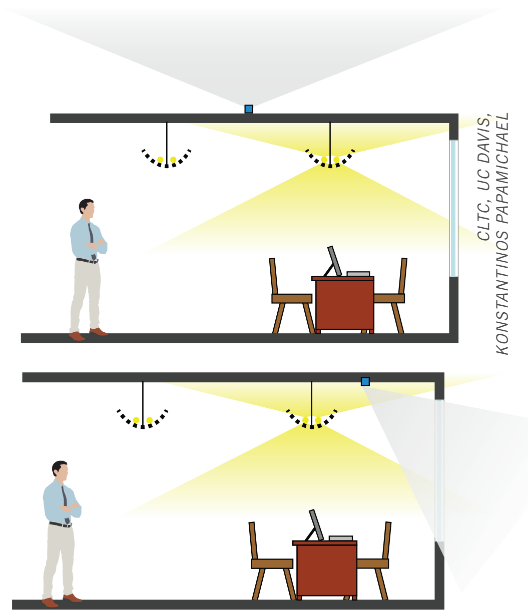

FIGURE 71 *Schematic drawings showing placement and field of view of photosensors for open-loop photo sensing.*

CLOSED-LOOP SENSING

In closed-loop sensing, the signal of the photosensor used to determine daylight levels is affected by the electric lighting being controlled. Closed-loop photo sensing has been traditionally implemented with photosensors that are placed indoors, aimed away from daylight apertures (**FIGURE 72**). Photosensor placement, direction and field of view are the most challenging decisions in closed-loop photo sensing. Ideally, closed-loop photosensors should be placed and oriented so that their signal is equally affected by daylight and electric light. Unbalanced contributions can be ineffective in sensing either daylight changes or electric light changes (**FIGURE 73**), since their field of view includes interior surfaces that are equally affected by electric light and daylight, which requires significant understanding of how daylight affects the brightness of interior surfaces throughout the year for different locations and window or clerestory orientation.

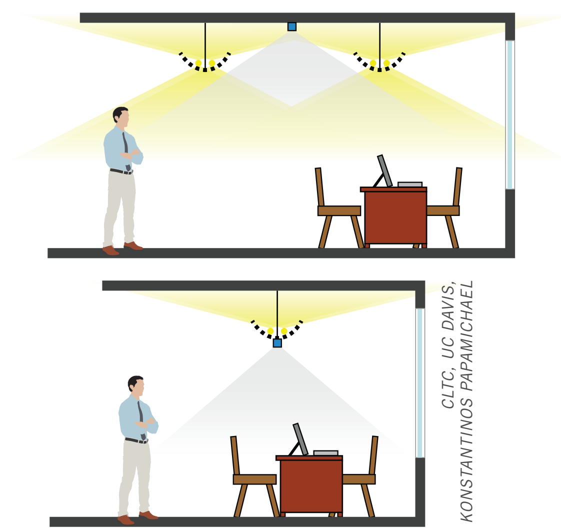

FIGURE 72 *Schematic drawings showing placement and field of view of photosensors for closed-loop photo sensing.*

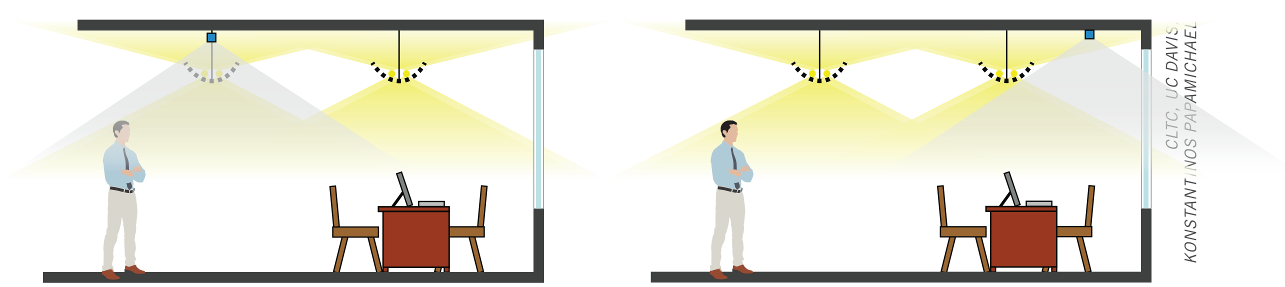

FIGURE 73 *Schematic drawings showing ineffective placement of photosensors that result in unreliable sensing of daylight changes (left) and electric lighting (right).*

ENERGY CODE

ADDITIONS

Projects adding square footage are considered additions and must meet Energy Code requirements. Lighting plans for building additions must meet the same mandatory and prescriptive or performance standards as lighting installed for a new construction project. If the performance approach is followed, the lighting power for the general lighting systems may be traded off with other building features.

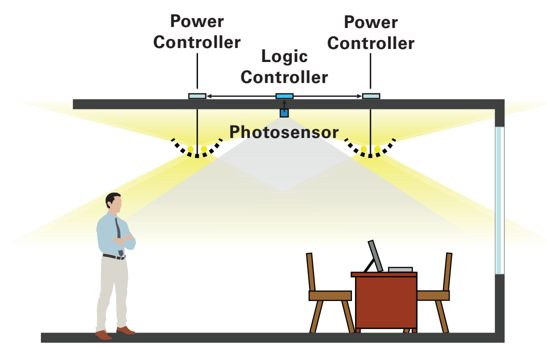

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FIGURE 74 *Schematic drawing showing the components of photosensor-based controls for daylight harvesting.*

CONTROL ALGORITHMS

Both open- and closed-loop approaches use algorithms, which are executed by the logic controller. These algorithms take the photosensor signals to determine daylight changes as input and the appropriate signal that is sent as output to the electric lighting power controller(s), which, in turn, adjusts the dimming level of the electric lighting (**FIGURE 74**). Power controllers use internal functions that map lamp output to supplied power (**FIGURE 75**).

There are two main algorithmic approaches that have been traditionally used to translate photosensor signals into signals that are sent to the power controller managing the electric lighting output. The first is the constant set point, or threshold algorithm, and the second is the sliding set point, or proportional algorithm. Both approaches require commissioning, which is the process of installing and configuring the overall control system on site. This includes photosensor placement and determination of key values for control parameters that customize the operation of the control system for the specific application. For more information, please see the **Commissioning** section of this guide.

CONSTANT SET POINT ALGORITHMS

The constant set point algorithm is applicable only to closed-loop sensing approaches and aims at adjusting electric lighting levels to maintain a specific photosensor signal, which is set on site during the commissioning of the control system, and is referred to as the set point. The set point must be equal to or higher than the sensor signal from the electric lighting

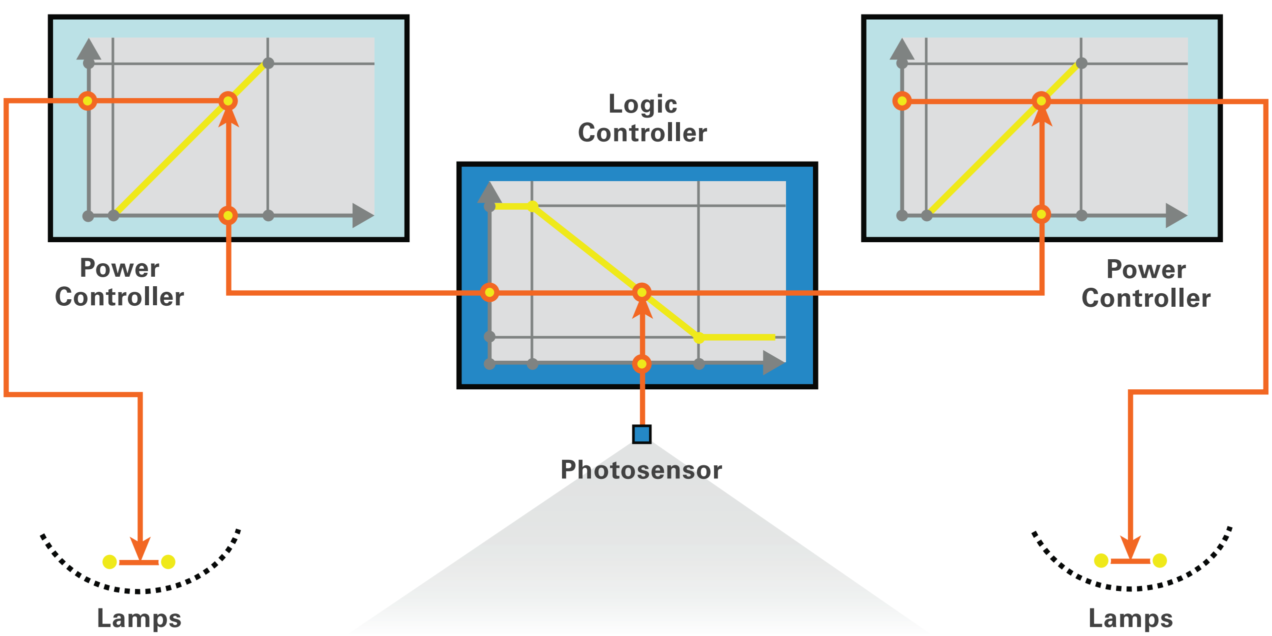

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FIGURE 75 *Schematic drawing showing the translation of the photosensor signal into a dimming signal to power controllers, which in turn translate that signal to power delivered to from the lamps.*

at full output, excluding contributions from daylighting. This signal can be determined effectively during night time with the electric lighting at full output. It can also be approximated during daytime, as the difference of the photosensor signal produced by turning the electric lighting ON and OFF.

There are two common approaches to maintaining the constant set point with somewhat similar outcomes (**FIGURE 76**). The first is based on setting a time delay before sending a signal to the power controller after the signal of the photosensor deviates from the set point. The second approach is based on setting a range encompassing the set point, defining the maximum allowable deviation above and below the set point. After the time delay of the signal being below or above the set point (first approach) or when the photosensor signal reaches the lower or higher points of the range (second approach), the logic controller sends "dim up" or "dim down" signals to the power controller(s) of the electric lighting system. Specific signals to power controllers depend on the lighting control protocol used. **FIGURE 77** shows measured responses of constant set point algorithms of commercial systems, producing 0–10 Volt output signals, which is a widely used control protocol. For more information on lighting control protocols, please see the publication **"Nonresidential Lighting and Electrical Power Distribution—A Guide to Meeting or Exceeding California's 2019 Building Energy Efficiency Standards."**

SLIDING SET POINT ALGORITHM

The sliding set point algorithm is applicable to both closed- and open-loop sensing approaches and generates an output to the power controller(s) that is proportional to the signal of the photosensor between a range defined by an offset point and a sliding set point, both of which are determined on site during the commissioning process (**FIGURE 78**).

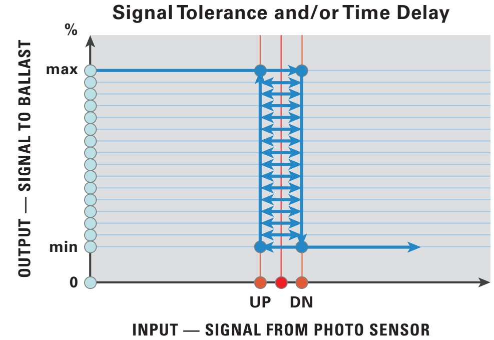

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FIGURE 76 *Schematic diagram showing the operation of typical constant set point algorithms, which is realized either by setting a time-delay before taking action after a deviation of the photosensor signal from the set point, or by setting a range that defines the maximum allowable deviation from the set point.*

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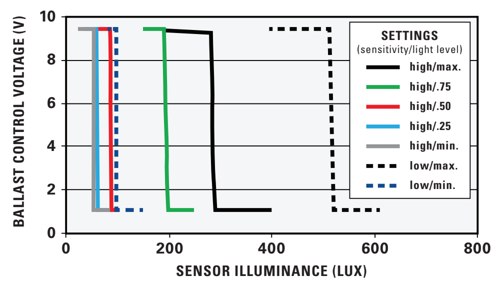

FIGURE 77 *Examples of constant set point algorithms at different sensitivity and light level combinations.*

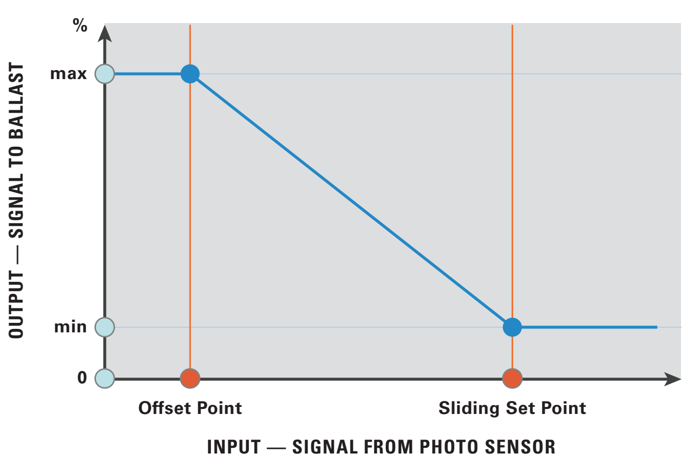

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FIGURE 78 *Schematic drawing showing the operation of typical sliding set point algorithms, where the signal to the power controller is proportional to the photosensor signal, with the proportionality relationship managed through a sliding set point.*

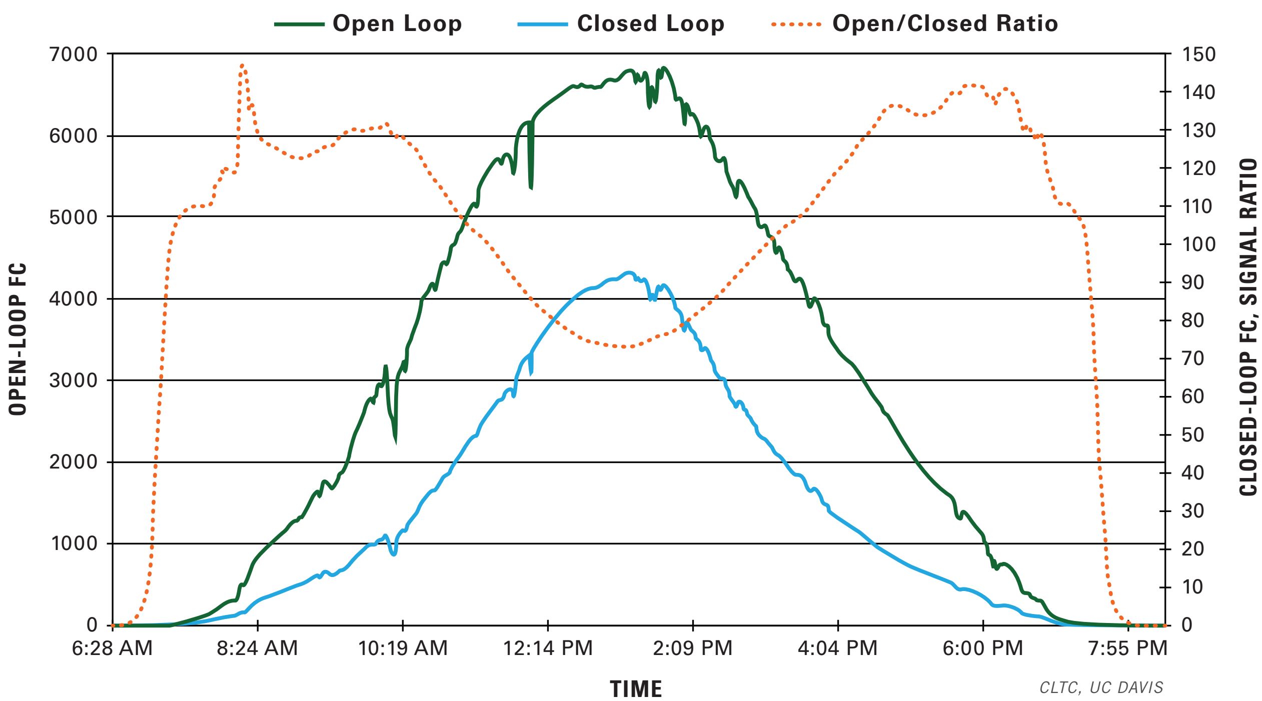

FIGURE 79 *Measured photosensor signals of open- and closed-loop sensing approaches and their ratio (open/closed loop). The open-loop sensing signal and open/closed ratio are measured on the left axis, with maximum values approaching 7,000 fc. The closed-loop sensing signal is measured on the right axis, with maximum values approaching 150 fc, meaning the closed-loop line would be barely visible if it were plotted against the left axis. The open/closed loop ratio shows the two signals are not proportional, especially during the sunrise and sunset periods.*

SHORTCOMINGS OF SINGLE PHOTOSENSOR APPROACHES

Both open- and closed-loop photo sensing approaches have advantages and disadvantages in terms of reliable sensing of daylight changes and cost associated with commissioning. The challenges of photosensing approaches are mostly evident during sunrise, sunset and partly cloudy sky periods, when daylight changes occur. Partly cloudy skies are the most challenging, as daylight changes can be dramatic as clouds pass in front of the sun, blocking direct sunlight.

The main disadvantage of open-loop, single photosensor approaches is the rapid change of outdoor light levels during sunrise and sunset periods, which is usually not reflected indoors (**FIGURE 79**). The dramatic open-loop changes during sunrise and sunset result in fast-paced over-dimming of the electric lighting system, which results in periods with lower than desired overall illuminance levels.

The main disadvantage of closed-loop, single photosensor approaches is the inability to differentiate between signal changes caused by daylight changes and signal changes caused by changes in the geometry or reflectance of the surfaces within the field of view of the sensor. The latter includes changes in floors, walls and furniture, but also occupants moving within the sensor's field of view. In long-term space changes, such as changes to interior surface color or texture and furniture arrangement, both open- and closed-loop systems need to be recommissioned to reflect the space changes, which adds to the cost of maintaining the system, as commissioning requires significant understanding of daylighting fundamentals and principles and extensive experience.

A common approach to addressing short-term changes, such as occupants with different colors of clothing passing under photosensors, is to include a time-delay in the algorithms before taking action, hoping that within the time-delay period, the person(s) will have passed and the signal of the photosensor will return to its previous level. This raises the issue of the length of the time delay. Short time-delays will not be able to account for low-speed person movement, while long-time delays increase the risk of ignoring a true daylight change, such as the sun blocked by passing clouds. The latter produces a dramatic change in indoor light levels, which is certainly perceived by occupants. Without immediate adjustment to the electric lighting output, occupants often consider the system ineffective and occasionally disable it, which can be easily done by covering the photosensor with tape, continuously keeping the electric lighting ON.

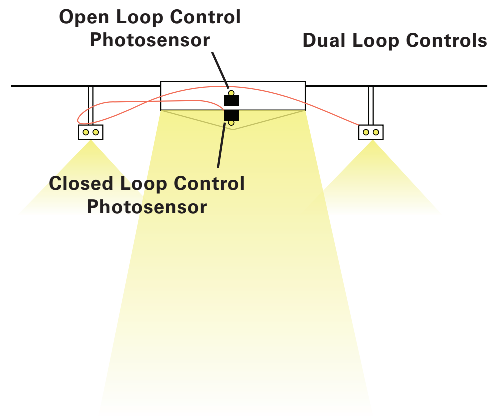

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FIGURE 80 *Schematic drawing showing dual-loop sensing approach in skylight applications.*

DUAL-LOOP AND REDUNDANT PHOTO-SENSING APPROACHES

The realization of the shortcomings of open- and closed-loop sensing approaches has led to the development of the dual-loop and redundant sensing approaches. The dual-loop approach was originally developed for skylight applications and it uses both open- and closed-loop sensing to reliably determine true daylight changes (**FIGURE 80**). The closed-loop photosensor is used to monitor light levels in the space, while the open-loop photosensor is used to help determine if the change of the signal of the closed-loop photosensor was produced by daylight changes. Compared to open-loop sensing for skylight applications, dual-loop has proven to be significantly more reliable, doubling the energy savings and eliminating complaints of low light levels during sunrise and sunset periods.

The dual-loop sensing approach can also be used in spaces with windows and clerestories. Moreover, a single open-loop photosensor can be paired with multiple closed-loop photosensors to serve a whole building.

Redundant sensing is equivalent to the dual-loop, but relies on the use of multiple closed-loop photosensors that collectively increase reliability of sensing daylight changes dramatically. Redundant sensing using luminaire integrated sensors may be the most reliable and cost-effective way to implement electric lighting controls for daylight harvesting.

Emerging dual-loop and redundant sensing technologies are expected to dramatically increase reliability and cost-effectiveness of electric lighting controls. Combined with SSL dimming, these approaches seem to remove all of the traditional barriers to implementing effective electric lighting controls for daylight harvesting.

CHAPTER 4

CONSTRUCTION, COMMISSIONING AND ACCEPTANCE TESTING

The design phase of a commercial building project with daylight harvesting is followed by the building construction, commissioning and acceptance testing phases. Each phase of the project is critical to realizing the full design intent for a high-performance building and specifically for realizing a high-performance daylight harvesting system. To properly install and commission the building systems, it is important to use trained workforces for each specific building system, such as the building's structural, envelope, mechanical, electrical and information technology systems.

CONSTRUCTION

During the design phase, it is critical to provide as much specificity in the building plans and documentation as possible to allow for the project team to fully realize the design intent. Additionally, it is recommended that the design team compile a document stating the design intent to detail the justification for each specified building component. This is especially important in instances where long timelines may preclude the procurement of a specific component. For instance, a component specified during the design phase may not be available at the time of installation, or the product part number may have been changed.

COMMISSIONING

ENERGY CODE

Energy Code, Section 120.8

ENERGY CODE

For newly constructed nonresidential buildings other than healthcare facilities with conditioned space of 10,000 ft^2 or more, the building design, construction and commissioning processes are defined in **Section 120.8**. This is broken down into the following standalone requirements:

Owner's or owner representative's project requirements (OPR): The energy-related expectations and requirements of the building.

Basis of design: A written explanation of how the design of the building systems and components meets the OPR shall be completed at the design phase of the building project.

Design phase design review: A mandatory design review kickoff meeting is required during the schematic design phase. The design review Certificates of Compliance documents must be completed by the designated design reviewer who adheres to the reviewer requirements.

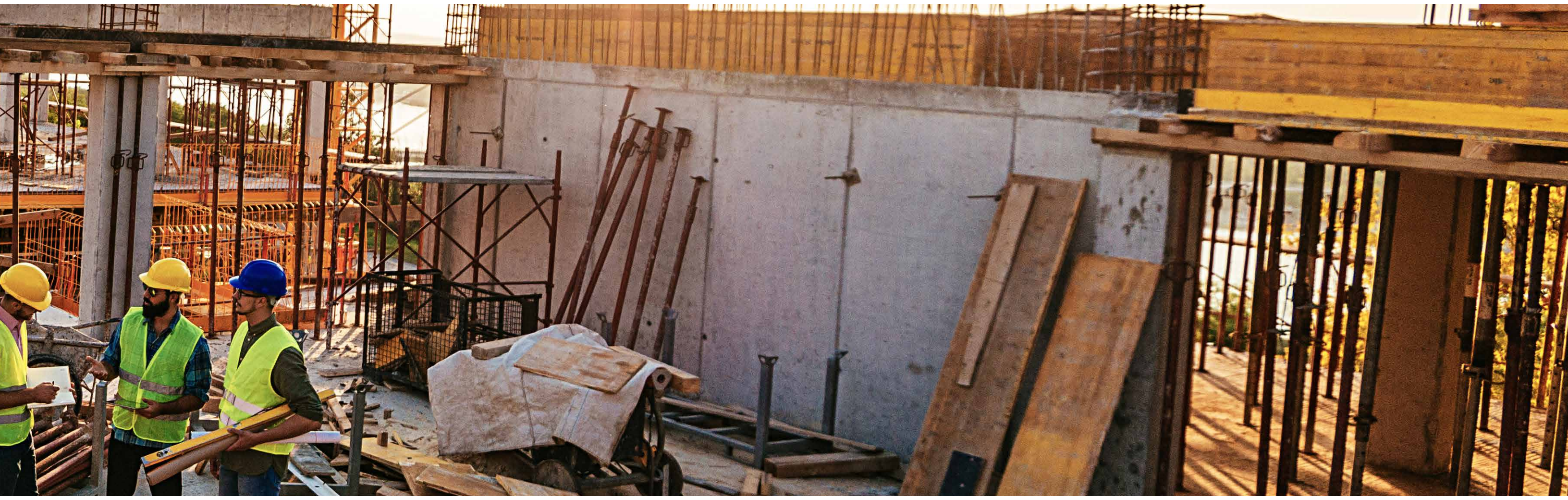
CONTINUED ON PAGE 67

The Energy Code requires specific building commissioning steps for newly constructed conditioned nonresidential buildings. Additionally, lighting control systems must be tested after they are installed and commissioned. Tests ensure that controls operate in accordance with the Energy Code and the building owner's requirements. Functional test results must also be included in commissioning documents.

ELECTRIC LIGHTING

Generally, commissioning electric lighting controls for daylight harvesting involves several steps:

1. Verification of luminaire types, placement and grouping based on daylit zones
2. Verification of installation and proper operation of clocks and photosensors
3. Adjustment of control parameters, such as photosensor set points for electric lighting dimming and time delays
4. Verification for proper operation of lighting controls during daylight changes



The photosensor signal depends on the geometry and reflectance of the surfaces within the field of view and the directional sensitivity of the photosensor. Unless the photo control system includes redundant sensing and automated calibration, it is important that the photosensor is installed so that the surfaces within its field of view are not going to be changing often and can accept equal levels of electric lighting and daylighting.

The verification of proper operation is the ultimate commissioning step and is best performed during times of daylight changes, such as sunrise, sunset and partly cloudy daytime periods. It is important that the commissioning of the electric lighting system happens after the interior design, including furniture, of the daylit space has been completed. The commissioning process should also include testing the effect of occupants on photosensor signals to make sure it is minimal or properly handled by automated calibration.

FENESTRATION

Currently, automated daylight management at the fenestration level is not yet widespread and there are no industry-accepted commissioning requirements or procedures. As daylight management systems respond to glare and the status of the electric lighting and HVAC systems, commissioning of daylight management systems should address all of these control criteria to ensure proper operation under a wide-range of scenarios.

As daylight management usually involves significant occupant control for non-energy related functions, such as view and privacy, it is important that the commissioning process includes testing of the harmonization of automated and manual controls, testing for alternative scenarios of manual controls overriding the automated operation and testing for when both automated and manual controls return back to harmonization.

ENERGY CODE

Energy Code, Section 120.8

Commissioning measures shown in the construction documents: Complete descriptions of all measures or requirements necessary for commissioning shall be included by the design team in the construction documents (plans and specifications).

Commissioning plan: Prior to permit issuance, a commissioning plan shall be completed to document how the project will be commissioned and shall be started during the design phase of the building project.

Functional performance testing: Functional performance tests shall demonstrate the correct installation and operation of each component, system and system-to-system interface in accordance with the acceptance test requirements.

Documentation and training: A Systems Manual and Systems Operations Training shall be completed.

Commissioning report: A complete report of commissioning process activities undertaken through the design, construction and reporting recommendations for post-construction phases of the building project shall be completed and provided to the owner or owner's representative.

For newly constructed nonresidential buildings with conditioned space of less than 10,000 ft^2, only the design review and commissioning measures shown in the construction document requirements apply.

ACCEPTANCE TESTING

For some building systems, additional function tests are required beyond commissioning, referred to as acceptance testing. Acceptance testing consists of visual inspection and functional performance tests of installed equipment, systems and controls. It was created to help increase Energy Code compliance by ensuring that lighting control systems are installed and operating correctly. Acceptance testing will identify any problems with the installation so that they can be corrected before the Certificate of Occupancy is issued. A properly functioning system saves energy and ensures that building owners and tenants realize the full benefits of an optimized electrical lighting control system and daylighting control system.

ENERGY CODE

Energy Code, Section 130.4

ACCEPTANCE TESTING

The Energy Code requires nonresidential buildings, high-rise residential buildings and hotel and motel buildings to comply with the applicable requirements found in **Section 130.4(a), 130.4(b), and 130.4(c)**. This includes the lighting control acceptance requirements, lighting control installation certificate requirements and the certification of the acceptance testing technicians.

Healthcare facilities are exempt from the Energy Code's acceptance testing requirements. Healthcare facilities comply with the applicable acceptance and installation documentation requirements of OSHPD.

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ACCEPTANCE TESTING

Acceptance testing helps ensure building equipment and systems perform properly. It is important to note that acceptance testing is not a replacement for the building commissioning requirements outlined in the previous section and **Section 120.8** in the Energy Code. The acceptance testing process is as follows:

1. **Plan Review** (installing contractors, engineer of record)
   Review plans and specifications to ensure they meet all Energy Code requirements. Typically done prior to signing a Certificate of Compliance.

2. **Construction Inspection** (installing contractor, engineer of record)
   Check that the equipment installed is capable of complying with the Energy Code requirements. Construction inspection also ensures that the equipment is installed and calibrated correctly.

3. **Functional Testing** (Certified Acceptance Test Technician)
   Acceptance tests are performed to ensure that all equipment performs as required by the Energy Code.

4. **Occupancy** (Enforcement Agency)
   Once all required Certificates of Acceptance are submitted, the enforcement agency completes final inspection and releases a Certificate of Occupancy.

Requirements specific to automatic daylight controls are provided below:

ENERGY CODE

LIGHTING CONTROL ACCEPTANCE REQUIREMENTS

Energy Code, Section 130.4

Before an occupancy permit is granted, indoor and outdoor lighting controls serving the building, area or site shall be certified as meeting the acceptance requirements for Energy Code compliance in accordance with **Section 130.4(a)**.

A Certificate of Acceptance shall be provided to the enforcement agency under **Section 10-103(a) of Part 1**, that certifies all lighting acceptance testing necessary to meet requirements of the Energy Code are completed and that the technician has followed the functional test requirements outlined:

CONSTRUCTION INSPECTION

Nonresidential Appendix, Section 7.6

After completion of construction, an inspection is required to verify that automatic electric lighting controls are properly installed and fully functional in accordance with each applicable requirement in **Section 130.1(d)**.

FUNCTIONAL TESTING

All photo controls serving more than 5,000 ft^2 of daylit area shall undergo functional testing. Photo controls that are serving smaller spaces may be sampled as follows:

For buildings with up to five (5) photo controls, all photo controls shall be tested. For buildings with more than five (5) photo controls, sampling may be done on spaces with similar sensors and cardinal orientations of glazing; sampling shall include a minimum of 1 photo control for each group of up to 5 additional photo controls. If the first photo control in the sample group passes the functional test, the remaining building spaces in the sample group also pass. If the first photo control in the sample group fails the functional test, the rest of the photo controls in the group shall be tested. If any tested photo control fails the functional test, it shall be repaired, replaced or adjusted until it passes the test.

CONTINUED ON PAGE 70

2019 NRCA-LTI-03-A

The Automatic Daylighting Control Acceptance document is one of the compliance forms that must be completed by an acceptance tester.

To view and download compliance forms, visit **energycodeace.com/NonresidentialForms/2019**.

STATE OF CALIFORNIA
AUTOMATIC DAYLIGHTING CONTROL ACCEPTANCE DOCUMENT
CEC-NRCA-LTI-03-A (Revised 01/20) CALIFORNIA ENERGY COMMISSION

CERTIFICATE OF ACCEPTANCE		NRCA-LTI-03-A
Automatic Daylighting Control Acceptance Document		(Page 1 of 6)
Project Name:	Enforcement Agency:	Permit Number:
Project Address:	City:	Zip Code:

Compliance Results: [COMPLIES *or* DOES NOT COMPLY]	Enforcement Agency Use: Checked by/Date

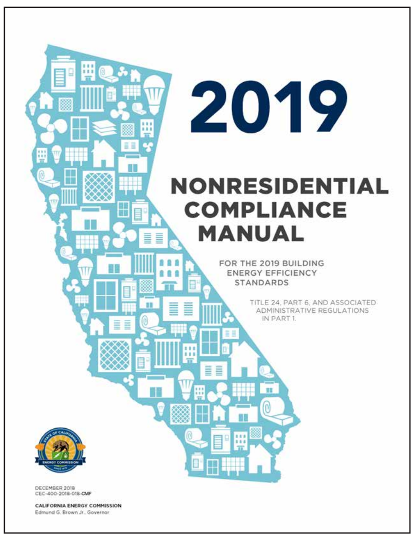
Intent:	This document is used to demonstrate compliance with acceptance requirements in §130.4(a)3 and Reference Nonresidential Appendix NA7.6.1 for automatic daylighting controls. Attach additional sets of pages 2 through 5, as required, for all controls that must be tested.

Indicate all control methods used for this project:	
☐	Continuous dimming controls *(Sections A and B-1 of this document should be completed)*
☐	Stepped switching / stepped dimming controls *(Sections A and B-2 of this document should be completed)*

2019 NONRESIDENTIAL COMPLIANCE MANUAL

For more information on acceptance requirements, refer to Chapter 13 of the 2019 Nonresidential Compliance Manual.

To view and download the 2019 Nonresidential Compliance Manual, visit **www.energy.ca.gov/programs-and-topics/programs/building-energy-efficiency-standards/2019-building-energy-efficiency**.



ENERGY CODE

Nonresidential Appendix, Section 7.6.1

For each photo control to be tested, do the following: test each group of lights controlled separately by the photo control according to the following protocol. In all interior spaces other than parking garages, a separate test shall be conducted for daylighting control of the primary sidelit zone separate from the secondary sidelit zone.

CONTINUOUS DIMMING CONTROL SYSTEMS

This requirement is for systems that have more than 10 levels of controlled light output in a given zone:

Step 1: Identify the minimum daylighting location in the controlled zone (Reference Location). This can be identified using either the Illuminance Method or the Distance Method.

- **Illuminance Method**
  1. Turn OFF controlled lighting and measure daylight illuminance within zones illuminated by controlled luminaires.
  2. Identify the reference location; this is the task location with lowest daylight illuminance in the zone illuminated by controlled luminaires. This location will be used for illuminance measurements in subsequent tests.
- **Distance Method**
  1. Identify the task location within the zone illuminated by controlled luminaires that is farthest away from daylight sources. This is the reference location and will be used for illuminance measurements in subsequent tests.

Step 2: No daylight test. Simulate or provide conditions without daylight. Verify and document the following:

1. Automatic daylight control system provides appropriate control so that electric lighting system is providing full light output unless otherwise specified by design documents.
2. Document the reference illuminance, which is the electric lighting illuminance level at the reference location identified in Step 1.
3. Light output is stable with no discernible flicker.

Step 3: Full daylight test. Simulate or provide bright conditions. Verify and document the following:

1. Lighting power reduction is at least 65% under fully dimmed conditions and light output is stable with no discernible flicker.
2. Only luminaires in daylit zones are affected by daylight control. If the daylighting controls control lighting outside of the daylit zones, including those behind obstructions as described in **Section 130.1(d)1**, the control system is not compliant.
3. If a Power Adjustment Factor is claimed for Daylight Dimming plus OFF controls in accordance with **Section 140.6(a)2H**, compliant systems shall automatically turn OFF the luminaires that are receiving this credit. This portion of the full daylight test does not apply to lighting systems that are not claiming a Power Adjustment Factor for Daylight Dimming plus OFF controls.

CONTINUED ON PAGE 71

ENERGY CODE

Nonresidential Appendix, Section 7.6.1

Step 4: Partial daylight test. Simulate or provide daylight conditions where illuminance (fc) from daylight only at the reference location is between 60 and 95% of reference illuminance (fc) documented in Step 2. Verify and document the following:

1. Measure that the combined illuminance of daylight and controlled electric lighting (fc) at the reference location is no less than the electric lighting illuminance (fc) at this location during the no daylight test documented in Step 2.2.
2. Measure that the combined illuminance of daylight and controlled electric lighting (fc) at the reference location is no greater than 150% of the reference illuminance (fc) documented in Step 2.2.
3. Light output is stable with no discernible flicker.

Energy Code, Section 130.4

LIGHTING CONTROL INSTALLATION CERTIFICATE REQUIREMENTS

To be recognized for compliance with the Energy Code, an Installation Certificate shall be submitted in accordance with **Section 10-103(a)** for any lighting control system, Energy Management Control System, track lighting integral current limiter, track lighting supplementary overcurrent protection panel, interlocked lighting system, lighting Power Adjustment Factor or additional wattage available for a videoconference studio, in accordance with the following requirements, as applicable:

1. Certification that when a lighting control system is installed to comply with lighting control requirements in the Energy Code, it complies with the applicable requirements of **Section 110.9**; and complies with **Reference Nonresidential Appendix NA7.7.1**.
2. Certification that when an Energy Management Control System is installed to function as a lighting control required by the Energy Code, it functionally meets all applicable requirements for each application for which it is installed, in accordance with **Sections 110.9, 130.0 through 130.5, 140.6 through 150.0 and 150.2**; and complies with **Reference Nonresidential Appendix NA7.7.2**.
3. Certification that interlocked lighting systems used to serve an approved area comply with **Section 140.6(a)1** and comply with **Reference Nonresidential Appendix NA7.7.5**.
4. Certification that lighting controls installed to earn a lighting Power Adjustment Factor (PAF) comply with **Section 140.6(a)2** and comply with **Reference Nonresidential Appendix NA7.7.6**.
5. Certification that additional lighting wattage installed for a videoconference studio complies with **Section 140.6(c)2Gvii**; and complies with **Reference Nonresidential Appendix NA7.7.7**.

ACCEPTANCE TEST TECHNICIAN CERTIFICATION

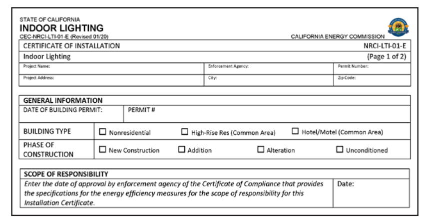
When certification is required by Title 24, Part 1, **Section 10-103.2**, the acceptance testing specified by **Section 130.4** shall be performed by a Certified Lighting Controls Acceptance Test Technician (CLCATT).

If the CLCATT is operating as an employee, the CLCATT shall be employed by a Certified Lighting Controls Acceptance Test Employer. The CLCATT shall disclose on the Certificate of Acceptance a valid CLCATT certification identification number issued by an approved Acceptance Test Technician Certification Provider. The CLCATT shall complete all Certificate of Acceptance documentation in accordance with the applicable requirements in **Section 10-103(a)4**.

CERTIFICATES OF INSTALLATION

These forms, signed by licensed professionals, certify that the lighting installed for the project corresponds with the lighting proposed on the Certificates of Compliance. NRCI-LTI-01-E is required for all indoor lighting.

To view and download compliance forms, visit **energycodeace.com/NonresidentialForms/2019**.



STATE OF CALIFORNIA
INDOOR LIGHTING
CEC-NRCI-LTI-01-E (Revised 01/20) CALIFORNIA ENERGY COMMISSION

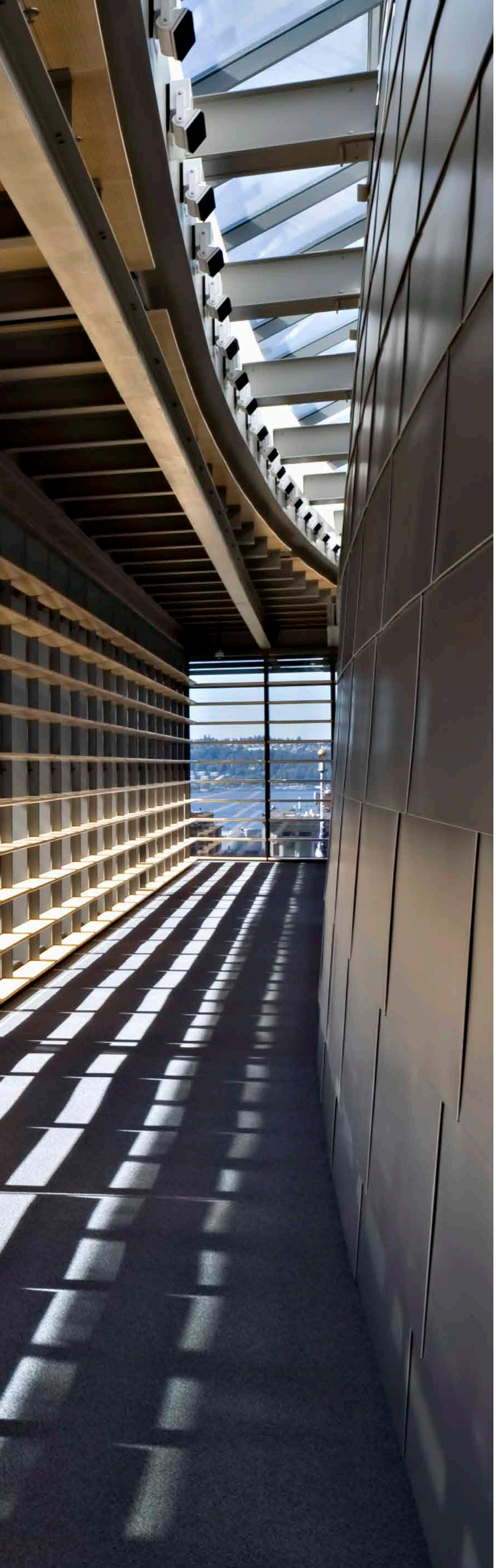
CERTIFICATE OF INSTALLATION		NRCI-LTI-01-E
Indoor Lighting		(Page 1 of 2)
Project Name:	Enforcement Agency:	Permit Number:
Project Address:	City:	Zip Code:

GENERAL INFORMATION				
DATE OF BUILDING PERMIT:	PERMIT #			
BUILDING TYPE	☐ Nonresidential	☐ High-Rise Res (Common Area)	☐ Hotel/Motel (Common Area)	
PHASE OF CONSTRUCTION	☐ New Construction	☐ Addition	☐ Alteration	☐ Unconditioned

SCOPE OF RESPONSIBILITY	
Enter the date of approval by enforcement agency of the Certificate of Compliance that provides the specifications for the energy efficiency measures for the scope of responsibility for this Installation Certificate.	Date:

ACCEPTANCE TESTING (AT) TECHNICIAN TRAINING

CALCTP **(calctp.org)** *and NLCAA* **(nlcaa.org)** *are two training and certification programs recognized and approved by the Energy Commission to carry out lighting controls acceptance testing as required by the Energy Code.*



CHAPTER 5

IN CLOSING

As solar energy has been a main factor in human evolution, daylight offers significant biological benefits in terms of circadian health and excellent color vision. Introducing daylighting in interior spaces offers additional psychological benefits by providing connection to the outdoors. The main challenge in realizing these benefits is the very high intensity and continuous change of direction of the direct solar radiation, which can produce significant luminous and thermal discomfort without proper shading. Introducing daylight in buildings through envelope apertures also affects energy requirements for lighting and HVAC systems.

DAYLIGHTING AND ENERGY EFFICIENCY

Daylighting can reduce electric lighting requirements for ambient and task lighting in work spaces through use of technologies that adjust electric lighting output based on available daylight. The effects of daylight on HVAC loads are more complicated, as it affects both heating and cooling loads, either directly (through fenestration convective and conductive heat gain and loss) and also through solar heat gain, which may be beneficial during heating periods but not during cooling periods. Moreover, daylight apertures can also be used for natural ventilation and cooling, further affecting HVAC loads.

The net annual impact of daylight on energy is the results of gains and losses varying throughout the year. Building location dictates climatic conditions and sun paths, while orientation of daylight apertures and external obstructions greatly affect incident solar radiation. As cooling is the most important electricity load in commercial buildings in California, avoiding solar heat gain is critical to contributing to building energy efficiency but can also compromise view and reduce electric lighting savings because of reduced indoor daylight levels. The latter is also true when shading systems are used to provide privacy or reduction of direct solar penetration for managing glare.

If energy were not an issue and view were the only benefit of daylight with glare from direct sun the only penalty, daylighting design would be very easy and simple, as low transmittance glazing provides view and resolves the glare issue. Realizing the energy benefits of daylighting requires significant balancing of all performance aspects affected by multiple decisions by different disciplines, from site selection and architectural design to fenestration, interior and lighting design. Realization of the benefits is also affected by decisions made during building construction, commissioning and operation.

CALIFORNIA GREEN BUILDING STANDARDS

The Energy Code only aims to specify minimum performance requirements. For example, a building that just meets Energy Code requirements is, by definition, the worst energy-performing building allowed by law in California. However, effective daylight designs can offer much higher performance, not only in terms of energy efficiency, but also in terms of important non-energy performance aspects, such as comfort and health.

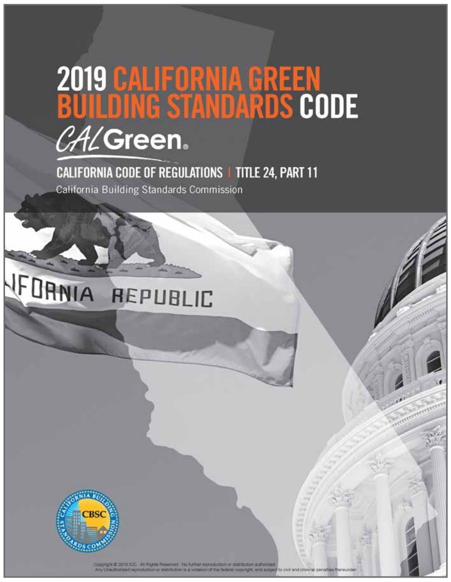
The California Building Standards Commission developed the California Green Building Standards Code, California Code of Regulations (CALGreen) in 2007 to address the California Global Warming Solutions Act of 2006 (AB 32) with the goal of a minimum of 80 percent reduction in greenhouse gas (GHG) emissions by the year 2050, compared to 1990 levels. CALGreen contains both mandatory and voluntary green building measures.

CALGreen's purpose is to 'improve public health, safety and general welfare by enhancing the design and construction of buildings through the use of building concepts having a reduced negative impact or positive environmental impact and encouraging sustainable construction practices in the following categories:

- Planning and design,
- Energy efficiency,
- Water efficiency and conservation,
- Material conservation and resource efficiency and
- Environmental quality.'

CALGreen is one step toward more efficient and responsible building design.

CALIFORNIA GREEN BUILDING STANDARDS CODE OF REGULATIONS (CALGREEN)
Detailed information on how to effectively comply with mandatory measures and implement voluntary measures can be found here: **www.dgs.ca.gov/BSC/Resources/Page-Content/Building-Standards-Commission-Resources-List-Folder/CALGreen**.



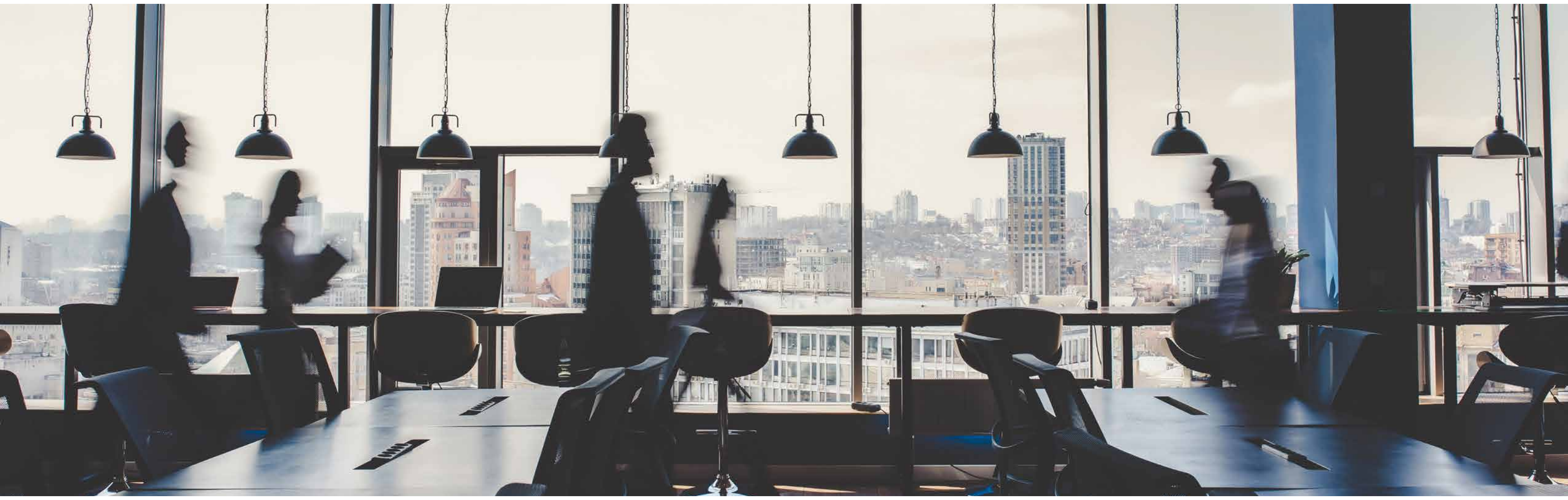
DAYLIGHT MANAGEMENT

Optimizing daylight performance is a challenging design task, as there are many performance aspects to be considered that depend on building and space type and are affected by a wide range of contextual parameters, such as building and space site and orientation. Such multi-criterion optimizations require prioritization of performance aspects; for example, keeping human comfort and health as top priorities, followed by energy efficiency.

Optimization of daylighting performance requires not only managing the electric lighting output based on available daylight, but also managing daylight transmittance through daylight apertures. Daylight management requires implementation of dynamic fenestration systems that automatically change status based on indoor and outdoor conditions, such as occupancy, daylight levels and the status of electric lighting and HVAC systems.

BENEFITS OF DAYLIGHT MANAGEMENT
Managing daylight penetration based on outdoor and indoor environmental conditions can greatly increase daylight harvesting benefits, and not only energy benefits, but also psychological, physiological and biological benefits.

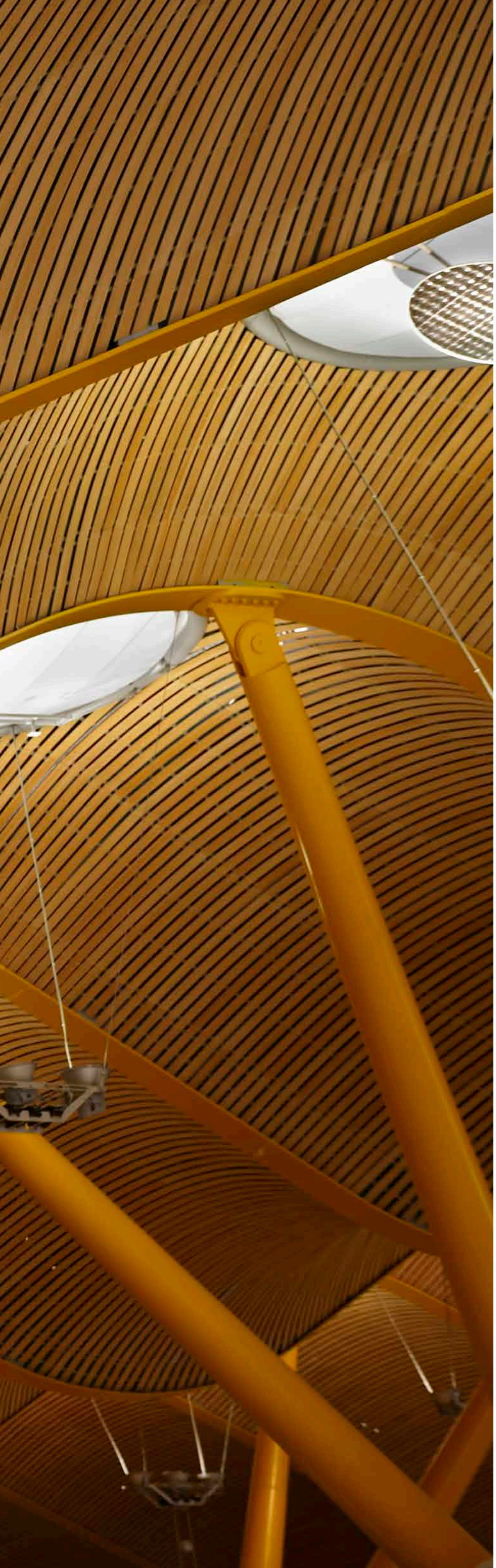
Automated daylight management at the aperture level is required in many applications to realize the minimal energy savings resulting from electric lighting controls. Daylight management is required in most applications to control glare from direct solar penetration. It is usually achieved through use of shading systems and dynamic glazings. Manual operation of such systems can result in dramatic reduction of electric lighting savings as occupants usually respond to needs, such as closing blinds to block direct solar penetration



or privacy, but do not respond to opportunities, such as opening the blinds when the sun has passed or privacy is no longer needed. Moreover, automated daylight management can greatly reduce energy loads during vacancy periods when occupants are not present to make adjustments. Such benefits include reduction in HVAC loads through control of direct solar penetration and natural ventilation and cooling through venting fenestration systems.

Electric lighting and HVAC controls can be autonomous by operating effectively based on photosensor and temperature and humidity sensors, respectively. Fenestration controls, however, also require information about the status of the electric lighting and HVAC systems to be effective in reducing energy and peak demand. The rapidly decreasing costs of sensors and communications is increasing development and marketing of integrated controls that support communication between fenestration controls and lighting and HVAC systems. Communication with HVAC systems is most important, as daylight management can result in significantly different operation during heating and cooling periods and effectively realize natural ventilation and cooling.

The continuously decreasing cost of sensors and communications is resulting in an increase of integrated controls for daylight management, electric lighting and HVAC. Eventually, they will become standard practice, maximizing both comfort and energy performance.



APPENDIX

GLOSSARY

A

Accent or display lighting: Lighting provided by directional light sources to illuminate specific areas or objects, such as display merchandise. Accent lighting sources can be recessed, surface mounted or mounted to a pendant, stem or track.

Ambient and general lighting: Lighting provided by non-directional light sources to provide low level illumination for comfortable navigation through spaces. Ambient lighting is generally supplemented by **task lighting** and **accent lighting**.

Astronomical time-switch control: An automatic lighting control device that switches lights ON or OFF at specified times of the day, or at times relative to astronomical events, such as sunset and sunrise. These devices can account for geographic location and calendar date and are commonly used in daylight harvesting applications.

Automatic daylight controls: Electric lighting control devices that automatically adjust lighting levels based on available daylight. They are usually based on astronomical time clocks and signals from photosensors.

C

Color rendering index (CRI): A color fidelity metric for light sources, based on chromaticity shifts of selected color samples compared to daylight for high CCT sources and incandescent light for low CCT sources.

D

Daylight: Radiation emitted by the sun, including the radiation scattering effects of the atmosphere.

Daylight autonomy: Percent of occupied time that daylight alone meets a specified work plane illuminance at a particular point in space. **Spatial daylight autonomy** refers to the percent of space that meets or exceeds a specific daylight autonomy.

Daylighting: The practice of utilizing daylight in buildings to provide view and illumination.

Daylit zone: The floor area under skylights or next to windows. The Energy Code includes building and lighting control requirements for specific types of daylit zones, including Primary Sidelit, Secondary Sidelit and Skylit zones.

Decorative lighting: Lighting provided for aesthetic purposes that is not meant to provide **ambient**, **task** or **accent lighting**.

Dimmer: A lighting control device that adjusts the light output of an electric lighting source by decreasing or increasing the power delivered to that system. **Step Dimmers** provide end users with one or more distinct light level settings (or steps) between maximum light output and OFF. **Continuous Dimmers** offer finer, more subtle control over a continuous range between maximum light output and the OFF setting.

E

Energy Management Control System (EMCS): A computerized control system designed to regulate energy consumption by supporting monitoring and control of the operation of one or more building systems, such as lighting and HVAC. An EMCS can also be programmed to provide automated control based on signals from sensors and utilities.

F

Fenestration: All glazed apertures in the building envelope that bring daylight in interior spaces.

Fluorescent: A low-pressure mercury electric discharge lamp in which a phosphor coating transforms some of the mercury ultraviolet energy into visible light.

Footcandle (fc): A unit of illuminance, commonly abbreviated as fc. One footcandle is one lumen per square foot (lm/ft^2).

G

Glass: An inorganic transparent material composed of silica (sand), soda (sodium bicarbonate), lime (calcium carbonate) and small quantities of alumina, boric or magnesia oxides.

Glazing: The combination of glass, plastic panes and coatings in a window, door or skylight.

H

High intensity discharge (HID) lamp: An electric discharge lamp in which the light-producing arc is stabilized by bulb wall temperature. HID lamps include groups of lamps known as **mercury**, **metal halide** and **high pressure sodium**.

High Pressure Sodium lamp: A **high intensity discharge (HID)** lamp in which light is produced by radiation from sodium vapor operating.

I

Illuminance: A measure of the density of incident light output on a surface (i.e., lumens per area). The unit is lux (lx) when the area is measured in square meters and footcandle (fc) when the area is measured in square feet.

Incandescent lamp: An electric lamp in which a filament gives off light when heated by an electric current.

L

Light-emitting diode (LED) Luminaire: A complete lighting unit consisting of LED-based light emitting elements and a matched driver together with parts to distribute light, to position and protect the light-emitting elements and to connect the unit to a branch circuit.

Luminaire: A light source consisting of a housing for lamp(s) and optics for specific light distributions.

Luminance (L): The intensity of light emitted from a light source or reflected off a surface, normalized by the area of the light source or the reflecting surface, projected on a plane vertical to the direction of view towards the light source or the surface (i.e., intensity or lumens per solid angle) per area. The units are Nit (cd/m^2) and FootLambert (cd/ft^2).

M

Mandatory measures checklist: A form used by the building plan checker and field inspector to verify a building's compliance with the prescribed list of mandatory features, equipment efficiencies and product certification requirements. The documentation author indicates compliance by initialing, checking or marking N/A (for not applicable) in the boxes or spaces provided for the designer.

Mercury lamp: A **high intensity discharge (HID)** lamp in which the major portion of the light is produced by radiation from mercury.

Metal Halide lamp: A **high intensity discharge (HID)** lamp in which the major portion of the light is produced by radiation of metal halides and their products of dissociation, possibly in combination with metallic vapors, such as mercury. Includes clear and phosphor-coated lamps.

Multi-level lighting control: A lighting control device that adjusts the output of electric lighting sources in multiple discrete steps.

O

Occupancy sensor: A device that detects occupants, using motion or noise sensing as a proxy.

P

Pendant: A luminaire that is suspended from the ceiling.

Photo controls: Automated lighting controls based on the signal of one or more photosensors, usually used for daylight harvesting.

R

Reach codes: Under state law, local ordinances that allow local jurisdictions to adopt building energy efficiency standards that are more stringent than the Energy Code, through an approval process by the Energy Commission.

Readily accessible: Capable of being reached quickly for operation, repair or inspection, without climbing or removing obstacles or resorting to using portable access equipment.

S

Skylight: A daylight aperture on a roof having a slope of less than 60 degrees from the horizontal plane.

Solar-optical properties: The aggregated effect of spectral properties (i.e., the transmittance, reflectance and absorptance across the solar and visible parts of the spectrum, respectively).

Solid-state lighting (SSL): A type of lighting technology that creates luminous output using semi-conductors, as opposed to filaments, plasma or gas. Examples of solid-state lighting technologies include semiconductor light-emitting diodes, organic light-emitting diodes and polymer light-emitting diodes.

T

Task lighting: Lighting designed to meet specific illumination needs for specific tasks.

Track lighting: An electric lighting system that utilizes luminaires mounted to a track, rail or cable.

W

Watt: The International System of Units (SI) unit of power, equivalent to one joule per second, corresponding to the power in an electric circuit in which the potential difference is one volt and the current one ampere.

APPENDIX

RESOURCES

COMPLIANCE RESOURCES

BUILDING ENERGY EFFICIENCY STANDARDS

www.energy.ca.gov/programs-and-topics/programs/building-energy-efficiency-standards/2019-building-energy-efficiency

The Energy Commission's Energy Efficiency Standards have saved Californians billions in reduced electricity bills since 1977.

APPLIANCE EFFICIENCY REGULATIONS

www.energy.ca.gov/rules-and-regulations/appliance-efficiency-regulations-title-20/appliance-regulations-certification

California's Appliance Efficiency Regulations were established in 1976 in response to a legislative mandate to reduce California's energy consumption. The regulations are updated periodically to allow consideration and possible incorporation of new energy efficiency technologies and methods.

NONRESIDENTIAL LIGHTING COMPLIANCE FORMS

www.energycodeace.com/NonresidentialForms/2019

As part of the Energy Code compliance process, the design team has to prepare and submit documents to verify compliance.

THE LIGHTING LIBRARY FROM ILLUMINATED ENGINEERING SOCIETY (IES)

ies.org/lighting-library/

The Lighting Library from IES presents reliable and comprehensive information on the latest lighting developments in a single source for lighting professionals.

ILLUMINATED ENGINEERING SOCIETY (IES) LIGHTING PRACTICE: DESIGNING AND SPECIFYING DAYLIGHTING FOR BUILDINGS (LP-3-20)

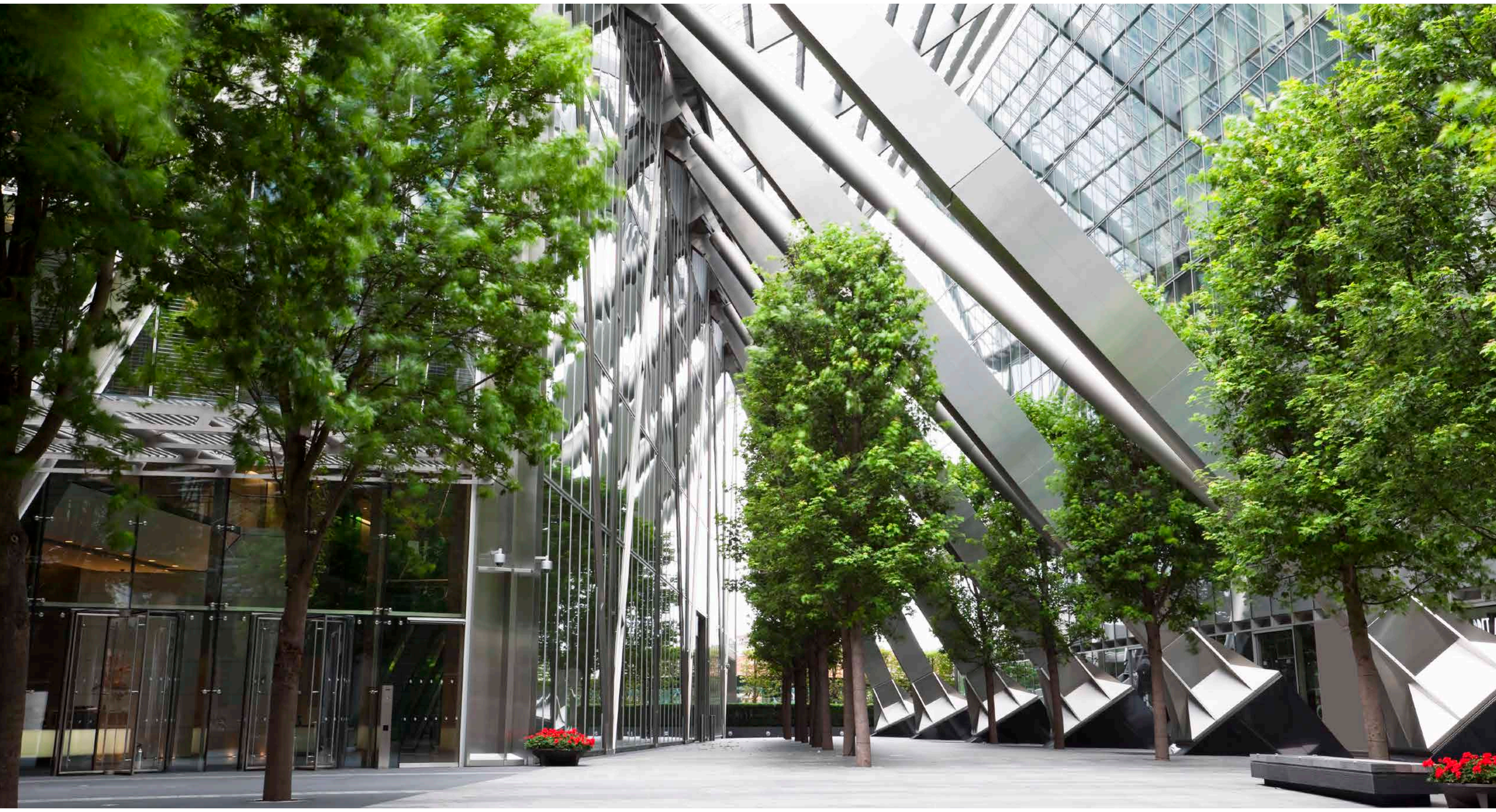
store.ies.org/product/lp-3-20-lighting-practice-designing-and-specifying-daylighting-for-buildings/

The IES' Lighting Practice: Designing and Specifying Daylighting for Buildings (LP-3-20) provides up-to-date technological solutions and data for addressing the challenges of daylighting while maximizing its benefits. The LP-3-20, which is the industry's reference guide for architects, engineers and lighting designers, includes information on daylight design techniques, delivery methods, glazing systems, shading techniques, control strategies and daylight performance simulation tools.

MODERNIZED APPLIANCE EFFICIENCY DATABASE SYSTEM (MAEDBS)

www.energy.ca.gov/rules-and-regulations/appliance-efficiency-regulations-title-20/appliance-regulations-certification

This online database of products certified to the Energy Commission has a Quick Search function allowing users to search by product type, brand or model.



CALIFORNIA GREEN BUILDING STANDARDS CODE, CALIFORNIA CODE OF REGULATIONS (CALGREEN)

www.dgs.ca.gov/BSC/Resources/Page-Content/Building-Standards-Commission-Resources-List-Folder/CALGreen

CALGreen's purpose is to 'improve public health, safety and general welfare by enhancing the design and construction of buildings through the use of building concepts having a reduced negative impact or positive environmental impact and encouraging sustainable construction practices in the following categories: planning and design, energy efficiency, water efficiency and conservation, materials conservation and resource efficiency and environmental quality.'

CALIFORNIA ADVANCED LIGHTING CONTROLS TRAINING PROGRAM (CALCTP)

calctp.org

CALCTP educates, trains and certifies licensed electrical contractors and state-certified general electricians in the proper installation, programming, testing, commissioning and maintenance of advanced lighting control systems.

NONRESIDENTIAL LIGHTING AND ELECTRICAL POWER DISTRIBUTION GUIDE

cltc.ucdavis.edu/publication/nonresidential-lighting-and-electrical-power-distribution-guide-2019-building-energy

The guide, developed by the California Lighting Technology Center, assists builders and lighting industry professionals in navigating the nonresidential lighting and electrical power distribution portions of the Energy Code.

RESIDENTIAL LIGHTING GUIDE

cltc.ucdavis.edu/publication/residential-lighting-design-guide-2016-standards

The California Lighting Technology Center's 2019 Residential Lighting Guide assists builders and lighting industry professionals in navigating the residential lighting portion of the Energy Code.

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For more information and resources about the Energy Code, visit the CLTC website at ***cltc.ucdavis.edu***.

4/2021