more above the sorting table or conveyor. Atmospheric and maintenance conditions will determine the type of luminaires (open, enclosed or filtered) to be used.

For medium inspections, large area sources may reduce reflected glare and improve diffusion of light. Medium-fine and fine inspection sometimes require special lighting equipment.

17.2 Parts Manufacturing and Assembly

Common tasks in manufacturing facilities include the manufacture of parts and the joining of those parts into larger subassemblies. Some of the important visual tasks and typical lighting systems are as follows:

Incoming raw materials: Raw materials are delivered to manufacturing facilities by truck or rail shipment. Both open-top and closed-top vehicles may be used. The visual task is to identify the materials and correlate the material and shipping documents. General lighting with supplementary portable lighting for trailer or rail car interiors is required.

Active storage areas: Raw materials are often unloaded in the receiving areas by lift trucks or overhead cranes. They are transported to the active storage areas or directly to the production process by the same means. The visual task is to identify the materials (by labels or markings) from the cab of an overhead crane or lift truck and to move the materials and deposit them at a designated location. Lighting requirements include general lighting with vertical illuminance for identifying labels and markings and horizontal illuminance for reading pick tickets. When an overhead crane is located in the processing area, it is important to provide adequate lighting under the crane, such as with luminaires mounted on the underside of the crane. This will fill in the shadows caused by the crane as it moves across the work area.

Parts manufacturing processes: Several different types and sizes of parts may be manufactured in a single plant using many unique processes. The designer should refer to other sections of this document for major activities that occur in manufacturing plants, such as machining, sheet metal fabrication, and casting. A number of different tasks may be performed. These are described under their own subheadings. General lighting is required with properly positioned supplementary lighting in areas or on equipment. These areas need special attention for glare control from direct sources, and from indirect sources such as an adjacent workstation. Machining, casting, and other such tasks require adjustable task lighting that will provide the appropriate contrast—and perhaps color quality—needed.

Parts assembly: In many manufacturing plants, individual components are assembled into subassemblies. The assembly process may combine manual, semiautomatic and automatic activities. The visual tasks are to select, orient, install and fasten a component to the subassembly. General lighting with supplementary lighting added to specific workstation positions will help to reduce shadows.

Testing: Highly diversified and complicated procedures and test equipment determine compliance with design specifications for many subassemblies. Testing activities may be manual, semiautomatic or automatic. The visual tasks are to secure the assembly to the testing device, perform tests on electrical or mechanical connections, read gauges and meters during tests, perform mechanical or electrical adjustments as required, complete test reports, and disconnect and remove the assembly from the testing device. General lighting and properly positioned supplementary lighting are required.

Final inspection: Inspection determines whether the manufactured part or subassembly is in total compliance with the design specification. The visual tasks are inspecting the part or subassembly for specification compliance and verifying that all intermediate inspections and tests are satisfactory. General lighting with supplementary lighting to inspect the part or subassembly is required. It is important to note that good color rendering light sources should be used.

Packing: Parts are manually or semi-automatically placed in boxes, containers or racks for shipment. The visual tasks are to identify the part and place it in a destination-designated shipping container or rack. General area lighting is required.

Shipping: Parts may be shipped to other plants or warehouses in enclosed rail cars and trucks. Lift trucks are generally used to load these vehicles. The visual tasks are to identify a shipping container or rack by part and destination and to load it into the designated rail car or truck. General lighting with adjustable or portable supplementary lighting will provide good vertical illuminance for the rail car or truck trailer interior. It is important to aim luminaires carefully to not cause discomfort glare or disability glare for the lift truck operator. It is cost efficient to provide small LED luminaires on both sides of a container or tractor-trailer at the point where the wall meets the ceiling.

17.3 Machining Metal Parts

While computer numerically controlled (CNC) machines do most precision work, much of the following information still applies, especially as pertaining to setup work. Machining of metal parts consists of the preparation and operation of machines such as lathes, grinders (internal, external and surface), millers (universal and vertical), shapers and drill presses, bench work, and inspection of metal surfaces. The precision of such machine operations usually depends on the accuracy of the setup and the careful use of the graduated feed-indicating dials rather than the observation of the cutting tool or its path. The work is usually checked by portable measuring instruments, and only in rare cases is a precision cut made to a scribed line. The fundamental visual task is to discriminate detail on planar or curved metallic surfaces.

Most of the visual tasks in the machining of metal parts are best lighted by large-area, low-luminance sources. The ideal general lighting system would have a large indirect component. While virtually any source types can be used for general lighting, large area sources, particularly in a grid pattern, are sometimes preferred for low mounting heights. High-reflectance room surfaces improve illumination and visual performance.

Since workers often refer to information on VDT screens, the needs of this visual task should be considered. In particular, this refers to veiling reflections on the VDT screen from luminaires, light surfaced walls, and windows.

17.4 Lighting and Visibility Issues for Sheet Metal Fabrication

Visual tasks in the sheet metal shop are often difficult because sheet metal (after pickling and oiling) has a reflectance similar to the working surface of the machine, resulting in poor contrasts between the machine and work. Low reflectance of the metal results in a low task luminance. High-speed operation of small presses reduces the available time for seeing, and bulky machinery obstructs the distribution of light from general-lighting luminaires. Luminaire aiming shall be done with care to not cause discomfort glare or disability glare. In addition, proper contrast is often needed for the operator to visualize the task and maintain the speed needed to produce the required number of parts per hour, and to maintain safety. It should also be noted that noise contributes to worker fatigue.

17.4.1 Punch Press. The visual task is essentially the same for a large press as it is for a small press, except that with a small press less time is available for seeing. The shadow problem, however, is much greater with a large press. The operator needs adequate illuminance on the task, often from supplementary or task lighting, in order to move the stock into the press, inspect the die for scrap after the operating cycle is completed, and inspect the product. Where an automatic feed is employed, the speed of operation is so great that the operator has time only to inspect the die for scrap clearance.

The general lighting system in press areas should provide illuminance adequate for the safe and rapid handling of stock in the form of unprocessed metal, scrap, or finished products. In large press areas, illumination should be furnished by high bay lighting equipment or by a combination of high bay (general area) lighting and supplementary task lighting. For moderate mounting heights, the illuminance should be supplied by luminaires having a widespread distribution to provide uniform illuminance for the bay and the die surface area.

The operator's ability to inspect the die is more directly related to the reflected brightness of the die surface than to the amount of light incident upon it. For example, a concentrated light placed on the operator's side of the press and directed toward the die may produce results much less satisfactory than a large-area source of low luminance placed at the back or side of the press. The luminance required for optimum visibility of the die has not been established; consensus suggests that 1,700 cd/m^2 is satisfactory.

Paint applied to both the exterior and the throat surfaces of a press contributes to the operator's ability to see. The reflectance of the paint selected for the exterior of the press should be not less than 40 percent. This treatment of vertical surfaces on the exterior provides for maximum utilization of light from the general lighting system. Similarly, the paint selected for throat surfaces should have a reflectance of 60 percent or higher.

17.4.2 Shear. The operator should be able to see a measuring scale in order to set the stops for gauging the size of cut. When a sheet has to be trimmed, either to square the sides or to cut off scrap from the edges, the operator should be able to see the location of the cut in order to minimize scrap.

The general lighting system should provide adequate illuminance in the area around the shear to safely feed the sheets at the front, collect the scrap at the back, and stack the finished pieces in preparation for removal. Local lighting should allow the worker to see where the cut will be made and the amount of scrap that will be trimmed. It also enables the operator, who is responsible for pressing the foot-release bar, to see quickly that all hands are clear of the guard.

17.5 Lighting for Large Component Subassembly and Final Assembly

This phase of manufacturing has special requirements not usually found in other industrial operations. Modern industrial requirements have necessitated the construction of buildings with clear bay areas, which may exceed 26,000 m^2 (300,000 ft^2) and truss heights of more than 24 m (80 ft) from floor level. The lighting problems in buildings of this size are not confined to the engineering and design concepts but include the tasks of maintenance and light source replacement. The use of either a system of catwalks or traveling-bridge cranes may be appropriate to allow access to the lighting units. In some cases, mobile telescoping cranes can be used to reach luminaires from the floor, but the heights involved and obstructions on the floor may make this method of maintenance impractical. Where access is available from the floor, disconnecting hangers and lowering chains can be an effective method for maintaining luminaires in high bay areas.

One special problem in providing lighting for certain assembly tasks is that the lighting is usually designed to specific task levels with the assumption that the areas will be completely open, whereas in reality that is seldom the case. The lighting from overhead systems is often reduced by the presence of large assemblies or large production equipment.

Typical of the types of assemblies found in these facilities are aircraft and automobile sub-assemblies, and the installation of sub-systems in these assemblies, for which supplementary lighting is often required. Large, portable luminaires can be used in areas that may block the overhead lighting, such as under aircraft wings. Appropriate equipment should be used in classified ("hazardous") locations.

Assembly of large aircraft sections, for instance, can present special lighting problems. Exterior lighting for joining these sections requires both horizontal and vertical illuminance, as well as lighting installed in such a manner that it will light the underside of the body and wings. The use of floodlights can provide both horizontal and vertical illumination on the exterior body while also providing light to the undersides of the body and wings. Specially mounted luminaires or portable lighting is required to light areas such as landing-gear pockets. High reflectance floor finishes will aid in lighting the underside of assemblies, but supplementary and specific task lighting is still usually required. While a high-reflectance floor finish can reduce light absorption, it can also sometimes cause reflected glare. With prolonged exposure, this can be discomfort glare, which can cause fatigue for workers. (See examples in **Figures 17-1** and **17-2**.)

Figure 17-1. Aircraft assembly areas require lighting from multiple sources and multiple angles, including onto the underside of the wings. (©canstock)

Figure 17-2. 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)

17.6 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 3-1 (a)** and **3-1 (b)** in **Section 3.4**).

17.7 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[24] 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.

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.[25])

18.0 Lighting for Specific Visual Tasks

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

18.1 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 18-1** shows this effect on a flat surface.

18.2 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.

18.3 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

Figure 18-1. Left: Metal ruler illuminated with an ambient lighting system. Right: Same object illuminated with a task light adjusted to reveal the embossed figures. (Images courtesy of Lighting Forensics LLC)

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 18-1**.

18.4 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.

18.5 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 18.7**.)

18.6 Flat Specular Surfaces

As with concave specular surfaces, large-area, low-luminance sources provide the best visibility. A luminance of approximately 1,700 cd/m^2 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 18-2**. 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 β_1 and β_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.

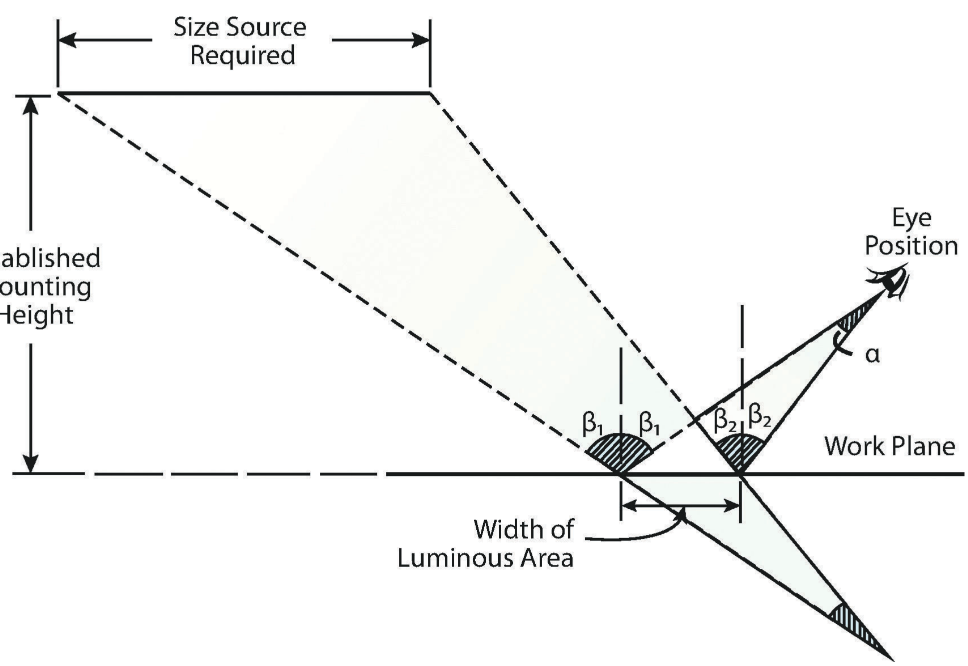

Figure 18-2. Procedure used for establishing the luminaire size necessary to obtain source reflections on a flat specular surface. (© Illuminating Engineering Society)

18.7 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/m^2 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 18-3**. 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). Lines are projected (as for flat surfaces) to define the luminaire width. This procedure can also be applied to concave surfaces.

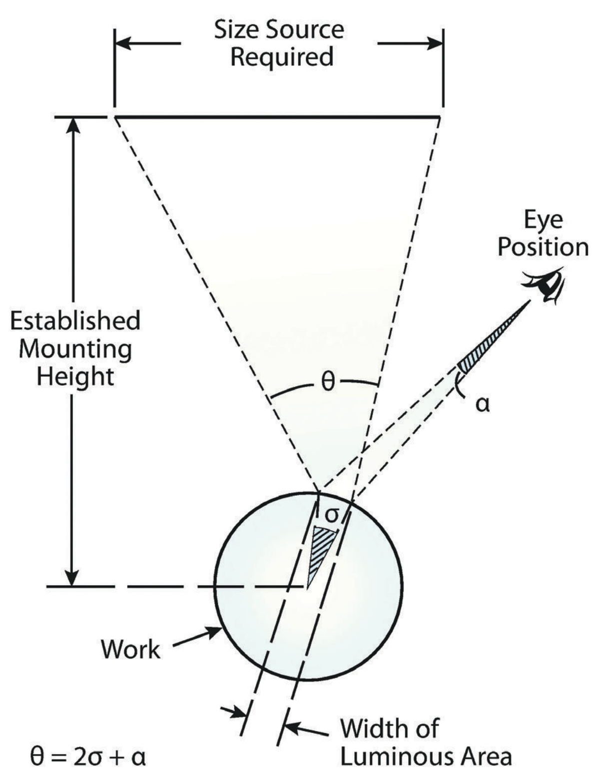

Figure 18-3. Procedure used for establishing the luminaire size necessary to obtain source reflections on a convex specular surface. In the diagram, $\theta = 2\sigma + \alpha$.
(© Illuminating Engineering Society)

19.0 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 4.1** of this document, as well as *ANSI/IES LP-3-20, Lighting Practice: Designing and Specifying Daylighting for Buildings*, and *ANSI/IES LP-6-20, Lighting Practice: Lighting Control Systems – Properties, Selection*, and Specification, for more information; see **Foreword**.)

19.1 Types of Warehouse Area and Storage Systems

A variety of storage areas and systems requiring specific tasks may occur in warehouses (see **Section 19.3.2** 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. In addition, the property's insurance provider will often have a list of requirements for the space. (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.

19.2 Warehouse Illuminance

19.2.1 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 19-1**). Caution should be used in selecting luminaires so that disability glare is not a factor for the operators in the space.

Figure 19-1. 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.

19.2.2 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**.

19.3 Warehouse Lighting Design Considerations

Although a variety of storage types exist (see **Section 19.1**), some general recommendations for designing lighting systems for typical areas within industrial warehouses can be provided.

19.3.1 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, the reader is referred to **Section 7.0 Lighting Controls** of this document and *ANSI/IES LP-6-20, Lighting Practice: Lighting Control Systems – Properties, Selection, and Specification* (see **Foreword**).

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.

19.3.2 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** for illuminance recommendations). 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, as well as 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 (refer to *ANSI/IES LS-6-20, Lighting Science: Calculation of Light and Its Effects*; see **Foreword**) 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. Luminaires may be mounted slightly above purlins to reduce damage from vertical equipment movements.

19.3.3 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 4.1** of this document, and *ANSI/IES LP-3-20, Lighting Practice: Designing and Specifying Daylighting for Buildings*; see **Foreword**.)

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.

20.0 Outdoor Area Lighting

20.1 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, as defined in the *IES/IDA MLO-2011, Model Lighting Ordinance*.[26] (See also *ANSI/IES LP-11-20, Lighting Practice: Environmental Considerations for Outdoor Lighting*.[22])

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.

20.2 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 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.

20.3 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.