Figure 24. Overhead and side windows combined with electric lighting provide relatively uniform lighting in this space. The light colored floor reflects light to the underside of the large structures.
(Image from iStock / PatrickHutter)

16.6 Control Rooms

The control room is the nerve center of facilities such as electric generating plants, electric dispatch facilities, steam or hot water generating plants, and chemical plants, and its equipment are continuously monitored. Lighting should be designed with special attention on the comfort of the operator; direct and reflected glare and veiling reflections need to be minimized, and luminance ratios should be low. Along with ordinary office-type visual tasks, the operator has to read gauges, meters and other monitoring devices, often at distances of 3 to 4.5 m (10 to 15 ft) away. It is important that reflected glare and veiling reflections be eliminated from these indicating devices, including those with curved glass faces.

While the practice is not standardized, most control-room lighting involves one of two general categories: diffuse lighting or directional lighting. Diffuse lighting may be from low-luminance, indirect lighting equipment, solid luminous plastic ceilings, or louvered ceilings. Directional lighting may be from recessed troffers that follow the general contour of the control board. (These luminaires should be accurately located to keep reflected light out of the glare zone.) Lighting for the rest of the room may be from any type of low-luminance general lighting equipment.

Digital control room data displays are increasingly more common, and the problems concerning lighting and VDTs are more in evidence. Many operators like to have black or dark colored backgrounds on their VDTs in order to increase the contrast between pixel derived data and its background. In this instance the veiling reflection problems are increased over those with light background panel meters. Under these conditions light colored walls behind the operator, walls and lighting outside of glass partitions, floors, and even light reflecting off the operator's clothing and the table surfaces next to the operator can show up as veiling reflections in the VDT screen.

Often, the orientation and tilt angle of these VDT screens may not be easily adjusted to reduce objectionable screen reflections. In these cases, control of sources of direct and reflected light relative to the screens and operators is even more critical. (See **Figures 1 (a)** and **1 (b)** in **Section 3.4**).

16.7 Manufacturing Electronic Assemblies

Electronics manufacturing is highly automated, with PC boards being populated, tested and inspected without direct human interface. However, there is routine gross handling of the boards and other large components from one automated process to another. Given that mishandling of the components can quickly destroy them, lighting is important to this manufacturing process.

As with most lighting applications, one should consider both quantity and quality of illumination. The quantity recommended by the Association of Connecting Electronics Industries in Standard IPC-A-610,[30] is 1,000 lux (100 footcandles) with CCT between 3000 K and 5000 K, and further states, "Light sources should be selected to prevent shadows."

This specification may suffice for manual or visual inspection; however, it gives little direction for the lighting designer.

Typically, most manual operations involving visual tasks larger than 2 mm^2 with adequate contrast and average speed can be accomplished with 300 lux (30 footcandles). If any one of these parameters is suspect, 500 lx (50 fc) should be adequate. Manual soldering and re-work may require the specified 1,000 lux. (Consult *The Lighting Handbook*, 10th ed., for more information.)

Correlated color temperature can be important; however, the range of 3000 K to 5000 K is overly broad and can be complied with by nearly any human-made light source.

Color rendering, however, is not specified by IPC-A-610 and may be one of the most important factors, given that most electronic components are color-coded. Therefore, light sources with a CRI higher than 70 should be used for tasks when color identification is important. Diffuse linear sources are best when shadows on the task are a concern. (For additional information, refer to IPC 610.[31])

17.0 LIGHTING FOR SPECIFIC VISUAL TASKS

This section describes certain industrial visual tasks and suggested lighting techniques for addressing them.

17.1 Convex Surfaces

Discriminating detail on a convex surface, as in reading a convex scale on a micrometer caliper, is a typical visual task. The reflected image of a large-area low-luminance source on the scale provides excellent contrast between the dark figures and divisions and the bright background without producing reflected glare. The use of a very small, intense source for such applications results in a narrow, brilliant band that obscures the remainder of the scale because of the harsh specular reflection and loss of contrast between the figures or divisions and the background. **Figure 25** shows this effect on a flat surface.

17.2 Flat Surfaces

In viewing a flat surface, such as a flat scale, the visual task is similar to that in reading a convex scale. With a flat scale, however, it is possible, depending on the size, location and shape of the source, to reflect the image of the source either on the entire scale or only on a small part of it. If the reflected image of the source is restricted to too small a part of the scale, the reflection is likely to be glaring.

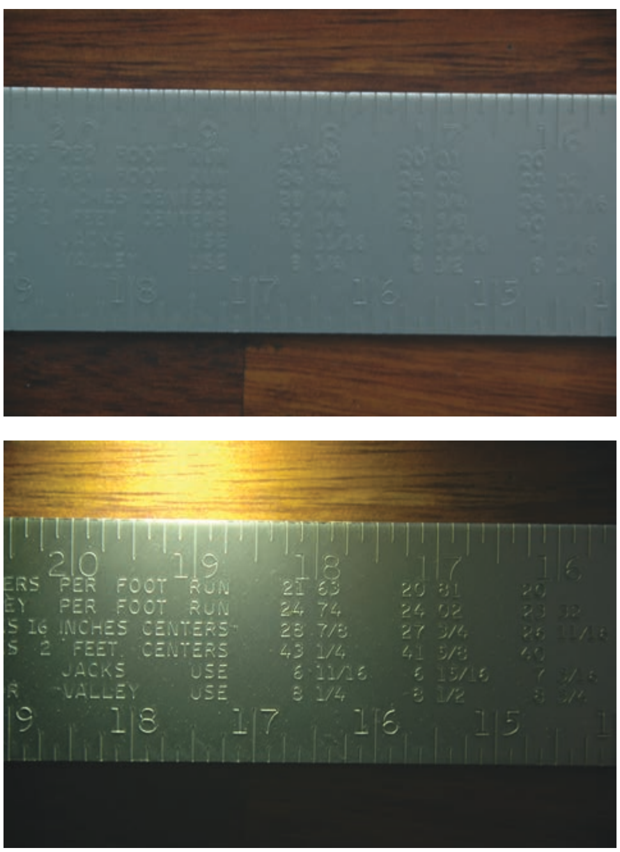

Figure 25. Top: Metal ruler illuminated with an ambient lighting system. Bottom: Same object illuminated with a task light adjusted to reveal the embossed figures. (Images courtesy of Doug Paulin)

17.3 Scribed Marks

The visibility of scribed marks depends upon the characteristics of the surface, the orientation of the scribed mark and the nature of the light source. Directional light produces good visibility of scribed marks on untreated cold-rolled steel if the marks are oriented for maximum visibility, so that the brightness of the source is reflected from the side of the scribed mark to the observer's eye. Unfortunately, this technique reduces the visibility of other scribed marks. Better results are obtained with a large-area, low-luminance source. If the surface to be scribed is first treated with a low-reflectance dye, the process of scribing will remove the dye and expose the surface of the metal. Such scribing appears bright against a dark background. The same technique is appropriate for lighting specular or diffuse aluminum. In this case, the scribed marks will appear dark against a bright background. A similar effect is shown in **Figure 25**.

17.4 Center-punch Marks

A visual task quite similar to scribing is that of seeing center-punch marks. Maximum visibility is obtained when the side of the punch opposite the observer reflects the brightness of a light source. A directional source located between the observer and the task provides excellent results when the light is at an angle of about 45 degrees with the horizontal.

17.5 Concave Specular Surfaces

The inspection of concave specular surfaces is difficult because of reflections from surrounding light sources. Large-area, low-luminance sources provide the best visibility. In the machining of small metal parts, a low-luminance source of approximately 1,700 cd/m^2 is desirable. The size of the source depends on the shape of the machined surface and the area from which it is desired to reflect the brightness. The techniques applicable to specular reflections can also be applied to semi-specular surfaces. (For more information, see **Section 17.7**.)

17.6 Flat Specular Surfaces

As with concave specular surfaces, large-area, low-luminance sources provide the best visibility. A luminance of approximately 1,700 cd/m² is desirable here as well. The size of the source depends on the shape of the machined surface and the area from which it is desired to reflect the brightness. The techniques applicable to specular reflections can also be applied to semi-specular surfaces.

The geometry for determining luminous source size is illustrated in **Figure 26**. The first step is to draw lines from the extremities of the surface that is to reflect the source, to the location of the observer's eye, forming angle α. At the intersections of these lines with the plane of the surface, vertical lines are erected from that plane, forming angles $\beta 1$ and $\beta 2$. These lines are then projected to the luminaire location to define the luminaire width, and then extended in the opposite direction until they intersect, forming an angle.

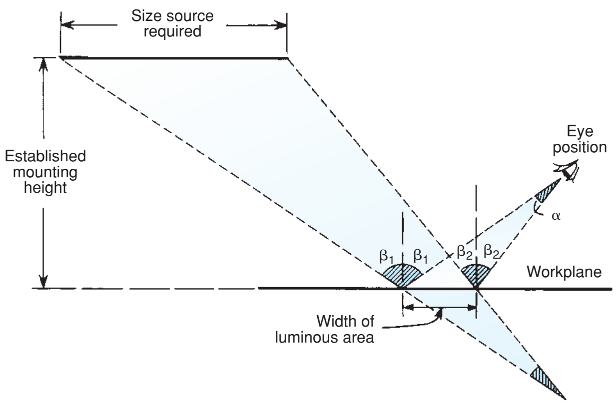

Figure 26. Procedure used for establishing the luminaire size necessary to obtain source reflections on a flat specular surface.

17.7 Convex Specular Surfaces

As with concave and flat specular surfaces, a large-area, low-luminance light source can provide the best visibility. A luminance of approximately 1,700 cd/m² is desirable here as well. The size of the source depends on the shape of the machined surface and the area from which it is desired to reflect the brightness. The techniques applicable to specular reflections can also be applied to semi-specular surfaces.

The width of the luminous area of the convex surface is shown in **Figure 27**. Lines are drawn from the location of the observer's eye to the edges of the surface's luminous area, forming angle α. The next step is to erect the normal at intersections of lines with the surface. At these intersections and on the other side of the normal, lines are constructed to form angles equal to those to the eye (the same procedure as that for flat surfaces described above).

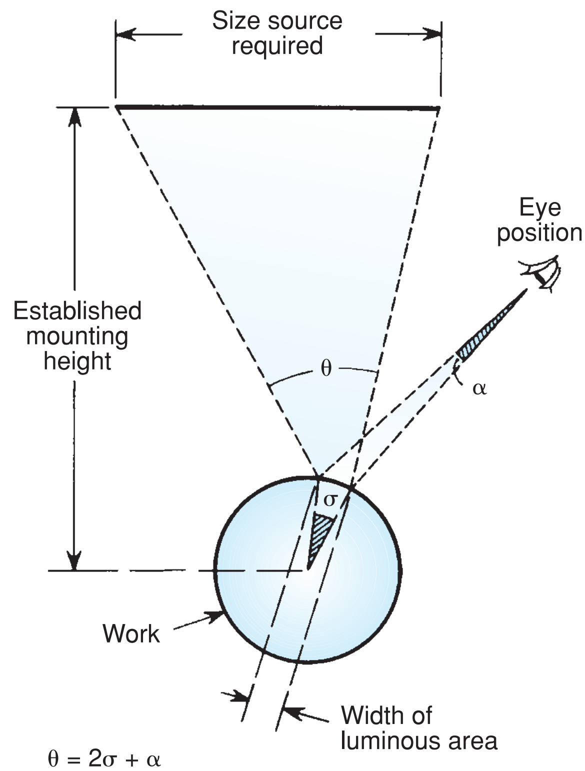

Figure 27. Procedure used for establishing the luminaire size necessary to obtain source reflections on a convex specular surface. In the diagram, $\theta = 2\sigma + \alpha$.

Lines are projected (as for flat surfaces) to define the luminaire width. This procedure can also be applied to concave surfaces.

18.0 WAREHOUSE AND STORAGE AREA LIGHTING

Placing items in storage, accounting for them, and later retrieving them are some of the most widespread activities requiring electric lighting in industrial facilities. Storage activities are found in business operations of every type, ranging from small local operations to multinational corporations.

Since rapid changes are taking place, the traditional concept of the warehouse needs to be expanded to encompass new techniques, including automation, high-rise storage, bar coding, cold storage, and shrink-wrap packaging.

Utilization of daylight is one of the most important items in the building design concept for a warehouse or storage type of space. The admission of daylight into the area contributes to the illumination targets, saves electrical energy through the integration of lighting controls, and provides significant health benefits to building occupants. (Refer to **Section 3.9** of this document, as well as IES RP-5-13[16] and IES LEM-7-13[17] more information.)

18.1 Types of Warehouse Area and Storage Systems

A variety of storage areas and systems requiring specific tasks may occur in warehouses (see **Section 18.3.2** for design considerations for these areas):

Open storage: Areas of material stored without the use of rack systems. This includes storage on the floor and on pallets, which may be stacked on each other.

High rise: Areas, generally automated, where storage bins may be rotated so that unused bins are kept high up, and with storage levels rising to over 30.5 m (100 ft).

Fixed racking: Areas with fixed racking may range from 1 to 4 m (3 to 12 ft) wide and from 2.5 to 9 m (8 to 30 ft) high. Items may be in bins, on racks, or in various types of containers. Labeling of the racks, containers or bins can vary from large black-on-white lettering to small, hard-to-read handwritten labels.

Mobile racking: A storage system now widely used in North America. Entire blocks of racking move on floor-mounted rails to open and close aisles as needed. In order to obtain maximum use from any lighting provided, the definition of the actual visual task should be considered.

Offices: Paperwork areas located within warehouses that require lighting appropriate for office tasks.

Stockroom area: In this type of area, identification marks on the sides of bulky materials, rolls of paper, and crates or boxes require vertical illumination. Additional lighting should be provided over the aisles, where high piles of stock can interfere with general lighting.

Cold storage: Areas that warehouse normally perishable food items and require low (sometimes below freezing) temperatures. (See **Section 11.5**.)

Hazardous materials storage: Areas where hazardous gases, vapors, or dust are or could be present, requiring specific methods of storage. Local building code requirements should be checked as to permissible luminaires for lighting areas where hazardous materials are stored or used. (See **Section 11.2**.)

Exit and emergency: Areas within warehouses that provide safe passage through to exit from the building and that are required to conform to life safety codes in case of emergency.

Shipping and receiving: Areas where materials are received into the warehouse for sorting prior to placement in storage areas, and areas that serve as staging areas for coordination of products to be sorted and placed on trucks or trains to be shipped.

Loading docks and staging areas: Areas, generally just outside the shipping area, that may be outdoors but are often covered and that are used to place items on and off trucks and railroad cars and to assemble goods.

Maintenance shops, forklift recharging areas and refrigeration equipment rooms: Separate areas or rooms generally set aside for these purposes, such as locations where general plant housekeeping activities occur.

18.2 Warehouse Illuminance

18.2.1 Vertical Illuminance. From the tasks encountered in the warehouse, it can be concluded that the majority of critical visual tasks occur in a vertical plane. A major consideration, therefore, in warehouse lighting design is providing illuminance on the vertical surfaces of stored goods. An effort should be made to illuminate the entire vertical seeing surface of the goods uniformly, from top to bottom and along the entire length of storage aisles (see **Figure 28**).

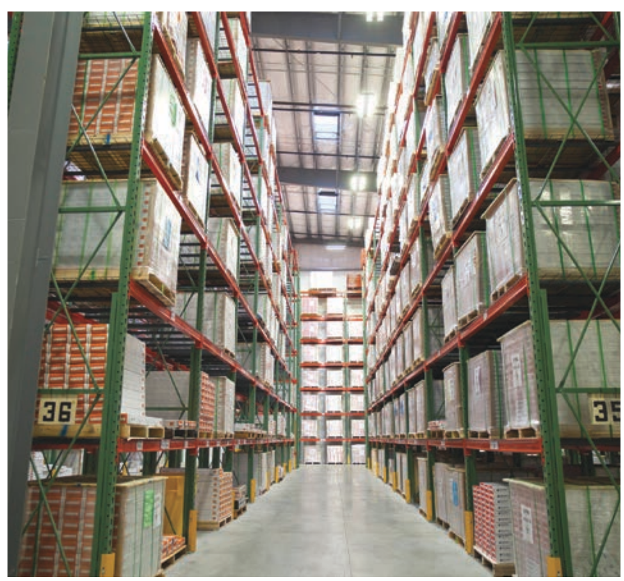

Figure 28. Warehouse with uniform distribution along the length of the storage aisle.
(Photo courtesy of Acuity Brands)

The reflectances of exposed surfaces can significantly affect lighting results. While the reflecting characteristics of stored goods cannot be controlled at the warehouse operating level, they should be taken into consideration when carton and container decisions are being made. Light colored packing material can contribute to efficient utilization of available light and increase visibility through greater contrast. Clear plastic wrappings over packages can reduce visibility of labels and markings due to reflected glare from the plastic wrap.

Some racks and storage locations may be partly or wholly empty at times. The lack of reflecting surfaces in the empty shelves may change the overall illuminance. This effect should be anticipated and included in the design parameters.

18.2.2 Horizontal Illuminance. While not as critical as the need for vertical illuminance, adequate horizontal illuminance should be provided for safety and navigation in the aisles. Other horizontal-plane tasks include reading of documents such as pick tickets.

Recommended illuminance levels (vertical and horizontal) for warehouses are shown in **Annex A.**

18.3 Warehouse Lighting Design Considerations

Although a variety of storage types exist (see **Section 18.1**), some general recommendations for designing lighting systems for typical areas within industrial warehouses can be provided.

18.3.1 Intermittent Use. Warehouse spaces are often accessed only intermittently. Regardless of the light sources used, it is therefore possible to save energy by controlling light output with passive infrared sensors or other control devices. Lamps are switched off or operated at reduced output at inactive times and then operated at full output only when the space is in use or, in the case of a passive infrared sensing system, when a person is present.

Lighting auxiliary devices, such as ballasts and drivers, capable of adjusting the lighting output of a luminaire based on the input sent by occupancy or daylight sensors are available and widely used for energy saving purposes throughout the industry.

Depending on the type and occupancy patterns of the space, a sensor can control a single luminaire, a wide group of luminaires (typically for open areas), or a portion or all of the luminaires within an aisle. Particular attention should be paid to the sensor's viewing area: a wide viewing angle is suitable for open storages, shipping and receiving, and loading areas, while sensors with a long, narrow viewing angle work well for aisles. Mounting options for occupancy sensors include ceiling surface or stem-mounted, wall-mounted, and luminaire-integrated. All the sensors shall be programmed with a proper delay time, calibrated, and commissioned as per the manufacturer's specifications and design requirements; a manual override option should be available to accommodate any emergency. (For more information, see **Section 7.0, Lighting Controls** of this document and IES LEM-7-13.[17])

Implementation of occupancy and daylighting controls in industrial warehouses can result in significant energy savings; however, close consideration shall be given to the safety and security aspects within the industrial facility.

18.3.2 Lighting Design Considerations by Area.

Open storage. Because this includes bulk materials and goods on the floor or on stand-alone or stacked pallets, it requires general area lighting that provides a balance of horizontal and vertical illumination (see **Annex A**). It is important to remember that temporary aisles that are created by materials may be frequently reconfigured.

Shipping and receiving. Because this includes sorting, packaging, and general forklift traffic, general illumination sufficient for document reading is needed, which can be provided by a suspended direct/indirect or diffuse type of lighting system. Some local task lighting at workstations may be required. Proper control of glare is essential.

Loading docks and staging areas. Because these areas include placement of materials on and off the tracks or railroad cars and assembly of goods, they require general illumination for safety and efficient movement of materials.

One of the most difficult visual tasks is reading markings on shipments, labels and bills of lading. General illumination may provide sufficient light for these tasks and for the operation of manual or powered forklift trucks, as well as for general traffic in the area.

Although this typically calls for overhead ambient lighting, the application often requires supplementary portable luminaires for the interior of the transport carriers; flexible "head & arms" projector-type luminaires are typically used to perform this duty. It is important that care be taken to avoid glare from these sources. If the conveyances are deep, then reel-type lighting or other portable lighting equipment may be necessary. Yard or loading-dock lighting should be installed for nighttime operation.

Fixed-location racking. This area generally results in long, narrow aisles; therefore, lighting layout and calculation procedures should be based on the dimensions of the aisle space rather than on the overall building size parameters. Luminaires should be located over the aisles (typically in the middle), regardless of the overall building configuration. Because of the special geometry of aisle space, which generally yields room cavity ratios higher than 10, and because the key visual tasks are in a vertical plane, the Lumen Method of average illuminance calculation (see **Annex D**) is not effective for warehouse applications. Lighting simulation software packages capable of performing point-by-point illuminance calculations for various calculation planes are available throughout the industry and should be used for such calculations.

Aisles, essentially narrow "rooms," can be lighted with point or linear light sources in high bay style luminaires, provided the luminaires are spaced reasonably close together to avoid unacceptable drop-off of vertical illuminance between luminaires. The spacing can be increased with luminaires that have a substantial uplight component when the ceilings have high reflectance. Other equipment choices include low bay luminaires, continuous rows of luminaires with linear light sources along the aisle, or special aisle luminaires that have an asymmetric light distribution. It is important that special care be taken at higher mounting heights to ensure that sufficient illuminance is produced along the entire height and length of the aisle stacks, especially when wider luminaire spacing is used.

18.3.3 Other Lighting Design Considerations.

Daylighting. Where possible, an opportunity to bring daylighting into the warehouse space using skylights, clerestories, or a piped sun-lighting system should be considered in order to gain the advantages of daylight illumination. The use of daylight necessitates a consideration of the potential for glare and the need to balance visible and thermal energy. Successful daylighting and electric lighting integration requires the design and implementation of lighting controls that switch or dim electric lighting based on available daylight, allowing significant electrical energy savings. (For more information, see **Section 3.9** of this document, and IES RP-5-13, *Recommended Practice for Daylighting Buildings*.)

Glare. To help ensure a productive work environment, glare from light sources should be minimized. This becomes particularly important when concentrated sources (including daylight openings) are used, because operators working beneath luminaires may encounter disability glare when looking up to the top of stacks. Proper shielding of the source needs to be considered, as well as viewing angles upward and along the aisles.

Color rendering. Color is sometimes used in labels on goods or storage racks, including aisle endcaps, to aid the warehouse worker in locating and identifying products. The lighting designer should be aware of the type of labeling used and employ a light source with good color rendering characteristics when this is the case.

Indirect lighting. Indirect lighting systems for warehouses, while not as efficient in producing task illuminance, can be useful in providing excellent visual comfort and have proved particularly useful in areas with computer terminals and where both storage and selling take place. Ceiling surfaces with high reflectance characteristics are important when considering indirect lighting systems.

19.0 OUTDOOR AREA LIGHTING

19.1 Lighting Zones

The impact of lighting is different in relative terms, depending on the lighting characteristics of the surrounding area. The addition of a lighting system using the higher end of the recommended horizontal and vertical illuminance levels will not have the same impact in an urban area with extensive ambient lighting from stores, signs and parking lots, as it will in a rural area with low ambient lighting levels. In order to appropriately address the needs of different areas, the IES has developed Lighting Zones describing different ambient lighting conditions. A brief description of each follows, excerpted from IES/IDA MLO-2011, *Model Lighting Ordinance*.[32]

Two different systems of lighting are commonly used to illuminate large, outdoor areas of industrial facilities: *projected* (long-throw) lighting and *distributed* lighting. Each has its advantages under specific situations.

19.2 Projected Lighting System

The function of this system is to provide illumination from a minimum number of locations throughout the various outdoor work areas. This is usually accomplished by use of aimable floodlighting luminaires.

The advantages of a projected lighting system are:

- The use of high poles on towers reduces the number of mounting locations.
- The light distribution is flexible; both general and local lighting are readily achieved.
- Floodlights are effective over long ranges, but careful aiming is critical.

LIGHTING ZONES

LZ0: No ambient lighting
Areas 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. 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 omitted or extinguished.

Parking lots may be minimally lighted, and certainly not continuously lighted where minimum levels are above zero. Above-ground parking garages are not expected in these areas; however, below-ground parking facilities can be lighted for safety and security as if they were in zones with higher ambient levels.

LZ1: Low ambient lighting
Areas 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 and convenience, but it is not necessarily uniform or continuous. After curfew, lighting may be extinguished or reduced as activity levels decline.

Parking lots are minimally lighted, and certainly not continuously lighted; minimum levels are never above zero. Above-ground parking garages are not expected in these areas; however, below-ground parking facilities can be lighted for safety and security as if they were in higher zones.

LZ2: Moderate ambient lighting
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 and convenience, but it is not necessarily uniform or continuous. After curfew, lighting may be reduced as activity levels decline.

LZ3: Moderately high ambient lighting
Areas of human activity where the vision of human residents and users is adapted to moderately high light levels. Lighting is generally desired for safety, security and/or convenience, and it is often uniform and/or continuous. After curfew, lighting may be reduced as activity levels decline.

LZ4: High ambient lighting
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 reduced in some areas as activity levels decline.

Various methods of quantifying and specifying equipment and application methods for each of these areas are being developed by the IES Roadway Lighting Committee but were not validated and available at the time of this revision.

- Lighting system maintenance is restricted to a few concentrated areas.
- Physical and visual obstructions are minimized.
- The electrical distribution system serves a small number of concentrated loads.

Typically, wide-beam floodlights, such as NEMA 5 through NEMA 7 distributions, are not used to cover areas wider than two mounting heights in front of their locations (transverse direction). Individual floodlights should not cover more than 90 degrees in the horizontal plane. This means that at least two luminaires are needed when the mounting location is at the side of an area. Four are needed for locations in the center of an area.

When coverage is more than two mounting heights transversely, narrower distributions, such as NEMA 2 and NEMA 3 are called for.

Coverage greater than four mounting heights from any one location is not recommended. The use of projected lighting has a greater potential for obtrusive light, including direct glare, than distributed lighting has.

Projected outdoor area lighting typically requires the fewest locations and thus the least amount of aerial structure. Structures are usually the most expensive part of the lighting system.

19.3 Distributed Lighting System

Distributed lighting differs from projected lighting in that luminaires are installed at many locations.

The advantages of this type of system are:

- Good illuminance uniformity on the horizontal plane
- Control of glare with proper luminaire selection
- Good utilization of light (less wasted spill light)
- Reduction of undesirable shadows
- Less critical aiming
- Lower mounting heights (luminaire maintenance is facilitated)
- Reduced losses to atmospheric absorption and scattering
- Electrical distribution system serves a large number of small, distributed loads

In the Distributed Lighting method, wall mounted equipment is often used at personnel and loading-dock doors. However, wall mounted equipment should rarely be used to cover a transverse dimension greater than two mounting heights and a longitudinal (to the side) area more than four mounting heights. This would place continuous area lighting equipment on a maximum spacing of four mounting heights along a wall.

Distributed outdoor area lighting systems have the least amount of glare because mounting heights can be lower. When floodlights are used, aiming angles can be less oblique, thus permitting glare control media such as louvers and visors to work. Care should be taken to ensure that aiming angles are less than 65 degrees above nadir.

19.4 Outdoor Tower Platforms, Stairways, and Ladders

Luminaires should provide uniform illumination and be shielded from direct view of persons using these structures. Enclosed and gasketed or weatherproof luminaires equipped with refractors or clear, gasketed lenses may be used for reading gauges. Luminaires above top platforms or ladder tops should be equipped with refractors or reflectors. Reflectors may be omitted on intermediate platforms around towers so that the sides of the towers will receive some illumination and the reflected light will mitigate deep shadows. If luminaires are attached to equipment, care should be taken in mounting the luminaires in order to reduce damage from equipment vibration.

Typical installations have intense HID sources located fairly close to personnel. Using coated instead of clear lamps may reduce glare in these situations, but may also significantly change the light distribution from the luminaires.

19.5 Special Equipment

Special lighting equipment may be needed for such functions as illuminating the insides of filters or other equipment whose operation has to be inspected through observation ports. If the equipment does not include built-in luminaires, concentrating-type reflector luminaires should be mounted at ports in the equipment housing.

Portable luminaires are utilized where access holes are provided for inside cleaning and maintenance of tanks and towers. Where applicable, hazardous-location luminaires (see **Section 11.2**) with portable cables are connected to industrial receptacles (either classified or standard as may be appropriate for the atmospheric conditions present) located near tower access holes or at other locations.

19.6 Low Illuminance and Visual Acuity Outdoors

In outdoor environments with low illuminance levels, the human eye's processes of visual adaptation operate in three categories of vision: *photopic, scotopic* and *mesopic*.

Photopic vision is the human eye's response at medium and high light levels where the cones in the eye account for vision. This vision is generally associated with adaptation to a luminance greater than 3 cd/m^2.

Scotopic vision is the human eye's response at very low light levels, such as starlight, where the rods in the eye account for vision. This vision is generally associated with adaptation to a luminance of 0.001 cd/m^2 and less. Scotopic vision is largely irrelevant to most lighting design practice.

Mesopic vision occurs under the majority of exterior nighttime lighting conditions and is a combination of photopic and scotopic vision. Both the rods and cones contribute to the visual response. This vision is generally associated with adaptation to a luminance between 0.001 and 3 cd/m^2. Low-illuminance design should take into account the presence of mesopic conditions.

When clarity, depth of field, peripheral detection, and perceived brightness are important, then a light source rich in short wavelength (violet, blue, green) light should be used. Current research[33] indicates improved peripheral detection at mesopic light levels with a light source rich in short wavelengths (metal halide, fluorescent) relative to a light source with few short-wavelength components (high pressure sodium, incandescent) at the same (photopically measured) illuminance levels.

Sources of different spectral composition that affect the eye equally at 3 cd/m^2 and above may not affect the eye equally when those same sources are used at lower adaptation levels. This includes color matching, reaction time for off-axis stimuli, and brightness perception. The spectral sensitivity of the eye and the effects of the spectral composition of light sources on brightness perception should not be confused with color rendering tasks or with color naming.[34,35]

ANNEX A – ILLUMINANCE RECOMMENDATIONS

Note: Citations in this annex refer to the ***References for Annex A****, found at the end of the annex.*

A.1 The Basis for Deviating From Recommended Illuminances

Occasionally the visual task in a specific space is not typical, and **Figures A1** and **A2** should be used to adjust the illuminance for that task. It is extremely important that the lighting designer have a clear understanding of the visual task being illuminated and then determine if the recommended illuminance is appropriate. It is also possible that more than one visual task is performed in a space. The designer should make provision to illuminate these tasks to the recommended levels unless other design criteria supersede illuminance as the primary design criterion.

A dramatic difference between an actual and a recommended illuminance (a difference of two standard deviations or more) would be one-third more or one-third less than the recommended value. The justification for any dramatic deviations should be carefully documented by the designer as part of good professional practice and for future reference.

A.1.1 Contrast

How to calculate:
$|L_b - L_t| / L_b$ or $|\rho_b - \rho_t| / \rho_b$,

where:
L = luminance (L_b and L_t have same units)
ρ = reflectance
b refers to the background
t refers to the *target*

Note: The definition of contrast using reflectance requires equal illuminance on task (target) and background.

How to interpret:
Low contrast: 0.3 or lower, but not near threshold*
High contrast: Above 0.3

This division is based on the plateau-escarpment nature of visual performance.*

* It should be noted that contrast threshold and the acuity limit are dependent on background luminance, duration of presentation, color, surround conditions, and in general any number of factors that affect visibility, including those idiosyncratic to the viewer. Above a contrast of 0.3 and a size of 4.0 x 10^{-6} sr, these factors are not very important to visual performance.

A.1.2 Size

How to calculate (refer to **Figure A1**):
Solid angle (sr) = $(d^2 \cos\theta)/l$,
and
Visual angle = $\tan^{-1}(d \cos\theta)/l$,

where:
d = the dimension (length or width) of the critical detail of the target
θ = the viewing angle
l = the viewing distance (d and l are in the same units)

Note: Only one dimension, d, is defined for the critical detail of the target. Visual performance for two different targets subtending the same area will be the same, even if the targets have different aspect ratios; e.g., a square-shaped target versus a long, rectangular-shaped object.[1,2]

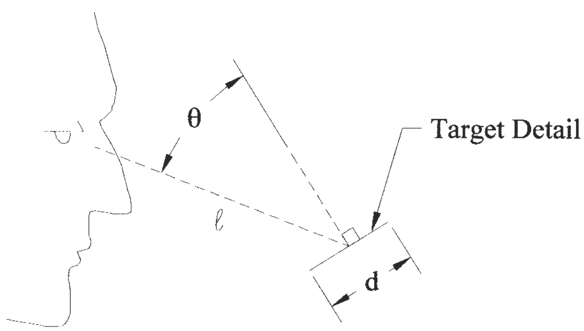

Figure A1. Determination of visual task parameters.

How to interpret:
Small size: 4.0×10^{-6} sr or smaller (solid angle), but not near the acuity limit**
Large size: Larger than 4.0×10^{-5} sr

Notes:
- 1° = 0.0175 radians = 60 minarc
- 1 sr = 66° visual angle for a circular target
- For a cone where θ is the half-cone angle, solid angle = 2π (1 – cos*q*)

This division, like that of contrast, is based on the plateau-escarpment of visual performance.[1,2]

Figure A2 shows numerous examples of visual angle and solid angle in real-world applications.

** It should be noted that contrast threshold and the acuity limit are dependent on background luminance, duration of presentation, color, surround conditions, and in general any number of factors that affect visibility, including those idiosyncratic to the viewer. Above a contrast of 0.3 and a size of 4.0×10^{-6} sr, these factors are not very important to visual performance.

Printed reading task from 15 in. (40 cm)

Typeface size	*Visual angle (°)**	*Solid angle (sr)*†
6 point	0.03	1.7×10^{-6}
8 point	0.04	3.1×10^{-6}
10 point	0.05	4.8×10^{-6}
12 point	0.06	6.9×10^{-6}
14 point	0.07	9.4×10^{-6}
24 point	0.12	2.8×10^{-5}
36 point	0.18	6.2×10^{-5}

*Angular width of single character stroke (vertical stroke, Times typeface).
†Average solid angle of total printed area of character for numerical digits (see reference 1).

Viewing a square-shaped object from 100 ft (30 m)

Object size	*Visual angle (°)*	*Solid angle (sr)*
3 x 3 in. (7.5 x 7.5 cm)	0.14	6.3×10^{-6}
6 x 6 in. (15 x 15 cm)	0.29	2.5×10^{-5}
12 x 12 in. (30 x 30 cm)	0.57	1.0×10^{-4}

Wire sizes (diameter in cross section) viewed from 15 in. (40 cm)

Wire size	*Visual angle (°)*	*Solid angle (sr)*
American Wire Gauge (AWG) 30 (0.25 mm diameter)	0.04	3.9×10^{-7}
AWG 24 (0.51 mm diameter)	0.07	1.6×10^{-6}
AWG 20 (0.81 mm diameter)	0.12	4.1×10^{-6}
AWG 16 (1.29 mm diameter)	0.18	1.0×10^{-5}
AWG 12 (2.05 mm diameter)	0.29	3.3×10^{-5}
AWG 8 (3.28 mm diameter)	0.47	6.7×10^{-5}

Circular drilled holes viewed from 15 in. (40 cm)

Hole diameter	*Visual angle (°)*	*Solid angle (sr)*
0.01 in. (0.25 mm)	0.04	3.5×10^{-7}
0.02 in. (0.51 mm)	0.07	1.4×10^{-6}
0.03 in. (0.76 mm)	0.11	3.1×10^{-6}
0.04 in. (1.02 mm)	0.15	5.6×10^{-6}

Figure A2. Examples of common visual angles and solid angles.