LIGHT

BACKGROUND

Light is a visible form of electromagnetic radiation, bordered in the spectrum by ultraviolet radiation at smaller wavelengths and infrared at larger wavelengths. Current lighting codes and guidelines provide illuminance recommendations for different room types, derived from usual lighting requirements for typical activities per room. These standards, created by technical groups such as Illuminating Engineering Society (IES), ensure good visual acuity in a variety of tasks to avoid eyestrain and to minimize productivity losses and headaches.

Light enters the eye and hits photoreceptors on the retina: rods, cones and intrinsically photosensitive retinal ganglion cells (ipRGCs). All of these cells absorb light and send it as information in the form of electrochemical signals to different parts of the brain. Rods facilitate peripheral vision and vision in dim lighting conditions, with peak sensitivity to green-blue light (498 nm). Cones facilitate daytime vision and color perception, and the peak sensitivity for the sensation of brightness with this system occurs at green-yellow light (555 nm).

In addition to facilitating vision, light influences the human body in non-visual ways. Humans and animals have internal clocks that synchronize physiological functions on roughly a 24-hour cycle called the circadian rhythm. The body responds to a number of zeitgebers—the external cues that align physiological functions to the solar day in this cycle. Light is the most important of these zeitgebers, keeping the body's internal clocks synchronized in a process known as circadian photoentrainment.

The ipRGCs are critical to the circadian system, sending information to various parts of the brain to trigger reactions downstream in the body. These cells demonstrate peak sensitivity to teal-blue light (≈480 nm). Notably, the ipRGCs project information to a specific part of the brain called the suprachiasmatic nucleus to let it know the time of day based on the light received, and this main clock then acts as an oscillator to likewise synchronize clocks in peripheral tissues and organs.

Multiple physiological processes—including those relating to alertness, digestion and sleep—are regulated in part by the variance and interplay of hormones involved in this cycle. A consideration of light exposure is particularly significant considering the role this plays in sleep, and given that the Institute of Medicine reports that about 50 to 70 million U.S. adults have a chronic sleep or wakefulness disorder. Further, such disorders and chronic sleep deprivation are associated with increased risk of certain morbidities, including diabetes, obesity, depression, heart attack, hypertension and stroke.

All light—not just sunlight—can contribute to circadian photoentrainment. Given that people spend much of their waking day indoors, insufficient illumination or improper lighting design can lead to a drift of the circadian phase, especially if paired with inappropriate light exposure at night. Humans are continuously sensitive to light, and under normal circumstances, light exposure in the late night/early morning will shift our rhythms forward (phase advance), whereas exposure in the late afternoon/early night will shift our rhythms back (phase delay). To maintain optimal, properly synchronized circadian rhythms, the body requires periods of both brightness and darkness.

INTENT

The WELL Building Standard® for Light provides illumination guidelines that are aimed to minimize disruption to the body's circadian system, enhance productivity, support good sleep quality and provide appropriate visual acuity where needed.

LIGHT FEATURE LEVEL MATRIX

	Core and Shell	New and Existing Interiors	New and Existing Buildings
53 VISUAL LIGHTING DESIGN			
1: Visual Acuity for Focus	-	P	P
2: Brightness Management Strategies	-	P	P
54 CIRCADIAN LIGHTING DESIGN			
1: Melanopic Light Intensity for Work Areas	-	P	P
55 ELECTRIC LIGHT GLARE CONTROL			
1: Luminaire Shielding	-	P	P
2: Glare Minimization	P	P	P
56 SOLAR GLARE CONTROL			
1: View Window Shading	O	P	P
2: Daylight Management	O	P	P
57 LOW-GLARE WORKSTATION DESIGN			
1: Glare Avoidance	-	O	O
58 COLOR QUALITY			
1: Color Rendering Index	-	O	O
59 SURFACE DESIGN			
1: Working and Learning Area Surface Reflectivity	-	O	O
60 AUTOMATED SHADING AND DIMMING CONTROLS			
1: Automated Sunlight Control	-	O	O
2: Responsive Light Control	-	O	O
61 RIGHT TO LIGHT			
1: Lease Depth	O	O	O
2: Window Access	-	O	O
62 DAYLIGHT MODELING			
1: Healthy Sunlight Exposure	O	O	O
63 DAYLIGHTING FENESTRATION			
1: Window Sizes for Working and Learning Spaces	O	O	O
2: Window Transmittance in Working and Learning Areas	O	O	O
3: Uniform Color Transmittance	O	O	O

53

VISUAL LIGHTING DESIGN

Adequate light levels are needed for a broad variety of activities, including reading various qualities and types of print, and working on detail-oriented tasks. Brightness levels also contribute to the perception of spaciousness, as well as to the overall visual appeal of illuminated spaces. Targeted task lighting can provide the necessary amount of light at workspaces without over-illuminating ancillary spaces; ambient light levels of 300 lux are sufficient for most tasks. Pairing adjustable direct task lighting with indirect or diffuse ambient lighting allows user customization and good visual acuity while providing more suitable background light. Light intensity for visual acuity is measured in lux (or foot candles), which is a measure of the way the eye responds to light weighted to the response of the cone cells—the main photoreceptors for daytime vision, located on the retina of the human eye.

Endocrine
Muscular
Nervous

Intent: To support visual acuity by setting a threshold for adequate light levels and requiring luminance to be balanced within and across indoor spaces.

Core and Shell	New and Existing Interiors	New and Existing Buildings
-	P	P

PART 1: VISUAL ACUITY FOR FOCUS

The following requirements are met at workstations or desks:

a. The ambient lighting system is able to maintain an average light intensity of 215 lux [20 fc] or more, measured on the horizontal work plane. The lights may be dimmed in the presence of daylight, but they are able to independently achieve these levels.

b. The ambient lighting system is zoned in independently controlled banks no larger than 46.5 m² [500 ft²] or 20% of open floor area of the room (whichever is larger).

c.[81] If average ambient light is below 300 lux [28 fc], task lights providing 300 to 500 lux [28 to 46 fc] at the work surface are available upon request.

PART 2: BRIGHTNESS MANAGEMENT STRATEGIES

-	P	P

Provide a narrative that describes strategies for maintaining luminance balance in spaces, which takes into consideration at least two of the following:

a.[174] Maximum brightness contrasts between main rooms and ancillary spaces, such as corridors and stairwells, if present. For example, projects may establish that, while still maintaining lighting variety, a main room cannot exhibit 10 times greater or lesser luminance than an ancillary space.

b.[174] Maximum brightness contrasts between task surfaces and immediately adjacent surfaces, including adjacent visual display terminal screens. For example, projects may establish that, while still maintaining lighting variety, a surface cannot exhibit 3 times greater or lesser luminance than an adjacent surface.

c.[174] Brightness contrasts between task surfaces and remote, non-adjacent surfaces in the same room. For example, projects may establish that, while still maintaining lighting variety, a surface cannot exhibit 10 times greater or lesser luminance than another remote surface in the same room.

d.[174] The way brightness is distributed across ceilings in a given room that maintains lighting variety but avoids both dark spots, or excessively bright, potentially glaring spots. For example, projects may establish that, while still maintaining lighting variety, one part of the ceiling cannot be 10 times greater or lesser luminance than another part of the ceiling in the same room.

54

CIRCADIAN LIGHTING DESIGN

Light is one of the main drivers of the circadian system, which starts in the brain and regulates physiological rhythms throughout the body's tissues and organs, affecting hormone levels and the sleep-wake cycle. Circadian rhythms are kept in sync by various cues, including light which the body responds to in a way facilitated by intrinsically photosensitive retinal ganglion cells (ipRGCs): the eyes' non-image-forming photoreceptors. Through ipRGCs, lights of high frequency and intensity promote alertness, while the lack of this stimulus signals the body to reduce energy expenditure and prepare for rest. The biological effects of light on humans can be measured in Equivalent Melanopic Lux (EML), a proposed alternate metric that is weighted to the ipRGCs instead of to the cones, which is the case with traditional lux. During Performance Verification, EML is measured on the vertical plane at eye level of the occupant. Tables L1 and L2 in Appendix C show how to calculate the EML of individual lamps and larger spaces.

Cardiovascular
Digestive
Endocrine
Immune
Muscular
Nervous

Intent: To support circadian health by setting a minimum threshold for daytime light intensity.

	Core and Shell	New and Existing Interiors	New and Existing Buildings
PART 1: MELANOPIC LIGHT INTENSITY FOR WORK AREAS	-	P	P

Light models or light calculations demonstrate that at least one of the following requirements is met:

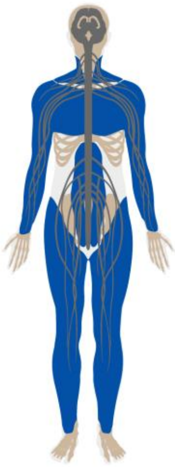
a. At 75% or more of workstations, at least 200 equivalent melanopic lux is present, measured on the vertical plane facing forward, 1.2 m [4 ft] above finished floor (to simulate the view of the occupant). This light level may incorporate daylight, and is present for at least the hours between 9:00 AM and 1:00 PM for every day of the year.

b.[174] For all workstations, electric lights provide maintained illuminance on the vertical plane facing forward (to simulate the view of the occupant) of 150 equivalent melanopic lux or greater.

55

ELECTRIC LIGHT GLARE CONTROL

Non-diffuse, bright indoor lights create uneven levels of brightness in the visual field. The resulting glare, defined as "excessive brightness of the light-source, excessive brightness-contrasts and excessive quantity of light", can cause visual discomfort (discomfort glare), fatigue, visual impairment and even injury (disability glare), and can be attributed to either direct or reflected glare. In the case of glare caused by electric light sources, lamps should be shielded based on their luminance. This quantity, often given in cd/m², can be measured directly or calculated from lighting specification sheets with sufficient detail. Light fixtures of greater luminous intensity require a greater shielding angle to reduce the likelihood of creating direct glare for occupants.



Muscular
Nervous
Skeletal

Intent: To minimize direct and overhead glare by setting limits on the luminous intensity of luminaires.

	Core and Shell	New and Existing Interiors	New and Existing Buildings
PART 1: LUMINAIRE SHIELDING	-	P	P
PART 2: GLARE MINIMIZATION	P	P	P

PART 1: LUMINAIRE SHIELDING

The following shielding angles (α = 90 - cutoff angle) must be observed for lamps in regularly occupied spaces with luminance values in the ranges specified:

a. No shielding required for less than 20,000 cd/m² (including reflected sources).

b.[79] α: 15° for 20,000 to 50,000 cd/m².

c.[79] α: 20° for 50,000 to 500,000 cd/m².

d.[79] α: 30° for 500,000 cd/m² and above.

PART 2: GLARE MINIMIZATION

At workstations, desks and other seating areas, one of the following requirements is met:

a.[174] Luminaires more than 53° above the center of view (degrees above horizontal) have luminances less than 8,000 cd/m².

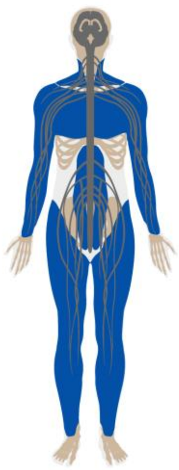
b. Workstations achieve a UGR of 19 (or less).

56

SOLAR GLARE CONTROL

Though bright light during the day is conducive to good health, uneven levels of brightness in the visual field can cause visual fatigue and discomfort. Glare, or excessive brightness, is caused by light scattering within the eye (intraocular scattering), thereby creating a "veil" of luminance that reduces the luminance contrast as received by the retina. In buildings, sources of glare are often unshielded or poorly shielded light, or sunlight directly hitting the eye or reflective surfaces.

Intent: To avoid glare from the sun by blocking or reflecting direct sunlight away from occupants.



Muscular
Nervous
Skeletal

	Core and Shell	New and Existing Interiors	New and Existing Buildings
PART 1: VIEW WINDOW SHADING	O	P	P
PART 2: DAYLIGHT MANAGEMENT	O	P	P

PART 1: VIEW WINDOW SHADING

At least one of the following is present for all glazing less than 2.1 m [7 ft] above the floor in regularly occupied spaces (excluding lobbies):

a.[80] Interior window shading or blinds that are controllable by the occupants or set to automatically prevent glare.

b. External shading systems that are set to prevent glare.

c. Variable opacity glazing, such as electrochromic glass, which can reduce transmissivity by 90% or more.

PART 2: DAYLIGHT MANAGEMENT

At least one of the following is required for all glazing greater than 2.1 m [7 ft] above the floor in regularly occupied spaces (excluding lobbies):

a.[80] Interior window shading or blinds that are controllable by the occupants or set to automatically prevent glare.

b. External shading systems that are set to prevent glare.

c. Interior light shelves to reflect sunlight toward the ceiling.

d. A film of micro-mirrors on the window that reflects sunlight toward the ceiling.

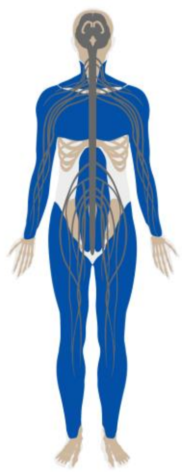
e. Variable opacity glazing, such as electrochromic glass, which can reduce transmissivity by 90% or more.

57

LOW-GLARE WORKSTATION DESIGN

Glare is commonly generated when high-intensity electric or natural light reflects off glossy surfaces that may be positioned at suboptimal angles in and around occupant spaces, in relation to windows. The resulting discomfort can be a hindrance to an otherwise comfortable and effective work environment. Adjusting the angle at which the light hits a surface can help guide the light away from reflecting directly into the eye, thereby avoiding glare.

Intent: To minimize visual discomfort by situating computer monitors in a way that avoids glare and luminance contrast.



Muscular
Nervous
Skeletal

Core and Shell	New and Existing Interiors	New and Existing Buildings
-	O	O

PART 1: GLARE AVOIDANCE

The following requirements are met:

a.[81] To minimize glare caused by incoming sunlight, all computer screens at desks located within 4.5 m [15 ft] of view windows can be oriented within a 20° angle perpendicular to the plane of the nearest window.

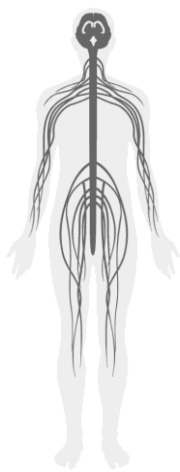
b. Overhead luminaires are not aimed directly at computer screens.

58

COLOR QUALITY

Color quality is a function of the spectral output of a light source, the spectral absorbance/reflectance of an object, and the sensitivity of the eye's cone photoreceptors to different wavelengths of light, which we perceive as color. Color quality impacts visual appeal and can either contribute to or detract from occupant comfort. Poor color quality can reduce visual acuity and the accurate rendering of illuminated objects. For instance, foods, human skin tones and plants may appear dull or unsaturated under lights that have low color quality metrics. Color rendering index (CRI) is a common way to measure color quality, capturing R1-R8 metrics. R9, while not always reported, is also included as part of this feature, as R9 values further take into consideration how we perceive the saturation of warmer hues.

Intent: To enhance spatial aesthetics and color differentiation through the use of lamps with quality color rendering abilities.



Nervous

	Core and Shell	New and Existing Interiors	New and Existing Buildings
PART 1: COLOR RENDERING INDEX	-	O	O

PART 1: COLOR RENDERING INDEX

To accurately portray colors in the space and enhance occupant comfort, all electric lights (except decorative fixtures, emergency lights and other special-purpose lighting) meet the following conditions:

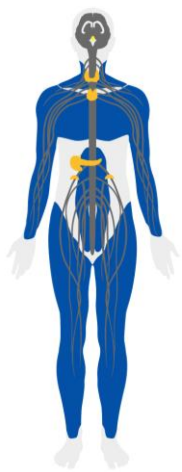
a.[80] Color Rendering Index Ra (CRI, average of R1 through R8) of 80 or higher.

b.[80] Color Rendering Index R9 of 50 or higher.

59

SURFACE DESIGN

Exposure to light not only facilitates image-formation and color perception, but can also trigger a series of non-visual effects involving the regulation of the circadian cycle. Light exposure mainly occurs via two ways: (1) directly from luminous sources, and (2) indirectly from reflected surfaces. Since most light encountered within buildings is reflective, quality of surfaces greatly affects the amount of light ultimately reaching the eye. Surfaces with lower light reflectance values (LRVs) absorb light from the source and result in lower overall light intensity. Higher LRVs mean that the surface reflects more light from the source, resulting in maximum light intensity and promoting alertness and activity. Choosing surfaces with higher LRV values thus represents a good strategy for ensuring that a sufficient amount of light reaches the eye without increasing energy consumption or glare.



Endocrine
Muscular
Nervous

Intent: To increase overall room brightness through reflected light from room surfaces and avoiding glare.

	Core and Shell	New and Existing Interiors	New and Existing Buildings
PART 1: WORKING AND LEARNING AREA SURFACE REFLECTIVITY	-	O	O

The following Light Reflectance Values (LRV) are met:

a.[80] Ceilings have an average LRV of 0.8 (80%) or more for at least 80% of surface area in regularly occupied spaces.

b.[80] Vertical surfaces have an average LRV of 0.7 (70%) or more for at least 50% of surface area directly visible from regularly occupied spaces.

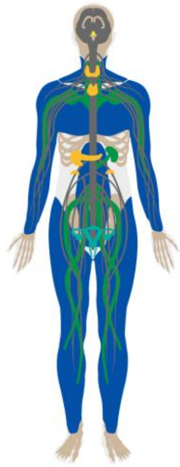
c. Furniture systems have an average LRV of 0.5 (50%) or more for 50% of surface area directly visible from regularly occupied spaces.

60

AUTOMATED SHADING AND DIMMING CONTROLS

Design features such as adjustable window shades and lights with dimmers must be actively managed to be effective. Automated controls can help to ensure that these systems continually operate as intended and meet intended benefits such as glare avoidance and energy reduction. Furthermore, setting these features to automatically adjust can greatly contribute to comfort without disrupting occupants from other tasks.

Intent: To prevent glare and encourage reliance on natural light through automated shading and dimming.



Endocrine
Immune
Muscular
Nervous
Reproductive
Skeletal

	Core and Shell	New and Existing Interiors	New and Existing Buildings
PART 1: AUTOMATED SUNLIGHT CONTROL	-	O	O
PART 2: RESPONSIVE LIGHT CONTROL	-	O	O

PART 1: AUTOMATED SUNLIGHT CONTROL

All windows larger than 0.55 m² [6 ft²] have the following:

a.[80] Shading devices that automatically engage when light sensors indicate that sunlight could contribute to glare at workstations and other seating areas.

PART 2: RESPONSIVE LIGHT CONTROL

The following requirements are met in all major workspace areas:

a.[80] All lighting except decorative fixtures is programmed using occupancy sensors to automatically dim to 20% or less (or switch off) when the zone is unoccupied.

b.[80] All lighting except decorative fixtures has the capacity and is programmed to dim continuously in response to daylight.

61

RIGHT TO LIGHT

Exposure to adequate levels of sunlight is critical for health and well-being, for effects ranging from visual comfort to potential psychological and neurological gains: there are measurable physiological benefits to receiving the quality of light provided by the sun, as well as positive subjective reports from occupants able to enjoy access to sunlight. Proximity to windows, outdoor views and daylight in indoor spaces are some of the most sought-after elements of design. As such, buildings should utilize daylight as a primary source of lighting to the greatest extent possible.

Intent: To promote exposure to daylight and views of varying distances by limiting the distance workstations can be from a window or atrium.

Cardiovascular
Digestive
Endocrine
Immune
Muscular
Nervous
Reproductive

	Core and Shell	New and Existing Interiors	New and Existing Buildings
PART 1: LEASE DEPTH	O	O	O
PART 2: WINDOW ACCESS	-	O	O

PART 1: LEASE DEPTH

The following requirement is met:

a. 75% of the area of all regularly occupied spaces is within 7.5 m [25 ft] of view windows.

PART 2: WINDOW ACCESS

The following conditions are met:

a. 75% of all workstations are within 7.5 m [25 ft] of an atrium or a window with views to the exterior.

b. 95% of all workstations are within 12.5 m [41 ft] of an atrium or a window with views to the exterior.

62

DAYLIGHT MODELING

Exposure to appropriate amounts of natural light reinforces the alignment of our circadian rhythms and reduces dependence on electricity for artificial lighting; however, excessive sunlight, during can cause glare and unwanted visual contrast. This is not only important to consider throughout the course of the day, but also throughout the course of the year, such that occupants are able to enjoy the benefits of daylight exposure in all seasons. Therefore, it is necessary to find a balance between Spatial Daylight Autonomy (sDA), which measures the percentage of floor area that receives adequate sunlight, and Annual Sun Exposure (ASE), which measures the percentage of floor area receives too much direct sunlight.

Intent: To support circadian and psychological health by setting thresholds for indoor sunlight exposure.

Cardiovascular
Digestive
Endocrine
Immune
Muscular
Nervous
Reproductive

	Core and Shell	New and Existing Interiors	New and Existing Buildings
PART 1: HEALTHY SUNLIGHT EXPOSURE	O	O	O

Lighting simulations demonstrate that the following conditions are expected:

a.[1] Spatial daylight autonomy (sDA300,50%) is achieved for at least 55% of regularly occupied space. In other words, at least 55% of the space receives at least 300 lux [28 fc] of sunlight for at least 50% of operating hours each year.

b.[1] Annual sunlight exposure (ASE1000,250) is achieved for no more than 10% of regularly occupied space. In other words, no more than 10% of the area can receive more than 1,000 lux [93 fc] for 250 hours each year.

63

DAYLIGHTING FENESTRATION

Exposure to natural light can improve occupant mood, alertness and overall health. Ideal lighting involves proper exposure to diffuse daylight, as well as careful design of windows and glazing to avoid excessive glare and heat gain. Windows are therefore a key variable for both ensuring that occupants receive enough light for positive physiological and subjective effects, but also not too much light that causes discomfort or becomes a source of distraction. Balancing energy performance, thermal comfort and access to quality daylight are essential to proper building design.

Intent: To optimize occupant exposure to daylight and limit glare through enhanced fenestration parameters.

	Core and Shell	New and Existing Interiors	New and Existing Buildings
PART 1: WINDOW SIZES FOR WORKING AND LEARNING SPACES	O	O	O
PART 2: WINDOW TRANSMITTANCE IN WORKING AND LEARNING AREAS	O	O	O
PART 3: UNIFORM COLOR TRANSMITTANCE	O	O	O

PART 1: WINDOW SIZES FOR WORKING AND LEARNING SPACES

The following conditions are met on façades along regularly occupied spaces:

a. Window-wall ratio as measured on external elevations is between 20% and 60%. Percentages greater than 40% require external shading or adjustable opacity glazing to control unwanted heat gain and glare.

b. Between 40% and 60% of window area is at least 2.1 m [7 ft] above the floor.

PART 2: WINDOW TRANSMITTANCE IN WORKING AND LEARNING AREAS

The following visible transmittance (VT) conditions are met for all non-decorative glazing:

a. All glazing (excluding skylights) located higher than 2.1 m [7 ft] from the floor has VT of 60% or more.

b. All glazing located 2.1 m [7 ft] or lower from the floor has VT of 50% or more.

PART 3: UNIFORM COLOR TRANSMITTANCE

All windows used for daylighting meet the following requirement:

a. The visible light transmittance of wavelengths between 400 and 650 nm does not vary by more than a factor of 2.