2020 CONSULTING - SPECIFYING engineer eBook Series

Lighting & Lighting Controls

» *Following an OPR to design lighting systems*

SPRING EDITION

Contents

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Visual perception and its impact on emergency illumination design

Emergency lighting provides illumination and wayfinding to allow building occupants to quickly and safely evacuate.

The purpose of emergency lighting is to provide adequate illumination and wayfinding guides to allow occupants to quickly and safely evacuate a building. The speed with which a person can evacuate a building during a fire directly impacts that person's risk of injury or death. This fact becomes even more pertinent in large buildings, like high-rises, where longer evacuation times with more convoluted egress routes out of the building are the norm.

Although the human eye has an incredible ability to see in a wide range of lighting conditions, a person's ability to interpret what they see may be impaired due to any number of reasons: lack of familiarity with surroundings; fatigue; exposure to a high-stress situation, such as a fire or similar disaster; etc. With what's at stake, emergency lighting designers must not only understand simple prescriptive code requirements, but they also must go beyond what is required and learn how to effectively leverage human-behavior concepts. Those concepts may seem to be common sense, but they are often ignored.

The human eye and low-light vision

It is true that the neurological responses associated with vision are extremely complicated and, even after years of research, still not fully understood. However, to design effective emergency lighting, it's important to have a basic understanding of how the human eye responds to light.

There are two types of photoreceptors in the human eye: rods and cones. Through a combination of inputs from these two different types of photoreceptors, there are three primary modes of vision:

Figure 2: *Exit signage using a pictograph compliant with international ISO standard and NFPA 170-2018. All graphics courtesy: McGuire Engineers Inc.*

- **Photopic vision:** full-range color vision under normal illumination.
- **Scotopic vision:** monochromatic night vision.
- **Mesopic vision:** the midrange overlap of photopic and scotopic vision.

The level of luminance (amount of light emitted by a source) determines which of these vision modes is dominant.

Note that luminance is not the same as illuminance (amount of light falling on a given surface). While values of luminance (cd/m^2) may appear to be used interchangeably here with illuminance (footcandles), the intent is to illustrate typical illuminance conditions at which any particular luminance is expected. This distinction between illuminance and luminance is extremely important and will be expanded on when discussing practical emergency lighting applications. Code requirements focus on illuminance levels, but the perception of brightness is dependent on the luminance of whatever you are looking at. For example, both a black and a white surface can have the same illuminance (footcandles) under a given light source. However, one will be perceived as being brighter due to that fact that it reflects more of the light, therefore it has a higher luminance.

Photopic vision is attributed primarily to sensory input from cones when exposed to luminance above 3 to 10 (cd/m^2) (illuminance ~0.3 fc). This lower threshold of luminance for photopic vision roughly corresponds to that from a bright full moon on a clear night. In this mode of vision, the eyes are sensitive to wavelengths of light from roughly 400 nm to 700 nm—this corresponds to a color-range spectrum from violet to red.

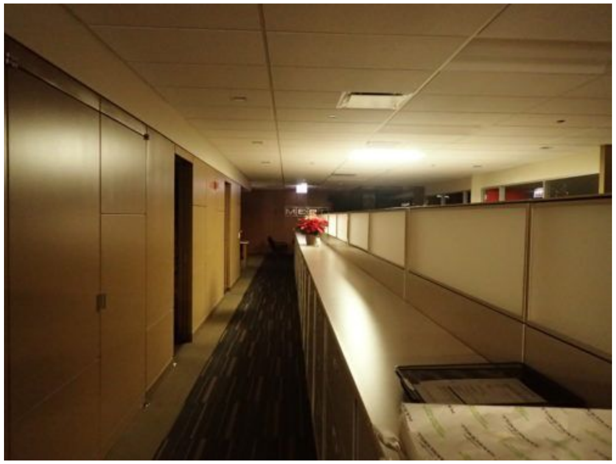

Figure 3b: *An illustration of emergency illumination.*

Scotopic vision is attributed primarily to sensory input from rods when exposed to a luminance of less than 0.001(cd/m^2). This level of luminance roughly corresponds to the light present on a moonless night with only stars in the sky. In this mode of vision, the eyes are sensitive to wavelengths of light from roughly 380 to 650 nm (violet to orange). Rods are insensitive to red sources of light. Even with this spectral-range sensitivity from violet to orange, all sensory inputs are perceived as being monochrome. You are functionally color blind when this mode of vision is dominant. In addition, visual acuity becomes fuzzy, making it difficult to resolve fine details, such as text on signs. Scotopic vision primarily allows the identification of shapes and motion. While the temptation is to emphasize the primary characteristics of scotopic vision when considering how to illuminate an egress path, it should be noted that the eyes require an extended period of time to become fully dark-adapted (up to 30 minutes). This length of time is usually greater than the acceptable maximum amount of time required to evacuate a building.

Although the human eye can "see" luminance values spanning over 10 orders of magnitude, the vast majority of emergency lighting scenarios involve illumination levels under which mesopic vision is dominant. In mesopic vision, both rods and cones are active. The luminance range associated with mesopic vision spans roughly 3 orders of magnitude and overlaps the high end of scotopic vision and low end of photopic vision. This is a transitional state—the perception of motion, shapes, color, and field of vision will be unstable and unpredictable.

Codes and standards for emergency lighting

The International Building Code's (IBC-2018) guidance for general lighting is a brief, one-size-fits-all statement in Section 1204.3: "Artificial light shall be provided that is adequate to provide an average illumination of 10 fc over the area of the room at a height of 30 in. above the finished floor." While the Illuminating Engineering Society Handbook may have expanded recommendations regarding the level of illumination that should be provided for a given task, ultimately, the Illuminating Engineering Society of North America's (IESNA) illumination-level recommendations are not required by code. What is appropriate is a qualitative, and not quantitative, assessment.

However, emergency lighting is different because there are specific illumination levels dictated for the designated components of means of egress by both NFPA 101-2018: Life Safety Code and the IBC. The required illumination for emergency lighting is an order of magnitude less than what is required by IBC for general illumination. Table 1 summarizes the related minimum code requirements for illumination at the floor level when a building is occupied.

Table 1: Minimum code requirements for egress illumination

Code	Average	Minimum	Average at 90 minutes	Minimum at 90 minutes	Maximum/Minimum
IBC 2018	1 fc	0.1 fc	0.6 fc	0.06 fc	40:1
NFPA 101-2018	1 fc	0.1 fc	0.6 fc	0.06 fc	40:1

Table 1: *This table summarizes the minimum code requirements for illumination at the floor level when a building is occupied.*

One common misinterpretation is that the 1-fc means-of-egress illumination requirement applies to every area of a building that a person can potentially occupy. While it is not part of the actual code language, the supporting annex material contained within NFPA 101 provides a definitive interpretation to where this requirement actually applies. The key item that the annex material highlights is the use of the word "designated" when referring to egress paths. For example, without this, in an open-office layout, an overly broad interpretation would result in the need to apply means-of-egress illumination to areas within each and every workstation instead of just the major aisle spaces. However, the portions of the exit access that require illumination are the "designated" stairs, aisles, corridors, ramps, escalators, and passageways leading to an exit. While what is considered "designated" is ultimately at the discretion of the authority having jurisdiction (AHJ), knowing that such guidance exists can be extremely useful.

IBC, Section 1008, is slightly more specific than NFPA 101, Section 7.8, in designating emergency lighting for the additional following areas:

- Egress pathways in rooms and areas that require two or more means of egress.

- Vestibule and areas on the levels of discharge used for exit discharge.
- Exterior landings as required for exit doorways that lead directly to the exit discharge.
- Electrical equipment rooms.
- Fire command centers.
- Fire pump rooms.
- Generator rooms.
- Public restrooms larger than 300 sq ft.

Figure 7: *Edge glow type exit sign with chevron-type directional indicators in compliance with UL 924: Standard for Emergency Lighting and Power Equipment and NFPA 101: Life Safety Code.*

The primary goal here is to illuminate the egress paths and provide wayfinding guides to allow occupants to quickly and safely evacuate a building. It is understood that under normal conditions, the general illumination in these areas will be dramatically greater than these minimum requirements. These minimum requirements only become the primary point of emphasis during an emergency condition when the primary source of power for the general lighting is lost and only emergency lighting is illuminated.

This is where the initial discussion of the three modes of vision becomes important. The code mandates an average illuminance level of 1 fc, a minimum of 0.1 fc, and a maximum-to-minimum ratio of 40:1. When operating under emergency power, emergency illumination levels are permitted to drop to 60% of those initial values after 90 minutes of operation. This is not an issue when operating from an auxiliary source with a stable voltage output, such as a diesel generator, but it is a concern for light fixtures with battery backup. Further complicating this is the fact that neither NFPA 101 or IBC requires that this drop -in illumination occur in a linear fashion. The initial illuminance level puts us at the low end of photopic vision, and after 90 minutes of emergency illumination, illuminance can decrease to a point that puts it firmly in the mesopic range. At that level, the range of luminance that can be perceived is significantly reduced as compared with normal photopic vision. This means that if unusually high levels of contrast (maximum-to-minimum ratio) are present in the path of egress, the ability for the eye to resolve any potential obstacles, identify signage, etc. becomes significantly impaired until scotopic vision takes over. Typically, in an emergency situation, the time required for this dark adaptation is unacceptably long.

Design considerations not in NFPA 101 or IBC

Simply specifying an illumination level for emergency lighting to meet the code requirement is not enough. While the code focuses on the level of illumination that needs to be provided on the floor, what good does that do if the occupants have trouble determining where the walls and doors are? This becomes a greater concern with highly directional sources of light that illuminate what they are pointed at and little else. Examples of such sources include sealed-beam halogen lamps associated with traditional wall-mounted unit battery lights. A guiding principle to remember is that wayfinding is generally accomplished by providing contrasting illumination on vertical surfaces to define the shape and volume of a space/path along with identifying any potential obstacles/hazards that may exist along that path. IThis will minimize a person's uncertainty and increase the

speed with which they can exit the building.

Shadows aren't created only by stationary objects. When highly directional emergency light sources are used, careful consideration must be given to the quantity and location of lights in relationship to potential obstructions that may cast shadows and impact the level of illumination along the egress path. These obstructions may include items such as furniture and modular workstation panels. However, potential obstructions that are seldom considered are the occupants themselves—a person traveling along the path of egress will cast shadows as well. If there is only one source of light located behind a person, it is reasonable to expect that the person's body will block that light along the direction of egress. If that person is in a stairwell trying to navigate down a flight of stairs, these types of considerations become even more important. The most appropriate design solution in most cases is to use more diffuse overhead light sources instead of highly directional wall-mounted unit battery lights. With the increased availability of UL 924: Standard for Emergency Lighting and Power Equipment -listed micro and mini lighting inverters and energy-efficient LED lighting, these types of solutions can be extremely cost-effective in comparison with traditional wall-mounted unit battery lights. Where the use of highly directional light sources cannot be avoided, resist the temptation to space them as far apart as possible. It is recommended that they be spaced more closely together and aimed so that the associated beams of light are slightly tangential to the path of travel. This will reduce the impact of shadows projected parallel to the path of egress and reduce the amount of glare from a light source pointed directly into a person's eyes.

Good emergency lighting design should leverage that human tendency to be attracted to light. While there is a focus on exit sign placement to provide wayfinding along the

path of egress, higher illumination levels for the emergency lighting should be used to help define the endpoints and changes in direction to the egress path. In combination with the code-required exit signage, this can dramatically simplify the decision-making process for someone attempting to escape a building. While photoluminescent tape on the floor can also be used to help define the egress path, note that the illumination provided by that tape is insufficient to meet the minimum code requirement and should only be considered as a supplemental wayfinding aid.

Figure 9: *Lamps for emergency illumination are often integrated into exit signs to reduce installation cost. The lamps need to be aimed to avoid blinding people who are walking toward the sign.*

Exit signage visibility

Exit signs provide easily identifiable directions to occupants on how to get out of a building. In many cases, without signage, it may not be clearly obvious to the occupants where the appropriate paths of egress are located. When appropriate signage is not present, most people will attempt to retrace their initial path. If that initial path leads back to an elevator instead of the nearest egress stairwell, how will the safety of the occupants be impacted? If there also happens to be a clear and immediate danger, such as a fire, limited visibility due to smoke, nonfunctional elevators, etc., any uncertainty or confusion in how to get out of a building may increase the potential for injury or death.

Chapter 7 of NFPA 101 provides requirements for the location of exit signs along the path of egress. The spacing between the signs, per 7.10.1.5.2, shall be "such that no point in an exit access corridor is in excess of the rated viewing distance or 100 ft, whichever is less, from the nearest sign." Note that not all exit signs are rated for the industry standard viewing distance of 100 feet. UL will also list exit signs for visibility from 50, 75 and 125 ft. For example, certain types of photoluminescent (glow-in-the dark) signs that require an external light source to recharge may only be rated for only a reduced 50-ft rated viewing distance and therefore require closer spacing between signs.

Many of the major requirements for locating exit signs are subjective, performance-based requirements and ultimately subject to interpretation by the AHJ:

- Exit doors, other than main exit doors that are obviously and clearly identifiable as exits, must be provided with an exit sign.
- Along horizontal egress paths where the continuation of the path is not obvious, such as an intersection of two corridors, a directional exit sign must be provided.
- Signs must be visible from the direction of travel.
- Where mounted above a door or other egress opening, the sign may not be mounted more than 6 ft 8 in. above the door. This is normally only an issue in an atrium or similar area with an unusually high ceiling.
- Where mounted to the side of a door or egress opening, the distance from the sign to the door/opening may not exceed the required width of the egress opening. For example, when mounted to the side of a 6-ft-wide double door, the sign may be offset no more than 6 ft.

One of the primary reasons why the visibility of an exit sign would be obstructed would be the presence of smoke. It is expected that as a smoke layer increases during a fire, the smoke will diffuse or absorb the light from a sign located at or near the ceiling. In some occupancy types (primarily assembly occupancies), floor-proximity exit signs are required to supplement those mounted at or near the ceiling. Where floor-proximity signs are required, the lower edge of the sign shall be mounted between 6 and 18 in. above the floor. The expectation is that if smoke is present, the floor signs will remain visible for a longer period of time and provide extra assistance for people trying to escape a smoke-filled environment, potentially while those people are crawling on their hands and knees to get below the smoke.

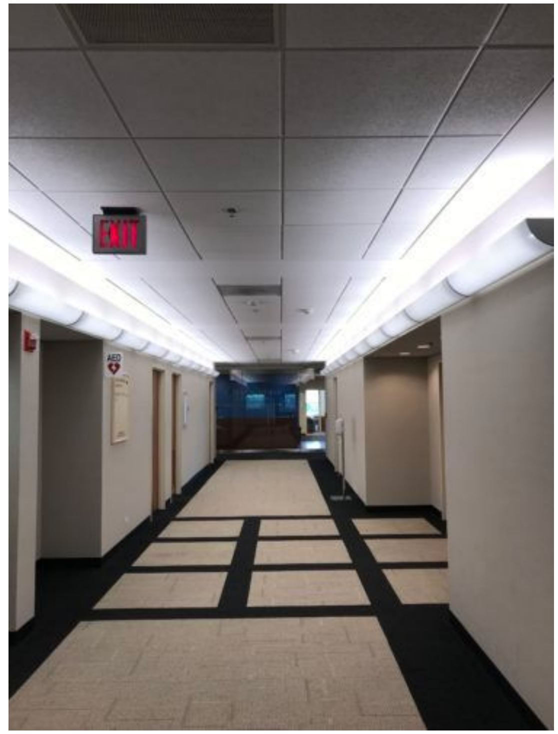

Figure 11: *Picture of an older incandescent exit sign where the sign is unusually dim and the direction chevron is difficult to see. Exit signs must have enough visual contrast from the surrounding environment to allow quick identification.*

Exit signs must have enough visual contrast from the surrounding environment to allow quick identification. The three variables that directly impact this are the color of the letters in relation to their background, the size of the letters, and the luminance of the letters. These variables are governed by UL 924. The primary goal of the standard is to ensure that the sign is visible from at least 100 ft. While some of the tests associated with evaluating this visibility are subjective, the accepted industry standard for letters on internally illuminated signs is that they are either green or red on a contrasting background and are at least 6 in. high, 2 in. wide with a ¾-in. stroke and a spacing of 3/8-in. between letters. Where larger letters are used (i.e., 8-in. letters in New York City), sign elements shall be scaled proportionately to their height.

While the "EXIT" letters must be visible from 100 ft, when a directional indicator (chevron) is used, that indicator must be identifiable from only 40 ft. Some municipalities, such as Chicago, require indicators in excess of this standard. As opposed to a chevron adjacent to either side of the word EXIT, a full-length arrow under EXIT must extend from one side of the word to the other in Chicago.

Research by the National Institute of Standards and Technology and Lighting Research Center performed nearly 30 years ago had concluded that a minimum luminance level of 10 (cdm2) is required for reasonable exit sign visibility in clear and smoky conditions. Most modern LED exit signs are dramatically brighter than this. However, the UL 924 requirements for self-luminous signs (photoluminescent or tritium signs) have no requirements for letter color and dramatically reduced luminance values based on a subjective test (typically around 0.21 (cdm2)); they are only required to be visible from 50 ft. To put this in perspective, reference these luminance values to the three different modes of vision previously discussed.

There is no easy answer for which exit sign letter and light-source color is best. The part of the country in which you practice engineering usually determines the color of exit signs that you usually specify. While red letters and illumination are the most prevalent, advocates of green-illuminated exit signs point out that red is normally associated with "stop" or "danger" and green indicates safety. Some locations, like Chicago, don't even

allow green or red illumination. Instead, they require white LEDs with the belief that a white light source also has the benefit of providing additional ambient illumination. Ultimately, the acceptable color is at the discretion of the local AHJ.

Outside of the United States, having a sign that says EXIT has little meaning if the local population doesn't speak English. In some parts of the world, it is entirely possible that multiple languages may be spoken by a building's occupants, none of which may be English. While not acceptable for substitution in place of EXIT in most jurisdictions within the United States, the prevailing exit sign standard everywhere else in the world is affectionately called the "running man" (see Figure 2) and shows a green-colored stick running toward a door. The greatest benefit of this pictograph is that it is universally understood and not specific to a particular language. While an ISO standard, this pictographic is also referenced in NFPA 170-2018: Standard for Fire Safety and Emergency Symbols.

Case study: Why illuminating vertical surfaces is important

This article includes a discussion of emergency lighting strategies that are not dictated by code requirements. One of these strategies is to illuminate vertical surfaces to define the shape and volume of the egress path rather than focus strictly on illuminating the horizontal plane of the floor.

In the following example, there is a representative aisleway in a generic open-office environment. The general lighting consists of a mixture of center basket fluorescent troffers, fluorescent linear wallwashers, and triple tube compact fluorescent downlights. The downlights and wallwashers are generally clustered at the far end of the picture and the 2x4s are spaced roughly 8 ft on center toward the viewer. The downlights are highly di-

rectional, with most of the light distributed straight down, while the 2x4s are volumetric, giving a high level of vertical illumination.

The picture of the normal illumination within the space indicates that the downlights at the far end of the picture are more effective at illuminating the floor than the 2x4s. The measured illumination at floor level under the exit sign at the far end of the picture is roughly 8 fc. The measured illumination at roughly the midpoint between the viewer and the exit sign is only half of that, 4 fc—which is partially attributed to ceiling shades from the lateral files in the picture. These illumination levels may seem low, but remember that these measurements are taken at the floor per code requirements for emergency lighting, not at work-surface height, 30in. above the floor. Regardless, the illumination across the spaces looks reasonably uniform due to the high levels of light on the vertical surfaces.

The picture of the emergency illumination in the same space (Figure 3b) paints a much different story. The downlights that were intended for emergency lighting at the far end have burned out light bulbs and do not contribute any illumination. The failure of the emergency downlights was not intentional and as a result, the only sources of illumination in the picture are the 2×4 in the foreground, the exit signs, and some incidental borrowed light from a glass door leading to another corridor just around the corner at the far end of the picture. Simply comparing the visibility of the decorative pattern in the carpet between the two pictures makes it clear that the floor is very poorly illuminated at the far end of the room. The light meter barely registers 0.1 fc—the code minimum. Even near the 2×4 emergency light, illumination is only 0.7 fc at the floor. Based solely on this measured level of illumination on the floor, the emergency lighting is inadequate. However, despite the nonfunctional downlights and the associated reduction in illumination,

the egress path is still surprisingly well-defined in the picture, and obstructions can be readily identified. This can be attributed mostly to the relatively high levels of contrasting illumination on vertical surfaces from the 2×4 light fixture. Even the far wall is reasonably visible due to the light from the 2×4 light fixture. The failure of the downlights was not intentional, but it does help emphasize the point that focusing solely on the code-required illumination on the floor minimizes the role that illuminating vertical surfaces has in defining the egress path. The code doesn't consider vertical illumination, but it is clear that light on vertical surfaces along the path of egress can significantly improve occupants' wayfinding ability.

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Electrical systems, from design to commissioning

Learn how to define the procedures of electrical schematic design, design development, construction documents, bidding, and construction administration including electrical commissioning.

The primary goal of any building electrical design is to provide a safe, energy-efficient system that meets the client's needs and is in compliance with codes. Life safety and preservation of property are two of the most important factors in the design of the electrical system.

NFPA 70: National Electrical Code (NEC), the International Building Code (IBC), the International Energy Conservation Code (IECC), the International Mechanical Code (IMC), the International Plumbing Code (IPC), the International Fire Code (IFC),the International Swimming Pool and Spa Code (ISPSC), the Building Industry Consulting Service International (BICSI), and other various codes provide rules and regulations to meet the minimum requirements to protect life and property. The electrical designer must meet these requirements for it to be a successful, code-compliant design.

System requirements for large facilities

The following are systems and equipment that typically are provided to satisfy functional requirements within large facilities:

- Building electrical service(s).
- Robust power distribution systems (NEC Article 700: Emergency, NEC Article 701: Legally Required Standby, NEC Article 702: Optional Standby).

- Lighting: interior and exterior (general, decorative, and task).
- Communication systems: telephone, data, TV.
- Fire alarm systems.
- Smoke-control systems.
- Transportation: elevators, escalators, moving walkways.
- Space conditioning and control: HVAC, building automation systems (BAS).
- Plumbing: hot- and cold-water systems.
- Security: electronic access systems, closed-circuit surveillance TV.
- Refrigeration equipment for kitchens.
- Food handling, dining facilities, and food preparation facilities.
- Lightning protection.
- Specialized audio/video systems for entertainment.

The following typically is provided by an architect seeking a fee to provide electrical engineering for permit and construction. Our example will include the following parameters:

- A high-rise hotel of 40 stories and 3,000 guestrooms.
- Guest rooms will consist of three types: a single-bay 450-sq-ft unit, a two-bay 900-sq-ft unit, and a three-bay 1,350-sq-ft suite.
- Three interior stairwells.
- An elevator bank of eight elevators, four accessing the first 30 floors and four high-speed accessing the upper 10 floors.
- A low-rise component containing a 100,000-sq-ft casino with 2,500 slot machines and 30 table games, such as blackjack, craps, etc.
- A convention facility of approximately 75,000 sq ft.

- A prefunction area of approximately 20,000 sq ft.
- A main kitchen of approximately 7,500 sq ft.
- A buffet of approximately 15,000 sq ft.
- A food court for six food vendors, each occupying approximately 4,000 sq ft.
- An open parking garage of approximately 6 stories and 1,500 spaces.
- Two 20,000-sq-ft restaurants with 6,000-sq-ft kitchens each.
- A small showroom of approximately 35,000 sq ft and 800 seats for an evening show of musical variety.
- A center sports bar with about 40 seats, approximately 2,500 sq ft.
- A sports book of 2,500 sq ft.
- Back-of-house offices, repair shops, electrical/mechanical rooms, central plant, corridors, employee bathrooms, etc. of approximately 400,000 sq ft. These are spaces the public typically never sees.
- A porte-cochere of 3,000 sq ft.
- A retail concourse of approximately 60,000 sq ft including the concourse. This has approximately 15 shops.

Schematic design

The schematic design (SD) phase sets up the general concept for the electrical design, and the expectations of it may vary widely from project to project based on factors such as construction estimates, deadlines, construction phases, project size, etc. As a first step, preliminary architectural drawings should be provided to the engineer to begin the design process and understand the complexity of the project. A list of questions should be generated based on the preliminary information to further define the scope.

The list of questions should be clarified during a kickoff meeting with the owner, architect, civil engineer, mechanical, electrical, plumbing, fire protection (MEP/FP) engineers, and other design professionals. In addition, during this meeting, the team should review preliminary floor plans, owner design standards/requirements, the project schedule, and expectations for each of the deliverables, phases, and packages in which the project will be separated.

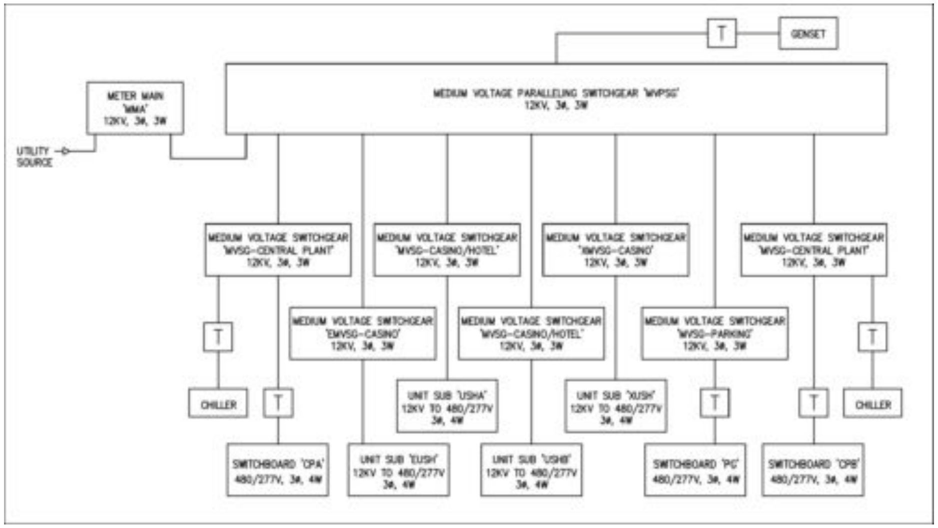

Figure 1: *A preliminary block single-line diagram showcases the sample project. Image courtesy: NV5*

A typical large facility may include a tower package, a podium package, and a parking garage package. These separate packages allow for associated construction to begin before later packages are completed. After attending the kickoff meeting, the electrical engineer should have a better understanding of the project scope and owner's design standards. This should allow the engineer to develop the preliminary scope of work and develop the basis of design (BOD) for the project.

The first step for the electrical team is to set up the electrical drawings for the SD package based on the preliminary architectural drawings received. Electrical drawings should include an overall site plan and overall floor plans for the tower, podium, and

parking garage packages, which will be used for the coordination of all the major electrical rooms and equipment distribution.

Next, the team will spend some time reviewing the owner's design standards to understand the power requirements for different areas of the building, and then research applicable codes including the NEC and energy and local codes to determine the systems' needs based on building areas' occupancy types.

Planning for the design of an electrical system for facilities of this size should begin with the determination and study of the size and nature of the total load to be served. This means load estimates on watts-per-square-foot basis and the estimation of the amount of other utilization loads and their concentrations throughout the building. Understanding of the major loads/equipment power requirements and their location in the building is essential to the selection of the recommended distribution systems.

Once the list of SD coordination questions has been responded to and most of the building occupancy types have been identified on the plans, the task for the electrical engineer is to prepare a rough estimate of electrical loads based on NEC Article 220. Consider the estimated connected loads with demand factors, diversity factors, and historical data. Our experience on large hotels is a 25% loading of transformers sized per the NEC and 35% loading of podium transformers. Service entrance equipment is typically estimated at a load of 35% to 45%. The preliminary generator load also should be estimated.

Once preliminary loads have been completed and utility service and switchgear ampacities have been estimated, a preliminary electrical distribution system should be

developed. The single-line diagram should include the main switchgear, step-down transformers from medium-voltage system to 480/277 V distribution, generators, automatic transfer switches (ATS), uninterruptable power supply (UPS), optional standby systems, 480V/277 V distribution boards, 480/277 V to 208/120 V transformers, panelboards, feeders, preliminary connections to chillers, air handling units, fire pumps, hydronic heat pumps, cooling towers, elevators, etc.

The electrical distribution system should include a topology, such as branches of power (mechanical, life safety, general purpose, lighting, etc.), and careful planning for future increases in electrical use. Conductors are not typically sized at this time for feeders because it is very preliminary. Submit the preliminary site plan with the preferred service point(s), preliminary single-line diagram, and estimated loads to the dry utility coordinator or directly to the serving utility for the preliminary work of serving the property. It is recommended to request available fault-current values form the serving utility at this time.

The electrical engineer should provide the architect with preliminary electrical room layouts to coordinate appropriate locations of major electrical equipment throughout the building. The electrical engineer is responsible for coordinating the space requirements for a proper electrical installation per NEC Article 110.26 requirements. In addition, the requested room spaces to house electrical equipment also should be able to accommodate the addition of future equipment. Equipment weights and sizes are estimated at this phase to assist the architect, structural engineer, and mechanical engineer with egress, structural coordination, and cooling needs.

Design development

The design development (DD) phase focuses and refines the electrical design. The architect should provide a further developed architectural set of drawings for the different areas of the facility. By now, the architectural drawings should include enlarged plans, preliminary reflected ceiling plans for back-of-house areas, kitchen areas, offices, restrooms, employee break rooms, etc. The architect should send its DD set to all the design professionals to continue developing their design.

It is during this early period that the electrical designer should emphasize the need for duct bank routing, structural reinforcement for heavy equipment, electrical rooms' wall ratings (if required), clearances around electrical equipment, egress doors for electrical rooms, transformers, busways, cable trays, panel boards and switchboards, and other items that may be required. It is much more difficult to obtain such things once the design proceeds to construction documentation (CD).

The electrical team should provide DD coordination questions to the architect and other consultants based on the owner's expectation for the electrical design at this phase and the progress of other design professionals' needs of electrical coordination, such as a kitchen consultant.

The goal for the electrical team in this phase of the project is to coordinate and lay out most of the back-of-house equipment, lighting, receptacles, and mechanical, plumbing, and power requirements from equipment specified by other consultants. Little, if any, branch circuitry is provided at this phase.

Depending on the order in which the information is received from other consultants provide, the team should plan on which areas to focus first. The electrical drawings included is typically as follow:

- Electrical cover sheet.
- Site plan(s).
- Power plan(s).
- Enlarged electrical room plan(s).
- Enlarged specialty lighting plan(s).
- Single-line diagrams.
- Lighting fixture schedule(s).
- Overall plan(s).
- Lighting plan(s).
- Enlarged food service plan(s).
- Enlarged guest room unit plan(s).
- Panels and dimmer schedules.

Electrical cover sheet—This drawing typically includes the electrical drawings sheet index, abbreviations, and electrical symbol legend.

Lighting fixture schedule—Incorporate preliminary front-of-house lighting specifications from the lighting consultant, if available. A back-of-house luminaire schedule will be created because these areas typically are under the responsibility of the electrical engineer.

Site plan—The electrical site plan should include the lighting layout only, based on the lighting consultant's design supplemented with back-of-house lighting of areas not accessible to the public. For instance, parking lot pole lights, walkways, and landscape lighting typically are provided by the lighting consultant. Building-mounted signage, site signage, and any of the site water features' power requirements also should be identified.

A dry utility consultant should assist the civil engineer, the local electric utility, and owner's representative with the site utility requirements. Utility switchgear and/or utility-furnished transformer locations should be indicated on the electrical site plan. Understanding the proposed routing, design, construction, etc. on site for the electrical utility, is important to understand at this phase.

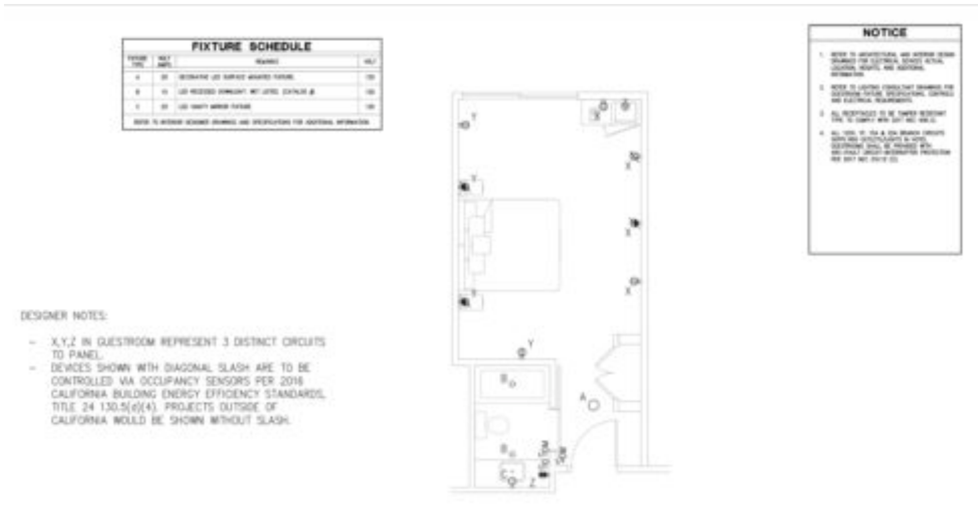

Figure 2: *A design development (DD) phase drawing shows an imaginary guest room and a more detailed single-line diagram. Courtesy: NV5*

Overall plans—Overall plans should include the electrical distribution equipment layout at each building level including main switchgear, generators, distribution boards, UPS equipment, panel boards, ATS, etc. Identify walls to the architect that should be 6 in. thick for recessed flush panels.

Power plans—Provide receptacle outlet layouts for back-of-house areas. Consider providing convenience receptacle outlets along the guest room tower corridors at possibly 50 feet on center, determine the estimated quantity of 20-amp branch circuits needed in the typical guest room, typically three for a standard guest room. For front-of-house areas, place convenience receptacles as required per code and additional ones as indicated by the interior designer, architect, and owner. Review all architectural, interior design, elevations, typical rooms, and other consultant drawings for outlet locations required, and capture them in this drawing set.

Coordinate spa, pool, internally illuminated signage, security/surveillance, telephone/data, and audio/video equipment power requirements with the design consultants in order to develop and design the supporting electrical infrastructure.

Incorporate mechanical and plumbing equipment layouts per the design consultants' requirements. Provide rooftop weatherproof and weather-resistant receptacles within 25 ft of mechanical equipment. Coordinate the elevator machine room, pit, shaft, and possibly top-of-elevator lights, switches, and receptacle requirements.

Advise the architect and owner which equipment loads are required to be on emergency (NEC 700) or legally required standby (NEC 701) power per code. Confirm with the architect and owner which equipment loads will be preferred to be connected to optional standby (NEC 702) or UPS power to properly meet the owner's needs. Provide the preliminary emergency/legally required/optional standby power systems design and include generator sizing and selection, the transfer system, preliminary load prioritization, load-shed criteria, and segregated emergency/legally required and optional standby distribution systems.

Generator fuel, storage, and quantities also should be reviewed at this time. Any and all outlets indicated in architectural drawings need to be captured on electrical power plans. A thorough review of all architectural floor plans, elevations, and typical rooms is required.

Lighting plans—Preliminary lighting-load allowance per area calculations for the back of house and front of house should be performed based on the applicable energy codes. The electrical engineer should notify the architect and lighting consultant of the lighting allowances, so they can design their lighting layouts to meet the energy requirements for each area and to understand control requirements for the applicable codes. There is a high level of coordination needed for architectural, interior design, mechanical design, and lighting plans in electrical drawings.

Preliminary back-of-house and front-of-house lighting layouts for normal and emergency lighting should be included. Back-of-house lighting cutsheets should be provided to the architect for review and approval. The electrical design team should provide rough photometric calculations to indicate preliminary compliance with emergency lighting footcandle requirements along the path of egress (1 fc is average). Emergency lighting should be considered in areas such as electrical rooms, stairways, information technology rooms, etc. Exit signage should be placed on the drawings and coordinated with the other design professionals' egress plans. Exterior emergency lighting above discharge doors should also be included on the drawings. Finally, lighting controls for back-of-house areas should be added to the plans based on applicable codes (NEC and energy).

Enlarged electrical room plans—Create enlarged 0.25- to 1-in.-scale plans for all electrical rooms. Show equipment clearances and electrical room egress door requirements per NEC Article 110.26.

Enlarged food service plans—Create enlarged 0.25- to 1-in.-scale plans for food service areas, which are sometimes handled by a separate consultant. Food-and-beverage electrical systems are based on the food service consultant's bulk loads and equipment locations. Place ground-fault circuit interrupter (GFCI) receptacle outlets per NEC 210.8(B)(2) within kitchen areas for food service power connection.

Enlarged guest room unit plans—Develop the design for the typical enlarged (typically 0.25- to 1-in.-scale) guest room units based on information provided by the architect/interior designer. Receptacle layouts shall comply with NEC 210.8(A), 210.12(C), and 210.60 requirements.

Single–line diagrams—At this point, the single-line diagram is expanding as electrical distribution systems are being added because different areas in the building are being further developed. Feeders or empty conduits stubbed into all tenant spaces should be incorporated. Update the single-line diagrams to include equipment ratings for main switchgear, generators, ATS, distribution boards, transformers, motor control centers, panel boards, etc.

The single-line diagrams should then be prepared in conformity with the serving utility's requirements. Send updated single-lines, estimated load calculations, and the site plan, including the recommended service location, to the serving utility for their review. Determine owner- and utility-furnished items. If fault-current values have been received from the serving utility, short-circuit calculations can begin in this phase of design.

Panels and dimmer schedules—Create the preliminary panel and dimmer schedules.

Book specifications—Typically for these types of projects, MasterFormat Division 26 specifications will be provided. Sections should be included based on project requirements.

Along with the DD package submitted to the architect, the electrical team should send an updated coordination list requesting information required from the owner, architect, and other consultants to proceed to the next phase of the design. This is the time to review the electrical drawings with the owner and owner's staff to coordinate specific needs. By reviewing with key personnel, changes in the construction document (CD) phase are avoided and the owner is a clear part of the design process.

Construction documentation

The CD phase fills in the details of the electrical design. The architect should provide finalized architectural drawings for all the different areas of the project along with any comments from the submitted electrical DD package. Architectural drawings should include all floor plans, enlarged plans, reflected ceiling plans, details, elevations, etc. for all areas of the building. The architect should distribute its construction documents to all the design professionals involved in the project to complete their design.

The design from the food service, interiors, low-voltage, lighting, vertical transportation, fire sprinkler, landscape, mechanical, plumbing, pool, structural, or other specialties should be finalized during this phase of the project. The electrical team typically is at the end of the line waiting on all other consultants' information to finalize the elec-

trical design. For this reason, it is important to request final information in a reasonable amount of time before the permit drawing set is scheduled to be issued.

To ensure everything has been provided as requested, it is during this phase that the designer should review the requested electrical spaces and clearances for electrical rooms, panel boards, motor control centers, and switchboards.

Plan-checking by the local building authority is an essential part of the permitting process. Finally, upon satisfaction of the plan reviewers, the CD set is ready to be issued to construct.

Electrical cover sheet—The electrical design team should verify the electrical symbols used in the electrical drawing set are incorporated into the electrical symbol legend. The sheet index should include all the electrical drawings.

Lighting fixture schedule—The back-of-house and front-of-house, site, façade, and guest rooms lighting-fixture schedules should include wattage, voltage, and driver type.

Energy–compliance forms—Include energy-compliance form calculations to demonstrate compliance with the applicable energy codes.

Site plan—The site lighting should be circuited, and lighting controls defined. Building-mounted signage, site signage, and any site water features' power connections and controls should be finalized.

Coordinate the location for generator(s), utility switchgear, and/or utility-furnished transformers and indicate them on the site plan. Electric vehicle charging stations should be shown if required by the codes or owner needs.

Overall plans—Verify that the electrical distribution equipment being used at each level of the building is included and clearly identified.

Power plans—Include circuiting for all devices and equipment indicated on the other design professional drawings. Clearly define the power system it is connected to (i.e., emergency, legally required standby, optional standby, UPS, etc.).

Lighting plans—Complete the back-of-house and front-of-house lighting circuiting, controls, and exit signs.

Enlarged electrical room plans—Finalize enlarged 0.25- to 1-in.-scale plans for all electrical rooms.

Enlarged food service plans—Complete the enlarged plans for food service areas by indicating all circuiting. Kitchen demand loads should be applied per NEC 220.56 and Table 220.56.

Enlarged guestroom unit plans—Finalize the circuiting and lighting/controls design for the typical enlarged guest room units based on information provided by architect/interior designer and other consultants. Consider the demands allowed by NEC Table 220.

Single-line diagrams—Finalize the single-line diagrams based on final design modifications and updated load analysis. Include feeder schedules, notes, load calculations (based on the design's connected load), the equipment schedule indicating equipment specs, etc. Provide selective coordination per NEC Articles 700.32 and 701.27. Provide fault-current analysis and voltage-drop analysis.

Panels and dimmer schedules—Finalize panel boards and dimmer schedules to include the ampere-interrupting-capacity rating, main lug only/main overcurrent protection, branch circuit breaker ratings, load volt-amps (VA), and load description.

Book specifications—Update MasterFormat Division 26 book specifications based on final design modifications. Review other sections of specifications, such as fire alarm, low-voltage, mechanical, and plumbing, to make sure coordination is achieved and the direction is clear and concise in compliance with code.

Bidding and construction administration

Once a completed set of construction documents has been issued and approved by the owner, it is ready for bid. The owner should submit the drawings to interested contractors, who will then bid the cost to construct the job.

Perform site observations during the construction phase to survey the status of the systems' installations. Review the contractor material submittals and shop drawings. Respond to requests for information and field-coordination issues.

Commissioning

Electrical commissioning (Cx) is an important step of the construction and design teams, and for the owner to understand, including what equipment will be reviewed and how it will be reviewed. This can be broken into several steps:

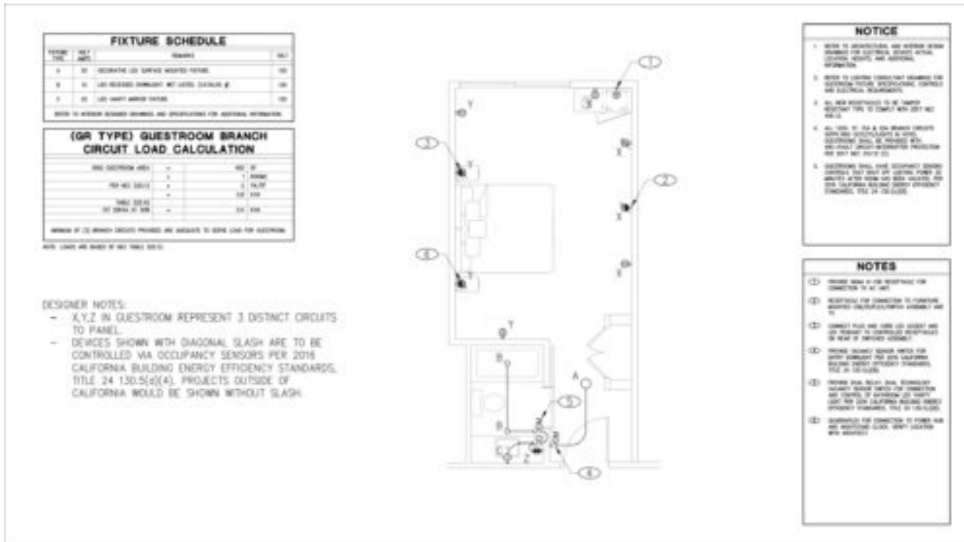

Figure 3: *A construction document (CD) phase single-line diagram highlights a part of the previous single-line and the guest-room CD level circuited. Courtesy: NV5*

1. Visual observation of all electrical equipment including components within electrical equipment, such as busing and cables, to confirm the equipment provided agrees with the drawings and specifications as produced by the engineer of record. This includes making sure that proper listing and labeling is completed and that the equipment provided is in compliance with its listing. Also, confirmation that the equipment being furnished and installed is in compliance with the specifications and manufacturers requirements.

2. Functional testing, such as ground-resistance measurements, relay settings on protection devices, ground-fault protection testing, and GFCI/arc-fault circuit-interrupter testing, is an observation of the contractor operating the equipment

in question to confirm its operation is as intended by the design documents and in conformance with codes. Also, load bank testing of generators to verify full functionality, paralleling equipment testing for a variety of agreed-upon scenarios, and fire pump starting as well as fire-smoke control interfacing to electrical systems.

3. Preventive maintenance base-point measurements for infrared scans of all equipment terminations, and ampacity and voltage readings for all equipment. Depending on the Cx scope, Cx organizations represented by the commission agent (CxA), and possibly U.S. Green Building Council LEED certification, certain requirements are outlined for documentation due to the owner. Also, review of operations and maintenance materials, a process for resolving issues pointed out by the CxA, etc.

Daniel Mendez and Rick H. Reyburn, PE, NV5, Las Vegas

Daniel Mendez *is project consultant, electrical at NV5.* ***Rick H. Reyburn*** *is the executive director of electrical engineering for NV5.*

Specifying the right electrical raceways, busways, wiring and cabling

Electrical and information cabling pathways are a vital component of any new or existing building

Electrical and information cabling are an integral part of all building systems and must be extensively routed throughout all building types. There are several methods available for design teams to specify; however, catering a solution to specific applications is often difficult and convoluted.

As the buildings that we live, work, entertain and otherwise occupy become more complex and modern, there is an ever–increasing need to provide electrical and information infrastructure throughout. All buildings have a plethora of devices that require an electrical or data connection. Often these devices require a combination of each.

The end-use connection is often quite simple in either a direct connection or outlet type form factor; however, how is the wiring or cabling transported to this point? How is it protected from point to point? The answer: Using pathway systems that are permitted and practical for the specific structure or building space that transport the cabling safely to mitigate the risks of electrical shock, fire and other hazards related to personnel and property. To continue the description of the available systems, we must first identify the applicable standards and terms.

The governing code for all electrical pathways is NFPA 70: National Electrical Code, which

dictates the uses permitted for the pathway systems and the terms used within the applicable standards. Information and communications technology cabling also are bound by the codes within the NEC, however there are applicable standards that take this a step further such as those set forth by the Building Industry Consulting Services International organization in its Telecommunications Distribution Methods Manual and the Telecommunications Industry Association and its applicable standards (commonly referenced as TIA-xxx, where xxx denotes a 3-digit number applicable to a specific document).

Figure 1: *This is a gutter installed in a high-rise building that is provided as an accessible splice point. The level above is the serving electrical room and there are sections of EMT that connect into the top of the gutter. Within the gutter the contractor has spliced, via wire nuts, to connect to the horizontal runs of MC to horizontally feed the guestrooms. Courtesy: NV5*

It is important to note that the NEC is an enforceable code that is meant to safeguard persons and property from the hazards arising from the use of electricity (NEC 90.1) and is a requirement; the standards surrounding ICT cabling are recommendations that optimize an ICT cabling system and are not safety related nor enforceable code.

Additionally, all pathway systems are listed by a nationally recognized testing laboratory for standards regarding fire rating, flame spread, use of products within air handling spaces (often referred to as plenums), etc. The most common NRTL is UL, which not only tests the products but also creates the applicable standards.

Types of wiring

The first step to understanding any pathway system is to understand the wiring that is being transported and protected. The NEC delineates between several different types of wiring. We will examine the most common types of wiring: 1,000 volts or less, Class 1, Class 2 and Class 3 circuits. The NEC also sets code minimum requirements for conductors exceeding 1,000 volts.

Class 1 wiring typically is identified as remote-control or signaling conductors that are either power limited to 30 volts and 1000 volts-ampere (NEC 725.41(A)) or where the conductors are used for remote-control or signaling circuits (NEC 725.41(B)). When used for remote-control or signaling circuits, the voltage may be increased to 600 volts; however, these will typically be seen as 120-volt circuits that operate relays, motor controllers or similar control devices. Class 1 circuits are required to be routed in a pathway as established within chapter 3 of the NEC (NEC 725.46) and they may be routed through the same pathway system as a power feeder or branch circuit if the conductor insulation is rated for at least the maximum voltage available within the raceway system (NEC 300.3(C)(1)).

Class 2 and class 3 circuits are identified with the NEC chapter 9, table 11(A). Class 2 circuits are typically seen as low-voltage circuits that are limited to 30 volts or less and 100 volts-ampere or less. These class 2 circuits are considered protected from fire or shock due to low energy and voltage levels. Due to this, class 2 circuits are permitted to be installed in plenum areas (when properly listed) and are not required to be installed in raceway systems outlined within chapter 3 of the NEC. Class 2 circuits are most commonly seen as category cabling (as defined by TIA-568-C and is most commonly unshielded, balanced twisted pairs of wire that are designed for data transmission), wiring for public address systems, programmable logic controllers and thermostats.

Class 3 circuits are typically classified as circuits that exceed 30 volts but operate from 0.5 to 100 volts-ampere and are often used for sound/speaker systems, clock/intercom systems and security systems. Although beyond the breadth of this article, it should be noted that class 3 circuits can reach higher voltage and current levels under specific circumstances as outlined by NEC 725.121; however, it is less common. Class 2 and 3 circuits are not required to be installed in a pathway system as outlined within NEC Chapter 3 and may be routed through plenum spaces when using listed cabling and supports. These circuits may be routed in this manner as they are power limited or carry a low-energy signal that does not present a risk for the initiation of fire or shock.

Design considerations

With the understanding of that cabling systems may require pathway systems outlined within chapter 3 of the NEC, we may now proceed to analyze the available pathway systems as well as their limitations and code requirements. There are several design considerations that need to be analyzed to provide the best pathway for a specific task. These consider-

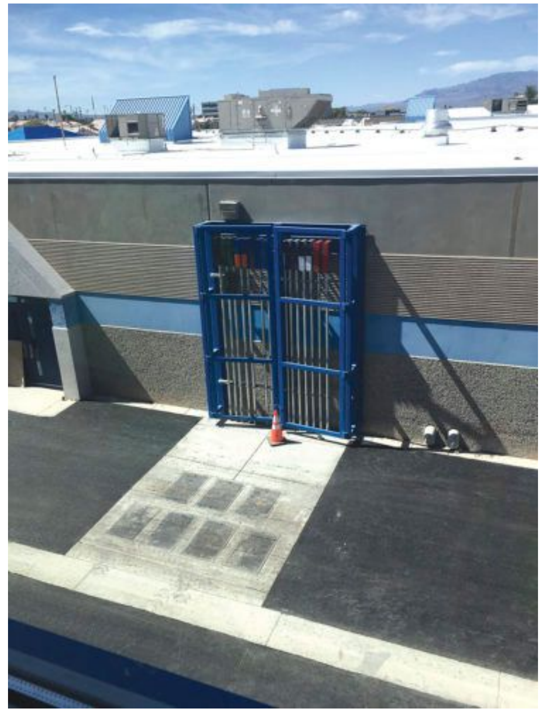

Figure 2: *This installation shows a structural cage that has been constructed to add protection to the conduit. This installation is within a fire lane for an educational facility and fine metal mesh will be added to the installation to prevent access to the interior of the conduit cage when the hinged doors are closed and locked. Additionally, the existing building footing was compromised during excavation and a structural cage was required around the conduit to add structural integrity of the exterior wall. The conduit bodies are specialized to have manufactured large radius sweeps to prevent tight bending of ICT and fiber optic cabling. Courtesy: NV5*

ations are: accessibility, pathway support requirements, distance that the pathway will travel, special protection requirements and the quantity of cables that must be transported.

Accessibility is one of the most important factors in any pathway system and is outlined in the NEC to require access to all junction boxes, gutters or splice points (NEC 314.29). Often, these pathways and boxes are installed above gypsum board or hard-lid ceilings where there is no practical way to reach the system without an access panel. When this type of a ceiling is used within a facility, it is critical to avoid system such as J-hooks and cable tray that are open and cannot be inspected to ensure that cabling is supported and secured. When not accessible, conduit or another type of raceway is the most practical choice.

Even with a raceway system, access panels will be required to access the following: a junction box for every 100 feet or every cumulative 180-degrees of bends for ICT cabling (TIA-569-D 9.8.2), a junction box for every cumulative 360-degrees of bends for line voltage wiring (for EMT NEC 358.26). In this aspect, the TIA standard is more stringent as it provides recommendations to ensure a minimum pulling force between access points is maintained. This ensures (as a rule of thumb) that the cable will not be subject to pulling tension in excess of the manufacturer's recommendations and thus allow the cable to pass manufacturer's field certifications and maintain signal integrity.

Often, junction boxes or gutters are used to provide a point to transition from electrical metallic tubing (type EMT) and wire to metal-clad cable (type MC cable) to traverse through inaccessible areas and route direct to the receptacles as required by the design (see Figure 1).

Often the ceilings or floors are accessible, such as with access floors or acoustic ceiling tile ceilings, commonly referred to as "lay-in" or "drop" ceilings. Where these types of building elements are installed, the designer has several choices for pathways that include additional options, as well as the raceway example previously presented.

Accessible building elements are advantageous where the systems need to accommodate moves, adds, changes and deletions (commonly referred to as MAC-Ds). Such building elements allow the use of cable trays (for power and ICT cabling) and J-hooks (ICT cabling). When installing these systems within a ceiling grid system such as ACT, it is imperative that the supports are not directly affixed to the ceiling grid supports (NEC 300.11(B)). The ceiling grid system should remain completely independent of all cabling, light fixture or other electrical systems.

When using a system such as a cable tray or J-hooks, the user may make changes to the cabling by removing ceiling tiles and simply laying a cable into the tray or J-hooks. Typically, these pathways are used in conjunction with conduit route within a wall to provide a connection to a junction box.

Another significant consideration for pathway systems is the required supports. Ideally, the best location for information on support requirements will be the manufacturer's installation instructions and the NEC. The NEC specifically notes the support requirements for different raceway types within chapter 3, for example, EMT conduit shall be supported in increments of 10 feet and within 3 feet of every junction box, conduit body, etc. (NEC 358.30).

When reviewing the support requirements, unless specifically mentioned, the NEC does not make the distinction between horizontal and vertical support requirements. Some

specific instances where the NEC does differentiate between vertical support requirements would be for industrial installations when using intermediate metal conduit (NEC 342.30(B)(2)) and rigid metal conduit (NEC 344.30(B)(2)). The NEC also defers the requirements for cable tray supports to the manufacturer's installation requirements (NEC 392.30(A)).

If the electrical or ICT designer's project is located within a seismic zone, additional requirements may be instituted and the support design may be required as a delegated design to a structural engineer. Additional conduit and cable options would be intermediate metal conduit (type IMC, NEC 342), rigid metal conduit (type RMC, NEC 344), fiberglass conduit (type RTRC, NEC 355), metal-clad cable (type MC, NEC 330) and each method has its specific application, support requirements and additional information that is all outlined within their respective NEC section.

Figure 3: *This is a vertical section of busway (or busduct) with no plug-on devices. The waterproof curb is visible in the bottom of the photo showing engineering supports bracing against the floor spanning the entire penetration. This has been sealed with intumescent material below the cover plate for fire protection between floors. Courtesy: NV5*

Cable distance

When considering distance, it's imperative to understand the cabling type that is being used. For line voltage power wiring, the main distance consideration is relative to the electrical load and the voltage drop that will be induced based on the wire's impedance. The standard for voltage drop is outlined as a fine–print note for NEC 210.19(A), FPN No. 4. This FPN advises that branch circuits should be sized to prevent a voltage drop in excess of 3% and that feeders should be restricted to 2% voltage drop.

The FPNs within the NEC are not enforceable by a code official (NEC 90.5(C)); however, some jurisdictions may have enforceable energy codes that mandate a maximum voltage drop (most commonly ASHRAE Standard 90.1). When considering ICT premises wiring systems, it's important to know the cabling media and the specific limitations associated with each type.

For example, category cabling is typically limited to 295 feet for the permanent link (wiring from the outlet to the patch panel or termination within the serving telecommunications space). However, if using fiber optic cabling, the distances vary based on fiber type (single-mode and multimode), the data transmission rate and the type of transceivers used. As the purpose of this article is not to examine the pros and cons of different ICT cabling, we will proceed with the more common Category-6 cabling standard (outlined to specific performance requirements within TIA-568-D) that limits this pathway to 295 feet.

When considering the aforementioned requirements, the pathway system will consist of either enclosed pathway (raceways) or open pathways (such as cable tray or J-hooks). While conduit and other enclosed pathways typically route directly to the receptacle or technology outlet location, an open pathway typically serves as an aggregation point, creating a less direct and often, longer path back to the serving equipment. Additionally, conduit may be used to collect cables to an aggregation point and if using the category cabling for

power over ethernet applications, the NEC requires that you de–rate the current carrying capacity of the cabling by the coefficient shown within NEC table 725.144. These requirements must be considered primarily for ICT cabling.

When routing any type of cabling through a building, it is important to understand each space's use and potential protection requirements. This extends from physical protection, to prevent mechanical damage, through fire protection or hazardous location requirements.

The first concept surrounding the subject of "physical damage" can be quite complex as no codes or standards clearly define the phrase, in fact, it is often conceded that this is subjective. Each authority having jurisdiction may approach this concept in different ways. On a basic level this should be applied in a common-sense approach where hard-use areas are treated with extra care for protection; it is important to note that the code intent is to prevent inadvertent physical damage and not to prevent damage from malice or intentional damage.

For example, hard–use areas should include but not be limited to: loading docks, enclosed sally ports for cash trucks, corridors with traffic of mechanical vehicles (pallet jacks, forklifts, etc.), mechanical rooms, gymnasiums, etc. Within these hard-use areas, the designer can defer to the uses permitted within chapter 3 of the NEC for pathways permitted in areas "subject to physical damage." This would typically require a thick-walled conduit such as intermediate metallic conduit or galvanized rigid conduit in lieu of any types of tubing such as EMT or any open–type pathways such as cable trays (see Figure 2).

Fire protection and fire stopping

When considering fire protection requirements, the designer should first consult any available fire protection reports or code consultants for the project. Rated walls and enclosures will be identified in the fire protection report and on the architectural set of drawings. Often, a book or sheet specification can handle fire protection requirements and any seal off requirements for hazardous locations; however, the pathway requirements do change. Within NEC 500 through NEC 503, there are additional requirements such as the requirement for threaded conduit systems (NEC 501.10(A)(1)(a) and NEC 502.10(A)(1)(a)) that also are required to be wrench tight to prevent a ground fault from arcing in an environment with flammable or explosive gases or dust (NEC 500.8(E)). Each classified area should be thoroughly examined for code compliance of all pathway (and miscellaneous electrical and ICT) systems. These identified areas also will be required to maintain the fireproof rating of the walls in that the pathway is penetrating.

In addition, where an open pathway is traversing through a plenum (or commonly referred to as an air handling space), a specialized plenum rated wiring method is required. A plenum rated cable is rated to burn within an air handling space and not introduce toxins or spread flame through the plenum; the mechanical designer for the project will identify plenum spaces that will assist the ICT designer to determine the cabling type required for the premises wiring system.

It should be noted by the electrical and ICT designers that a system designed to comply with NEC 645, Information Technology Equipment Rooms, may be exempt from the plenum rating requirement if the raised floor is used as a plenum rated space; the heating, ventilation and air conditioning is entirely separate of the building system HVAC; and there

is a dedicated shunt trip for the electrical system and for the HVAC system (NEC 645.10).

Cable capacity and ampacity

As the electrical or ICT designer is identifying cabling types, available pathway routing and protection requirements, another consideration must be made for the ampacity or quantity of cables required. Electrical designers typically defer the cable routing to a "means and methods" process that involves the contractor's judgment unless larger ampacity feeders, medium–voltage or utility routing is considered. When considering these larger ampacity installations, it is important that parallel feeder runs are routed in compliance with NEC 300.3(B)(1) and NEC 310.10(H) that requires that each parallel conduit run consist of an identical phase, neutral and ground conductor (as applicable). These parallel feeders must be of the same length, conductor material, size, insulation type and be terminated in an identical manner.

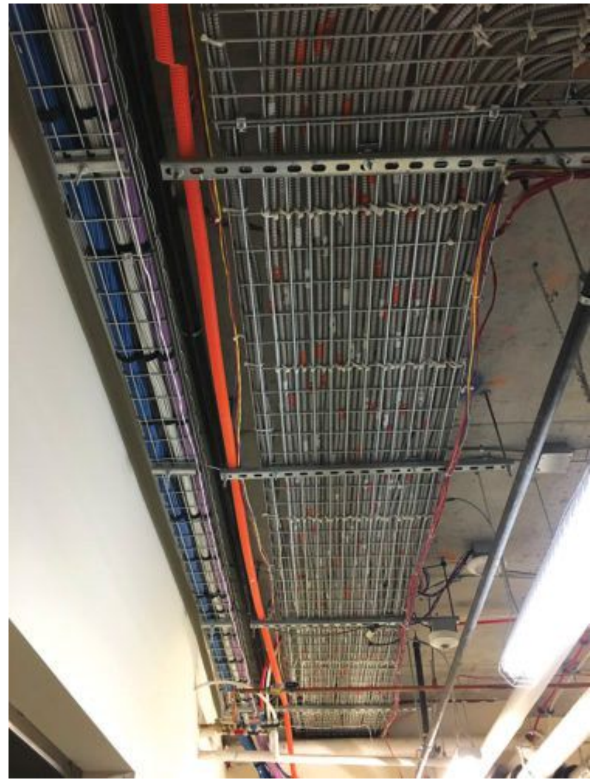

Figure 4: *On the right, cable tray is used to support and secure MC wiring as a main routing point down the corridor. In the center, there is an orange innerduct that is used for fiber routing and on the left, there is a cable tray with cleanly segregated low-voltage cabling. Courtesy: NV5*

Often, when considering higher ampacity feeders or modular designs, it may be applicable to use busway. Busway is common for high-rise commercial hotel applications, industrial installations, larger data centers and greenhouse facilities. Large high-rise hotels typically are designed with a large ampacity busway installed vertically throughout the tower and plug-on units (specially designed disconnects or enclosed circuit breakers) are used for horizontal distribution feeders to panelboards.

Busways require a penetration through each floor of a tower and a fire protection report or code consultant should be consulted to discuss fire protection options for the room or penetration. Additionally, the NEC requires that the penetration is provided with a water-proof curb to prevent ingress of water and general flooding down the stacked electrical rooms (NEC 368.10(C)(2)(b)). If this waterproof curb is compromised, water may eventually work its way down the busduct and could result in a violent explosion due to a short circuit (see Figure 3).

When considering industrial, data center or grow facilities, it is not uncommon to see a combination of horizontal runs that are supplied with plug-on units to deliver load centers or 3-phase power at specific locations. This allows a modular design where power can be delivered in large ampacities throughout the run of busduct. This typically is catered to very specific owner and equipment requirements and can vary in application.

Although the depth of uses for busduct is beyond this article, it is a critical piece of any electrical designer's arsenal and a minimum general understanding is required to provide the most efficient and thoughtful designs.

The analogy of large–ampacity installations for ICT designers would be the quantity of cables. Typically for large cable quantities an ICT designer will consider designing a cable tray layout with varying sizes that correlate to the quantity of cables at each junction or

branch. This gives the primary horizontal cabling a support and routing backbone. These trays are sized in accordance with NEC 392 that has myriad complicated formulas and subsections that depend on tray type, cable type and ampacity (if applicable), to calculate a maximum fill percentage.

Instead of wading through this code section, often electrical designers will use a manufacturer's cable tray calculation tools that are specifically programmed for compliance with the NEC. When discussing a cable tray consisting of only ICT cabling, a 40% fill ratio is recommended via the TIA-569-B standard. Typically, an ICT cable tray backbone is installed in a tapered manner in that the closer the installer is to the end use device or outlet, the smaller the cable tray; the closer the installer is to the serving telecommunications room, the larger the cable tray typically is. This is to accommodate the aggregation of cables within the cable trays.

With all the above considerations, an electrical or ICT designer should be knowledgeable and capable of applying all the above considerations to provide a code-compliant and practical design for a particular occupancy or building. Often the pathway system will consist of a combination of all the aforementioned (see Figure 4).

An example for ICT premises wiring system could include a cable tray with a fire rated penetration through a corridor wall that transitions to EMT above a hard–lid section of ceiling, only to transition back to cable tray once the routing reaches another accessible ceiling space. From here, the contractor may use J-hooks to route individual cables to specific technology outlets within each space. This would combine several types of pathways to provide the client or occupant a flexible system that is code compliant.

Definitions

Several key terms will need to be identified to clearly convey the requirements of the specific systems available to the system designers:

Busway (or busduct): A manufactured, enclosed pathway made of sheet metal with solid copper or aluminum busbars for higher ampacity installations in a compact footprint.

Cable tray: Nonenclosed tray type pathway designed to physically support premises wiring systems.

Pathway: Any physical method of supporting, enclosing, protecting or otherwise transporting wiring systems.

Premises wiring system: The wiring or cabling throughout a building, structure or compound downstream of the service connection or demarcation point.

Raceway: Any enclosed physical pathway designed to protect or shield premises wiring systems.

Stephen Berta, EI, NV5, Las Vegas

***Stephen Berta** is the associate director of electrical at NV5 and has experience in multiple market sectors including high-rise hospitality, gaming, K-5 education and data centers.*

Following an OPR to design lighting systems

Lighting designers must consider many factors when specifying lighting systems and lighting controls for nonresidential buildings, including the owner's project requirements

One of the first things a lighting designer should do on a project is to obtain the owner's project requirements. The OPR contains elements for design and should contain requirements for illumination and related items.

Other items typically found in an OPR:

- Lighting construction budget.
- Code requirements.
- Desired light source, color temperature, color rendering index, etc.
- Desired luminaire type and style. Note that a luminaire definition in NFPA 70: National Electrical Code is defined as "a complete lighting unit consisting of a lamp or lamps together with the parts designed to distribute the light, to position and protect the lamps and to connect the lamps to the power supply." A lighting fixture typically includes the metal or plastic components and the lens and may or may not include the ballast or driver or the actual lamps themselves.
- Illumination levels, minimum foot-candle levels, maximum foot-candle levels, maximum to minimum foot-candle ratios, etc.
- Desired controls systems.
- Special requirements such as emergency lighting, daylighting harvesting, dark skies, etc.

- Sustainability goals.
- Commissioning requirements.
- Training requirements.
- Operations and maintenance requirements.

With smaller projects, the lighting designer may not receive an OPR. In this case, the lighting designer should go over the key lighting elements with the owner. Another approach is to work with the architect to develop a basis of design that lists the key lighting elements and the design approach. This document should be presented to the owner for approval before design.

Lighting construction budget

The budget for luminaires and controls can vary greatly. The lighting designer will need to know the lighting budget to assess if it is realistic for the project's OPR. Typical installed (including labor and material) square foot costs can range from $5/square foot for a lighting upgrade project to $15/square foot for higher-end commercial projects.

Code requirements

The OPR should state the desired energy-efficiency goals. For example, the OPR may state the project shall meet or exceed state energy codes by a minimum of 15% including lighting. The lighting designer will need to keep this in mind while selecting luminaires and their efficacy (lumens per watt) and total input watts per luminaire.

How does a lighting designer know what codes and standards apply to the designer's project? A very useful resource can be found at the U.S. Department of Energy's

website, which lists the energy codes for each state. Local codes should also be checked by the lighting designer because local codes may supersede state codes in some states. Also, if a project pursues U.S. Green Building Council LEED certification that will also have an impact on which energy code should be followed.

Figure 2: *A daylight harvest sensor is mounted on the ceiling in an open multispace room. This sensor will automatically dim the LED lighting in this space based upon ambient daylight. Courtesy: Metro CD Engineering LLC*

It is highly recommended to enter luminaires into the COMcheck or other lighting compliance form that is required by the local code authority during the schematic phase or design development phase of the lighting design. Waiting until the end of the 100% construction documents design to check for compliance may result in noncompliance and require changing to different luminaires with lower total input watts per luminaire. This can delay the schedule as typically the architect and owner need to determine if the suggested replacement luminaire is acceptable. There is an online article that shows a lighting designer a step-by-step procedure to complete the COMcheck form.

Light source

The OPR should state the owner's preference for the light source. Most owners want

LED lighting due to their long life, lack of hazardous materials (whereas fluorescent lamps contain mercury) and high efficacy.

Color temperature is an important detail; if it's missing in the OPR, it should be obtained. A typical office color temperature is 3,500 Kelvin. However, some owners may want a higher color temperature such as 4,100 Kelvin, and some want even higher color temperature.

Conversely, some owners — especially in the hospitality industry — want warmer color temperatures such as 2,700 Kelvin. It is important for lighting designers to find out the desired color temperature because it can be costly to replace entire luminaires or components of a luminaire if the incorrect color temperature is specified.

Some retail owners may require high CRI. The minimum CRI level should be stated in the OPR.

The R9 color rendering index is another value that owners may state. LEDs may have difficulty rendering red colors well. High R9 values are desirable in restaurant, food and retail applications.

Desired luminaire type, style

Typically, lighting designers work with architects and owners to determine the type and style of luminaires selected for a project. For example, an owner may require linear LED luminaires that are end-to-end for a long corridor with a frosted lens. The lighting designer should ask for additional details if it is missing from the OPR. For example, if

Visual perception and its impact on emergency illumination design

Electrical systems, from design to commissioning

Specifying the right electrical raceways, busways, wiring and cabling

Following an OPR to design lighting systems

Commissioning lighting occupancy sensors

the OPR did not state frosted lens and the lighting designer specified a clear lens, then this could result in a costly change order if ordered and installed.

A recent project involved an architect that requested clear lenses for recessed can LED luminaires without consulting the owner. After installation was completed, the owner said the glare from the luminaires was unacceptable and frosted lenses replaced the clear lenses.

It is also critical that the lighting designer select the correct luminaire for the ceiling type. An example of improper coordination is when a lighting designer specified a surface-mounted luminaire for multiple operating rooms and the architect specified a lay-in ceiling. The luminaire was custom-built and more than 100 were ordered. Unfortunately, the luminaire could not be modified with to fit within a lay-in ceiling. This delayed the opening of the operating rooms and new luminaires had to be purchased.

Illumination levels

The lighting designer needs to know if the owner would like to meet Illuminating Engineering Society lighting levels or if there is another requirement. The IES has recommended minimum lighting levels depending upon the type of space and the users or occupants in that space. The age of users also comes into play as older occupants may require higher light levels compared to younger occupants.

A typical OPR may state: "The lighting levels (a combination of the natural lighting and electric lighting) in the open-office area shall provide a maintained illumination average of 30 horizontal foot-candles (minimum) without the use of task lighting measured

at the work plane height. Daylight harvesting shall be used to achieve the required foot-candle levels." It is important to know where the measurement of light levels occur. Typically, this is at the work plane level, which is an industry standard of 30 inches above finished floor.

The OPR may leave out requirement for lighting levels for certain rooms/areas that are deemed noncritical or for transition areas like corridors. The IES recommended corridor light levels are typically much lower than what is stated for recommended office light levels. Some owners have been dissatisfied with low corridor light levels even though these levels meet the recommended IES level. The owners wanted light levels in the corridors similar to office light levels. The lighting designer needs to ensure the OPR has recommended light levels for all areas/rooms to avoid these types of issues.

The owner may have maximum foot-candle levels as well in the OPR. Some owners do not want spaces/rooms to be over lit.

Maximum to minimum light level ratios may be included in the OPR. This is how uniform the light levels are in an area. This typically is used for parking lots to ensure uniform lighting for safety. A typical recommendation is 15:1 for parking lot lighting.

Controls systems

The type of lighting controls should be stated in the OPR. The owner may want a lighting controller tied into the building automation system to control all lighting with time-of-day shut-off.

The OPR should also state if wireless controls are acceptable. Some owners do not want wireless controls; they prefer hard-wired options.

Owners may want a different lighting control for a room than what is acceptable by the energy code. For example, an owner may want only light switches in a conference room and no other type of control. However, the energy code may require an automatic shut-off device such as an occupancy sensor. The lighting designer shall review the OPR and advise the owner of conflicts between the OPR and codes to avoid issues later in the project. The engineer of record (usually a licensed professional engineer) for a project shall comply with the applicable codes, including the energy code. The owner cannot mandate that codes be ignored.

For instance, an owner of a jewelry store wanted a new high-end jewelry store to be built. The OPR stated to use all halogen light sources in the sales area. At the schematic design level, the lighting designer informed the owner that the current energy codes would not allow all halogen light sources in the sales area. Ceramic metal halide light sources were used that were acceptable to the owner and also met the energy code. After the new store was completed, the owner decided he liked the new ceramic metal halide luminaires more than the halogen light sources.

Owners may require occupancy sensors in private offices to control both luminaires and heating, ventilation and air conditioning devices. For example, if the occupancy sensor does not detect anyone in an office, the owner may require the lighting be turned off in the room and have the HVAC variable air volume box move the damper to the minimum code–required position to save energy.

Dimming should also be covered in the OPR. Does the owner want 1% dimming? If so, dimming controls will need to be specified that are compatible with the dimming luminaires.

Scene control in certain rooms such as large classrooms and auditoriums should be specified in an OPR. For example, an owner may want pre-programmed scenes for a classroom with audiovisual projectors.

Site lighting control in the OPR should state if photocells should be used in each exterior luminaire or if one photocell is to be used for control of all luminaires. Time–of–day control also can be used to control outdoor lighting instead of photocells.

Special requirements

Owners should state in the OPR how emergency lighting is to be powered. Emergency egress lighting is typically powered through battery packs, an inverter or a generator. There are some owners that want all lighting in the facility on generator power. The lighting designer needs to follow code requirements for egress lighting while also meeting the OPR.

Owners may want to implement daylighting harvesting to save energy. It is important for lighting designers to determine the extent of daylighting harvesting that owners desire. Simply stating "incorporate daylighting harvesting" in an OPR does not provide enough information for the lighting designer.

The OPR should state which rooms daylighting harvesting is desired. The lighting de-

signer should keep in mind that energy codes may mandate which spaces are required to have daylighting harvesting and if multiple daylighting zones are desired. The OPR should also include dimming levels (1% or 10%) and also how many rows of luminaires should be controlled per room/area.

Owners may state in an OPR they require exterior lighting fixtures to have certain backlight, uplight and glare ratings. BUG is an acronym coined by the IES and the International Dark-Sky Association. The BUG rating of a luminaire determines how much light trespass the luminaire produces. The OPR may state to meet the LEED BUG requirements.

Circadian lighting is a growing movement for owners to incorporate into their buildings. The color and intensity of light can be used to regulate the timing of humans' biological clocks, also known as circadian rhythms. There are claims of improved employee productivity, reduction in obesity, shorter hospital stays and other benefits of using circadian luminaires.

Owners may want to meter or track the lighting energy usage and run–time of luminaries. There are several strategies to incorporate this such as installing a sub-meter on the lighting panelboards and tracking energy usage through the lighting control software or BAS.

Tracking the amount of time luminaires are on can help an owner with determine when it is time to replace luminaries as they approach their end of life.

Sustainability goals

The OPR should state sustainability goals such as certifications such as LEED, WELL Building Standard, Green Globes, etc.

Figure 3: *A wireless occupancy sensor installed in an office has a 10-year battery life with normal usage. Courtesy: Metro CD Engineering LLC*

For example, an OPR states the minimum level of LEED certification and sustainability goals. The statement could be: "Project shall achieve a minimum of LEED v4 Silver Certification."

The lighting designer will typically need to complete the LEED (or other certification) online template documentation for each lighting credit. Also, the lighting designer will most likely need to work with the person doing the building energy model to incorporate controls and specialty items such as daylighting harvesting into the model.

Commissioning requirements

Commissioning of lighting systems is important to ensure the systems are working as the lighting designer intended.

An OPR should state if the owner's commissioning requirements for lighting and other systems that use energy and affect operation of a building. Energy codes and LEED certification have made commissioning of lighting controls a requirement. ASHRAE Standard 90.1: Energy Standard for Buildings Except Low-Rise Residential Buildings requires functional testing of lighting controls and systems.

LEED and other sustainability certifications require commissioning in order to obtain certification.

Ongoing commissioning should be recommended to an owner. This process is to ensure that the lighting systems continue to operate and save energy as originally designed.

The lighting designer should work with the commissioning authority/agent early in the project, preferably the pre-design stage to determine the commissioning requirements for the lighting systems. For example, the commissioning authority or agent may do a review of the design documents and review lighting related shop drawings. The commissioning authority/agent reviews the OPR and the design team's BOD to ensure the OPR are met.

Training requirements

Training for an owner's facility personnel is important to ensure the lighting system is operating after the construction is completed and the building is turned over to the owner. The OPR may state training is to be videotaped and provided by a factory–trained or authorized representative from the lighting controls company. The lighting

designer needs to incorporate the owner's training requirements into the specifications

O&M requirements

In addition to training, the OPR should state what documentation is required for the contractor to turn over to the owner's facility staff form operations and maintenance of the lighting system. This typically includes record drawings of as-built conditions and the specifications. Shop drawings of the luminaires and the control devices are usually required as well.

The lighting designer shall incorporate into the specifications the requirements for the O&M manual as directed by the OPR.

An OPR is critical to the success of a lighting project. There are many critical lighting items that need to be listed in an OPR. The lighting designer shall meet these requirements in the design for an energy-efficient lighting system.

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Michael Chow *is the founder and President of Metro CD Engineering. He holds a BSEE from Ohio Northern University and is the current Chair of the university's Engineering Advisory Board, a member of the Consulting-Specifying Engineer editorial advisory board and a 2009 40 Under 40 winner.*

Commissioning lighting occupancy sensors

Installing lighting occupancy sensors and commissioning the devices have many benefits, including reducing operational and maintenance costs

Many of us have seen or personally experienced a person frantically waving their arms in circular motions when the lighting turns off in a space controlled by an occupancy sensor. While this may seem comical at first, users in these spaces tend to get frustrated at the occupancy sensor and override it to avoid being left in the dark. Occupancy sensors then get a bad rap. Why did the occupancy sensor fail to keep the lights on?

Lighting uses approximately 20% of the total energy consumed in commercial buildings, according to the U.S. Department of Energy. There is great potential for energy savings by reducing the lighting levels or turning the lighting off when not needed.

Occupancy and vacancy sensors are devices that use sensors to detect when a space is unoccupied and accordingly automatically turn off (or dim) the lighting fixtures. This saves energy by turning the lighting off in a space or room if it is not occupied. The device can turn the lighting fixtures on automatically upon detecting the presence of occupants and thus is referred to as an occupancy sensor.

Vacancy sensors are like occupancy sensors and use similar sensor technology. However, vacancy sensors require the occupant to turn the lighting fixtures on in a room or space by pressing a manual switch, which typically is integral to the motion sensor. See Figure 1 for an example of a wall-mounted vacancy sensor with dual technology (pas-

sive infrared and ultrasonic). The button with the light bulb is pressed as a manual on to turn on the lighting fixtures manually.

Vacancy sensors should provide greater energy savings than occupancy sensors because they give the occupant a choice of whether to turn on the lighting fixtures. For example, if there is enough ambient light in an office with windows for daylight entering through the windows, the occupant may choose not to turn on the lights at all. Conversely, with an occupancy sensor, the lighting fixtures will turn on automatically regardless of how much daylight is in the room.

This article will use the term "occupancy sensors," which can be either occupancy or vacancy sensors depending upon the owner's project requirements.

Studies have shown that adding occupancy lighting controls can reduce lighting energy use 10% to 90% or more, depending on the use of the space in which the sensors are installed, according to the U.S. Department of Energy (see Table 1).

One study conducted by the U.S. Department of Energy on a university campus found that installing wired occupancy sensors to control lighting in more than 200 rooms in 10 buildings provided an annual cost savings of about $14,000 with a simple payback of 4.2 years.

Occupancy sensors are also mandated by energy codes. ASHRAE Standard 90.1-2010 and 2013: Energy Standard for Buildings Except Low-Rise Residential Buildings requires that lighting automatically turn off or be reduced in output in spaces/areas such as conference rooms, classrooms, breakrooms, storage rooms, private offices, etc., with

a 30-minute maximum timeout setting, both for new construction and for major retrofits. Occupancy sensors help achieve this requirement.

It is important to understand occupancy sensors need to be commissioned to realize these savings in practice.

Table 1: Occupancy sensor savings

Room type	Occupancy sensory lighting energy savings
Breakroom	29%
Classroom	40% to 46%
Conference room	45%
Corridor	30% to 80%
Office, open	10%
Office, private	13% to 50%
Restroom	30% to 90%
Storage area	45% to 80%
Warehouse	35% to 54%

Table 1: *The table shows typical savings by room type when using occupancy sensors. Courtesy: U.S. Department of Energy*

Commissioning guidelines

How does an engineer or commissioning agent commission occupancy sensors lighting controls? Fortunately, there are guidelines and processes: ASHRAE Guideline 0-2019: The Commissioning Process and ASHRAE Standard 202-2018: Commissioning Process for Buildings and Systems; the ACG (AABC Commissioning Group) Commissioning Guideline; and IES DG-29-11: The Commissioning Process Applied to Lighting and Control Systems.

The IES Lighting Handbook defines commissioning of lighting systems as "a systematic process that ensures that all elements of the lighting control system perform interactively and continuously according to documented design intent and the needs of the building owner."

Energy codes and U.S. Green Building Council LEED certification have made commissioning of lighting controls a requirement. Standard 90.1 requires functional testing of lighting controls and systems.

IES DG-29-11 breaks down the commissioning of lighting control systems into the following phases:

- Pre-design.
- Design.
- Construction.
- Occupancy and operations.

Figure 1: *An occupancy sensor with dual technology (passive infrared and ultrasonic) is shown. The button with the light bulb image is pressed as a manual on or off to control the lighting fixtures manually. Courtesy: Metro CD Engineering*

The pre-design phase is when the commissioning team is formed and is led by the commissioning authority. The commissioning team, consisting of the construction manager, subcontractors and lighting engineer/designer, creates the commissioning plan, develops the owner's project requirements and provides procedures to identify and track issues during the commissioning process.

The OPR should include performance requirements for lighting control systems. For example, a section of the OPR for occupancy sensors may state:

- Occupancy sensors shall be used to turn off lighting when a space/area is unoccupied. The sensors should be set for a maximum 30-minute timeout to shut off lighting.

- Occupancy sensors shall use vacancy mode to turn lighting on in enclosed private offices with automatic off.

- Occupancy sensors shall integrate with the heating, ventilation and air conditioning system and the building automation system in private offices to turn off lighting when unoccupied and provide code minimum ventilation levels.

- Daylighting harvest sensors shall be installed in all open office areas. Daylighting controls shall dim the lighting automatically to maintain a minimum of 30 foot-candles measured at the desktop height above finished floor.

In the design phase, the design engineer should complete the basis of design that explains the concepts that the engineer will employ to achieve the performance requirements of the OPR. For example, suppose the OPR states: “Vacancy sensors shall be used in all enclosed private offices.”

A BOD to achieve this OPR may state: “Vacancy sensors using passive infrared and ultrasonic, self-adaptive technologies shall be used in all private enclosed office. Sensors shall turn the lighting off within five minutes after an office is unoccupied.”

Typically, the contractual design phases of a project consist of schematic design, design development, construction documentation, construction administration and final punch list.

The schematic design contains an outline of the lighting control system to fulfill the OPR. The design development phase includes detailed drawings and specifications.

The construction documentation incorporates commissioning in the specifications. It is highly recommended that the commissioning specifications be incorporated no later than the design development phase. The specifications would be updated in the construction documents phase.

The specifications include lighting controls to be tested and roles and responsibilities of the commissioning authority and the contractor(s). Including these items helps reduce or even eliminate conflicts and issues during commissioning tasks such as functional testing. For example, a commissioning specification may state, “The contractor shall notify the commissioning agent in writing at least 14 days in advance of all pre-functional testing.”

The commissioning authority reviews the lighting control design documents to check compliance with the OPR and the commissioning plan. For example, the commissioning authority may check that occupancy sensors are located correctly in each space/area. Another example includes verification that occupancy sensors are located more than 6 to 8 feet from HVAC diffusers (especially for sensors that use microphonics).

Here are some typical occupancy sensor design items that should be reviewed by the commissioning authority:

- Occupancy sensors are not allowed to control lighting fixtures in electrical rooms as stated in the NFPA 70: National Electrical Code.

- Time delay setting of occupancy sensors stated in the specifications shall match the OPR. How long should the lighting fixtures stay on once no motion is detect-

ed? The less time the lighting fixtures stay on, the higher the savings will be. The commissioning authority should discuss this with the owner and the design team. With LED lighting now the standard and with frequent switching of LED lighting fixtures having little effect on the longevity of LED light sources, time delay settings should be 15 minutes or less. National Electrical Manufacturers Association guidelines recommend a 15-minute time delay. However, you may want to start with a 10-minute delay for greater energy savings and adjust to a longer time delay if occupants request it (refer to the U.S. Department of Energy).

- Location of occupancy sensors.
    - Sensors should not be installed within 5 feet of HVAC supply diffusers.
    - For enclosed spaces, locate a wall-mounted sensor where it will not be blocked when the door is open.
    - Do not install sensors on an angled or inclined ceiling as they typically do not perform well when positioned at an angle.
    - Verify that the type of sensor used will sense both minor and major movement.
    - Restrooms should typically use ceiling-mounted ultrasonic sensors to detect movements in the stalls. Many lighting engineers/designers may use just one wall sensor to detect movement when an occupant enters a restroom, but this sensor may not detect an occupant in a restroom stall. It is good

practice to have adequate lighting in restrooms in an unoccupied mode should the lighting be turned off at inappropriate times.

- Ceiling height should be considered when placing a sensor. Most sensors should not be installed with ceiling heights over 15 feet.

The commissioning authority always notifies the design team of issues discovered during the review of the documents. The design team should then reply formally to the commissioning authority's comments and resolve all issues.

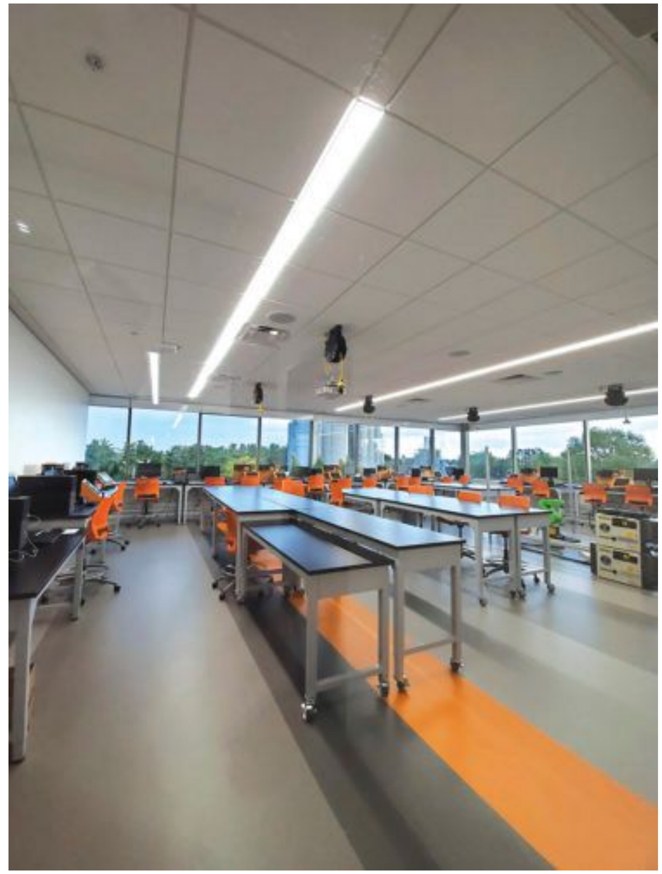

Figure 2: *Ohio Northern University's James Lehr Kennedy Engineering Building has increased laboratory space and an abundance of natural daylight in the building. Courtesy: Tara Grove, Metro CD Engineering*

The construction administration phase involves training of the facility personnel on the operation and maintenance of the lighting and control system. A good example of a training program includes explanation on how occupancy sensors can be modified (e.g., change from occupancy to vacancy mode).

Also included in this phase is performance testing. For lighting control systems, the commissioning authority, electrical contractor, operators, manufacturer representatives and other stakeholders are typically present for the testing. A sample partial performance test for occupancy sensors may include verification that the lighting fixtures in a space turn on within 3 feet of entering a space in a private office.

The commissioning authority maintains an issues log that begins at the pre-design phase. The log includes details of each issue and who is responsible to resolve each issue one.

A systems manual, with specified sections provided by the construction manager, is handed by the commissioning team to the owner at the project turnover. The systems manual provides details, which are now described by LEED v4, on the operation and maintenance of the lighting controls. Also included are record drawings, submittals (shop drawings), the issues log, the OPR and BOD, as well as operations and maintenance manuals. Training should always include a review of the systems manual and its use in normal operation of the building.

The occupancy and operations phase begin at substantial completion. This includes providing completion of any deferred testing and training as well as maintaining the systems manual.

The commissioning requirements of Standard 90.1-2010 require that the construction documents identify who will conduct and certify the testing. All specified lighting controls and associated software must be calibrated, adjusted, programmed and assured to operate in accordance with construction documents and manufacturer installation

instructions. Specific requirements are identified for occupancy sensors, programmable schedule controls and photosensors.

For example, at a minimum, the party conducting the testing must confirm that the placement, sensitivity and timeout settings for any installed occupancy sensors provide acceptable performance — for example, the lights must turn off only after the space is vacated and must turn on only when the space is occupied. Time switches and programmable schedule controls must be programmed to turn the lights off. And photocontrol systems must reduce light levels produced by the electric lighting based on the amount of usable daylight in the space as specified.

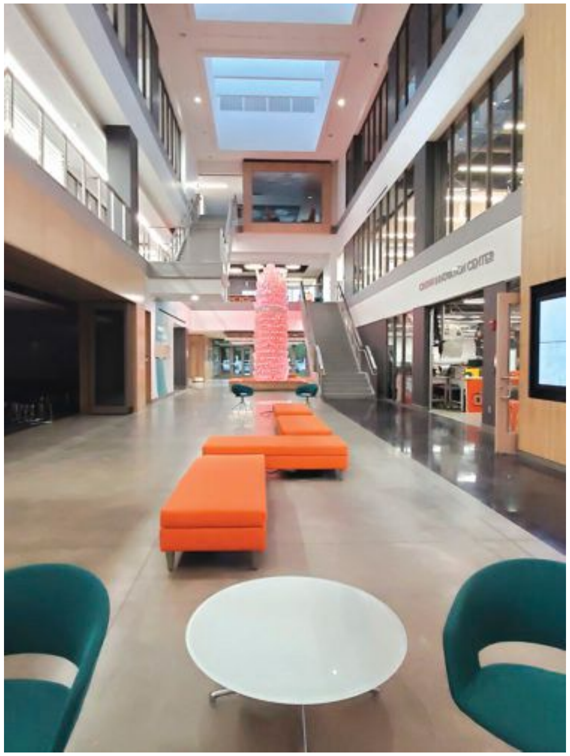

Figure 3: *The 105,000-square-foot, $30 million, three-story James Lehr Kennedy Engineering Building at Ohio Northern University, Ada, Ohio, was completed in fall 2019. The new facility in allows more engineering student enrollment, increases laboratory space and encourages student-faculty collaboration. Courtesy: Tara Grove, Metro CD Engineering*

Standard 90.1-2010 requires a commissioning authority be engaged that is not involved in the design or construction team. The commissioning authority verifies that the lighting controls are adjusted, programmed and functioning in accordance with the design and the manufacturer's installation instructions. The commissioning authority then submits documentation certifying that the lighting systems are in compliance with or exceed the performance requirements outlined for the project in the OPR.

Installing occupancy sensors and commissioning the devices have many benefits, including reducing operational and maintenance costs. And with properly designed and commissioned occupancy sensors, it's time to say goodbye to days of people frantically waving their arms when the lights turn off.

Michael Chow, PE, CxA, LEED AP BD+C, Metro CD Engineering, Columbus, Ohio

Michael Chow *is the founder and President of Metro CD Engineering. He holds a BSEE from Ohio Northern University and is the current Chair of the university's Engineering Advisory Board, a member of the Consulting-Specifying Engineer editorial advisory board and a 2009 40 Under 40 winner.*

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