UFC 3-530-01
09 February 2023

UNIFIED FACILITIES CRITERIA (UFC)

INTERIOR AND EXTERIOR LIGHTING SYSTEMS

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INTERIOR AND EXTERIOR LIGHTING SYSTEMS

Indicate the Military Department Preparing Activity responsible for the document.

U.S. ARMY CORPS OF ENGINEERS

NAVAL FACILITIES ENGINEERING SYSTEMS COMMAND (Preparing Activity)

AIR FORCE CIVIL ENGINEER CENTER

Record of Changes (changes are indicated by **1**\ ... /**1**/)

Change No.	Date	Location

This UFC supersedes UFC 3-530-01 Change 4, dated 01 November 2019.

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FOREWORD

The Unified Facilities Criteria (UFC) system is prescribed by MIL-STD 3007 and provides planning, design, construction, sustainment, restoration, and modernization criteria, and applies to the Military Departments, the Defense Agencies, and the DoD Field Activities in accordance with USD (AT&L) Memorandum dated 29 May 2002. UFC will be used for all DoD projects and work for other customers where appropriate. All construction outside of the United States, its territories, and possessions is also governed by Status of Forces Agreements (SOFA), Host Nation Funded Construction Agreements (HNFA), and in some instances, Bilateral Infrastructure Agreements (BIA). Therefore, the acquisition team must ensure compliance with the most stringent of the UFC, the SOFA, the HNFA, and the BIA, as applicable.

UFC are living documents and will be periodically reviewed, updated, and made available to users as part of the Military Department's responsibility for providing technical criteria for military construction. Headquarters, U.S. Army Corps of Engineers (HQUSACE), Naval Facilities Engineering Systems Command (NAVFAC), and Air Force Civil Engineer Center (AFCEC) are responsible for administration of the UFC system. Technical content of UFC is the responsibility of the cognizant DoD working group. Defense Agencies should contact the respective DoD Working Group for document interpretation and improvements. Recommended changes with supporting rationale may be sent to the respective DoD working group by submitting a Criteria Change Request (CCR) via the Internet site listed below.

UFC are effective upon issuance and are distributed only in electronic media from the following source:

- Whole Building Design Guide website https://www.wbdg.org/ffc/dod.

Refer to UFC 1-200-01, *DoD Building Code*, for implementation of new issuances on projects.

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CHAPTER 1 INTRODUCTION

1-1 PURPOSE AND SCOPE.

This UFC provides requirements for the design of interior and exterior lighting systems and controls based on the Illuminating Engineering Society (IES) Lighting Library® and the Energy Policy Act of 2005. This UFC meets the current IES standard of practice and addresses general lighting requirements for DoD facilities.

1-2 REISSUES AND CANCELS.

This UFC reissues and cancels UFC 3-530-01, Design: Interior, Exterior Lighting and Controls, Change 4, 01 November 2019.

1-3 APPLICABILITY.

This document applies to the interior or exterior lighting systems for construction, repair, and maintenance projects. This UFC establishes the baseline requirement for:

- Energy efficiency
- Control strategy
- Lighting criteria
- Lighting best practices

For applications that are not listed in this UFC, refer to the IES Lighting Library for lighting criteria and lighting best practices.

1-4 GENERAL BUILDING REQUIREMENTS.

Comply with UFC 1-200-01, *DoD Building Code*. UFC 1-200-01 provides applicability of model building codes and government unique criteria for typical design disciplines and building systems, as well as for accessibility, antiterrorism, security, high performance and sustainability requirements, and safety. Use this UFC in addition to UFC 1-200-01 and the UFCs and government criteria referenced therein.

1-4.1 ASHRAE Compliance.

ASHRAE 90.1 applies to all projects except low-rise residential, which must comply with IECC. Refer to UFC 1-200-02 for applicable year of ASHRAE. Note that the requirements of this UFC refer to ASHRAE 90.1-2013. When UFC 1-200-02 adopts a newer publication year of ASHRAE 90.1, it will have precedence over these UFC requirements.

1-5 ENVIRONMENTAL SEVERITY AND HUMID LOCATIONS.

In corrosive and humid environments, provide design details and use materials, systems, components, and coatings that are durable and minimize the need for preventative and corrective maintenance over the expected service life of the component or system. UFC 1-200-01, section titled “Corrosion Prone Locations” identifies corrosive environments and humid locations requiring special attention. UFC 1-200-01, section titled “Requirements for Corrosion Prone Locations” provides examples of necessary actions. To determine Environmental Severity Classifications (ESC) for specific project locations, refer to UFC 1-200-01 Appendix titled “Environmental Severity Classifications (ESC) for DoD Locations”.

1-6 CYBERSECURITY.

All facility-related control systems (including systems separate from a utility monitoring and control system) must be planned, designed, acquired, executed, and maintained in accordance with UFC 4-010-06, and as required by individual Service Implementation Policy.

1-7 GLOSSARY.

APPENDIX F contains acronyms, abbreviations, and terms.

1-8 REFERENCES.

APPENDIX G contains a list of references used in this document. The publication date of the code or standard is not included in this document. Unless otherwise specified, the most recent edition of the referenced publication applies.

CHAPTER 2 TECHNICAL REQUIREMENTS – INTERIOR LIGHTING

2-1 PRIORITIES FOR INTERIOR LIGHTING SYSTEMS.

Design interior lighting systems to reduce energy consumption, reduce maintenance costs, and improve lighting quality, at the lowest life cycle cost in DoD facilities.

2-1.1 Energy Reduction.

Provide Solid State Lighting/Light Emitting Diode (SSL/LED) systems for all interior lighting. SSL/LED systems are established technologies for interior lighting applications that have been proven to save energy over traditional light sources. There are few exceptions in specific medical applications where SSL systems are not allowed; refer to UFC 4-510-01 Design: Military Medical Facilities.

Reduce energy consumption by using energy efficient technologies, maintaining effective illuminance levels, and implementing control strategies. Maintain illumination level prescribed averages and uniformity ratios as closely as possible, in order to provide sufficient light levels without contributing to excessive energy usage.

2-1.2 Maintenance Reduction.

Reduce maintenance by technology selection, reducing equipment quantities, and implementing controls strategies. Select light sources, drivers, and controls that are rated and warranted for long useful lives to increase the amount of time between maintenance cycles. Minimize light source types on an individual project.

2-1.3 Luminaire Placement.

Locate luminaires in locations to ensure access for regular servicing such as driver replacement and cleaning.

Coordinate luminaire locations with ceiling obstructions, such as structure, HVAC, and fire suppression systems.

2-1.4 Lighting Quality.

Apply the following to ensure the priority of lighting quality is achieved.

2-1.4.1 Direct Glare.

In regularly occupied spaces, use luminaires with a luminance of less than 650 cd/ft^2 (7,000 cd/m^2) between 45 and 90 degrees from nadir. Exceptions include high and low bay luminaires in industrial applications, luminaires properly aimed at walls, and indirect luminaires that provide uplighting only, provided there is no view down into these uplights from a regularly occupied space above.

In non-regularly occupied spaces, shield light sources in luminaires with louvers, perforations, lenses, or other refracting technologies to avoid a direct view of the light sources and the resultant direct glare.

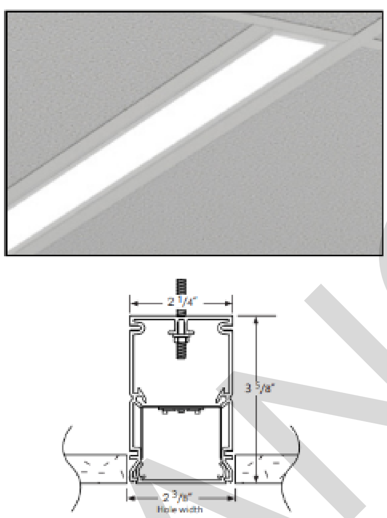
2-1.4.1.1 Luminance Comparison

Figure 2-1 compares the luminance of two linear LED products. One has a nominal 2" (610 mm) wide lens and the other has a nominal 4" (1219 mm) wide lens. Both products have the same lumen output. The smaller lensed luminaire has values greater than 650 cd/ft^2 (7,000 cd/m^2) between 45 and 90 degrees from nadir. Therefore, this luminaire does not meet the luminance requirements and must be installed with a dimmer, see Alternate Path 1, because of its higher luminance values.

Figure 2-1 Luminance Comparison

CANDELA ARRAY

2 3/8" lens width, 500 lumens/foot output



LUMINANCE DATA (cd/sq.m)

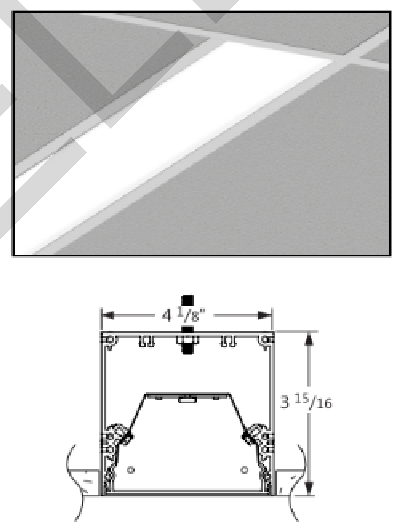
Angle In Degrees	Average 0-Deg	Average 45-Deg	Average 90-Deg
45	11217	10095	9128
55	9632	8440	7438
65	7960	6924	6018
75	6129	5389	4649
85	4080	3765	3452

LUMINANCE OVER 7,000 CD/M^2
BETWEEN 45 AND 90 DEGREES

*IES file used: Axis Lighting, Beam 2
BRLED-500-80-35-FL-4
Source: https://www.axislighting.com/families/beam-2

CANDELA ARRAY

4 1/8" lens width, 500 lumens/foot output



LUMINANCE DATA (cd/sq.m)

Angle In Degrees	Average 0-Deg	Average 45-Deg	Average 90-Deg
45	5663	5301	4953
55	5035	4638	4265
65	4380	4017	3698
75	3648	3414	3163
85	2721	2561	2455

*IES file used: Axis Lighting, Beam 4
BBRLED-500-80-35-FL-4
Source: https://www.axislighting.com/families/beam-4

- Alternate Path 1: Luminance values greater than 650 cd/ft^2 (7,000 cd/m^2) between 45 and 90 degrees from nadir are allowed when continuous dimming is provided and accessible to occupants.

- Alternate Path 2: Achieve a Unified Glare Rating (UGR) of <19 using software modelling calculations of the designed lighting calculated for the space.

2-1.4.2 Disability Glare.

Avoid disability glare caused by using bright luminaire components such as visible light sources or bright lenses that can reflect in the surface of tasks with glossy or specular finishes.

2-1.4.3 Luminance of Room Surfaces.

Illuminate surfaces to control the contrast between an occupant's task and the surrounding surface in the field of view. Avoid dark backgrounds when an occupant views a bright computer screen in the foreground. Control high luminance ratios for daylight fenestrations when direct sun is allowed to penetrate.

2-1.4.4 Uniformity.

Uniformly illuminate the task plane as well as room surfaces to avoid shadows or distracting patterns of light. Avoid large, backlighted translucent surfaces such as floors or walls that may be disorienting, especially for people with vision impairments.

2-1.4.5 Shadowing.

Minimize contrast with ambient and task lighting to fill in harsh shadows, especially for work surfaces where people are performing detail-oriented tasks. Shadows are beneficial when distinguishing between stair treads and risers.

2-1.4.6 Color Appearance.

Minimize contrast with ambient and task lighting to fill in harsh shadows, especially for work surfaces where people are performing detail-oriented tasks. Shadows are beneficial when distinguishing between stair treads and risers.

2-1.4.6.1 Color Temperature.

Provide light sources with a correlated color temperature (CCT) of no greater than 4100 K as stated on the manufacturer's luminaire information sheet for all interior spaces. Maintain one CCT in an area and maintain one CCT throughout the entire building where possible. The recommended CCT for most interior applications is 3500 K. For residential and hospitality applications, a CCT of 2700 K is recommended.

2-1.4.6.2 Tunable White Lighting.

Provide tunable white or dim-to-warm light sources in applications where the desired color temperature of light is variable. Residential, hospitality, and childcare applications are the most common recommended uses of adjustable color temperature. Use tunable white light if the quantity of light must remain constant. Use dim to warm light if warmer color temperatures are desirable only when there is also a reduction in light levels.

Tunable white lighting is not a substitute for spectral tuning and does not provide circadian rhythm-specific lighting conditions. For more information on circadian rhythm lighting, refer to APPENDIX D.

2-1.4.6.3 Color Rendering Index.

Use LED light sources with a color rendering index (CRI) of 80+ for all interior applications to accurately render the color of accent walls, architectural features, and artwork. In many high and low bay applications, a CRI of 70+ is acceptable unless a higher CRI is required for the task occurring in the space.

For applications where color identification is of high importance, such as copy/print rooms, command and control centers, kitchens, and areas with art installations, use light sources with a fidelity index greater than or equal to 80 ($R_f \geq 80$), and a gamut index between 97 and 110 ($97 \leq R_g \leq 110$), as defined in IES TM-30. If gamut and fidelity indices are not available, provide light sources with a CRI of 90+ with an R_9 value of at least 50 ($R_9 > 50$). Point(s) of Interest.

2-1.4.7 Modeling of Faces or Objects.

Include indirect lighting from multiple directions and angles for ambient lighting. Use multiple systems such as sconces, pendants, and wall washers to ensure the proper appearance of three-dimensional forms.

Focus visual attention and provide wayfinding with accent lighting. Create visual interest in special spaces as well as guidance through transitional areas with lighting highlights on wall displays and accenting signs.

2-1.4.8 Source/Task/Eye Geometry.

Locate luminaires in response to task areas to avoid shadows and direct and reflected glare.

2-1.4.9 Appearance of Space and Luminaires.

Use creative lighting design with aesthetic appearance of the space and of the luminaires for public building areas.

2-1.4.10 Surface Characteristics.

Review finish selection with Architect and Interior Designer. Coordinate selected surface characteristics with lighting calculations.

2-2 INTERIOR LIGHTING EQUIPMENT.

2-2.1 Light Source Technology.

Provide SSL/LED systems unless there is no equivalent SSL/LED product for the application. If another light source other than SSL/LED is specified, provide documentation regarding the selection of that light source in the project's Basis of Design. Refer to UFC 4-510-01 for specific medical applications that require alternatives to SSL/LED systems.

2-2.1.1 SSL/LED Drivers.

Provide lighting systems with accessible and replaceable drivers. Prioritize drivers that are integral to the luminaire. Use dimmable drivers compatible with standard dimming control circuit of 0-10V, DALI dimming, or DMX dimming. All dimming protocols must comply with cybersecurity requirements in paragraph 1-6.

2-2.1.2 Retrofit LED Lamps.

Provide linear LED lamps that are UL Type A. The datasheet must comply with ANSI C78.54. Use linear LED lamps with a beam angle of 270 degrees. When acceptable products with a 270-degree beam angle are not available, products with a beam angle of at least 180 degrees are allowable.

Retrofit LED light source replacements (screw base) are only permitted for the replacement of incandescent or compact fluorescent light sources. These must be NEMA SSL 7A[1] compliant and provided with a NEMA SSL 7A compliant dimmer to ensure that the electrical infrastructure is adequate to dim the lamps without flicker or dropouts in dimming range.

2-2.1.3 Incandescent and Tungsten-Halogen.

Do not use incandescent or tungsten halogen light sources, unless specifically required for medical applications where alternatives such as SSL/LED are unavailable.

2-2.2 Surge Protection Device.

Provide metal oxide varistor (MOV) surge protection devices at panel boards for all lighting panels or all circuits feeding interior lighting systems. For lighting circuits fed from load centers, surge protection devices are not required if surge protection is provided by the upstream panelboard.

2-3 LUMINAIRE BRACING AND SUPPORT.

Provide redundant supports to ensure that failure of a single supporting component does not result in luminaire falling. Mount overhead luminaires weighing more than 20 pounds (9 kilograms) with either rigid or flexible systems to reduce the likelihood that they will fall and injure building occupants or damage equipment. Ensure luminaires do not move horizontally in any direction more than 1 inch (25 mm) when subjected to force specified herein. Design equipment mountings to resist forces of 0.5 times the equipment weight in any horizontal direction and 1.5 times the equipment weight in the downward direction. This does not preclude the need to design equipment mountings

[1] Department of Energy. *Dimming LEDs with Phase-Cut Dimmers: The Specifier's Process for Maximizing Success.* October 2013.

for forces required by other criteria such as seismic design criteria of non-structural systems.

2-3.1 Luminaires Subject to Wind Loads.

In interior areas with a wind load, such as aircraft hangar bays or vehicle maintenance facilities with drive through maintenance bays, mount luminaires with stem hangers. If a single stem is used, provide a secondary means of support to ensure that failure of the stem does not result in luminaire falling.

2-4 INTERIOR LIGHTING CONTROLS.

Refer to CHAPTER 3 for control requirements specific to common applications and space types. Provide commissioning per ASHRAE 90.1 requirements, except for low-rise residential. Refer to ANSI/IES LP-6 for additional considerations for lighting control systems and ANSI/IES LP-8 for commission guidance for specific applications.

2-4.1 Control Strategies.

Provide a combination of control strategies per space as required in each Application page in CHAPTER 3. Indicate the control strategy for each space or subspace in the contract documents.

2-4.1.1 Manual Control.

Locate manual control devices at all room entries unless manual control devices are not required for the application. Locate manual control devices at the latch side of doors rather than the hinge side if space permits. Provide all required scenes at main entrances and exits, with secondary devices at secondary entrances and exits. Secondary devices are not required to provide full dimming and scene control, but they must provide at least one ON scene and one full OFF scene for the entire space. Provide additional manual control devices as required for specific applications as noted in CHAPTER 3.

Manual control devices consist of scene wallstations, wallbox switches, and wallbox dimmers. Provide clear labeling for scene wallstations, with buttons for each scene required for the application. If using wallbox dimmers instead of scene wallstations, provide wallbox dimmers for each luminaire type in the room, unless otherwise noted. Wallbox dimmers must allow for full range of dimming down to 10% minimum. Some applications, such as auditoriums and briefing rooms, may require dimming down to 1% or less.

2-4.1.2 Occupancy and Vacancy Sensing.

Provide occupancy and vacancy sensors to control lighting within a space or zone by detecting human activity. Occupancy mode is set for auto-on/auto-off, which is mostly utilized in large spaces, corridors, and spaces with no daylight. Vacancy mode is set for manual-on/auto-off, which is utilized in smaller spaces and spaces with daylight. This allows occupants to choose to turn lights on when entering the space, depending on surrounding light, daylighting, and individual activity.

Some applications allow for full or partial automatic on when occupancy is detected. This can be achieved either by turning all lights on to no more than 50% of full light output, or by turning on select luminaires, such as task-oriented luminaires, while leaving other luminaires off.

2-4.1.3 Ramped Dimming.

When automated dimming is required, program a gradual dimming rate so occupants of the space do not perceive a sudden change in light levels. This is especially important in maintenance spaces such as aircraft hangar bays and maintenance shops where personnel may be working in close proximity to energized equipment or running motors.

2-4.1.4 Time Schedules.

Time schedules built into centralized and distributed systems to allow for scheduled OFF and ON scenes, based on time of day. Provide time scheduled shutoffs for spaces that do not allow or require full OFF with vacancy sensors. In some networked lighting control systems, time schedules can be used to change response profiles for occupancy/vacancy controls. These profiles may include changes in time-delay, occupancy or vacancy mode, or associated control zones as defined in paragraph 2-3.3.6.

2-4.1.5 Daylighting Control.

Provide automatic control of the ambient electric lighting in response to daylight as defined in ASHRAE 90.1 for all spaces with access to daylight unless otherwise noted for the specific application. For spaces that receive daylight from windows, curtain walls, or any other sidelight area, the primary and secondary sidelighted areas must be controlled independently of each other. For spaces that receive daylight from skylights or roof monitors, the lighting control system must control the ambient electric lighting in response to daylight. For spaces that receive daylight from toplighting and sidelighting, the ambient lighting in overlapping zones must be controlled together. Consider daylighting modeling and analysis for determining daylighting control zones in complex spaces.

Provide automatic response to daylight with the following functionality:

- Ambient electric lighting with continuous dimming capable of dimming to 10% of full output or lower.
- Program a ramp dimming so occupants of the space do not perceive a sudden change in light levels.
- Photocontrol sensors. Layout, quantity, and programming of photocontrol sensors vary by manufacturer and strategy.

- Refer to APPENDIX B for additional daylighting control information.

2-4.1.5.1 Automated Shading.

When automated shading is provided to control glare and unwanted heat gain from daylighting, coordinate daylighting controls with automated shading controls. Refer to APPENDIX B Daylighting Controls Best Practices for additional information.

2-4.1.6 Zoning.

Areas of control are divided into separate zones for larger spaces, typically above 250 square feet (23 square meters). The specific zoning requirements will vary depending on the application. Provide separate, independent control for each zone. When required for the application, provide separate control for each luminaire type, within each area. Unless otherwise noted, follow control zone square footage requirements as outlined in ASHRAE 90.1.

Zoning may differ depending on control strategy, even within the same area. Establish occupancy and vacancy control zones based on tasks performed in each area. Establish daylighting control zones based on proximity and access to daylight, according to Daylighting Control Best Practices discussed in APPENDIX B.

2-4.1.6.1 Associated Control Zones.

In large spaces containing multiple zones, provide associated control zones where required for the application. Associated control zones connect adjacent zones that are visible and less than 600 square feet (56 square meter), such that activity in an occupied zone will trigger nearby unoccupied zones to provide a reduced level of light by turning on adjacent zones for comfort and security. Utilize associated control zones in regularly occupied spaces during hours of darkness to illuminate egress paths and adjacent unoccupied zones to a reduced level.

2-4.2 Controls for Means of Egress.

Comply with NFPA 101 for the lighting and controls in Means of Egress. Provide UL924 compliant lighting controls that interface with the fire alarm system where required by NFPA 101.

2-4.3 Controls for Electrical Workspaces.

Comply with NFPA 70 when controlling luminaires in working spaces around electrical equipment. Do not use occupancy sensors, vacancy sensors, or timers to control luminaires that provide illumination of the working space around electrical equipment such as service equipment, switchboards, switchgear, panelboards, or motor control centers. To reduce energy consumption, luminaires in the adjacent space that do not provide illumination of the working space may be dimmable a maximum of 50% of full light output and cannot be stepped dimmed. For this application, the luminaires may be controlled by an integrated or separate occupancy or vacancy sensor.

2-4.4 Wireless Networks.

The use of wireless networks must be pre-approved by the System Owner (SO) and the Authorizing Official (AO) as part of the Control System Impact Rating determination defined in UFC 4-010-06.

Coordinate wireless networks with base spectrum manager prior to specification in case of restrictions for wireless usage within the installation.

2-5 DAYLIGHTING.

Refer to UFC 1-200-02 and UFC 3-101-01 for Daylighting requirements. Coordinate architectural daylight design and lighting contribution into electrical lighting and controls design.

Refer to APPENDIX B for daylighting controls best practices.

2-6 ELECTRICAL ENERGY MONITORING.

For construction and renovation of buildings greater than 25,000 SF (2,322 m^2), terminate lighting branch circuits in dedicated lighting panelboards.

2-7 ELEVATORS.

Provide lighting in accordance with UFC 3-490-06.

2-8 ILLUMINATION FOR MEANS OF EGRESS.

Provide in accordance with NFPA 101.

2-8.1 Emergency Lighting.

Emergency lighting units must be LED. For renovation and retrofit projects, replacement of emergency lighting units with LED units is highly encourage but not required.

Install emergency lighting equipment in conspicuous and accessible locations to facilitate the periodic testing requirements.

2-8.2 Exit Signs.

Internally illuminated signs must be LED type and comply with UFC 3-600-01.

2-9 LIGHTING SYSTEM ALTERATIONS.

Alterations occur when luminaires are added, replaced, removed, when more than 10% have been relocated, or when ballasts or lamps are replaced with anything other than the original ballast or lamp. This does not include routine maintenance. Provide alterations to the lighting system to achieve the following benefits:

- Reduce energy through technology selection, providing appropriate illuminance levels and implementing control strategies. Energy savings in commercial applications of 47% on average is achieved by a combination of LED adoption and Networked Lighting Controls implementation.[2]

- Reduce maintenance through decreasing equipment quantities (luminaires), replacing obsolete light source technology with SSL/LED light sources, and implementing control strategies.

- Improve lighting quality through improved photometric distribution and glare reduction. Refer to IES LP-9 Upgrading Lighting Systems in Commercial and Institutional Spaces for additional information.

2-9.1 Lighting System Alteration Requirements.

Comply with the lighting power density (LPD) and control requirements of ASHRAE 90.1 as well as the control requirements in this UFC. Provide computer-generated photometric plans based on ANSI/IES LM-79 data for each space to verify proposed lighting alteration meets the required performance criteria using the applicable light loss factor (LLF). See 3-2 for more information on lighting calculations.

2-9.2 Types of Lighting System Alterations.

Lighting system alterations include redesign, luminaire replacement, luminaire conversion kits to light source retrofits. Redesign will maximize the long-term energy and sustainment savings while improving the lighting quality in existing spaces.

Only provide alternatives to redesign when a full redesign is either not necessary or not feasible.

2-9.2.1 Redesign.

Redesign includes new luminaires, luminaire layout, electrical circuits, and controls designed to meet current lighting criteria. Redesign lighting systems when the existing:

- Illuminance levels are not within <u>20% below or 50% above</u> the illuminance levels listed in the specific application's performance requirements

- Lighting does not illuminate perimeter surfaces in regularly occupied spaces or shelving in warehouses and storage

- Lighting does not produce uniform illumination

- Luminaire spacing is too wide, or partition height obstructs light distribution

[2] DesignLights Consortium. *Energy Savings Potential of DLC Commercial Lighting and Networked Lighting Controls*. July 2018.

- Luminaires (or luminaire layout) are for when the tasks or physical layout of the space has changed or partition height obstructs light distribution
- Luminaires are in poor condition
- Lighting controls are inadequate

2-9.2.2 Luminaire Replacement.

Luminaire replacement is when existing luminaires are replaced with new luminaires. Luminaire replacement is acceptable when:

- Illuminance levels are within 20% below or 50% above the illuminance levels listed in the specific application's performance requirements
- Lighting produces excessive glare
- Lighting illuminates perimeter surfaces in regularly occupied spaces or shelving in warehouses and storage
- Lighting layout produces uniform illumination
- Luminaires (or luminaire layout) are appropriate for the tasks or physical layout of the space

2-9.2.3 Luminaire Conversion Kit.

Luminaire conversion kits replace reflectors, lampholders, ballast and light source within the housing of an existing luminaire. Conversion kits must meet UL 1598C and the resulting system must produce light levels and uniformity equivalent to the existing system or meet the lighting levels and uniformity required in the current criteria, whichever is lower. Luminaire conversion kits are only acceptable when:

- Illuminance levels are within 20% below or 50% above the illuminance levels listed in the specific application's performance requirements
- Lighting illuminates perimeter surfaces in regularly occupied spaces or shelving in warehouses and storage
- Lighting layout produces uniform illumination
- Luminaires (or layout) are appropriate for the tasks or physical layout of the space

Direct replacement of an incandescent, fluorescent, induction, or HID lamp to LED lamp, without any electrical or mechanical changes, is not considered a luminaire conversion. Linear LED lamp or tubular LED (TLED) are not allowed in luminaire conversion kits.

2-9.2.4 Lighting Source Retrofit.

Light source retrofit, sometimes referred to as a direct lamp replacement, is a system designed in the same form factor as the existing light source. An example is a linear LED lamp, or TLED, which is a direct replacement for a linear fluorescent lamp. Light source retrofit is only acceptable when no modifications to the existing luminaire are required (direct replacement) and when:

- Existing luminaires and lamp holders are in good condition
- Existing luminaires do not produce excessive glare
- Existing luminance levels are within 20% below or 50% above the illuminance levels listed in the specific application's performance requirements
- Existing lighting illuminates perimeter surfaces in regularly occupied spaces or shelving in warehouses and storage
- Existing lighting layout produces uniform illumination
- Existing luminaires (or layout) are appropriate for the tasks or physical layout of the space
- Existing lighting control systems function as intended without flicker and in full dimming range

2-9.2.5 Lighting Source Retrofit Requirements.

Do not use LED retrofit light sources or LED lighting modules that have been designed and constructed to be installed in existing HID or mercury vapor luminaire enclosures. LED retrofits are approved for replacement of CFL or incandescent sources (A-Type lamp replacements with Edison bases). Inserting a LED retrofit in an existing luminaire may void the luminaire's warranty.

Linear LED lamp retrofits are allowed with the following criteria:

- UL 1993 Type A Certification.
- Type A is designed to operate with the existing fluorescent ballast and does not require mechanical or electrical changes to the luminaire. Dual Mode Lamps (UL Type A/Type B) designed to operate off the existing fluorescent ballast and line voltage are not acceptable.
- Compatible with existing ballast type. Do not bypass or remove the ballast of the existing luminaire. If the linear LED lamps are not compatible with the existing ballast, the existing ballast may be replaced with a compatible fluorescent lamp ballast suitable for ASHRAE 90.1 compliant lighting controls.
- Resulting glare from the luminaire is not increased

- Has been manufactured within one year of installation
- Dimmable without flicker fade outs
- Frosted or diffuse optic with a minimum beam angle of 270 degrees.
- Resulting system must produce light levels equivalent to the existing system or meet the lighting levels and uniformity required in the current criteria, whichever is lower.
- Inserting a linear LED lamp in an existing luminaire may void the luminaire’s warranty.

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CHAPTER 3 INTERIOR LIGHTING APPLICATIONS

3-1 INTRODUCTION.

This chapter identifies typical interior facility applications. Each application details a conceptual lighting design example. The requirements for each application are for general ambient lighting. Coordinate accent and specialty lighting with architect and interior designer. Designs must meet the lighting performance and controls requirements defined in the application details, but layout, luminaire selection, and time schedules may vary.

Verify special lighting equipment requirements in hazardous (classified) locations.

3-2 LIGHTING CALCULATIONS.

Provide computer-generated photometric plans for each space to verify proposed lighting design meets the required performance criteria using the applicable light loss factor (LLF). Luminaire photometric files used in calculations must be derived from ANSI/IES LM-79 test results. Typical LLF is 0.81 for an office with luminaires that are L80 at 60,000 hours, and a 25-year life cycle. LLF varies based on environment, application, LED lumen depreciation, and building life cycle. It is understood that designers can use their discretion and experience to determine exactly where to draw calculation grids to provide informative calculations that meet the intent of the recommendations.

Target illumination levels are provided for each Interior Application. Depending on the application and the recommendations provided by the IES, values are given as one of the following:

- Minimum: No values anywhere on the calculation grid may be less than this value, within a 10% margin of error.
- Average: An average, taken over the entire general area for the application, may not be less than this value, within a 10% margin of error.
- Maximum: No values anywhere on the calculation grid may be greater than this value, within a 10% margin of error.
- Uniformity: Unless otherwise noted, uniformity is calculated as a ratio of the average calculated illuminance over the minimum calculated illuminance of the calculation grid.

3-2.1 Schematic Design and Concept Design.

For schematic and concept design phases prior to 60%, provide narrative indicating the following:

- Target average maintained illuminance level.

- Target lighting power density (watts per square foot or per square meter).

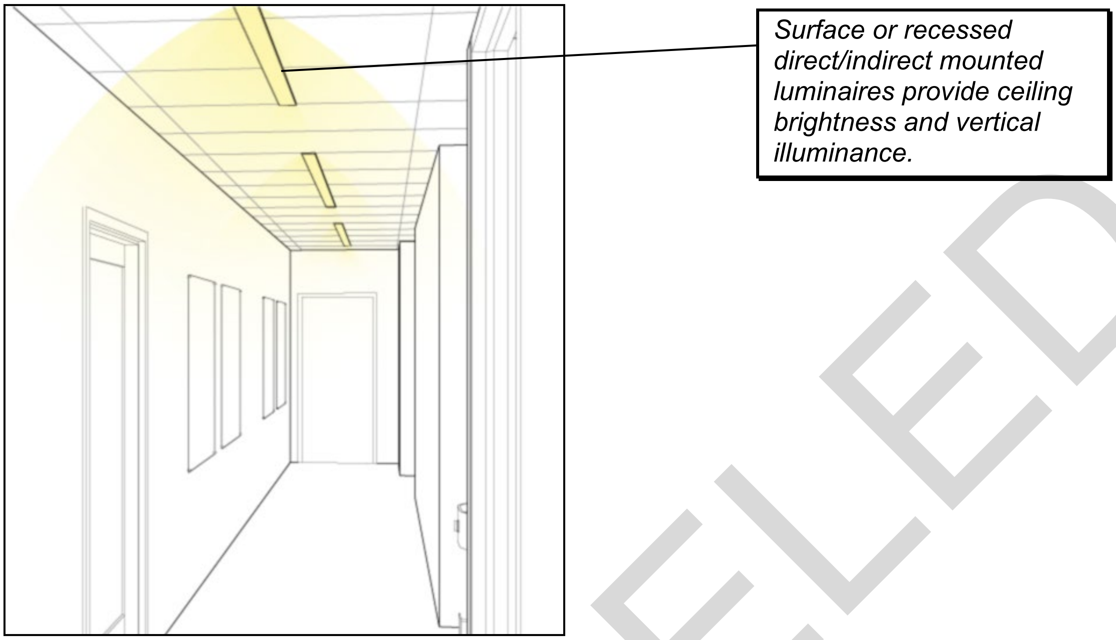
3-2.2 Designs at 60% or later.

For designs submitted at 60% or later, provide photometric plan calculations to include the following:

- The point by point spacing of the calculation grid of horizontal illuminance measurements at the workplane or other designated height above finished floor. The point spacing must be 1/3 of the luminaire mounting height, taken across the general area.
- Where applicable, vertical illuminance measurements at designated surface, taken at a maximum of every one foot (305 mm) across task area.
- Minimum and maximum maintained illuminance levels.
- Average maintained illuminance level.
- Average to minimum and maximum to minimum ratios for horizontal illuminance.
- Lighting power density (watts per square foot or per square meter).
- Where applicable, model the furniture, partitions in the lighting calculations with the proper reflectances, to accurately calculate the light levels of the space.
- Calculate the egress illuminance levels per NFPA 101 requirements.

3-3 GENERAL BUILDING SPACES.

3-3.1 Corridors.



3-3.1.1 Control Requirements.

Manual Control	None required if remote local control device is installed per ASHRAE 90.1
Occupancy/Vacancy	Automatic ON to 100% unless daylight is present Automatic full OFF after 20 minutes vacancy OR Automatic dimming to a maximum of 50% of full output after 20 minutes vacancy
Time Schedule	Scheduled full OFF when building is scheduled to be vacant unless occupants enter the building, then use Manual Control and Occupancy/Vacancy sensor criteria
Daylight	Automatic responsive daylight dimming when daylight is present
Zoning	Per ASHRAE 90.1 requirements

3-3.1.2 Performance Requirements.

Target Criteria	Daytime/Nighttime
Average Horizontal Illuminance	5 fc (50 lux) at floor
Horizontal Illuminance Uniformity	3:1 average to minimum

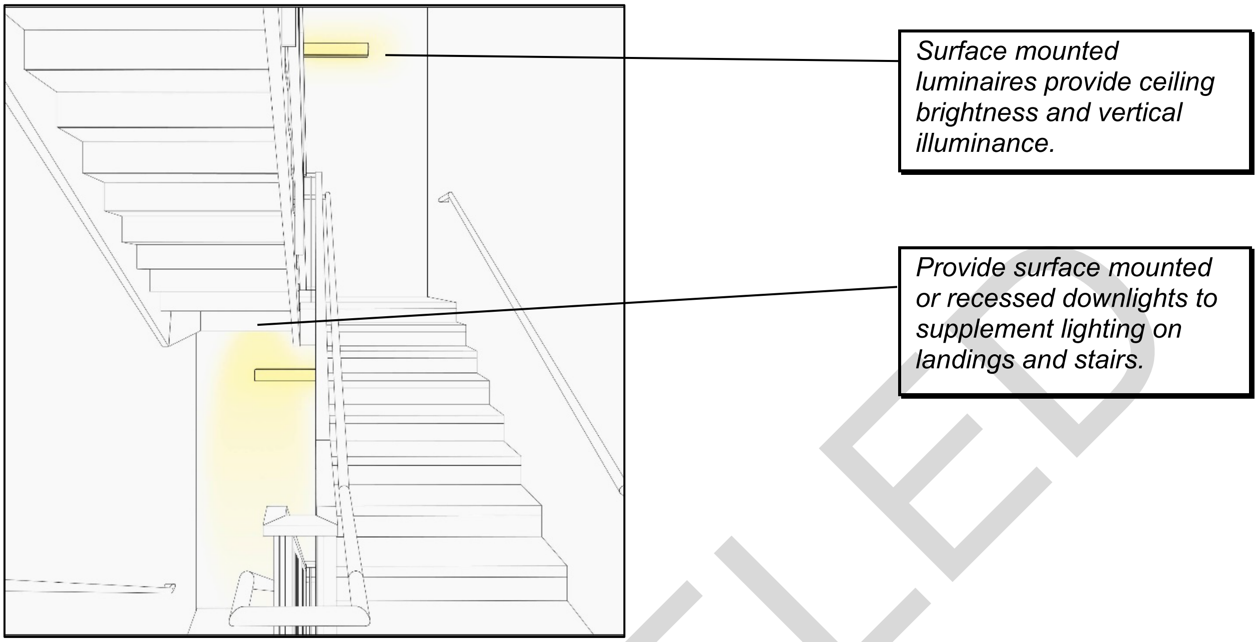
3-3.1.3 Critical Design Issues.

- Means of egress must comply with NFPA 101 control requirements and minimum light level requirements. When the corridor is means of egress, automatic off is allowable when control requirements are met. If area adjacent to corridor is lighted to illuminances greater than 50 fc, then immediate adjacent corridors may be lighted to a 1:10 ratio to minimize visual transition from brightly lighted area to darker corridor.

- When a corridor is adjacent to the open and visually accessible work or task areas, the illuminances of the passageway proper should be no less than 20% of the nearby task illuminances (ANSI/IES RP-1).

- Illuminate feature artwork and/or feature wall finishes.

3-3.2 Stairways.



3-3.2.1 Control Requirements.

Manual Control	None required if remote local control device is installed per ASHRAE 90.1
Occupancy/Vacancy	Automatic ON to 100% unless daylight is present Automatic dimming to a maximum of 50% after 20 minutes vacancy
Time Schedule	None required.
Daylight	Automatic responsive daylight dimming when daylight is present
Zoning	None

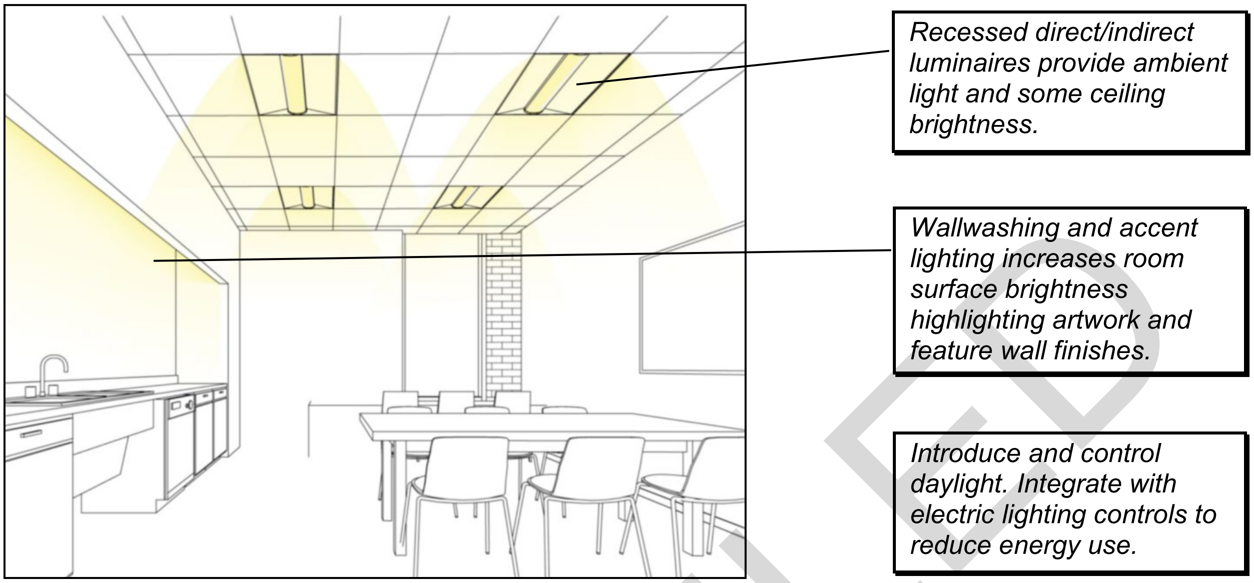
3-3.2.2 Performance Requirements.

Target Criteria	**Daytime/Nighttime**
Minimum Illuminance	10 fc (100 lux) at walking surface (includes stair treads)
Horizontal Illuminance Uniformity	2:1 average to minimum

3-3.2.3 Critical Design Issues.

- Horizontal illuminance is calculated on stair treads and landings.
- Do not locate luminaires on the ceiling above the treads. Locate luminaires where they are easily accessible for maintenance.
- Means of egress must comply with NFPA 101 control requirements and minimum light level requirements. When the corridor is means of egress, automatic off is allowable when the NFPA 101 control requirements are met.

3-3.3 Lounge Areas/Breakroom.



3-3.3.1 Control Requirements.

Manual Control	Scene wallstation with at least one preset scene with all lights dimmed between 30% and 70% of full lighting power OR One wallbox dimmer per luminaire control zone
Occupancy/Vacancy	Manual ON Automatic full OFF after 20 minutes of vacancy OR Automatic ON to a maximum of 50% of full lighting power Automatic full OFF after 20 minutes of vacancy
Time Schedule	None required
Daylight	Automatic responsive daylight dimming when daylight is present
Zoning	Provide separate control for task lighting and ambient lighting

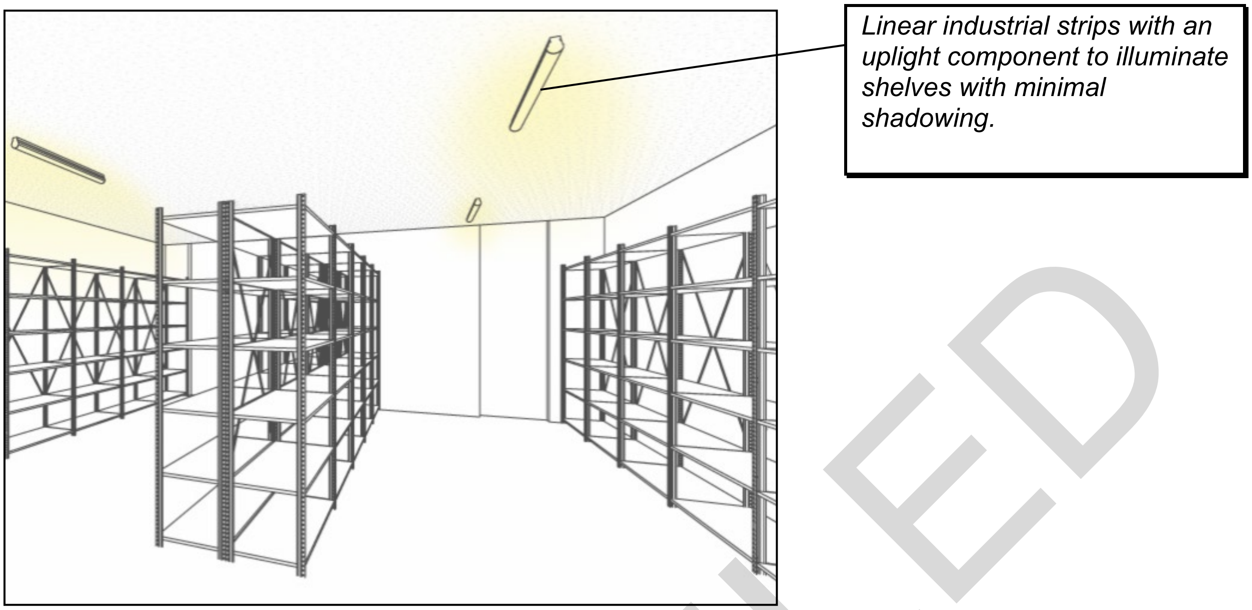
3-3.3.2 Performance Requirements.

Target Criteria	Daytime/Nighttime
Average Horizontal Illuminance, Dining area, social	10 fc (100 lux) at 2'-6" (762 mm) AFF
Average Horizontal Illuminance, Leisure reading	20 fc (200 lux) at 2'-6" (762 mm) AFF
Average Horizontal Illuminance, Food prep, clean up, work areas	30 fc (300 lux) at 2'-6" (762 mm) AFF
Horizontal Illuminance Uniformity	3:1 average to minimum

3-3.3.3 Critical Design Issues.

- Illuminate feature artwork and/or feature wall finishes.
- Illuminate sink areas and/or food prep areas.

3-3.4 Storage Rooms.



3-3.4.1 Control Requirements.

For storage rooms under 50 square feet:

Manual Control	A minimum of one wallbox switch
Occupancy/Vacancy	Automatic full ON Automatic full OFF after 20 minutes of vacancy
Time Schedule	None required
Daylight	No daylight sensing required
Zoning	None

For storage rooms greater than 50 square feet:

Manual Control	At least one wallbox switch or dimmer
Occupancy/Vacancy	Manual ON Automatic full OFF after 20 minutes of vacancy OR Automatic ON to 50% of general lighting power Automatic full OFF after 10 minutes of vacancy
Time Schedule	None required
Daylight	Automatic responsive daylight dimming when daylight is present
Zoning	None

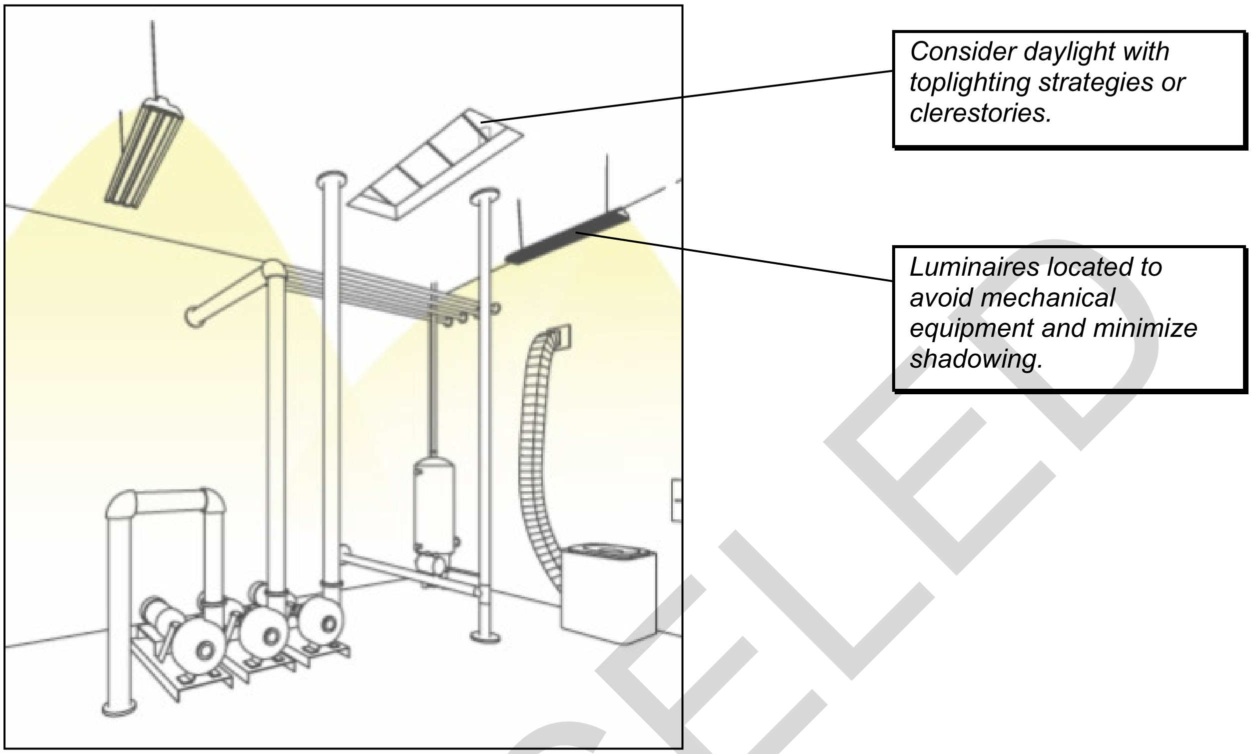
3-3.4.2 Performance Requirements.

Target Criteria	Daytime/Nighttime
Average Horizontal Illuminance	10 fc (100 lux) at floor
Average Vertical Illuminance	7.5 fc (75 lux) at 4'-0" (1219 mm) AFF
Horizontal Illuminance Uniformity	3:1 average to minimum

3-3.4.3 Critical Design Issues.

- Lighting controls, including occupancy and vacancy sensors, should account for the shelving and layout of the room.

3-3.5 Mechanical Rooms.



3-3.5.1 Control Requirements.

Manual Control	A minimum of one wallbox switch at each room entrance
Occupancy/Vacancy	None required
Time Schedule	None required
Daylight	Automatic responsive daylight dimming when daylight is present
Zoning	None required

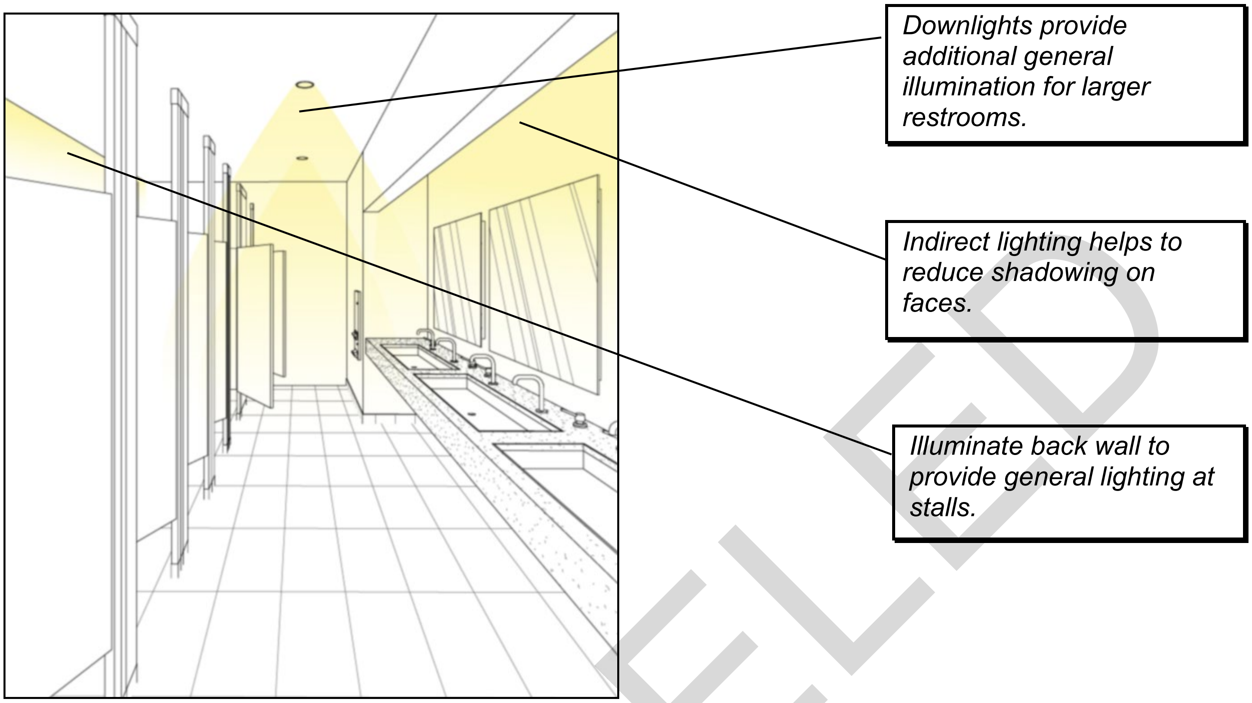
3-3.5.2 Performance Requirements.

Target Criteria	**Daytime/Nighttime**
Average Horizontal Illuminance	20 fc (200 lux) at 3’-6” (1067 mm) AFF
Horizontal Illuminance Uniformity	3:1 average to minimum

3-3.5.3 Critical Design Issues.

- Coordinate luminaire locations with equipment.
- Calculation points within the equipment footprint may be removed.

3-3.6 Restrooms.



3-3.6.1 Control Requirements.

Manual Control	For single-occupancy restrooms only: one wallbox switch
Occupancy/Vacancy	Automatic ON with automatic full OFF after 20 minutes of vacancy
Time Schedule	Scheduled full OFF when building is scheduled to be vacant unless occupants enter the building, then use Manual Control and Occupancy/Vacancy sensor criteria
Daylight	Automatic responsive daylight dimming when daylight is present
Zoning	None required

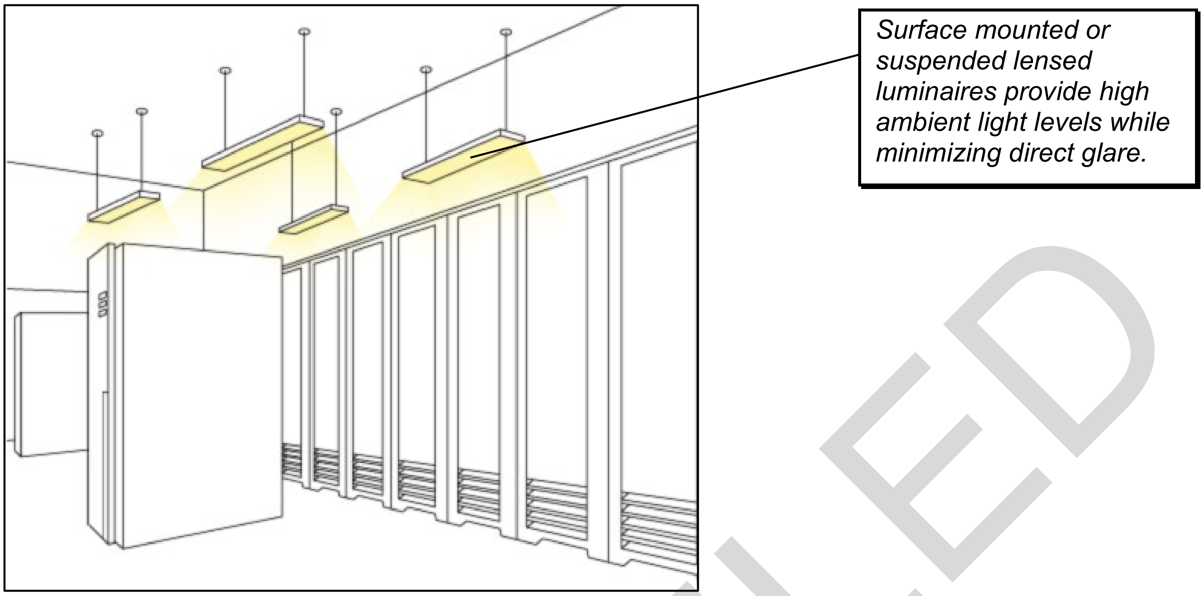
3-3.6.2 Performance Requirements.

Target Criteria	**Daytime/Nighttime**
Average Horizontal Illuminance, General	5 fc (50 lux) at floor
Average Horizontal Illuminance, Fixtures and vanities	15 fc (150 lux) at vanity surface
Average Horizontal Illuminance, Showers	10 fc (100 lux) at floor
Horizontal Illuminance Uniformity	3:1 average to minimum

3-3.6.3 Critical Design Issues.

- Utilize ultrasonic or dual-tech occupancy sensors.
- Locate occupancy sensors so that activity at restroom entrance and within stalls will trigger sensors.
- No local control required for multi-occupant restrooms.

3-3.7 Telecommunication/Equipment Rooms.



3-3.7.1 Control Requirements.

Manual Control	One wallbox switch
Occupancy/Vacancy	None
Time Schedule	None
Daylight	Automatic responsive daylight dimming when daylight is present
Zoning	None

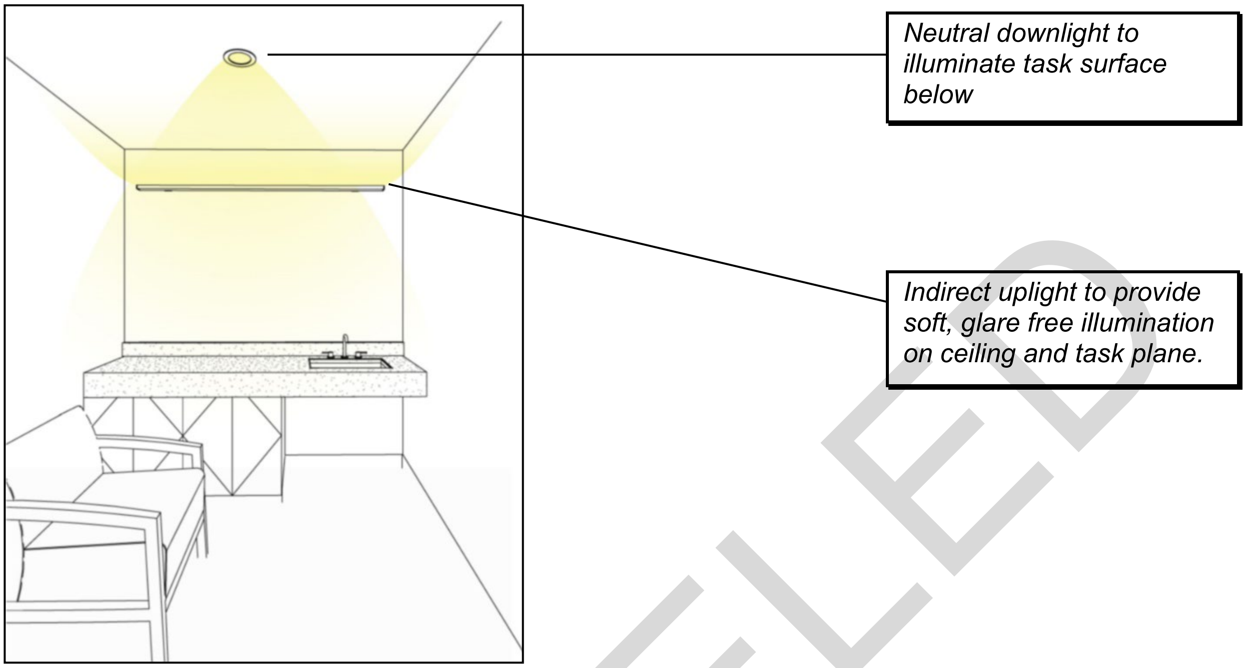
3-3.7.2 Performance Requirements.

Target Criteria	**Daytime/Nighttime**
Minimum Horizontal Illuminance	50 fc (500 lux) at 3’-0” (914 mm) AFF
Minimum Vertical Illuminance	30 fc (300 lux) at 3’-0” (914 mm) AFF
Horizontal Illuminance Uniformity	3:1 average to minimum

3-3.7.3 Critical Design Issues.

- Coordinate luminaire locations with ceiling obstructions and cable trays. Do not mount luminaires directly above cable trays.

3-3.8 Nursing and Lactation Rooms.



3-3.8.1 Control Requirements.

Manual Control	Scene wallstation with at least one preset scene with all lights dimmed between 30% and 50% of full lighting power OR One wallbox dimmer per luminaire type
Occupancy/Vacancy	Manual ON with automatic full OFF after 20 minutes of vacancy
Time Schedule	None
Daylight	Automatic responsive daylight dimming when daylight is present
Zoning	Provide separate control for downlight and ambient uplight

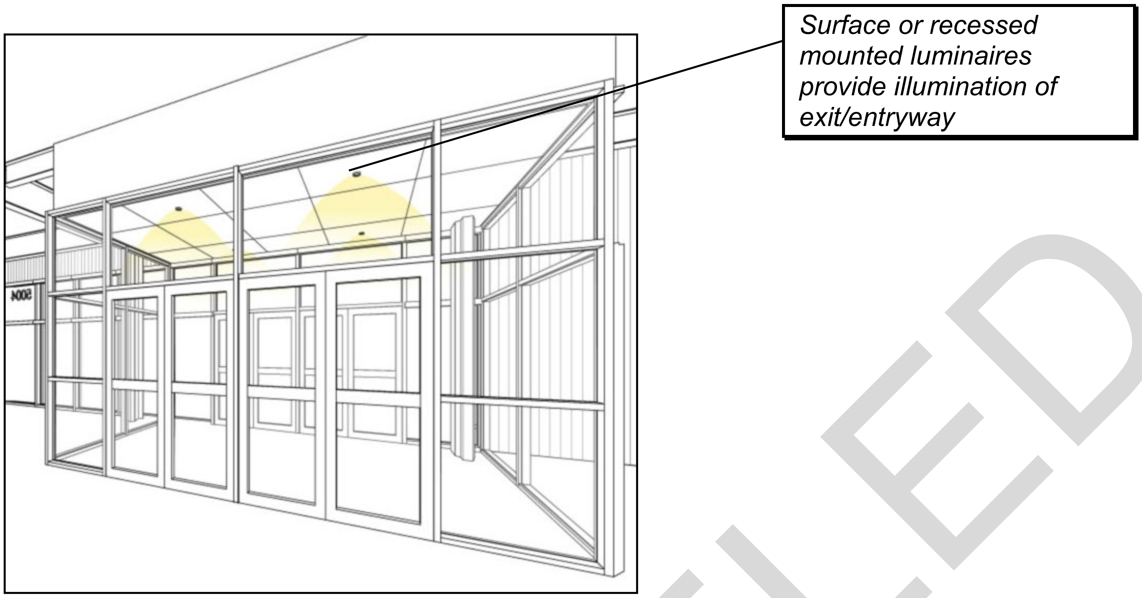
3-3.8.2 Performance Requirements.

Target Criteria	Daytime/Nighttime
Average Horizontal Illuminance	20 fc (300 lux) at 2'-6" (762 mm) AFF
Horizontal Illuminance Uniformity	3:1 average to minimum

3-3.8.3 Critical Design Issues.

- Minimize glare with solutions such as a diffuse lens, regressed lens, indirect optics, and/or shielded louvers.
- Light room surfaces to balance luminance ratios.

3-3.9 Building Entry Vestibules.



3-3.9.1 Control Requirements.

Manual Control	None required if remote local control device is installed per ASHRAE 90.1
Occupancy/Vacancy	Automatic ON to 100% unless daylight is present Automatic full OFF after 20 minutes vacancy OR Automatic lighting reduction by at least 50% after 20 minutes of vacancy
Time Schedule	Scheduled full OFF when corridor is scheduled to be vacant, only if occupancy sensing does not utilize full OFF noted above
Daylight	Automatic responsive daylight dimming when daylight is present
Zoning	Per ASHRAE 90.1 requirements

3-3.9.2 Performance Requirements.

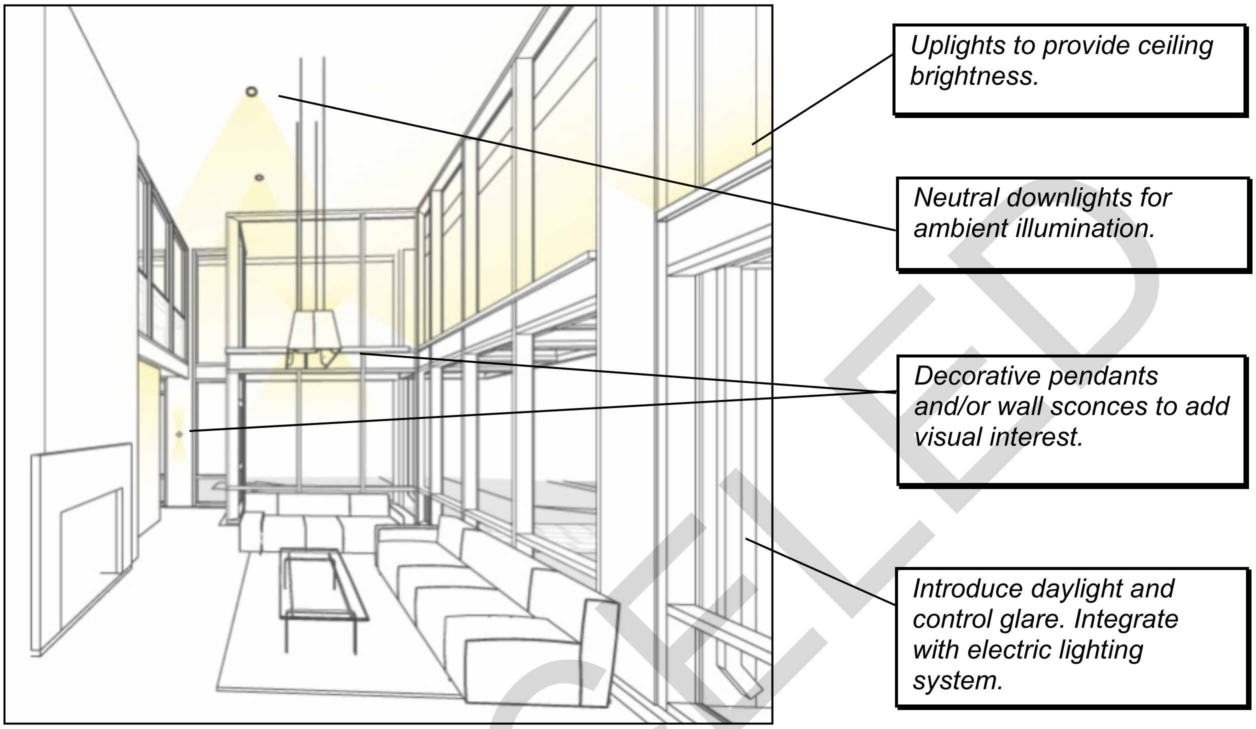
Target Criteria	**Daytime**	**Nighttime**
Average Horizontal Illuminance, Main building entrance	15 fc (150 lux) at floor	4 fc (40 lux) at floor
Average Horizontal Illuminance, Secondary building entrance	10 fc (100 lux) at floor	5 fc (50 lux) at floor
Average Horizontal Illuminance, Interior vestibule	4 fc (40 lux) at floor	N/A
Horizontal Illuminance Uniformity	4:1 average to minimum	

3-3.9.3 Critical Design Issues.

- Means of egress must comply with NFPA 101 control requirements and minimum light level requirements. When the vestibule is means of egress, automatic off is allowable when control requirements are met.
- Illuminate feature artwork and/or feature wall finishes.
- For buildings unoccupied at night, nighttime light level adjustments are not required.

3-4 ADMINISTRATIVE SPACES.

3-4.1 Large Lobbies.



3-4.1.1 Control Requirements.

Manual Control	Scene wallstation OR One wallbox dimmer per luminaire type
Occupancy/Vacancy	Automatic ON to 100% of daytime illuminance criteria unless daylight is present. During the night, automatic ON to 100% of nighttime illuminance criteria. Automatic dimming to a maximum of 50% after 20 minutes vacancy
Time Schedule	Scheduled full OFF when building is scheduled to be vacant unless occupants enter the building, then use Manual Control and Occupancy/Vacancy sensor criteria.
Daylight	Automatic responsive daylight dimming when daylight is present
Zoning	Provide separate control for each luminaire type

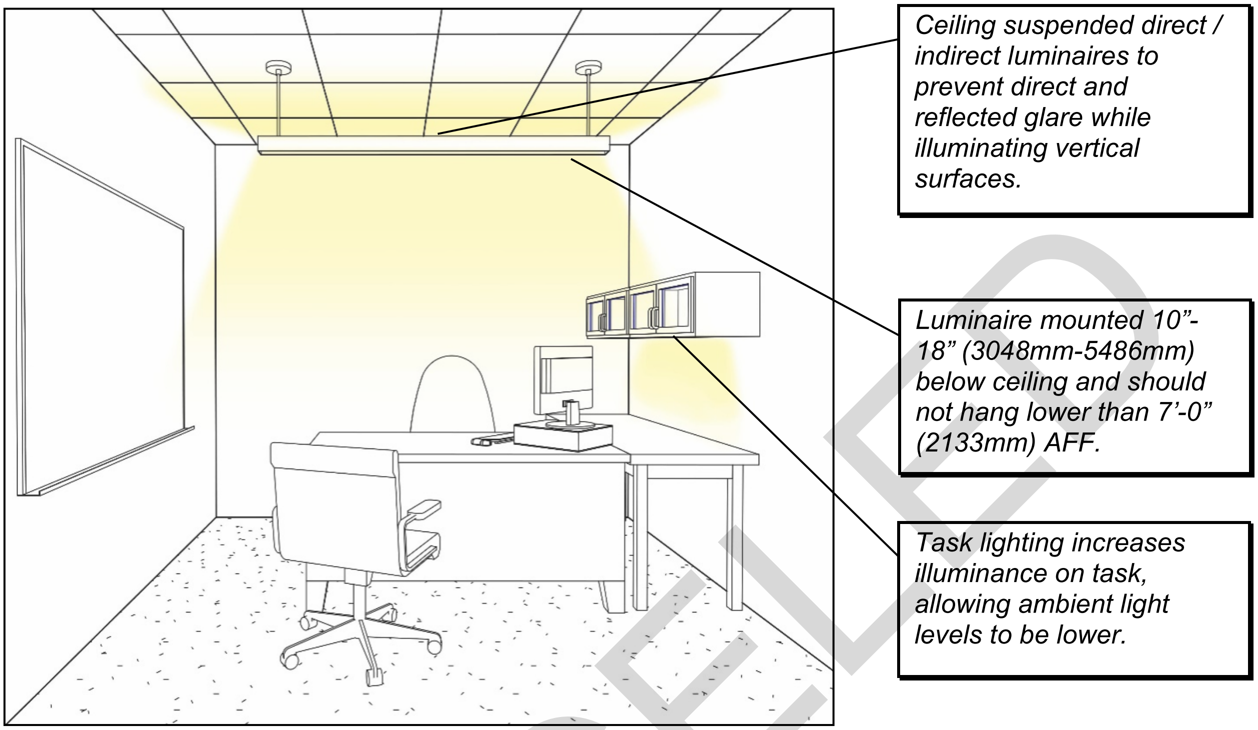
3-4.1.2 Performance Requirements.

Target Criteria	Daytime	Nighttime
Average Horizontal Illuminance, Social, waiting	10 fc (100 lux) at floor	5 fc (50 lux) at floor
Average Horizontal Illuminance, Reception desk	15 fc (150 lux) at 3'-6" (1067 mm) AFF	
Average Horizontal Illuminance, Security screening	20 fc (200 lux) at 3'-0" (910 mm) AFF	
Horizontal Illuminance Uniformity	3:1 average to minimum	

3-4.1.3 Critical Design Issues.

- Avoid visual clutter by selecting luminaires that are aesthetically pleasing.
- Eliminate harsh shadows by lighting surfaces within the space.
- Provide wayfinding guidance such as path to reception desk and elevators.
- Light room surfaces to balance luminance ratios.
- Illuminate feature walls.
- Means of egress must comply with NFPA 101 control requirements and minimum light level requirements. When the lobby is means of egress, automatic off is allowable when control requirements are met.
- Lighting controls must be within the lobby or easily accessible in order for building personnel to manually override controls.
- For elevator lobbies, the light levels should be approximately 1.5 times greater than the average horizontal illuminance of the adjacent corridor or equal to the average horizontal illuminance of the adjacent corridor with added vertical surface brightness (ANSI/IES RP-1).

3-4.2 Individual Offices.



3-4.2.1 Control Requirements.

Manual Control	Scene wallstation with at least one preset scene with all lights dimmed between 30% and 70% of full lighting power OR One wallbox dimmer per luminaire type Task lighting may be toggle switch on luminaire
Occupancy/Vacancy	Manual ON with automatic full OFF after 20 minutes of vacancy Task lighting may be automatic ON
Time Schedule	Scheduled full OFF when building is scheduled to be vacant unless occupants enter the building, then use Manual Control and Occupancy/Vacancy sensor criteria
Daylight	Automatic responsive daylight dimming when daylight is present
Zoning	Provide separate control for ambient lighting and task lighting

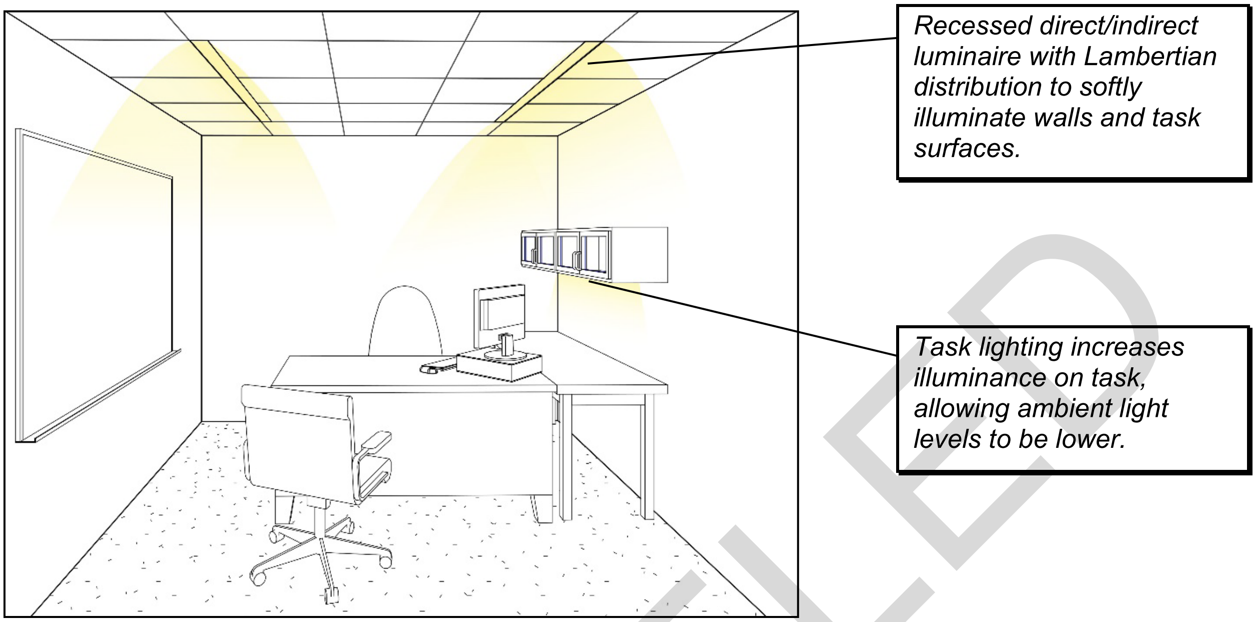
3-4.2.2 Performance Requirements.

Target Criteria	**Daytime/Nighttime**
Average Horizontal Illuminance	30 fc (300 lux) at 2'-6" (762 mm) AFF
Horizontal Illuminance Uniformity	2:1 average to minimum

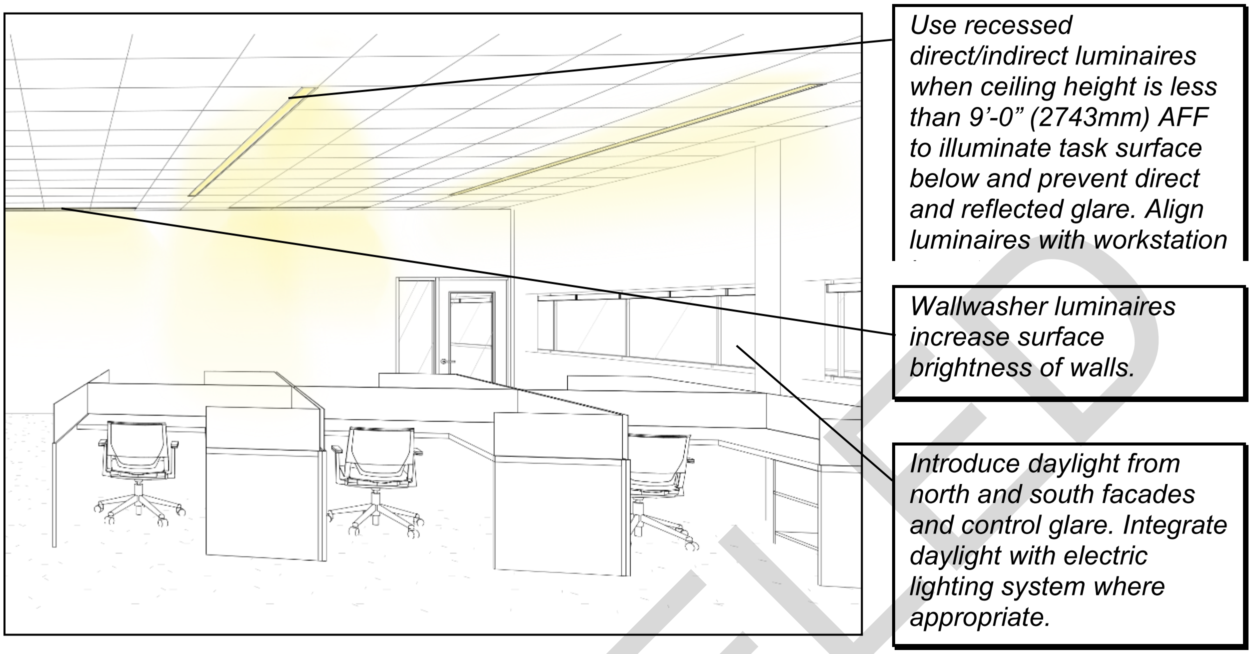
3-4.2.3 Critical Design Issues.

- Minimize glare with solutions such as a diffuse lens, regressed lens, indirect optics, and/or shielded louvers.
- Light room surfaces to balance luminance ratios.
- Coordinate luminaire mounting with ceiling obstructions.
- Provide illumination for vertical writing surfaces mounted on walls.
- Task lighting provided for each work area.

3-4.3 Individual Offices (Alternative Scheme).



3-4.4 Open Offices.



3-4.4.1 Control Requirements.

Manual Control	Scene wallstation with at least one preset scene with all lights dimmed between 30% and 70% of full lighting power OR One wallbox dimmer per luminaire type Task lighting may be toggle switch on luminaire
Occupancy/Vacancy	Automatic ON to a maximum of 50% of full lighting power Automatic full OFF after 20 minutes of vacancy Task lighting may be automatic ON
Time Schedule	Scheduled full OFF when building is scheduled to be vacant unless occupants enter the building, then use Manual Control and Occupancy/Vacancy sensor criteria.
Daylight	Automatic responsive daylight dimming when daylight is present. Activate associated control zones if applicable when daylight is not present.
Zoning	Zones must be a minimum of 600 square feet (56 square meters) and a maximum of 2,500 square feet (232 square meter) Provide associated control zones for zones under 250 square feet (23 square meter). Provide separate control for ambient lighting and task lighting

3-4.4.2 Performance Requirements.

Target Criteria	**Daytime/Nighttime**
Average Horizontal Illuminance	30 fc (300 lux) at 2'-6" (762 mm) AFF
Horizontal Illuminance Uniformity	2:1 average to minimum

3-4.4.3 Critical Design Issues.

- Coordinate luminaire locations with ceiling obstructions such as structure, HVAC, and fire suppression systems.
- Minimize glare with solutions such as a diffuse lens, regressed lens, indirect optics, and/or shielded louvers.
- Light room surfaces to balance luminance ratios.
- Luminaire mounted 10"-18" (3048 mm - 5486 mm) below ceiling and should not hang lower than 7'-0" (2133 mm) AFF.
- In retrofit applications, ensure that heat management of luminaires is adequate and does not compromise rated life of luminaire.
- Provide undercabinet or desk mounted task lights to increase illuminance on task surface. Task lights must have occupancy sensor.
- Provide lighting control zones no larger than 2,500 square feet (232 square meter).
- Means of egress must comply with NFPA 101 for aisles and passageways leading to an exit.

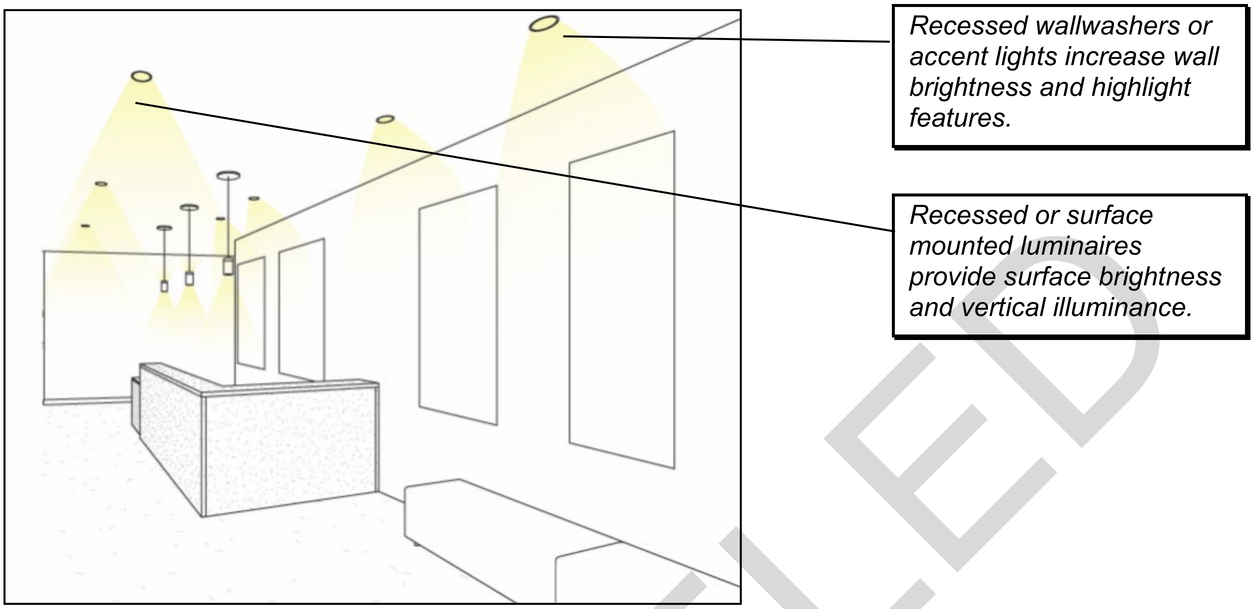
3-4.5 Open Offices (Alternative Scheme).

Locations of ceiling suspended direct / indirect luminaires are coordinated with ceiling obstructions and provide ambient indirect illumination to task surface below while preventing direct and reflected glare.

Wallwasher luminaires increase surface brightness of walls.

Introduce daylight from north and south facades and control glare. Integrate daylight with electric lighting system where appropriate.

3-4.6 Waiting Areas and Lobbies.



3-4.6.1 Control Requirements.

Manual Control	Scene wallstation OR One wallbox dimmer per luminaire type
Occupancy/Vacancy	Manual ON Automatic full OFF after 20 minutes of vacancy OR Automatic ON to a maximum of 70% of full lighting power Automatic full OFF after 20 minutes of vacancy
Time Schedule	Scheduled full OFF when building is scheduled to be vacant unless occupants enter the building, then use Manual Control and Occupancy/Vacancy sensor criteria
Daylight	Automatic responsive daylight dimming when daylight is present
Zoning	Provide separate control for each luminaire type

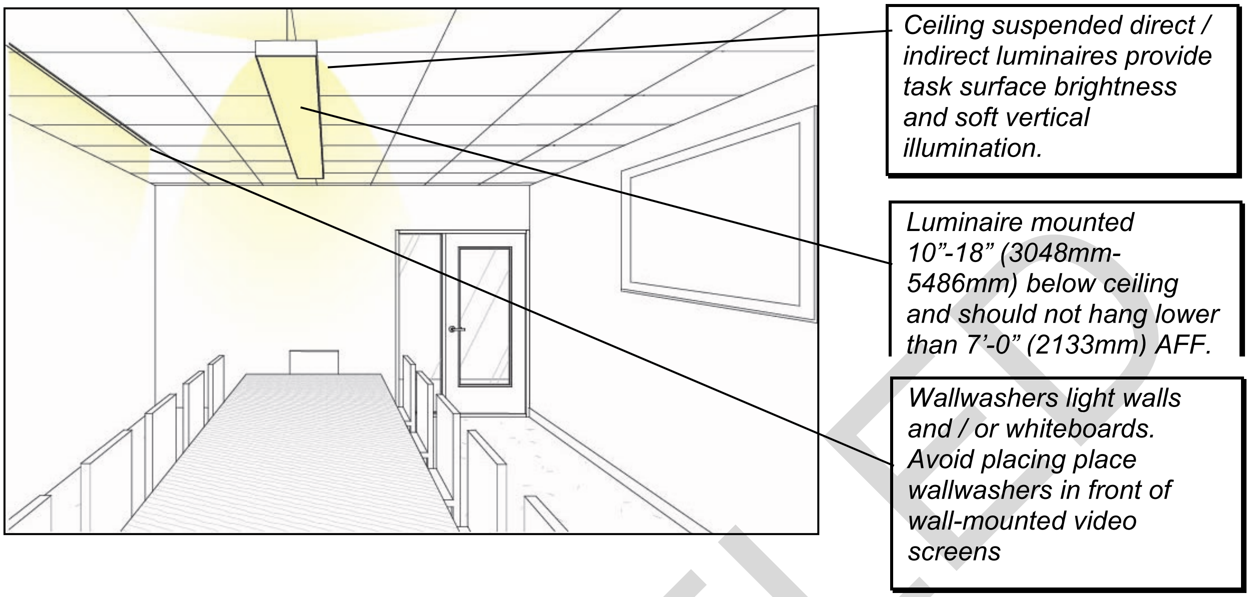
3-4.6.2 Performance Requirements.

Target Criteria	Daytime	Nighttime
Average Horizontal Illuminance, Social, waiting	10 fc (100 lux) at floor	5 fc (50 lux) at floor
Average Horizontal Illuminance, Reception desk	15 fc (150 lux) at 3'-6" (1067 mm) AFF	
Average Horizontal Illuminance, Security screening	20 fc (200 lux) at 3'-0" (910 mm) AFF	
Horizontal Illuminance Uniformity	3:1 average to minimum	

3-4.6.3 Critical Design Issues.

- Select aesthetically pleasing luminaires.
- Light room surfaces to balance luminance ratios.
- Provide task lighting for reception desk and security screening areas to meet performance requirements.
- Means of egress must comply with NFPA 101 control requirements and minimum light level requirements. When the waiting area and lobbies are means of egress, automatic off is allowable when control requirements are met.
- For circulation spaces, the light levels should be approximately 1.5 times greater than the average horizontal illuminance of the adjacent corridor or equal to the average horizontal illuminance of the adjacent corridor with added vertical surface brightness (ANSI/IES RP-1).

3-4.7 Small Meeting Rooms.



3-4.7.1 Control Requirements.

Manual Control	Scene wallstation with at least one preset scene with all lights dimmed between 30% and 70% of full lighting power and continuous dimming capabilities OR One wallbox dimmer per luminaire type
Occupancy/Vacancy	Manual ON with automatic full OFF after 20 minutes of vacancy
Time Schedule	Scheduled full OFF when building is scheduled to be vacant unless occupants enter the building, then use Manual Control and Occupancy/Vacancy sensor criteria.
Daylight	Automatic responsive daylight dimming when daylight is present
Zoning	Provide separate control for ceiling luminaires and wallwash luminaires

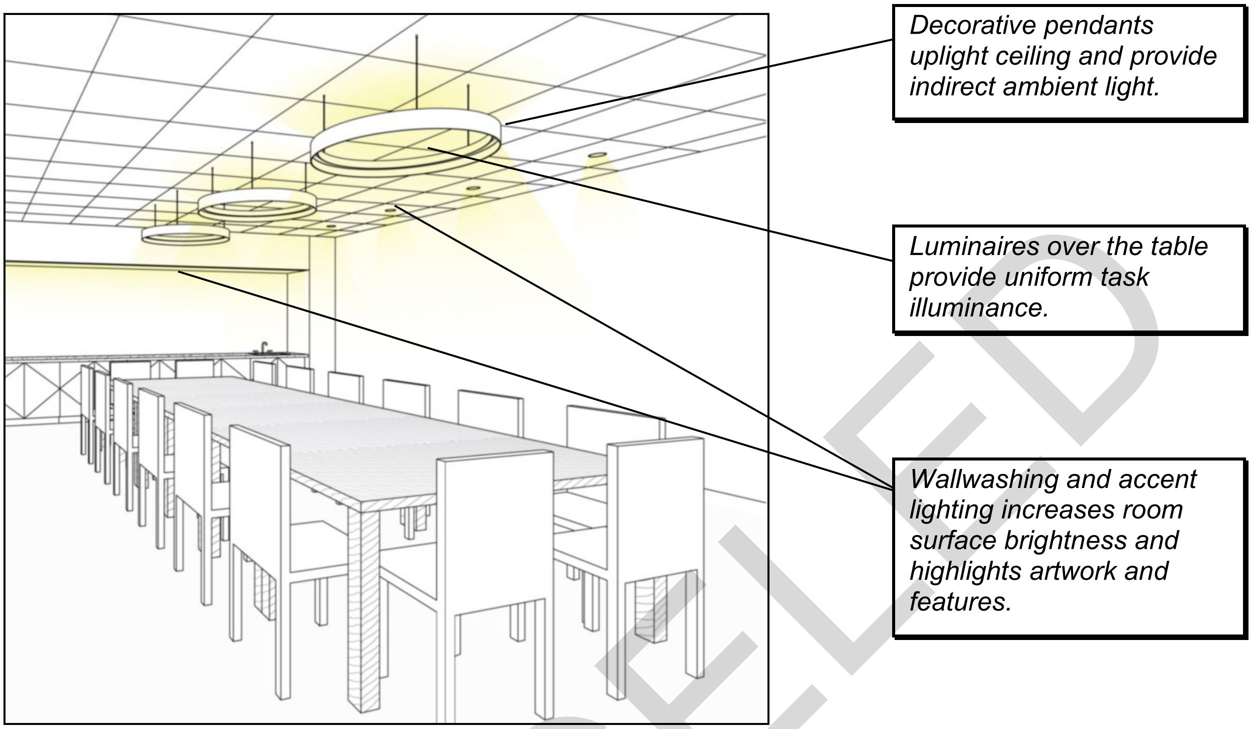
3-4.7.2 Performance Requirements.

Target Criteria	**Daytime/Nighttime**
Average Horizontal Illuminance	30 fc (300 lux) at 2’-6” (762 mm) AFF
Horizontal Illuminance Uniformity	3:1 average to minimum

3-4.7.3 Critical Design Issues.

- Minimize glare with solutions such as a diffuse lens, regressed lens, indirect optics, and/or shielded louvers.
- Select aesthetically pleasing luminaires.
- Light room surfaces to balance luminance ratios.
- Coordinate luminaire locations with ceiling mounted AV equipment.
- Use recessed or surface mount direct/indirect luminaires if ceiling height is too low for suspended luminaires.
- Luminaires immediately adjacent to a display monitor should be on a separate control zone. This would allow those luminaires to be OFF while the display monitor is in use and allow the rest of the lighting in the room to be raised and lowered independently.
- In rooms used for video teleconferencing, use indirect lighting as much as possible to illuminate vertical surfaces such as faces to reduce shadowing and increase uniformity.

3-4.8 Multipurpose / Boardrooms / Large Conference Rooms.



3-4.8.1 Control Requirements.

Manual Control	Scene wallstation with at least one preset scene with all lights dimmed between 30% and 70% of full lighting power and continuous dimming capabilities OR One wallbox dimmer per luminaire type
Occupancy/Vacancy	Manual ON with automatic full OFF after 20 minutes of vacancy
Time Schedule	Scheduled full OFF when building is scheduled to be vacant unless occupants enter the building, then use Manual Control and Occupancy/Vacancy sensor criteria
Daylight	Automatic responsive daylight dimming when daylight is present
Zoning	Provide separate control for each luminaire type Provide an additional zone for luminaires that are illuminating a whiteboard, projection screen, or television

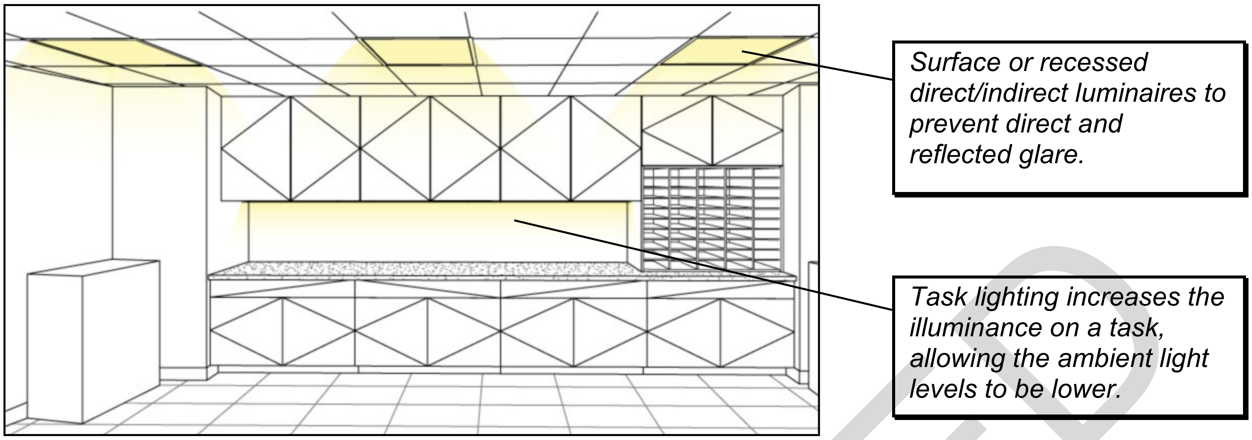
3-4.8.2 Performance Requirements.

Target Criteria	Daytime/Nighttime
Average Horizontal Illuminance	30 fc (300 lux) at 2'-6" (762 mm) AFF
Average Vertical Illuminance	15 fc (150 lux) at 4'-0" (1524 mm) AFF
Horizontal Illuminance Uniformity	3:1 average to minimum

3-4.8.3 Critical Design Issues.

- Minimize glare with solutions such as a diffuse lens, regressed lens, indirect optics, and/or shielded louvers.
- Select aesthetically pleasing luminaires.
- Light room surfaces to balance luminance ratios.
- Coordinate luminaire locations with ceiling mounted AV equipment.
- Consider means of egress requirements if the conference room is over 300 sq ft and has multiple entrances.

3-4.9 Copy/Print and Office Support Areas.



3-4.9.1 Control Requirements.

Manual Control	Scene wallstation with at least one preset scene with all lights dimmed between 30% and 70% of full lighting power OR One wallbox dimmer per luminaire type
Occupancy/Vacancy	Manual ON Automatic full OFF after 20 minutes of vacancy for all lighting, including undercabinet. OR Automatic ON to a maximum of 50% of full lighting power Automatic full OFF after 20 minutes of vacancy for all lighting, including undercabinet.
Time Schedule	Scheduled full OFF when building is scheduled to be vacant unless occupants enter the building, then use Manual Control and Occupancy/Vacancy sensor criteria.
Daylight	Automatic responsive daylight dimming when daylight is present
Zoning	Provide separate control for task lighting and ambient lighting

3-4.9.2 Performance Requirements.

Target Criteria	**Daytime/Nighttime**
Average Horizontal Illuminance, General (ambient)	10 fc (400 lux) at 0’-0” (0 mm) AFF
Average Horizontal Illuminance, Machines (task)	30 fc (300 lux) at task surface
Average Horizontal Illuminance, Printed material inspection (task)	50 fc (500 lux) at task surface
Horizontal Illuminance Uniformity	3:1 average to minimum

3-4.9.3

3-4.9.4 Critical Design Issues.

- Illuminate task surfaces with task lighting.
- Light room surfaces to balance luminance ratios.

3-4.10 Command and Control / Operation Centers.

3-4.10.1 Control Requirements.

Manual Control	Scene wallstation with at least one preset scene with all lights dimmed between 30% and 70% of full lighting power and continuous dimming to 1% OR One wallbox dimmer per luminaire type with dimming to 1% Task lighting may be toggle switch on luminaire
Occupancy/Vacancy	None
Time Schedule	None
Daylight	Automatic responsive daylight dimming when daylight is present
Zoning	Provide separate control for ambient lighting and task lighting

3-4.10.2 Performance Requirements.

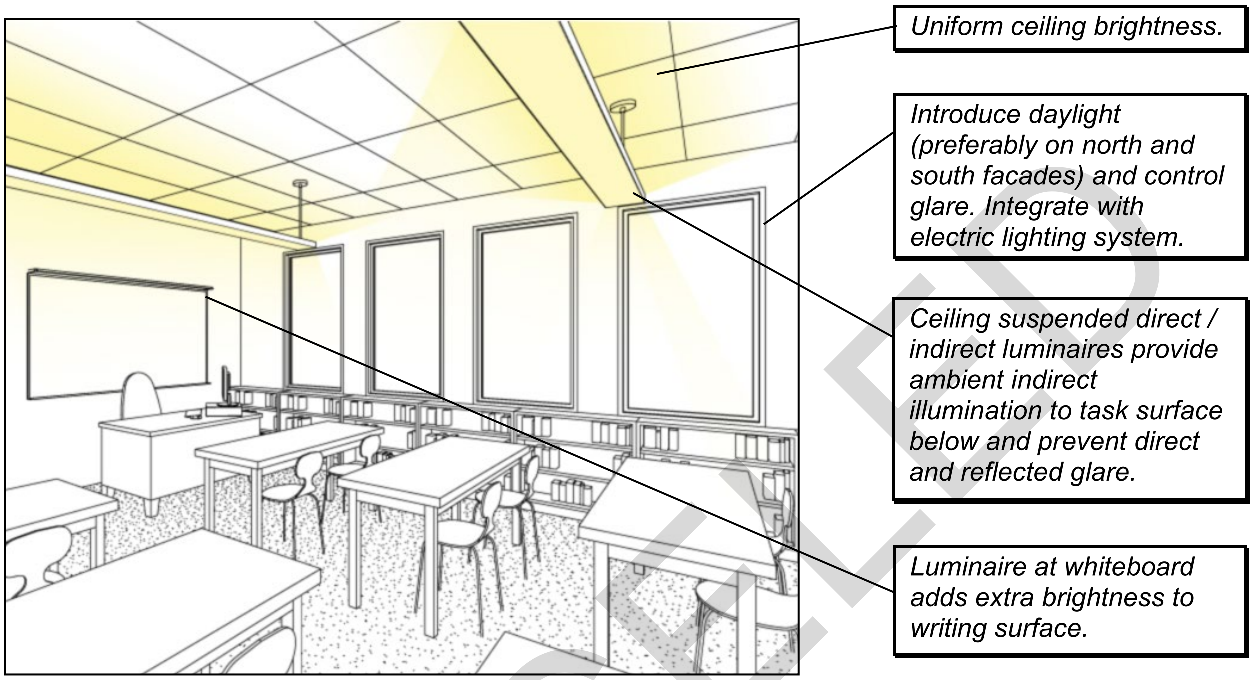
Target Criteria	**Daytime/Nighttime**
Average Horizontal Illuminance	30 fc (300 lux) at 2'-6" (762mm) AFF
Horizontal Illuminance Uniformity	2:1 average to minimum

3-4.10.3 Critical Design Issues.

- Eliminate direct and reflected glare.
- Luminaires may have to dim to lower than 1% due to special circumstances or tasks performed in the space.
- Task lighting should be shielded and directed so as not to disturb other occupants in the room.
- Only use recessed direct/indirect luminaires when ceilings are less than 9' or less.
- Ceiling reflectance can be no less than 80%.
- Means of egress must comply with NFPA 101 control requirements and minimum light level requirements. When the space is designated as a means of egress, automatic off is allowable when control requirements are met.
- Operation centers operate on 24-hour schedules, therefore no occupancy sensing needed.
- Consider spectral tuning luminaires when designing for spaces that routinely operate 24-hour schedules.

3-5 EDUCATIONAL SPACES.

3-5.1 Classroom / Training Rooms.



3-5.1.1 Control Requirements.

Manual Control	Scene wallstation with at least one preset scene with all lights dimmed between 30% and 70% of full lighting power and continuous dimming capabilities OR One wallbox dimmer per luminaire type
Occupancy/Vacancy	Manual ON with automatic full OFF after 20 minutes of vacancy
Time Schedule	Scheduled full OFF when building is scheduled to be vacant unless occupants enter the building, then use Manual Control and Occupancy/Vacancy sensor criteria.
Daylight	Automatic responsive daylight dimming when daylight is present
Zoning	Provide a separate zone for luminaires that are illuminating a white board, projection screen, or television

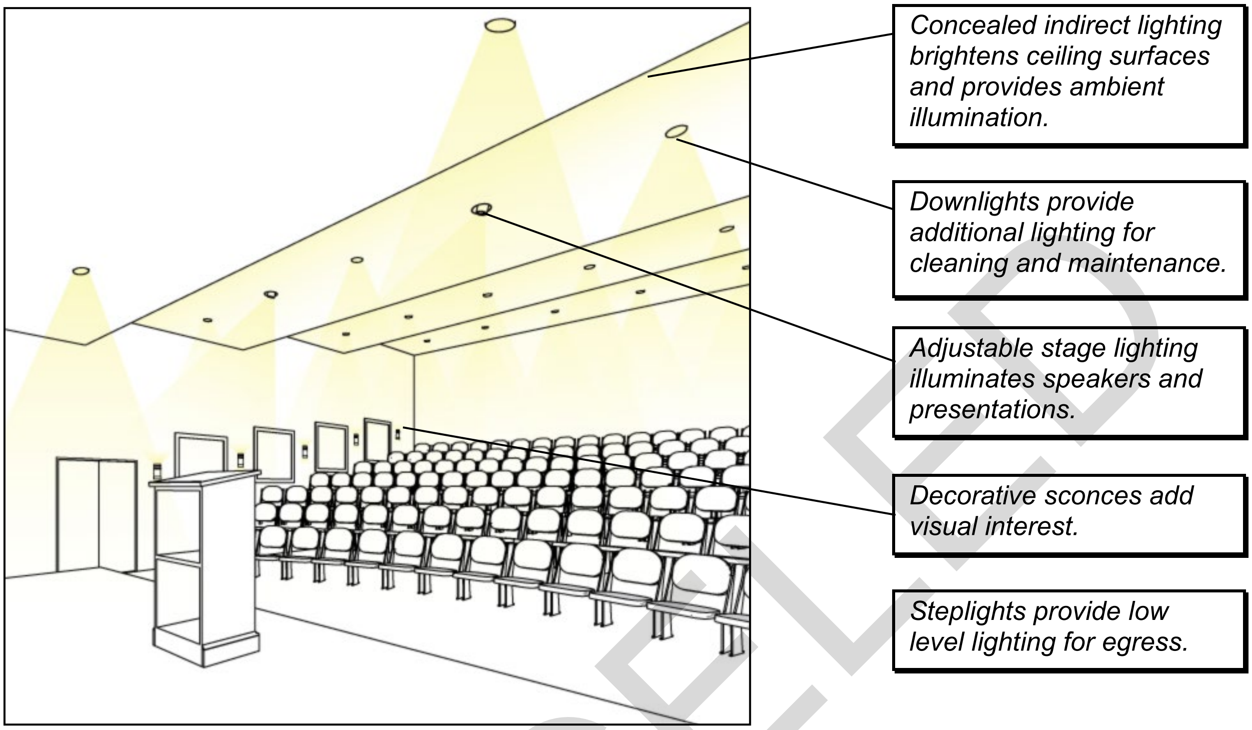
3-5.1.2 Performance Requirements.

Target Criteria	Daytime/Nighttime
Average Horizontal Illuminance	40 fc (400 lux) at 2'-6" (762 mm) AFF
Average Vertical Illuminance	15 fc (150 lux) at 4' (1,219 mm) AFF on presentation wall
Horizontal Illuminance Uniformity	2:1 average to minimum

3-5.1.3 Critical Design Issues.

- Control glare from windows and clerestories.
- Provide even illumination (both electric and daylight) to the space.
- Minimize glare with solutions such as a diffuse lens, regressed lens, indirect optics, and/or shielded louvers.
- Light room surfaces to balance luminance ratios.
- Ceiling suspended direct/indirect luminaire mounted 10" - 18" (3048 mm - 5486 mm) below ceiling and should not hang lower than 7'-0" (2133 mm) AFF.
- Use recessed or surface mount direct/indirect luminaires if ceiling height is too low for suspended luminaires.
- Coordinate luminaire locations with ceiling mounted AV equipment.
- Additional guidance provided in ANSI/IES RP-3, Recommended Practice Lighting Educational Facilities.
- Luminaires may have to dim lower than 10% due to special circumstances.
- Provide scene wallstation near instructor's desk at the front of the classroom.

3-5.2 Auditoriums.



3-5.2.1 Control Requirements.

Manual Control	At least one scene wallstation with: At least one preset "Presentation" scene At least one preset "All On" scene for cleaning Continuous dimming to 10% for all luminaires.
Occupancy/Vacancy	Manual ON with automatic full OFF after 20 minutes of vacancy
Time Schedule	Scheduled full OFF when building is scheduled to be vacant unless occupants enter the building, then use Manual Control and Occupancy/Vacancy sensor criteria.
Daylight	Automatic responsive daylight dimming when daylight is present
Zoning	Provide separate control for each luminaire type Provide an additional zone for luminaires that are illuminating a speaker podium or stage.

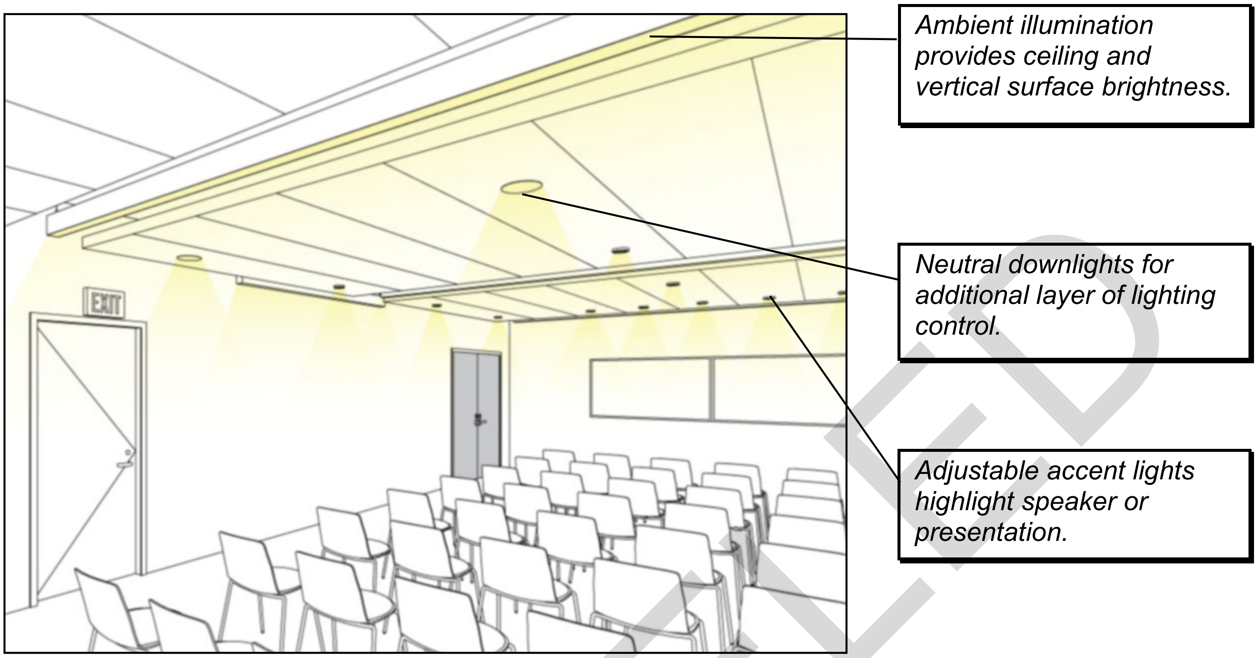
3-5.2.2 Performance Requirements.

Target Criteria	Daytime/Nighttime
Average Horizontal Illuminance, Audience (ambient)	5 fc (50 lux) at 2’-0” (910 mm) AFF
Average Horizontal Illuminance, Panel Speaker (task)	30 fc (300 lux) at 2’-6” (762 mm) AFF
Average Horizontal Illuminance, Stage Demonstration (task)	50 fc (500 lux) at 3’-0” (1067 mm) AFF
Horizontal Illuminance Uniformity	2:1 average to minimum
Average Vertical Illuminance, Stage	20 fc (200 lux) at 5’-0” (1524 mm) AFF

3-5.2.3 Critical Design Issues.

- Minimize glare with solutions such as a diffuse lens, regressed lens, indirect optics, and/or shielded louvers.
- Use downlights with specular cones to minimize glare.
- Allow for low ambient lighting through zoning and dimmable controls.
- Provide accent lighting on speaker.
- Avoid harsh shadows by lighting the speaker from both sides.
- Provide egress lighting along the edge of the aisles per NFPA 101.
- Light room surfaces to balance luminance ratios.
- Coordinate luminaire locations with ceiling mounted AV equipment.
- Provide lighting for front of room vertical writing surfaces.
- Provide Scene Wallstation close to Podium and locate at Podium if possible. Provide additional scene control at all primary entrances.

3-5.3 Large Presentation and Briefing Areas.



3-5.3.1 Control Requirements.

Manual Control	Scene wallstation with at least one preset scene with all lights dimmed between 30% and 70% of full lighting power and continuous dimming capabilities OR One wallbox dimmer per luminaire type
Occupancy/Vacancy	Manual ON with automatic full OFF after 20 minutes of vacancy
Time Schedule	Scheduled full OFF when building is scheduled to be vacant unless occupants enter the building, then use Manual Control and Occupancy/Vacancy sensor criteria.
Daylight	Automatic responsive daylight dimming when daylight is present
Zoning	Provide separate control for each luminaire type Provide an additional zone for luminaires that are illuminating a speaker podium, projection screen, or television

3-5.3.2 Performance Requirements.

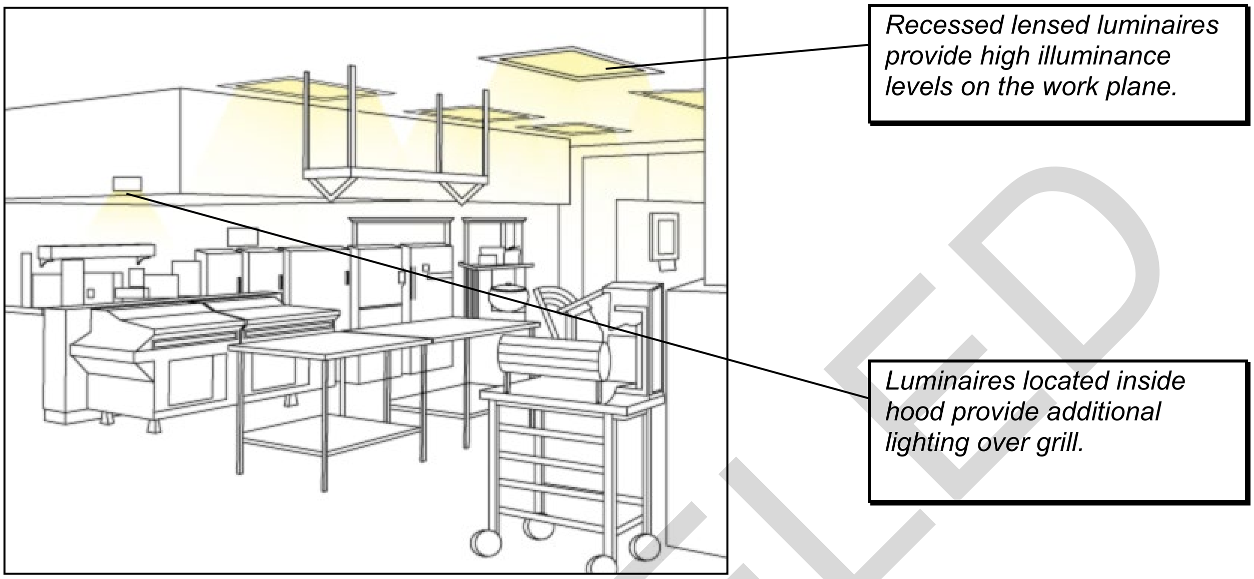
Target Criteria	Daytime/Nighttime
Average Horizontal Illuminance	10 fc (100 lux) at 2'-6" (762 mm) AFF
Average Horizontal Illuminance, Panel Speaker (task)	30 fc (300 lux) at 2'-6" (762 mm) AFF
Average Horizontal Illuminance, Stage Demonstration (task)	50 fc (500 lux) at 3'-0" (1067 mm) AFF
Horizontal Illuminance Uniformity	2:1 average to minimum
Average Vertical Illuminance, Stage	20 fc (200 lux) at 5'-0" (1524 mm) AFF

3-5.3.3 Critical Design Issues.

- Allow for low ambient lighting through zoning and dimmable controls.
- Provide dimming capabilities down to 10% for all lighting in the space.
- Provide accent lighting on speaker.
- Light room's surfaces to balance luminance ratios.
- Coordinate luminaire locations with ceiling mounted AV equipment.
- Means of egress must comply with NFPA 101 control requirements and minimum light level requirements. When the space is designated as a means of egress, automatic off is allowable when control requirements are met.

3-6 FOOD SERVICE SPACES.

3-6.1 Commercial Kitchens.



3-6.1.1 Control Requirements.

Manual Control	Scene wallstation with at least one preset scene with all lights dimmed between 30% and 70% of full lighting power OR One wallbox dimmer per luminaire type
Occupancy/Vacancy	Manual ON OR Automatic ON to a maximum of 50% of full lighting power
Time Schedule	None
Daylight	Automatic responsive daylight dimming when daylight is present
Zoning	Provide separate control for task lighting and ambient lighting

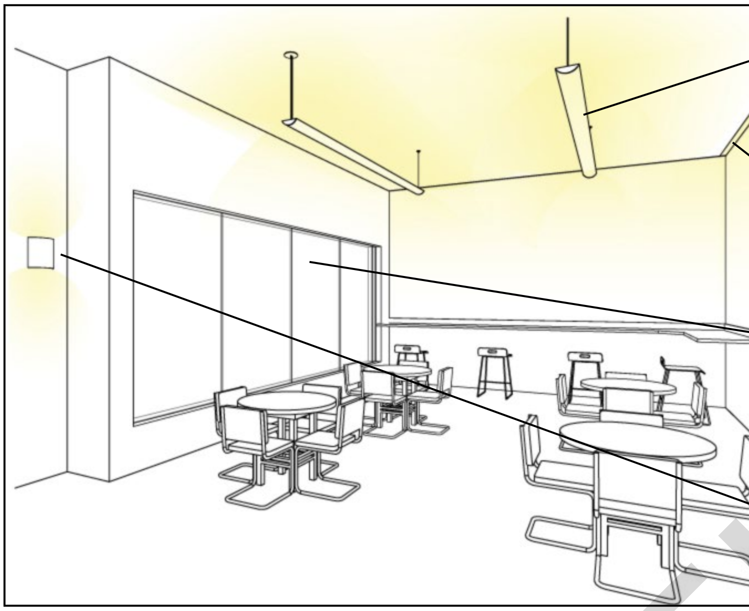
3-6.1.2 Performance Requirements.

Target Criteria	Daytime/Nighttime
Average Horizontal Illuminance, Food prep, handling, cleaning (task)	50 fc (500 lux) at food preparation surface
Average Vertical Illuminance, Food prep, handling, cleaning (task)	20 fc (200 lux) at food preparation surface
Horizontal Illuminance Uniformity	3:1 average to minimum at food preparation surface
Average Horizontal Illuminance, Dishwashing, pot washing (task)	20 fc (200 lux) at task surface
Average Vertical Illuminance, Dishwashing, pot washing (task)	10 fc (100 lux) at 4'-0" (1219 mm) AFF

3-6.1.3 Critical Design Issues.

- Locate luminaires to minimize shadows.
- Select luminaires designed for food processing facilities.
- Use high, 90+ CRI light sources in kitchen for proper rendering of food color.

3-6.2 Cafeterias.



3-6.2.1 Control Requirements.

Manual Control	Scene wallstation with at least one preset scene with all lights dimmed between 30% and 70% of full lighting power OR One wallbox dimmer per luminaire type
Occupancy/Vacancy	Manual ON Automatic full OFF after 20 minutes of vacancy OR Automatic ON to a maximum of 50% of full lighting power Automatic full OFF after 20 minutes of vacancy
Time Schedule	None
Daylight	Automatic responsive daylight dimming when daylight is present
Zoning	Provide separate control for task lighting and ambient lighting

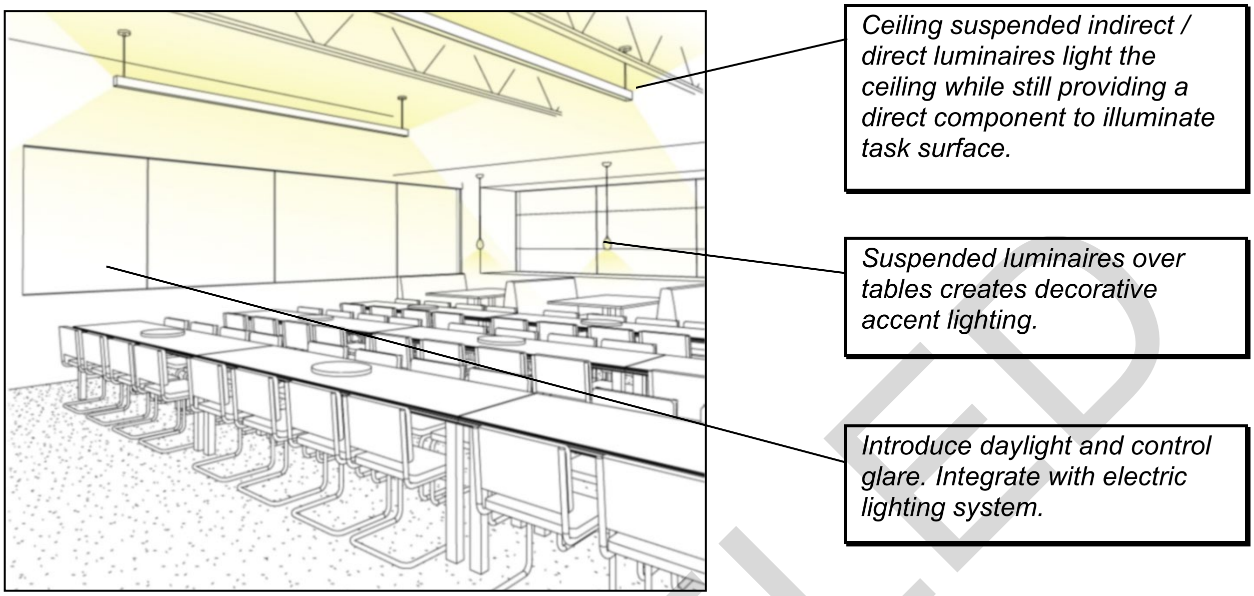
3-6.2.2 Performance Requirements.

Target Criteria	**Ambient**	**Food Display**	**Food Servery**
Average Horizontal Illuminance	15 fc (150 lux) at 2’-6” (762 mm) AFF	50 fc (500 lux) at food preparation surface	20 fc (200 lux) at task surface
Average Vertical Illuminance	NA	20 fc (200 lux) at food preparation surface	20 fc (200 lux) at task surface
Horizontal Illuminance Uniformity	3:1 average to minimum		

3-6.2.3 Critical Design Issues.

- Use accent lighting to provide wayfinding.
- Light room surfaces to balance luminance ratios.
- Means of egress must comply with NFPA 101 control requirements and minimum light level requirements. When the space is designated as a means of egress, automatic off is allowable when control requirements are met.
- Areas of food preparation do not have to have occupancy sensors.

3-6.3 Enlisted Dining Rooms.



3-6.3.1 Control Requirements.

Manual Control	Scene wallstation with at least one preset scene with all lights dimmed between 30% and 70% of full lighting power OR One wallbox dimmer per luminaire type
Occupancy/Vacancy	Manual ON Automatic full OFF after 20 minutes of vacancy OR Automatic ON to a maximum of 50% of full lighting power Automatic full OFF after 20 minutes of vacancy
Time Schedule	None
Daylight	Automatic responsive daylight dimming when daylight is present
Zoning	Provide separate control for task lighting and ambient lighting

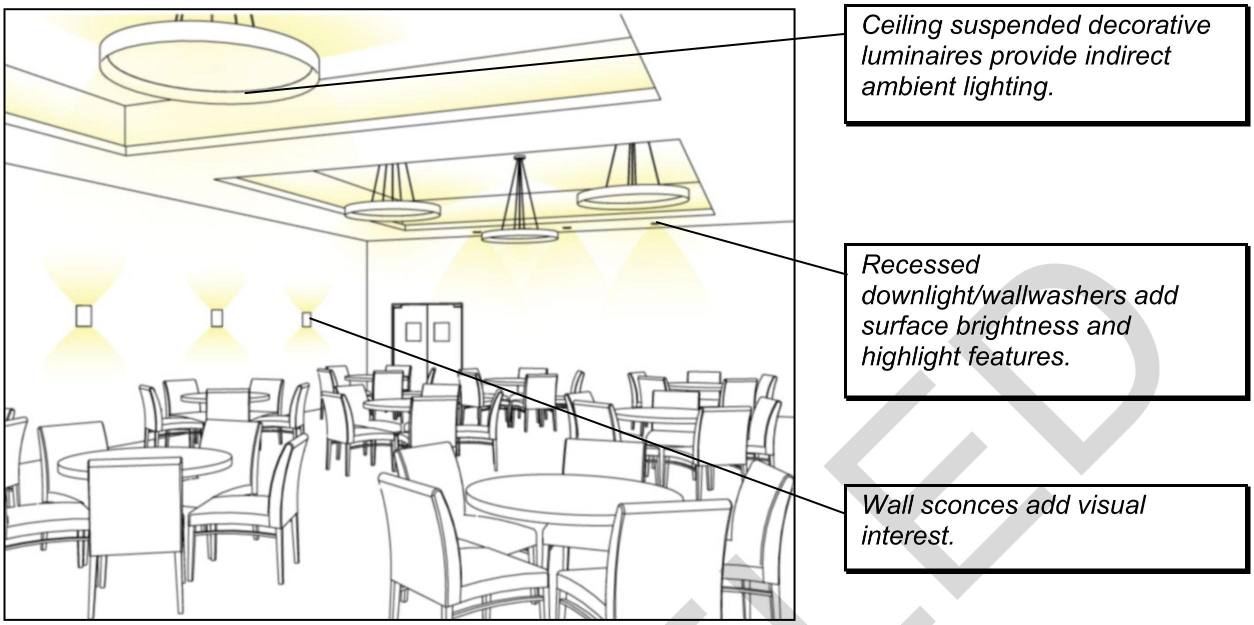
3-6.3.2 Performance Requirements.

Target Criteria	**Ambient**	**Food Display**
Average Horizontal Illuminance	15 fc (150 lux) at 2'-6" (762 mm) AFF	50 fc (500 lux) at food preparation surface
Average Vertical Illuminance	NA	20 fc (200 lux) at food preparation surface
Horizontal Illuminance Uniformity	3:1 average to minimum	

3-6.3.3 Critical Design Issues.

- Use accent lighting to provide wayfinding.
- Provide luminaires with low lumen output and dimming to avoid excessive brightness.
- Light room surfaces to balance luminance ratios.
- Means of egress must comply with NFPA 101 control requirements and minimum light level requirements. When the space is designated as a means of egress, automatic off is allowable when control requirements are met.

3-6.4 Officer Dining Rooms.



3-6.4.1 Control Requirements.

Manual Control	Scene wallstation with at least one preset scene with all lights dimmed between 30% and 70% of full lighting power and continuous dimming capabilities OR One wallbox dimmer per luminaire type
Occupancy/Vacancy	Manual ON Automatic full OFF after 20 minutes of vacancy OR Automatic ON to a maximum of 50% of full lighting power Automatic full OFF after 20 minutes of vacancy
Time Schedule	None
Daylight	Automatic responsive daylight dimming when daylight is present
Zoning	Provide separate control zone for each luminaire type.

3-6.4.2 Performance Requirements.

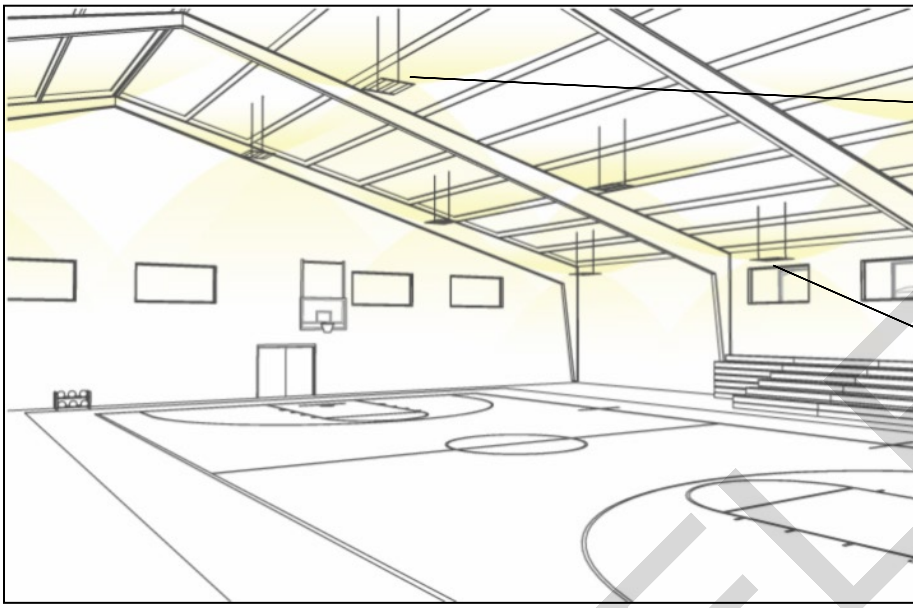
Target Criteria	**Ambient**	**Food Display**
Average Horizontal Illuminance	10 fc (100 lux) at table plane	50 fc (500 lux) at food preparation surface
Average Vertical Illuminance	NA	20 fc (200 lux) at food preparation surface
Horizontal Illuminance Uniformity	3:1 average to minimum	

3-6.4.3 Critical Design Issues.

- Select aesthetically pleasing luminaires.
- Provide luminaires with low lumen output and dimming to avoid excessive brightness.
- Light room surfaces to balance luminance ratios.
- Means of egress must comply with NFPA 101 control requirements and minimum light level requirements. When the space is designated as a means of egress, automatic off is allowable when control requirements are met.

3-7 RECREATIONAL SPACES.

3-7.1 Indoor Multi-use Gymnasiums.



3-7.1.1 Control Requirements.

Manual Control	Scene wallstation with preset scenes: - All lights on to 10% -40% (normal) - All lights on to 50% - 70% (recreation) - All lighting on to 80% - 100% (league play)
Occupancy/Vacancy	Automatic ON to a maximum of 50% of full lighting power with automatic full OFF after 20 minutes of vacancy
Time Schedule	Scheduled full OFF when building is scheduled to be vacant unless occupants enter the building, then use Manual Control and Occupancy/Vacancy sensor criteria.
Daylight	Automatic responsive daylight dimming when daylight is present
Zoning	Provide separate zones for each defined activity space, if more than one.

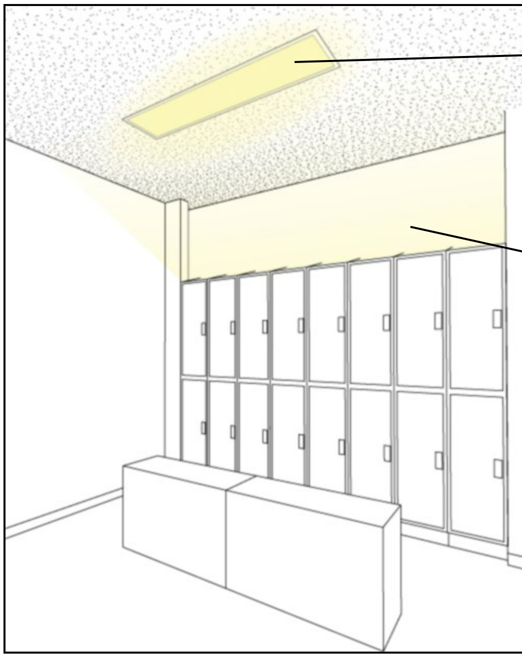
3-7.1.2 Performance Requirements.

Target Criteria	**Recreational**
Average Horizontal Illuminance	Refer to ANSI/IES RP-6 for specific indoor sport
Horizontal Illuminance Uniformity	Refer to ANSI/IES RP-6 for specific indoor sport

3-7.1.3 Critical Design Issues.

- Provide luminaires with lenses or louvers to minimize glare.
- Refer to ANSI/IES RP-6, *Recommended Practice: Lighting Sports and Recreational Areas* for specific criteria for different indoor sports. Use Class IV for all recreation lighting criteria. If more than one type of sport is intended to be played in the gymnasium, design the light levels for the sport requiring the most light.
- Refer to ANSI/IES RP-6, *Recommended Practice: Lighting Sports and Recreational Areas* for direction in luminaire placement to avoid glare.
- Provide uniform illuminance on the court.
- Minimize shadows to enhance view of objects and people.
- Light room surfaces to balance luminance ratios.
- Coordinate luminaire locations with ceiling equipment such as HVAC, and sports equipment.
- Use wire guards or polycarbonate lens where appropriate to protect luminaire.
- Refer to UFC 4-740-02 for additional requirements and considerations regarding recreational spaces in fitness centers.
- Provide keyed box for lighting controls near main entrance.

3-7.2 Locker Rooms.



3-7.2.1 Control Requirements.

Manual Control	At least one scene wallstation or wallbox dimmer
Occupancy/Vacancy	Manual ON Automatic full OFF after 20 minutes of vacancy OR Automatic ON to a maximum of 50% of full lighting power Automatic full OFF after 20 minutes of vacancy
Time Schedule	Scheduled full OFF when building is scheduled to be vacant unless occupants enter the building, then use Manual Control and Occupancy/Vacancy sensor criteria.
Daylight	Automatic responsive daylight dimming when daylight is present
Zoning	None

3-7.2.2 Performance Requirements.

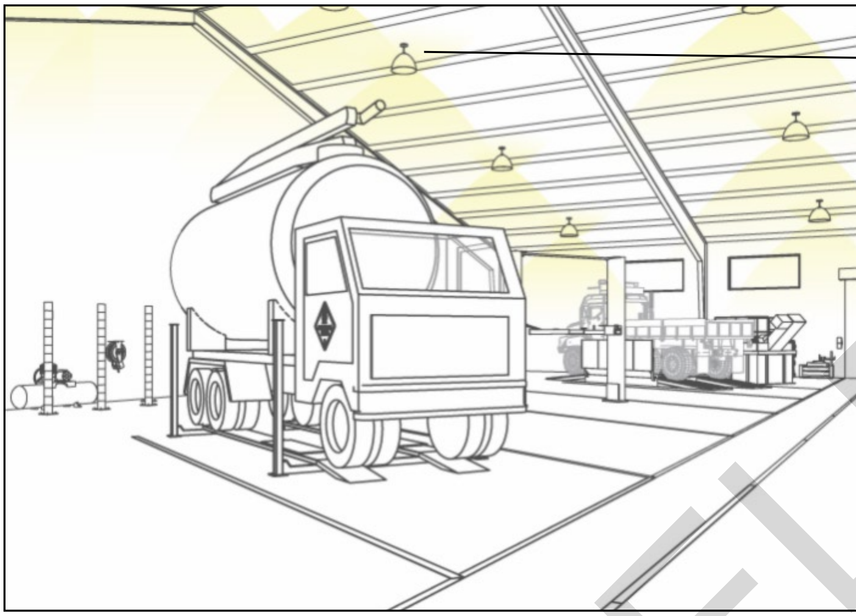
Target Criteria	**Daytime/Nighttime**
Average Horizontal Illuminance	5 fc (50 lux) at floor
Average Vertical Illuminance	10 fc (100 lux) at locker faces
Horizontal Illuminance Uniformity	3:1 average to minimum

3-7.2.3 Critical Design Issues.

- Provide luminaires with translucent, non-breakable, protective covers.
- Provide luminaires that are damp rated if they are located in close proximity to showers, pools, or other humid spaces.
- Light room surfaces to balance luminance ratios.
- Minimize shadows by providing diffuse lighting, especially at lockers and counters.
- Refer to UFC 4-740-02 for additional requirements and considerations regarding recreational spaces in fitness centers.
- For locker rooms greater than 300 square feet, means of egress must comply with NFPA 101 for passageways leading to an exit.

3-8 MAINTENANCE SPACES.

3-8.1 Vehicle Maintenance Areas.



Direct / indirect luminaires reduce direct glare.

Luminaire spacing provides uniform illuminance on task plane.

3-8.1.1 Control Requirements.

Manual Control	Manual OFF with scene wallstation with at least three preset scenes: full ON, lights dimmed between 30% and 70% of full lighting power, and OFF.
Occupancy/Vacancy	Manual ON Automatically dimmed by at least 50% after 20 minutes of vacancy
Time Schedule	Scheduled Full OFF when building is scheduled to be vacant unless occupants enter the building, then use Manual Control and Occupancy/Vacancy sensor criteria.
Daylight	Automatic responsive daylight dimming when daylight is present
Zoning	Zone each service bay separately.

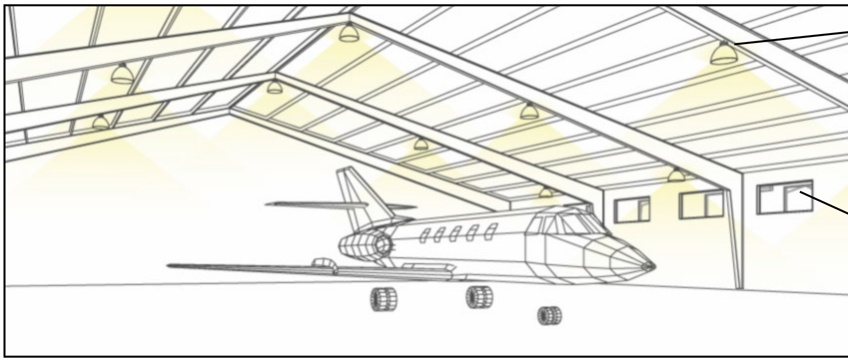
3-8.1.2 Performance Requirements.

Target Criteria	**Daytime/Nighttime**
Average Horizontal Illuminance	30 fc (300 lux) at floor
Average Vertical Illuminance	7.5 fc (75 lux) at 4’-0” (1219 mm) AFF
Horizontal Illuminance Uniformity	3:1 average to minimum

3-8.1.3 Critical Design Issues.

- Use stem mounted luminaires in all drive through vehicle maintenance bays.
- Provide redundant supports to ensure that failure of a single supporting component does not result in luminaire falling.
- Locate lighting equipment to minimize shadows.
- Automated dimming must be ramped.
- Light room surfaces to balance luminance ratios.
- Uniformly light the work plane.
- Verify special lighting equipment requirements in hazardous (classified) locations.
- These service facilities employ ambient and task lighting systems. The two primary lighting strategies are:
- Wall-mounted luminaires to illuminate tasks (the bench and vehicle hood areas) or
- Strategically located luminaires at the ceiling at the tasks (hood areas).
- White ceilings and walls are necessary to maximize efficiency and diffusion.
- Target illuminance requirements are applicable when all luminaires are energized.
- Occupancy/Vacancy automatic OFF is not allowed.
- Manual control override of scheduled shutoff will not turn the lighting on for more than 2 hours during scheduled off periods.

3-8.2 Aircraft Hangar Bay.



3-8.2.1 Control Requirements.

Manual Control	Manual OFF with scene wallstation with at least three preset scenes: full ON, lights dimmed between 30% and 70% of full lighting power, and OFF.
Occupancy/Vacancy	Manual ON Automatically dimmed by at least 50% after 20 minutes of vacancy
Time Schedule	Scheduled dimmed to 20% or user defined level when hangar bay is scheduled to be vacant unless occupants enter the bay, then use Manual Control and Occupancy/Vacancy sensor criteria.
Daylight	Automatic responsive daylight dimming per zone when daylight is present.
Zoning	Each aircraft maintenance area is a separate lighting control zone. ASHRAE 90.1 does not apply to aircraft maintenance areas.

3-8.2.2 Performance Requirements.

Target Criteria	**Daytime/Nighttime**
Average Horizontal Illuminance	50 fc (500 lux) at 2'-6" (762 mm) AFF
Average Vertical Illuminance	50 fc (500 lux) at aircraft surface
Horizontal Illuminance Uniformity	3:1 average to minimum

3-8.2.3 Critical Design Issues.

- If there are no afterhours security requirements, the lights in the hangar bay may be shut off via Time Schedule. Coordinate security lighting requirements with security officer.
- Use stem mounted luminaires in aircraft hangar bays.

- Provide redundant supports to ensure that failure of a single supporting component does not result in luminaire falling.

- Locate lighting equipment to minimize shadows.

- Uniformly light the work plane.

- Automated dimming must be ramped.

- Occupancy/Vacancy automatic OFF is not allowed.

- Verify special lighting equipment requirements in hazardous (classified) locations.

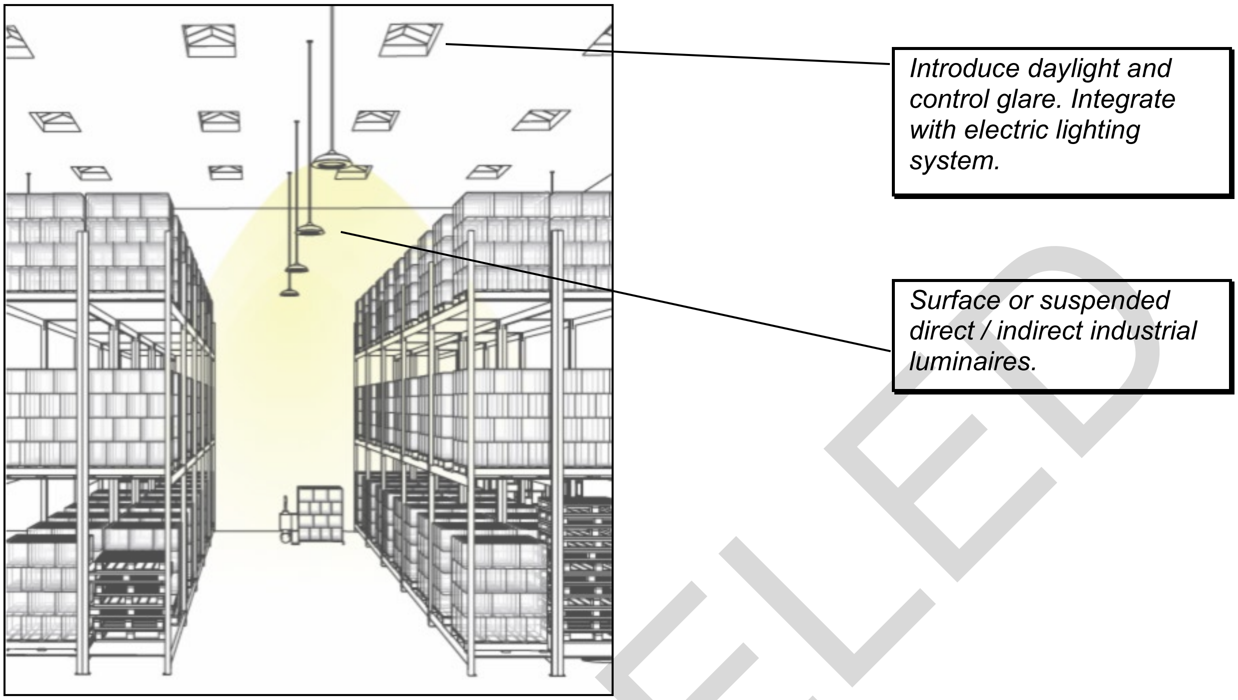
- Refer to ANSI/IES RP-7 for additional considerations.

- Account for permanent illuminance-reduction installation features, such as instances where luminaires are installed above bird netting. 10% performance reduction is assumed in these situations. Ensure that luminaires be accessible for maintenance when bird netting is installed.

- UFC 4-211-02 requires 100 fc average for corrosion control hangar bays.

- Coordinate skylight and clerestory locations with aircraft control to ensure no visual light trespass conflicts with control tower night operations.

3-8.3 Warehouses.



3-8.3.1 Control Requirements.

Manual Control	Scene wallstation with at least one preset scene with all lights dimmed between 30% and 70% of full lighting power OR One wallbox dimmer per zone
Occupancy/Vacancy	Manual ON Automatically dimmed by at least 50% after 20 minutes of vacancy OR Automatic ON to 50% of general lighting power Automatically dimmed by at least 50% after 20 minutes of vacancy
Time Schedule	Scheduled full OFF when building is scheduled to be vacant unless occupants enter the building, then use Manual Control and Occupancy/Vacancy sensor criteria.
Daylight	Automatic responsive daylight dimming when daylight is present
Zoning	Provide zones that are no larger than 2,500 square feet, unless space is over 10,000 square feet, then larger zones can be used.

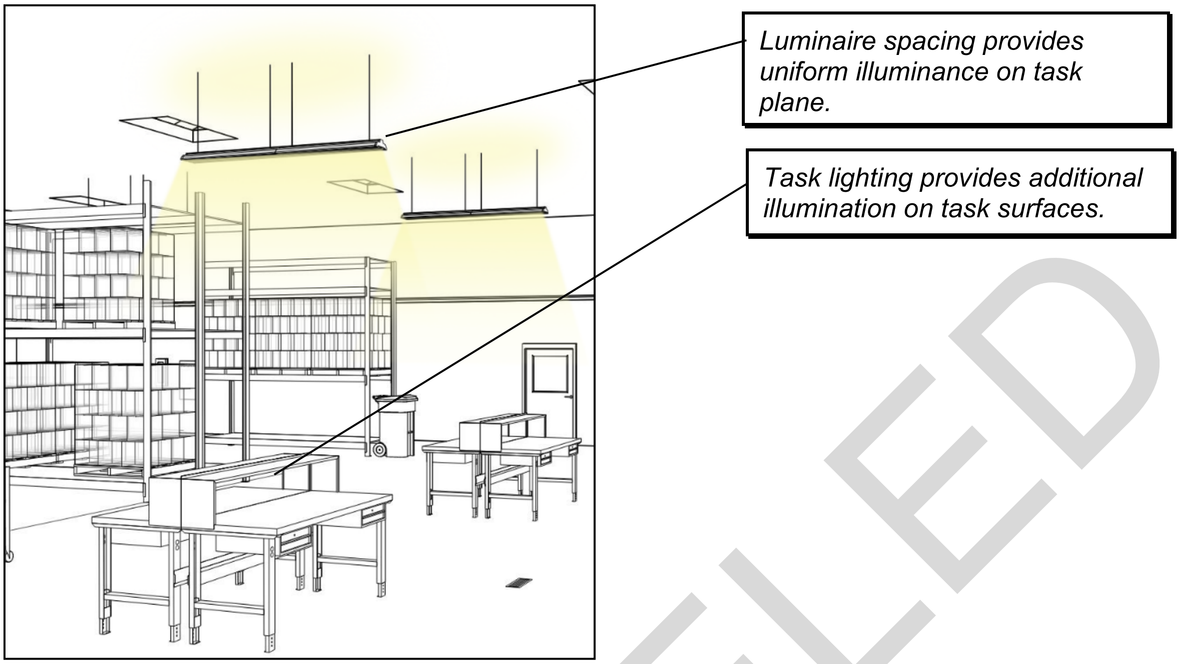
3-8.3.2 Performance Requirements.

Target Criteria	Small items	Medium items	Large items, infrequent use
Average Horizontal Illuminance	20 fc (300 lux) at floor	10 fc (100 lux) at floor	5 fc (50 lux) at floor
Average Vertical Illuminance	10 fc (100 lux) at 4'-0" (1220 mm) AFF	7.5 fc (75 lux) at 4'-0" (1220 mm) AFF	2 fc (20 lux) at 4'-0" (1220 mm) AFF
Horizontal and Vertical Illuminance Uniformity	3:1 average to minimum		

3-8.3.3 Critical Design Issues.

- Locate lighting equipment to minimize shadows.
- Coordinate lighting equipment locations with permanent shelving
- Light room surfaces to balance luminance ratios.
- Uniformly light the work plane.
- Distribution of luminaire to illuminate vertical surfaces of shelving.
- When spaces are larger than 10,000 square feet, zones can be larger in accordance with ASHRAE.
- Recommended occupancy zoning by aisle.
- Manual control override of scheduled shutoff will not turn the lighting on for more than 2 hours during scheduled off periods.

3-8.4 Maintenance Shops.



3-8.4.1 Control Requirements.

Manual Control	Manual OFF with scene wallstation with at least three preset scenes: full ON, lights dimmed between 30% and 70% of full lighting power, and OFF. Individual control for task lighting at work benches.
Occupancy/Vacancy	Manual ON Automatically dimmed by at least 50% after 20 minutes of vacancy
Time Schedule	Scheduled full OFF when building is scheduled to be vacant unless occupants enter the building, then use Manual Control and Occupancy/Vacancy sensor criteria.
Daylight	Automatic responsive daylight dimming when daylight is present
Zoning	None

3-8.4.2 Performance Requirements.

Target Criteria	**Ambient**	**Task**
Average Horizontal Illuminance	30 fc (300 lux)	50 fc (500 lux) at 3'-6" AFF
Horizontal Illuminance Uniformity	3:1 average to minimum	

3-8.4.3 Critical Design Issues.

- Maintenance shops are often located within other space types. Design lighting in the maintenance shop areas to be on own control zone and design to the light levels listed in the performance requirements.

- Locate lighting equipment to minimize shadows.

- Automated dimming must be ramped.

- Light room surfaces to balance luminance ratios.

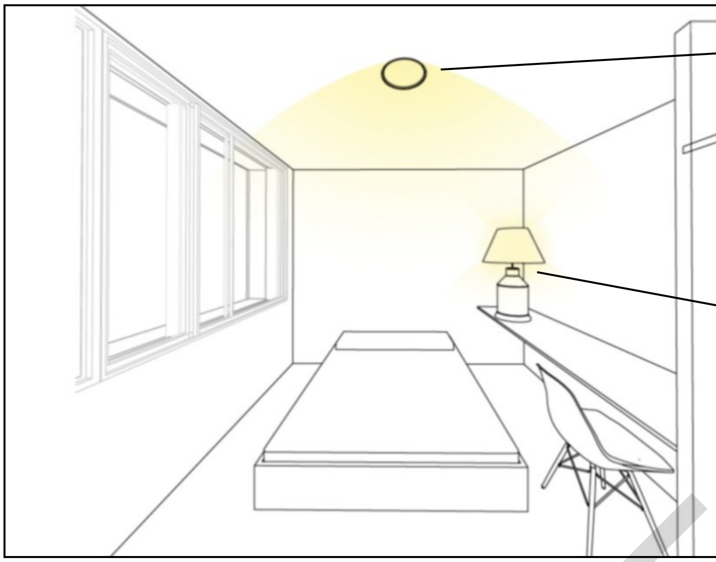
- Uniformly light the work plane.

- Verify special lighting equipment requirements in hazardous (classified) locations.

- Manual control override of scheduled shutoff will not turn the lighting on for more than 2 hours during scheduled off periods.

3-9 HOUSING.

3-9.1 Bedrooms.



3-9.1.1 Control Requirements.

Manual Control	At least one wallbox dimmer with continuous dimming for ambient lighting.
Occupancy/Vacancy	None
Time Schedule	None
Daylight	None
Zoning	Provide separate switching for ambient lighting and task lighting.

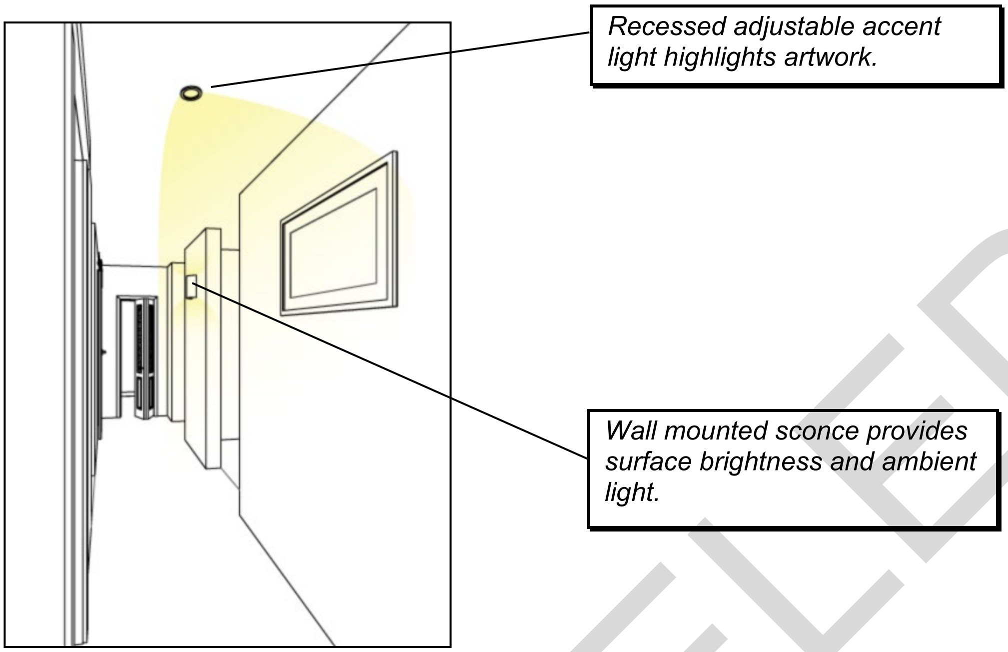
3-9.1.2 Performance Requirements.

Target Criteria	Daytime/Nighttime
Average Horizontal Illuminance	5 fc (50 lux) at 2'-0" (610 mm) AFF
Horizontal Illuminance Uniformity	5:1 average to minimum

3-9.1.3 Critical Design Issues.

- Light room surfaces to balance luminance ratios.
- Provide three-way switches at Unit/Room entrance and bedroom(s) doors.
- Provide overhead ambient lighting in bedrooms, separately switched and dimmed for each occupant side of the room.
- Per FC 4-721-10N Unaccompanied Housing, no “cloud type” light luminaires are allowed.
- Refer to FC 4-721-10N Unaccompanied Housing and UFC 3-353-1 for further guidance.

3-9.2 Hallways.



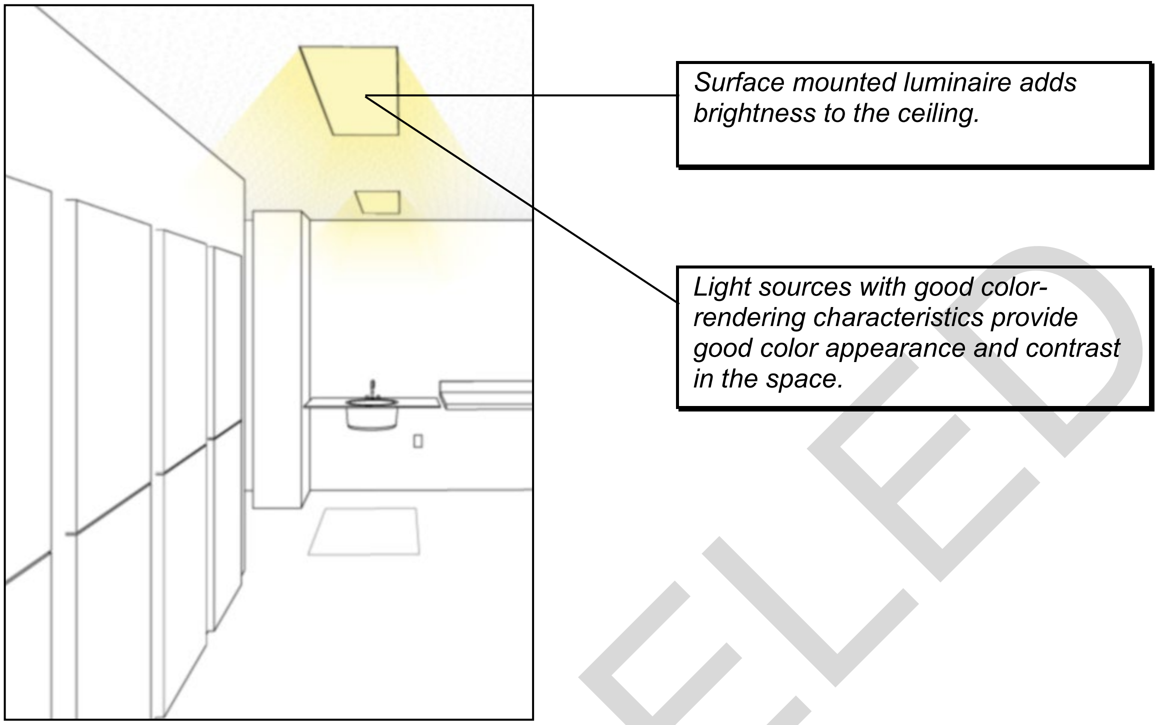
3-9.2.1 Control Requirements.

Manual Control	At least one wallbox dimmer or scene wallstation
Occupancy/Vacancy	Manual ON Automatically dimmed between 30% and 70% after 5 minutes of vacancy OR Manual ON Automatic OFF after 5 minutes of vacancy
Time Schedule	None
Daylight	None
Zoning	Provide separate switching for ambient lighting and accent lighting

3-9.2.2 Performance Requirements.

Target Criteria	**Daytime/Nighttime**
Average Horizontal Illuminance	3 fc (30 lux) at floor
Horizontal Illuminance Uniformity	5:1 average to minimum

3-9.3 Laundry Rooms.



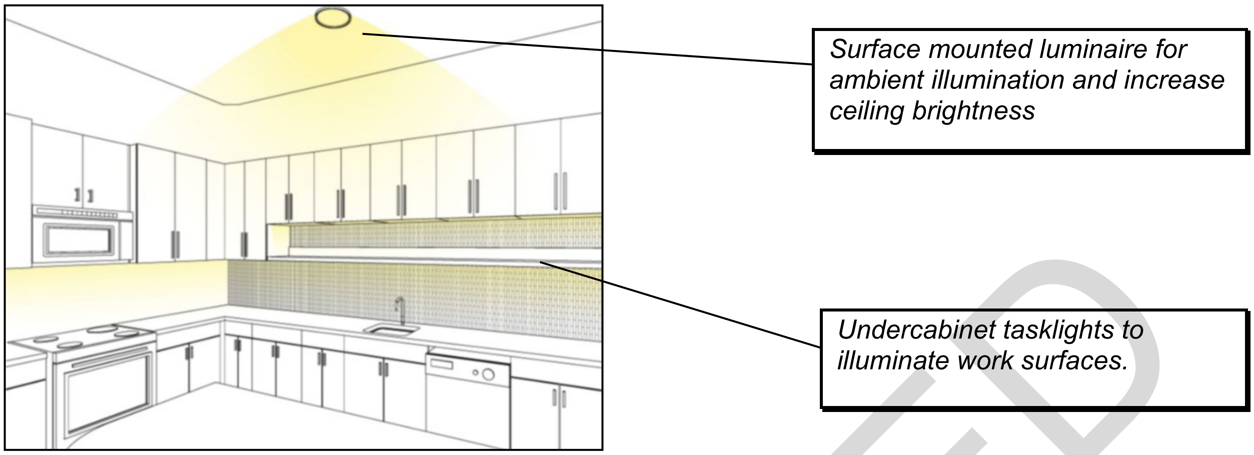
3-9.3.1 Control Requirements.

Manual Control	At least one wallbox dimmer or scene wallstation
Occupancy/Vacancy	Manual On Automatic full OFF after 5 minutes of vacancy
Time Schedule	None
Daylight	None
Zoning	None

3-9.3.2 Performance Requirements.

Target Criteria	**Daytime/Nighttime**
Average Horizontal Illuminance	20 fc (200 lux) at 3'-0" (914 mm) AFF
Horizontal Illuminance Uniformity	3:1 average to minimum

3-9.4 Kitchens.



3-9.4.1 Control Requirements.

Manual Control	At least one wallbox dimmer or scene wallstation per luminaire type
Occupancy/Vacancy	None
Time Schedule	None
Daylight	None
Zoning	Provide separate switching or scene control for ambient lighting and task lighting. Provide separate switch for task lighting above sink and/or work surfaces.

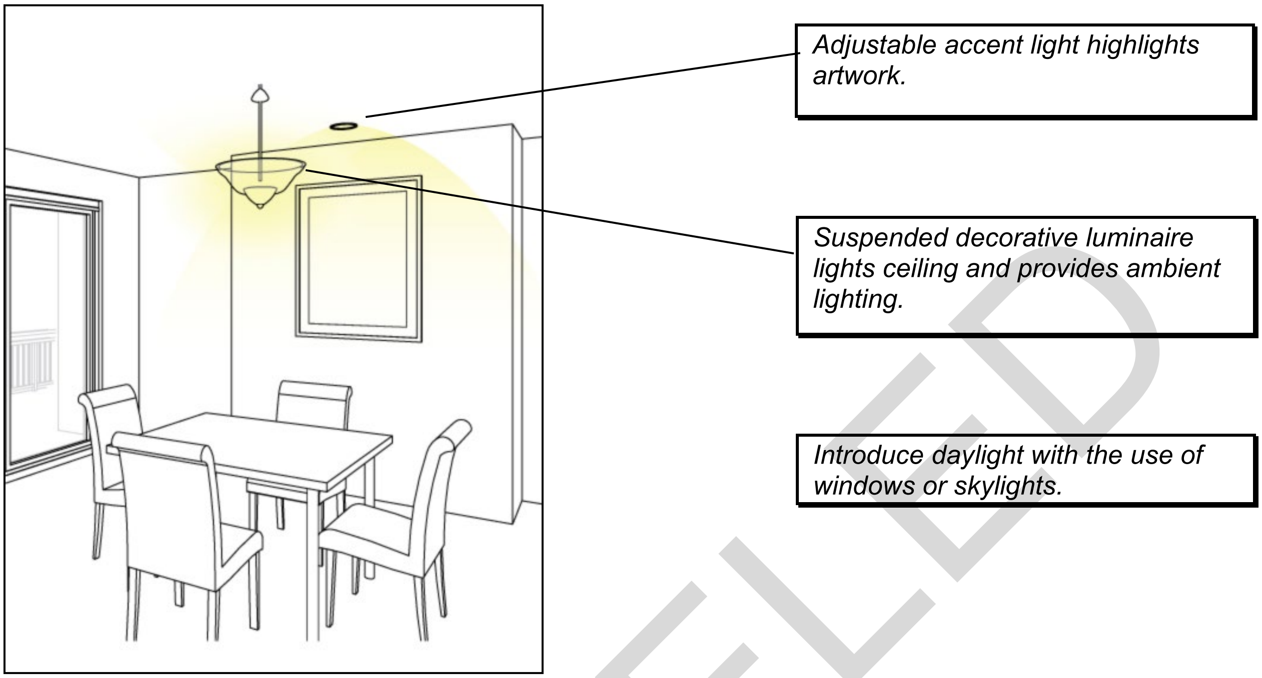
3-9.4.2 Performance Requirements.

Target Criteria	**Daytime/Nighttime**
Average Horizontal Illuminance, General	5 fc (50 lux) at floor
Average Horizontal Illuminance, Task Surface	30 fc (300 lux) at cooking surface
Horizontal Illuminance Uniformity	3:1 average to minimum

3-9.4.3 Critical Design Issues.

- Locate lighting equipment to minimize shadows.
- Light room surfaces to balance luminance ratios.
- Illuminate work surfaces.

3-9.5 Dining Rooms.



3-9.5.1 Control Requirements.

Manual Control	Local ON/OFF control device AND At least one scene wallstation or wallbox dimmer with continuous dimming
Occupancy/Vacancy	None
Time Schedule	None
Daylight	None
Zoning	Provide separate switching for ambient lighting and accent lighting. Each lighting type may dim as separate zone or part of scene controller

3-9.5.2 Performance Requirements.

Target Criteria	**Daytime/Nighttime**
Average Horizontal Illuminance	5 fc (50 lux) at table plane
Horizontal Illuminance Uniformity	4:1 average to minimum

3-9.6 Living Rooms.

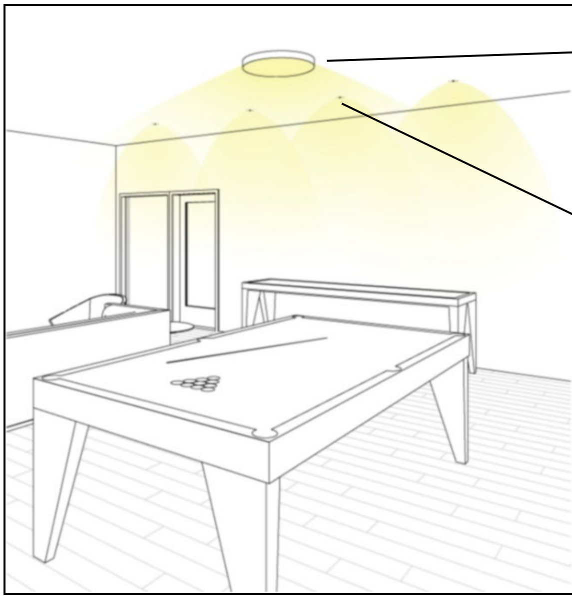
3-9.6.1 Control Requirements.

Manual Control	At least one wallbox dimmer or scene wallstation
Occupancy/Vacancy	None
Time Schedule	None
Daylight	None
Zoning	Provide separate switching or scene control for ambient lighting and task lighting

3-9.6.2 Performance Requirements.

Target Criteria	**Daytime/Nighttime**
Average Horizontal Illuminance	3 fc (30 lux) at floor
Horizontal Illuminance Uniformity	5:1 average to minimum

3-9.7 Rec Rooms.



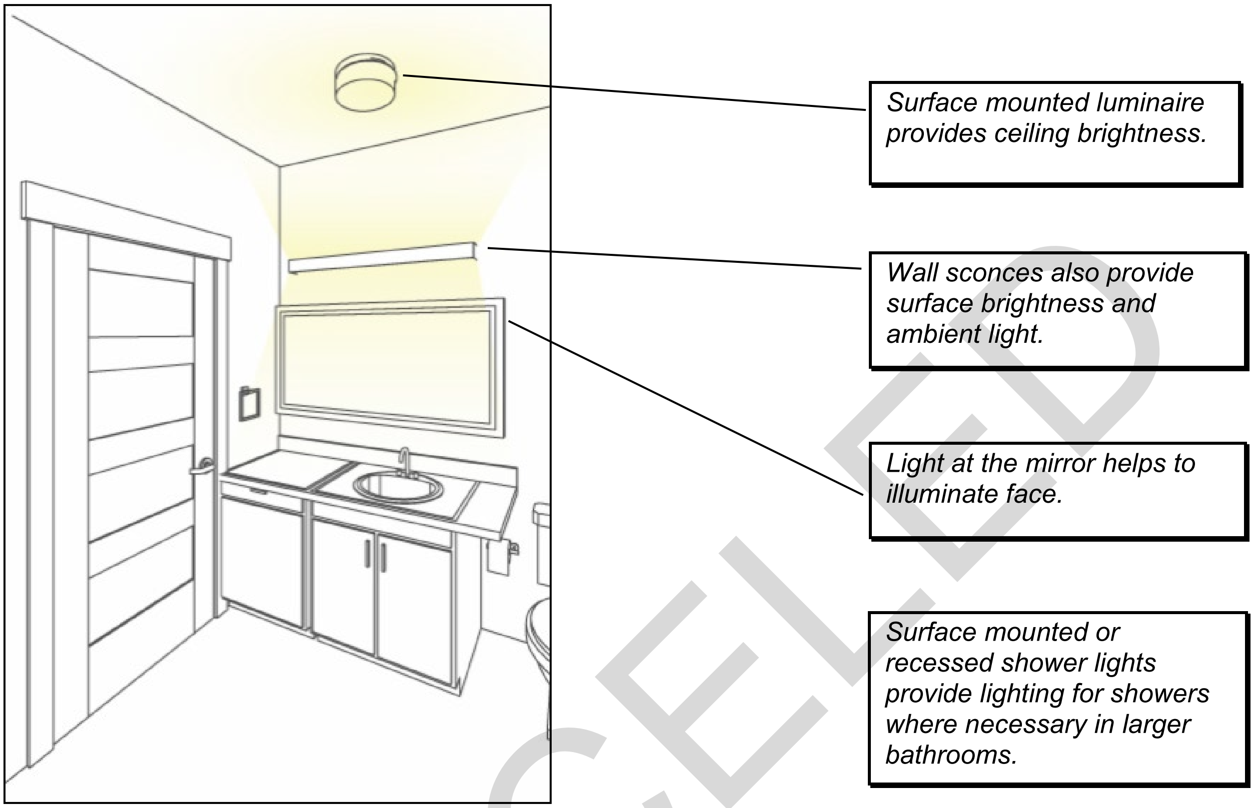
3-9.7.1 Control Requirements.

Manual Control	At least one wallbox dimmer or scene wallstation
Occupancy/Vacancy	Manual ON Automatic full OFF after 20 minutes of vacancy OR Automatic ON to a maximum of 50% of full lighting power Automatic full OFF after 20 minutes of vacancy
Time Schedule	None
Daylight	None
Zoning	Provide separate switching or scene control for ambient lighting and accent lighting

3-9.7.2 Performance Requirements.

Target Criteria	**Daytime/Nighttime**
Average Horizontal Illuminance	20 fc (200 lux) at 2’-6” (762 mm) AFF
Horizontal Illuminance Uniformity	3:1 average to minimum

3-9.8 Bathrooms.



3-9.8.1 Control Requirements.

Manual Control	At least one wallbox dimmer or scene wallstation per luminaire type
Occupancy/Vacancy	Manual ON Automatic full OFF after 20 minutes of vacancy
Time Schedule	None
Daylight	None
Zoning	None

3-9.8.2 Performance Requirements.

Target Criteria	**Daytime/Nighttime**
Average Horizontal Illuminance	30 fc (300 lux) at 3’-0” (914 mm) AFF
Horizontal Illuminance Uniformity	3:1 average to minimum

3-9.9 Garages.

3-9.9.1 Control Requirements.

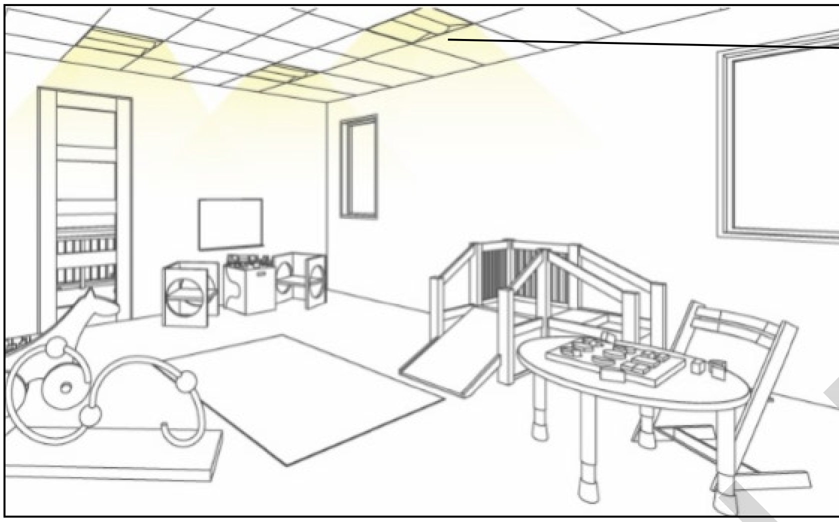
Manual Control	At least one wallbox switch or scene wallstation
Occupancy/Vacancy	Manual ON Automatic full OFF after 10 minutes of vacancy
Time Schedule	None
Daylight	None
Zoning	None

3-9.9.2 Performance Requirements.

Target Criteria	**Daytime/Nighttime**
Average Horizontal Illuminance	20 fc (200 lux) at 3’-0” (914 mm) AFF
Horizontal Illuminance Uniformity	3:1 average to minimum

3-10 CHILDCARE SPACES.

3-10.1 Daycare Indoor Play Areas.



3-10.1.1 Control Requirements.

Manual Control	Scene wallstation with at least one preset scene with all lights dimmed between 30% and 50% of full lighting power OR One wallbox dimmer per luminaire type
Occupancy/Vacancy	Manual ON Automatically dimmed by at least 50% after 20 minutes of vacancy
Time Schedule	Scheduled shutoff for all lights in the space when the building is scheduled to be vacant unless occupants enter the building, then use Manual Control and Occupancy/Vacancy sensor criteria
Daylight	Automatic responsive daylight dimming when daylight is present
Zoning	None

3-10.1.2 Performance Requirements.

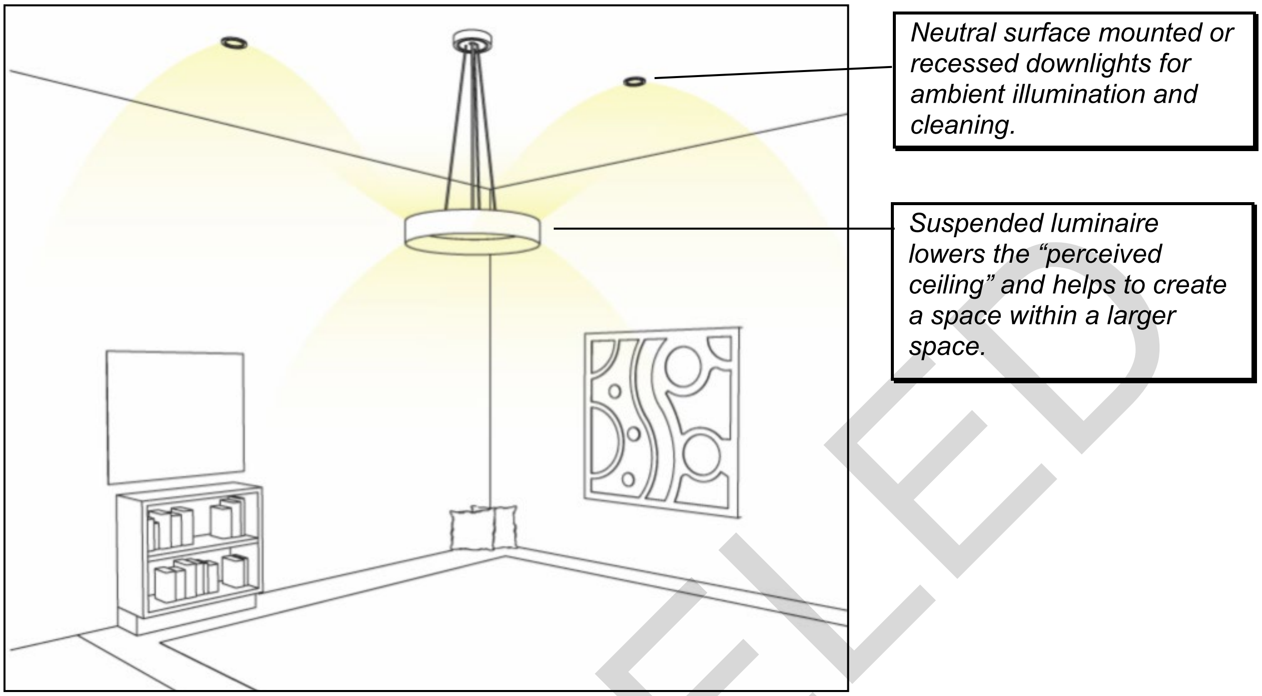
Target Criteria	**Daytime/Nighttime**
Average Horizontal Illuminance	30 fc (300 lux) at 2’-0” (910 mm) AFF
Horizontal Illuminance Uniformity	3:1 average to minimum

3-10.1.3

3-10.1.4 Critical Design Issues.

- Light room surfaces to balance luminance ratios.
- Provide wall sconces to add decorative interest and illuminate wall surfaces.
- Refer to UFC 4-740-14 and FC 4-740-14N for additional requirements and considerations regarding child development centers.

3-10.2 Daycare Indoor Rest Areas.



3-10.2.1 Control Requirements.

Manual Control	Scene wallstation with continuous dimming and preset scene for rest time
Occupancy/Vacancy	Manual ON Automatically dimmed by at least 50% after 20 minutes of vacancy
Time Schedule	Scheduled shutoff for all lights in the space when the building is scheduled to be vacant unless occupants enter the building, then use Manual Control and Occupancy/Vacancy sensor criteria.
Daylight	Automatic responsive daylight dimming when daylight is present
Zoning	None

3-10.2.2 Performance Requirements.

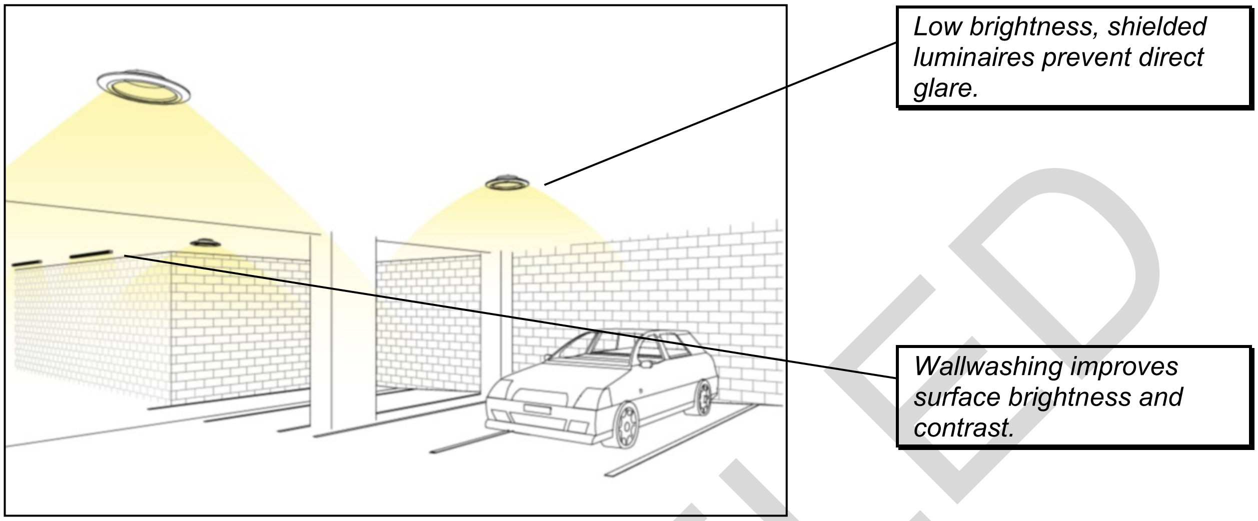
Target Criteria	**Daytime/Nighttime**
Minimum Horizontal Illuminance	1 fc (10 lux) at 2’-0” (910 mm) AFF (at all times)
Maximum Horizontal Illuminance	5 fc (50 lux) at 2’-0” (910 mm) AFF (during rest time)
Average Horizontal Illuminance	20 fc (200 lux) at 2’-0” (910 mm) AFF (outside of rest time)

3-10.2.3 Critical Design Issues.

- Provide dimmable lighting zones to reduce light levels during rest periods.
- Use dim-to-warm LED light sources to provide a warm CCT suitable for areas of rest.
- Provide layout of ambient lighting for cleaning.
- Refer to UFC 4-740-14 and FC 4-740-14N for additional requirements and considerations regarding child development centers.

3-11 PARKING.

3-11.1 Parking Structures.



3-11.1.1 Control Requirements.

Manual Control	None
Occupancy/Vacancy	Automatic ON with detected motion Automatically dimmed by at least 50% after 20 minutes of vacancy
Time Schedule	Scheduled shutoff for all lights in the space when the space is scheduled to be vacant
Daylight	Automatic reduction of daylight transition lighting to general light levels from Sunset to Sunrise Responsive continuous daylight dimming of luminaires within 20 feet of large perimeter wall openings
Zoning	Zones must be 3,600 square feet or less

3-11.1.2 Performance Requirements.

Target Criteria	Daytime	Nighttime
Minimum Horizontal Illuminance, General areas, active	1 fc (10 lux) at floor	1 fc (10 lux) at floor
Minimum Vertical Illuminance, General areas, active	0.5 fc (5 lux) at 5’-0” (1524mm) AFF	0.5 fc (5 lux) at 5’-0” (1524 mm) AFF
Minimum Horizontal Illuminance, General areas, inactive	0.2 fc (2 lux) at floor	0.2 fc (2 lux) at floor
Minimum Vertical Illuminance, General areas, inactive	0.1 fc (1 lux) at 5’-0” (1524 mm) AFF	0.1 fc (1 lux) at 5’-0” (1524 mm) AFF
Minimum Horizontal Illuminance, Vehicular entries and exit	50 fc (500 lux) at floor	1 fc (10 lux) at floor
Minimum Vertical Illuminance, Vehicular entries and exit	25 fc (250 lux) at 5’-0” (1524 mm) AFF	0.5 fc (5 lux) at 5’-0” (1524 mm) AFF
Minimum Horizontal Illuminance, Stairway	10 fc (100 lux) at walking surface	10 fc (100 lux) at walking surface
Minimum Vertical Illuminance, Stairway	25 fc (250 lux) at 5’-0” (1524 mm) AFF	1.2 fc (12.5 lux) at 5’-0” (1524 mm) AFF
Horizontal and Vertical Illuminance Uniformity	10:1 maximum to minimum	

3-11.1.3 Critical Design Issues.

- Provide daylight transition lighting at parking structure entrances.
- Stairs not on path of egress should use IES light levels in RP-8.

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CHAPTER 4 EXTERIOR LIGHTING

4-1 PRIORITIES FOR EXTERIOR LIGHTING SYSTEMS.

Design exterior lighting systems to minimize energy consumption, reduce maintenance costs, improve lighting quality on DoD Installations, at the lowest life cycle cost.

4-1.1 Energy Reduction.

Provide SSL/LED systems for all exterior lighting. SSL/LED systems are established technologies for exterior lighting applications that have been proven to save energy over traditional light sources.

Minimize energy consumption by providing energy efficient technologies, maintaining effective luminance and illuminance levels, and implementing control strategies. Maintain illumination level prescribed averages as closely as possible, in order to provide sufficient light levels without contributing to excessive energy usage.

4-1.2 Maintenance Reduction.

Reduce maintenance by technology selection, reducing equipment quantities, and implementing controls strategies.

Select light sources, drivers, and controls that are rated and warranted for long useful lives to increase the amount of time between maintenance cycles. Match light sources in adjacent areas when appropriate.

4-1.3 Luminaire Placement.

Locate luminaires to reduce impact to adjacent properties. This is particularly important when lighting areas adjacent to residential neighborhoods and environmentally sensitive areas, including waterways.

4-1.4 Lighting Quality.

Apply the following to ensure the priority of lighting quality is achieved.

4-1.4.1 Direct Glare.

Avoid direct glare from luminaires and excessive contrast of surfaces. Use shielded light sources and as low a lumen output as possible. When using ANSI/IES TM-15 BUG ratings, a low ‘G’ rating would provide reduced glare.

4-1.4.2 Light Pollution / Trespass.

Use ANSI/IES TM-15 U0 luminaires to eliminate direct light above the horizontal plane. Refer to maximum allowable uplight (U) and backlight (B) ratings in specific lighting zones.

4-1.4.3 Modeling of Faces and Objects.

Provide light from multiple directions to accurately render objects and people.

4-1.4.4 Reflected Glare.

Select and locate luminaires to minimize wet surface reflected glare and polished surface reflection of a light source.

4-1.4.5 Shadows.

Locate poles such that the light from the luminaires minimizes shadows that could conceal potential hazards.

4-1.4.6 Vertical Illuminance.

Provide vertical illuminance on individuals' faces as well as potential hazards.

4-1.4.7 Appearance of Space and Luminaires.

Carefully select luminaires to match the aesthetic character of the building and contribute to a welcome designation to the building entry. Refer to the base-wide architectural plan to consolidate luminaire types.

4-1.4.8 Light Distribution on Surfaces.

Illuminate the walkway uniformly to avoid dark patches.

4-1.4.9 Point(s) of Interest.

Provide lighting for wayfinding and indicate points of interests, such as the building entry.

4-2 EXTERIOR LIGHTING EQUIPMENT.

4-2.1 Light Source Technology.

Provide SSL/LED systems unless there is no equivalent SSL/LED product for the application. If another light source other than SSL/LED is specified, provide documentation regarding the selection of that light source in the project's Basis of Design.

4-2.1.1 SSL/LED Light Sources.

Provide light sources with a CCT of no greater than 3000 K as stated on the manufacturer's specification information to reduce skyglow in exterior applications and minimize impact to human and animal circadian rhythms.[3 & 4] Use monochromatic amber LEDs in place of low pressure sodium (LPS) for sensitive environments such as wildlife habitat, wildlife nesting, or to meet dark sky requirements (observatories). Incorporate Fish and Wildlife, State, and local governing authority recommendations for lighting systems design and installation.

4-2.1.2 CCT and CRI.

Use a color rendering index (CRI) of no less than 70 for exterior applications. In some applications, where motorists' vision is of high importance, such as areas with high speeds and high vehicle conflicts, a CCT of 4000 K may be used.

4-2.1.3 SSL/LED Drivers.

Provide lighting systems with accessible and replaceable drivers. For current and future dimming requirements (smart grid, curfew, adaptive), use dimmable drivers compatible with standard dimming control circuit of 0-10V or DALI. Other dimming protocols must comply with cybersecurity requirements.

4-2.2 Surge Protection.

Provide MOV type surge protection devices at panelboards for all circuits feeding exterior lighting systems. LED luminaires require integral metal oxide varistors (MOV) type surge protection device with elevated 10-kVA surge protection.

4-2.3 Over Current Protection Device.

Provide in-line fuse in pole base or splice box for street and area lights.

4-2.4 Poles.

Do not use square poles. Provide compatible poles with all pole-mounted luminaires. Provide breakaway bases for poles adjacent to vehicle traffic in accordance with the American Association of State Highway and Transportation Officials (AASHTO) GL-6. Non-breakaway poles must be protected by a barrier or be barrier-mounted.

4-3 EXTERIOR LIGHTING CONTROLS.

Refer to CHAPTER 5 for control requirements specific to common applications. Refer to ANSI/IES LP-6 for additional considerations for lighting control systems, and ANSI/IES LP-8 for commission guidance for specific applications.

[3] IES TM-12-12, Lamp Spectral Effects at Mesopic Lighting Levels. The Illuminating Engineering Society. New York, NY.
[4] IES TM-18-18, Light and Human Health. The Illuminating Engineering Society, New York, NY.

4-3.1 Control Strategies.

Indicate in the contract documents the control strategy for each area type in accordance with required strategies in CHAPTER 5.

4-3.1.1 Manual Control.

The lights are manually turned on and manually turned off. This approach can only be used when other control strategies cannot be implemented due to operational requirements.

4-3.1.2 Motion Sensing.

Upon sensing vacancy, the lights dim to 30% of full light output. Do not provide motion sensing that fully turns off all lighting within a control zone.

4-3.1.3 Time Schedule.

Time scheduling controls the light based on a preset schedule. This is most beneficial when lights are controlled based on business hours. Time scheduling may be used in place of photosensing, for turning lights on when there is no longer sufficient daylight, and for turning lights off during hours of daylight. Use an astronomical timeclock when controlling exterior lighting using this method to ensure the schedule adjusts as sunrise and sunset shifts throughout the year.

When using time scheduled controls that are based on operating business hours, provide at least 15 minutes of luminaire operation before business open, when before dawn, and at least 15 minutes of luminaire operation after business close, when after dusk. Do not use time scheduled controls to completely turn off exterior lighting if occupants regularly occupy the building after officially scheduled hours.

4-3.1.4 Photosensing.

Photosensing measures the amount of daylight currently available and controls luminaires according to this. Typically, at sunset or shortly after, the lights automatically turn on. At sunrise or shortly before, the lights automatically turn off. Photocells may be located on each luminaire individually or located at the lighting control center. Photocells are typically used for exterior lighting systems that are not connected to a building lighting control system.

Provide photosensors with zero-cross technology to withstand severe in-rush current and extend relay life.

4-3.1.5 Zoning.

Provide separate control circuits for each luminaire application. For example, area lights may be on the same control circuit. However, area lights and step lights should not be on the same control circuit. Provide separate control zones for each use area.

4-3.2 Wireless Networks.

Coordinate wireless networks with base spectrum manager prior to specification in case of restrictions for wireless usage within the installation.

4-3.3 Control Equipment.

Provide lighting control equipment capable of meeting the strategies described in the contract documents. Control equipment must be designed to control the specific light sources and luminaires specified for each application. Provide photocells which meet elevated 10-kV/10-VA requirements per IEEE designed to operate exterior LED luminaires in order to eliminate inrush current system malfunction.

4-3.3.1 Multi-pin Receptacle.

Provide streetlights and parking lot lighting that are installed with an ANSI C136.41 seven-pin receptacle which accepts a standard three-pin photocell or shorting cap. This allows streetlights and parking lot lighting to be connected to a wireless control system in the future, since many wireless control system nodes are compatible with seven-pin receptacles.

4-4 EXTERIOR LIGHTING ZONES.

Lighting zones reflect the base (or ambient) light levels desired for an area. Adopt the lowest possible lighting zone. Lighting zones are best implemented as an overlay to the established zoning especially on installations where a variety of zone districts exist within a defined area or along an arterial street. Where zone districts are cohesive, it may be possible to assign lighting zones to established land use zoning. It is recommended that the lighting zone includes churches, schools, parks, and other uses embedded within residential communities or to any land assigned to a lower zone.

For DoD installations, it is important to consider all activities of an area's land use. Lighting zones must consider the surrounding areas as well. For example, adjacent lighting zones must not hinder nighttime operations. Additionally, outside the United States and its territories, it is important that the installation does not stand out as an exceptionally bright area compared to the adjacent development. Figure 4-1 and Table 4-1 show examples of how lighting zones from the IDA-IES *Model Lighting Ordinance* may be applied to DoD installations.

Figure 4-1 Example Lighting Zones on a Sample Installation

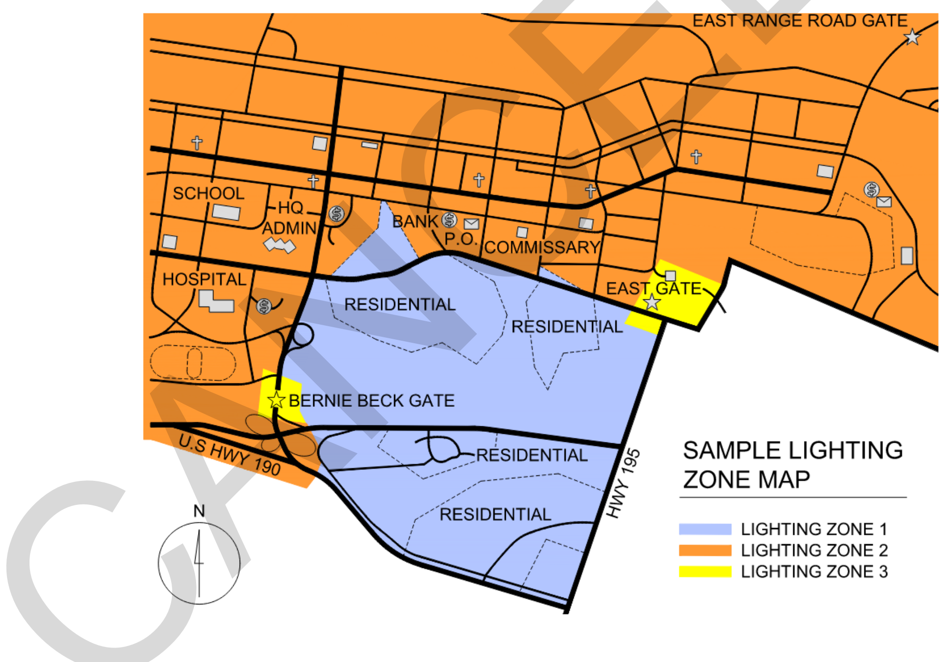

Table 4-1 Lighting Zones and DoD Applications.

MLO Lighting Zones	Title	DoD Installation/Application	
LZ0	No Ambient Lighting	**Training areas** Night vision training areas, endangered waterfront areas and other areas where there is expected no nighttime activity.	INCREASING NIGHTTIME ACTIVITY ↓
LZ1	Low Ambient Lighting	**Personnel Support Districts** Unaccompanied quarters, single and multi-family residential, campgrounds, administration, and other non-nighttime use areas, golf course, exercise fields and paths **Airfield** (Nearby facilities may be higher zone)	
LZ2	Moderate Ambient Lighting	**Waterfront or Airfield Facilities** Administrative areas, common areas, service areas, parking. **Training Facilities** Academic instruction, educational services, applied instruction, reserve training, operational simulators **Administrative Facilities** Offices, conference centers, command centers, parking **Personnel Support Districts** Officer clubs, lodge, food service, fire and security, ITT, medical and dental clinics, family services, schools, childcare facilities, youth programs, religious facilities, banks, exchange, commissary, libraries, morale, welfare and recreation, hobby shops, theaters, gyms indoor sport facilities, outdoor pools, sports (tennis, basketball) courts, baseball and football fields **Industrial Facilities** Shipyards, ordinance handling/storage, manufacturing facilities, maintenance shops, depots	
LZ3	Moderately High Ambient Lighting	**Waterfront Facilities** Wharf and pier areas **Airfield Facilities** Aircraft hangars, air operations and headquarters, line shacks, terminal facilities, training areas, utility service areas **Entry Control Facilities** **Access Control Points**	
LZ4	High Ambient Lighting	No areas qualify for this lighting zone.	

4-5 ELECTRICAL ENERGY MONITORING.

For new construction buildings greater than 25,000 SF (2,322 m^2), terminate exterior lighting branch circuits in dedicated lighting panelboards. Provide metering requirements as required by UFC 1-200-02.

4-6 SOLAR LIGHTS.

Solar lights are permitted for use when:

- Electric utility services do not exist in the desired location of lighting.
- Centralized solar panels can be deployed to provide power to the lights.
- Sufficient battery capacity is provided to meet illumination requirements.
- Used with curfew controls to maximize battery life.

Solar lights are not permitted for use for security lighting or safety applications.

4-7 LIGHTING SYSTEM ALTERATIONS.

4-7.1 Types of Lighting System Alterations.

4-7.1.1 Redesign.

Redesign includes new luminaires, circuits, and controls designed to meet current lighting criteria. A new design must ensure reduced energy consumption, reduced maintenance, and lighting quality is improved at the lowest life cycle cost. Lighting redesign is required when a renovation involves changing lighting technologies such as fluorescent to LED and when renovation involves changing lighting with more efficient lighting within the same technology. Redesign lighting systems when existing:

- Illuminance levels are too low or too high
- Lighting produces glare
- Luminaire layout produces non-uniform illumination
- Luminaires are in poor condition
- Lighting control systems are inadequate
- Luminaires (or luminaire layout) is not appropriate because the physical layout of the area has changed

4-7.1.2 One-for-One Luminaire Replacement.

A luminaire replacement consists of the entire luminaire being replaced, including the housing. A luminaire replacement may be considered when the lighting design is sufficient, but more efficient luminaires are available. In instances where the existing luminaire is operating under dimming control, the lighting controls must be upgraded to be compatible with the operating characteristics of the replacement luminaire. Luminaire replacement is only acceptable when the resulting illuminance levels, glare, and distribution meet the current criteria.

4-7.1.2.1 Pole Modifications.

SSL/LED luminaire replacements have a different weight and Effective Projected Area than legacy luminaires, which impacts the structural performance of the pole. Most frequently, a reduction in weight at the top of the pole increases wind-induced vibration or pole galloping. Impact dampers reduce this phenomenon. Design and implementation of impact dampers must be coordinated with pole manufacturer or structural engineer.

4-7.1.2.2 Control Equipment Modifications.

Provide upgraded photocell replacements for all SSL/LED luminaire replacements that are controlled by photocell. Provide photocells which meet elevated 10 kV/10-VA requirements per IEEE designed to operate exterior LED luminaires in order to eliminate inrush current system malfunction.

4-7.1.3 Light Source Retrofit.

A light source retrofit is the replacement of the light source within the luminaire housing or the lighting module that has been designed to be installed in existing luminaire enclosures.

Do not use LED retrofit light sources or LED lighting modules that have been designed and constructed to be installed in existing HID, mercury vapor, or linear fluorescent luminaire enclosures. LED retrofits are only approved for replacement of CFL or incandescent sources (A-lamp replacements) with Edison bases.

4-8 SITE DESIGN COORDINATION.

Coordinate the design, luminaire selection, and placement with the location of trees, shrubs, and other site furnishing.

4-9 AIRFIELDS.

UFC 3-260-01 limits light emissions – either directly or indirectly (reflected) – that may interfere with pilot vision in runway clear zones. Exterior lighting must meet all FAA and airfield operational regulations. These regulations restrict the height, location, and technology of lighting located near airfields. Certain light sources may also interfere with night vision technologies. Obtain approval of lighting from installation's airfield safety office.

Use luminaires with a U0 rating to reduce glare and uplight which may affect airfield operations. If U0 rated luminaires are unable to satisfy lighting levels and performance criteria, utilize interior and external shielding to minimize glare and uplight. Do not exceed a glare rating of G2. Refer to UFC 3-535-01 for additional information.

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CHAPTER 5 EXTERIOR LIGHTING APPLICATIONS

5-1 INTRODUCTION.

This chapter identifies typical exterior facility applications. Each application details a conceptual lighting design example. Designs must meet the lighting performance and controls requirements defined in the application details.

5-2 CALCULATIONS OF LIGHTING FOR EXTERIOR AREAS.

Computer-generated photometric plans for each area are required to verify proposed luminaires and locations meet the required performance criteria of the design using the applicable light loss factor (LLF).

Target illumination levels are provided for each Exterior Application. Depending on the application and the recommendations provided by the IES, values are given as one of the following:

- Minimum: No values anywhere on the calculation grid may be less than this value, within a 10% margin of error.
- Minimum Average: An average, taken over the entire task area for the application, may not be less than this value, within a 10% margin of error.
- Maximum: No values anywhere on the calculation grid may be greater than this value, within a 10% margin of error.
- Maximum Average: An average, taken over the entire task area for the application, may not be greater than this value, within a 10% margin of error.
- Uniformity: Unless otherwise noted, uniformity is calculated as a ratio of the average calculated illuminance over the minimum calculated illuminance of the calculation grid.

5-2.1 Schematic and Concept Design.

For Schematic and concept design phases prior to 60%, provide narrative indicating the following:

- When listing target criteria, include lighting zone in basis of design.
- Average maintained illuminance (or luminance for roadways) level.
- Lighting power density (watts per square foot or per square meter).

5-2.2 Designs submitted at 60% or later.

For designs submitted at 60% or later, provide photometric plan calculations to include the following:

- The point spacing of the calculation grid of horizontal illuminance (or luminance for roadways) measurements at finished grade, are to be 1/3 of the luminaire mounting height taken across the general area.

- Where applicable, vertical illuminance measurements at designated surface, taken at a maximum of every one foot (305 mm) across task area.

- Minimum and maximum illuminance (or luminance for roadways) levels.

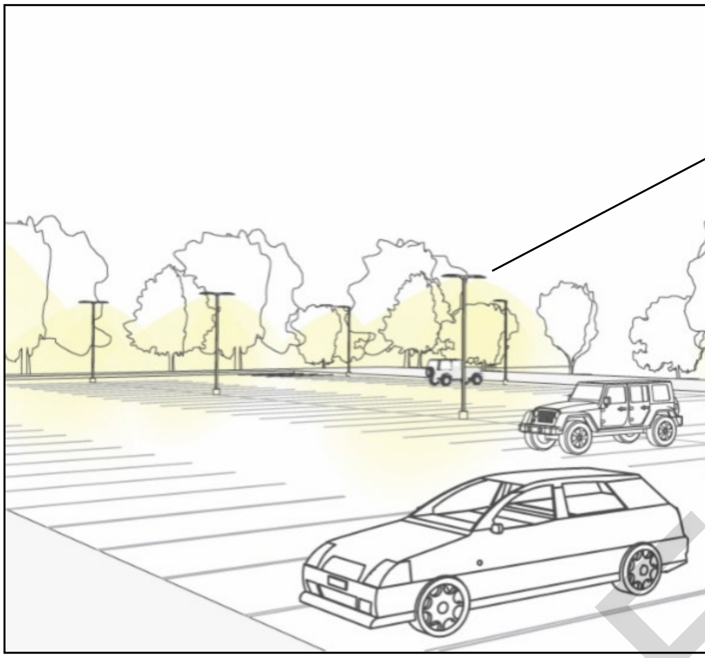
- Average maintained illuminance (or luminance for roadways) level.

- Average to minimum and maximum to minimum ratios for horizontal illuminance (or luminance for roadways).

- Lighting power density (watts per square foot or per square meter).

5-3 PARKING FACILITIES.

5-3.1 Parking Lots.



5-3.1.1 Control Requirements.

Manual Control	None
Motion Sensing	None
Time Schedule	Automatic dimming to 30% within 15 minutes after business close and automatic full ON within 15 minutes before business open Astronomical timeclock ON at dusk and OFF at dawn, if not using photosensing
Photosensing	ON and OFF based on daylight availability, if not using astronomical timeclock
Zoning	None

5-3.1.2 Performance Requirements.

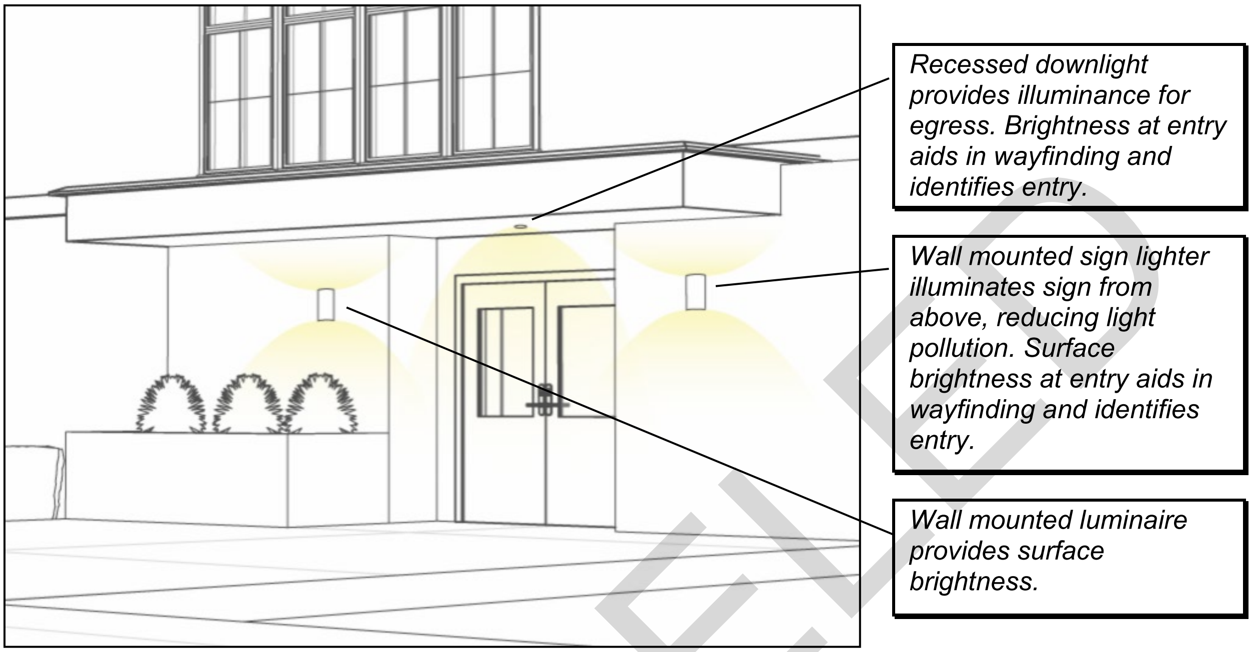
Target Criteria	**All Lighting Zones**
Minimum Horizontal Illuminance	0.2 (2 lux) at grade
Minimum Vertical Illuminance in center of drive lane, in direction of traffic flow	0.1 (1 lux) at 5’-0” (1524 mm) AFF
Horizontal Illuminance Uniformity	20:1 maximum to minimum

5-3.1.3 Critical Design Issues.

- Provide no greater than G2 and U0 rated luminaires with low lumen output to minimize glare and light pollution.
- Provide Type V distributions for luminaires within the center of parking areas. Use Type III and IV distributions along the perimeters to minimize light trespass on a neighboring property or building unless luminaires are intended to illuminate adjacent property or building.
- Use photocells specifically designed to operate SSL/LED lighting.
- Use an ANSI 7-pin photocell receptacle.

5-4 BUILDING LIGHTING.

5-4.1 Primary Entrances.



5-4.1.1 Control Requirements.

Manual Control	None
Motion Sensing	Automatically dim lights to 30% after 10 minutes of no detected motion
Time Schedule	Automatic dimming to 30% within 1 hour after business close and automatic full ON within 1 hour before business open Astronomical timeclock ON at dusk and OFF at dawn, if not using photosensing
Photosensing	ON and OFF based on daylight availability, if not using astronomical timeclock
Zoning	None

5-4.1.2 Performance Requirements.

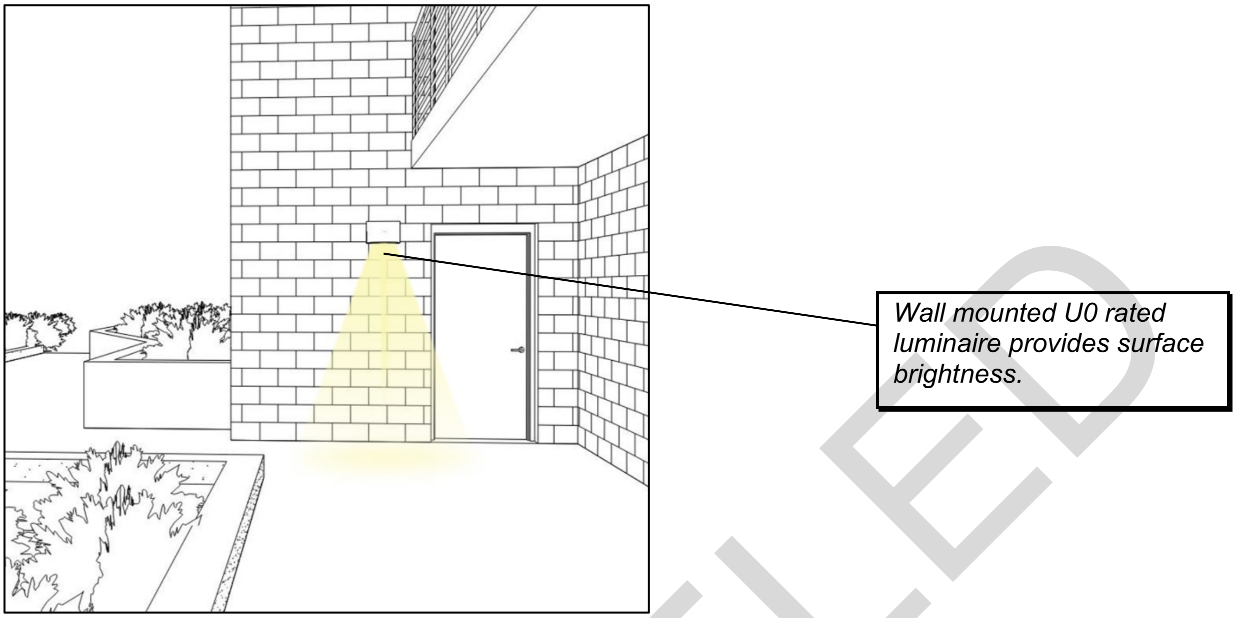
	LZ1 Low ambient	**LZ2 Moderate ambient**	**LZ3 Moderately high ambient**
Average Horizontal Illuminance	1 fc (10 lux) at grade*	Between 1 fc (10 lux) and 2 fc (20 lux) at grade	Between 2 fc (20 lux) and 4 fc (40 lux) at grade
Uniformity	5:1 average to minimum		

*If exit is in path of egress, meet LZ2 criteria.

5-4.1.3 Critical Design Issues.

- Select luminaires to match the aesthetic character of the building and contribute to a welcome designation to the building entry.
- Comply with NFPA 101 lighting requirements for each exit discharge.
- All luminaires must use shielded optics and/or low lumen light sources to minimize glare and light pollution.
- Select and locate lighting to eliminate shadows near entries and provide wayfinding.
- Exterior building mounted luminaires are to match the aesthetic design of the building.
- Luminaires may remain on to assist with building security and law enforcement.

5-4.2 Exits.



5-4.2.1 Control Requirements.

Manual Control	None
Motion Sensing	Automatically dim lights to 30% after 10 minutes of no detected motion
Time Schedule	Automatic full OFF within 1 hour after business close and automatic full ON within 1 hour before business open Astronomical timeclock ON at dusk and OFF at dawn, if not using photosensing
Photosensing	ON and OFF based on daylight availability, if not using astronomical timeclock
Zoning	None

5-4.2.2 Performance Requirements.

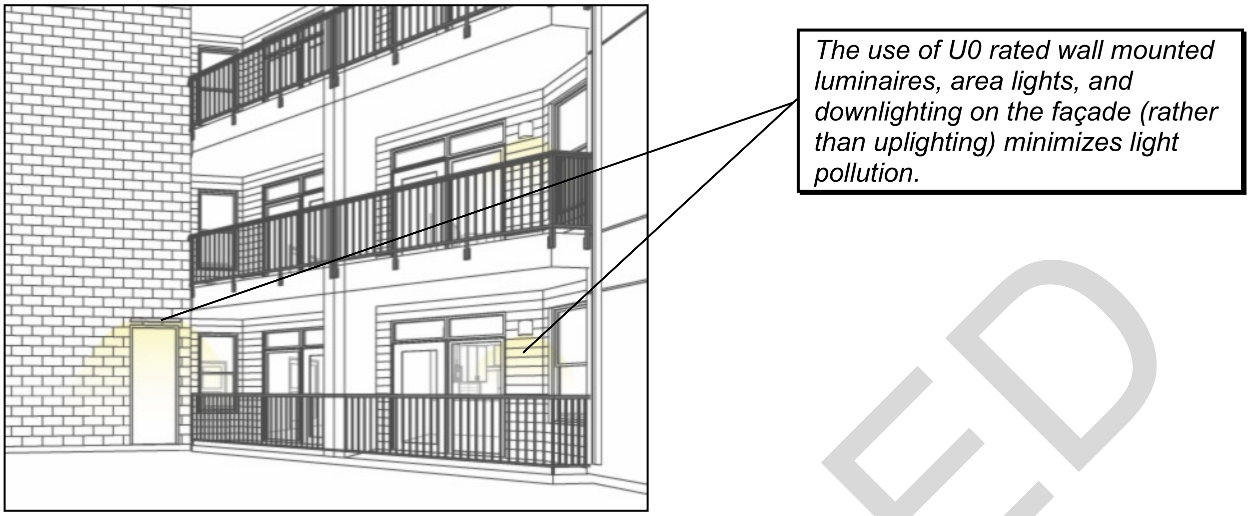
	LZ1 Low ambient	**LZ2 Moderate ambient**	**LZ3 Moderately high ambient**
Average Horizontal Illuminance	Between 0.5 fc (5 lux) and 2 fc (20 lux)* at grade	Between 1 fc (10 lux) and 3 fc (30 lux) at grade	Between 1 fc (10 lux) and 5 fc (50 lux) at grade
Uniformity	5:1 average to minimum		

*If exit is in path of egress, meet LZ2 criteria.

5-4.2.3 Critical Design Issues.

- Select luminaires to match the aesthetic character of the building.
- Comply with NFPA 101 lighting requirements for each exit discharge.
- All luminaires must use shielded optics and/or low lumen light sources to minimize glare and light pollution.
- Luminaires may remain on to assist with building security and law enforcement.

5-4.3 Housing Areas.



5-4.3.1 Control Requirements.

Manual Control	Wall-mounted LED luminaires at individual unit entries and patios are controlled by local control within the housing unit.
Motion Sensing	For lighting not at individual unit entries: Automatically dim lights to 30% after 15 minutes of no detected motion
Time Schedule	For lighting not at individual unit entries: Astronomical timeclock ON at dusk and OFF at dawn, if not using photosensing
Photosensing	For lighting not at individual unit entries: ON and OFF based on daylight availability, if not using astronomical timeclock
Zoning	Zone building-mounted lighting separately from site area lighting

5-4.3.2 Performance Requirements.

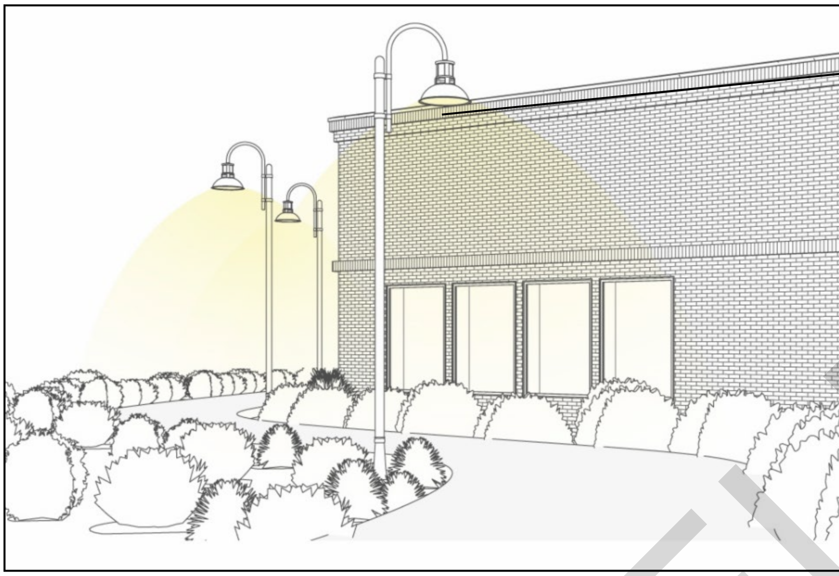
See requirements for Building Entries.

5-4.3.3 Critical Design Issues.

- Use U0 or U1 rated luminaires.
- Use G0 or G1 rated luminaires
- All luminaires must use shielded optics and/or low lumen light sources to minimize glare and light pollution.
- In locations underneath covered balcony or walkway, utilize indirect lighting solutions to provide vertical illumination of surfaces and occupants passing through the space.

5-5 PEDESTRIAN AREAS.

5-5.1 Walkways.



Luminaires with low lumen output reduce direct glare and provide adequate vertical illuminance while minimizing light pollution and trespass.

5-5.1.1 Control Requirements.

Manual Control	None
Motion Sensing	Automatically dim lights to 30% after 15 minutes of no detected motion
Time Schedule	Astronomical timeclock ON at dusk and OFF at dawn, if not using photosensing
Photosensing	ON and OFF based on daylight availability, if not using astronomical timeclock
Zoning	None

5-5.1.2 Performance Requirements.

	LZ1 Low ambient	LZ2 Moderate ambient	LZ3 Moderately high ambient
Average Horizontal Illuminance, adjacent to landscape	Between 0.2 fc (2 lux) and 0.4 fc (4 lux) at grade	Between 0.4 fc (4 lux) and 0.8 fc (8 lux) at grade	Between 0.5 fc (5 lux) and 1.5 fc (15 lux) at grade
Average Horizontal Illuminance, adjacent to architecture, exits, hardscapes, and waterfronts	Between 0.5 fc (5 lux) and 1.0 fc (10 lux) at grade	Between 1 fc (10 lux) and 2 fc (20 lux) at grade	Between 1 fc (10 lux) and 3 fc (30 lux) at grade
Uniformity	10:1 average to minimum		

5-5.1.3 Critical Design Issues.

- Match aesthetics of decorative poles to that of adjacent buildings.
- All luminaires must be U0 or U1 and must use shielded optics, such as a lens or louver.
- Use G0 or G1 low wattage light sources to minimize glare and light pollution.
- Place poles at potential conflict locations, such as intersections.

5-5.2 Plazas.

5-5.2.1 Control Requirements.

Manual Control	None
Motion Sensing	Automatically dim lights to 30% after 15 minutes of no detected motion
Time Schedule	Astronomical timeclock ON at dusk and OFF at dawn, if not using photosensing When associated with business, automatic full OFF within 1 hour after business close and automatic full ON within 1 hour before business open For landscape and façade lighting, automatically turn OFF the lighting at midnight or close of business (whichever is later)
Photosensing	ON and OFF based on daylight availability, if not using astronomical timeclock
Zoning	Provide separate control for each luminaire type

5-5.2.2 Performance Requirements.

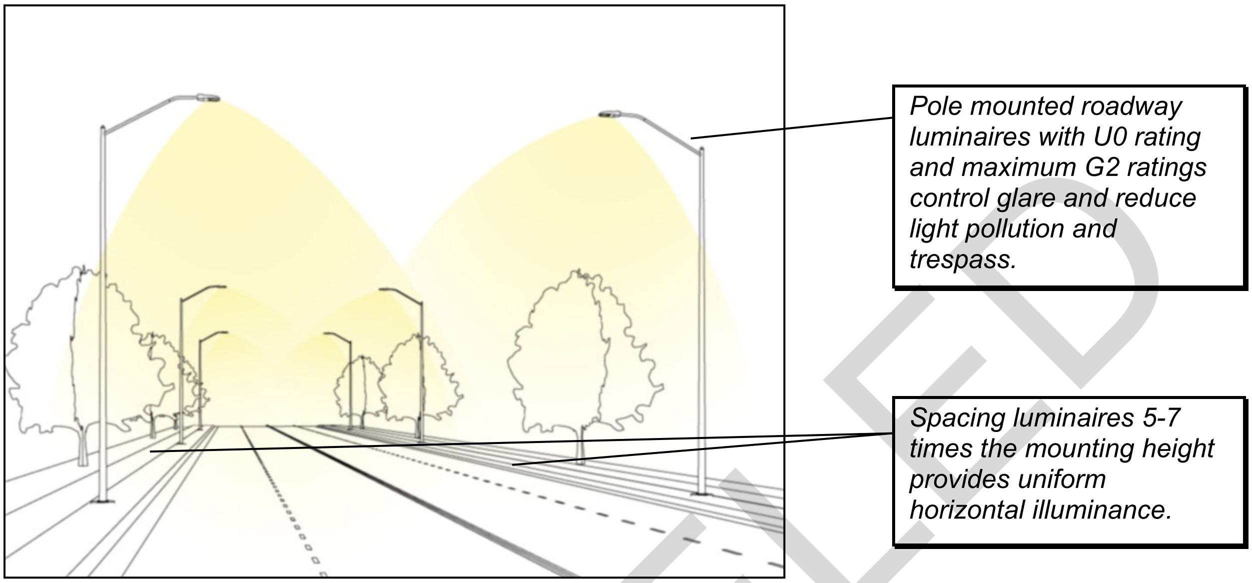
	LZ1 **Low ambient**	**LZ2** **Moderate ambient**	**LZ3** **Moderately high ambient**
Average Horizontal Illuminance	Between 0.5 fc (5 lux) and 1.0 fc (10 lux) at grade	Between 1 fc (10 lux) and 2 fc (20 lux) at grade	Between 1 fc (10 lux) and 3 fc (30 lux) at grade
Uniformity	10:1 average to minimum		

5-5.2.3 Critical Design Issues.

- Use U0 or U1 rated luminaires.
- Use G0 or G1 rated luminaires.

5-6 VEHICLE TRAFFIC AREAS.

5-6.1 Roadways and Streets.



5-6.1.1 Control Requirements.

Manual Control	None
Motion Sensing	None
Time Schedule	None
Photosensing	ON and OFF based on daylight availability
Zoning	None

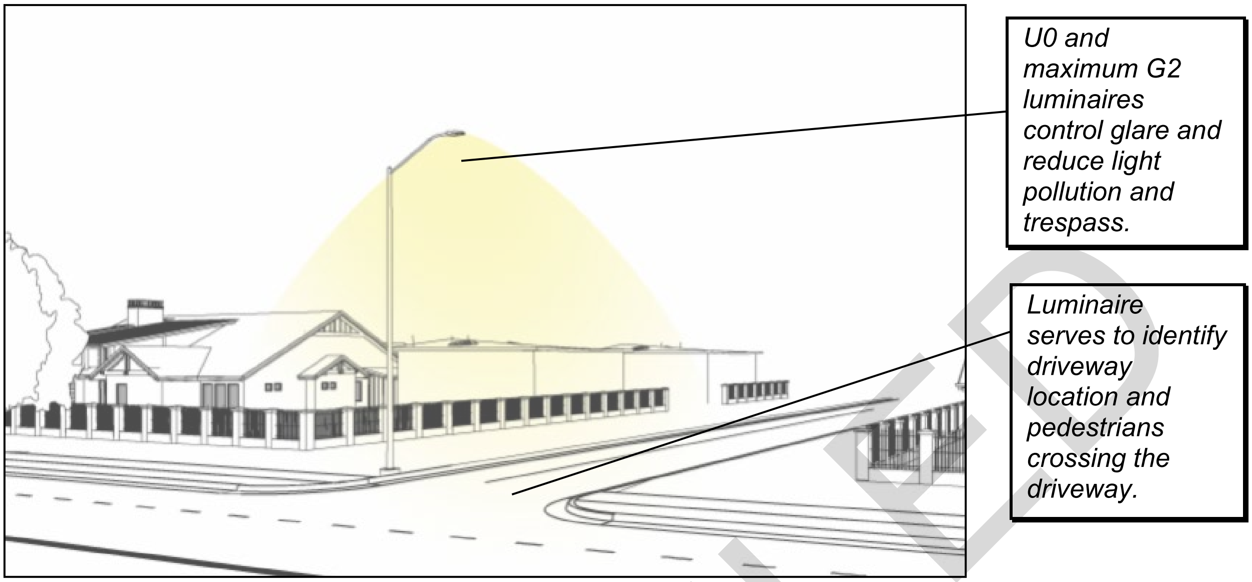
5-6.1.2 Performance Requirements.

Target Criteria	**All Lighting Zones**
Average Horizontal Luminance	ANSI/IES RP-8, *Recommended Practice: Lighting Roadway and Parking Facilities*
Uniformity (Average to Minimum)	

5-6.1.3 Critical Design Issues.

- Use U0 and maximum G2 luminaires to minimize glare and reduce light pollution.
- Locate poles in an opposite pattern versus a staggered pattern to increase visibility.
- Provide luminaires and poles to match installation standard.
- Use photocells specifically designed to operate SSL/LED lighting.
- Use an ANSI 7-pin photocell receptacle.
- Use breakaway bases in accordance with AASHTO GL-6 unless there are sidewalks adjacent to the street where pedestrians could be present.
- Follow ANSI/IES RP-8, Recommended Practice: Lighting Roadway and Parking Facilities for crosswalks located on roadways.

5-6.2 Driveways.



5-6.2.1 Control Requirements.

Manual Control	None
Motion Sensing	None
Time Schedule	None
Photosensing	ON and OFF based on daylight availability
Zoning	None

5-6.2.2 Performance Requirements.

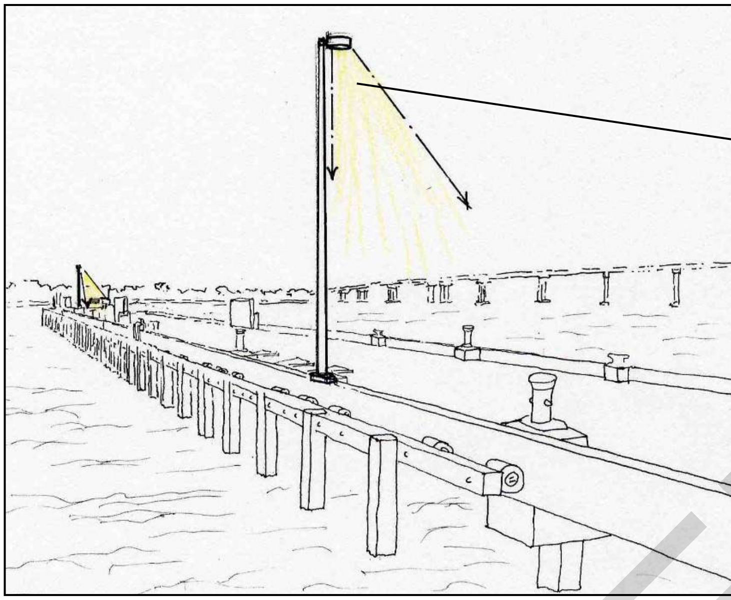
Install one pole mounted, U0 and maximum G2 rated roadway luminaire at the entrance to the driveway. Applies to all lighting zones.

5-6.2.3 Critical Design Issues.

- Use U0 and maximum G2 luminaires to minimize glare and reduce light pollution.
- Use photocells specifically designed to operate SSL/LED lighting.
- Use an ANSI 7-pin photocell receptacle.

5-7 OUTDOOR ACTIVIY AREAS.

5-7.1 Marinas.



Pole mounted luminaires with U0 rating and regressed light source control glare and reduce light pollution and trespass.

5-7.1.1 Control Requirements.

Manual Control	None
Motion Sensing	Automatically dim lights to 30% after 10 minutes of no detected motion, if not dimming by Time Schedule
Time Schedule	Automatic dimming to 30% within 1 hour of business close and automatic full ON within 1 hour of business open, if not utilizing motion sensing Astronomical timeclock ON at dusk and OFF at dawn, if not using photosensing
Photosensing	ON and OFF based on daylight availability, if not using astronomical timeclock
Zoning	None

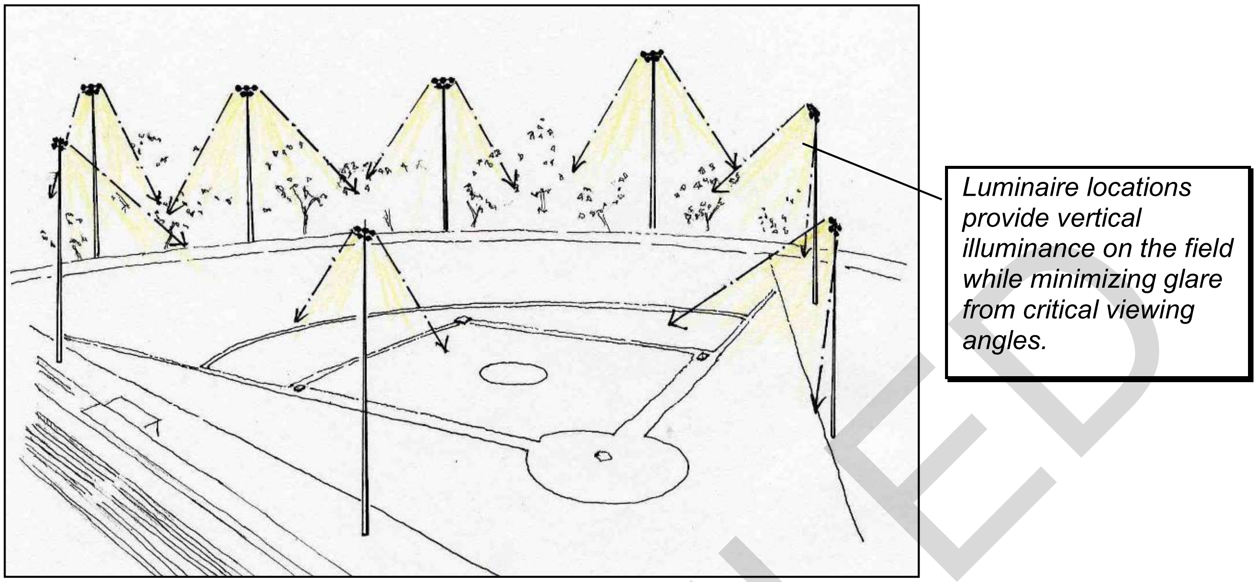
5-7.1.2 Performance Requirements.

Target Criteria	**All Lighting Zones**
Average Horizontal Illuminance	0.5 fc (5 lux) at grade

5-7.1.3 Critical Design Issues.

- Use U0 luminaires to minimize glare and to reduce light pollution. Use luminaires with regressed lenses to reduce glare, especially in environmentally sensitive areas.
- Use G0 or G1 rated luminaires
- Use luminaires with appropriate light distributions to eliminate light reflecting off of the water
- Use monochromatic LEDs for sensitive environments such as wildlife habitat, observatories, wildlife nesting, or to meet Dark Sky requirements.
- In instances where cranes are used, coordinate pole location and height with portal crane clearances.

5-7.2 Baseball and Softball Fields.



5-7.2.1 Control Requirements.

Manual Control	Manual on
Motion Sensing	None
Time Schedule	Automatic partial ON to 50% within 1 hour before field scheduled to be open Automatic full OFF within 1 hour after field scheduled to be closed. Astronomical timeclock ON at dusk and OFF at dawn, if not using photosensing
Photosensing	ON and OFF based on daylight availability
Zoning	Provide separate zones per field

5-7.2.2 Performance Requirements.

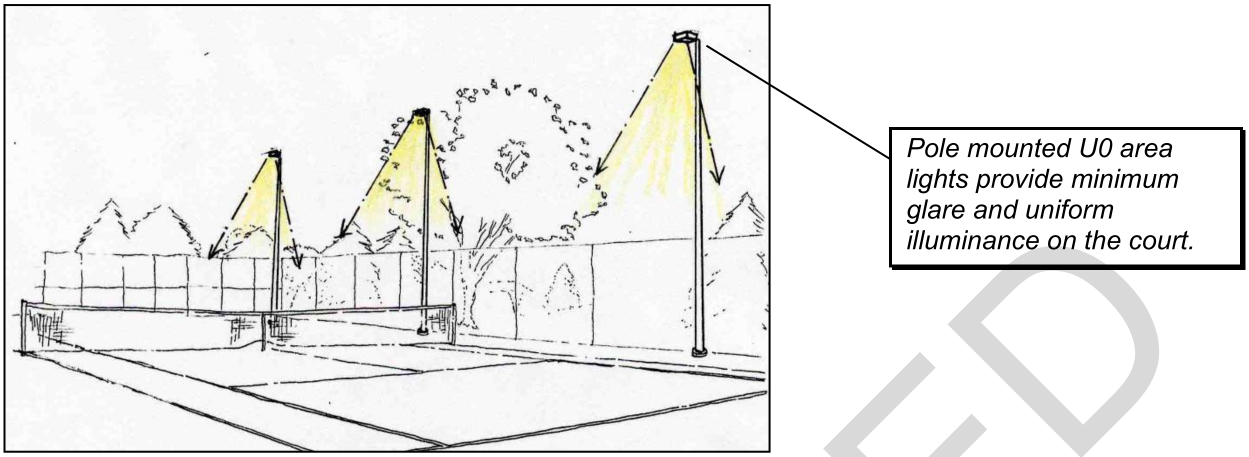
Target Criteria **(Class IV – Recreational*)**	**Infield**	**Outfield**
Average Horizontal Illuminance	30 fc (300 lux) at 3’-0” (910 mm) AFF	20 fc (200 lux) at 3’-0” (910 mm) AFF
Uniformity (Maximum to Minimum)	2.5:1	3:1

*For other classes of play, see ANSI/IES RP-6. Criteria apply to all lighting zones.

5-7.2.3 Critical Design Issues.

- Locate lighting poles outside of critical glare zones.
- Refer to ANSI/IES RP-6, Recommended Practice: Lighting Sports and Recreational Areas.
- Provide uniform illuminance on the field.
- Coordinate aiming of luminaires to minimize light trespass and glare.

5-8.1 Tennis Courts.



5-8.1.1 Control Requirements.

Manual Control	Manual On
Motion Sensing	None
Time Schedule	Automatic partial ON to 50% within 1 hour before courts scheduled to be open Automatic full OFF within 1 hour after courts scheduled to be closed. Astronomical timeclock ON at dusk and OFF at dawn, if not using photosensing
Photosensing	ON and OFF based on daylight availability
Zoning	Provide separate zones per court

5-8.1.2 Performance Requirements.

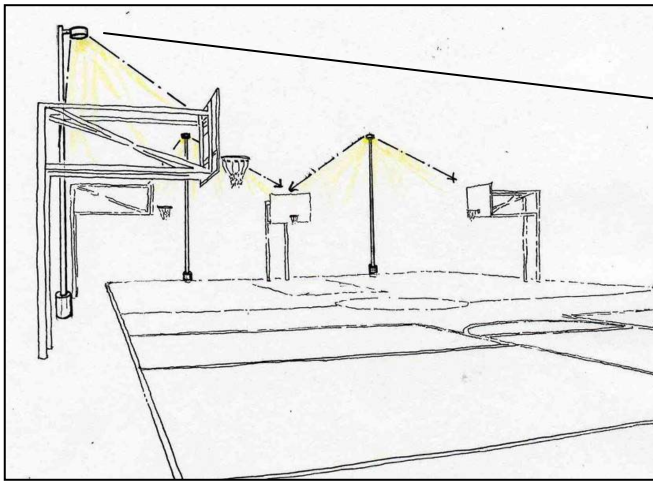
Target Criteria (Class IV – Recreational*)	**All Lighting Zones**
Average Horizontal Illuminance	30 fc (300 lux) at 3'-0" (910 mm) AFF
Uniformity (Maximum to Minimum)	2.5:1

*For other classes of play, see ANSI/IES RP-6. Criteria apply to all lighting zones.

5-8.1.3 Critical Design Issues.

- Use U0 luminaires to minimize glare and to reduce light pollution.
- Locate luminaires parallel to the direction of play.
- Locate lighting poles outside of critical glare zones.
- Refer to IES RP-6 for additional information on sports and recreational area lighting.
- Coordinate aiming of luminaires to minimize light trespass and glare.
- Provide uniform illuminance on the field.

5-8.2 Basketball Courts.



Pole mounted U0 luminaires are spaced to provide uniform illuminance and minimize direct glare.

5-8.2.1 Control Requirements.

Manual Control	Manual On
Motion Sensing	None
Time Schedule	Automatic partial ON to 50% within 1 hour of courts scheduled to be open Automatic full OFF within 1 hour of courts scheduled to be closed. Astronomical timeclock ON at dusk and OFF at dawn, if not using photosensing
Photosensing	ON and OFF based on daylight availability
Zoning	Provide separate zones per court

5-8.2.2 Performance Requirements.

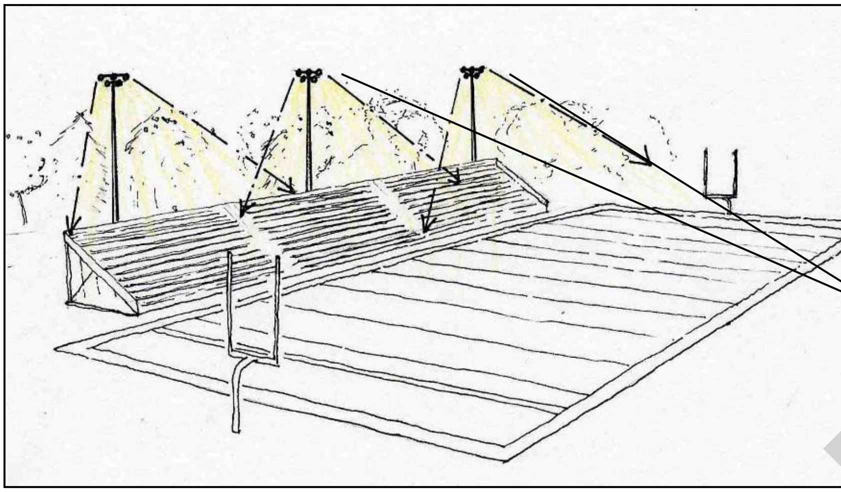
Target Criteria (Class IV – Recreational*)	**All Lighting Zones**
Average Horizontal Illuminance	20 fc (200 lux) at 3'-0" (910 mm) AFF
Uniformity (Maximum to Minimum)	4:1

*For other classes of play, see ANSI/IES RP-6. Criteria apply to all lighting zones.

5-8.2.3 Critical Design Issues.

- Use U0 luminaires to minimize light trespass and glare.
- Provide uniform illuminance on the court.
- Locate lighting poles outside of critical glare zones.
- Refer to ANSI/IES RP-6, for additional information on sports and recreational area lighting.
- Coordinate aiming of luminaires to minimize light trespass and glare.

5-8.3 Football Fields.



Pole mounted modular rack of adjustable sports lighting with internal and external shielding. Luminaire spacing provides uniform illuminance on the field.

5-8.3.1 Control Requirements.

Manual Control	Manual On
Motion Sensing	None
Time Schedule	Automatic partial ON to 50% within 1 hour before field scheduled to be open Automatic full OFF within 1 hour after field scheduled to be closed. Astronomical timeclock ON at dusk and OFF at dawn, if not using photosensing
Photosensing	ON and OFF based on daylight availability
Zoning	Provide separate zones per field

5-8.3.2 Performance Requirements.

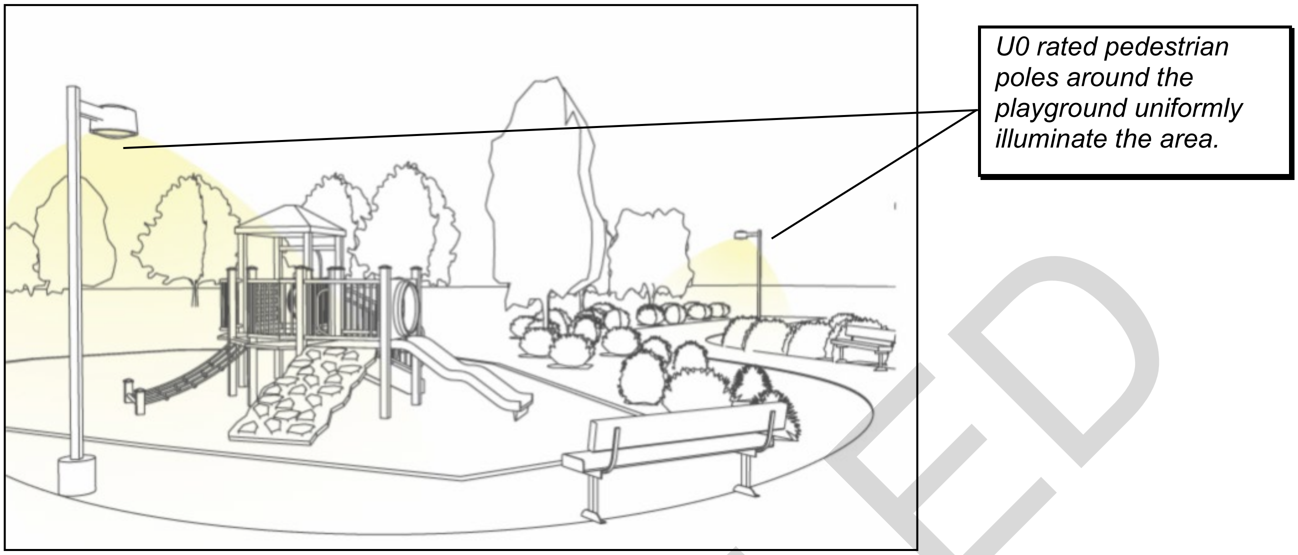
Target Criteria (Class IV – Recreational*)	**All Lighting Zones**
Average Horizontal Illuminance	20 fc (200 lux) at 3'-0" (910 mm) AFF
Uniformity (Maximum to Minimum)	4:1

*For other classes of play, see ANSI/IES RP-6. Criteria applies to all lighting zones.

5-8.3.3 Critical Design Issues.

- Locate lighting poles outside of critical glare zones.
- Refer to ANSI/IES RP-6 for additional information on sports and recreational area lighting.
- Provide uniform illuminance on the court.
- Coordinate aiming of luminaires to minimize light trespass and glare.

5-8.4 Playgrounds.



5-8.4.1 Control Requirements.

Manual Control	None
Motion Sensing	None
Time Schedule	None
Photosensing	ON and OFF based on daylight availability
Zoning	None

5-8.4.2 Performance Requirements.

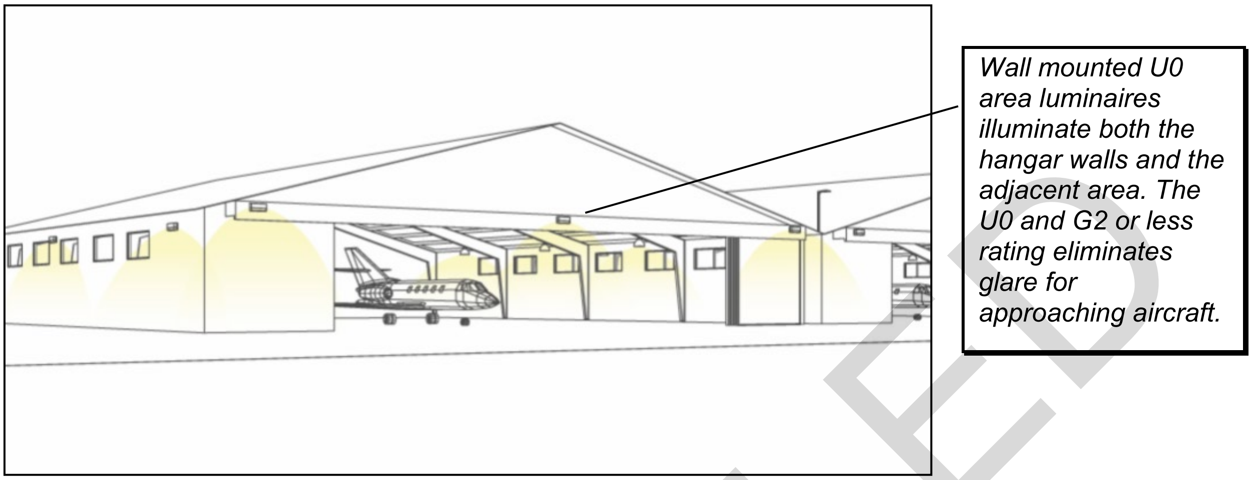
Target Criteria	All Lighting Zones
Average Horizontal Illuminance	1 fc (10 lux) at grade
Uniformity	5:1 average to minimum

5-8.4.3 Critical Design Issues.

- Provide uniform illuminance on the area surrounding the playground.
- Use U0 and maximum of G1 rated luminaires.
- All luminaires must use shielded optics and/or low lumen light sources to minimize glare and light pollution.

5-9 OTHER AREAS.

5-9.1 Airfields (Hangar Exterior).



5-9.1.1 Control Requirements.

Manual Control	None
Motion Sensing	None
Time Schedule	None
Photosensing	ON and OFF based on daylight availability
Zoning	Control separately from other building mounting lighting systems

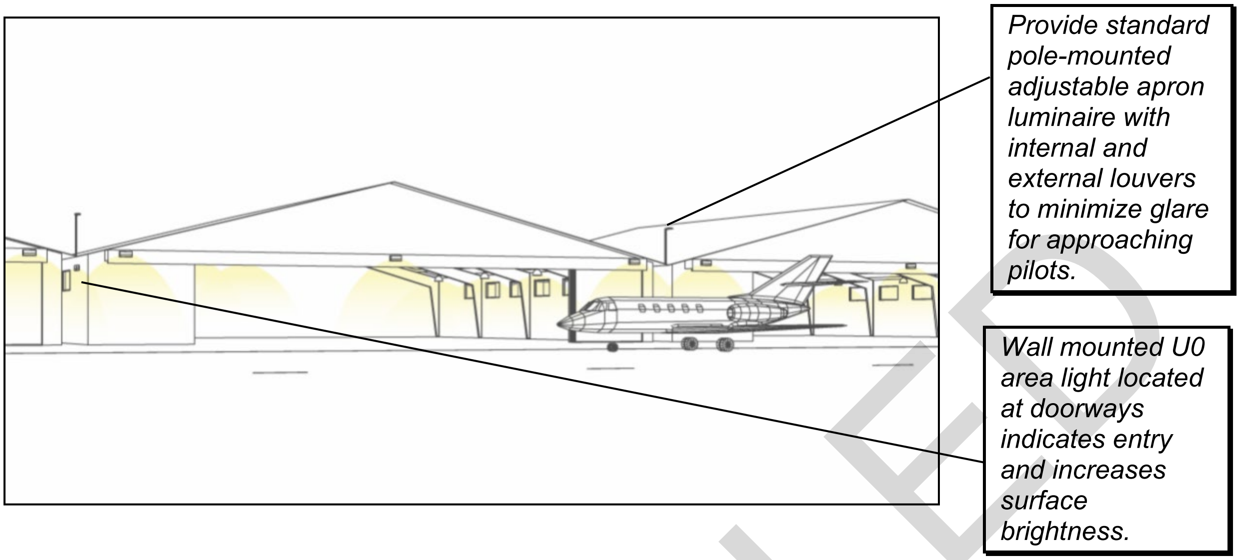
5-9.1.2 Performance Requirements.

Target Criteria	**All Lighting Zones**
Average Horizontal Illuminance	1 fc (10 lux) at grade
Uniformity	5:1 maximum to minimum

5-9.1.3 Critical Design Issues.

- Provide U0 and G2 rated luminaires with low lumen output to minimize glare and light pollution.
- Refer to section 4-9 for additional airfield lighting requirements.

5-9.2 Airfields (Apron).



5-9.2.1 Control Requirements.

Manual Control	None
Motion Sensing	None
Time Schedule	None
Photosensing	ON and OFF based on daylight availability
Zoning	Control separately from other building mounting lighting systems

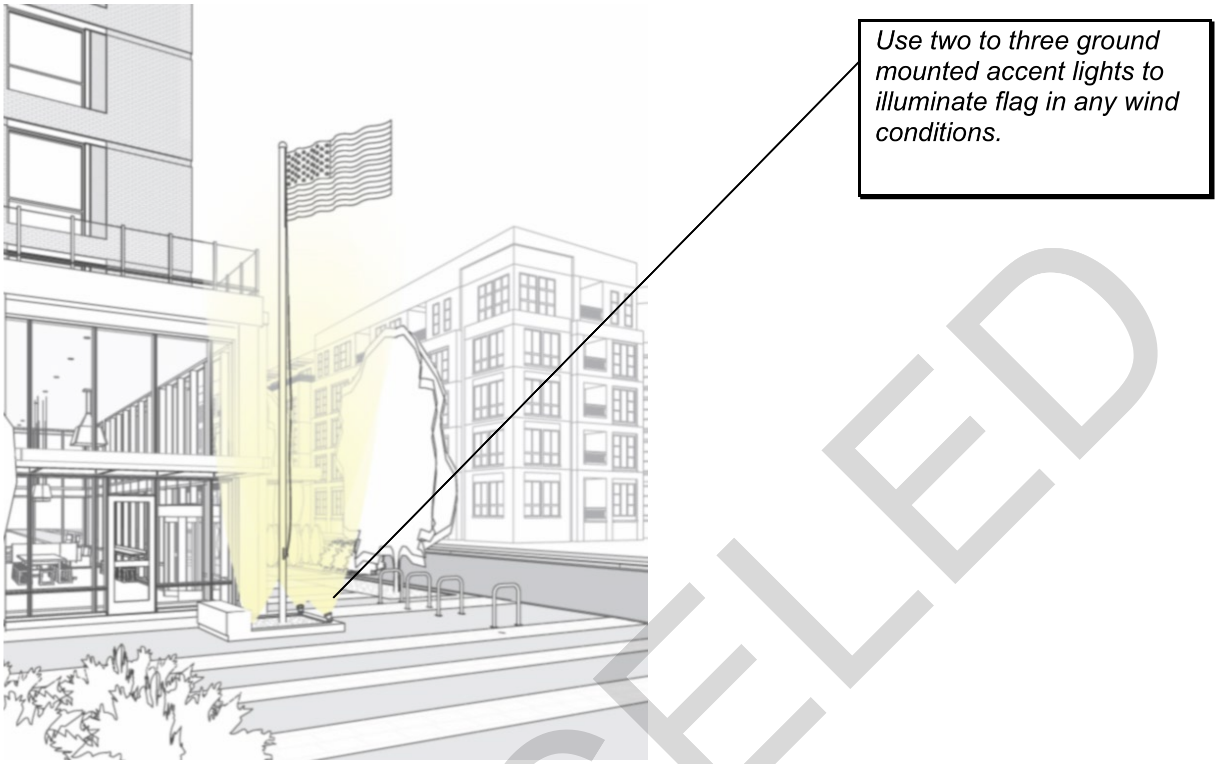
5-9.2.2 Performance Requirements.

Target Criteria	**Maintenance and service**
Average Horizontal Illuminance, Maintenance and service	2 fc (20 lux) at grade
Average Horizontal Illuminance, Aircraft parking	0.5 fc (5 lux) at grade
Average Horizontal Illuminance, Loading and unloading	2 fc (20 lux) at grade
Average Horizontal Illuminance, Other apron areas	1 fc (10 lux) at grade
Uniformity	4:1 average to minimum

5-9.2.3 Critical Design Issues.

- Coordinate with airfield manager for control methodologies.
- Provide U0 and maximum G2 rated luminaires with low lumen output to minimize glare and light pollution.
- Refer to section 4-9 for additional airfield lighting requirements.
- Reference UFC 3-535-01, Table 10-1, for uniformity criteria and apron area.

5-9.3 Flagpoles.



5-9.3.1 Control Requirements.

Manual Control	None
Motion Sensing	None
Time Schedule	Automatic full OFF within 1 hour after business close and automatic full ON within 1 hour before business open Astronomical timeclock ON at dusk and OFF at dawn
Photosensing	None
Zoning	None

5-9.3.2 Critical Design Issues.

- Ground mounted accent lights experience less water intrusion than in-grade uplights.
- In environmental sensitive areas and Lighting Zones 0 and 1, use integrated flagpole downlighting to eliminate uplight.
- If flags are removed at dusk, lighting is not required

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CHAPTER 6 TECHNICAL REQUIREMENTS – SECURITY LIGHTING

6-1 INTRODUCTION.

Exterior security lighting is an important issue for many facilities and not all of the specific criteria are addressed in this section. For lighting requirements, this UFC supersedes MIL-HDBK-1013/1A*, Design Guidelines for Physical Security of Facilities*. Security lighting provides illumination during periods of darkness or in areas of low visibility to aid in the detection, assessment, and interdiction of aggressors by security forces. Security lighting is sometimes referred to as protective lighting.

Refer to CHAPTER 2 and CHAPTER 4 for addition requirements for interior and exterior lighting and controls.

6-2 PHYSICAL SECURITY.

Physical security describes the part of security concerned with physical measures designed to safeguard personnel; to prevent or delay unauthorized access to equipment, installations, material, and documents; and to safeguard them against espionage, sabotage, damage, and theft.

6-2.1 Physical Security System.

A physical security system is comprised of people, equipment, and operational procedures that control access to critical facilities or assets. Security lighting is one of the elements that comprise the equipment component of a physical security system.

6-2.2 Security Lighting Objectives.

Security lighting is one component of a larger physical security system. While the level of protection may vary, the lighting must supplement and facilitate other measures taken to ensure the security of an asset. These other measures may take the form of security forces at an entry control point, sensitive inner areas, boundaries, or the use of video cameras. In all cases, the lighting enhances visibility for either an individual or device and facilitates their performance.

In the simplest form, security lighting provides a clear view of an area for security personnel while reducing concealment opportunities for aggressors. A physical security system must be able to detect a threat, assess the threat, and then neutralize the threat.

6-2.3 Deterrent Value.

Security lighting at a site may deter lesser threats and aggressors. While a security lighting system does not deter sophisticated criminals or terrorists, it may influence unsophisticated criminals or vandals. The mere presence of light increases the probability of detection or capture and may induce these types of aggressors to look for an easier target.

Similarly, the effective use of lighting can enhance the perception of security, which is important to the personnel who work within a secure area. This can be accomplished with glare reduction, lighted surfaces, proper uniformity, and adequate illuminance.

6-2.4 Defining Requirements.

Defining the requirements of a physical security system and its components involves an interdisciplinary planning team. The team considers all interests relating to a project to determine how security fits into the total project design.

Base the specific membership of the planning team on local considerations, but in general, the following functions are to be represented: facility user, antiterrorism officer, operations, security, logistics, engineering, life safety, and others as required. Use the process in UFC 4-020-01 to identify the design criteria, which includes the assets to be protected, the threats to those assets (the Design Basis Threat), and the levels of protection to be provided for the assets against the identified threats. In addition to those criteria elements, the team must also identify user constraints such as appearance, operational considerations, labor requirements or limitations, energy conservation and sustainment costs. Some areas such as water boundaries that cannot be patrolled do not require lighting.

6-2.5 Security Lighting Design.

The security lighting system must aid in the detection of aggressors and assist personnel in the assessment and response to potential threats. All security lighting designs must be coordinated with Security Forces. The type of site lighting system provided depends on the installation environment and intended use.

6-2.5.1 Continuous Lighting.

The most common security lighting system is a series of fixed lights arranged to illuminate a given area continuously.

6-2.5.2 Standby.

With this system, the luminaires are either automatically or manually turned on at times when suspicious activity is detected by security personnel or an intrusion detection system. A standby system creates the impression of activity and may offer a deterrent value while also achieving energy conservation. Use LED light source systems in lieu of light sources that require re-strike.

6-2.6 Controlled Lighting.

Controlled lighting is best used when it is necessary to limit the width of the lighted strip along the perimeter due to adjoining property. Minimize or eliminate silhouetting or illuminating security personnel on patrol. Illumination levels for controlled lighting must be adequate to detect a moving aggressor, either visually or by use of video cameras. Provide U0 rated luminaires mounted in the horizontal plane to minimize glare. Glare may hinder security personnel visibility and interfere with authorized activities or activities outside the installation. Figure 6-1 and Figure 6-2 show different configurations of controlled lighting.

Figure 6-1 Example of controlled lighting: single fence line

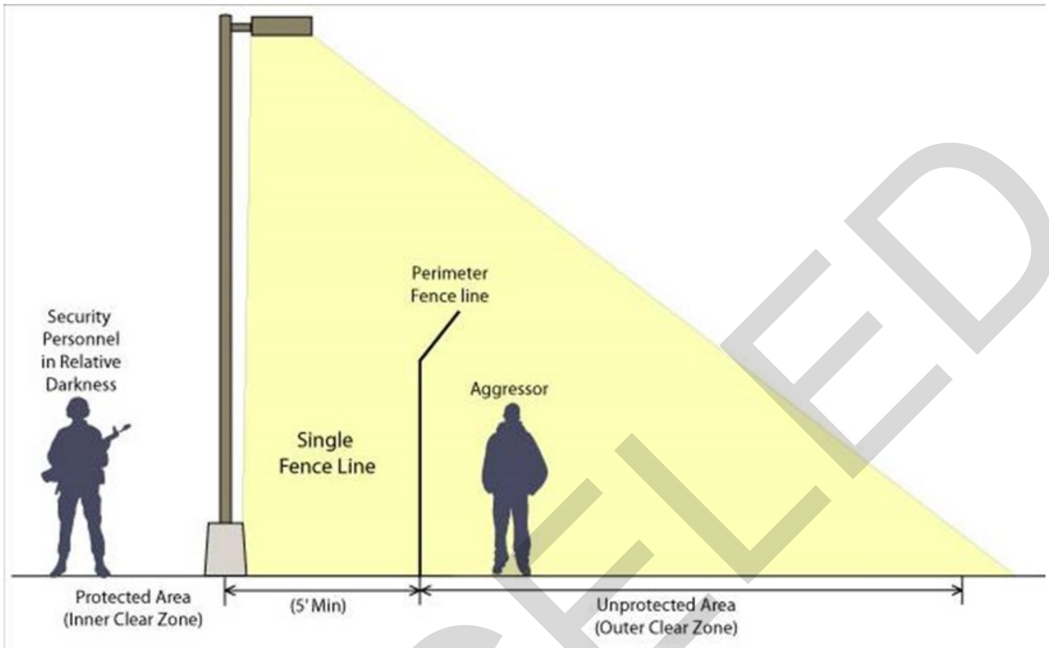
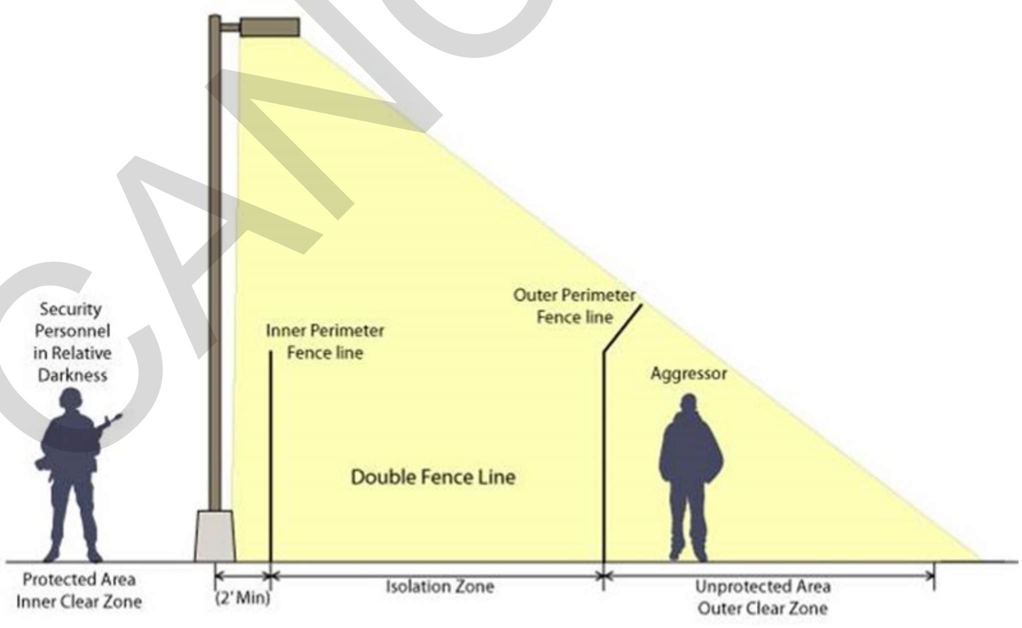


Figure 6-2 Example of controlled lighting: double fence line



6-2.6.1 Glare Projection.

Glare projection is a lighting strategy used in isolated or expeditionary locations to increase the assessment zone by illuminating large flat areas outside the fence line. One technique for glare projection lighting is to place lights slightly inside a security perimeter and directed outward. Glare projection may be a deterrent to potential intruders because it makes it difficult to see inside the area being protected. It also protects security personnel by keeping them in comparative darkness and enabling them to observe intruders at a considerable distance beyond the perimeter. Figure 6-3 and Figure 6-4 show examples of glare projection

Figure 6-3 Example of glare projection: single fence line

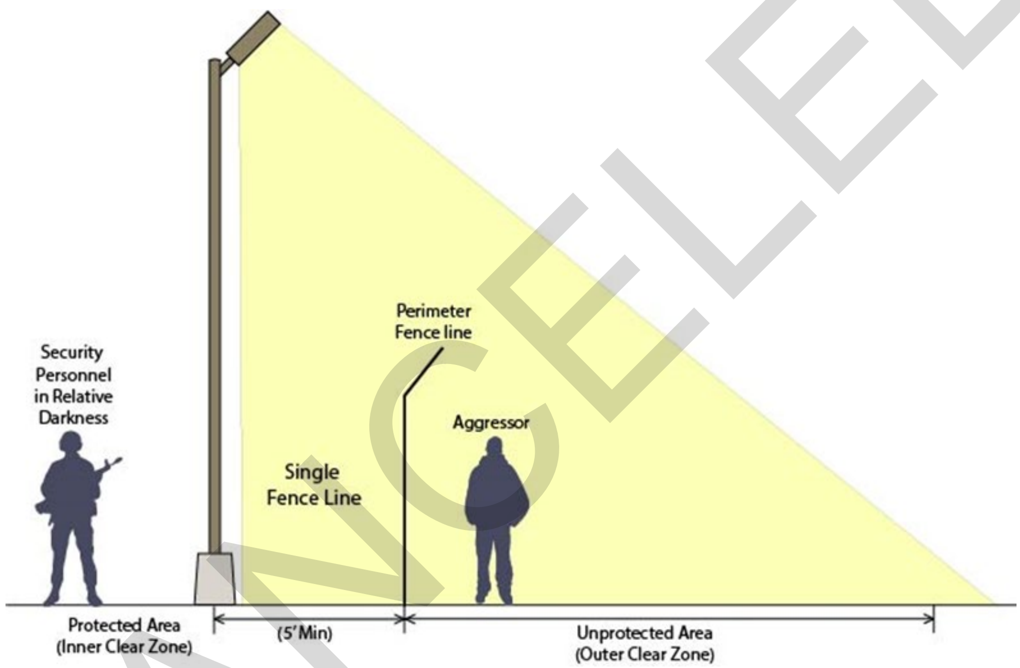
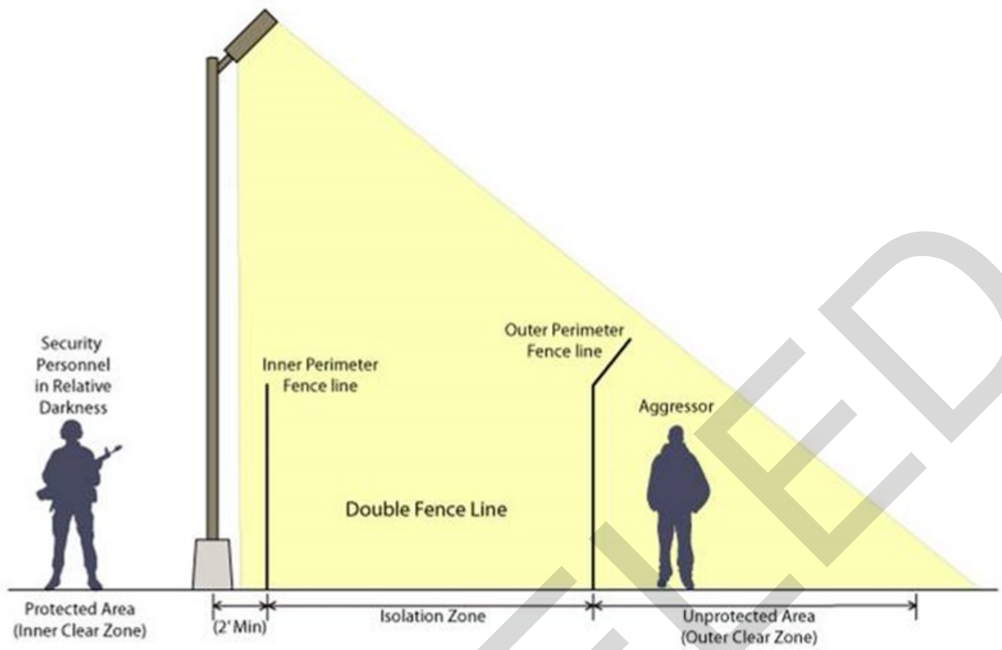


Figure 6-4 Example of glare projection: double fence line



6-2.7 Security Lighting Criteria.

In all cases, mission safety or operational requirements govern over security lighting requirements. For example, if security lighting requires 0.2 fc (2 lux), and a lighting level of 5 fc (50 lux) is required to perform a task or operation, then 5 fc (50 lux) is the requirement. Illuminance values appropriate for security personnel may range from a minimum of 0.1 fc (1 lux) for large open areas to a minimum of 10 fc (100 lux) in area of ID checks for entry control points. If guards must perform any written task (such as inside a guardhouse), the illuminance on the task plane may reach an average 30 fc (300 lux). Illuminance values in excess of this may inhibit the individual's ability to adapt to lower lighted areas outside.

6-2.7.1 Low Level of Protection (LLOP).

Illumination is only required at building entries and exits. Use low brightness and well shielded luminaires so that it does not become a glare source in the much darker surroundings.

6-2.7.2 Medium Level of Protection (MLOP).

Requires LLOP criteria and illumination of the building exterior. U0 rated luminaires mounted on the building wall can illuminate the exterior of the building without adding light to the surrounding area or cause light trespass to neighboring properties.

6-2.7.3 High Level of Protection (HLOP).

Requires MLOP criteria and illumination of the area around the facility. This lighting may still be accomplished with wall mounted lighting on the building. By using a different luminaire distribution, light can be directed to the surrounding area rather than just at the building. For larger areas, poles may be necessary to light further from the building. With U0 rated luminaires, a perimeter width of 2-3 times the mounting height can be illuminated. When a perimeter fence is required for security, HLOP would dictate illumination of the perimeter fence including any required clear or isolation zones to aid in the detection, assessment, and interdiction of aggressors by security forces. Use controlled lighting, except when dictated by local threat environment.

6-3 SECURITY LIGHTING APPLICATIONS.

Refer to the CHAPTER 7 on Security Lighting Applications for additional information.

6-3.1 Building Entrances and Exits.

Increasing the lighting level at the building entrance guides visitors and other personnel to the appropriate building entry. It also serves as exit lighting to guide individuals out of a building for life safety in case of an emergency. The security lighting at these locations protects against forced entry and provide enough light for threat assessment. Building entrances and exits must be lighted for all levels of protection. Use concealed, U0 rated luminaires and/or low brightness sources to limit glare while still providing adequate illumination.

6-3.2 Building Exterior.

Lighting of the building frequently includes some area lighting as well. By using U0 rated, wall mounted luminaires; both the building and the adjacent area can be illuminated. Mounting luminaires at the top of the facade and aiming the light down increases the facade brightness and reduces light trespass and light pollution.

6-3.3 Perimeter Lighting.

Illumination of a restricted area perimeter when required includes the exterior and interior clear zones adjacent to the fence or, in some applications, the area between a dual fence line (isolation zone). Provide poles, power circuits, and transformers within the protected area. Coordinate pole locations with the user to ensure that the applicable egress requirements and patrol routes of the clear zone are not violated. Provide poles that are not less than 5 feet (1.5 meters) from a single fence line, or less than 2 feet (0.6 meters) for a dual fence line. This 5-foot (1.5 meter) separation may not apply to a perimeter that is a solid wall. In the case of a solid wall, the designer needs to coordinate with the local security and service to determine the best approach. Provide perimeter lighting that is either continuous or standby, controlled or glare projection depending on the application and local threat environment. See Table 6-2 for additional criteria.

6-3.4 Entry Control Facilities, Access Control Points.

Refer to UFC 4-022-01 for Entry Control Facility/Access Control Points (ECF/ACP) Criteria and *Entry Control Facility/Access Control Point Lighting Analysis* for additional information. Entry Control Facilities/Access Control Points are separated into several zones, see Figure 6-5. These zones can be further subdivided into lighting zones, see Figure 6-6.. The lighting design for each zone is described in the following paragraphs.

Figure 6-5 ECF/ACP Zones*

Zone	Location	Goals
Safety	Extends in all directions beyond passive and active barriers.	Protect assets and personnel from explosions.
Approach	Installation boundary to a point just before the ID checkpoint.	Reduce speed, sort vehicles, provide stacking room, identify potential threats.
Access Control	A point just before and after the ID checkpoint.	Identify vehicles and personnel; provide surveillance, random inspection, visitor processing, and rejection capabilities.
Response	A point just after the ID checkpoint to the active vehicle barriers.	Provide measures to react to and resist a threat.

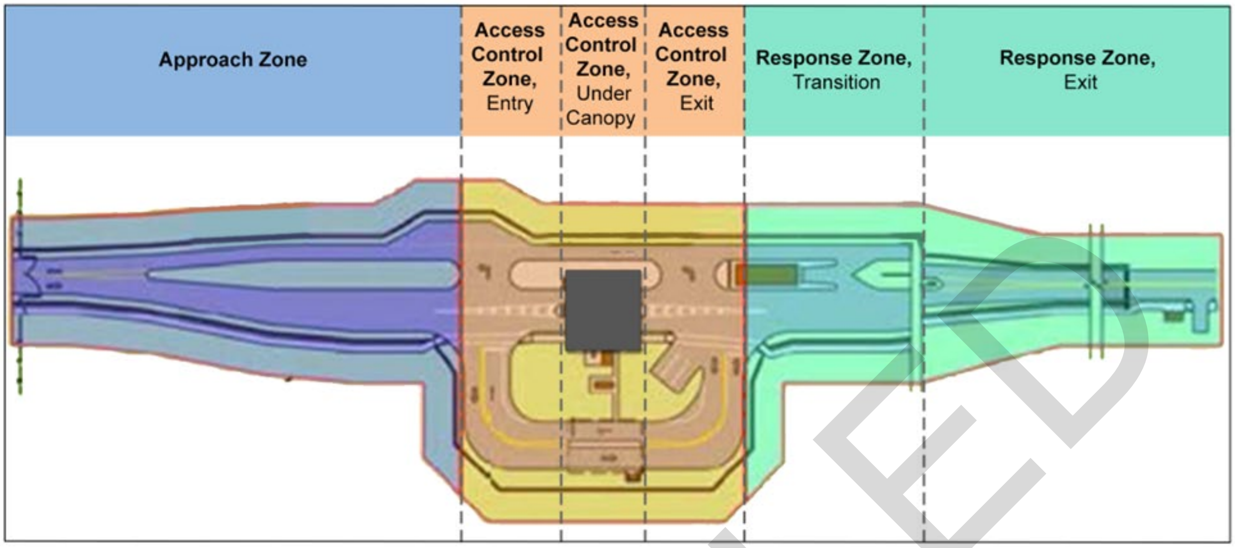
*Source: UFC 4-022-01.

6-3.4.2 Approach Zone.

Illuminate the Approach Zone to lead motorists safely to the Access Control Zone. Use U0 rated luminaires mounted in the horizontal plane to minimize glare. Glare rating not to exceed G2. To reduce glare for security personnel, provide signage to instruct motorists to turn off headlights as they approach the Access Control Zone.

To reduce adaptation issues for the motorist, gradually increase (transitional lighting) lighting levels as the motorist approaches the Access Control Zone, which has the highest light levels. Motorist's eyes take time to adjust to sudden changes in light level, especially high to low. Extensive discussion of transitional lighting can be found in ANSI/IES RP-8. Typically, a minimum Approach Zone of 200 ft. (61 m) is adequate to achieve acceptable transitional lighting in the Approach Zone.

Figure 6-6 ECF/ACP Lighting Zones



6-3.4.3 Access Control Zone.

Lighting in the Access Control Zone/Access Control Points provides the highest light levels in the Entry Control Facility/Access Control Points. To provide the proper lighting adaptation levels for drivers and security personnel, the Access Control Zone is broken into three areas, see Figure 6-6. Increased light levels in the Access Control Zone, Entry allows the motorist to adapt to the brightness. Decreased light levels in the Access Control Zone, Exit, allows the motorist to adapt to lower light levels upon exit of the Access Control Zone.

The lighting system must provide for identification and inspection. For most of the Access Control Zone, U0 rated luminaires provide adequate lighting for most of these visual tasks. However, vertical illuminance on motorists' faces can be improved with the use of low brightness light sources (less than 3500-lumen light source output). Luminaires mounted to the side and behind security personnel improves identification tasks. Use a glare rating not to exceed G2.

6-3.4.4 Response Zone.

From the Access Control Zone, gradually return roadway lighting to lower light levels (transitional lighting) while still providing adequate uniformity; see Figure 6-6. Provide U0 rated luminaires mounted in the horizontal plane to minimize glare for motorists and security personnel in the Response Zone. Use a glare rating not to exceed G2. In addition, provide signage to instruct motorists to turn headlights back on after leaving the Access Control Zone.

6-3.4.5 Pedestrian Access.

Pedestrian zones must provide light for both pedestrians and security personnel. Pedestrians must have a clear view of gates and card access readers and security personnel must be able to see pedestrians approaching the ECF/ACP. Provide U0 rated luminaires mounted in the horizontal plane to minimize glare. Use a glare rating not to exceed G2.

6-3.4.6 Vehicle Inspection.

In areas where security personnel must identify visitors, check credentials, and read shipping manifests, provide lighting that does not interfere with the operations while vehicles approach, stop for inspection, and proceed. Having to continually adapt to different illuminance and brightness levels could lead to eyestrain and reduced performance by security personnel. Provide additional task lighting from behind the guard and light the person to identify or the vehicle to inspect.

6-3.4.7 Gatehouse/Guard Booth.

Inside the gatehouse, task lighting must be provided for reviewing identifications, paperwork, and possibly computer tasks. However, the interior light levels must be kept at a lower ambient light level than the exterior. Otherwise, the security personnel will have reduced visibility and those approaching the shack will have a clear view of the interior. While the ambient light level may be very low, task lighting at a desk or workstation can still be increased to a higher level. The location and shielding of interior lighting must minimize the chance of veiling reflections on the glass that may limit visibility to the outside. All luminaires must be dimmable to adjust inside lighting levels. Do not use colored light for task lighting when color is to be distinguished in the task.

6-3.4.8 Overwatch Position.

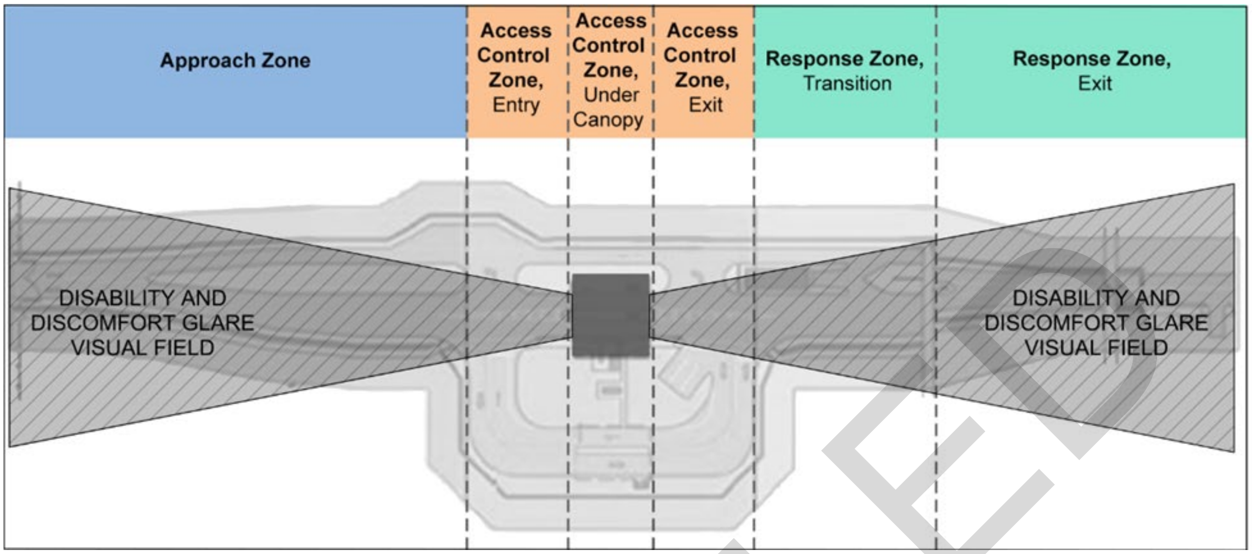
These locations must maintain an unobstructed view through the access and Response Zones. Additionally, inside the overwatch itself, lighting must be kept to extremely low levels or eliminated entirely to prevent the lighting of the security personnel. All luminaires must be dimmable to adjust lighting levels. While red colored light has been used in such applications to maintain the eye’s dark adaptation, do not use colored light for task lighting when color is to be distinguished within the Overwatch position.

6-3.4.9 Disability and Discomfort Glare Visual Field.

The Disability and Discomfort Glare Visual Field is the visual coverage of security personnel stationed at an ECF/ACP, located within the Access Control Zone. Luminaires within this field are most likely to cause disability and discomfort glare for Security Personnel.

Figure 6-7 overlays the Disability and Discomfort Glare Visual Field on the typical ECF/ACP layout. This figure is an example layout. ECF/ACP layout must consider the impact of the Disability and Discomfort Glare Visual Field on the lighting layout. See the *Entry Control Facility/Access Control Point Lighting Analysis* for more information.

Figure 6-7 ECF/ACP Disability and Discomfort Glare Visual Field



All luminaires placed within this visual field must take glare as a consideration in design:

- Minimize light source visibility from the security personnel position.
- The glare rating should be no greater than G1.
- Use Table 6-1 to establish maximum luminaire mounting heights per distance from security personnel position.

Table 6-1 Maximum Luminaire Mounting Height in the Disability and Discomfort Glare Visual Field

Distance from Security Personnel Position	At 20' (6 m)	At 30' (9 m)	Between 40' (12 m) and 60' (18 m)	Between 60' (18 m) and 80' (24 m)	Between 80' (24 m) and 100' (34 m)	>100' (34 m)
Maximum Luminaire Mounting Height*	14' (4 m)	18' (5 m)	Between 22' (7 m) and 32' (10 m)	Between 32' (10 m) and 40' (12 m)	Between 40' (12 m) and 50' (15 m)	>50' (15 m)

*Maximum luminaire mounting height is measured to the underside of luminaire.

6-3.5 Waterfront.

Refer to UFC 4-025-01 for Waterfront Security Criteria. Waterfront areas consist of a defined perimeter (landside and waterside), restricted area, Entry Control Facilities at the entrance into the waterfront area, access control points located at each pier, and pedestrian access control points along the perimeter. In waterfront areas, utilize high mast lighting to reduce the number of poles minimizing obstructions to waterfront operations and maintaining clear paths for equipment and vehicles. Provide U0 rated luminaires mounted in the horizontal plane to limit direct and reflected glare. Use a glare rating not to exceed G2. In some regions, white light sources may interfere with the marine environment. Coordinate marine issues with the local environmental authority.

Security lighting can visually interfere with lighting used as aids to navigation (ATON) by ships. Lighting ashore can camouflage, outshine, or otherwise conceal ATON. Ensure that lighting ashore and in the waterfront compound does not conflict with or otherwise conceal the ATON lights. Coordinate security lighting requirements with Port Operations.

6-3.5.1 Piers, Wharves and Shipyards.

Provide U0 rated luminaires to limit glare and uplight. Use a glare rating not to exceed G2. In general, high mast lighting provided for waterfront operations supply adequate illuminance for security requirements. Coordinate number, height, and location of poles and the associated concrete pedestals to minimize obstructions to pier, wharf and shipyard operations. Refer to UFC 4-152-01 for Pier and Wharf operational lighting requirements. Refer to for the minimum lighting intensity requirements for shipyards.

6-3.5.2 Pierhead and Wharf Guard Towers.

Lighting inside the guard towers must not degrade security personnel’s nighttime visibility. All luminaires must be dimmable and mounted at or near desk level. Switch task and general lighting separately. When colors are not used to distinguished tasks (colored lights or controls for alarm annunciations), consider red light sources for task lighting to reduce adaptation problems. Manually operated searchlights may be required to assist security personnel to locate and assess waterside threats within the restricted zone. Lighting controls must be under the direct control of security personnel. Coordinate lighting requirements with security personnel.

6-3.5.3 Water Surface.

High mast lighting on pier and wharves provides adequate illuminance for security requirements. Glare, poor distribution, and excessive light levels reduce security personnel’s ability to assess surface and subsurface threats.

6-3.5.4 Underwater Lighting.

Underwater lighting is not normally required for detection of subsurface threats and is discouraged due to limited benefit, high installation cost, and maintenance issues.

6-3.5.5 Underdeck Lighting.

Dedicated luminaires located beneath the pier are not normally required and are discouraged due to limited benefit, high installation cost, and maintenance issues.

6-3.5.6 Lower Deck Lighting.

On the lower deck of a double deck pier, provide utility and work areas with illuminance levels based on the tasks performed. Lower deck lighting in roadway and open areas must be multilevel and divided into sections to localize lighting control. Alternate control of luminaires between photocell and manual light switch or implement an intelligent control system. Provide an average of 0.5 fc (5 lx) with luminaires under photocell control. To reduce energy consumption, consider occupancy or vacancy sensors for control of lighting in enclosed spaces.

6-3.6 Video Cameras.

Cameras respond to a luminous environment differently than the human eye. The field of view of a camera refers to the extent of the scene that can be viewed at one time. Some devices may use motorized swivels to pan across a scene and increase the viewing area. Cameras adjust the view based on the brightest point in this field. If it must adjust for a hot spot, areas under low illuminance levels may not be visible at all. Uniform illuminance and U0 rated luminaires are vital to limit hot spots and improve video camera system performance. **Figure 6-8** illustrates how a large portion of the camera's view may be washed out if it must adjust to an excessively bright light source. Any luminaire that falls within the camera's field of view at any time must be shielded. If a light source can be seen directly by the camera, the glare and high contrast limit the visibility of the entire scene. Therefore, the source of illumination is best located above the level of the camera. Refer to UFC 4-021-02 *Electronic Security Systems* for additional information.

Figure 6-8 Video camera's view of scene with excessive glare

6-3.6.2 Color Rendering Index.

For color cameras, the color rendering index of the sources lighting the area must be above 80. Color rendering is less important for monochrome systems.

6-3.6.3 Uniform Vertical Illuminance.

Video cameras typically record objects and people in elevation. Therefore, the security lighting system must provide adequate and uniform vertical illuminance. As in many security lighting applications, the amount of vertical illuminance is far more important than horizontal. Vertical illuminance criteria average is 0.2 to 0.5 fc (2 to 5 lux) at 5 feet (1524 mm) above the ground. Uniformity criteria is 4:1 average to minimum. These criteria refer to vertical illuminance values measured in the same direction of the camera line of sight. Vertical illuminance does not need to be this high in all directions. Color cameras may require higher light levels than monochrome cameras. Review camera manufacturer recommendations and coordinate with the security system designer when designing the lighting system.

6-3.6.4 Infrared (IR) Cameras.

IR cameras utilize IR sources to illuminate the field of view. Light in the IR spectrum is not visible to the human eye. IR cameras then pick up the reflections of these wavelengths from objects in the area.

6-3.6.5 Thermal Imaging.

Devices using thermal technology do not require any light source to operate. They create images based on the heat differences between humans, vehicles, the ground, and foliage. Unlike other camera technologies, thermal imagery is not affected by glare from headlights or light sources. While this technology can indicate the presence of people and objects in complete darkness, they do not provide the detailed images obtainable from visible light or IR cameras.

6-3.6.6 Specific Lighting Criteria.

The specific lighting criteria and design issues may vary with application. Table 6-2 summarizes the minimum (not average) horizontal and vertical illuminance levels for typical facility applications. The inner clear zone noted in the table refers to the area along a perimeter fence line within the facility or installation. The isolation zone refers to the area between a double fence line. The outer clear zone describes the area along the perimeter fence on the outside of the protected area. Isolation and clear zones are typically 30 feet (9.1 meters) in width. It is important to note, however, that over-lighting and glare can cause just as many visibility problems as underlighting.

Table 6-2 Minimum Lighting Criteria for Unaided Guard Visual Assessment

Application				**Minimum or Average Illuminance (All Lighted Areas)**		**Maximum Uniformity**
Type	Lighting	Area	Width Feet (m)	Locations to Light	Footcandles (lux)[a]	(Avg:Min)
Perimeter	Controlled	Inner Clear Zone	20-30 (6.1-9.1)[c]	Outer edge fence	0 (0)[e] min	10:1
	Controlled	Outer Clear Zone	30 (9.1)[d]	Outer edge	0.2 (2) or 0.4 (4)[g] min	10:1
	Controlled	Isolation Zone[f]	30 (9.1)	Between fence lines	0.5 (5) or 1.0 (10)[b] min	6:1
Building Lighting	Controlled	LLOP	--	Building Entry and Exits	Refer to 5-4.1 and 5-4.2	20:1
	Controlled	MLOP	--	Same as LLOP and exterior walls.	0.2 to 0.5 (2 to 5) min	15:1
	Controlled	HLOP	30 (9.1)	Same as MLOP and area around facility.	0.5 to 1.0 (5 to 10) min	10:1

a. Horizontal plane at 3 feet (914 mm) above finished grade unless otherwise noted.
b. Vertical illuminance 6 inches (152 mm) above finished grade.
c. Width of inner clear zone is asset dependent. Refer to Service guidance for asset being protected.
d. Width of outer clear zone is asset dependent (typical clear zones is 30 feet (9144 mm). Refer to Service guidance for asset being protected. Glare projection may be required in areas with larger clear zones such as forward areas or high threat environments or when the assessment zone is extended beyond the clear zone.
e. Minimize illuminance in inner clear zone to prevent illuminating security personnel. Some applications may require illumination of inner clear zone (backlighting).
f. Only applies to dual fence line applications.
g. Vertical illuminance 3 feet (0.9 meters) above finished grade, at outer edge.

6-4 LIGHTING CONTROLS.

Refer to CHAPTER 7 for control requirements specific to common applications. Refer to CHAPTER 2 and CHAPTER 4 for information on lighting controls and control strategies.

6-5 ELECTRICAL REQUIREMENTS.

Backup power is not required for all security lighting systems. The results from assessment of risk and asset value determine this need. For critical security lighting systems, several different types of systems are available for providing backup power in the event of a power outage. All offer various advantages and disadvantages. They vary in amount of time that they can provide power, amount of downtime between a power outage and backup power, and cost. Refer to service specific guidance regarding facilities and equipment authorized backup power.

6-5.1 Generators.

Generators are commonly used to provide backup power but have some downtime between the outage and when the generator restores power. Minimum downtime can be as low as seconds. While this is one of the least expensive solutions, operations must be able to sustain the short period of darkness.

6-5.2 Uninterruptible Power Supply.

An uninterruptible power supply (UPS) is a battery source that provides instantaneous power in case of a power loss. UPS systems have a high initial cost and are expensive to maintain. Therefore, only provide a UPS for security lighting systems associated with the protection of critical assets or security operations when continuous, full brightness lighting is required.

6-5.3 Flywheels.

Flywheels provide instantaneous power in the case of power loss in the form of the kinetic energy in a constantly rotating wheel. This energy can be harnessed immediately in the event of a power outage and used to power critical lighting. These devices vary widely in price and capacity.

6-5.4 Battery Backup.

Individual battery packs are available for some luminaires. In the event of a power outage, these packs can power the lighting for times ranging from five minutes to two hours, depending on the battery capacity. For LED light sources, the battery powers the driver directly although the light source may not provide full light output.

6-5.5 Circuiting Techniques.

To minimize security degradation during faults, divide lighting system into two or more circuits. Circuiting luminaires onto separate circuits in the same space does not provide backup power but limits vulnerabilities during a fault or circuit failure. If the lighting system is divided onto two or more circuits, the loss of one does not affect the entire lighting system. Install multiple circuits, except where their use is clearly impractical. Locate the overcurrent devices, transformer, and wiring within the protected area. Locate circuits underground to minimize the possibility of sabotage or vandalism.

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CHAPTER 7 SECURITY LIGHTING APPLICATIONS

7-1 INTRODUCTION.

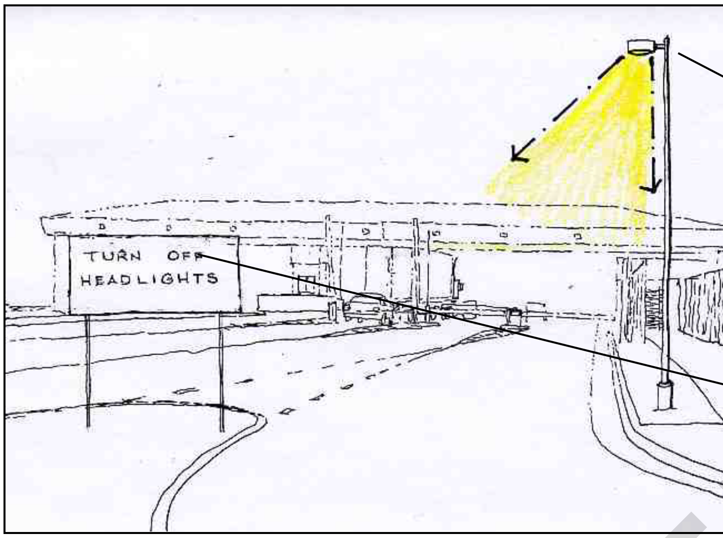
This section identifies typical security lighting applications. Each application details a conceptual lighting design example. Designers must meet the lighting performance and controls requirements.

7-2 CALCULATIONS FOR SECURITY LIGHTING.

Refer to CHAPTER 3 for lighting calculation requirements for interior lighting and CHAPTER 5 for calculations for exterior systems.

7-3 ENTRY CONTROL FACILITY/ ACCESS CONTROL POINTS.

7-3.1 Approach Zone.



U0 rated luminaire reduces glare for approaching drivers and for security personnel. Increase light level at Approach Zone to provide transition to the higher level at the access control point.

Post signs that instruct motorists to turn off headlights when approaching the Access Control Zone.

7-3.1.1 Control Requirements.

Manual Control	None
Motion Sensing	None
Time Schedule	None
Photosensing	ON and OFF based on daylight availability
Zoning	None

7-3.1.2 Performance Requirements.

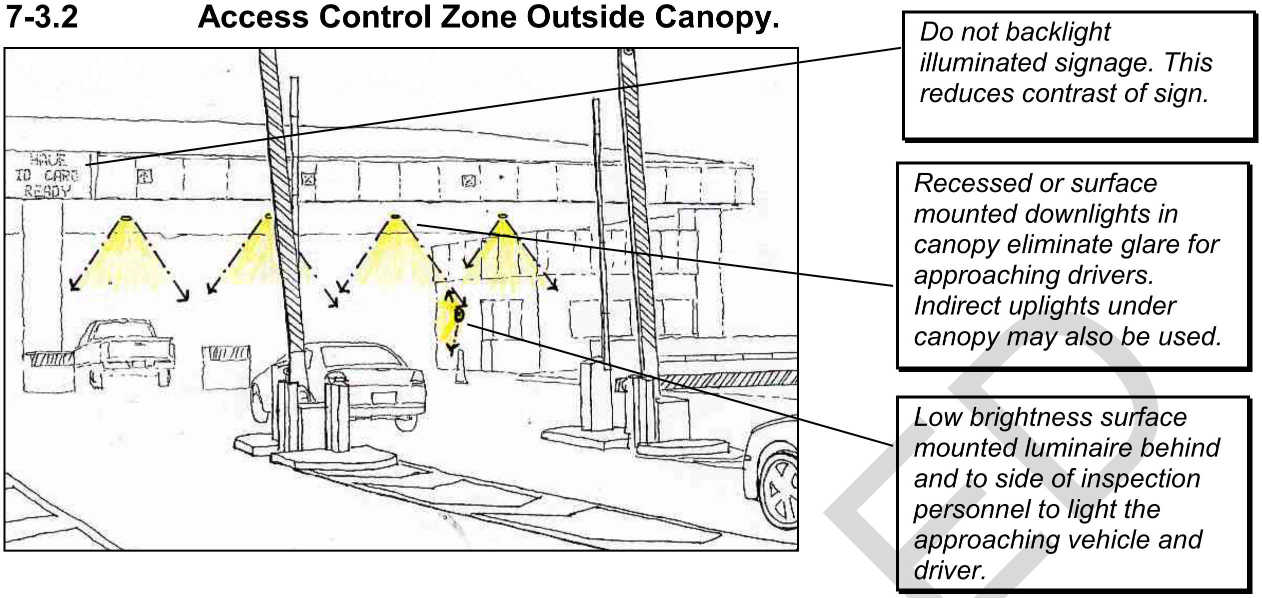
Target Criteria	**Minimum Distance**	**All Lighting Zones**
Average Horizontal Illuminance, Approach Zone	200' (61 m)	1.5 fc (15 lux) at grade
Uniformity	4:1 average to minimum	

7-3.1.3 Critical Design Issues.

- See Response Zone and UFC 4-022-01 for additional information on transition lighting.
- Refer to Figure 6-6 for diagram of ECF/ACP lighting zones.

- Provide transitional lighting between bright and dark regions for the Approach Zone of the gate to improve visual adaptation.
- Use luminaires with a G-Rating of G0 or G1, only use G2 for special conditions for roadway or area luminaires.
- For luminaires in the Discomfort and Disability Glare Visual Field, follow the design parameters outlined in section 6-3-4.1.

7-3.2 Access Control Zone Outside Canopy.



7-3.2.1 Control Requirements: Primary ECF/ACP.

Manual Control	Wallbox switch or scene wallstation in nearby accessible location with manual ON and manual OFF
Motion Sensing	None
Time Schedule	None
Photosensing	ON and OFF based on daylight availability with manual override
Zoning	None

7-3.2.2 Control Requirements: Secondary ECF/ACP.

Manual Control	Wallbox switch or scene wallstation in nearby accessible location with manual ON and manual OFF
Motion Sensing	None
Time Schedule	Automatic dimming to 50% 1 hour after ECF/ACP closing and automatic full ON 1 hour before opening
Photosensing	ON and OFF based on daylight availability with manual override
Zoning	None

7-3.2.3 Control Requirements: Limited Use ECF/ACP.

Manual Control	Wallbox switch or scene wallstation in nearby accessible location with manual ON and manual OFF
Motion Sensing	None
Time Schedule	None
Photosensing	ON and OFF based on daylight availability with manual override
Zoning	None

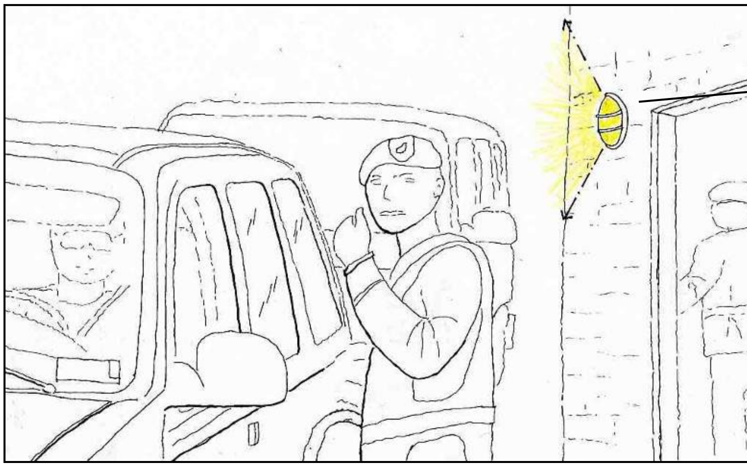
7-3.2.4 Performance Requirements.

Target Criteria	Minimum Distance	All Lighting Zones
Average Horizontal Illuminance, Access Control Zone, Entry	40’ (12 m)	3 fc (30 lux) at grade
Average Horizontal Illuminance, Access Control Zone, Exit	40’ (12 m)	3 fc (30 lux) at grade
Uniformity	4:1 average to minimum	

7-3.2.5 Critical Design Issues.

- Refer to UFC 4-022-01 for additional criteria on signage.
- Refer to Figure 6-6 for diagram of ECF lighting zones.
- Use luminaires with a G-Rating of G0, G1, or G2 for roadway or area luminaires.
- For luminaires in the Discomfort and Disability Glare Visual Field, follow the design parameters outlined in section 6-3-4.1.

7-3.3 Access Control Zone Underneath Canopy.



Locate low brightness luminaire behind and to side of inspection personnel to light the approaching vehicle and driver. This also eliminates glare for the guard.

7-3.3.1 Control Requirements: Primary ECF/ACP.

Manual Control	Wallbox switch or scene wallstation in nearby accessible location with manual ON and manual OFF
Motion Sensing	None
Time Schedule	None
Photosensing	ON and OFF based on daylight availability with manual override
Zoning	None

7-3.3.2 Control Requirements: Secondary ECF/ACP.

Manual Control	Wallbox switch or scene wallstation in nearby accessible location with manual ON and manual OFF
Motion Sensing	None
Time Schedule	Automatic dimming to 30% 1 hour after ECF/ACP closing and automatic full ON 1 hour before opening
Photosensing	ON and OFF based on daylight availability with manual override
Zoning	None

7-3.3.3 Control Requirements: Limited Use ECF/ACP.

Manual Control	Wallbox switch or scene wallstation in nearby accessible location with manual ON and manual OFF
Motion Sensing	None
Time Schedule	None
Photosensing	ON and OFF based on daylight availability with manual override
Zoning	None

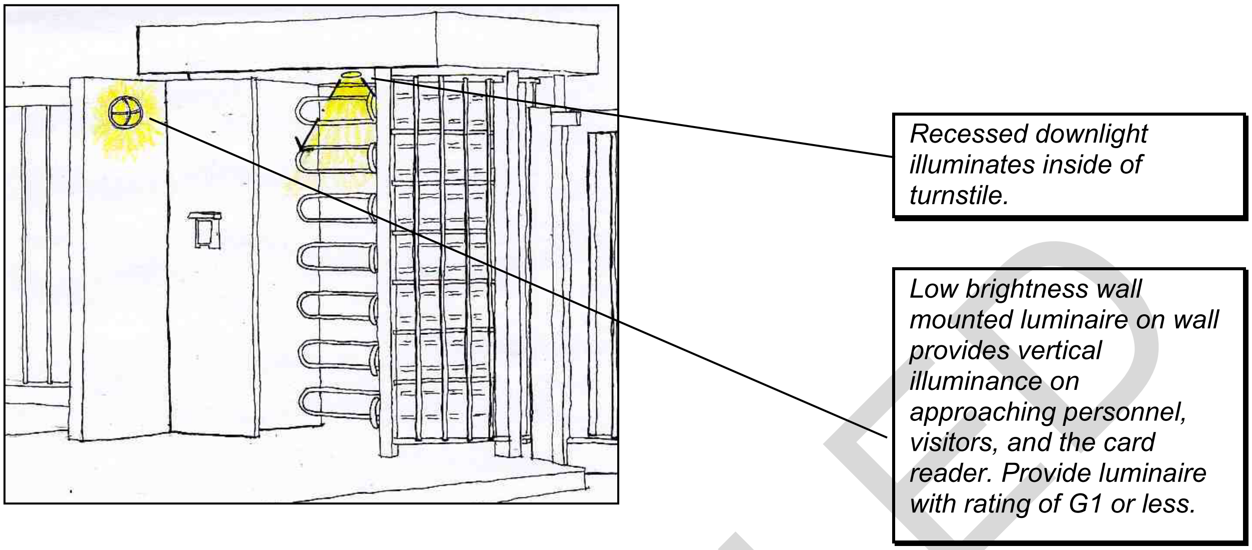
7-3.3.4 Performance Requirements.

Target Criteria	**All Lighting Zones**
Average Horizontal Illuminance under canopy at ID check	10 fc (100 lux) at grade
Uniformity under entire canopy	3:1 average to minimum

7-3.3.5 Critical Design Issues.

- Refer to Figure 6-6 for diagram of ECF/ACP lighting zones.
- Luminaires located on the wall must be less than 3500 initial light source lumens.
- Use luminaires with a G-Rating of G0 or G1 for canopy luminaires.
- Canopy luminaires should be semi-recessed or surface mounted with an uplight component. They will provide more illuminance onto the canopy ceiling surface, which improves uniformity and reduces contrast.
- Underneath the canopy, prioritize lighting at the ID check island, where ID Check is occurring.

7-3.4 Pedestrian Access.



7-3.4.1 Control Requirements.

Manual Control	None
Motion Sensing	None
Time Schedule	None
Photosensing	ON and OFF based on daylight availability
Zoning	None

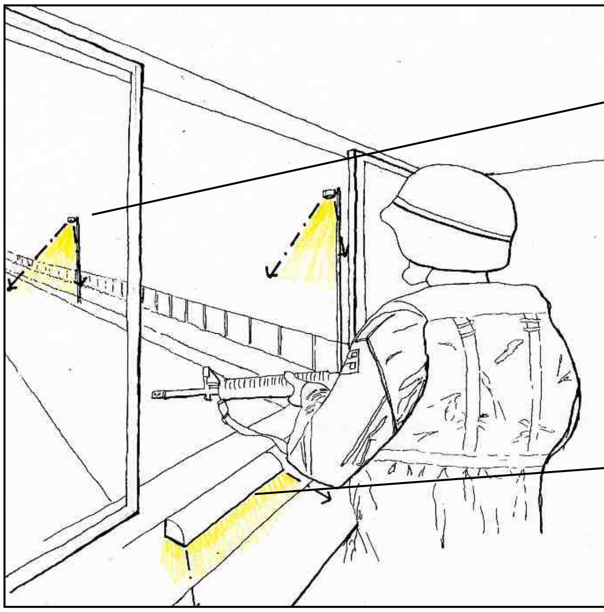
7-3.4.2 Performance Requirements.

Target Criteria	**All Lighting Zones**
Average Horizontal Illuminance	2 fc (20 lux)
Uniformity	3:1 average to minimum

7-3.4.3 Critical Design Issues.

- Luminaires located on the wall must be less than 3500 initial light source lumens.
- Locate luminaires to avoid harsh shadows.
- Refer to UFC 4-022-01 for additional criteria on signage.

7-3.5 Response Zone.



7-3.5.1 Control Requirements.

Manual Control	For interior task light, provide wallbox dimmer or scene wallstation with manual ON and manual OFF and manual dimming
Motion Sensing	None
Time Schedule	None
Photosensing	ON and OFF based on daylight availability
Zoning	None

7-3.5.2 Performance Requirements.

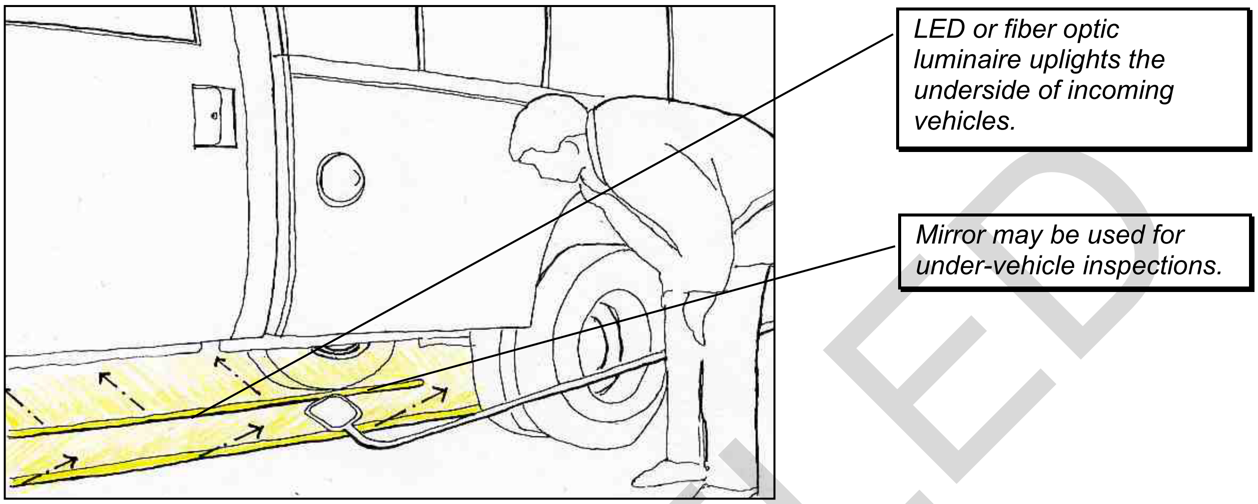
Target Criteria	**Minimum Distance**	**All Lighting Zones**
Average Horizontal Illuminance, Response Zone, Transition	60’ (18 m)	1.5 fc (15 lux) at grade
Average Horizontal Illuminance, Response Zone, Exit	80’ (24 m)	0.5 fc (5 lux) at grade
Uniformity	3:1 average to minimum	

7-3.5.3 Critical Design Issues.

- Refer to Figure 6-6 for diagram of ECF/ACP lighting zones.
- Use luminaires with a G-Rating of G0, G1, or G2 for roadway or area luminaires.
- Provide transitional lighting between bright and dark regions for the Response Zones of the gate to improve visual adaptation.
- For luminaires in the Discomfort and Disability Glare Visual Field, follow the design parameters outlined in section 6-3-4.1.

7-4 OTHER AREAS.

7-4.1 Under-Vehicle Inspection.



7-4.1.1 Control Requirements.

Manual Control	Wallbox switch or scene wallstation in nearby accessible location with manual ON and manual OFF
Motion Sensing	None
Time Schedule	None
Photosensing	ON and OFF based on daylight availability with manual override
Zoning	None

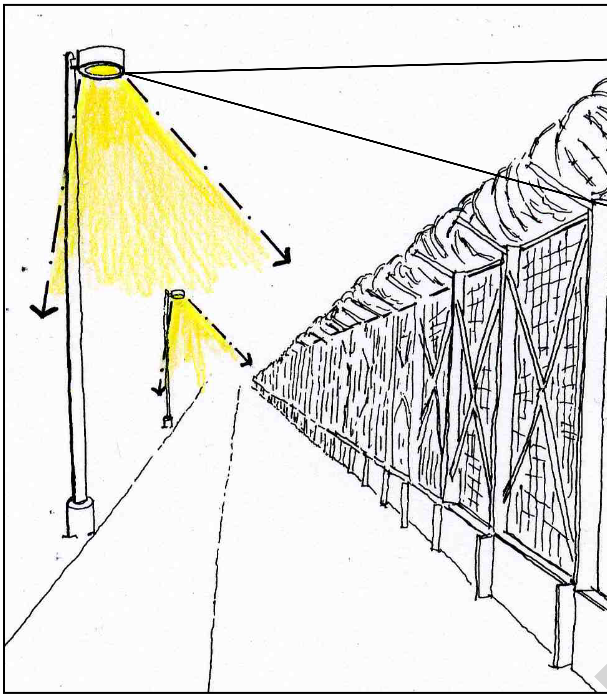
7-4.1.2 Performance Requirements.

Target Criteria	Daytime	Nighttime
Minimum Horizontal Illuminance calculated from below	10 fc (100 lux) at 1’-0” (305 mm)	
Average Horizontal Illuminance at center of drive lane for surrounding parking and roadway	3 fc (30 lux)	
Uniformity	3:1 average to minimum	

7-4.1.3 Critical Design Issues.

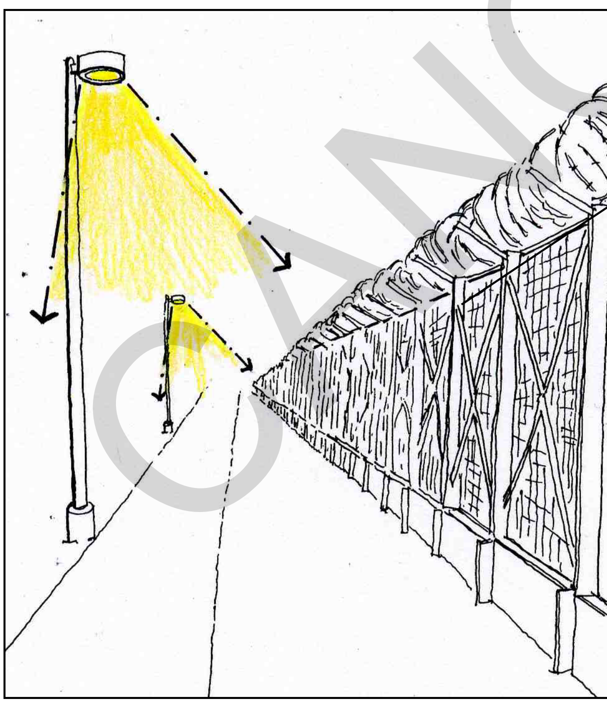
- Luminaire brightness must be kept at a low level.
- Uniformly illuminate the underside of the vehicle.

7-4.2 Controlled Perimeters – Single Fence Line.



Pole mounted U0 luminaires provide uniform illuminance and limit glare and light trespass.

Pole mounted, U0 area luminaire located opposite the fencing or incorporated into the fence with break-away connections. (This connection in a pole does not support the weight of a person and will cause the pole to collapse if climbed.)



Increasing the brightness on the outside of the fence permits vision through for someone on the inside but limits it for those on the outside.

7-4.2.1 Control Requirements.

Manual Control	None
Motion Sensing	None
Time Schedule	None
Photosensing	ON and OFF based on availability of daylight with manual override
Zoning	None

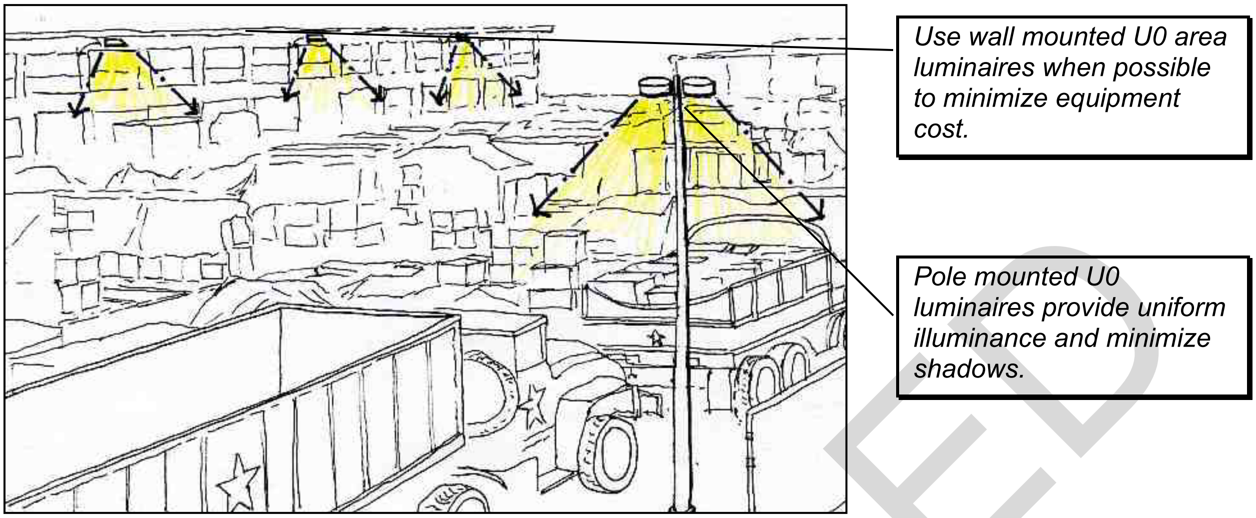
7-4.2.2 Performance Requirements.

Target Criteria	**All Lighting Zones**
Minimum Horizontal Illuminance	Between 0.2 and 4 fc (2 and 40 lux)
Uniformity	10:1 maximum to minimum

7-4.2.3 Critical Design Issues.

- Provide U0 rated and G2 or less luminaires with low lumen output to minimize glare and light pollution.
- Uniformly illuminate the area to minimize shadows along the perimeter.
- Coordinate lighting system with emergency backup power availability.

7-4.3 Restricted Area.



7-4.3.1 Control Requirements.

Manual Control	None
Motion Sensing	Automatically dim lights to 50% after 15 minutes of no detected motion
Time Schedule	None
Photosensing	ON and OFF based on daylight availability
Zoning	None

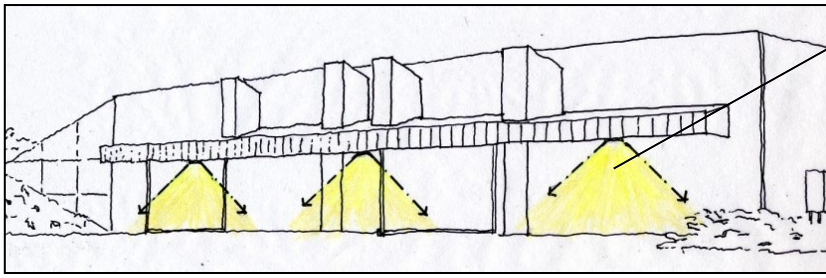
7-4.3.2 Performance Requirements.

Target Criteria	**All Lighting Zones**
Average Horizontal Illuminance	Between 2 and 5 fc (20 and 50 lux)

7-4.3.3 Critical Design Issues.

- Provide U0 rated and G2 or less luminaires with low lumen output to minimize glare and light pollution.

7-4.4 Magazines.



U0 rated area luminaire mounted under canopy lights the door area while minimizing glare.

7-4.4.1 Control Requirements.

Manual Control	None
Motion Sensing	Automatically dim lights to 50% after 15 minutes of no detected motion
Time Schedule	None
Photosensing	ON and OFF based on daylight availability with manual override
Zoning	None

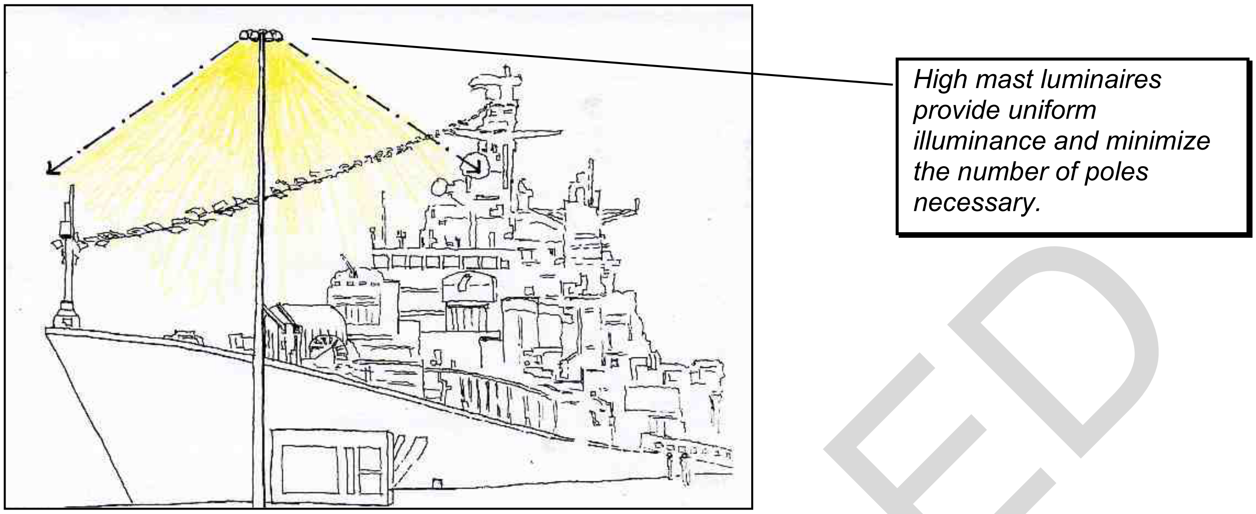
7-4.4.2 Performance Requirements.

Target Criteria	**All Lighting Zones**
Average Horizontal Illuminance	Between 0.2 and 5 fc (2 and 50 lux)

7-4.4.3 Critical Design Issues.

- Provide U0 and G2 or less luminaires with low lumen output to minimize glare and light pollution.
- Coordinate lighting system with emergency backup power availability.
- Reference UFC 4-420-01 for specific lighting requirements.

7-4.5 Piers and Wharves.



7-4.5.1 Control Requirements.

Manual Control	Optional: Two levels, operational and non-operational Switch location – guard position?
Motion Sensing	None
Time Schedule	None
Photosensing	ON and OFF based on daylight availability Turn lights to most recent manual setpoint
Zoning	None

7-4.5.2 Performance Requirements.

Target Criteria	**Active Work Areas**	**Other Areas**
Average Horizontal Illuminance	Between 3 and 5 fc (30-50 lux)	0.5 fc (5 lux)

7-4.5.3 Critical Design Issues.

- Provide U0 rated luminaires.
- Use the minimum number of high mast lighting poles and luminaires that provide uniformity.
- Refer to 29 CFR 1915.82 for the minimum lighting intensity requirements for shipyards.
- Refer to UFC 4-152-01 for Pier and Wharf operational lighting requirements.

APPENDIX A BEST PRACTICES: INTERIOR LIGHTING

A-1 MAINTENANCE.

Refer to ANSI/IES LP-9 Section 3.6 Service and Maintenance Issues, for maintenance best practices.

A-2 VISIBILITY.

Large tasks generally require less illuminance, brightness, and contrast to be performed. Small, detailed tasks may require task lighting to increase the light level significantly. Knowing a description of the task is essential to designing the lighting for that task. The luminance or brightness of a task increases the task visibility. Brighter tasks are easier to see, so long as it is not so much brighter than its surroundings that it becomes uncomfortable or a source of direct glare. As task contrast decreases, the light level required to see it increases. If the contrast is too low, it is difficult to distinguish various components of the task, reducing visibility.

A-2.1 Glare.

Direct glare can be minimized with careful equipment selection and placement. Indirect or reflected glare is caused by light reflecting off the task in such a manner that the contrast is "washed out." Many work situations position the light directly in front of the task, producing reflected glare. See Figure A-1 for examples of direct glare.

Like direct glare, indirect glare can be minimized with the type and layout of lighting equipment. Locate direct light to the side or behind a critical task. Use semi-indirect light to bounce light off surfaces in order to provide uniform low glare light with less reflected disability glare. Direct luminaires that are immediately over an individual can cause glare even though the light source is not in the field of view. This type of glare can produce the same negative effects as direct or reflected glare including eye strain and headaches.

Figure A-1 Examples of Direct Glare

A-2.1.2 Considerations to Minimize Glare.

- Indirectly light the ceiling and walls for interior ambient lighting systems.
- Use direct light only in limited amounts for task and accent light.

A-2.2 Uniformity.

Lighting level or illuminance uniformity is important on work surfaces where sustained tasks are performed as well as on wall and ceiling surfaces that make up a significant portion of the field of view. See Figure A-2 and Figure A-3 for examples of uniformity. Poor uniformity can cause adaptation problems. It is very important to prevent "spotty" lighting especially in interior areas where people are working.

Figure A-2 Uniform ceiling brightness

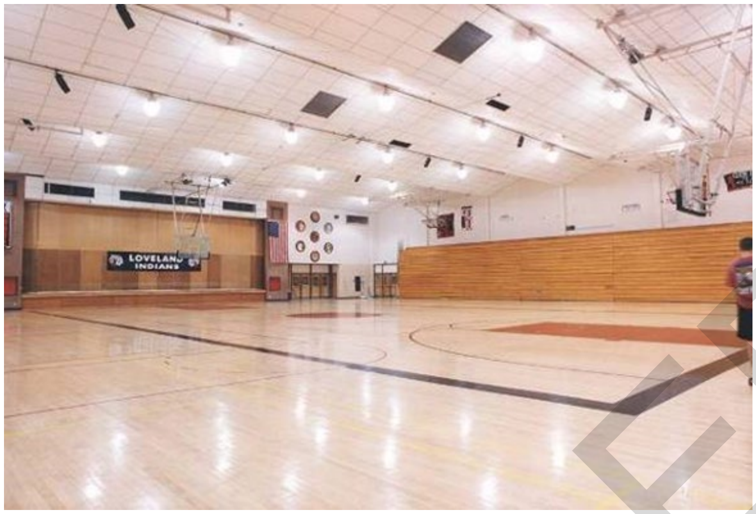


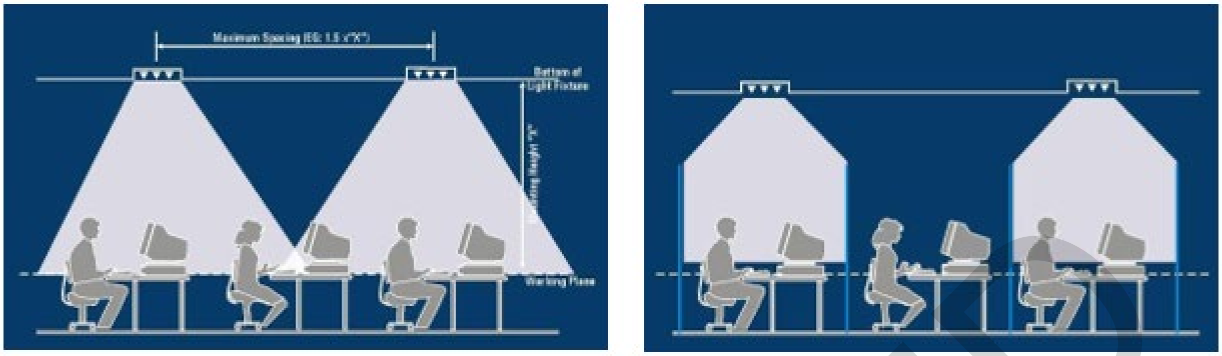
Figure A-3 Uniform illuminance

A-2.3 Maintaining Uniformity.

Carefully consider changes in lighting systems and furniture systems so that lighting uniformity is not compromised. As shown in Figure A-4, a lighting system that provides uniform illuminance on the work-plane in one furniture configuration may not provide the same uniformity in a different configuration.

In the case shown, an additional luminaire is required to adequately light the center workstation. This increases the amount of energy required to light the same area. In such a condition, the use of a semi-indirect, pendant system provides better uniformity and at the same time allow for flexibility in the workstation layout.

Figure A-4 Task plane illuminance uniformity[5]



A-2.3.2 Considerations for Uniformity.

- In office areas, uniformity should not exceed 5:1 average to minimum in immediate work surrounds, not including accent lighting.

A-2.4 Illuminance.

In many cases illuminance is no longer a top priority. Lighting wall and ceiling surfaces is usually more important than providing high levels of horizontal illuminance. In order to provide flexibility and interest in a space, light ceiling and wall surfaces with lower ambient lighting levels. Provide higher illuminance levels with individualized task lighting.

A-2.4.1 Considerations for Adequate Illuminance.

- Design ambient lighting levels to 1/3 to 1/2 task lighting levels. Add task lighting to increase light level at the task.

- Use white light for exterior lighting.

A-2.5 Surface Brightness.

Traditionally, illuminance has been the basis of lighting design; however, we see brightness. We do not see lighting levels. There are three different types of visual responses: Photopic or our day vision (5 cd/m² and higher), Scotopic or our night vision (0.001 cd/m² and below) and mesopic or a combination of night and day vision (0.001 cd/m² to 5 cd/m²). (ANSI/IES LS-1-21).

We “see” brightness (luminance); we don’t see lighting levels or (footcandles or lux). Our perception of spaces depends on how surfaces are lighted. The factors that lead to brightness as a response are object luminance, surround luminance, state of adaptation, gradient, and spectral content.[6] It is important to light vertical surfaces such

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[5] Used with permission. Hayden McKay Lighting Design.
[6] ANSI/IES LS-8-20, Lighting Science: Vision – Perceptions and Performance. (New York: Illuminating Engineering Society; 2021.)

as walls and building facades as a first priority, then horizontal surfaces such as ceilings and canopies. The least effective surfaces to light are floors. Downlighting results in spaces feeling dark and “cave-like”, see Figure A-5. Lighting surfaces improves the feel of the space, see Figure A-6.

Figure A-5 Downlighting only

Figure A-6 Improved surface brightness

A-2.6 Low Ceiling Applications.

In some applications, the ceiling height may be low and cannot be increased to accommodate pendant mounted lighting equipment. In these cases, the lighting design should still try to address the issue of surface brightness. One way to achieve surface brightness with low ceiling conditions is with recessed downlight/wallwash luminaires. The reflector on these luminaires looks similar to a standard downlight, but also uses a modification to light adjacent walls evenly. It is also designed to put light high on the wall next to the ceiling.

A-2.6.1 Indirect lighting.

Indirect lighting provides better visibility for offices and computer tasks than parabolic luminaires. Additionally, the installation cost of pendants can be lower than recessed direct/indirect troffer luminaires due to the reduced number of connection points. In low ceiling applications where a semi-indirect pendant system is not feasible, consider semi-indirect recessed for lighting the interior of the space. Downlight/wallwashers around the perimeter of the space increase the surface brightness of the walls. This strategy is a better choice to eliminate glare than the use of lensed troffers. However, avoid troffers designed to spread the light. These achieve wide distributions by lowering the light sources in the luminaire and thereby increasing the glare.

A-2.6.2 Semi-indirect pendant.

Semi-indirect pendant manufacturers offer short pendant luminaires for low ceiling applications. These luminaires use refined optics to spread light out and light the ceiling with a pendant length of under 12 in (0.3 m). These luminaires allow semi-indirect lighting systems in spaces with a ceiling height of 8 ft (2.4 m).

A-2.7 Considerations for Surface Brightness.

- Provide high surface reflectances for walls (60% minimum) and ceilings (85% minimum).
- Light ceilings with semi-direct wall or pendant mounted lighting.
- Light walls with wall washers.
- Direct daylight to ceilings and walls.
- For exterior applications, light vertical surfaces that are in pedestrians’ field of view.

A-3 LIGHT SOURCES.

A-3.1 Technical Considerations.

Refer to ANSI/IES LP-4-20, *Lighting Practice: Electric Light Sources – Properties, Selection, and Specification*.

A-3.2 Light Source Efficacy.

Refer to ANSI/IES LP-4-20, *Lighting Practice: Electric Light Sources – Properties, Selection, and Specification*.

A-3.3 Material Issues.

Fluorescent, metal halide, induction, and high-pressure sodium light sources contain liquid mercury to produce the mercury vapor necessary for operation. When light sources are broken or incinerated the mercury may be released into the soil or the atmosphere. Mercury has been linked to potential health risks. Some light source manufacturers offer product series that feature reduced mercury content.

A-3.4 Recycling.

Traditional light source types except incandescent sources contain some level of mercury. These light sources should be recycled to avoid release of any mercury into landfills. The cost of recycling light sources should be included in any life-cycle cost analysis.

A-4 EQUIPMENT PERFORMANCE.

A-4.1 Flicker.

Most light sources flicker but remain mostly imperceptible. SSL luminaires are particularly sensitive to noticeable flicker when dimmed, especially with incompatible dimming controls and inadequate electrical infrastructure. Utilizing 0-10V and DALI dimming protocols are recommended to reduce flicker across dimming ranges. For applications where these dimming protocols are not available, such as screw-base lamp replacements, provide dimmer compatible with SSL luminaires and ensure that electrical infrastructure is adequate to operate SSL luminaires.

A-4.2 Noise.

Provide LED drivers with a Class A noise rating.

A-4.3 Interference.

LED drivers have the potential to cause electromagnetic interference (EMI) and radio frequency interference (RFI) when operated near other high frequency electronic equipment. This can be a significant issue when installed near electronic medical equipment. LED drivers should be selected and rated for use near sensitive equipment, complying with FCC Title 47 Part 15.

A-4.4 Effects of Temperature.

Ambient air temperature affects the performance and output of fluorescent, SSL, and induction light sources. Low temperature has a positive effect on SSL sources, improving their life. For SSL luminaires, ANSI/IES LM-79 and ANSI/IES LM-80 testing reports show the lumen depreciation over time and temperature.

A-4.5 Life.

The operating temperature of drivers and power control units directly affects the life. The luminaire housing or enclosure should provide for adequate dissipation of heat. When drivers operate at excessive temperatures, the insulation degrades, resulting in a shortened driver life. High operating current in SSL luminaires can also shorten life. Review ANSI/IES LM-80, ANSI/IES LM-79, and ANSI/IES TM-21 data to determine actual life with designated operating current.

The life expectancy data given by LED light source manufacturers refers to the approximate operating time over which the LED light source will maintain 70% (L_{70}) of its initial light output.

A-5 CONTROL APPROACHES.

Lighting controls have the benefit of reducing energy use when lighting is not required. Lighting controls are required in meeting ASHRAE 90.1 energy codes. It is important to note that electric lighting controls should be incorporated with a daylight design to gain any energy savings from the daylight.

A-5.1 Occupancy Based Controls.

Occupancy sensors automatically turn the lights on when an occupant enters a space and automatically turn the lights off after a predetermined period in which no human activity is sensed. Vacancy sensors automatically turn the lights off after a predetermined period in which no human activity is sensed. The occupant manually turns on the lights when he or she enters the space. The operating technologies behind either an occupancy or vacancy sensor are passive infrared, ultrasonic, or dual technology.

Occupancy based controls may be ceiling mounted to cover large spaces or they may be integrated with wall switches for smaller spaces. Occupancy based controls are ideal for areas of convenience such as storage rooms where individuals often have their hands full when entering or leaving. For private offices without daylight, it may be ideal to have an auto-on occupancy sensor that turns the lights on to a preset light level, such as 50% with a manual 100%, and then automatically turns the lights off. Manual override may be necessary in spaces where the lights occasionally need to be turned off with occupants such as classrooms and conference rooms. It may also be useful to group luminaires and control with a single occupancy or vacancy sensor. Controls should have a time delay that can be adjusted up to 30 minutes. If the sensor fails, local override control should be available, or the system should revert to the ON position. Table B-1 summarizes strategies for selecting the appropriate occupancy-based control sensor.

A-5.2 Bilevel and Multi-level Switching.

Bilevel switching is less prevalent with SSL sources. It is most commonly seen today in direct/indirect luminaires with two circuits: one circuit controls the indirect, or uplight, component, and the other controls the direct, or downlight, component. It is also occasionally used to provide step dimming in areas, without requiring dimming controls. However, as SSL sources are less expensive to dim than their fluorescent predecessors, step dimming is seen less frequently. Bilevel switching should be used in stairwells and similar low occupancy spaces such as hallways to reduce energy consumption without the use of dimming controls. Controls should fail in the full-on position. Spaces should be equipped with bilevel luminaires controlled by an integrated or separate occupancy sensor. When the space is unoccupied; lighting should be reduced by a minimum percentage of 50% and maintain the minimum life safety code requirement for egress when the building is occupied. When utilizing bilevel switching in Means of Egress, the lighting and controls must comply with NFPA 101.

A-5.3 Daylight Dimming.

Daylight dimming is used to reduce the light output and energy usage of the electric lighting in spaces with daylight. This is achieved with the placement of photosensors to measure the amount of light on a task surface or the amount of available daylight outside. Electric light is either dimmed or shut off in response to the amount of light detected and the programming on the control system. Best practices of daylight dimming are discussed in detail in Appendix C.

A-5.4 Light Level Tuning.

Light level tuning is used to adjust the maximum light level to precisely set the lighting requirements based on the preference of the occupants in the space and the color of the carpets, office furniture, cubicles, and walls. Different spaces can have different maximum light levels and the ability to adjust the high-end output of the luminaire can offer typical lighting energy savings of 20% or more.

A-5.5 Scene Based Dimming.

One button touch allows multiple zones of light within a space to go to the appropriate light levels, known as a scene, for a specific task or use. Scene-based control should allow the integration of AV controls, shading, and lighting to work seamlessly with one button touch (lights dim, projection screen lowers, and shades go down).

A-5.6 Manual Switching.

Manual switching may be an ideal strategy where automatic control is not allowed, such as electrical rooms. The energy savings is diminished though, so a switch should be integrated with an occupancy-based sensor, where allowed.

A-5.7 Timeclocks.

Timeclocks control larger areas or groups of luminaires. They automatically adjust lighting levels based on the time of day or astronomical events such as sunrise and sunset. This type of control may be applicable in spaces where there is constant occupancy, limited daylight, and minimal activity in non-peak hours of the day.

A-5.8 Personal Control.

This provides an occupant with the ability to control and dim their own lighting even in an open office configuration. Personal controls may be accomplished with personal control over task lighting at a workstation.

A-5.9 Network Control Systems.

A network control system is required to integrate into a building automated, energy management system. Even in cases where integration with a building management system is not feasible, it may be appropriate to have a stand-alone network lighting control system. There are varying methods to create a network control system. A network-based system may provide the greatest flexibility and configuration options because zones can be created through software for spaces that may be reconfigured over time. A network control system with the capability of controlling each luminaire allows maximum flexibility for energy savings and reconfiguration of the spaces. When possible, a network control system will also allow use of control devices like occupancy sensors by other systems, such as controlled receptacle circuits.

A-6 CONTROL EQUIPMENT.

A-6.1 Sensors.

A-6.1.1 Occupancy Based Controls.

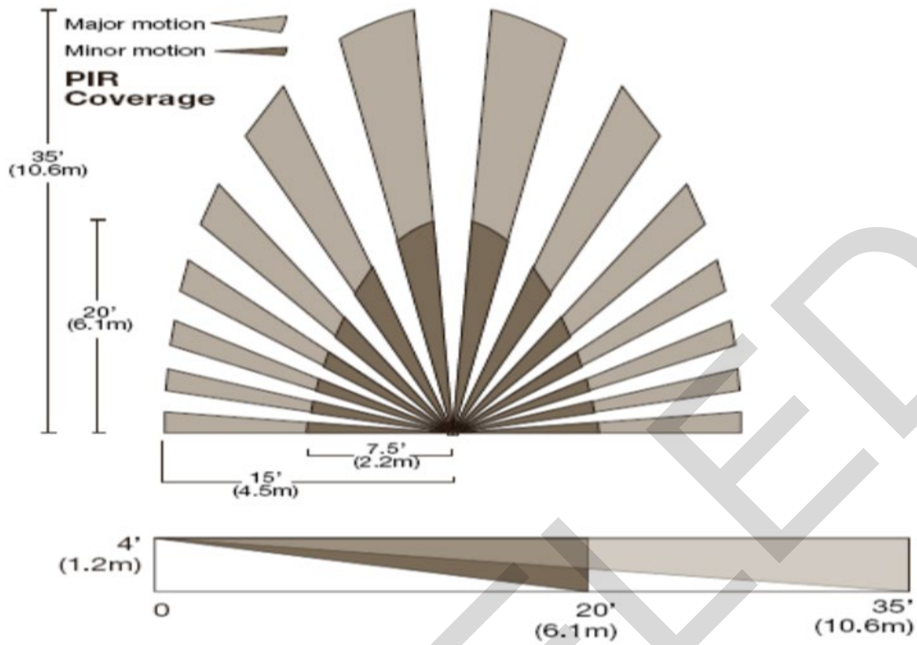
An occupancy sensor is used for interior applications to automatically turn the lights on when an occupant enters the space and automatically turn the lights off after a period of undetected occupancy.

A vacancy sensor requires the occupant to manually turn the lights on when they enter the space, and the sensor automatically turns the lights off after a period of undetected occupancy. More energy is saved when using vacancy sensors as occupants may not always require electric lighting when entering a space.

A-6.1.1.1 Passive Infrared.

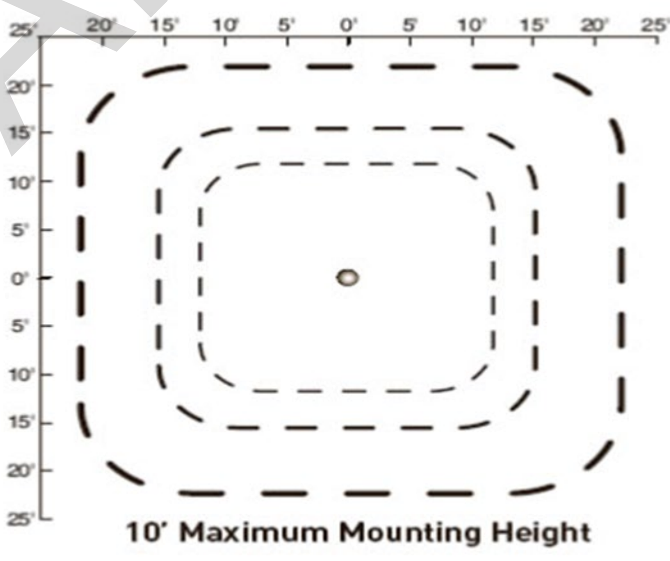
Passive infrared (PIR) sensors detect the difference in heat between a human and the surroundings. Because of this, the sensor has to be able to “see” the entire space and any obstruction such as partitions, shelves, or cabinets block detection. Changes in ambient temperature also reduce the effectiveness of the infrared sensors. The pattern of occupancy is dispersed in a fan shape where the distance between fan blades is small near the sensor but increases as the fan blades are directed away from the sensor, see Figure A-7.

Figure A-7 Coverage Pattern of PIR Sensor



Ultrasonic technology relies on high frequency sound waves to detect movement in the space, see Figure A-8 for typical coverage pattern. This movement could be a person moving, or air movement created by a person's activity. This type of sensor is therefore appropriate for spaces that have partitions such as restrooms or open office areas. Such sensors need to be located so that they do not sense the "false-occupancy" of an air vent or a passer-by in an adjacent space. Room finishes such as carpeting may absorb the ultrasonic waves and reduce effectiveness.

Figure A-8 Coverage Pattern of Ultrasonic Sensor

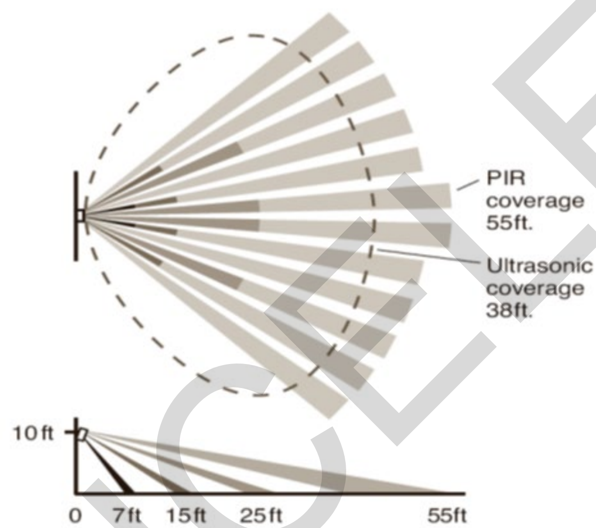


A-6.1.1.2 Dual Technology.

Dual technology sensors combine both the capabilities of PIR and ultrasonic to detect occupancy. See Figure A-9 for coverage pattern. Both an ultrasonic and PIR detection of occupancy is required for the lights to turn on but only one sensor technology is required for the lights to remain on. This type of sensor is best used in large spaces with low occupant activity levels.

Figure A-9 Coverage Pattern of Dual Technology Sensor

(Courtesy of Wattstopper/Legrand)



A-6.1.1.3 Microphonic.

Microphonic passive occupancy sensors are available with dual sensors. These sensors use PIR technology to first detect motion in the space and then use a microphone to monitor sounds to indicate continued occupancy.

Micophonic sensor technology is not recommended for most spaces since noise from HVAC, refrigerators, traffic, radios, telephones, and other systems may cause false occupancies detection.

A-6.1.1.4 Sensor Considerations.

See Table A-1 for guidance on where to use sensor types. Each type of occupancy or vacancy sensor should be equipped with a time delay. This time delay leaves the lights on for a predetermined amount of time after the last occupant has been detected. The purpose of the time delay is to ensure that occupants are not left without lighting and to reduce the number of on/off cycles. Since occupancy patterns vary with time of day as well as day of the week, and are not easily scheduled, it is best to select a time delay that works for both periods of increased and decreased occupant activity. Manufacturers typically have preset time delays at 5, 10, 15, 20, or 30 minutes. It is recommended that a time delay setting of 20 minutes be used for most spaces. Should another time delay setting be selected, consideration should be given to the increased energy consumption, driver type, and increased life of the light source due to the reduced number of on/off cycles.

In addition to the time delay, there should also be a setting for the sensitivity. The sensitivity needs to be calibrated appropriately according to the activity in the space. For example, if there is limited movement in the space, the sensitivity should be calibrated to detect very slight movement.

Table A-1 Guide for Using Sensors

DO	DON'T
Use ultrasonic sensors in large open areas with partitions or furniture	Use ultrasonic sensors where there is high air flow.
Place sensors in proximity to where the main activity in the space will occur.	Install an in-wall sensor where it is blocked by furniture or behind the door.
Use PIR in enclosed spaces.	Use ultrasonic sensors in small, enclosed spaces where they may react to activity outside the space.
For large areas, create zones of light to manage light.	Install ultrasonic or dual tech sensors higher than 12 feet.
Overlap sensor coverage patterns by at least 20% to ensure adequate coverage.	Install sensors within 6 feet of an HVAC vent.
Ensure PIR line of sight does not extend out doorways. This can be achieved by either sensor placement or lens masking.	Use PIR sensors when there are multiple obstructions (furniture, partitions) which prevent line of sight of the sensor.

A-6.1.1.5 Self-Adapting.

Self-adapting technologies “learn” how the space is used by occupants and adjusts the lights as necessary. The technology responds in real-time and automatically adjusts both the sensitivity of the sensor and the delay time. Self-adapting sensors are best used in spaces where neither the occupants nor the activities vary from day to day. Self-adapting technology is not recommended for classrooms and conference rooms but may be ideal for private offices.

A-6.2 Manual Controls.

Considerable energy savings can be achieved by allowing occupants to control (on/off) or vary the light levels.

Energy savings from dimming lights is nearly linear. Furthermore, users seldom require maximum light levels and studies show that allowing users to adjust illuminance for different tasks saves 35% - 42% lighting energy.

A-6.2.1 Switches.

Manual controls for occupants can be a good way to increase worker autonomy and give occupants greater control ability, although the energy savings is not as great as automatic controls and is not allowed by the energy code in most regularly occupied spaces.

A-6.2.2 Dimmers.

Manual dimming occurs with a control action initiated by the occupant. This type of dimming may be useful in spaces where several different activities can take place. A conference room is an example where the lights may need to be dimmed for an A/V presentation, but also may need to be full output for meetings. Manual dimming also results in high satisfaction rating for occupants and should be encouraged for regularly occupied areas.

A-6.3 Time Controls.

A-6.3.1 Time Switch.

Automatic switching takes place in conjunction with occupancy controls when the space becomes unoccupied. The lights turn off after a designated period of inactivity.

A-6.3.2 Timeclock.

A timeclock is a device that automatically adjusts the lights at a specific time or based on astronomical events such as sunrise or sunset. Manufacturers typically allow the preset time to vary between 5 minutes and 12 hours. This type of control may be applicable in spaces where there is constant occupancy, limited daylight, and minimal activity in non-peak hours of the day.

A-6.3.3 Schedule.

A preset schedule can be programmed to automatically turn the lights on or off based upon trends in occupancy. Different schedules are created for weekdays, weekends, evenings, and holidays.

A-7 NETWORK CONTROL SYSTEM.

A network control system can be connected in a number of different ways. Implementing addressable drivers provides digital addresses for all drivers and connects them as a system through network cabling. The digital addresses allow control over each driver individually and allow for flexibility of the system as the needs of the space evolve over time. A wireless system communicates with all devices (sensors, dimming drivers, and area controllers) over radio frequency. The zoning of such a system is configured through software and provides flexibility as the needs of the space evolve over time.

ANSI/IES LP-6 provides technical information regarding the varying architectures, topologies, and protocols that are currently available for lighting controls. The document may be useful especially when integrating one protocol with another or integrating a lighting control system with a building automation system. Typical uses are outlined along with limits/extents, interoperation with other protocols, and designer responsibilities specification recommendations.

A-8 EMERGENCY AND EXIT LIGHTING.

Mark and illuminate means of egress in accordance with NFPA 101. The purpose of emergency lighting is to ensure the continuation of illuminance along the means of egress from a building and provide adequate light for the orderly cessation of activities in the building. The purpose of exit lights is to identify the means of egress. Both types of lighting are powered from both a normal power source and an emergency source, with automatic switching from one to the other.

In some specific situations, emergency lighting might be required for specific spaces or work areas that are not on the means of egress. There are often areas where work of a critical nature has to continue regardless of loss of normal power, such as a computer server room. In health care facilities, including hospitals, skilled nursing homes, and residential custodial care facilities, lighting for the means of egress (including exit signs) and elevator cabs is considered “life safety” lighting and connected to the life safety branch of the facility’s emergency power system. Task illumination at anesthetizing locations, patient care areas, laboratories, intensive care units, recovery rooms, and other locations as required by NFPA 70, Article 517 are considered “critical” lighting and powered from the critical power branch of the facility’s emergency power system. In applications where the loss of light, even momentary, would endanger personnel or risk other loss or damage, provide lighting systems to maintain constant illumination through the use of an uninterruptible power supply of sufficient capacity to permit an orderly cessation of activity.

A-8.1 Testing of Emergency Lighting Equipment.

Because of the periodic testing requirements, accessibility of equipment is an important design consideration. Consider self-testing or self-diagnostic emergency lighting equipment.

A-9 REPLACEMENT OF LUMINAIRES.

A-9.1 Fluorescent Industrial Luminaires, Wraparound, Strip Lights, and Recessed Direct/Indirect Troffers.

Convert T-12 and T-8 lighting systems to dedicated LED luminaire. Properly dispose of fluorescent lamps that contain mercury.

A-9.2 Incandescent Downlights.

Where possible, replace incandescent downlights with dedicated LED luminaire replacements. If a full replacement is not possible, retrofit LED lamps are available for direct one-to-one replacement for most incandescent lamps. Confirm appropriate CCT selection, lumen output, and dimming capabilities. Many retrofit LED lamps are not rated for enclosed luminaires. Check lamp specifications prior to installation.

A-9.3 HID, Floodlights, Downlights and Other Luminaires.

Replace existing luminaires with LED systems. This replacement is especially appropriate for applications where switching or dimming could be encouraged to save energy in addition to improving visibility. LED retrofit kits are not a one-for-one replacement of HID luminaires but rather an alternate lighting system.

A-9.4 Exit Signs.

Retrofit incandescent exit signs with LED type.

A-9.5 Lighting Control System.

Consider lighting controls for a lighting replacement project to improve the energy efficiency of the space. Use the installed cost of the system when analyzing the life-cycle cost for a lighting replacement with controls. Integrate the lighting control system directly into the HVAC system to provide reduced HVAC load requirements and improve the buildings energy efficiency.

APPENDIX B BEST PRACTICES: DAYLIGHTING CONTROLS

B-1 INTRODUCTION.

Refer to ANSI/IES LP-3-20, *Lighting Practice: Designing and Specifying Daylighting for Buildings* for additional information.

B-2 SYSTEM INTEGRATION.

If the majority of areas are daylighted, then the electric lighting becomes supplemental during daytime periods. Since our appetite for light is less in the evening and nighttime hours, daylighting does not need to be duplicated with electric lighting. Design electric lighting to supplement the daylighting. For example, when daylight is plentiful, the electric lighting dims near the daylight source. In other areas where the daylight penetration is not as great, the electric lighting can be increased. Electric lighting controls (daylight, occupancy, and vacancy sensors) can typically save up to 50% of the lighting energy in existing buildings and up to 35% in new buildings.[7]

B-3 CONTROLS.

B-3.1 Daylight Sensor Technologies.

Open loop photosensors determine the light level by measuring the outside light availability. Based upon the light level measured, a signal is sent to the electric lighting to either increase or decrease the light level depending on the exterior daylight availability.

Closed loop photosensors determine the light level in a space by measuring the inside light availability. Based upon the light level measured, a signal is sent to the electric lighting to either increase or decrease the light level depending on the interior daylight availability. Table B-1 provides a summary of daylight sensor technologies.

B-3.1.1 Larger Areas.

In larger areas with one daylight zone adjacent to the same window wall and no corner windows, open loop sensor works well. In other spaces, with multiple zones, closed loop works well with one sensor per zone. Networked lighting control systems typically deploy closed loop sensors.

[7] New Buildings Institute, Inc. “Lighting Controls”, *Advanced Lighting Guidelines,* Chapter 8. 2001 Edition, p. 8-1

Table B-1 Summary of Daylight Sensors

Use This Equipment	In This Type of Space	And Be Aware for These Issues
Open loop	Spaces where the outside daylight availability gives an accurate representation of the daylight into the space.	- Sensor should be placed outside or inside pointed towards the daylight opening - Use multiple sensors for spaces with more than one daylight opening - Outside conditions are accounted for, but not space conditions (geometry and reflectance)
Closed loop	Spaces where a constant level of illumination is desired.	- Room surfaces (reflectances) and physical obstacles may affect the light level readings - More reliable and effective at measuring light levels than open loop photosensors

A hybrid adaptation of open loop and closed loop sensors is available. Open loop systems only measure changes in daylight, and not changes in electric lighting. This reduces the likelihood of system imbalance, but by locating these sensors outside of the space does not provide the most accurate daylight dimming but can cause some system imbalance. A hybrid system is located in the space for accurate daylight dimming, but by subtracting the electric lighting contribution to the sensor, system imbalance is not a problem.

B-3.2 Automatic Lighting Controls.

Continuous dimming provides a seamless transition of light level to occupants. The light level is adjusted over a period of typically several seconds does not distract occupants which is ideal for daylight availability dimming. Step dimming creates more abrupt changes in light level. The range of dimming is limited to a few preset light levels and does not allow for transitions and may be noticeable, even distracting, to occupants.

B-3.3 Task Dominant Areas.

Task dominant area examples include offices, conference rooms, classrooms, maintenance areas, and other regularly occupied areas. Daylight dimming provides the highest level of satisfaction since the lighting smoothly responds to daylight availability versus an abrupt on/off. Ideally, manual dimming with an upper daylight limit provides the greatest flexibility and highest acceptance since people have control over their areas. In addition, occupancy and vacancy sensors turn off the lighting if no one is in the area.

B-3.4 Non-task Dominant Areas.

Non-task dominant area examples include transition areas such as corridors, lobbies, atriums, or support areas such as cafeterias, restrooms, and storage areas. Exterior lighting is typically a non-task dominated area. Automatic daylight on/off or bilevel switching is acceptable in these areas, yet dimming is still preferred. Occupancy sensors in these public areas save the most energy, though lights can be turned off with an energy management system. If occupancy devices allow adequate time, especially in transition areas, then the lighting is not disrupted during normal hours of operation.

B-3.5 Control Strategies.

Luminaires in primary and secondary zones switch or dim in response to daylight. See Figure B-1 for layout of primary and secondary zones. Locate sensors according to manufacturer's recommendations. Integrate electric lighting with daylight controls. The electric lighting should begin to dim when the daylight contribution exceeds the target illuminance level on the task plane. Continuous dimming is recommended instead of step dimming to minimize visual disruption to occupants. Harvesting daylight is best suited in spaces that are frequently occupied and a significant amount of daylight enters the space.

When selecting daylight zones, consider the exterior environment in addition to the proximity to glazing. As Figure B-1 and Figure B-2 indicate, if exterior buildings or foliage are blocking some of the daylight contribution into the building, treat those zones as secondary, see Figure B-3. Note that the zoning changes depending on the floor level. Locate the electric lighting parallel to the daylight zones for dimming control.

Figure B-1 Daylight Control Zones

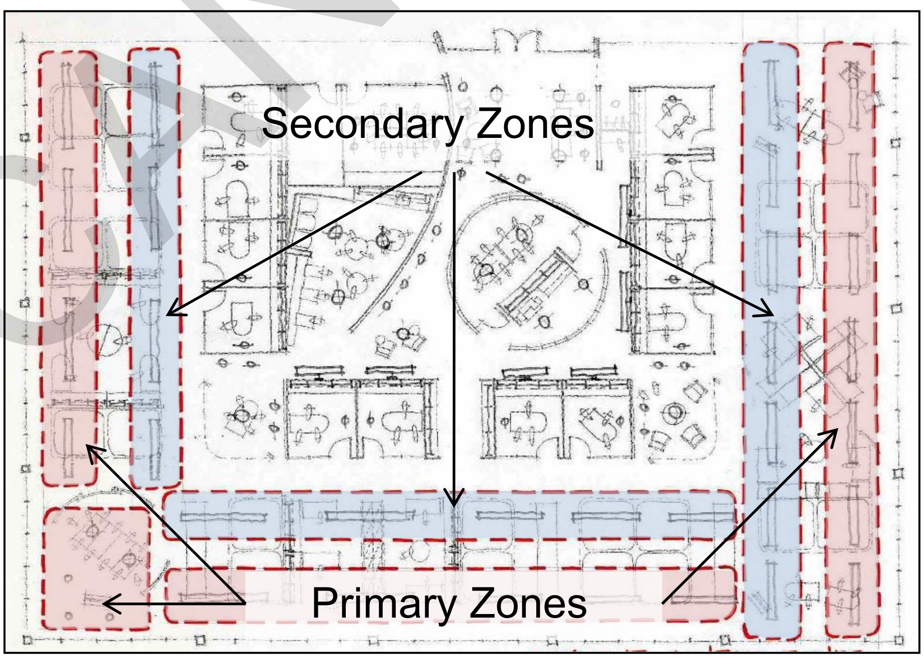


Figure B-2 Daylight Control Zones with Obstructions (Upper Floors)

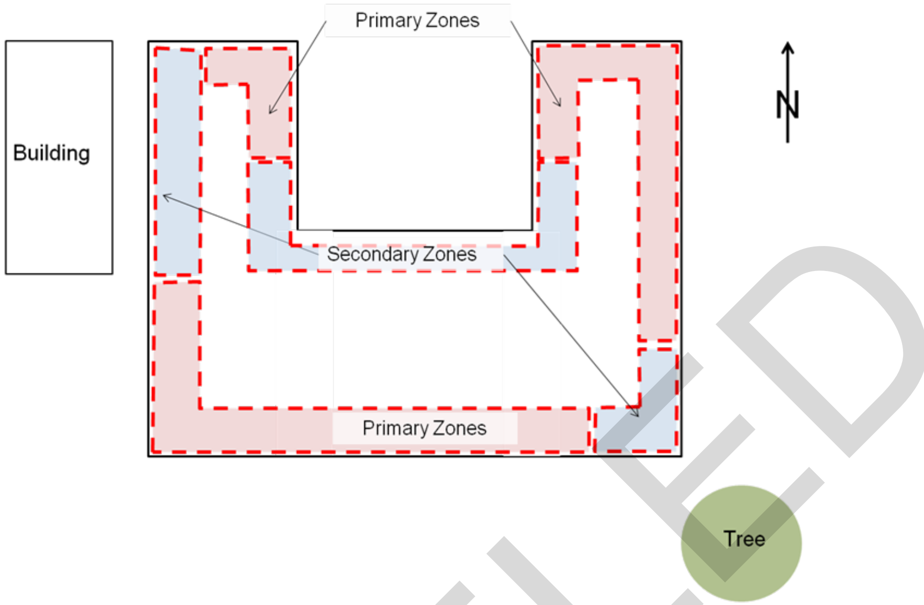
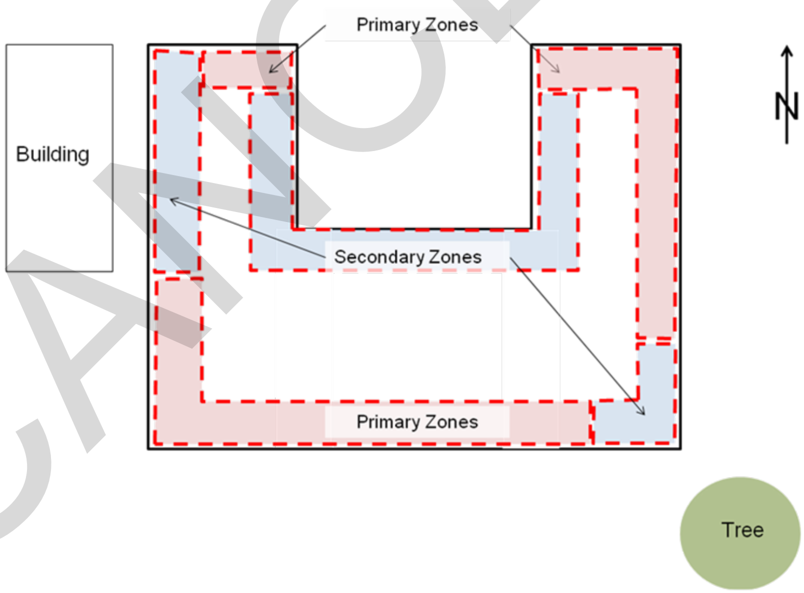


Figure B-3 Daylight Control Zones with Obstructions (Lower Floors)



B-4 AUTOMATED SHADING.

When utilizing automated shading, coordinate daylighting controls with automated shading controls.

APPENDIX C BEST PRACTICES: EXTERIOR LIGHTING

C-1 LIGHTING QUALITY.

C-1.1 Luminance.

There are three different types of visual responses: Photopic or our day vision (5 cd/m² and higher), Scotopic or our night vision (0.001 cd/m² and below) and mesopic or a combination of night and day vision (0.001 cd/m² to 5 cd/m²). Reference ANSI/IES LS-7-20, *Lighting Science: Vision – Eye and Brain*, Sections 5 through 5.4, for more on the ranges for photopic and scotopic vision. The majority of exterior lighting is designed in the mesopic range.

C-1.1.1 Mesopic.

Since light source lumen ratings are all based on photopic sensitivity, they need to be adjusted for nighttime applications. Photopic and mesopic lumens are determined from the spectral power distribution of the light source. In addition, photopic luminous efficiency function applies to visual fields 2 degrees or smaller. This means that only tasks that are on-axis or one that is focusing straight ahead apply to the photopic light source lumen ratings. Any task that is in our peripheral vision does not. Peripheral vision shifts to shorter wavelength sensitivity.

Mesopic multipliers may be used to account for the improved visibility provided by white light. The process for calculating mesopic multipliers can be performed with luminance values or with illuminance values that are converted to luminance values as a function of the background reflectance. Point-by-point mesopic multipliers, as outlined in CIE 191:*2010 Recommended System for Mesopic Photometry Based on Visual Performance* adjust not only the average luminance, but also the uniformity.

C-1.2 Light Pollution.

Light pollution or sky glow is caused by light aimed up into the sky and by light reflected off the ground or objects, see Figure C-1. Sky glow prevents the public and astronomers from seeing the night sky.

Floodlights, wall packs, and other un-shielded luminaires; see Figure C-2, are the major contributors to sky glow. Over-lighting, even with shielded luminaires, reflects unnecessary light back into the atmosphere and adds to the sky glow. This often occurs at outdoor areas such as motor pools and sports fields.

Figure C-1 Los Angeles, 1908 (left), Los Angeles, 2002 (right) [8]

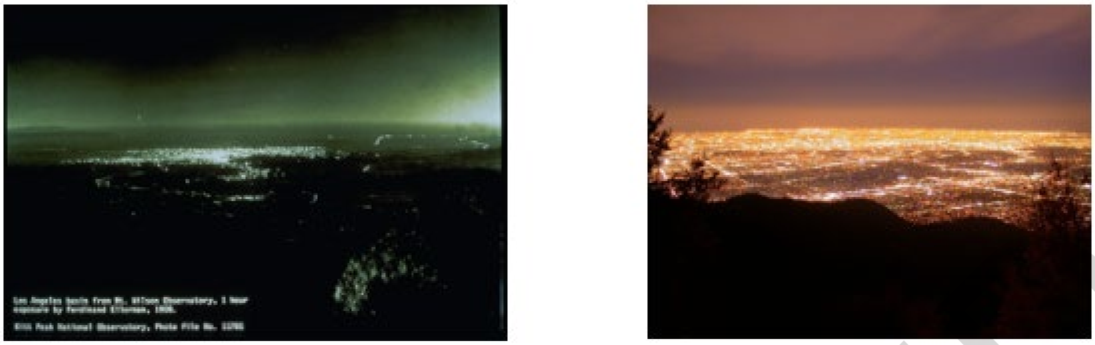
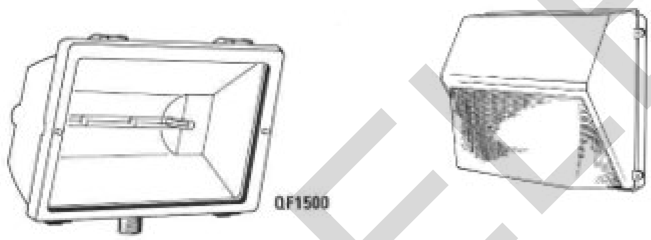
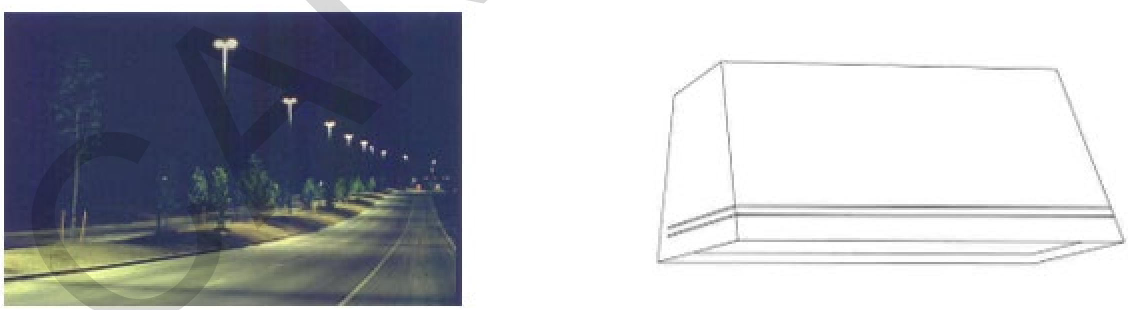


Figure C-2 Unshielded and Non-Cutoff Luminaires



To minimize light pollution, use U0 rated luminaires for area and roadway lighting as illustrated in Figure C-3. Provide uniform low glare lighting and do not over-light exterior areas. Also, control lighting with time clocks, photocells, and motion sensors such that lighting is only energized when needed.

Figure C-3 Examples of IES TM-15 U0 rated luminaires



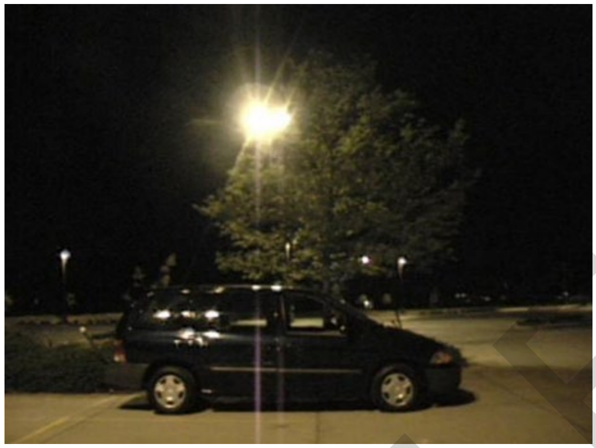
C-1.3 Light Trespass.

Light trespass is referred to as nuisance glare or the "light shining in my window" effect. It is usually caused by a glare source that is bright compared to the darker night surround, see Figure C-4. Since glare inhibits our ability to "see" tasks and decreases contrast, minimize glare. Uncontrolled light sources (floodlights) are usually the cause of

[8] © 2003 by Prof. Dr. Gerhard Eisenbeis University of Mainz/Germany

light trespass. Not only does light trespass cause neighbor annoyance, but it also increases light pollution.

Figure C-4 Uncontrolled Light Source



To minimize light trespass, use only U0 and a maximum of G1 rated luminaires for area lighting, see Figure C-5. When unshielded luminaires such as wall packs and decorative luminaires are used at low mounting heights, reduce the light source brightness to that of a 4,200-lumen light source or less. Do not over-light areas because reflected light can also result in complaints and poor visibility by increasing visual adaptation. Also, consider dimming or turning lighting off when not needed and activate with motion sensors or timers when activity occurs.

Figure C-5 IES TM-15 U0 Rated Luminaires

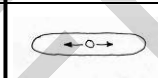
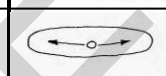
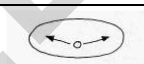
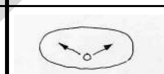
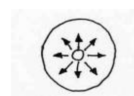
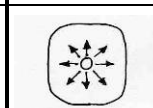
C-2 CLASSIFICATION SYSTEMS FOR OUTDOOR LUMINAIRES.

There are three systems in use today for categorizing outdoor light fixtures, two defined by the Illuminating Engineering Society (IES) and one by the National Electrical Manufacturers Association (NEMA). In two of the systems, the luminaires are categorized according to the distribution of light emitted from the luminaire, and in the third by the pattern of light produced on the ground.

C-2.1 The IES Categories.

The IES categorizes outdoor area and roadway luminaires (non-floodlights) according to the pattern of illumination they produce on the ground, from Type I, which doesn't project very far forward to backward but tends to be very wide from side to side, to Type V and Type VS, which have symmetric round and square-shaped distributions, respectively. Table C-3 shows these classifications and the general shape of each distribution's pattern of illumination.

Table C-1 Exterior Luminaire Distribution Classification.

Type	Description	Plan View
Type I	Narrow, symmetric illuminance pattern.	
Type II	Slightly wider illuminance pattern than Type I.	
Type III	Wide illuminance pattern.	
Type IV	Widest illuminance pattern.	
Type V	Symmetrical circular illuminance pattern.	
Type VS	Symmetrical, nearly square illuminance pattern.	

C-2.2 NEMA Classifications.

NEMA classifies floodlights, including those used for sports applications, according to the intensity distribution of the light within the beam, considering the "horizontal" and "vertical" parts of the beam separately. The categories range from 1 to 7, with the smaller numbers indicating tighter beams and thus a longer useful projection distance or "throw". Table C-2 shows the NEMA beam type categories. The broader the beam, the more difficult it is to control the light distribution and prevent stray light, including glare and unwanted uplight.

Table C-2 NEMA Beam Angle Classifications.

Beam Type	Beam Spread Degree Range	Projection Distance
1	10 to 18	240 ft and greater
2	18 to 29	200 to 240 ft
3	29 to 46	175 to 200 ft
4	46 to 70	145 to 175 ft
5	70 to 100	105 to 145 ft
6	100 to 130	80 to 105 ft
7	130 and up	under 80 ft

C-2.3 BUG Ratings.

The classification of exterior luminaires changed in a significant way in 2011. The former "cutoff" classification system was abandoned and was replaced by a new system, defined and explained in ANSI/TM-15, first published in 2007. In 2011, the Backlight-Uplight-Glare (BUG) rating system was added.

BUG ratings for luminaires are useful in evaluating optical performance in exterior environments. BUG ratings are based on zonal lumen output. It is difficult to compare the BUG ratings to the previously used cutoff classifications, as the cutoff classifications were determined from the luminaire's luminous intensity values (measured in candelas) above 80 degrees, rather than luminaire lumens. Table C-3 illustrates the lack of correlation between the previous classification system and the current BUG ratings. The three components of BUG ratings are illustrated in Figure C-6 and Table C-4 and are explained further in the subsections that follow.

Table C-3 Correlation between BUG Ratings and Cutoff Classifications

BUG Rating	Full Cutoff	Cutoff	Semi-Cutoff	Non-Cutoff
B	B0-B5	B0-B5	B0-B5	B0-B5
U	U0	U1-U5	U1-U5	U1-U5
G	G0-G5	G0-G5	G0-G5	G0-G5

Figure C-6 Exterior Luminaire BUG Classification

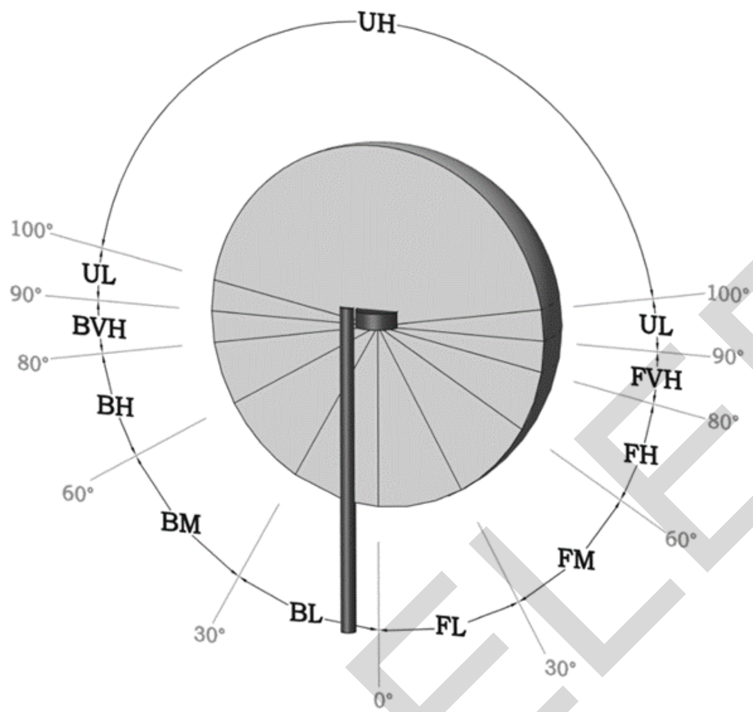


Table C-4 Exterior Luminaire BUG Classification Key

UH	Uplight High
UL	Uplight Low
BVH	Backlight Very High
BH	Backlight High
BM	Backlight Medium
BL	Backlight Low
FVH	Forward Light Very High
FH	Forward Light High
FM	Forward Light Medium
FL	Forward Light Low

C-2.3.2 Backlight (B) Rating.

Backlight from a luminaire can create light trespass if the luminaire is located near the edge of a property. The “B” rating takes into account the amount of backlight in the low

(BL), medium (BM), high (BH), and very high (BVH) zones, which are generally to the "rear" of the luminaire. The closer to a property line a luminaire is located, the stricter, or lower, the "B" rating should be. If the luminaire is located more than two mounting heights from the property line, then a higher B rating may be appropriate.

C-2.3.3 Uplight (U) Rating.

Uplight is a significant source of sky glow. Uplight emitted at angles near horizontal (UL) cause the most sky glow and negatively affects professional and academic astronomy. Higher-angle uplight (UH) not reflected off a surface is mostly energy waste. The "U" rating defines the amount of light emitted into the upper hemisphere, with greater concern for the light at or near the horizontal (UL).

C-2.3.4 Glare (G) Rating.

Glare can be annoying or visually disabling. The "G" rating takes in to account the amount of forward-emitted light in the high (FH) and very high (FVH) zones and the amount of backward-emitted light in the high (BH) and very high (BVH) zones.

C-2.3.5 Considerations.

In general, a higher BUG rating means that more light is emitted in the relevant solid angles, and the allowable rating increases with higher-numbered lighting zones (see Section C-4). However, a higher "B" (backlight) rating simply indicates that the luminaire directs a significant portion of light behind the pole, so allowed "B" ratings are based on the location of the luminaire with respect to the property boundary. A high "B" rating maximizes the luminaire's spread of light and is effective and efficient when used far from the property boundary. When luminaires are located near the property boundary, a lower "B" rating prevents unwanted light from interfering with neighboring properties.

C-3 LIGHTING ZONES.

C-3.1 LZ0: No Ambient Lighting.

LZ0 areas are those where the natural environment will be seriously and adversely affected by lighting. Impacts include disturbing the biological cycles of flora and fauna and/or detracting from human enjoyment and appreciation of the natural environment. In these areas, human activity is subordinate in importance to nature. The vision of human residents and users is adapted to the total darkness, and they expect to see little or no lighting. When not needed, lighting should be extinguished.

C-3.2 LZ1: Low Ambient Lighting.

LZ1 areas are those where lighting might adversely affect flora and fauna or disturb the character of the area. The vision of human residents and users is adapted to low light levels. Lighting may be used for safety, security, and/or convenience, but it is not necessarily uniform or continuous. After curfew, most lighting should be extinguished or reduced as activity levels decline.

C-3.3 LZ2: Moderate Ambient Lighting.

LZ2 areas are areas of human activity where the vision of human residents and users is adapted to moderate light levels. Lighting may typically be used for safety, security, and/or convenience but it is not necessarily uniform or continuous. After curfew, lighting may be extinguished or reduced as activity levels decline.

C-3.4 LZ3: Moderately High Ambient Lighting.

LZ3 areas are areas of human activity where the vision of human residents and users is adapted to moderately high light levels. Lighting may typically be used for safety, security and/or convenience and is often uniform and/or continuous. After curfew, lighting may be extinguished or reduced as activity levels decline.

C-3.5 LZ4: High Ambient Lighting.

LZ4 areas are areas of human activity where the vision of human residents and users is adapted to high light levels. Lighting is generally considered necessary for safety, security and/or convenience and it is mostly uniform and/or continuous. After curfew, lighting may be extinguished or reduced in some areas as activity levels decline.

C-3.6 Potential Reasons for Classifying an Area at a Lower Lighting Zone.

- Very low or no activity at night
- Adjacent lighting zone, either DoD or Civilian, is lower and has a low level of activity

C-3.7 Potential Reasons for Classifying an Area at a Higher Lighting Zone.

- Sensitive areas requiring a high level of security
- High level of activity at night as well as high number of users

C-4 CONTROL APPROACHES.

C-4.1 Manual Switching.

Manual switching is not ideal for controlling exterior lighting.

C-4.2 Photocontrol.

A photocell is a device that measures the illuminance level and is set to turn on or off the luminaire at a preset illuminance level. The light levels are set to ideally have the luminaires turn on before sunset and extinguish after sunrise.

C-4.3 Occupancy Based Controls.

The use of motion sensors in exterior applications is widely accepted in residential applications. In commercial or industrial applications, occupancy sensors can be implemented in some applications. It is important to ensure that the occupancy sensor being used does not leave any 'dead' zones where occupancy cannot be detected for safety concerns.

C-4.4 Adaptive Lighting.

Adaptive lighting is concept of adjusting the light levels to suit the activity level. This is accomplished with bilevel switching and motion sensors or preset continuous dimming. When no occupancy is detected in a zone, or late at night when traffic and pedestrian volumes are known to be minimal, lighting levels are reduced to a minimum of 30% full light output. Adaptive lighting is ideally suited for wall-mounted, roadway, area, pathway, parking lot, or pedestrian luminaires.

All street lighting luminaires are required to have a multipin receptacle that is capable of accepting a dimming control node. With a similar form factor to that of a standard photocell, a dimming control node is installed on top of the luminaire. The control node communicates through a networked control system to allow for two-way communication. See Section A-5.9 Network Control Systems for additional information.

C-5 CONTROL EQUIPMENT.

C-5.1 Sensors.

C-5.1.1 Photosensors.

Photosensors can be used as an exterior lighting control strategy. A single photosensor can be installed on each luminaire or on a lighting control center linking a group of luminaires together. Diligently maintain the photosensor.

C-5.1.2 Motion Sensors.

Motion sensors used for exterior luminaires are the same as for interior luminaires. As such, the coverage patterns can be too small and result in coverage gaps when used to control exterior luminaires.

C-5.2 Timeclocks.

Timeclocks or time switches are used to automatically turn the lights on or off on a daily basis. Typically, time clocks are programmed to turn on and off based on astronomical events such as sunset and sunrise or when activity has ceased. The astronomic time clock automatically keeps track of what day it is and geographic location of the luminaires. As the exact time of sunset and sunrise fluctuates throughout the year, the time clock adjusts accordingly.

C-5.3 Network Control Systems.

Exterior control systems are beginning to follow the same path as interior addressable systems. By communicating with the driver or power control unit of each roadway or area luminaire, a centralized control system can monitor a wide range of characteristics including energy consumption and outages. Additionally, this control strategy accommodates the concept of adaptive lighting standards. This concept recognizes that lighting criteria provides for the worst-case scenario – conditions that may only exist for a fraction of the night or year. With more advanced control systems and dimmable sources, exterior lighting can provide the appropriate amount of light for the time of day, time of year, and weather conditions, while significantly reducing energy use.

C-5.3.1 Power Line Frequency.

A power line carrier network system uses the physical electrical wiring to communicate between devices. Each luminaire has its own device and therefore its own unique address. The devices can then all be linked together to form a network that is adjustable through a software program. From the software, zoning can be established as well as scheduling. Additionally, maintenance issues can be identified. In order to dim, a separate dimming driver may be required.

C-5.3.2 Radio Frequency.

A radio frequency (RF) lighting control system uses embedded RF transmitters and receivers to connect devices (sensors, user controls, power equipment) to one another. These systems can be stand alone or part of a networked lighting control solution. Care should be taken to evaluate the RF lighting control solution on the frequency range it operates in (is it densely or sparsely populated?), how the system propagates and ensures proper RF communication between devices, RF device installation and cost, and whether the type of space being controlled supports the use of RF devices. A mockup of the RF lighting control system is a recommended best practice to ensure that the system will perform as expected in the application/operating environment.

APPENDIX D BEST PRACTICES: LIGHTING FOR CIRCADIAN RHYTHMS

D-1 INTRODUCTION

The human body operates on an approximately 24-hour sleep-wake cycle that regulates our natural biological processes. These variations are known as the human circadian rhythms (animals and plants have them also), and the primary driver of this cycle is light.[9] This process is called entrainment and involves the synchronization of different rhythmic cycles that interact with each other. Nearly every cell in the human body has a circadian clock. Correct entrainment has been shown to lower risk of cancer, neurodegenerative diseases, substance addiction, and obesity.[10]

Humans have evolved under the sun during the day and in darkness at night. For millennia, the presence of absence of daylight has informed our bodies of each day's start and end. In the modern world, people are no longer continuously exposed to daylight during daytime hours, but instead are often exposed to much lower light levels in our homes and workplaces. Regulating our circadian rhythms is more difficult with less sunlight exposure and with electric lighting operating during periods of what would normally be natural darkness.[11] [12] [13]

D-2 RECOMMENDATIONS.

The lighting recommendations in this appendix are based on the current known research of circadian lighting design. While human well-being is important, it is nearly impossible to predict the outcomes and changes due to a circadian lighting design, both positive and negative.

D-3 OVERVIEW.

Electric lighting systems that are designed to impact the human circadian rhythm are referred to as circadian lighting systems. The concept behind these systems is that electric light could be used to support human health and typically revolves around the potential for melatonin suppression using light. Circadian lighting systems and luminaires are designed by modulating the quantity and spectral distribution of the light source.

[9] Boyce PR. Human Factors in Lighting. 3rd ed. London, England: CRC Press; 2017.

[10] Roenneberg T, Merrow M. The circadian clock and human health. Curr Biol. 2016;26(10):R432–43.

[11] Wright KP Jr, McHill AW, Birks BR, Griffin BR, Rusterholz T, Chinoy ED. Entrainment of the human circadian clock to the natural light-dark cycle. Curr Biol. 2013;23(16):1554–8.

[12] Stothard ER, McHill AW, Depner CM, Birks BR, Moehlman TM, Ritchie HK. Circadian entrainment to the natural light-dark cycle across seasons and the weekend. Curr Biol. 2017;27(508–13):12 041.

[13] Chen S, Wei M, Dai Q, Huang Y. Estimation of possible suppression of melatonin production caused by exterior lighting in commercial business districts in metropolises. LEUKOS. 2020;16(137–44):1523013.

D-3.1 Light and the Human Circadian System.

Human circadian rhythms are mediated by the suprachiasmatic nuclei (SCN), which is the part of the brain that controls the internal daily clock.[14] Within the human eye, there are three known groups of photoreceptors. Two of these groups, the rods and cones, are image-forming photoreceptors while the third group, the intrinsically photoreceptive retinal ganglion cells (ipRGCs), are non-image-forming. ipRGCs are essential in converting neural signals from the retina to the SCN.

The ipRGCs contain a photopigment called melanopsin, also known as the "darkness hormone," which is a photopigment that is especially sensitive to blue wavelengths.[15] [16] Melatonin production begins at the retina and travels to the SCN which signals the pineal gland to release the hormone in nighttime conditions.[6] This photopigment is believed to be the main aspect of the non-image-forming system.[17] The research on these cells and how they operate is ongoing, but researchers have concluded that the ipRGCs respond best to blue light, and that the ipRGCs are not limited to circadian entrainment alone.[18]

D-3.2 Circadian Lighting Metrics

Current metrics have been developed, researched, and vetted to try and measure what spectrum, timing, duration, quantity, and distribution of light will elicit a circadian response. Current ways to measure circadian lighting include but are not limited to:

- Equivalent Melanopic Lux (EML, used by the WELL Building Standard)
- Melanopic Irradiance (CIE)
- Melanopic Equivalent Daylight Illuminance (mEDI, by CIE)
- Melanopic Daylight Efficacy Ratio (mDER, by CIE)
- Circadian Stimulus (CS, by LHRC)
- Circadian Bio-Active Blue (CIRCADIAN Light)
- Melanopic/Photopic (M/P) ratio

[14] Boyce PR. Human Factors in Lighting. 3rd ed. London, England: CRC Press; 2017.

[15] Arendt J. Melatonin and the pineal gland: influence on mammalian seasonal and circadian physiology. Rev Reprod. 1998;3(1):13–22.

[16] Berson DM, Dunn FA, Takao M. Phototransduction by retinal ganglion cells that set the circadian clock. Science. 2002;295(5557):1070–3.

[17] Lasauskaite R, Hazelhoff EM, Cajochen C. Four minutes might not be enough for light colour temperature to affect sleepiness, mental effort, and light ratings. Light Res Technol. 2019;51(7):1128–38.

[18] Schmidt TM, Chen S-K, Hattar S. Intrinsically photosensitive retinal ganglion cells: many subtypes, diverse functions. Trends Neurosci. 2011;34(11):572–80.

D-4 INFLUENCING FACTORS FOR CIRCADIAN LIGHTING SYSTEMS.

Spectrum, timing, duration, quantity, and distribution at the retina are all critical components in creating a circadian lighting response.[19] A circadian lighting system must consider all of these components in the design.

D-4.1 Spectrum.

The relative light output from a luminaire across the visual spectrum is referred to as its spectral power distribution (SPD). The goal in circadian design is to link the SPD of a luminaire to the effectiveness of stimulating ipRGCs. The peak sensitivity of the ipRGCs is generally accepted to be 480 nm, with multiple studies suggesting different peak sensitivities between 477 nm and 480 nm.[20] These wavelengths are found in the blue region of the spectrum. Research to determine the peak spectral sensitivity of the ipRGCs remains inconclusive, since they are positioned in such a way that they receive input from the rods and cones as well.[21]

D-4.2 Timing.

Time of day is a contributing factor in determining the impacts that spectrum and quantity of light have on human well-being. Sunlight in the morning is the best solution for entraining and establishing a healthy circadian rhythm.[22,23] Sunlight not only contains the necessary wavelengths, but is also sufficiently bright to stimulate the ipRGCs.

Reducing the amount of light in the evenings is equally important. Depending on when someone is exposed to light, a delay or advancement in their biological clock may occur, which is known as phase shifting. Studies show that blue light can entrain or disrupt the circadian rhythm, depending on the time of day someone was exposed to it.[24]

[19] Bommel WJM, Beld GJ. Lighting for work: A review of visual and biological effects. Light Res Technol. 2004;36(4).

[20] Bailes HJ, Lucas RJ. Human melanopsin forms a pigment maximally sensitive to blue light (λmax ≈ 479 nm) supporting activation of G(q/11) and G(i/o) signalling cascades. Proc Biol Sci. 2013;280(1759):20122987.

[21] Schmidt TM, Chen S-K, Hattar S. Intrinsically photosensitive retinal ganglion cells: many subtypes, diverse functions. Trends Neurosci. 2011;34(11):572–80.

[22] Münch M, Nowozin C, Regente J, Bes F, De Zeeuw J, Hädel S, et al. Blue-enriched morning light as a countermeasure to light at the wrong time: Effects on cognition, sleepiness, sleep, and circadian phase. Neuropsychobiology. 2016;74(4):207–18.

[23] Figueiro MG, Steverson B, Heerwagen J, Kampschroer K, Hunter CM, Gonzales K. The impact of daytime light exposures on sleep and mood in office workers. Sleep Health. 2017;3(204–15):03 005.

[24] Figueiro M, Steverson B, Heerwagen J, Kampschroer K, Rea M. Light, entrainment, and alertness: A case study in offices. In: PROCEEDINGS OF the 29th Quadrennial Session of the CIE. International Commission on Illumination, CIE; 2019.

D-4.3 Duration.

The phase-shifting effects of light is dependent on duration and pattern of light. Phase-shifts vary exponentially dependent upon duration.[25] Phase-shifting has a different response when the light exposure is continuous versus intermittent. Current research reveals that intermittent light at the eye induces a greater phase shift than predicted by a simple linear response to optical radiation duration.[17,26,27]

D-4.4 Quantity.

The quantity of light Illuminance) received at the eye influences the effect that the light will have on the human circadian rhythms. Studies have shown that luminaires with higher correlated color temperatures (CCT), such as 6500 K, can have little to no impact on melatonin suppression if they are under a certain threshold. For one specific study, the threshold was found to be 30 lux.[28] It has also been found that using the “nightshift” mode on self-luminous displays has little to no impact on melatonin suppression if the brightness is still high.[29]

D-4.5 Distribution.

Distribution of light at the retina also plays an important role. Most standards and guidelines for lighting are developed for lighting a horizontal plane, such as working surfaces and roadways, but vertical illuminance is important for circadian lighting. Light exposure on the lower retina (thus, coming from above) has been found to suppress melatonin at a higher rate than light hitting the upper or central retina (thus, coming from below or straight ahead).[18] From a design standpoint, this could mean that circadian disruption could be reduced if there were less light at night falling on the lower half of the retina. Research continues to uncover more information about how the different aspects of light can have an impact on human well-being.

D-5 CIRCADIAN LIGHTING LUMINAIRES.

Commercially available circadian lighting luminaires are marketed by lighting manufacturers as tools to be used to improve the well-being and productivity of workers in typical indoor environments. These luminaires differ from systems that are often referred to as “white-tuning” luminaires, which allow the user to change how the light appears by modulating the correlated color temperature. Circadian lighting luminaires

[25] Illuminated Engineering Society. (2018). Light and Human Health: An Overview of the Impact of Optical Radiation on Visual, Circadian, Neuroendocrine, and Neurobehavioral Responses.

[26] Gronfier, C., et al., “Efficacy of a single sequence of intermittent bright light pulses for delaying circadian phase in humans.” American Journal of Physiology - Endocrinology and Metabolism, 2004. 287(1): p. E174-81.

[27] 149 Rimmer, D. W., et al., “Dynamic resetting of the human circadian pacemaker by intermittent bright light.”

American Journal of Physiology- Regulatory, Integrative, and Comparative Physiology, 2000. 279(5): p. R1574-9.

[28] Mariana G. Figueiro MSR. A working threshold for acute nocturnal melatonin suppression from “white” light sources used in architectural applications. J Carcinog Mutagen [Internet]. 2013;04(03).

[29] Glickman G, Hanifin JP, Rollag MD, Wang J, Cooper H, Brainard GC. Inferior retinal light exposure is more effective than superior retinal exposure in suppressing melatonin in humans. J Biol Rhythms. 2003;18:71–9.

also change the appearance of the light, but as a result of modulating the spectrum of the light. The timing, duration, quantity, and distribution of the light from these luminaires is entirely dependent on the quantity and mounting locations of the luminaires, as well as the programming of the lighting control system.

D-5.1 Spectral Power Distribution.

The specific group of wavelengths that are emitted from a luminaire across the visible spectrum is referred to as its spectral power distribution (SPD). When the SPDs of red, green, and blue light are combined, white light is produced. Additionally, different CCTs of white light can be combined to allow for more variety of spectra. Within a luminaire, the higher number of different LEDs, the more options that are available for creating different spectra. Figure D-1 shows the normalized SPD of sunlight compared to a typical 3500-K LED luminaire.

D-5.1.1 White Tuning.

For example, a typical white-tuning LED luminaire that can fluctuate between 2700 K and 6500 K is a combination of two different LED diodes, 2700 K and 6500 K. The only spectra that can be produced by this luminaire is a combination of the SPDs of each of these diodes. Figure D-2 has the following diodes: 2700 K and 6500 K. This is considered a two-channel luminaire.

D-5.1.2 Multichannel.

To produce a wider variety of spectra, a multi-channel luminaire is used. Not only does this provide more options for different color temperatures, but it also allows designers to target specific wavelengths without drastically changing the color of the produced light. The luminaire in graph in Figure D-3 has the following diodes: red, green, blue, 2700 K, two 3500 K, and 6500 K.

D-5.1.3 Circadian.

Circadian lighting design attempts to recreate daylight, which changes in SPD throughout the day, by mixing the light from several different LED diodes within the luminaire. However, these luminaires are not able to perfectly replicate daylight.

Figure D-1 SPD of Sunlight and 3500-K LED Luminaire

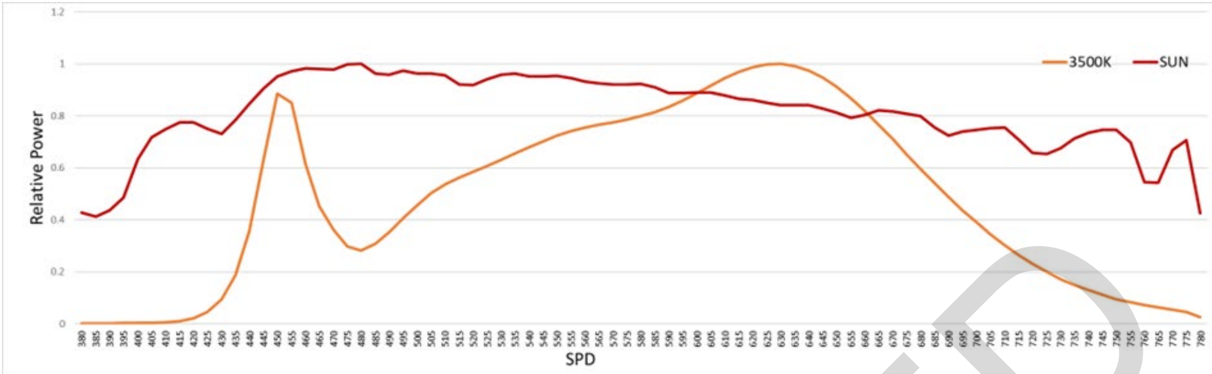


Figure D-2 SPD of a Two Channel Luminaire

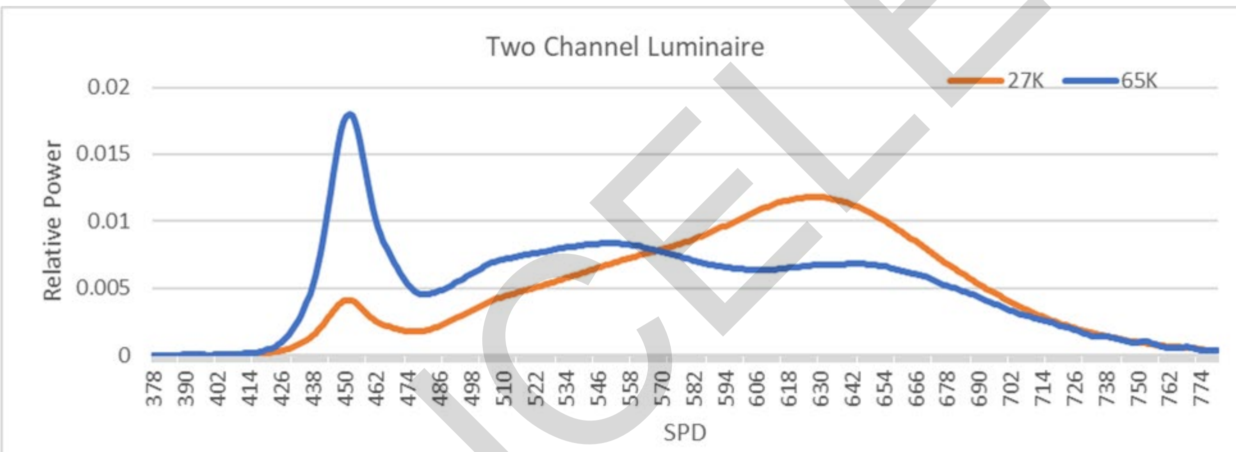
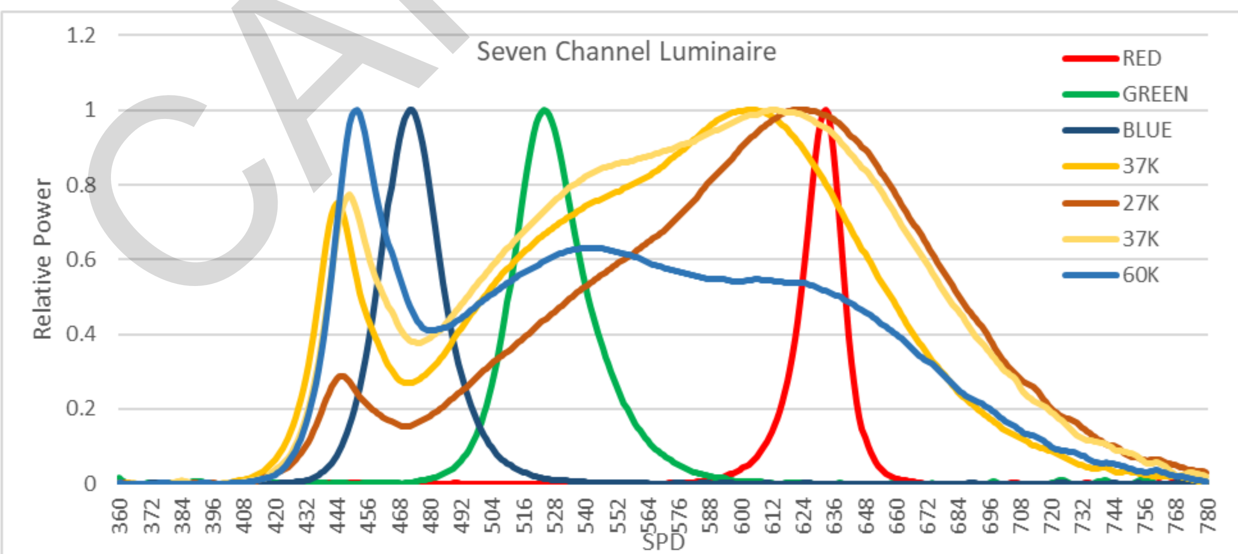


Figure D-3 SPD of a Six Channel Luminaire



D-6 DAYLIGHT AND VIEWS.

The daylighting and views in typical office spaces, where occupants work eight-hour shifts during daylight hours, will help workers maintain healthy circadian rhythms that are in synch with their home/work schedule. Harnessing the power of daylight reduces energy usage, provides daylight, and promotes a healthier condition for human well-being in an office environment.

Daylight and views in office spaces have been linked to improved sleep quality and mood among office workers.[30] Several elements influence how a worker can have better circadian entrainment, including location of workspace, the view of the outside, and window treatments.[31]

D-6.1 Harvesting the Benefits of Daylight.

To maximize the benefits of circadian lighting, workstations should be within 20 feet of a window. If the workstation is over 20 feet from a window, the view of the worker should be facing towards the nearest window. If there are any windows in the office space, blinds should be opened to let natural light into the space and allow workers to look outside. To maximize the circadian potential of daylight, high quality daylight and views should be present in the workspace. This requires coordinating with the architect and other members of the daylighting design team to optimize window placement, maximize views internal and external shade controls, while minimizing glare.

D-7 IMPLEMENTING CIRCADIAN LIGHTING SYSTEMS.

Circadian lighting metrics are all based on the assumption that it takes a certain combination of spectrum, timing, duration, quantity, and distribution of light to produce melatonin suppression, which will result in phase shifting. However, current research reveals that implementing a circadian lighting design in indoor environments can cause circadian disruption for some individuals more than others.[32] The other assumption is that melatonin suppression will cause a parallel phase shift in the circadian clock, but there is evidence of divergent phase shifting and melatonin response in humans.

The evidence is inconclusive that a certain dosage of light will create a phase shift and melatonin suppression in the indoor lighting environment. Most notably, it cannot be stated with assurance that all people will react in the same way to indoor lighting environments. Research has shown a wide range of results regarding the implementation of circadian lighting, both having positive and negative effects on human well-being. These inconsistencies cannot predict how human well-being will be impacted on a large-scale by circadian lighting design. It is not recommended that

[30] Figueiro MG, Steverson B, Heerwagen J, Kampschroer K, Hunter CM, Gonzales K. The impact of daytime light exposures on sleep and mood in office workers. Sleep Health. 2017;3(204–15):03 005.

[31] Altenberg Vaz N, Inanici M. Syncing with the sky: Daylight-driven circadian lighting design. LEUKOS. 2020;1–19.

[32] Vetter, C., Flynn-Evans, E., Phillips, A., Zeitzer, J.(2021, February 1). "Ask Me" Session: Connecting the Dots Between Light & Health Research and Practice [video file]. Retrieved from https://www.energy.gov/eere/ssl/2021-lighting-rd-workshop.

universal approaches be applied at this time, since shifts to occupants' circadian cycles cannot be done with enough certainty and consistency.

D-7.1 Typical Work Environments.

Without more research, it is not recommended to install a lighting system specifically engineered to shift occupants' circadian cycles in typical workspaces, where occupants work the majority of their shift during the day. However, daylight and views may be used; this resource provides many benefits to indoor work environments, including natural impacts to circadian cycles.

D-7.2 Secure Environments.

Some work environments are unable to provide regular, continuous access to daylight due to the type of work or security of the facility. When possible, provide breakrooms with windows with clear views to exterior.

D-7.3 24-Hour Facilities.

In 24-hour facilities, occupants are not typically working a normal daytime shift, and therefore their circadian rhythms may not be in tune with a normal day. The goal of the lighting in these environments is to stimulate occupants during their shift to keep them alert without disrupting melatonin. Circadian disruption has been associated with increased risk for metabolic syndrome, diabetes, cardiovascular disease, and cancer.[33] However, there are inconsistencies and contradictions in different studies linking light at night to certain disease risks.[34] Therefore, broadly implementing circadian lighting systems is not recommended even in 24-hour facilities.

Electric lighting can provide both a positive and negative effect on human well-being, depending on how it is designed.[35] [36] [37] For a lighting system to be successful in a circadian lighting application, it must be able to adapt to the changing and evolving research on the spectral sensitivity of the ipRGCs and the recommendations made by experts in the field.

D-7.4 Circadian Lighting Luminaire Selection.

If there is a desire to explore circadian lighting implementation in a specific room or area, select equipment that allows for flexibility and modifications as research evolves. Luminaires must have at least four channels: red, green, blue, and 3500 K. However, it

[33] Mariana G. Figueiro. Lighting interventions to reduce circadian disruption in rotating shift workers. National Institute for Occupational Safety and Health. 2015;

[34] Hunter C.M., Figueiro M.G. Measuring Light at Night and Melatonin Levels in Shift Workers: A Review of the Literature. Biol. Res. Nurs. 2017;19:365–374.

[35] Chen S, Wei M, Dai Q, Huang Y. Estimation of possible suppression of melatonin production caused by exterior lighting in commercial business districts in metropolises. LEUKOS. 2020;16(137–44):1523013.

[36] Bellia L, Pedace A, Barbato G. Lighting in educational environments: an example of a complete analysis of the effects of daylight and electric light on occupants. Build Environ. 2013;68(50–65):04 00.

[37] Zielinska-Dabkowska KM. Make lighting healthier. Nature. 2018;553(7688):274–6.

is recommended that each luminaire should have at least six channels: red, green, blue, 2700 K, 3500 K, and 6500 K. Regardless of the number of channels, the control system must be adaptable to different light outputs and must be able to adjust the spectral power distribution throughout the day. By implementing a luminaire with more channels, more spectral power distributions are possible. The six-channel luminaire will be able to adapt to future recommendations more effectively.

Current findings do not recommend blue light at night because the risk it causes of disrupting the daily circadian rhythms. Research is being conducted to analyze the effectiveness in stimulating alertness by using red light, which does not cause circadian disruption.[38]

[38] Mariana G. Figueiro. Lighting interventions to reduce circadian disruption in rotating shift workers. National Institute for Occupational Safety and Health. 2015;

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APPENDIX E BEST PRACTICES: GERMICIDAL ULTRA-VIOLET LIGHTING

E-1 INTRODUCTION.

Germicidal ultraviolet (GUV) systems emit ultraviolet radiation (UVR) that inhibits microbial reproduction. They are used to sterilize surfaces, liquids, and air. GUV systems have generated significant interest due to their ability to kill antibiotic-resistant microbes. While GUV systems may be a step towards better disinfection when in conjunction with other Centers for Disease Control and Prevention (CDC) protocols, it is important to note the safety concerns and limitations of this equipment. There is limited industry consensus on the best and most appropriate way to use these systems, which is especially important to keep in mind as some lighting manufacturers are ready to produce and sell GUV products during the heightened concern for sanitizing spaces due to the Covid-19 pandemic. Without this consensus, widely implementing these strategies in DoD facilities is not currently recommended, but there are some limited applications and approaches that may be appropriate should decision-makers determine that GUV systems are to be deployed despite the risks. This appendix will explain GUV systems, review current known limitations and cautions, and discuss potential design applications.

In addition, refer to ANSI/IES RP-44-21 for specific guidance on the use of these kinds of systems.

E-2 OVERVIEW.

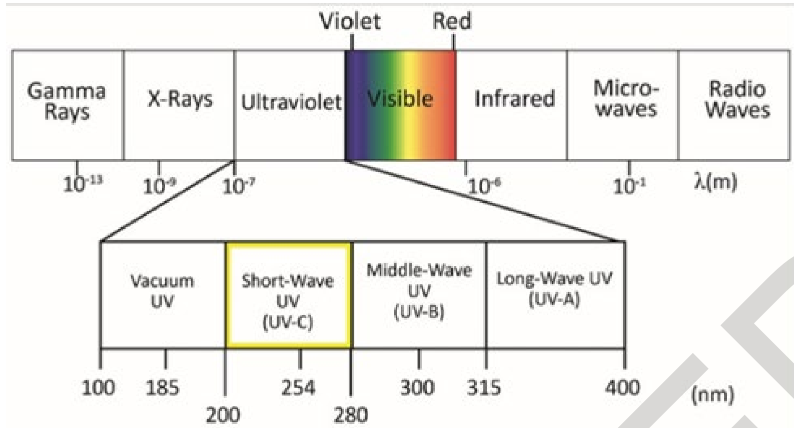
E-2.1 Ultraviolet (UV) Interactions with Microbes.

There are three primary types of UVR, including ultraviolet A (UV-A), ultraviolet B (UV-B), and ultraviolet C (UV-C). UV-A radiation has the longest wavelengths of UVR, ranging from 315 nm to 400 nm, UV-B radiation falls in the middle, with wavelengths ranging from 280 nm to 315 nm, and UV-C radiation has the shortest wavelengths, ranging from 200 nm to 280 nm. UVR interacts with microorganisms through two primary mechanisms. UV-A excites photoreactive molecules, creating active species that damage DNA and other biological components.[39] UV-B and UV-C directly damage DNA, thus hindering reproduction.[40]

[39] Oguma, K., Katayama, H., & Ohgaki, S. (2002). Photoreactivation of Escherichia coli after low-or medium-pressure UV disinfection determined by an endonuclease sensitive site assay. Applied and environmental microbiology, 68(12), 6029-6035.

[40] Taylor, W., Camilleri, E., Craft, D. L., Korza, G., Granados, M. R., Peterson, J., ... & Mok, W. W. (2020). DNA damage kills bacterial spores and cells exposed to 222-nanometer UV radiation. Applied and Environmental Microbiology, 86(8).

Figure E-1 Spectrum of UV Light (www.ies.org)



UVR exposure is measured as “dosage” which is the product of the irradiance and the duration of exposure. Irradiance is a function of the source strength moderated by the distance from the target to the emitter and any attenuation that may occur along the way. The target’s material properties may also affect dosage, influencing how much energy is absorbed, reflected, or transmitted. While small amounts of UVR are reflected off of surfaces, for UVR to be an effective sterilizer direct exposure is required.

E-2.1.2 GUV Effectiveness.

Viruses and bacteria can only be inactivated by direct GUV, so the effectiveness varies based on which surfaces are exposed to GUV and whether water, air droplets, or humidity is present. Generally, shorter wavelengths are more effective than longer wavelengths, with a peak efficacy around 260 nm.[41,42] Far UV-C (< 222 nm) is nearly as effective as 254-nm UV-C. Some bacteria have the ability to repair themselves using the energy provided by UV-A and visible light, so short, intense exposures may be more effective than long, low-intensity applications.[43,44,45,46]

[41] Gerchman, Yoram, Mamane, Hadas, Friedman, Nehemya, and Mandelboim, Michal. "UV-LED Disinfection of Coronavirus: Wavelength Effect." Journal of Photochemistry and Photobiology. B, Biology 212 (2020): 112044.

[42] Besaratinia, A., Yoon, J. I., Schroeder, C., Bradforth, S. E., Cockburn, M., & Pfeifer, G. P. (2011). Wavelength dependence of ultraviolet radiation-induced DNA damage as determined by laser irradiation suggests that cyclobutane pyrimidine dimers are the principal DNA lesions produced by terrestrial sunlight. The FASEB Journal, 25(9), 3079-3091.

[43] Harris, G. D., Adams, V. D., Sorensen, D. L., & Curtis, M. S. (1987). Ultraviolet inactivation of selected bacteria and viruses with photoreactivation of the bacteria. Water Research, 21(6), 687-692.

[44] Bohrerova, Z., Shemer, H., Lantis, R., Impellitteri, C. A., & Linden, K. G. (2008). Comparative disinfection efficiency of pulsed and continuous-wave UV irradiation technologies. Water research, 42(12), 2975-2982.

[45] Sommer, R., Haider, T., Cabaj, A., Pribil, W., & Lhotsky, M. (1998). Time dose reciprocity in UV disinfection of water. Water science and technology, 38(12), 145-150.

[46] Bowker, C., Sain, A., Shatalov, M., & Ducoste, J. (2011). Microbial UV fluence-response assessment using a novel UV-LED collimated beam system. Water research, 45(5).

E-2.1.3 UVR Dosage.

Currently, there are no specific industry standards or operation protocols defining the frequency and duration of UVR exposure with regard to its effectiveness. It is difficult to define standardized dose-response curves for different microbes in different mediums, but most of the literature suggest that relatively small dosages of UV-C radiation can eliminate microbial communities on surfaces and in the air.

This increased susceptibility to high dosages may explain why pulsed UV exposure appears to be more effective at neutralizing bacteria than continuous exposures of the same total dosage. Pathogens that are incapable of self-repair do not display this behavior.[47] Other studies, with different methodologies, have found no significant difference in the efficacy of pulsed vs. continuous exposure.[48] However, they do state that pulsed dosages can often be delivered in much shorter time frames, facilitating clinical applications and potentially limiting reactivation. In most cases, however, sterilization is a function of total dosage and is not impacted by dose rate.

E-2.1.4 Normal Solar Exposure.

Average annual UV dose from solar exposure ranges from 1,000 - 3,000 mJ/cm^2 in Europe and the U.S.[49] The spectral composition of this irradiance is heavily weighted toward UV-A, with a small UV-B component. UV-C radiation is completely filtered out in the upper atmosphere. In healthy adults, most UVR is filtered by the lens and the cornea, with very little reaching the retina. Children and adults who have undergone cataract surgery are at risk of increased exposure. UV-B radiation that does reach the retina can cause DNA damage and oxidative stress.[50] The current recommended daily maximum exposure is 32 mJ/cm^2 in an 8-hour period.[51] The effects of overexposure tend to be minor and short-lived.[52] However, repeated or long-term exposure can cause premature aging and increases the risk of cancer.[53] There is some evidence that

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[47] Bohrerova, Z., Shemer, H., Lantis, R., Impellitteri, C. A., & Linden, K. G. (2008). Comparative disinfection efficiency of pulsed and continuous-wave UV irradiation technologies. Water research, 42(12), 2975-2982.

[48] Wang, T., MacGregor, S. J., Anderson, J. G., & Woolsey, G. A. (2005). Pulsed ultra-violet inactivation spectrum of Escherichia coli. Water research, 39(13), 2921-2925.

[49] Godar, D. E. (2005). UV doses worldwide¶. Photochemistry and photobiology, 81(4), 736-749.

[50] Mahendra, C., Tan, L., Pusparajah, P., Htar, T.T., Chuah, L.H., Lee, V., Low, L., Tang, S.Y., Chan, K.G., & Goh, B. (2020). Detrimental Effects of UVB on Retinal Pigment Epithelial Cells and Its Role in Age-Related Macular Degeneration, Oxidative Medicine and Cellular Longevity, vol. 2020, 29 pages.

[51] International Commission on Non-Ionizing Radiation Protection. (2004). Guidelines on limits of exposure to ultraviolet radiation of wavelengths between 180 nm and 400 nm (incoherent optical radiation). Health Physics, 87(2), 171-186.

[52] Andrea Trevisan, Stefano Piovesan, Andrea Leonardi, Matteo Bertocco, Piergiorgio Nicolosi, Maria Guglielmina Pelizzo, and Annalisa Angelini. "Unusual High Exposure to Ultraviolet-C Radiation." Photochemistry and Photobiology 82, no. 4 (2006): 1077-079.

[53] Matsumura, Yasuhiro, and Ananthaswamy, Honnavara N. "Toxic Effects of Ultraviolet Radiation on the Skin." Toxicology and Applied Pharmacology 195, no. 3 (2004): 298-308.

intermittent exposure patterns are correlated with an increased risk of skin cancer compared to more regular exposure patterns.[54]

E-3 LIMITATIONS OF GUV.

Even though GUV, and especially UV-C, technology is known to inactivate viruses and bacteria, it has not been widely implemented. Because of this, there are significant gaps in data and long-term research. True sterilization is difficult and may create undesired side effects, which are important to consider. GUV radiation affects microbial interactions, building occupants, and building materials, in addition to increasing energy usage. All of these concerns must be addressed when considering a GUV design.

E-3.1 Secondary Microbial Interactions.

While GUV systems show significant potential, there are a number of moderating factors to consider. 100% sterilization is difficult, and surviving microbes will adapt; both bacteria and viruses have been shown to develop UV resistance with repeated exposure. Recent research advocates for an approach in which the interior microbiome is considered as a living system that can be beneficially managed rather than something to be exterminated.[55,56]

GUV radiation kills or inactivates all microbes, good and bad, within its path, which could potentially harm our environment. The rise of antibiotic-resistant bacteria due to the overuse of antibiotics is rapidly becoming a global health crisis. GUV systems can be a useful tool in the fight against antibiotic-resistant bacteria, but care should be taken to avoid similar mistakes.[57,58] Many studies have shown that repeated exposure to UV

[54] Kricker, A., Armstrong, B. K., English, D. R., & Heenan, P. J. (1995). Does intermittent sun exposure cause basal cell carcinoma? A case-control study in Western Australia. International journal of cancer, 60(4), 489-494.

[55] Velazquez, S., Griffiths, W., Dietz, L., Horve, P., Nunez, S., Hu, J., ... & Van Den Wymelenberg, K. G. (2019). From one species to another: A review on the interaction between chemistry and microbiology in relation to cleaning in the built environment. Indoor air, 29(6), 880-894.

[56] Horve, P. F., Lloyd, S., Mhuireach, G. A., Dietz, L., Fretz, M., MacCrone, G., ... & Ishaq, S. L. (2019). Building upon current knowledge and techniques of indoor microbiology to construct the next era of theory into microorganisms, health, and the built environment. Journal of Exposure Science & Environmental Epidemiology, 1-17.

[57] Guo, M. T., Yuan, Q. B., & Yang, J. (2013). Microbial selectivity of UV treatment on antibiotic-resistant heterotrophic bacteria in secondary effluents of a municipal wastewater treatment plant. Water research, 47(16), 6388-6394.

[58] McKinney, C. W., & Pruden, A. (2012). Ultraviolet disinfection of antibiotic resistant bacteria and their antibiotic resistance genes in water and wastewater. Environmental science & technology, 46(24), 13393-13400.

radiation leads to the proliferation of bacteria and viruses that are more resistant to UV irradiation.[59,60,61]

E-3.2 Interactions with Building Occupants.

Exposure to UVR can have detrimental impacts on building occupants and, while these negative effects tend to heal quickly, there is a risk that repeated exposure could increase the risk of developing certain skin cancers. Far UV-C (<222 nm), which is nearly as effective as 254-nm UV-C, is of particular interest because it does not penetrate human skin or eye tissue.

E-3.2.1 Far UV-C Radiation.

Mice models and human clinical trials show that 222-nm far UV-C radiation, even in extreme doses, does not cause skin damage or irritation but does reduce bacterial counts on skin.[62,63] This suggests that it may be deployed in occupied spaces without causing direct harm to humans.[64,65] However, as far UV-C radiation is not naturally encountered within our atmosphere, there are potentially significant unknown consequences that could arise if it were widely deployed. The use of far UV-C radiation lessens the likelihood of direct harm to humans when compared to longer wavelengths of UVR, but the long-term effects are still unknown.

E-3.3 Interactions with Building Materials.

UVR impacts interior materials, causing visual degradation and structural damage that can reduce the lifespan of these materials and, if significant surface wear occurs, pathogens can potentially be harbored in the resultant pits or cracks. Surface properties also impact the efficacy of GUV systems. Rough surfaces can limit uniform exposure, while high-reflectance surfaces tend to scatter more visible light, potentially increasing

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59 Carratala, A., Shim, H., Zhong, Q., Bachmann, V., Jensen, J. D., & Kohn, T. (2017). Experimental adaptation of human echovirus 11 to ultraviolet radiation leads to resistance to disinfection and ribavirin. Virus evolution, 3(2), vex035.

60 Tom, E. F., Molineux, I. J., Paff, M. L., & Bull, J. J. (2018). Experimental evolution of UV resistance in a phage. PeerJ, 6, e5190.

61 Goldman, R. P., & Travisano, M. (2011). Experimental evolution of ultraviolet radiation resistance in Escherichia coli. Evolution: International Journal of Organic Evolution, 65(12), 3486-3498.

62 Yamano, N., Kunisada, M., Kaidzu, S., Sugihara, K., Nishiaki-Sawada, A., Ohashi, H., ... & Nishigori, C. (2020). Long-term effects of 222 nm ultraviolet radiation C sterilizing lamps on mice susceptible to ultraviolet radiation. Photochemistry and Photobiology.

63 Fukui, T., Niikura, T., Oda, T., Kumabe, Y., Ohashi, H., Sasaki, M., ... & Matsumoto, T. (2020). Exploratory clinical trial on the safety and bactericidal effect of 222-nm ultraviolet C irradiation in healthy humans. PloS one, 15(8), e0235948.

64 Nouji Narita, Krisana Asano, Keisuke Naito, Hiroyuki Ohashi, Masahiro Sasaki, Yukihiro Morimoto, Tatsushi Igarashi, Aki Nakane. (2020). 222-nm UVC inactivates a wide spectrum of microbial pathogens. Journal of Hospital Infection.

65 Buonanno, Manuela, Ponnaiya, Brian, Welch, David, Stanislauskas, Milda, Randers-Pehrson, Gerhard, Smilenov, Lubomir, Lowy, Franklin D, Owens, David M, and Brenner, David J. "Germicidal Efficacy and Mammalian Skin Safety of 222-nm UV Light." Radiation Research 187, no. 4 (2017): 483-91.

bacterial photorepair.[66] Relative humidity has also been shown to moderate the impacts of UVR on certain bacteria and viruses in addition to influencing their transmission and survival characteristics.

- Polymers, plastics, and rubbers tend to chalk, crack, and lose strength.67,68
- Varnishes and coatings blister and crater.69
- Artificial flooring material treated with UV-resistant coatings displayed an increased formaldehyde release rate when exposed to UVR.70
- Wood becomes discolored even after brief UV exposure.71,72 Surface treatments can mitigate these effects, which are dependent on the surface grain patterns, with exposed end-grains being more susceptible to damage.73

E-3.3.1 Repeated Exposure.

Repeated exposure to UVR could cause surface damage to many common interior materials, potentially creating structures that may harbor pathogens and inhibit future disinfection efforts. Interestingly, both increased surface roughness and reflectivity have been shown to decrease sterilization efficiency.[74,75] The former is likely due to non-uniform 'clumps' of pathogens collecting in surface topological features, thereby increasing the chance that some survive. The latter effect may be due to increased photoreactivation caused by reflected visible light.

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[66] Chinnis, D., Karlicek, R., Pfund, D. (2020, August 30). IALD Webinar: Lighting Design and GUV Technology [video file]. Retrieved from https://www.youtube.com/watch?v=prEFfrtQGjQ

[67] *Youn, B. H., & Huh, C. S. (2005). Surface degradation of HTV silicone rubber and EPDM used for outdoor insulators under accelerated ultraviolet weathering condition. IEEE Transactions on Dielectrics and Electrical Insulation, 12(5), 1015-1024.*

[68] Boubakri, A., Guermazi, N., Elleuch, K., & Ayedi, H. F. (2010). Study of UV-aging of thermoplastic polyurethane material. Materials Science and Engineering: A, 527(7-8), 1649-1654.

[69] Hu, J., Li, X., Gao, J., & Zhao, Q. (2009). UV aging characterization of epoxy varnish coated steel upon exposure to artificial weathering environment. Materials & Design, 30(5), 1542-1547.

[70] Kagi, N., Fujii, S., Tamura, H., & Namiki, N. (2009). Secondary VOC emissions from flooring material surfaces exposed to ozone or UV irradiation. Building and Environment, 44(6), 1199-1205.

[71] Timar, M. C., Varodi, A. M., & Gurău, L. (2016). Comparative study of photodegradation of six wood species after short-time UV exposure. Wood science and technology, 50(1), 135-163.

[72] Müller, Uwe, Rätzsch, Manfred, Schwanninger, Manfred, Steiner, Melanie, and Zöbl, Harald. "Yellowing and IR-changes of Spruce Wood as Result of UV-irradiation." Journal of Photochemistry and Photobiology. B, Biology 69, no. 2 (2003): 97-105.

[73] Chang, S. T., Hon, D. N. S., & Feist, W. C. (2007). Photodegradation and photoprotection of wood surfaces. Wood and Fiber Science, 14(2), 104-117.

[74] Ringus, D. L., & Moraru, C. I. (2013). Pulsed Ligh inactivation of Listeria innocua on food packaging materials of different surface roughness and reflectivity. Journal of food engineering, 114(3), 331-337.

[75] Stannard, C. J., Abbiss, J. S., & Wood, J. M. (1985). Efficiency of treatments involving ultraviolet irradiation for decontaminating packaging board of different surface compositions. Journal of food protection, 48(9), 786-789.

E-3.4 Effectiveness.

As most materials reflect UVR less effectively than visible light, direct exposure is necessary to ensure effective sterilization.[76] Similarly, dirt or grime has the potential to shield pathogens from UVR, so sterilization efforts with UVR should be preceded by some form of surface cleaning. Increased relative humidity (RH) has been shown to increase the resistance of aerosolized bacteria to 254-nm UVR. As RH does not impact overall UV irradiance, this effect must be a result of interactions at the particle level. Certain bacteria may increase in size or water content as RH rises, potentially shielding their DNA from UVR.[77,78] The effect seems to be most pronounced as RH rises above 50%.[79]

E-3.5 Sustainability Concerns.

To reduce the increased energy and material usage, do not install a GUV system in every space, and do not schedule such systems to run continuously. If implemented, a GUV system must only be installed in spaces that have a high risk of disease transmission and must only operate periodically.

E-3.5.1 Energy Use.

The energy usage and cost of a building with installed GUV systems will be higher than the current baseline. As stated previously, it is not recommended that a GUV system be used in place of traditional sanitation practices. Therefore, there would be no direct cost savings by implementing this system. However, during periods of increased risk of infection from pathogens, buildings may integrate more features at the expense of increased energy usage, including improved HVAC systems with better filtration and increased airflow; utilizing pathogen detection tools in the building; and implementing a GUV system in certain areas.

Currently, North American energy codes do not provide guidance for GUV systems. This results in ambiguity for how GUV systems will impact energy code compliance at this time. GUV lamps are exempt from California's Title 20 efficacy standards.

E-3.5.2 Lamp Replacement and Waste.

GUV systems will also require continuous maintenance, including lamp, ballast, or driver replacement. Many GUV systems utilize mercury vapor lamps, which require proper disposal to limit mercury contamination.

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[76] Chinnis, D., Karlicek, R., Pfund, D. (2020, August 30). IALD Webinar: Lighting Design and GUV Technology [video file]. Retrieved from https://www.youtube.com/watch?v=prEFfrtQGjQ

[77] Ko, G., First, M. W., & Burge, H. A. (2000). Influence of relative humidity on particle size and UV sensitivity of Serratia marcescens and Mycobacterium bovis BCG aerosols. Tubercle and Lung disease, 80(4-5), 217-228.

[78] Peccia, J., Werth, H. M., Miller, S., & Hernandez, M. (2001). Effects of relative humidity on the ultraviolet induced inactivation of airborne bacteria. Aerosol Science & Technology, 35(3), 728-740.

[79] Riley, R. L., & Kaufman, J. E. (1972). Effect of relative humidity on the inactivation of airborne Serratia marcescens by ultraviolet radiation. Applied microbiology, 23(6), 1113-1120.

E-4 TYPES OF GUV LAMPS.

There are currently three primary types of GUV lamps: mercury vapor, light-emitting diodes (LED), and excimer lamps. Each lamp type has special considerations. It is important to note that all GUV lamps have relatively low lifetime hours, as listed below, compared to standard lamps and need to be replaced more often. While lamps used for general illumination are evaluated in terms of lumens per watt, GUV lamps cannot be defined with the same metric because they do not produce light in the visual spectrum (i.e., lumens) unless specifically engineered to do so as a safeguard. As such, efficiency for GUV lamps is defined as the percentage of the lamp's total input power that produces UVR.

- Low-pressure mercury vapor (LPM) lamps are the most efficient and most widely used GUV source currently available. These lamps emit monochromatically at a peak of 254 nm and are approximately 30% efficient, which is the highest among the three types. Their lifetime hours are approximately 10,000 hours, and they are the lowest cost GUV lamp.
- LEDs are the least efficient of this group, with efficiency around 3% to 7%. These lamps emit wavelengths that typically range from 265 nm to 280 nm, with an L_{70} of 5,000 to 10,000 hours. LED sources have been manufactured to produce far UV-C wavelengths. However, production of these shorter wavelengths is even less efficient than for longer wavelengths.
- Excimer lamps are slightly less efficient than LPM lamps, with a similar lifetime. Excimer lamps emit at a lower wavelength of 222 nm (far UV-C).

Conventional GUV systems use low-pressure lamps that emit monochromatically at a peak of 254 nm. Medium-pressure lamps that emit a broad range of UV light from 200 nm to 600 nm are also available and, more recently, UV LEDs and plasma-excimer lamps have been developed with emission peaks as low as 210 nm.[80]

E-5 TYPES OF GUV LIGHTING SYSTEMS.

GUV radiation has been proven effective for disinfection in multiple kinds of applications, including water treatment, hospitals, and HVAC integration. During the Covid-19 pandemic, many lighting manufacturers began creating and advertising new GUV systems. Some of these systems have been around for many years, with the intent of disinfecting environments such as surgical suites that require complete sterilization. There are also newer systems that have not been widely implemented. GUV systems are typically deployed in four different configurations: direct fixtures, indirect upper-room fixtures, moveable units, and lamps integral to HVAC equipment.

[80] Taniyasu, Y., Kasu, M., & Makimoto, T. (2006). An aluminium nitride light-emitting diode with a wavelength of 210 nanometres. Nature, 441(7091), 325-328.

E-5.1 Building-Integrated GUV Fixtures.

Building-integrated systems use direct GUV luminaires for surface disinfection. These are permanent installations in the building. GUV radiation can be integrated into luminaires used for lighting the space or installed as independent luminaires for the sole purpose of GUV disinfection. This style, especially with UV-A and UV-B lamps, has been utilized for several years in select hospital spaces where sterilization is a priority. Direct, building-integrated UV-C luminaires have not been widely implemented and are a recent development. As such, there are no industry standards or specific recommendations that manufacturers must adhere to when designing and implementing these systems.

E-5.1.1 Uses.

Direct GUV fixtures can be effective against surface contamination, but the presence of shadows reduces the effectiveness of the installation. Direct GUV luminaires continue to be an effective option for healthcare settings when used selectively. They may also be an effective solution during times of increased risk of disease in office spaces with high-touch spaces like conference rooms and gathering spaces when used while the spaces are not occupied.

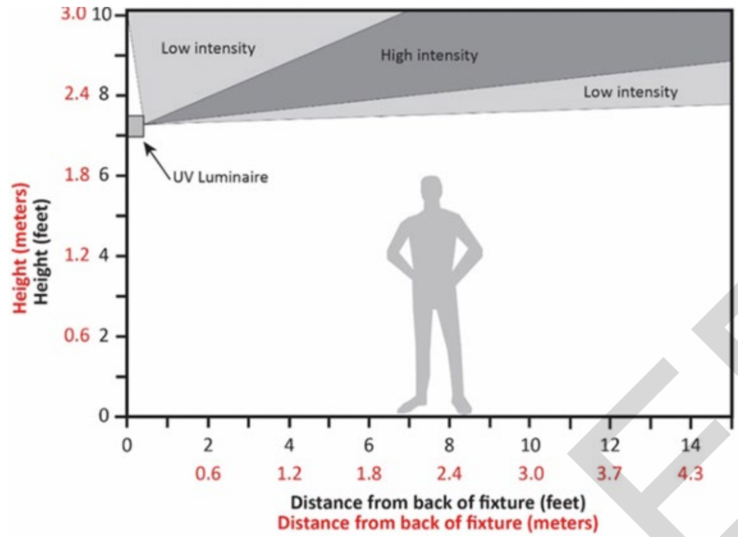
E-5.1.2 Additional Considerations.

Due to safety considerations, advanced controls must be implemented to guarantee that GUV luminaires are energized only when occupants are not present, especially with longer wavelength UV-A, UV-B, and some UV-C lamps. These systems pose a safety risk, which needs to be mitigated appropriately with adequate fail-safe measures. While far UV-C radiation does not currently show any risk to occupants, there are still too many unknowns to recommend continuous use while occupants are present. Further research is recommended, in addition to the development of industry standards.

E-5.2 Indirect Upper-Room GUV Systems.

Indirect upper-room systems are designed with GUV luminaires aimed toward the upper portion of the room, with no direct exposure in the occupied volume, see 0. This type of system can deactivate viral particles in the air, reducing the risk of airborne spread in occupied areas. Indirect upper-room GUV systems are functionally part of the HVAC system, and implementation should be coordinated with the mechanical engineer. A lighting engineer will likely not be involved with this system beyond controls integration.

Figure E-2 Upper-Air GUV Installation (www.ies.org)



E-5.2.2 Uses.

This design should be used in a room with high ceilings. There should be enough space such that a significant amount of air can pass over the system, while leaving the bottom of the system at 7 feet AFF, minimum. This design works best when the air is constantly moving via fans and the HVAC system. Extensive coordination with mechanical engineers is necessary. This system may operate in areas that are occupied, since it is indirect and above head height, but continuous operation is not recommended.

E-5.2.3 Additional Considerations.

This design heavily relies on the airflow within a room. To reduce odor and CO_2 in a room, a relatively low air change per hour (ACH) rate of 1-2 ACH needs to occur. When using an indirect upper-room GUV system, the ACH rate needs to be significantly higher, at 6-12 ACH.[81] The additional energy consumption and HVAC equipment needs to be noted.

The effectiveness of this type of system is highly dependent on the number of air changes per hour. The exact number depends on the desired level of risk mitigation. There are many variables that are specific to each space and HVAC configuration that impact pathogen distribution. In general, a higher ACH rate is generally better from a ventilation perspective.

E-5.2.4 Other Upper-Room Fixture Styles.

Similar to indirect upper-room systems, there are also luminaires with integrated fans and indirect GUV lamps. These are intended to operate similarly to indirect upper-room GUV systems but are self-contained fixtures. Typically, these luminaires contain a UV

[81] Illuminated Engineering Society. IES CR-2-20-V1, *Committee Report: Germicidal Ultraviolet – Frequently Asked Questions*. New York: IES; 2020.

emitter that is internal to the body of the fixture. These could be used to eliminate viral particles in the air and could be used to mitigate risk during occupied hours. However, these also require extensive coordination with mechanical engineers. Without industry standard protocols, designers must understand standard best practice based on current research and commonly used protocols. It is not recommended that designers rely on the manufacturer's claims regarding the system's effectiveness and deployment strategies. Therefore, these systems must be considered with caution but may be considered if upper-room GUV disinfection is desired but not implementable due to ceiling height.

E-5.3 Moveable GUV Units.

Moveable GUV systems are mounted in carts or handheld emitters and are temporarily transported into spaces to be used to sterilize surfaces as part of a cleaning regime. This system is best for disinfecting surfaces in areas that would not normally have permanent GUV installations, such as temporary medical shelters, emergency response areas, operating rooms, and other areas needing disinfection.

Movable GUV systems can be used to disinfect air or surfaces in rooms that do not have permanent systems. While this is an option, there still must be significant airflow within the room, just as in a permanent installation, and the room needs to be unoccupied during GUV operation to limit direct UVR exposure. If the UV emitter is internal to an enclosure or angled upward out of direct view, it could be used to eliminate viral particles in the air and could be used to mitigate risk during occupied hours.

E-5.3.1 Portable handheld devices.

Portable handheld devices may be used to disinfect surfaces in areas that do not have permanent direct GUV systems. The GUV emitted from the device needs to be applied to a surface area for several seconds to disinfect properly. If not applied long enough, the result may be only partially sanitized surfaces, which then contribute to a false sense of security, and this method must then be implemented in addition to traditional cleaning practices. Additionally, these systems rely on an operator to safely direct the UV source away from any humans.

E-5.3.2 Additional Considerations.

Moveable GUV systems that purify the air within a room require a high ACH rate, so their implementation must be coordinated with mechanical engineers. They are best suited for use in small rooms in order to be efficient. Since these are moveable devices, the user needs to make sure the proper controls are in place to protect the safety of the occupants and user. Movable units, especially handheld devices and self-contained home-use sterilization boxes, are not certified by UL.

E-5.4 Integral to HVAC System.

GUV systems that are integral to HVAC systems are installed within HVAC ductwork and kill or inactivate pathogens in the passing airstream. A lighting engineer would not be involved in selecting or implementing this kind of system, since this is the responsibility of the mechanical engineers. This use of GUV radiation has been around for many years as part of HVAC systems.

These systems have little effect on person-to-person pathogen transmission in a room and are no more effective than a simple HEPA air filter. Properly filtering air via the HVAC system is highly recommended, whether using physical or GUV filters, and will reduce airborne viral concentrations without interrupting occupancy. It is important to note that too much airflow will reduce the efficacy of these systems.

E-6 IMPLEMENTING GUV SYSTEMS.

The lack of standards for GUV systems makes it difficult to determine the best products to select and the most efficient use of them. Without standards, designers and engineers are given few resources with which to evaluate products that manufacturers market with few restrictions. With any new technology, claims around UV-C radiation should be considered with skepticism until industry standards have been developed, peer reviewed, and widely accepted by experts. The architectural engineering community has not reached consensus on the best type of GUV system, nor how widely it should be implemented.

E-6.1 Determining if a GUV System is appropriate.

Determining if any GUV system is right for a given space or building will not be determined solely by the lighting designer or electrical engineer. Selecting the correct disease mitigation strategy will require input from the building owner, project manager, public health officials, infectious disease experts, mechanical engineers, and lighting engineers. There are many recommended strategies that building designers can implement to reduce the potential spread of pathogens within the building. Many of these are modifications to the HVAC system design, including increased fresh air, filtration, and air flow. These modifications do not have any known complications, nor will they fully sterilize the environment which increases the risk of viral and bacterial mutations.

If improving the HVAC system is not feasible or is determined to be an insufficient measure on its own, then a GUV system may be considered if implemented correctly. The most effective GUV system is still unknown and varies widely by area type or building.

E-6.2 Selecting a GUV System.

Research indicates that far UV-C radiation is the preferred choice because it is at least as effective as UV-A or UV-B radiation, and it is safer for occupants. This will reduce the risk of exposure and complications if controls do fail. Even though it is not currently recommended to use a direct far UV-C system when occupants are present, further research may indicate that the unintended consequences are minimal, and deployment of the system could be modified to increase usage during times of occupation. UV-A, UV-B, and UV-C systems should never be used in this application.

E-6.2.1 Evaluating GUV Systems.

Many manufacturers are promoting UV-C technology as safe and effective solutions, but these systems are not without complications. Yet currently, there are no standards for GUV-system selection criteria and operation. As noted previously, continuous operation of far UV-C should not be implemented without extreme caution, since this range of wavelengths is not naturally present in our atmosphere and there remain many unknowns regarding long-term effects on humans and the environment. Designers must use caution when selecting a GUV system and must remain vigilant to manufacturers' assertions regarding their products, including but not limited to:

- Unrealistic claims about how frequently the system should be operated
- Disregarding unintended consequences and unknown long-term effects
- No mention of controls
- Stating that it is a catch-all disinfectant that can replace regular cleaning practices

Manufacturers that understand the limitations of GUV systems are likely to suggest a system that is a realistic strategy.

E-6.2.2 System Selection.

GUV systems are an integrated solution that needs input from specialists in HVAC, risk management specialists, and public health officials. Lighting manufacturers are promoting GUV technology since these systems have many shared properties with light. However, lighting designers and electrical engineers do not typically have the expertise to make decisions about the sanitation of facilities. Other disciplines must be involved, especially in the decision-making process. Heavy coordination is required with mechanical engineers to evaluate whether appropriate airflow can be achieved to effectively deploy indirect GUV systems.

Select far UV-C systems for the most flexibility in use: If control safeguards fail during operation, there will be no direct or immediate harm to any humans present in the space. Additionally, if far UV-C radiation is determined to be completely safe, even regarding long-term effects, then the system may potentially be used when the space is occupied in the future.

E-6.3 Deployment.

GUV radiation can be a useful addition to infection control options but should be deployed as part of a multi-pronged response to specific conditions and criteria.

Ubiquitous, continuous deployment is not recommended, to minimize the risk of unknown potential side effects.

- Use surface-cleaning systems in addition to traditional sanitation procedures to increase their effectiveness.
- Use air-cleaning systems to mitigate spread, even in occupied spaces, during high-risk events.
- Coordinate with HVAC for potential GUV deployment in air handling units and/or fan coil units

As with any system, there are trade-offs that should be considered, weighing the needs of the moment against future hazards. If deployed carefully, GUV systems can significantly reduce the risk of disease transmission within buildings and help combat the spread of antibiotic-resistant bacteria. The use of a GUV system should not be continuous, and such a system should be used along with regular cleaning protocols, not instead of these protocols. These GUV systems may also be installed in the air handling units and/or fan coil units. The most successful and safe deployment will be heavily reliant on reliable controls, which will require that the GUV system communicates with both the building automation system (BAS) and the lighting control system. Refer to ANSI/IES RP-44-21, *Recommended Practice: Ultraviolet Germicidal Irradiation (UVGI)*, Section 9.0 Systems: Comparison, for details on how to select and compare systems based on application type. Also refer to Section 9.5 Summary Tables for comparisons of systems, including various systems' advantages and disadvantages.

E-6.3.1 GUV System Controls.

GUV systems must be controlled completely independently from the lighting systems within any given space. However, the GUV system controls must also communicate with the BAS and lighting control system to receive occupancy status, building occupancy schedules, and ACH data. For each space, control of GUV systems needs special consideration regarding the use of the space and the type of system installed in order to protect public safety and health. These control systems must be implemented in order to protect maintenance personnel from direct exposure during maintenance operations.

- The GUV system must be controlled independent of the lighting system.
- Each room or area that contains a GUV system must be controlled independently of any other room or area.
- Direct GUV systems must not operate when occupancy sensors detect that the room is occupied. This information can be obtained through the lighting control system. This is especially important for direct UV-A, UV-B, and UV-C systems, where exposure can be immediately harmful to humans.

- All GUV systems must have local, manual shut-off. Refer to ANSI/IES RP-44-21, *Recommended Practice: Ultraviolet Germicidal Irradiation (UVGI)*, Section 9.0 Systems: Comparison, for details on how to select and compare systems based on application type. Also refer to Section 9.5 Summary Tables for comparisons of systems including various systems' advantages and disadvantages.

- Moveable GUV units, which cannot be connected to the lighting control system, should be operated via a remote control.

- It is recommended that the GUV system be only turned on in association with a higher risk event, which should also coincide with increased fresh air and airflow.

E-6.3.2 System Maintenance.

Do not implement a GUV system without considering system commissioning and on-going maintenance. Without industry guidelines for deploying and maintaining these systems, specifiers must evaluate manufacturer's recommendations, if any, regarding the long-term use of these products. Do not consider manufacturers that do not address the longevity or maintenance of their systems.

Typically, Operations and Maintenance staff will not have the expertise or tools available to monitor, control, and update a GUV system. When specifying a GUV system, establish protocol for on-going maintenance, including continuous support from outside specialists. Specialists must:

- Verify that the system is functioning as intended with calibrated meters

- Utilize personal protective equipment (PPE) when working under energized UVR fixtures

- Maintain lamp replacement schedule to ensure proper function

E-6.3.2.1 Lamp Replacement.

GUV systems must provide a notification system indicating that the GUV lamp life has deteriorated and must be replaced. There are currently no standards for notification systems. Unless regular UV measurements are taken in-field, this notification system will be based on estimated lamp life by the lamp manufacturer.

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APPENDIX F GLOSSARY

F-1 ACRONYMS.

ACP	Access Control Point
AFF	above finished floor
ANSI	American National Standards Institute
ASHRAE	American Society of Heating, Refrigerating, and Air-Conditioning Engineers
CCT	correlated color temperature
CRI	color rendering index
DoD	Department of Defense
ECF	Entry Control Facility
FC	Facilities Criteria
HID	high-intensity discharge
Hz	hertz
kW	kilowatts
kWh	kilowatt-hours
LEC	light-emitting capacitor
LED	light-emitting diode
LLD	lamp lumen depreciation
NEC	National Electric Code
NEMA	National Electrical Manufacturers Association
NESC	National Electrical Safety Code
NFPA	National Fire Protection Association
SF	square foot
SPD	spectral power distribution
SSL	Solid state lighting

THD total harmonic distortion

TLED tubular light-emitting diode

UFC Unified Facilities Criteria

UFGS Unified Facilities Guide Specifications

UL Underwriters Laboratories

V volt

W watt

F-2 DEFINITIONS OF TERMS.

The definitions of lighting terms are from ANSI/IES LS-1-21, *Lighting Science: Nomenclature and Definitions for Illuminating Engineering*.

Adaptation: The process by which the retina becomes accustomed to more or less light than it was exposed to during an immediately preceding period. It results in a change in the sensitivity to light.

Aircraft Maintenance Area: The full area designated for aircraft parking and maintenance area. Typically includes the depth from the hangar bay door to the back wall and width from the centerline boundary of the neighboring aircraft maintenance zones or to the side wall.

Altitude: The angular distance of a heavenly body measured on the great circle that passes perpendicular to the plane of the horizon, through the body and through the zenith. It is measure positively from the horizon to the zenith, from 0 degrees to 90 degrees.

Ambient Lighting: Lighting throughout an area that produces general illumination

Area Lighting Luminaire: A complete lighting device consisting of a light source and driver, where appropriate, together with its direct appurtenances such as globe, reflector, refractor, housing, and such support as is integral with the housing. The pole, post, or bracket is not considered part of the luminaire.

Luminance: Luminance is a property of a geometric ray. Luminance as measured by conventional meters is averaged with respect to two independent variables, area and solid angle; both must be defined for a complete description of a luminance measurement.

Azimuth: The angular distance between the vertical plane containing a given line or celestial body and the plane of the meridian.

Baffle: A single opaque or translucent element to shield a source from direct view at certain angles, to absorb or block unwanted light, or to reflect and redirect light.

Ballast: A device used with an electric-discharge light source to obtain the necessary circuit conditions (voltage, current, and waveform) for starting and operating.

Bollard: A type of luminaire having the appearance of a short, thick post, used for walkway and grounds lighting. The optical components are usually top-mounted.

Bowl: An open-top diffusing glass or plastic enclosure used to shield a light source from direct view and to redirect or scatter the light.

Bracket (mast arm): An attachment to a light source post or pole from which a luminaire is suspended.

BUG (Backlight, Uplight, Glare): Backlight – the amount of percent lamp lumens or the luminaire zonal lumens distributed behind a luminaire between zero degrees vertical (nadir) and 90 degrees vertical. Uplight – the percent lamp lumens or the amount of luminaire zonal lumens distributed above a luminaire between 90 and 180 degrees vertical. Glare – the amount of percent lamp lumens or the luminaire zonal lumens distributed 60 and 90 degrees vertical.

Candela, cd: The SI unit of luminous intensity, equal to one lumen per steradian (lm/sr).

Candlepower (cp): Another term for luminous intensity," expressed in candelas.

Clerestory: That part of a building that rises clear of the roofs or other parts and whose walls contain windows for lighting the interior.

Coefficient of Utilization (CU): The ratio of luminous flux (lumens) calculated as received on the work plane to the total luminous flux (lumens) emitted by the light sources alone. It is equal to the product of room utilization factor and luminaire efficiency.

Color Matching: The action of making a color appear the same as a given color.

Color Rendering: Effect of an illuminant on the color appearance of objects by conscious or subconscious comparison with their color appearance under a reference illuminant.

Color Rendering Index (of a light source) (CRI): A measure of the degree of color shift objects undergo when illuminated by the light source as compared with those same objects when illuminated by a reference source of comparable color temperature.

Color Temperature (of a light source): See Correlated Color Temperature.

Contrast: *See Luminance Contrast.*

Correlated Color Temperature (of a light source) (CCT): The absolute temperature of a blackbody whose chromaticity most nearly resembles that of the light source.

Daylight Availability: The luminous flux from the sun plus sky at a specific location, time, date, and sky condition.

Diffused Lighting: Lighting provided on the work plane or on an object that is not incident predominantly from any particular direction.

Dimmer: A device used to control the intensity of light emitted by a luminaire or light source by controlling the voltage or current available to it.

Direct Component: That portion of the light from a luminaire that arrives at the work plane without being reflected by room surfaces.

Direct Glare: Glare resulting from high luminances or insufficiently shielded light sources in the field of view. It is usually associated with bright areas, such as luminaires, ceilings, and windows that are outside the visual task or region being viewed. A direct glare source can also affect performance by distracting attention.

Direct-Indirect Lighting: A variant of general diffuse lighting in which the luminaires emit little or no light at angles near the horizontal.

Direct Lighting: Lighting involves luminaires that distribute 90 to 100% of the emitted light in the general direction of the surface to be illuminated. The term usually refers to light emitted in a downward direction.

Directional Lighting: Lighting provided on the workplane or on an object, predominantly from a preferred direction.

Disability Glare: The effect of stray light in the eye whereby the contrast of the retinal image is reduced and, consequently, whereby visibility and visual performance are reduced. A direct glare source that produces discomfort can also produce disability glare by introducing a measurable amount of stray light in the eye.

Discomfort Glare: Glare that produces discomfort. It does not necessarily interfere with visual performance or visibility.

Downlight: A small direct lighting unit that directs the light downward and can be recessed, surface-mounted, or suspended.

Efficacy: See *Luminous Efficacy of a Source of Light.*

Efficiency: See *Luminaire Efficiency*.

Electroluminescence: The emission of light from a phosphor excited by an electromagnetic field.

Emergency Exit: A way out of the premises that is intended to be used only during an emergency.

Emergency Lighting: Lighting designed to supply illumination essential to the safety of life and property in the event of a failure of the normal supply. The system must be capable of providing minimum required illuminance specified in NFPA 101.

Exit Sign: A graphic device including words or symbols that indicates or identifies an escape route or the location of, or direct to, an exit or emergency exit.

Floodlight: A projector designed for lighting a scene or object to a luminance considerably greater than its surroundings.

Fluorescent Light Source: A low pressure mercury electric-discharge light source in which a fluorescing coating (phosphor) transforms some of the UV energy generated by the discharge into light.

Flush-mounted or Recessed Direct/Indirect Luminaire: A luminaire that is mounted above the ceiling (or behind a wall or other surface) with the opening of the luminaire level with the surface.

Footcandle, fc: A unit of illuminance equal to 1 lm/ft^2.

Glare: The sensation produced by luminances within the visual field that are sufficiently greater than the luminance to which the eyes are adapted, which causes annoyance, discomfort, or loss in visual performance, and visibility. Direct glare is caused by excessive light entering the eye from a bright light source. The potential for direct glare exists anytime one has a direct view of a light source. With direct glare, the eye has a harder time seeing contrast and details. A system designed solely on lighting levels, tends to aim more light directly towards a task, thus producing more potential for glare. Direct glare can be minimized with careful equipment selection and placement.

Globe: A transparent or diffusing enclosure intended to protect a light source, to diffuse and redirect its light, or to change the color of the light.

High Ambient Temperatures: Above 50 degrees Celsius.

High-Intensity Discharge (HID) Light Source: An electric-discharge light source in which the light-producing arc is stabilized by bulb wall temperature, and the arc tube has a bulb wall loading in excess of 3 W/cm^2. HID light sources include groups of light sources known as mercury, metal halide, and high-pressure sodium.

High-Mast Lighting: Illumination of a large area by means of a group of luminaires that are designed to be mounted in a fixed orientation at the top of a high mast, generally 20 m (65 ft.) or higher.

High-Pressure Sodium (HPS) Light Source: A high intensity discharge (HID) light source in which light is produced by radiation from sodium vapor.

Illuminance: The areal density of the luminous flux incident at a point on a surface. Units: lux or footcandles.

Illuminance (footcandle or lux) Meter: An instrument for measuring illuminance on a plane. The instrument comprises some form of photodetector with or without a filter driving a digital or analog readout through appropriate circuitry.

Illumination: An alternative but deprecated term for illuminance. In this document, it is used in its more general sense of simply "lighting."

Incandescent Filament Light Source: A light source in which light is produced by a filament heated to incandescence by an electric current.

Indirect Component: The portion of the luminous flux from a luminaire that arrives at the workplane after being reflected by room surfaces.

Indirect Lighting: Lighting involving luminaires that distribute 90 to 100% of the emitted light upward.

Induction Lighting: Lighting technology that uses electric current to induce an electromagnetic field within the phosphor coated light source. No filaments are used. Its advantages include instant on/off operation, white light with good color rendering characteristics, and a long light source life of 100,000 hours.

Intensity (candlepower) Distribution Curve: A curve, often polar, that represents the variation of luminous intensity of a light source or luminaire in the plane through the light center.

Isolux (Isofootcandle) Line: A line plotted on any appropriate set of coordinates to show all the points on a surface where the illuminance is the same.

Kelvin: The unit of absolute temperature used to designate the color temperature or correlated color temperature of a light source. Symbol: K.

Light Source: A generic term for a source created to produce optical radiation.

Light Source Lumen Depreciation (LLD) Factor: The fractional loss of light source lumens at rated operating conditions that progressively occurs during light source operation.

Lens: A glass or plastic element used in luminaires to change the direction and control the distribution of light rays.

Light: Radiant energy that is capable of exciting the retina and producing a visual sensation.

Light-Emitting Diode (LED): A p-n junction solid state diode whose radiated output is a function of its physical construction, material used, and exciting current.

Light Loss Factor (LLF): Formerly called maintenance factor. The ratio of illuminance (or exitance or luminance) for a given area to the value that would occur if light sources operated at their (initial) rated lumens and if no system variation or depreciation had occurred.

Light Meter: A common name for an illuminance meter.

Light Source Color: The color of the light emitted by a source.

Louver: An optical-control element, usually used in multiples, to shield a source from view at certain angles, to absorb or block unwanted light, or to reflect or redirect light.

Low-Bay Lighting: Interior lighting where the roof trusses or ceiling height is approximately 6.1 m (20 ft.) or less above the floor.

Low-Pressure Mercury Vapor (LPM) Light Source: A discharge light source (with or without a phosphor coating) in which the partial pressure of mercury vapor does not exceed 100 Pa during operation.

Low-Pressure Sodium (LPS) Light Source: A discharge light source in which light is produced by radiation from sodium vapor.

Lumen, lm: SI unit of luminous flux. Radiometrically, it is determined from the radiant power (see luminous flux). Photometrically, it is the luminous flux emitted within a unit solid angle (one steradian) by a point source having a uniform luminous intensity of one candela.

Lumen Depreciation: The decrease in lumen output that occurs as a lamp is operated, until failure.

Lumen Method: A procedure used to determine the relationship between the number and types of lamps, light sources and luminaires, the room characteristics, and the average level of illuminance on the work plane. It takes into account both direct and reflected flux.

Luminaire (light fixture): A complete lighting unit consisting of a light source or light sources and driver(s) (when applicable) together with the parts designed to distribute the light, to position and protect the light sources, and to connect the light sources to the power supply.

Luminaire Dirt Depreciation (LDD): The ratio of lumens emitted from a luminaire with dirt accumulated to the lumens emitted from the same luminaire when clean.

Luminaire Efficiency: The luminous flux emitted by a luminaire, divided by the luminous flux emitted by the source(s). Sometimes called light output ratio (LOR).

Luminance: The apparent brightness of a surface, measured in candelas per foot (cd/ft^2) or square meter (cd/m^2), sometimes called nits.

Luminance Contrast: The relationship between the luminances of an object and its immediate background.

Luminance Ratio: The ratio between the luminances any two areas in the visual field.

Luminous Efficacy of a Source of Light: The quotient of the total luminous flux emitted to the total light source power input. It is expressed in lumens per watt.

Luminous Flux: The time rate of flow of radiant energy, evaluated in terms of a standardized visual response. Units: lumens.

Matte Surface: A surface from which the reflection is predominantly diffuse, with or without a negligible specular component.

Means of Egress: An unobstructed and continuous way of exit from any point in a building or structure to a public way. It consists of three distinct parts: the exit access, the exit, and the exit discharge. A means of egress consists of the vertical and horizontal travel ways, including intervening room spaces, doorways, hallways, corridors, passageways, ramps, stairs, lobbies, horizontal exits, escalators, enclosures, courts, balconies, and yards.

Mercury Light Source: A high-intensity discharge (HID) light source in which the major portion of the light is produced by radiation from mercury operating at a partial pressure in excess of 10s Pa.

Mesopic Vision: Vision with fully adapted eyes at luminance conditions between those of photopic and scotopic vision.

Multi-level Switching: Multi-level switching allows multiple light sources within a luminaire to be switched independently. For example, a three light source luminaire would offer four light output settings: 100%, 66%, 33%, and OFF.

Orientation: The position of a building with respect to compass directions.

Overhang: In roadway lighting: the distance between a vertical line passing through a specified point (often the photometric center) of a luminaire and the curb or edge of a roadway.

Pendant Luminaire: *See Suspended* luminaire.

Peripheral Vision: The seeing of objects displaced from the primary line of sight and outside the central visual field.

Photometry: The measurement of quantities associated with light.

Photopic Vision: Vision mediated essentially or exclusively by the cones. It is generally associated with adaptation to a luminance of at least 5 cd/m^2.

Point-by-Point Method: A method of lighting calculation, now called the point method.

Point Method: A procedure for predetermining the illuminance at various locations in lighting installations by use of luminaire photometric data. The direct component of illuminance due to the luminaires and the interreflected component of illuminance due to the room surfaces are calculated separately. The sum is the total illuminance at a point.

Point Source: A source of radiation, whose dimensions are sufficiently small, compared with the distance between the source and the irradiated surface, that these dimensions can be neglected in calculations and measurements.

Pole (roadway lighting): A standard support generally used where luminaires are located.

Quality of Lighting: Pertains to the distribution of luminance in a visual environment. The term is used in a positive sense and implies that all luminances contribute favorably to visual performance, visual comfort, ease of seeing, safety, and aesthetics for the specific visual tasks involved.

Ramped Dimming: A gradual dimming rate that ensures occupants in the space will not perceive a sudden change in light levels.

Rated Light Source Life: The life value assigned to a particular type of light source. This is commonly a statistically determined estimate of average or of median operational life.

Reflected Glare: Glare resulting from reflections of high luminances in polished or glossy surfaces in the field of view.

Reflection: A general term for the process by which the incident flux leaves a (stationary) surface or medium from the incident side without change in frequency.

Reflector: A device used to redirect the flux from a light source by the process of reflection.

Scotopic Vision: Vision mediated essentially or exclusively by the rods. It is generally associated with adaptation to a luminance below about 0.001 cd/m².

Self-Ballasted Light Sources: Any arc discharge light source of which the current limiting devices is an integral part.

Solid State Lighting: Light sources that generate light through electroluminescence rather than filaments or gas discharge. SSL sources include light emitting diodes (LEDs), organic light emitting diodes (OLEDs), and polymer light emitting diodes (PLED).

Spacing: For roadway lighting, the distance between successive lighting units, measured along the centerline of the street.

Spacing-to-Mounting-Height Ratio: The ratio of the actual distance between luminaire centers to the mounting height above the horizontal ground or work plane.

Suspended (pendant) Luminaire: A luminaire that is hung from a ceiling by supports.

Table Lamp: A portable luminaire with a short stand, suitable for mounting on furniture.

Translucent: Transmitting light diffusely or imperfectly.

Transmission: A general term for the process by which incident flux leaves a surface or medium on a side other than the incident side, without change in frequency.

Transmittance: The ratio of the transmitted flux to the incident flux.

Transmittance, Visible (T_{vis}): The percentage of the visible spectrum transmitted.

Transparent: Having the property of transmitting rays of light through its substance so that bodies situated beyond or behind can be distinctly seen.

Troffer: A long recessed direct/indirect lighting unit usually installed with the opening flush with the ceiling.

Tungsten-Halogen Light Source: A gas-filled tungsten filament incandescent light source containing a certain proportion of halogens in an inert gas whose pressure exceeds 3 atm.

Uniformity: Lighting level or illuminance uniformity is important to work surfaces where sustained tasks are performed as well as on wall and ceiling surfaces that make up a significant portion of the field of view. Poor uniformity can cause adaptation problems. Flicker or strobing of luminaires can cause annoyances as well as headaches and fatigue.

Valance: A longitudinal shielding member mounted across the top of a window or along a wall (and is usually parallel to the wall) to conceal light sources, giving both upward and downward distributions.

Valance Lighting: Lighting comprising light sources shielded by a panel parallel to the wall at the top of a window.

Veiling Reflection: Regular (specular) reflection, superimposed on diffuse reflection from an object, that partially or totally obscures the details to be seen by reducing the contrast. This sometimes is called reflected glare. Another kind of veiling reflection occurs when one looks through a pane of glass. A reflected image of a bright element or surface may be seen superimposed on what is viewed through the glass pane.

Visibility: The quality or state of being perceivable by the eye. In many outdoor applications, visibility is defined in terms of the distance at which an object can be just perceived by the eye. In indoor applications, it usually is defined in terms of the contrast or size of a standard test object when observed under standardized viewing conditions and having the same threshold as the given object.

Volt: The difference in electrical potential between two points in a circuit.

Watt: The unit of power (rate of doing work). In electrical calculation, one watt is the power produced by a current of one ampere across a potential difference of one volt.

Workplane: The plane on which a visual task is usually done, and on which the illuminance is specified and measured. Unless otherwise indicated, this is assumed to be a horizontal plane 0.76 meters (30 inches) above the floor.

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APPENDIX G REFERENCES

AMERICAN ASSOCIATION OF STATE HIGHWAY AND TRANSPORTATION OFFICIALS

https://www.transportation.org

AASHTO GL-6, *Roadway Lighting Design Guide*

AMERICAN NATIONAL STANDARDS INSTITUTE

https://www.ansi.org

ANSI C78.54, *American National Standard for Electric Lamps - Specification Sheet for Tubular Fluorescent Replacement and Retrofit LED Lamps*. 2019

ANSI C136.41, *Roadway and Area Lighting Equipment – Dimming Control Between an External Locking Type Photocontrol and Ballast or Driver.* 2013

AMERICAN SOCIETY OF HEATING REFRIGERATION AND AIR CONDITIONING ENGINEERS

https://www.ashrae.org/

ANSI/ASHRAE/IES 90.1, *Energy Standard for Buildings Except Low-Rise Residential Buildings,* 2013

DEPARTMENT OF ENERGY

https://www.energy.gov/

Department of Energy. Dimming LEDs with Phase-Cut Dimmers: The Specifier's Process for Maximizing Success. October 2013

ENERGY POLICY ACT OF 2005

https://www.wbdg.org/ffc/fed/congressional-acts/energy-policy-act-2005

ILLUMINATING ENGINEERING SOCIETY

https://www.ies.org/

ANSI/IES LM-79-19, *Approved Method: Electrical and Photometric Measurements of Solid State Lighting Products*, 2019

ANSI/IES LM-80-20, *Approved Method: Measuring Luminous Flux and Color Maintenance of LED Packages, Arrays and Modules,* 2020

ANSI/IES LP-3-20, *Lighting Practice: Designing and Specifying Daylighting for Buildings,* 2020

ANSI/IES LP-6-20, *Lighting Practice: Lighting Control Systems – Properties, Selection, and Specification,* 2020

ANSI/IES LP-8-20, *Lighting Practice: The Commissioning Process Applied to Lighting and Control Systems,* 2020

ANSI/IES LP-9-20, *Lighting Practice: Upgrading Lighting Systems in Commercial and Institutional Spaces,* 2020

ANSI/IES RP-1-20, *Recommended Practice: Lighting Office Spaces,* 2020

ANSI/IES RP-3-20, *Recommended Practice: Lighting Educational Facilities,* 2020

ANSI/IES RP-6-20, *Recommended Practice: Lighting Sports and Recreational Areas,* 2020

ANSI/IES RP-7-21, *Lighting Practice: Lighting Industrial Facilities*, 2021

ANSI/IES RP-8-21, *Recommended Practice: Lighting Roadway and Parking Facilities,* 2021

ANSI/IES TM-15-20, *Technical Memorandum: Luminaire Classification System for Outdoor Luminaires,* 2020

ANSI/IES TM-21-19, *Technical Memorandum: Projecting Long Term Lumen, Photon, and Radiant Flux Maintenance of LED Light Sources,* 2019

IDA-IES *Model Lighting Ordinance (MLO) with User's Guide,* 2011

INTERNATIONAL COMMISSION ON ILLUMINATION

https://cie.co.at/

CIE 191, *Recommended System for Mesopic Photometry Base on Visual Performance*, 2010

NATIONAL ELECTRICAL MANUFACTURERS ASSOCIATION

https://www.nema.org/

SSL 7a-2015: *Phase-Cut Dimming for Solid State Lighting-Basic Compatibility*

NATIONAL FIRE PROTECTION ASSOCIATION

https://www.nfpa.org/

NFPA 70, *National Electric Code*

NFPA 101, *Life Safety Code*

NAVAL FACILITIES ENGINEERING COMMAND

MIL-HDBK-1013/1A, *Design Guidelines for Physical Security of Buildings*.

UNIFIED FACILITIES CRITERIA

https://www.wbdg.org/ffc/dod/unified-facilities-criteria-ufc

UFC 1-200-01, *DoD Building Code*

UFC 1-200-02, *High Performance and Sustainable Building Requirements*

UFC 3-101-01, *Architecture*

UFC 3-260-01, *Airfield and Heliport Planning and Design*

UFC *3-490-06, Elevators*

UFC 3-535-01, *Visual Air Navigation Facilities*

UFC 3-600-01, *Fire Protection Engineering for Facilities*

UFC 4-010-06, *Cybersecurity of Facility-Related Control Systems*

UFC 4-020-01, *DoD Security Engineering Facilities Planning Manual*

UFC 4-021-02, *Electronic Security Systems*

UFC 4-022-01, *Security Engineering: Entry Control Facilities/Access Control Points*

UFC 4-025-01, *Security Engineering: Waterfront Security*

UFC 4-152-01, *Design: Piers and Wharves*

UFC 4-510-01, *Design*: Military Medical Facilities

UFC 4-740-02, *Fitness Centers*

UFC 4-740-14, *Design*: *Child Development Centers*

FC 4-721-10N, *Navy and Marine Corps, Unaccompanied Housing*

FC 4-740-14N, Navy and Marine Corps Child Development Centers

WHOLE BUIDING DESIGN GUIDE RESOURCES

Entry Control Facility/Access Control Point Lighting Analysis

https://www.wbdg.org/FFC/DOD/UFC/ufc_3_530_01_ecf_acp_lighting_analysis.pdf