401 ELECTRIC POWER AND LIGHTING SYSTEMS

Overview

DESIGN CONSIDERATIONS

Section 401 of the 90.1 Code contains requirements for electric power and lighting systems. For the most part, Section 401 addresses electric lighting systems and equipment; however, additional requirements apply to electrical distribution systems and electric motors. Section 401 of the 90.1 Code is organized as follows:

- Part 401.1 addresses electrical distribution systems, prescribing requirements for the subdivision of electrical feeders, and for the provision of information about the electrical system.
- Part 401.2 assigns minimum efficiencies for electric motors.
- Part 401.3 contains requirements for interior and exterior lighting power, lighting controls, and fluorescent and high intensity discharge lamp ballasts.

Electric lighting accounts for approximately 40% of all commercial building energy consumption in this country,[1] accounting for about 5% of total energy consumption in the United States. Electric lighting also adds heat to building spaces that must be removed by the cooling system. As a rule-of-thumb, an air conditioner will use an additional 15 to 20 kWh to remove the heat produced by each 100 kWh of installed lighting energy.

Using efficient lighting sources is probably the best way to insure lighting energy efficiency while maintaining or even improving lighting conditions. Modern fluorescent lighting systems, such as electronically-ballasted T-8 systems, can provide the same quantity of light as older fluorescent lighting while consuming as little as one-half of the energy. Similarly, compact fluorescent sources are four to five times more efficient than the traditional incandescent lamps they have been designed to replace.

A primary goal in most building designs is to minimize initial construction costs. Consequently, without codes or incentives, inefficient lighting equipment is often installed, due to lower first costs. This approach is short-sighted. A life-cycle cost evaluation of competing lighting systems would identify more efficient components with lower long-term operating and environmental costs.

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[1] Source: United States Environmental Protection Agency

The 90.1 Code encourages the use of energy-efficient lighting equipment and design practice by assigning lighting power allowances for both interior and exterior lighting systems. The space or building complies with the code when its installed lighting power is less than the lighting power allowance. This approach promotes design flexibility while assuring a minimum level of efficiency.

SCOPE

The electrical power and lighting system requirements of the 90.1 Code only apply to new high rise residential and commercial buildings. The lighting system requirements apply to the design of the first installed lighting system, even if the space already exists. In many modern buildings, the core and shell are constructed under a separate building permit from the tenant improvements. The core and shell along with the *initial* tenant improvements are all considered new construction.

Most electrical power, including interior and exterior lighting systems, is regulated by the 90.1 Code. Buildings that are included and those that are exempt from the electrical and lighting requirements are listed in Section 101 of the Code. Lighting systems used for specialized commercial and display purposes, such as outdoor manufacturing, sports lighting, theatrical productions, medical procedures and research, and museum lighting, are exempt and do not need to be considered. Also exempt are electrical and lighting systems or portions of systems required for emergency use. Specific lighting systems that are exempt from code requirements are discussed in detail in the sections on interior and exterior lighting power.

For the most part, applying Section 401 of the 90.1 Code is relatively simple. However, there are a number of specific cases pertaining to lighting systems where additional information may be helpful in interpreting the code requirements:

- *Exterior and Interior Lighting.* The 90.1 Code contains separate requirements for exterior and interior lighting systems. Exterior and interior lighting must comply separately with their respective requirements. Trade-offs between the two are not allowed.
- *Lighting in Multibuilding Facilities.* Each building in campus-like facilities must comply separately with the interior lighting power requirements, even if they are covered under a single building permit. The exterior lighting power allowance, however, applies for the entire site.
- *Lighting in Speculative Buildings.* Speculative buildings are built before the tenants are known. The initial building permit application usually includes just the shell and core with lighting installed only for common areas of the building, such as corridors, toilets, stairwells, and lobbies. Lighting for tenant spaces is provided as part of the tenant improvements and is often customized for each tenant. Interior lighting power allowance for speculative buildings may be determined by one of two approaches (see the next section), but each portion of the building must separately satisfy the requirements of the 90.1 Code, irregardless of the time of tenant occupancy. Generally, lighting power in tenant spaces is higher (on a per square ft basis) than it is in common areas, such as corridors and restrooms.
- *Lighting in Shell Buildings.* Shell buildings are built before the building's use is known. The space could become light manufacturing, office, warehouse or any other use depending on the requirements of the tenant. In shell buildings, the lighting system is rarely installed before the space is leased. Leasing a building to a tenant effectively defines its use and allows for a determination of the

interior lighting power allowance. When a developer wants to install a lighting system before the use is known, the interior lighting power allowance shall be set at 0.2 $W/ft,^2$ which is the 90.1 Code allowance for unlisted spaces.

- *Garages and Parking Areas.* A covered garage is treated as interior space and is included as part of the interior adjusted lighting power. Open parking lots (including rooftop parking), however, are treated as exterior lighting.

Example 401A Application to First Tenant Spaces

Q The core and shell of a high-rise office was completed prior to the effective date of the 90.1 Code. The construction included the building envelope, the base HVAC system, and lighting improvements for the common areas only. Lighting improvements for each tenant space will be made on a tenant-by-tenant basis when each space is leased.

Tenant space on two floors of the building remain empty and unimproved until they are leased a year later, after the code takes effect. At this time the tenant files a permit application for the construction of a lighting system along with other tenant improvements. Does the code apply to the design of the lighting system?

A Yes. The first tenant improvements in a building are considered new construction, and the lighting standards apply.

Table 401A Lighting Acronyms Used with the Energy Code

AF	Area factor. An adjustment used with the systems performance method to account for the size and shape of a specific room. The area factor ranges in value from 1.0 to 1.8.
ALP	Adjusted lighting power. This is the interior connected lighting power (CLP) less the lighting power control credits (LPCC).
CLP	Connected lighting power. The sum of all non-exempt interior lighting power, measured in watts.
ELPA	Exterior lighting power allowance. The maximum lighting power that may be used for exterior lighting.
GLA	Gross lighted area. The lighted floor area of the building measured to inside wall surfaces. Used to calculate interior lighting power allowance (ILPA) with the building space method.
ILPA	Interior lighting power allowance. The connected lighting power or the adjusted lighting power must be less than this value which may be determined by either the whole building or specific space method.
LPB	Lighting power budget. Used with the space-by-space approach this value, measured in watts, is equal to the area of the space times a base unit lighting interior power allowance (ULPA) times the area factor (AF) of the room plus the appropriate lighting power control credit (LPCC).
LPCC	Lighting power control credit. The benefit of qualifying automatic lighting controls expressed as an equivalent reduction in installed lighting power. For a single control circuit, the LPCC = CLP × PAF.
PAF	Lighting power adjustment factor. The fraction of interior lighting power that is expected to be saved from the installation of a qualifying automatic lighting control. See LPCC.
ULPA	Unit lighting power allowance. The maximum watts per ft^2 of lighting for a specific building type, from the building space method The whole building ILPA is determined by multiplying the gross lighted area by the ULPA.
UPD	Unit power density. The maximum watts per ft^2 of lighting for a specific building space function or activity, from the specific space method. The space-by-space ILPA is determined by multiplying the floor area of each space or group of spaces by the UPD and the appropriate AF.

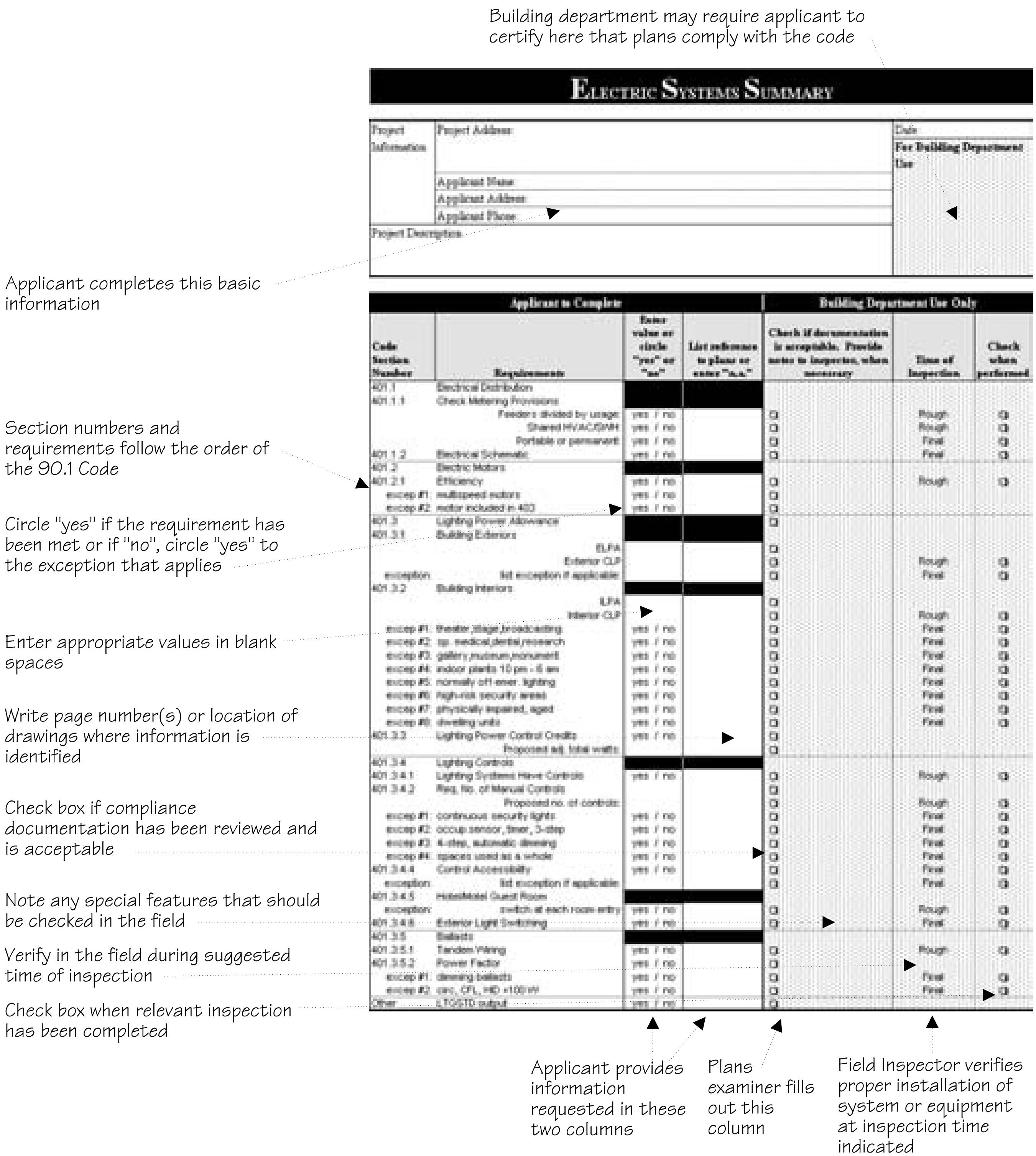
CHAPTER ORGANIZATION

Form
401.2.1

The Electric Systems Summary form, annotated in Figure 401A, provides an organizing element for this chapter. The form itemizes each requirement and provides a place to reference on the drawings where compliance with each requirement is documented. This form is filled out by the permit applicant and is then used by the plan's examiner and the field inspector to verify energy code compliance. The text of this chapter follows the order of the Summary form. As each requirement is addressed, an icon of the Summary form appears in the margin highlighting the appropriate 90.1 Code reference on the form.

The Compliance and Enforcement section of this chapter describes how to fill out this form in more detail, and introduces the Lighting Wattage and Lighting Controls worksheets. These additional worksheets are provided for the applicant (or the lighting designer) to calculate the allowed and proposed lighting wattages and the required and proposed number of installed lighting controls. It will be helpful for the reader to refer to these forms as each requirement is addressed below. Blank copies of all forms are found in Appendix D.

Figure 401A Annotated Electric Systems Summary Form



ELECTRIC SYSTEMS SUMMARY

Project Information	Project Address:	Date:
		For Building Department Use
	Applicant Name:	
	Applicant Address:	
	Applicant Phone:	
Project Description:		

Applicant to Complete				Building Department Use Only		
Code Section Number	Requirements	Enter value or circle "yes" or "no"	List reference to plans or enter "n.a."	Check if documentation is acceptable. Provide notes to inspector, when necessary	Time of Inspection	Check when performed
401.1	Electrical Distribution					
401.1.1	Check Metering Provisions					
	Feeders divided by usage:	yes / no		☐	Rough	☐
	Shared HVAC/SWH:	yes / no		☐	Rough	☐
	Portable or permanent:	yes / no		☐	Final	☐
401.1.2	Electrical Schematic	yes / no		☐	Final	☐
401.2	Electric Motors					
401.2.1	Efficiency	yes / no		☐	Rough	☐
excep #1:	multispeed motors	yes / no		☐		
excep #2:	motor included in 403	yes / no		☐		
401.3	Lighting Power Allowance			☐		
401.3.1	Building Exteriors					
	ELPA			☐		
	Exterior CLP			☐	Rough	☐
exception:	list exception if applicable:			☐	Final	☐
401.3.2	Building Interiors					
	ILPA			☐		
	Interior CLP			☐	Rough	☐
excep #1:	theater,stage,broadcasting	yes / no		☐	Final	☐
excep #2:	sp. medical,dental,research	yes / no		☐	Final	☐
excep #3:	gallery,museum,monument	yes / no		☐	Final	☐
excep #4:	indoor plants 10 pm - 6 am	yes / no		☐	Final	☐
excep #5:	normally off emer. lighting	yes / no		☐	Final	☐
excep #6:	high-risk security areas	yes / no		☐	Final	☐
excep #7:	physically impaired, aged	yes / no		☐	Final	☐
excep #8:	dwelling units	yes / no		☐	Final	☐
401.3.3	Lighting Power Control Credits	yes / no		☐		
	Proposed adj. total watts:			☐		
401.3.4	Lighting Controls					
401.3.4.1	Lighting Systems Have Controls	yes / no		☐	Rough	☐
401.3.4.2	Req. No. of Manual Controls			☐		
	Proposed no. of controls:			☐	Rough	☐
excep #1:	continuous security lights	yes / no		☐	Final	☐
excep #2:	occup.sensor, timer, 3-step	yes / no		☐	Final	☐
excep #3:	4-step, automatic dimming	yes / no		☐	Final	☐
excep #4:	spaces used as a whole	yes / no		☐	Final	☐
401.3.4.4	Control Accessibility	yes / no		☐	Final	☐
exception:	list exception if applicable:			☐	Final	☐
401.3.4.5	Hotel/Motel Guest Room					
exception:	switch at each room entry	yes / no		☐	Rough	☐
401.3.4.6	Exterior Light Switching	yes / no		☐	Final	☐
401.3.5	Ballasts					
401.3.5.1	Tandem Wiring	yes / no		☐	Rough	☐
401.3.5.2	Power Factor	yes / no		☐		
excep #1:	dimming ballasts	yes / no		☐	Final	☐
excep #2:	circ, CFL, HID <100 W	yes / no		☐	Final	☐
Other	LTGSTD output	yes / no		☐		

Requirements

This section explains the electrical and lighting requirements of the 90.1 Code, which include requirements that must be satisfied for electrical distribution systems, electric motors, exterior and interior lighting power, lighting controls, and fluorescent and high intensity discharge lamp ballasts. If the energy cost-budget method is used (See Appendix A), then the interior lighting power requirements do not apply, but all other requirements of Section 401 do apply.

ELECTRICAL DISTRIBUTION SYSTEMS

The requirements for electrical distribution systems apply to all single-tenant buildings with a connected electrical load of more than 250 kVA, as well as to tenant spaces in multi-use buildings with a connected electrical load greater than 100 kVA. The connected load is defined as all electrical sources powered from panels within the building, and to all building and equipment loads, such as kitchen equipment, air conditioning, and central computer units.

Check Metering

Form
401.1.1

The 90.1 Code requires that provision be made for check metering of a building's electrical distribution system. Check metering is the division of electrical power feeders by end use and/or by tenant. The intent of this requirement is to promote the efficient use of systems and equipment, through the easy accommodation of separate metering. If users can track their energy use, it is easier for them to operate their systems and equipment efficiently and to determine cost-effective investments in energy efficiency.

The code requires two separate provisions for check metering. First, electrical power feeders must be subdivided by end use. In addition, in multitenant buildings, feeders must be subdivided by user. These provisions are discussed below.

Subdivided Service By Use

Electrical feeders are required to be subdivided for check metering by end use according to at least three categories:

- Lighting and receptacle (plug) loads, including office equipment, such as fax machines, desktop computers, copy machines, and other plug-in equipment
- HVAC systems and equipment
- Service water heating, elevators, and any other special occupant equipment or systems of more than 20 kW

The last category includes individual equipment or systems that independently draw more than 20 kW. Examples include central computer systems (commonly feed through an uninterruptable power supply), printing equipment, kitchen equipment, and baling presses. Smaller equipment such as desktop computers, small printers, and small copying machines can be included with the receptacle loads.

Up to 10% of the load on any of the three feeder categories listed above may be from another usage or category. For instance, receptacle loads of up to 2,750 watts could be included along with feeders serving a 25 kW kitchen equipment load, but a 10 kW elevator load would need to be on a separate feeder.

Subdivided Service For Tenant Spaces

Tenants in buildings with connected loads of more than 100 kVA must have provisions for check metering. Each applicable tenant's feeders must also be subdivided by use, as listed previously. In addition, all central HVAC or service hot water (SWH) systems servicing multiple tenants in a building must be subdivided with separate check metering capability for each tenant.

Provisions For Metering

Each subdivided feeder required by this section must have either a permanent electrical meter, provisions for future installation of a permanent meter, or provision for a portable meter. Where permanent meters are not installed, provisions for future installation or portable meters can be provided in either a dedicated electrical cabinet through which the feeders pass, or within an electrical cabinet such as a breaker panel.

The measuring function available for dedicated panels shall be clearly identified. Qualified persons must have safe access to the enclosures through which feeder conductors pass, and there must be sufficient room to attach either a clamp-on or split core transformer on each feeder. Compliance with this requirement also assures that later installation of monitoring equipment, such as energy management systems, may be performed relatively easily.

Example 401B Subdivision of Feeders

Q A medium size retail space has 300 kVA of connected electrical load. This load is divided into the following uses: 50% for lighting and receptacle loads, 45% for HVAC systems and equipment, and the remaining 5% for the service water heating system. How many separate feeders are required for this project?

A As the connected electrical load of this building exceeds 250 kVA it must meet the requirement for the subdivision of feeders. Only two feeders are required: one serving the lighting and receptacles; a second serving the HVAC systems and equipment. The service water heating load can be combined with either of the two above, as its load is 10% or less of both the HVAC and the lighting/receptacle loads. Note, however, that providing a separate feeder for the service water heating would help the building manager to verify whether that system was working efficiently and as designed.

Example 401C Minimum kVA

Q If the building described in Example 401B had only 200 kVA of connected electrical load, what subdivision of feeders would be required?

A None. As the total connected electrical load is less than 250 kVA, and since this is a single-tenant building, the space is not required to have any subdivision of feeders.

Example 401D Subdivision of Feeders for a Water-Loop Heat Pump System in a Multitenant Building

Q For a proposed new office building, the mechanical designers have specified a water-loop heat pump system, consisting of a central cooling tower, electric boiler, and loop pumps that circulate water through water-source heat pumps. Some of the water-source heat pumps serve common areas within the building. Others serve the tenant spaces. Which systems should be fed from the tenant electrical feeders?

A The water-loop heat pump units that serve individual tenants must be connected and fed through the electrical feeders for that individual tenant's HVAC system and equipment. The central equipment, including the cooling tower, boiler, circulation pumps, and water-loop heat pump units that serve common areas must be fed through the main building feeders for HVAC systems and equipment.

Example 401E Subdivision of Feeders for Tenant Spaces with a Booster Heater on a Central Service Water Heating System

Q A tenant in a multitenant building installs an electric booster heater on a central service water heating system. Should the booster heater be connected to the tenant's electrical feeders?

A Yes. As the booster heater serves the tenant's needs, this system should be fed from the tenant's electrical system.

Electrical System Documentation

Form
401.1.2

The 90.1 Code states that the person responsible for the installation of the electrical distribution system must provide maintenance information about the system to the building owner. The intent of this requirement is to provide the owner with all information that will enable optimal and efficient operation of the building electrical system.

Documentation about the electrical distribution system shall be contained in a single-line diagram, which must include all of the following:

- The location of check-metering access
- Schematic diagrams of non-HVAC control systems
- Electrical equipment manufacturer's operating and maintenance literature

Designers and installation contractors are encouraged to exceed the 90.1 Code requirements by supplying any applicable information about the electrical system that will facilitate the efficient operation of all applicable equipment. For example, including a recommended maintenance schedule for electric systems can help promote the optimal operating efficiency of electrical and lighting equipment.

ELECTRIC MOTORS

Form
401.2.1

Electric motors provide an excellent opportunity for cost-effective energy efficiency improvements. Electric motors are used for a variety of purposes in buildings. Motors power HVAC fans, pumps, and compressors, service water heating pumps, escalators, elevators, conveyors, and lifts.

Electric motors are available in a wide range of efficiencies. In motors, the electrical energy not converted to motion is dissipated as heat that may have to be removed by the air conditioner. Depending on the motor type, size, and service, waste heat can account for 1% to 30% of the energy used by the motor. Given the prevalence of electric motors in buildings and the availability of efficient motors on the market, motors are commonly targeted by many utility incentive programs.

Table 401B Minimum Acceptable Nominal Full-Load Efficiency for Single-Speed Polyphased Motors

Horsepower	Minimum Efficiency (%)
1-4	78.5
5-9	84.0
10-19	85.5
20--49	88.5
50-99	90.2
100-124	91.7
125 or greater	92.4

Applicable Motors

The 90.1 Code requirements apply to all permanently wired polyphased (generally three-phase) electric motors of one horsepower or larger. Minimum efficiency is required for all applicable electric motors that operate more than 500 hours per year at speeds of 3,600, 1,800, 1,200, and 900 RPM. Applicable motors shall have a nominal full-load motor efficiency no less than those shown in Table 401.2.1 of the code, reproduced as Table 401B.

Exceptions #1 and #2

Form
401.2.1

Multispeed motors are exempt from the minimum efficiency requirements, as are motors that are components in HVAC equipment that already complies with the minimum equipment efficiency requirements of Section 403 of the 90.1 Code.

Example 401F Minimum Motor Efficiencies – Water-Source Heat Pump

Q A water-source heat pump system serving a multitenant office building has two circulation pumps, each of which has a five hp open drip-proof motor (four-pole, 1,800 rpm). What are the minimum efficiencies required for these motors?

A As these motors are over one horsepower, and as they are expected to operate more than 500 hours a year, they must have a nominal efficiency equal to or in excess of 84.0% (Table 401.2.1).

Example 401G Minimum Motor Efficiencies – HVAC Equipment

Q A packaged gas-electric unit has a 10 hp standard efficiency fan motor that does not meet or exceed the nominal efficiency requirements of Table 401.2.1. If this unit as a whole meets or exceeds requirements of Section 403, will it comply?

A Yes. This unit complies as its ratings include the electrical use of the fan motor, and as the unit complies with the requirements for HVAC equipment listed in Section 403. However, if the manufacturer offers the same unit with a high or premium efficiency motor, the designer may want to consider specifying this option, as it is likely to be cost effective.

Example 401H Minimum Motor Efficiencies – Two Speed

Q A two-speed 7-1/2 hp motor is used for an exhaust fan which serves a gymnasium. Is this motor required to meet the nominal efficiencies of Table 401.2.1?

A No. As this is a two-speed motor, it is not required to meet the minimum efficiencies of Table 401.2.1.

EXTERIOR LIGHTING POWER

Form
401.3.1

A building or facility complies with the exterior lighting power requirement if the total exterior connected lighting power (CLP) does not exceed the exterior lighting power allowance (ELPA). The 90.1 Code separates the maximum power requirements for exterior and interior lighting systems.

Scope and Application

Most exterior lighting is covered by the 90.1 Code, including all permanent lighting fixtures intended for lighting the building and its grounds.

- *Building-Mounted Exterior Lighting.* All lighting mounted on the building, less specific exceptions as noted below, is governed. This means that all lanterns, soffit lights, floodlights, step lights, wall packs, and additional decorative lighting such as neon outlining, low-voltage light strips, and ornamental pendants and globes must be included in the ELPA calculation.
- *Grounds, Roads, Parking Lots, and Other Exterior Lighting.* All lighting on the building site, less specific exceptions as noted below, is governed. This generally includes pole-mounted lighting, landscape lighting, bollards, step lights, wall packs, and all other lighting for the roads, walks, parking lots, gardens, trees, and other portions of the site. Note that lighting not powered by the building electrical system, such as municipal street lights, is exempt.
- *Parking Areas*. Open-air parking lots, rooftop parking, and carports are included in the exterior lighting requirements. Covered, enclosed parking areas, such as garages are part of the interior lighting requirements and are *not* included with the exterior lighting.

Exceptions

Form
401.3.1
Exception

The 90.1 Code does not regulate lighting used for safety, security, or exterior manufacturing or similar commercial needs. Lighting over which the designer has little choice or control is also exempt. The following are specific exceptions to the exterior lighting power requirements.

- *Lighting for Outdoor Manufacturing, Commercial Greenhouses, and Processing Facilities.* This exemption applies to outdoor commercial, agricultural, and industrial work areas, such as refineries.
- *Sports Lighting.* Lighting for outdoor athletic facilities of all types is exempt.
- *Exterior Lighting for Public Monuments.* All exterior lighting intended primarily for the display of public monuments, statues or other items of historical interest or importance is exempt.
- *Code-Required Lighting and Lighting for Designated High-Risk Security Areas.* If a local code or ordinance requires lighting for safety or security, then it is exempt. It is not exempt if it is used for safety or security *and* for non-mandated lighting. An emergency light is exempt if it is normally off and switched through life-safety controls; however, if the light also serves as a general light source, it is not exempt. Typically exempt lighting also includes exit signs, security lights (such as for automatic teller machines), and other lights required by national, state or local security or safety standards. Lighting

Table 401C Exterior Lighting Power Allowance

Area Description	Allowance
Exit (with or without canopy)	25 W/lin ft of door opening
Entrance (without canopy)	30 W/lin ft of door opening
Entrance (with canopy):	
High traffic (retail, hotel, airport, theater, etc.)	10 W/ft^2 of canopy area
Light traffic (hospital, office, school, etc.)	4 W/ft^2 of canopy area
Loading area	0.40 W/ft^2
Loading door	20 W/lin ft of door opening
Building exterior surfaces/façades	0.25 W/ft^2 of surface area to be illuminated
Storage and non-manufacturing work areas	0.20 W/ft^2
Other activity areas for casual use, such as picnic grounds, gardens, parks and other landscaped areas	0.10 W/ft^2
Private driveways/walkways	0.10 W/ft^2
Public driveways/walkways	0.15 W/ft^2
Private parking lots	0.12 W/ft^2
Public parking lots	0.18 W/ft^2

for safety or security that is required by the most current version of the National Electrical Code typifies lighting that is considered by the 90.1 Code to be exempt.

- *Sign Lighting.* Both self-contained and exterior illumination for signs are exempt.

Lighting for Retail Storefronts and for Exterior Enclosed Display Windows. Lighting used to illuminate enclosed displays or other examples of retail merchandising lighted from outside the building is exempt. *Exits* are doors or groups of doors to a building not ordinarily used as an entrance and primarily used as an emergency, nighttime, or convenience exit.

Entrance (without canopy) refers to a door or group of doors to a building ordinarily used by tenants or the public to enter or exit the building for normal use or business, but having no ornamental or functional canopy or shelter.

Entrance (with canopy) means a door or group of doors to a building with an exterior awning, soffit, canopy, or ornamental or functional structure generally signifying a "main" or "proper" entrance to a building. A canopy does not have to be shelter; the major issue here is identification or marketing.

Public Driveways, Walkways, and Parking Lots are defined in Section 100 as those exterior transit areas that are intended for use by the general public. Typical examples would include parking, driveways, and roads for hotels, airports, shopping centers, and other areas used primarily by the occasional and/or unfamiliar user of the building. Other examples include roads leading to a private building, such as an office building, as well as the visitor parking, and all walks leading into the main entry.

Private Driveways, Walkways, and Parking Lots are defined as exterior transit areas that are associated with a commercial or residential building and intended for use solely by the employees or tenants and not by the general public. Typical situations include private driveways, walkways, and parking lots.

Determining Exterior Lighting Power Compliance

Determining whether or not a building complies with the exterior lighting power is a two-step process. Page 1 of the Lighting Wattage Worksheet may be used to perform the calculations required. The first step is to calculate the exterior lighting power allowance (ELPA), using the top portion of Page 3 of the Lighting Wattage Worksheet. The ELPA is calculated by multiplying each lighted area or width of door opening (Column I in the Worksheet) by the appropriate exterior lighting unit power allowance (Column D) from Table 401.3.1. This table is repeated as Table 401C in this chapter. The total ELPA is then transferred to the Electric Systems Summary form, under the heading for building exteriors (401.3.1).

The second step in determining exterior lighting compliance is to calculate the exterior connected lighting power (CLP) of the proposed design. The exterior CLP is determined by totaling the exterior lighting power for all proposed exterior luminaires that are not exempt from the exterior lighting requirements. The bottom portion of Page 1 of the Lighting Wattage Worksheet provides an easy means of counting light fixtures and summing their respective input wattages. When determining input wattages for luminaires it is important to include ballast losses for all fluorescent and HID sources. The input wattage tables in the Reference section of this chapter may be used to calculate CLP of specific light sources if luminaire manufacturer data are unavailable.

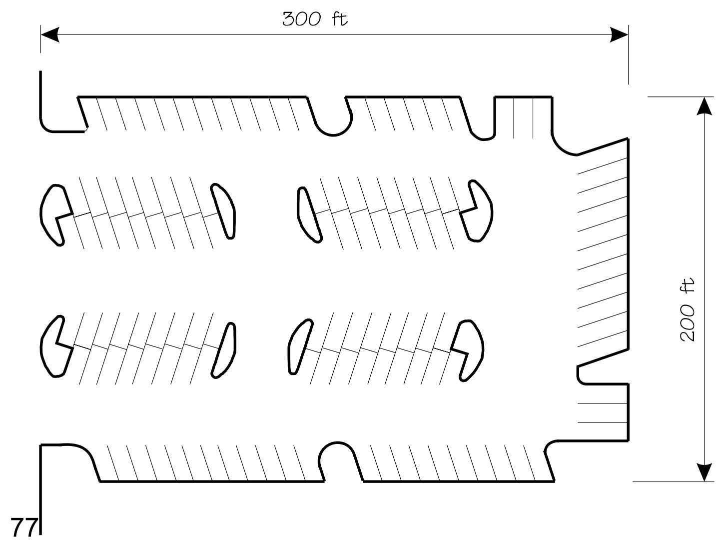
Once the total CLP of the proposed design has been determined, the value should be transferred onto the Electric Systems Summary for comparison with the previously-calculated ELPA. The project complies with the exterior lighting requirement if the exterior CLP is less than or equal to the ELPA.

As an alternative to calculating the exterior CLP and ELPA by hand, the designer may choose to use the LTGSTD program to calculate the two values. LTGSTD is discussed later in this chapter.

Trade-offs are not allowed between the exterior lighting systems and any other building systems, including interior lighting power. However, for multibuilding facilities, the ELPA applies to the entire site. Thus, trade-offs are permitted between different *exterior* lighting systems on the site, provided the total exterior CLP does not exceed the total ELPA.

Example 401I Exterior Lighting – Parking Lot

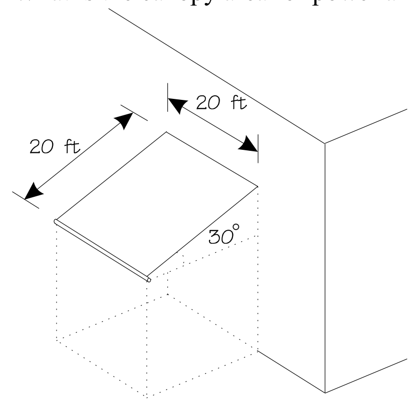
Q A parking lot measures 200 ft by 300 ft, with planters between parking aisles. What is the area of the lot and the lighting power allowance?



A The area of the parking lot is 200 ft by 300 ft, or 60,000 ft^2. The planter medians between the parking aisles are included as part of the parking lot area; however, planting areas around the lot are not. The exterior lighting unit power allowance is 0.12 W/ft^2 (private) or 0.18 W/ft^2 (public). The exterior lighting power allowance is, therefore, 7,200 watts (private) or 10,800 watts (public). In addition, the walkways, drives, and intersections associated with the lot are allowed lighting power, either 0.10 (private) or 0.15 (public) W/ft^2. The parking lot is public if it is available for use by the general public; it is private if it is intended for use solely by the employees or tenants.

Example 401J Exterior Lighting – Roof Canopy

Q A roof canopy slopes at an angle of 30 degrees and has an absolute surface area of 20 ft by 20 ft = 400 ft^2. What is the canopy area for power allowance calculations?



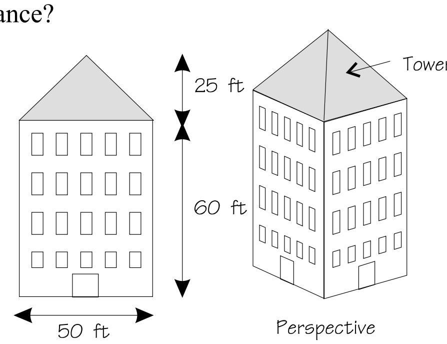
A The projected area below the canopy is given by:

$$20 \times 20 \times \cos 30° = 20 \times 20 \times 0.866 = 346.4\ ft^2$$

If the canopy is dimensioned in plan, the measurements are 17 ft 4 in. by 20 ft.

Example 401K Exterior Lighting – Building Facade

Q A building consists of a four-sided pyramid atop a four-sided tower with no cornices or soffits. What building facade area shall be used for determining the exterior lighting power allowance?



A If all sides of the building as well as the pyramid are intended to be illuminated, the entire surface area of the building may be used as the basis of the ELPA. Each vertical surface is 60 ft by 50 ft or 3,000 ft^2 for a total area of 12,000 ft^2. The area of each triangular face of the pyramid is determined by multiplying the base (50 ft) times height (25 ft) and dividing by two. This yields a total area of 2,500 ft^2 for the pyramid. The overall facade area, therefore, is 12,000 + 2,500 = 14,500 ft^2. The unit power allowance is 0.25 W/ft^2 of surface area to be illuminated, therefore, the maximum power allowance for the building is 3,625 W. Please note that the unit power allowance only applies to the surface area intended to be illuminated, not the entire surface.

Example 401L Exterior Lighting – Building Cornice

Q A cornice that is designed to be illuminated protrudes from the facade of a building. Does it receive any special power allowance?

A It receives a power allowance based on its projected area; thus it does not matter how far it protrudes. Ordinarily, the cornice top is not intended to be illuminated, so its area is ignored.

Example 401M Exterior Lighting – Office Park

Q A three-building site has the following elements:

- A four-story parking garage with the top level open. The building footprint is 10,000 ft.^{2} The garage is for employees only.
- A visitor parking lot of 5,000 ft^2
- Main site entrance road of 2,400 ft^2 surface area and 600 ft^2 of sidewalks, all powered from the local street lighting system
- Drive to the visitor lot of 1,200 ft^2 plus walk of 300 ft^2, powered from the building's system
- Drive to the garage of 1,500 ft^2 plus walk of 450 ft^2, powered from the garage's system
- Drives to each building's loading dock of 800 ft^2 each, plus a dock exterior parking and service lot of 900 ft^2
- Walks interconnecting the buildings and access walks of 1,800 ft^2
- A landscaped area of 12,000 ft^2
- An employee athletic field of 20,000 ft^2
- A canopied entrance to each building of 400 ft^2
- Two exits from each building, each with 5 linear feet of double doors
- Each building is a flat rectangular box 30 ft high, 80 ft deep, and 120 ft long

What is the exterior lighting allowance?

A The ELPA for the building facade may be calculated at a maximum area of 36,000 ft^2. The allowance only applies, however, to the facade area actually lighted. For example, if only the front of each building is to be floodlighted, then only (30 × 120) = 3,600 ft^2 of each building is used as the basis for the ELPA.

Description	Area or Length	Allowed W/Unit	Total Watts Allowed	Comments
Garage				
Interior spaces	30,000 ft^2	*	*	Interior space: see 401.3.2
Top level	10,000 ft^2	0.12	1,200	Private parking lot
Visitor lot	5,000 ft^2	0.18	900	Public parking lot
Main road	2,400 ft^2	n.a.	n.a.	Exempt: not powered by building
Main road walk	600 ft^2	n.a.	n.a	Exempt: not powered by building
Visitor lot drive	1,200 ft^2	0.15	180	Public driveway/walkway
Visitor lot walk	300 ft^2	0.15	45	Public driveway/walkway
Garage drive	1,500 ft^2	0.10	150	Private driveway/walkway
Garage walk	450 ft^2	0.10	45	Private driveway/walkway
Dock drives	2,400 ft^2	0.10	240	Private driveway/walkway
Dock lots	2,700 ft^2	0.12	324	Private parking lot
Inter-building walks	1,800 ft^2	0.15	270	Public driveway/walkway
Landscaped area	12,000 ft^2	0.10	1,200	Activity area
Athletic field	20,000 ft^2	n.a.	n.a.	Exempt
Canopied entrances	1,200 ft^2	4.00	4,800	Light traffic
Exits	30 linear ft	25.00	750	Exit
Building facades	36,000 ft^2	0.25		
Total			10,104 watts	

INTERIOR LIGHTING POWER

Form
401.3.2

Interior lighting power complies with the 90.1 Code requirements when the interior connected lighting power (CLP) of all non-exempt interior lighting is less than or equal to the interior lighting power allowance (ILPA). As with exterior lighting power, determining compliance with the interior lighting power requirements is a two-step calculation procedure, which may be performed using the last two pages of the Lighting Wattage Worksheet.

This section identifies the lighting equipment that must be included in the calculations of interior lighting power and describes lighting equipment that is exempt. It describes the two methods that may be used to calculate ILPA. It explains how to calculate the interior CLP and describes how to apply lighting power control credits to determine an adjusted lighting power (ALP) that may be compared with the ILPA if the nonadjusted lighting power is excessive. This section concludes with a description of the LTGSTD computer program, which is a useful tool for performing many of the lighting calculations required for compliance.

Scope and Application

Most interior lighting, including both permanent and portable luminaires, must be included in the calculations of connected and/or adjusted interior lighting power. Emergency lighting, interior lighting for dwelling units, and lighting used for specialized applications are exempt from the code. Details about exempt lighting, as well as information about certain special circumstances, are described in more detail as follows.

Form
401.3.2
Exception
#1 - #8

Interior lighting required for safety, security, or special commercial needs is not regulated. The following types of lighting applications and equipment are exempt:

1. Lighting used for theatrical, stage, broadcasting, and similar applications
2. Specialized lighting equipment used for medical, dental, and research applications
3. Exhibit display lighting for museums, monuments, and galleries
4. Lighting used for indoor plant growth (when used between 10:00 p.m. and 6:00 a.m.)
5. Emergency lighting that remains off during periods of normal building operation
6. Lighting for designated high-risk security areas
7. Lighting for use in specifically designed areas for the physically impaired or aged
8. Lighting inside dwelling units

The 90.1 Code is relatively clear about what must be included in calculations for interior lighting power. Nevertheless, the following examples of relatively common situations can be confusing.

- *Covered Parking Garages.* As shown in Example 401M, while the exterior lighting power requirement applies to open parking areas, covered parking garages are included in the requirements for interior lighting.
- *Portable Equipment.* Although the designer cannot prevent users from plugging-in portable lighting of their own choosing, the designer must account for portable

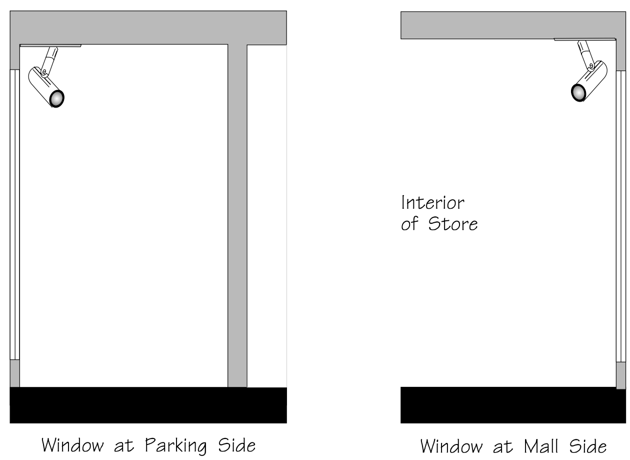
lighting intended for the space, such as furniture-mounted task lights and lighting in permanent displays. Even if the designer of the project is not responsible for specifying portable lighting, the calculations should include an allowance for the expected use of this equipment.

- *Reasonable Lamp Wattages.* In the event that a luminaire can accommodate lamps of various wattages, the lamp wattage used for demonstrating compliance must be reasonable for the intended use. This is particularly applicable to incandescent track lights and other incandescent luminaires with medium screw-based sockets.

Example 401N Exempt Interior Lighting – Retail Store Windows

Q

A proposed retail store in a mall will have storefront windows on the parking-lot (exterior wall) side and windows on the mall (interior) side. The parking-lot side window displays will be closed-off from the store interior, but the displays on the mall side are directly accessible from inside the store. What lighting is exempt?



A

All lighting in the windows on the parking-lot side is exempt; the lighting for the mall-side windows are *not* exempt. However, if the mall-side windows were isolated from the store by any full-height partition, including glass, then they, too would be exempt.

Example 401O Exempt Interior Lighting – Laboratory Test Lights

Q A laboratory is studying the effects of lighting on the treatment of a new chemical process. Ordinary fluorescent luminaires are arranged over the test areas and connected to timers. In addition, general lighting is used throughout the laboratory. What lighting is exempt?

A The lighting arranged for the test is exempt. However, the lighting should be installed in a manner consistent with the permanence of the experiments; if they are only temporary, then the lighting should not be recessed or otherwise installed in a relatively permanent fashion.

Example 401P Exempt Interior Lighting – Retirement Home Cafeteria

Q A cafeteria in a retirement home is open to the public and visitors. The dining room ordinarily used by the residents of the home is restricted to residents only. Are either of these rooms exempt?

A The dining room is exempt. The 90.1 Code exempts lighting in spaces specifically designed for primary use by the physically impaired or aged. However, the cafeteria is exempt only if it serves alternatively as a dining room for residents. If the cafeteria is primarily for visitors and/or staff, it is *not* exempt.

Calculating Interior Lighting Power Allowance (ILPA)

The ILPA is the yardstick by which either the connected lighting power (CLP) or adjusted lighting power (ALP) is measured to determine whether or not a building complies with the requirements for interior lighting power. Two methods may be used to calculate the interior lighting power allowance: the building space method and the specific space method. Each has advantages and disadvantages, depending on the application. Page 2 of the Lighting Wattage Worksheet may be used to determine ILPA, using either of the two calculation methods.

Building Space Method (Table 401.3.2a)

The building space method assigns a single interior lighting power allowance in watts/ft^2 based on the building or space activity. The allowance is multiplied by the gross lighted area (see the Reference section) of the building or space to determine the ILPA. The building space method is easy to use, quick, and straightforward. It also offers a very easy way to determine ILPA, regardless of the complexity of the design process used to develop the proposed lighting system. It is most useful with speculative buildings or during the early design stages. While it is valuable during the design process for making quick calculations of allowable interior lighting, it has some limitations when compared with the more comprehensive specific space method:

- It is insensitive to specific space functions and room configurations.
- It may not allow as much interior lighting power as the specific space method. (see Example 401Q)
- It is an option for the most common, but not all, building types.

There are three intended applications for the building space method: in buildings with simple lighting requirements; where minimal effort to achieve compliance is the primary concern; and during schematic design and design development, when final room sizes and/or occupancies may not be known. By being able to quickly assess the ILPA, the designer can periodically check the ongoing design decisions for probable compliance with the code. This makes the building space method especially valuable as a design tool.

The ILPA can be calculated on Page 2 of the Lighting Wattage Worksheet by multiplying the gross lighted area (GLA) of the building or space activity times the applicable unit lighting power allowance (ULPA) from Table 401.3.2a. If the Worksheet is used, the resulting ILPA should be transferred to the Electric Systems Summary. The ILPA is then compared with the proposed interior connected lighting power (CLP) or adjusted lighting power (ALP) to determine interior lighting power compliance. As an alternative to using the Lighting Wattage Worksheet, the LTGSTD computer program, described later in this chapter, may be used to calculate the building space ILPA. The hardest part is determining the gross lighted area, which must be done by hand.

Gross Lighted Area. The gross lighted area of each building space is multiplied times the allowance for that building space based on the square footage of the entire building. For instance, a 3,000 ft^2 building with half retail and half office would have ULPAs of 3.08 for the retail and 1.81 for the office, both selected from the column for 2,001 to 10,000 ft^2 in Table 401.3.2a. When the major occupancy in multi-use buildings is greater than 90%, the lighting power allowance for the major occupancy may be used for the entire building. The sum of all ILPAs for all building spaces is the total building ILPA. Example 401R illustrates this procedure.

Unit Lighting Power Allowance and Applicable Building Types (401.3.2.2). The building space method is limited to the building types listed in Table 401.3.2a. Each common building type is associated with a unit lighting power allowance (ULPA), which varies depending on the size of the gross lighted area of the total building.

Where a building description is directly applicable, it can be applied without further explanation. Otherwise, Section 401.3.2.2 of the 90.1 Code is useful in determining which building space to use. Some projects may contain building spaces that are not specifically listed in Table 401.3.2a, but often a similar building or space type can be used. If a similar building space is used for compliance, a written explanation should accompany the compliance documents.

Example 401Q Comparison of Building Space and Specific-Space ILPAs – Retail Store

Q Which method, building space or specific space, provides a more generous interior lighting power allowance for a small "high fashion" retail store with many feature displays? The ceiling height is 16 ft, the gross lighted area is 3,000 ft^2, the retail area is 2,400 ft^2, the dressing rooms are 300 ft^2 with a ceiling height of 10 ft, and the storage area is 300 ft^2.

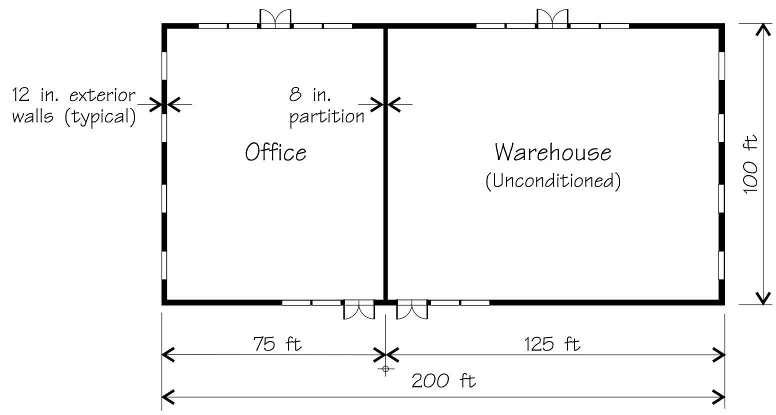
A The building space method (Table 401.3.2a) allows 3.08 W/ft^2 or 9,240 total watts.

With the specific space method, the allowance has to be calculated separately for the retail area, the dressing rooms, and the storage area. For the 2,400 ft^2 retail area Table 401.3.2c allows 3.2 W/ft^2 and Figure 401.3.2e gives an area factor of 1.15, resulting in a total of 8,832 watts. This is based on Type 2 retail (fine merchandising). The dressing rooms are allowed 1.4 W/ft^2 with an area factor of 1.35 or 567 total watts. The storage area, listed in Table 402.3.2b (Active Storage, Fine) is allowed 1.0 W/ft^2 with an area factor of 1.35 or 405 total watts. The total allowed lighting power with the specific space method is therefore 8,832 + 567 + 405 or 9,804 watts.

In this case, the specific space method would allow 564 more watts of lighting power than the building space method.

Example 401R Gross Lighted Area

Q A one-story building measures 200 ft by 100 ft and consists of an office and a conditioned warehouse. The building has 12-in. thick exterior walls. The partition that separates the office and the warehouse is 8-in. thick. The office area is 75 ft by 100 ft measured from the outside edge of the exterior walls to the center of the partition wall. The warehouse is 125 ft by 100 ft measured from the outside edge of the exterior walls to the center of the partition wall. What is the gross lighted area?



A Gross lighted area is measured from the *inside* of the perimeter (exterior) walls and includes the dimensions of all interior partitions. The gross area of this building, which includes the exterior wall thicknesses, is 200 ft by 100 ft or 20,000 ft^2. Of this total, 600 ft^2 is accounted for by the thickness of the exterior walls: 1 ft x (200+100+200+100) = 600 ft^2 Therefore, the GLA of the entire building is 20,000 - 600 = 19,400 ft^2 To determine the GLA for the office and warehouse, assign half the area of the interior partition thickness to each of the two areas. The office GLA is 7,250 ft^2 and the warehouse GLA is 12,150 ft^2

Specific Space Method (Tables 401.3.2b, 401.3.2c, and 401.3.2d)

The specific space method is the second of the two optional methods for determining interior lighting power allowance. While this approach provides greater flexibility and is applicable for all building types, it requires a greater effort. However, since the specific space method accounts for the space functions and room geometries of the proposed design, it yields a more appropriate power allowance for each project.

The specific space method requires calculations to account for room geometry, and visual tasks within each room must be identified. As with the building space method, Page 2 of the Lighting Wattage Worksheet may be used to calculate the specific space method ILPA. However, to simplify the use of the specific space method, the calculation procedure has been incorporated in the LTGSTD computer program (Version 2.1). This program is very easy to use and may make the process more efficient. It can also be a useful tool in early design phases. The application, use, and limitations of the LTGSTD program are described in detail later in this chapter.

Unit power density (UPD) allowances in W/ft^2 are listed for more than 130 space functions or activities in Tables 401.3.2b, 401.3.2c, and 401.3.2d. For a given activity type, for example "conference/meeting room," the lighting power budget (LPB) is equal to the unit power density (UPD) multiplied by the area (A) of the specific space. This product is also multiplied by an area factor (AF) that accounts for the room geometry. The result is a lighting power budget for the respective room or groups of rooms. Thus:

$$\text{LPB} = \text{A} \times \text{UPD} \times \text{AF}$$

The total interior lighting power allowance (ILPA) for the building is the sum of the LPBs for each specific space.

Definitions and Considerations. Applying the UPD values to different specific spaces to determine the lighting power budget is not difficult. Nevertheless, some of the terms used can be confusing to the occasional user. The list of explanations below address some of the more troublesome terms and issues.

- *Area of the Space.* The area of each specific space is measured to the surface of the perimeter walls or partitions and does not include interior or exterior wall thickness. Note that area of the space is not the same thing as gross lighted area (see Reference section)

- *Unlisted Spaces.* "Unlisted spaces" is a catch-all term which refers to everything not listed in the three UPD tables used for the specific space method. Unlisted space is assumed to be the difference in area between the gross lighted area and the sum of all listed spaces. Unlisted spaces are assigned a unit power density of 0.2 W/ft^2, as shown for the last entry in Table 401.3.2b. The LTGSTD computer program accounts for unlisted spaces automatically.

- *Area Factor*. The area factor (AF) accounts for the effect of room geometry on lighting systems. For the most part, rooms with high ceilings relative to floor area require more lighting power for a given level of illuminance than rooms with comparatively lower ceilings. This is due to the increased absorption of light by the walls above the task in high-ceilinged spaces. The area factor is determined from Figure 401 3.2e or from the area factor formula from page 32 of the 90.1 Code. Rooms with identical ceiling heights and activities may be evaluated as a group by using the average area of the rooms to determine the area factor.

- *Area Factor Limitations and Defaults.* Regardless of the calculated value, the area factor for any given space may be no less than 1.0 and no greater than 1.8. The same limits hold for values obtained from Figure 401.3.2e. Furthermore, some building spaces are assigned specific area factors. Typical spaces are footnoted in the tables (see the discussion on special cases).

- *Grouping of Like Spaces*. The designer can save time by evaluating a lighting design in advance and identifying spaces of the same size, height, and use. The calculations can be performed once for each typical room and the LPB for that room may then be multiplied times the number of rooms that are like it.

Organization of the UPD Tables (Tables 401.3.2b, 401.3.2c, and 401.3.2d). The unit power density (UPD) tables used for the specific space method are divided into three parts:

- Table 401.3.2b applies to common activities that may occur in many types of buildings.

- Table 401.3.2c gives UPD values for specific space functions or activities that occur in specific building types.

- Table 401.3.2d applies to *indoor athletic areas*.

The use of Table 401.3.2d is fairly clear, but the differences between Tables 401.3.2b and 401.3.2.c are more subtle. The case of a lobby may be used to illustrate the difference. Table 401.3.2b allows 1.0 W/ft^2 for general waiting and reception lobbies, and 0.8 W/ft^2 for elevator lobbies. These values may be used for all building types. Table 401.3.2c, however, allows 1.9 W/ft^2 for hotel and conference center lobbies, 1.1 W/ft^2 for post office lobbies, and 1.5 W/ft^2 for theater lobbies. These higher values may be used for these specific building types. When the same activities are listed in both Tables 401.3.2b and 401.3.2c (as in the case with lobbies), the values in Table 401.3.2b will always be lower.

Use the following rules in applying Tables 401.3.2b, c, and d:

- The more definitive table always takes precedence. For example, use Table 401.3.2c to determine the UPD of a hospital corridor, since it specifically lists *hospital/nursing home corridor*, rather than Table 401.3.2b, which simply lists *corridor*.

- If a general space type is not listed in a building where Table 401.3.2c lists of facility-specific space types are provided, but is specifically listed under Table 401.3.2b, then use Table 401.3.2b. For example, since there is not a specific listing for "office" under the heading for Hotel/Conference Center in Table 401.3.2c, the UPD for this space must be determined from Table 401.3.2b.

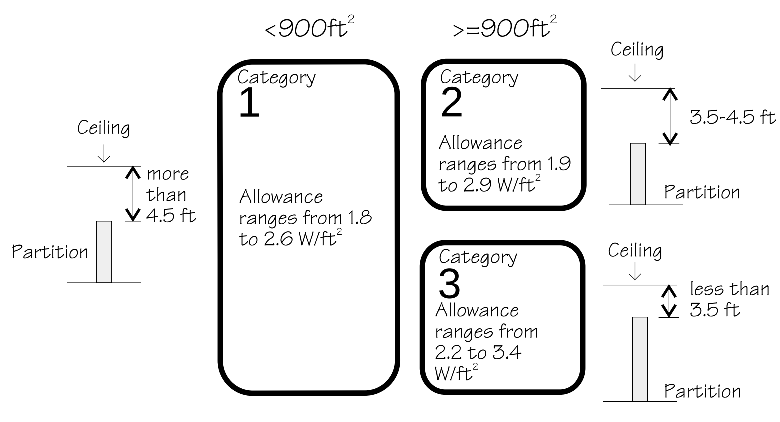
- The definitions of space types are intended to be as specific as possible. For example, *banking activity area* is any area where the activities associated with *banking* take place. The *customer area* is less well defined and in general means those areas where customers stand, sit, wait, or move through, as in the lobby. Note that the teller area, the open-plan loan and account offices, the customer counters, and similar areas are *banking activities*.

- The use of terms such as active versus inactive requires judgment on the part of the designer and authority having jurisdiction.

Sports Lighting Applications (Table 401.3.2d). Sports definitions in Table 401.3.2d allow the choice of two or more levels of play quality. Several factors must be considered in selecting values, as follows:

- *Tournament* levels may be selected for any facility that offers or intends to offer tournaments at amateur or professional levels. Generally, the presence of a full- or part-time professional in the sport at the facility suggests the intent to offer classes and to arrange tournaments. *Clubs* are intended to mean less organized facilities, such as the community house in a non-sports oriented apartment complex.
- *College* level is associated with the frequent use of the facility for the sport by classes and intramural activity; strictly recreational and intramural activity receives less illumination.
- *Professional* level is associated with the non-televised play of the sport by professional athletes.
- A local tennis club is *recreational* if classes aren't taught there and *club/college* if classes are. However, only facilities with extensive tennis facilities, including grandstands, are *professional*.
- A hockey arena is *amateur* if it is generally rented to the public or available through a department of parks and recreation; however, if regularly scheduled games between high school, college or professional teams are played in the arena, then the higher level is allowed. The occasional use of a facility by a higher-grade activity generally does not qualify for the higher UPD.

Figure 401B Office Categories from Table 401.3.2.b



Special Cases. Special cases applicable to building and space activities listed in Tables 401.3.2b, 401.3.2c, and 401.3.2d are indicated by footnotes in each of the respective tables. It is important to consider the table footnotes when calculating ILPA using the specific space method. The footnotes have several different functions, from providing additional information about determining area factors to noting spaces that may qualify for a supplementary lighting allowance.

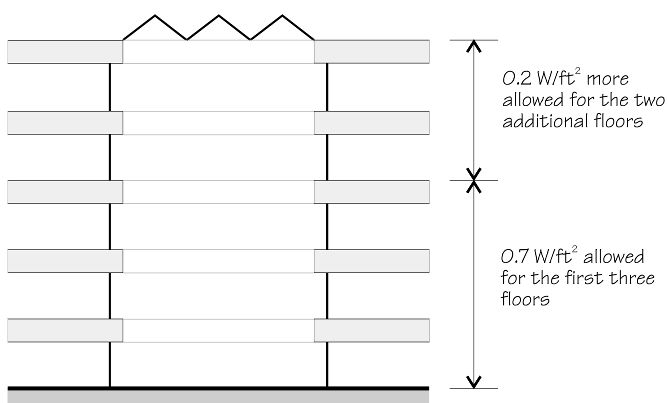
Simultaneous Activities (Footnote "a" in the UPD tables). If two or more space/function activities are expected to occur simultaneously in the same room then the weighted average of the activities' UPD shall be used. The weighting should be the fairest possible prorating between the two, as follows:

- Determine the area served by each activity in the space.
- Establish a prorating factor using the ratio of each activity's area to the total room area.
- Using the prorating factor multiply the room's total area by the weighted average UPD of the activity.

Multifunction Rooms and Supplementary Lighting Systems (Footnote "b" in the UPD tables). The 90.1 Code recognizes that some building spaces may occasionally require supplementary lighting systems to accommodate multiple functions. Typical examples include auditoriums, conference and meeting rooms, and banquet or multipurpose rooms, and are footnoted in the UPD tables. In these cases, the code allows for a 50% increase in the lighting power budget, provided the following conditions are met:

- A supplementary lighting system is installed.
- The supplementary system does not comprise more than 33% of the adjusted lighting power for the space.
- The supplementary system is independently controlled.

Figure 401C Atrium Allowance from Table 401.3.2.b



Area Factor Assignments (Footnotes "c" and "e" in the UPD tables): Some building spaces are assigned a specific area factor (typically 1.0) to be used in the calculations. Other spaces, such as hospital corridors, are limited to an area factor of 1.55 or less. For instance, Footnote *"c"* to Table 401.3.2b sets the area factor to 1.0 for non-hospital corridors and for electrical and mechanical equipment and control rooms. In these instances, the ILPA is equal to the area of the space times the applicable UPD.

Area of Athletic Activity (Footnote "f" in Table 401.3.2d). The area of an athletic activity is considered to extend to a point 10 ft belong the actual physical boundaries of the playing space in each direction. Thus the entire playing space as well as the additional 10 ft in all directions would receive the appropriate UPD for that activity. This area, however, may not exceed an area less than or equal to the total floor area of the sports space less spectator seating areas.

Unfinished Areas. The ILPA for unfinished areas within a fairly well-defined building may be determined by using the building space lighting power allowance from Table 402.3.2a for building space most closely associated with the unknown area. If this is done, area factors cannot be used, and the lighting power budget is equal to the gross lighted area times the applicable unit lighting power allowance from Table 402.3.2a. This provision is intended as an interim procedure for unfinished spaces, such as an unfinished floor of an office building or school. Once space functions are defined, the power allowance shall be based on the actual space activities.

Recording the ILPA

Form
401.3.2
ILPA

After the ILPA has been calculated, it should be recorded under heading 401.3.2 of the Electric Systems Summary form, where it is compared with the proposed interior connected lighting power (CLP) or adjusted lighting power (ALP) to determine whether the requirements for interior lighting power have been met. The next section describes the procedure for performing the CLP and ALP calculations that are used in the comparison.

Calculating Connected Lighting Power

The Lighting Wattage Worksheet may be used to calculate the interior connected lighting power (CLP) of the proposed lighting equipment. Interior CLP is simply the sum of the input wattages of all non-exempt interior luminaires in a building. Typical input wattages for common lamp and ballast combinations are provided in the Reference section of this chapter. These tables may be used as an aid in calculating CLP when specific manufacturer-supplied input wattage data for lamp, ballast, and fixture combinations are not available. The building complies with the requirement for interior power if the CLP is less than or equal to the interior lighting power allowance (ILPA). If the CLP exceeds the ILPA, the CLP may be adjusted through the use of automatic lighting control equipment. The resultant adjusted lighting power (ALP) is then compared with the ILPA to determine compliance. The procedure for using lighting power control credits (LPCCs) to reduce the CLP is described in the remainder of this section.

Form
401.3.3

Adjusted Lighting Power

Adjusted lighting power (ALP) is the connected lighting power less any lighting power control credits (LPCC). If credit is not taken for qualifying automatic lighting controls, the ALP is the same as the CLP. The project complies with the interior lighting power requirement if the ALP is less than or equal to the ILPA. The calculation of ALP and the application of power adjustment factors (PAFs) are described in detail below.

The lighting power control credit (LPCC) need be considered only when the connected lighting load exceeds the ILPA. When qualifying lighting controls are used, the CLP may be reduced by the LPCC to account for the energy savings of these controls. The LPCC is applicable only to devices that reduce lighting power and/or time of use *automatically*. Manual light switches and wallbox type dimmers do not qualify for credits. The lighting controls listed below do.

- Daylight sensing lighting controls (continuous dimming and stepped)
- Lumen maintenance controls
- Programmable timers
- Occupancy sensors
- Combinations of the above

Each of the control devices or combination thereof listed above is assigned a power adjustment factor (PAF) that is applied to the relevant lighting circuit to determine the LPCC. PAFs for all qualifying controls are listed in the code as Table 401.3.3 and consolidated in this manual as Table 401D. The LPCC for the entire building is equal to the sum of the credits for each individually controlled circuit.

Qualifying lighting controls must meet stringent criteria, and there are specific rules determining how power adjustment factors shall be applied. Limitations are summarized as follows:

- The PAF "*is limited to the specific area controlled by the automatic control device*." The power adjustment factor is only applicable to areas and lights actually controlled by the control device (or combination of devices).
- *"Only one power adjustment factor may be used for each building space or luminaire..."* Note that some PAF values apply to combinations of control devices, such as .40 (40%) for occupancy sensors combined with continuous dimming daylighting sensing controls.
- *"...50% or more of the controlled luminaire shall be within the applicable space*." This is especially important when assessing daylighted zones and luminaires controlled by daylight sensors. Daylight sensing controls shall control all luminaires to which the PAF is applied; those luminaires must direct a minimum of 50% of their light output into the daylighted zone. "Daylighted zone" is defined in Section 201 of the 90.1 Code. The "Daylighted Zone" explanation in the Reference section of Chapter 402 in this manual should be helpful in determining the extent of daylight zones for vertical and horizontal (skylight) glazing.
- *"Controls shall be installed in series with the lights and in series with all manual switching devices..."* This means that manual switches may not be wired to bypass the normal control operation of photocells, occupancy sensors, or lumen

maintenance controls. Lighting control systems that use low-voltage relays are exempt from this requirement, since, although they are parallel-wired on the low voltage side, the net effect is similar to non-bypassing series operation, as intended.

- *"When sufficient daylight is available, daylight sensing controls shall be capable of reducing electrical power consumption for lighting (continuously or in steps) to 50% or less of maximum power consumption."* Continuous dimming systems typically reduce luminaire input power to about 30% to 40% of maximum, so most will satisfy this criterion if they control all the lighting in the daylighted space. A three-level stepped control system (off, 50% on, 100% on) will also meet the criteria if the system controls all the lighting in the daylighted space.
- *"Programmable timing controls shall be able to program different schedules for occupied and unoccupied days, be readily accessible for temporary override with automatic return to the original schedule, and keep time during power outages for at least four hours*." In most cases, this means the use of modern digital time controllers operating in parallel with a momentary override switch. Latching systems, such as mechanically-held contactors and low-voltage relays, are especially appropriate for this application. In some situations, a mechanical seven-day time switch with spring reserve might be allowable if the override is readily accessible.

Recording the CLP or ALP

Form
401.3.2
Proposed
Total Watts

After the proposed interior lighting wattage has been calculated on the Lighting Wattage Worksheet, the relevant CLP or ALP value should be recorded under heading 401.3.2 of the Electric Systems Summary form, where it will be compared with the interior lighting power allowance (ILPA), as previously calculated using either the building space or specific space method. If the CLP or ALP is less than the ILPA, the building complies with the interior lighting power requirement.

Table 401D Lighting Power Adjustment Factors (Similar to Table 401.3.3 the 90.1 Code)

		In Combination with the Following Type of Daylighting Control		
Automatic Control Type or Combination	**With No Daylighting Control**	**On/Off**	**Multiple Step**	**Continuous Dimming**
Daylighting alone	n.a.	0.10	0.20	0.30
Programmable timer	0.15	0.15	0.25	0.35
Occupancy sensor	0.30	0.35	0.35	0.40
Lumen maintenance	0.10	n.a.	n.a.	n.a.
Programmable timer and lumen maintenance	0.15	0.20	0.30	0.40
Occupancy sensor and lumen maintenance	0.35	0.35	0.40	0.45
Occupancy sensor and programmable timing control	0.35	n.a.	n.a.	n.a..

Example 401S Building Space Method ILPA – Multi-use Facility

Q The gross lighted area of a multi-use facility consists of 100,000 ft^2 of mall concourse, 250,000 ft^2 of retail lease space, 500,000 ft^2 of office, and 50,000 ft^2 of parking garage. What is the ILPA?

A The GLA of the project is 900,000 ft^2. The ILPA of the project is 1,425 kW as derived below. The ULPA figures are taken from the greater than 250,000 ft^2 column of Table 401.3.2a of the 90.1 Code.

Usage Category	Gross Lighted Area (ft^2)	ULPA (W/ft^2)	ILPA (W)
Office	500,000	1.50	750,000
Mall concourse	100,000	1.40	140,000
Retail	250,000	2.10	525,000
Garage	50,000	0.20	10,000
Totals	900,000		1,425,000

Example 401T Area Factor – Rectangular Room

Q A room is 12 ft 6 in. by 10 ft 3 in. from inside wall to inside wall. The ceiling height is 10 ft. What is the area factor?

A The room area is 128 ft^2. The area factor according to Figure 401.3.2e is about 1.7. Plugging the room dimensions into the Area Factor formula produces a result of 1.68, as shown below.

$$\textit{Area Factor} = 0.2 + 0.8 \times (1 / 0.9^{n})$$

$$\text{Where n} = \frac{10.21 \times (\textit{Ceiling Height} - 2.5)}{\sqrt{\textit{Room Area}}} - 1;$$

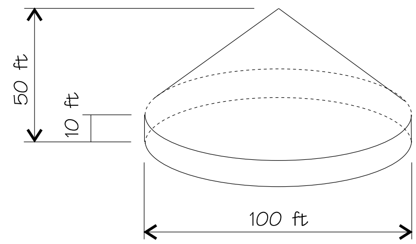
$$\textit{Therefore } n = \frac{10.21 \times (10 - 2.5)}{\sqrt{12.5 \times 10.25}} - 1 = \frac{76.58}{\sqrt{128.13}} - 1, \text{ or } 5.77;$$

$$\textit{Thus, area factor} = 0.2 + 0.8 \times (1 / 0.9^{5.77}) = 0.2 + (0.8 \times (1 / 0.54))$$

$$= 1.68$$

Example 401U Area Factor– Non-rectangular Room

Q A circular room has a sloping ceiling rising to a point in the center, much like a sharpened pencil. The diameter of the room is 100 ft. The walls are 10 ft high, and the center of the ceiling is 50 ft. What is the area factor?



A The room area is 7,854 ft^2 as calculated below:

$$A_{Room} = \pi \times (\frac{100}{2})^2 = 7{,}854\ ft^2$$

To calculate the area factor, the average ceiling height is used. The average ceiling height is calculated as shown below:

$$\mathrm{H} = 50 - \frac{2}{3}(50 - 10) = 23.3\ \mathrm{ft}$$

According to Figure 401.3.2e, the area factor is about 1.13. It may also be calculated with the Area Factor formula that accompanies Figure 401.3.2e, as shown below:

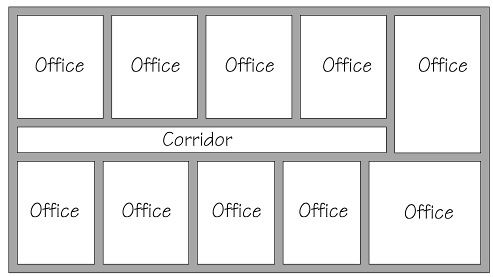
$$n = \frac{10.21 \times (23.3 - 2.5)}{\sqrt{7{,}854}} - 1 = 1.40$$

$$AF = 0.2 + 0.8 \times (\frac{1}{0.9^{1.40}}) = 1.13$$

Example 401V Specific Space Method ILPA – Office Building

Q A project consists of the following:

- 10 similar private offices ranging from 10 ft by 12 ft to 10 ft by 14 ft in size and totaling 1,350 ft^2 (average size 135 ft^2)
- 150 ft^2 corridor
- 9 ft ceilings
  What is the ILPA?



A Since the offices have similar geometry, a single area factor can be calculated and applied to all the rooms.

From Table 401.3.2b under enclosed offices (Category 1) with reading, typing, and filing tasks, the offices are assigned a UPD of 1.8 W/ft^2. Figure 401.3.2e gives an area factor of about 1.6 for the average office area of 135 ft^2 and 9 ft ceiling height. However, footnote "e" in Table 401.3.2b limits the area factor calculation to 1.55. The UPD for the corridor is 0.8 W/ft^2 and footnote "c" sets the area factor to 1.0. Using these data, the ILPA is calculated as shown below:

$$\begin{aligned} \text{ILPA} &= 1{,}350\text{ft}^2 \times 1.8\text{W} / \text{ft}^2 \times 1.55 \\ &\quad + 150\text{ft}^2 \times 0.80\text{W} / \text{ft}^2 \times 1.00 \\ &= 3{,}887\text{watts} \end{aligned}$$

Example 401W Interior Lighting Power Allowance – Multi-use Hotel Ballroom

Q A 8,000 ft^2 hotel ballroom with a 16 ft ceiling serves also as a meeting/exhibition room. A fluorescent lighting system (8,400 watts) is used for the meeting and exhibition functions, while other lighting (17,520 watts), downlights, chandeliers, and sconces are used for the ballroom function. What is the lighting power allowance for this room?

A The lighting power allowance for this room is determined as follows: From Figure 401.3.2e the area factor of this room is 1.05. From Table 401.3.2c under "Hotel/Conference Center – Banquet Room/Multipurpose" the UPD is 2.4. The unadjusted lighting power allowance is:

ILPA = 8,000 x 1.05 x 2.4 = 20,160 watts

An adjustment factor of 1.5 is available for multipurpose rooms (Note "b" in Table 401.3.2c). To comply, the fluorescent lighting system must be independently controlled and draw no more power than 33% of the adjusted LPB for the space. The adjusted ILPA is:

- $ILPA_{adjusted}$ = 20,160 x 1.5 = 30,240 watts
- 0.33 x 30,240 watts = 9,979 watts

As the fluorescent lighting is less than 9,979 watts, the adjustment factor may be used, provided appropriate controls are installed.

Example 401X Weighted Interior Lighting Power Allowances for Simultaneous Tasks – Architect's Office

Q An architectural firm office measures 80 ft by 50 ft from the interior of the perimeter walls and has a 20 ft ceiling. The firm employs several people in a single open room that are engaged in drafting and general office work. The drafting area is 3000 ft^2. The office area is 1000 ft^2. What is the adjusted lighting power allowance for this room?

A This space is classified as *Office Category 1* in Part B of Table 401.3.2. The activities and their associated lighting allowances are as follows:

- Drafting: 2.6 W/ft^2 (Area factor not to exceed 1.55)
- Reading, typing, filing: 1.8 W/ft^2 (Area factor not to exceed 1.55)
- The drafting workstations and surrounds comprise approximately 75% of the total room; the office workstations and surrounds account for the remaining approximately 25%.
- The prorating factor for the drafting task is 0.75
- The prorating factor for the reading task is 0.25
- The UPD is $(2.6\ W/ft^2 \times .75) + (1.8\ W/ft^2 \times .25) = 2.4\ W/ft^2$.

Applying the area factor as in the other examples, the power allowance can be determined. Using Figure 401.3.2e, a 4000 ft^2 space with a 20 ft high ceiling is shown to have an area factor of approximately 1.15. Applying the area factor to the prorated UPD yields an area factor-adjusted UPD of 2.76 $W/ft.^2$ The total ILPA for the building is 2.76 W/ft^2 x 4000 ft^2 = 11,040 watts.

Example 401Y Determination of ILPA – Specific Space Method – Department Store

Q What is the ILPA of the department store presented in the table below? All spaces have 9 ft ceilings.

A 118,910 watts are allowed as calculated below. The UPD values are selected from Tables 401.3.2b and 401.3.2c. Since the specific space method is used, all areas are measured from the interior wall surfaces. The areas and area factors are calculated from the dimensions listed in the building plans and are summarized in the table below. Note that General Apparel is defined in Table 402.3.2c as a Type 4 Retail Establishment, while Housewares qualifies as a Type 5 Retail Establishment. The ILPA is the product of the area of each space, the UPD for that space type and the area factor.

Space Classification	**Area of the Space (ft^2)**		**UPD (W/ft^2)**		**AF**		**ILPA (W)**
General apparel	25,000	x	3.10	x	1.00	x	77,500
Housewares	10,000	x	2.80	x	1.00	x	28,000
Tailoring	1,000	x	2.10	x	1.10	x	2,310
Washrooms (2 at 250 ft^2)	500	x	0.80	x	1.32	x	528
Active storage (bulky)	1,000	x	0.30	x	1.10	x	330
Active storage (fine)	2,000	x	1.00	x	1.04	x	2,080
Dressing/fitting rooms	750	x	1.40	x	1.13	x	1,187
Offices (20 at 125 ft^2)	2,500	x	1.80	x	1.55	x	6,975
Totals	42,750						118,910

*Example 401Z Determination of ILPA – Specific Space Method **–** Tenant Improvement*

Q A tenant takes over a floor in an office building summarized in the table below. All spaces on the floor have 9 ft ceilings. What is the ILPA of the project?

A 26,005 watts are allowed as calculated below. The UPD values are selected from Table 401.3.2b. The areas and area factors are calculated based on the dimensions shown in the building plans. Note that 3,750 ft^2 of the office space consists of small enclosed offices, defined as *Category 1* in Table 401.3.2b, while 5,570 ft^2 of the office space is defined at *Category* 2, consisting of a large (>900 ft^2), open plan, room with partitions 3.5 to 4.5 ft below the ceiling. The conference room is a multi-use space with an independently-controlled supplementary lighting system, which qualifies the space for a 1.5 power adjustment factor. The coffee room is used as an employee break area. Since it has no cooking facilities, it is classified as *Recreation/Lounge*.

Space Classification	**Area (ft^2)**		**UPD (W/ft^2)**		**AF**		**ILPA (W)**
Office, Category 1	3,750	×	1.80	×	1.55	×	10,463
Office, Category 2	5,570	×	1.90	×	1.00	×	10,583
Conference	670	×	1.80 × 1.5	×	1.14	×	2,062
Corridors	640	×	0.80	×	1.00	×	512
Employee lounge	220	×	0.70	×	1.35	×	208
Lobby	450	×	1.00	×	1.20	×	540
Elevator lobby	350	×	0.80	×	1.25	×	350
Computer room	250	×	2.10	×	1.32	×	693
Coffee/Copy room	300	×	1.40	×	1.28	×	538
Telephone equipment	80	×	0.70	×	1.00	×	56
Totals	12,280						26,005

Example 401AA Calculation of PAF with Combined Controls

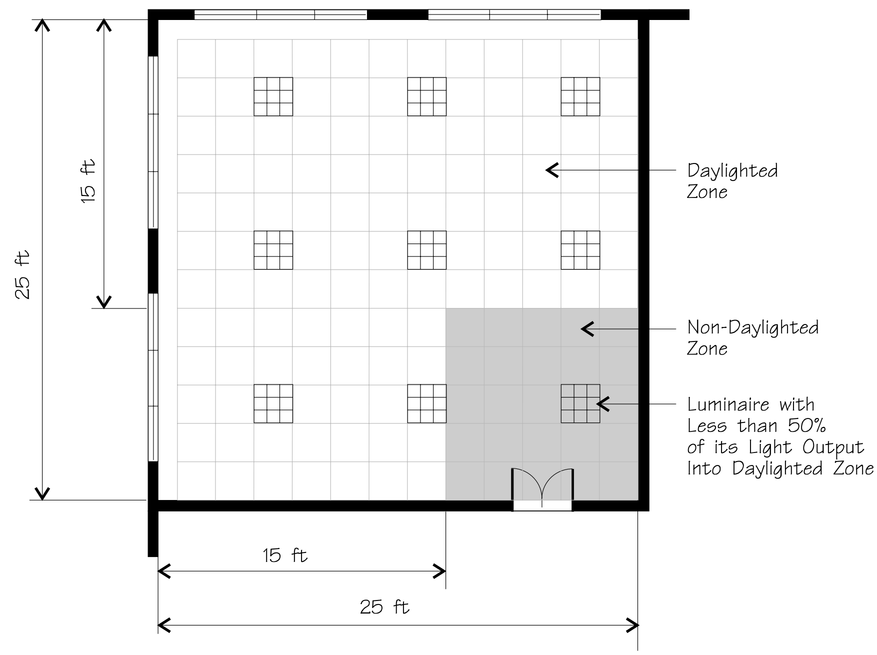
Q The lighting in a perimeter office is connected to a building Energy Management System (EMS) that uses an automatic timeclock to shuts off all lighting circuit after building operating hours. In addition, the office lights are controlled with an automatic three-step (on, 50%-on, off) daylight sensing control. What is the appropriate PAF for the lights in this office?

A 0.25. Item 5 in Table 401.3.3 is a combined multiple-step daylight sensing control and programmable timing control. This combined system has a PAF of 0.25. Note that multiple-step daylight sensing controls and programmable timing controls have separate PAFs of 0.20 (item 2) and 0.15 (item 12), respectively. These separate values are may *not* be added together to determine the PAF. The PAF listing for the combined system is applied, even if the controllers are not a prepackaged set.

Example 401BB Power Adjustment Factors – Daylighting Controls

Q A room 25 ft by 25 ft with a 10 ft ceiling has windows along two sides. 2 ft x 2 ft fluorescent parabolic troffers are installed in the ceiling in a regular pattern (see drawing). A daylight sensing controller is to be used. Which luminaires are controlled?

A All luminaires except the one well outside of the daylighted zone (shaded area) can be connected to the daylight sensing controller. Separate switches for the daylight sensor-controlled lighting and the lone non-controlled luminaire are recommended so that a user can choose to illuminate only the dark corner electrically and not turn on, even at low level, the other luminaires.



LIGHTING CONTROLS

The purpose of the lighting control requirements is to reduce energy use by enabling people to turn off lights when they are not needed. The code directs that *all lighting systems shall have controls.* This mandate applies to both interior and exterior lighting. All enclosed building spaces must have separately-controlled lighting systems, and all lighting systems must be controlled by devices that are readily accessible. The code also requires multiple points of control for separate spaces or tasks within a room.

A separate Lighting Controls Worksheet is included with this manual to assist in complying with the lighting control requirements.

Lighting Systems

Form
401.3.4.1

All lighting systems, except those used for emergency or exit lighting, must be provided with manual, automatic, or programmable controls. Acceptable control devices include manual switches, programmable timeclocks, photocells, and occupancy sensors. Circuit breakers, fuses, and other devices not intended and/or suited for lighting control fail to satisfy this requirement.

Minimum Number of Manual Controls

Form
401.3.4.2

The 90.1 Code requires that a minimum number of manual lighting controls be installed in all building spaces. Each space enclosed by walls or ceiling height partitions shall have a minimum of one *manual* on/off switch plus an additional *manual* control for each task location or group of task locations within an area of 450 ft^2 or less. The 90.1 Code also limits each control *device* (manual or automatic) to a maximum of 1,500 watts of lighting. For example, a space with 2,000 watts of lighting load will require a minimum of two manual or automatic controls, plus whatever is required for control of task locations.

Most interior building spaces where work is performed will require a minimum of two manual controls or the equivalent, as described below. However, there are four special cases:

Form
401.3.4.2
Exception
#1 - #4

1. Continuous (24-hour) security lighting systems are exempt from the minimum number of controls.
2. Occupancy sensors, local programmable timers, three-level (off, 50%-on, 100%-on) stepped controls, or preset dimming controls count as *two* manual controls. However, at least one control device must be installed for every 1,500 watts of connected lighting power.
3. Four-step switching (typically switching with off, 33%-on, 66%-on, and 100%-on capabilities) or preset dimming controls and systems controlled by automatic continuous dimming controls can be substituted for *three* manual controls. Again, each 1,500 watts of connected lighting load must have at least one control device.
4. Spaces that are used as a whole are exempt from the requirement for a minimum number of manual controls. Typical examples include areas where the lighting is usually controlled from a central location, such as public lobbies of office buildings, hospitals, and hotels, retail and department stores, warehouses, storerooms, and corridors.

Despite this, the second and third exceptions listed above illustrate how the 90.1 Code rewards the use of automatic lighting controls, such as occupancy sensors and daylighting controls. Each automatic control device "counts" for more than one manual switch when it comes to calculating the minimum required number of manual controls. This "exchange system" is based on a device's effectiveness at saving energy. More effective control devices substitute for a larger number of manual controls. Table 401E lists the equivalent number of manual controls for a number of energy-saving automatic control devices.

With the 450 ft^2 rule, the required number of controls is rounded to the next highest whole number and each space within the building must separately meet its lighting control requirements. A private office will generally require at least two controls (one for the enclosed space and one for the task). This means that each private office must have a switch that is capable of providing bi-level illumination (through use of two switches, or one), or have an occupancy sensor or other device from Table 401E that earns at least the equivalent of two manual controls. Locally switched, permanently-mounted task lights (e.g. in furniture systems) count as one manual control.

Regardless of the number of controls required or earned, at least one control must be provided for each 1,500 watts of connected interior lighting power, except for spaces that must be used as a whole (see the next subsection).

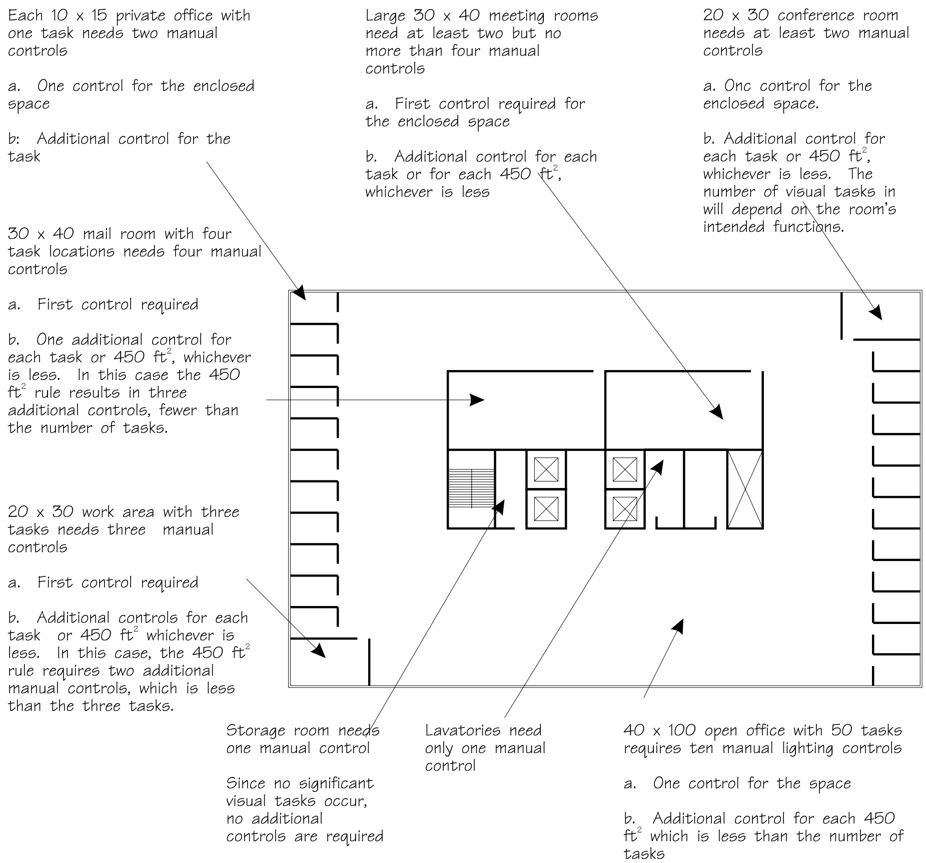
Figure 401D shows a partial floor plan of a typical office building and shows how the control point methodology is applied.

It is important to note that manual controls that control the same lighting load from more than one location may only be counted as one control. Thus, three-way and four-way switches that control the same lighting only count as a single manual control.

Table 401E Exchange Rates for Automatic Lighting Controls

Type of Control	**Equivalent No. of Manual Controls**
Manually operated on-off switch	1
Occupancy Sensor	2
Timer (programmable from the controlled space)	2
Three-level, including off, step control or preset dimming	2
Four-level, including off, step control or preset dimming	3
Automatic or continuous dimming	3

Figure 401D Required Lighting Controls



Q A storeroom of 120 ft^2 has storage on walls all around the room. How many manual controls are required?

A One manual control. The 90.1 Code defines a "task location" as *an area of the space where significant visual functions are performed and where lighting is required above and beyond that required for general ambient use*. A storage room does not have any significant visual functions, and therefore, only one point is required for the room itself.

Q A classroom has 30 desks and is 600 ft^2. How many manual lighting controls are required?

A Three manual controls or the equivalent, if automatic controls are used. The 30 desks are not considered 30 separate tasks but one common group of tasks. The required number of manual controls are calculated as follows: one control for the room itself and two controls for groups of tasks of 450 ft^2 (or less). Although 600 ft^2/450 ft^2 = 1.33 < 2, the required number of manual controls is always rounded up to the next whole number.

Q An airport waiting area of 1,600 ft^2 has 150 seats. The lighting power is about 1,900 watts. How many lighting controls are required?

A The minimum number of lighting controls requirement does not apply in this case because of the exception for rooms which must be controlled together. The lights of this waiting area may be controlled as a unit and the lighting controls may be remote from the room.

Q A retail department store has literally hundreds of visual tasks. How many manual controls are required?

A The minimum number of controls requirement does not apply in this case because of the exception for rooms that must be controlled together. The lights of a retail store may be controlled as a unit, and the lighting controls may be in a remote location.

Control Accessibility

Lighting controls shall be readily accessible to personnel occupying or using the space. This means that the lighting controls must be visible to occupants, easy to get to, and easy to operate. This requirement is applicable for manual controls only.

Form
401.3.4.4
Exception

Automatic control devices, such as occupancy sensors and daylighting controls are exempt from the requirement for lighting control accessibility. Additional exceptions to this requirement include the following:

- Controls for spaces that must be used as a whole
- Programmable controls
- Controls requiring trained operators
- Lighting required for safety and security

Example 401DD Accessibility and Location of Lighting Controls

Q Can lighting for corridors in a mall be grouped and switched from a remote location?

A Yes, because the space is used as a whole. By switching from a remote location, any unusual appearance or functional discrepancy caused by partial lighting can be avoided.

Q Does a programmable time device for a retail store need to be located in the store?

A No, programmable or automatic controls are exempt from this requirement and may be located in a remote location.

Q Do lighting controls in airports, building lobbies, banks, libraries, and department stores need to be accessible?

A No, there is an exception to the accessibility requirement for safety and security reasons.

Hotel/Motel Guest Rooms

Form
401.3.4.5

One or more master lighting switches are required at the entry door of hotel and motel guest rooms. Master switches operate all the permanently wired luminaires and switched receptacles. These switches are usually three-way devices wired in combination with local controls. In multiple room suites, a standard control device is required at the entrance to each separate room.

Bathroom lighting in hotel and motel guest rooms are exempt from the master switching requirement.

Exterior Lighting Controls

Form
401.3.4.6

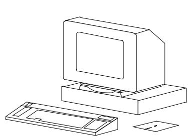
All exterior lighting that is not intended for 24-hour use shall be automatically switched by photocells, time switches, or a combination of the two. Timers must be seven-day and have some means of seasonal daylight adjustment. Timers must be equipped with power backup provisions to allow accurate time keeping through a minimum four-hour power loss.

Traditionally, exterior lights have been controlled by electro-mechanical clocks with mechanical trippers that toggle circuit switches. These devices typically are equipped with a manual override. Many of these traditional devices have neither seasonal correction nor four-hour backup. As such, they do not meet the requirements of 401.3.4.6. The following devices will meet the requirements:

- Photocells
- Seven-day electrically-driven, mechanical clocks with trippers, astronomical dial, and four-hour spring-wound storage
- Seven-day or calendar year, electronic programmable time switches with astronomic correction and battery backup
- Either of the timers above with a photocell (in place of astronomical correction)

Of all these devices, a photocell-timeclock combination is the most effective, since its integral photocell automatically and continuously compensates for changes in the seasons. In addition, the redundancy of the timeclock control allows for continued operation if the photocell fails.

THE LTGSTD PROGRAM



The LTGSTD program may be used to determine the exterior lighting power allowance (ELPA) and interior lighting power allowance (ILPA). It contains all of the exchange rates for equivalent number of manual lighting controls, and selections of area/activities can be made by scrolling through a list on the screen. The program also calculates area factors for the specific space method and helps to organize the data that are entered and required. LTGSTD calculates the following:

- Exterior lighting power allowance (ELPA)
- Building space ILPA
- Specific space ILPA
- Required number of manual lighting controls (see below)
- Installed number of equivalent lighting controls

An important difference between LTGSTD and the 90.1 Code is that LTGSTD uses the term "control points" to refer to the number of manual controls. This term has the same meaning as the control exchange rate discussed previously in this chapter. Each point is the same as one equivalent manual control. Thus, in the LTGSTD program, a manual on-off control is assigned one control point, an occupancy sensor is worth two points, etc.

LTGSTD does have some limitations, and it is important that the designer consider what the program can and cannot do. The program does not calculate either the interior or exterior connected lighting power (CLP). Nor does it calculate the interior adjusted lighting power (ALP). These values (including any credits for automatic lighting controls) must be calculated by hand and entered as data into the program. In addition, the program does not recognize the exception to the 1,500 watts per control requirement for building spaces that must be controlled as a whole.

Example 401EE Use of the LTGSTD Program – Department Store Building

Q

Lighting plans have been submitted for a 42,750 ft^2 department store building. In addition to the merchandising areas, the building will have private offices, storage areas, and other areas of non-sales activities. The interior spaces of the building are described in detail in Example 401Y. The building will have three entrances requiring lighting: (1) a covered, high traffic entry for customers; (2) a smaller side door; and (3) a loading dock. In addition, the designer intends to light a large area on the front of the building. Using the LTGSTD program, will the interior and exterior lighting of this building comply?

A

Yes. The process of compliance is illustrated in the following discussion. The main screen for the LTGSTD program requests the following information.

Building Type Pressing the F6 function key will provide a directory of different building types. These correspond to the prescriptive categories from Table 401.3.2a. A total of three different building types may be combined for a multi-use project. In this case, "D (retail building)" is the appropriate selection.

Building Area: Enter the gross lighted area of the building in ft^2.

Building Design: Enter total design watts (adjusted) for both interior and exterior lighting power. In this case, the interior adjusted lighting power is 111,900 watts; once this is entered, the program computes the power density value of 2.618 W/ft^2. The exterior connected lighting power is 900 watts.

The program is extremely useful for keeping track of projects as they develop or change. Each data file can be saved and later modified as required. The program is also extremely helpful in developing compliance documents. The two-page output provides almost all of the data required for interior and exterior lighting power and control point compliance. If the LTGSTD program is used to demonstrate compliance with the lighting requirements, the two-page output should be submitted along with the Lighting Wattage Worksheet when the compliance

Example 401EE Use of LTGSTD Program – Department Store Building (continued)

forms are completed. In addition, the designer should note on the bottom of the Electric Systems Summary form that LTGSTD output is included.

Prescriptive Criteria: The program uses this term to refer to building space method of determining ILPA. If a value has been entered for building type, the program will now look up the unit lighting power allowance (from Table 402.3.2a), in W/ft^2 of gross lighted area (GLA), and compute the total interior lighting power allowance. In this case the design adjusted lighting power is higher than the ILPA allowed by the prescriptive criteria. As such, the designer must either redesign the lighting, or perform a *system performance criteria* (specific space method) test to see if it will comply.

System Performance Criteria: LTDSTD used this term in reference to the specific space method of determining ILPA. This measure provides flexible lighting power allowances for different types of building spaces. However, to comply under this criteria, extensive details about all building spaces must be determined. The first step is to get to the space screen and begin entering values. The F5 function key will bring up the space screen.

Number: This column is used to enter room numbers to identify individual spaces in the building. The department store has eight common groups of spaces, which are numbered from 1 to 8.

Type: Pressing the F6 key supplies a list of code numbers that describe the different space types. These descriptions correspond to those listed in Tables 402.3.2b, 401.3.2c, and 401.3.2d of the 90.1 Code. Each of the descriptions has a code number, which are also presented in Table B-2. After entering the appropriate code number for each of the eight different types of space, the program will automatically print out a description of each space.

Space Dimensions/Area: Enter the length and width of each space, in feet. These dimensions are from the interior side of the walls at each space. If these values are entered, the program will automatically calculate the area. Alternatively, simply enter the area value directly, as done in the example. For the washrooms (of which there are two) and the offices (of which there are 25), the areas entered are for an individual space *not* the total area of all spaces.

Ceiling Height: The ceiling height, in feet, should be entered here. For sloped ceilings, enter the average ceiling height. Our example building has a constant ceiling height of 9 ft. The program uses this value to calculate the area factor of the space.

Number of Spaces: Enter the number of spaces in the building that are like the one described. In the example, note that there are two washrooms of 250 ft^2, as well as 25 separate office spaces. This number acts as a multiplier, allowing entry of multiple single spaces on one line.

The above values should be entered for each different type of space in the building. Each space will occupy a separate line in the program. The program then computes the values listed below for each space type.

Area Factor (AF): Accounts for effect of room configuration on lighting power utilization.

Unit Power Density (UPD): Refers to the lighting power density for the space in W/ft^2. This value is taken from Table 401.3.2b, 401.3.2c or 401.3.2d.

Base Unit Lighting Power Allowance (Pb): Changes the power density to adjust for the area factor; it is equal to the product of the AF and the UPD.

Example 401EE Use of LTGSTD Program – Department Store Building (continued)

Lighting Power Budget (LPB): Allowed watts for lighting power in each respective space.

Total Lighting Power Budget (LPB): The same as ILPA, equal to the total allowed lighting power for each of the space types. The program will enter the total of this column under system performance criteria.

In the department store example, use of the system performance criteria has given a higher interior lighting power allowance of 118,808 watts. Since the design interior adjusted lighting power is only 111,900 watts, the interior lighting of the store complies. Compliance is shown on Screen A. Specific space lighting power budgets are shown on Screen B.

Control Points: The LTGSTD program assigns control points to account for the equivalent number of manual controls requirement. The program will calculate both lighting control points required (required number of manual controls) and equivalent lighting control points installed (equivalent number of lighting controls). Pressing the F5 key from the space screen will access the Controls Data Input Screen. The information that must be entered for each space includes the following: the number of tasks in the space; the type of controls installed; and the number of similar controls installed. The control types are accessed by codes that are presented in Appendix B. Up to two types of controls may be entered for a single space. The specific space control point summary is presented on Screen C.

Exterior Lighting: The LTGSTD program will also calculate the exterior lighting compliance. Pressing the F8 key will access the Exterior Data Input Screen. The information requested includes: the exterior area code (from Table B-3) and the length (ft) or area (ft^2) of that type in the project. The program then calculates the allowed watts. The exterior lighting compliance is presented on Screen D.

Screen A -- LTGSTD Compliance Summary

```
       LIGHTING PRESCRIPTIVE AND SYSTEM PERFORMANCE COMPLIANCE CALCULATION PROGRAM
                                        VERSION 2.1
                              ASHRAE/IES STANDARD 90.1-1989
      ENERGY EFFICIENT DESIGN OF NEW BUILDINGS EXCEPT LOW-RISE RESIDENTIAL BUILDINGS

BUILDING
    DATE

BUILDING TYPE                             AREA
  D Retail                                42750 ft2
                                    -----------
                                          42750 Gross ft2
BUILDING DESIGN
  Interior Lighting Power       111900 W      2.618 W/Gross ft2
  Exterior Lighting Power          900 W
--------------------------------------------------------------------------

 PRESCRIPTIVE CRITERIA
   Unit Lighting Power Allowance              2.500 W/Gross ft2
   Interior Lighting Power Allowance         106875 W

 SYSTEM PERFORMANCE CRITERIA
   Unit Power Density                         2.781 W/Gross ft2
   Interior Lighting Power Allowance         118908 W

 EXTERIOR LIGHTING CRITERIA
   Exterior Lighting Power Allowance           1045 W

***************************************************************************
                                  PASSES
***************************************************************************
```

Screen B -- LTGSTD Space Summary (1 of 2): Interior Lighting Power Allowance

SPACE NO.	TYPE	DESCRIPTION	SPACE DIMENSIONS	AREA	CLG HT	NO. SPACES	AF	UPD	Pb	LPB	TOTAL LPB
1	101	Type D (Spec		25000	9.0	1	1.00	3.10	3.10	77500	77500
2	102	Type E (Fine		10000	9.0	1	1.00	2.80	2.80	28000	28000
3	105	Tailoring		1000	9.0	1	1.10	2.10	2.31	2306	2306
4	13	Toilet and W		250	9.0	2	1.32	0.80	1.06	264	528
5	45	Bulky Active		1000	9.0	1	1.10	0.30	0.33	329	329
6	46	Fine Active		2000	9.0	1	1.04	1.00	1.04	2084	2084
7	106	Dressing/Fit		750	9.0	1	1.13	1.40	1.58	1186	1186
8	26	Reading, Typ		100	9.0	25	1.55	1.80	2.79	279	6975

Screen C -- LTGSTD Space Summary (2 of 2): Lighting Control Points

SPACE NO.	TYPE	DESCRIPTION	SPACE DIMENSIONS	AREA	CLG HT	NO. SPACES	NO. TASKS	CONTROL TYPE	CONTROL NO.	CONTROL TYPE	CONTROL NO.	CONTROL PTS. INST.	CONTROL PTS. REQD.
1	101	Type D (Spec		25000	9.0	1	2	MANUAL	17	0	0	17	51
2	102	Type E (Fine		10000	9.0	1	2	MANUAL	5	0	0	5	18
3	105	Tailoring		1000	9.0	1	1	MANUAL	2	0	0	2	2
4	13	Toilet and W		250	9.0	2	1	OCCUPANCY	1	MANUAL	1	3	2
5	45	Bulky Active		1000	9.0	1	1	MANUAL	1	OCCUPANCY	1	3	2
6	46	Fine Active		2000	9.0	1	1	MANUAL	1	OCCUPANCY	0	1	2
7	106	Dressing/Fit		750	9.0	1	1	TIMER	1	0	0	2	2
8	26	Reading, Typ		100	9.0	25	1	OCCUPANCY	1	0	0	2	2

Screen D -- LTGSTD Exterior Lighting Power Allowance

EXTERIOR LIGHTING REQUIREMENTS

AREA CODE	AREA DESCRIPTION	AREA OR LENGTH	ALLOWANCE WATTS
3	Entrance (with canopy) High Traffic	60.00 ft^2	600.00
5	Entrance (with canopy) Loading Area	100.00 ft^2	40.00
2	Entrance (without canopy)	6.00 ft	180.00
7	Building Exterior Surfaces/Facades	900.00 ft^2	225.00

FLUORESCENT AND HID LAMP BALLASTS

Form
401.3.5

Additional 90.1 Code requirements apply to fluorescent and high intensity discharge (HID) lamp ballasts. The ballast requirements address wiring procedures for one-lamp and three-lamp fluorescent ballasts, as well as minimum power factors for both fluorescent and HID ballasts.

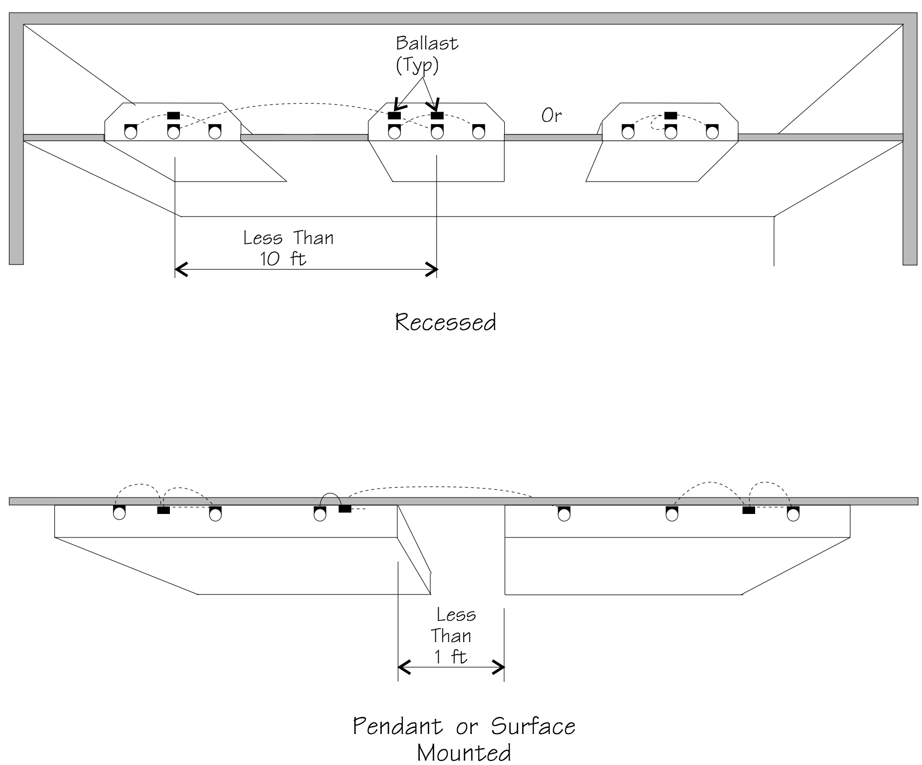
Tandem Wiring

Form
401.3.5.1

Two-lamp fluorescent ballasts for the common standard lamps (F40, F96T12 slimline, and F96T12HO) are inherently more efficient than one-lamp ballasts. Use of single-lamp fluorescent ballasts shall be minimized as follows:

- One-lamp and three-lamp fluorescent luminaires in the same room and within 10 ft (center-to-center distance) of one another shall be tandem-wired to eliminate the use of single-lamp ballasts.
- Surface mounted or pendant fluorescent luminaires within 1 ft of one another must also be tandem-wired to eliminate the use of single-lamp ballasts.
- Use of three-lamp ballasts is permitted in place of tandem-wiring of two-lamp ballasts. Electronic three-lamp ballasts are a common and cost-effective alternative to tandem wiring.

Figure 401E Tandem Ballasting Requirements



Form 401.3.5.2 Exception #1 and #2

Power Factor

All fluorescent and high intensity discharge lamp ballasts *"shall have a power factor of at least 90%."* Ballasts meeting this criterion are designated by manufacturers as "high power factor" or "HPF" ballasts. There are several exceptions to this requirement:

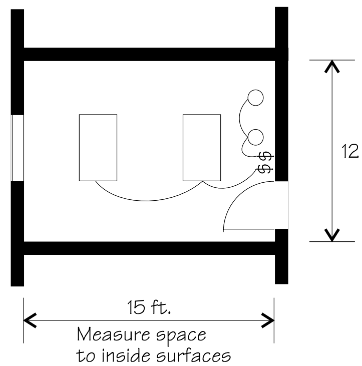
- Dimming ballasts
- Ballasts for circline fluorescent lamps
- Compact fluorescent lamp ballasts
- Ballasts for low-wattage (≤ 100 watts) HID lamps

Although the 90.1 Code does not require the use of electronic high frequency ballasts for fluorescent applications, these products are inherently superior to the electromagnetic ballasts they are designed to replace. Electronic ballasts offer the following advantages:

- Higher efficiency
- Silent operation
- Flicker free lamp performance
- Easy dimming of lamps
- Easy integration with lighting control technologies
- More cost effective

Example 401FF Applying the Lighting Requirements to a Private Office

Q



A 12 ft by 15 ft private office with a 9 ft ceiling has two recessed three-lamp parabolic luminaires for general and task lighting, as well as two recessed low-voltage downlights that accent artwork on the wall. Each parabolic fixture has a three-lamp electronic ballast and F32T8 lamps. The parabolic fixtures are controlled by a wallbox occupancy sensor, and the wall washers are controlled by a manual wallbox dimmer. Does this space comply with the lighting requirements?

A

Yes. This space complies with all applicable requirements for lighting power, controls, and ballasts.

Using the specific space method, the ILPA for this space is 1.8 W/ft^2, based on the listing for Office Category 1 for reading, typing, and filing tasks in Table 401.3.2b. The area factor is 1.41, based on the room area of 180 ft^2 and the ceiling height of 9 ft. A total of 457 watts is permitted (1.8 x 180 x 1.41). The two low voltage downlights use 50W MR16 lamps, while the input wattage of the parabolic fixtures is 89 watts apiece. The connected lighting power, therefore, is only 278 watts, well under the ILPA. The 179 watts not used may be used elsewhere in the building, if needed.

Two manual controls are required for the space: one for the enclosed room, and one for the work task at the desk. Since an occupancy sensor is used in addition to the dimmer for the downlights, this space has the equivalent of three manual controls, one more than required. The extra equivalent manual control may <u>not</u> be used to satisfy the requirement for minimum number of manual controls in other spaces. Note also that the manual dimmer counts as only one manual control.

Since two three-lamp ballasts are used to control the parabolic luminaires, the requirement for tandem wiring does not apply. The electronic ballasts used have a power factor of 98% (typical of most electronic ballasts), and comply with the 90% or better requirement.

SUMMARY FORMS AND WORKSHEETS

One summary form and two worksheets are provided to assist with the calculations and documentation necessary in showing compliance with the electric power and lighting systems requirements of the 90.1 Code. . Applicants who use the energy-cost budget method (See Appendix A) are not required to complete the interior connected lighting power section of the Lighting Wattage Worksheet. Blank copies of the compliance forms and worksheets are included in Appendix D of this manual. The Case Study section of this chapter provides examples of completed forms. A general description of the forms is provided below.

Summary Form and Checklist (1 page, front and back)

The front page of this form contains basic project information; the back lists information to be put on drawings submitted for an electrical permit. The applicant completes the top and left hand side of the front page and refers to the appropriate plan page on the drawings for each item on the checklist.

Unless included on the plans, two additional worksheets are likely to be needed:

- The Lighting Wattage Worksheet for the interior and exterior lighting wattage
- Lighting Controls Worksheet (not needed if the LTGSTD output is submitted)

The plans examiner then compares this information with the drawings, requests corrections from the applicant, notes any features which merit special attention by the inspector, and then forwards it to the inspector.

The inspector verifies all categories where there is an inspection check box, unless the applicant has written in “NA” and the plans examiner has concurred. After the inspections, the final version of the form can be filed with the building permit drawings as a record of construction.

Lighting Wattage Worksheet (3 pages)

This worksheet is used to demonstrate that the total proposed exterior (page 1) and interior (pages 2 and 3) connected lighting power (CLP) is less than the maximum allowed by Sections 401.3.1 (exterior) and 401.3.2 (interior), respectively. While it would be ideal if these calculations were included on the plans, this is not standard practice. (The shaded areas of the form indicate information that is to be taken from the plans.)

For the allowed interior wattage, complete *either* the building space option *or* the specific space option. The building space option is the simplest, but has the least flexibility. The specific space option provides more flexibility, but requires more work for both the designer and code official. Take the areas (and ceiling height, if the specific space option is used) from the plans.

For the proposed exterior and interior wattage, the plans must show the number, wattage, and description of each fixture type. For the allowed exterior wattage, take the area and lineal feet from the plans.

Compliance can be shown on an overall basis for the exterior and interior lighting. However, tradeoffs between exterior and interior lighting are not allowed (Section 401.3.1.1).

Lighting Controls Worksheet (1 page, front and back)

This worksheet is used to demonstrate whether the controls to be installed (both manual and automatic) meet the minimum requirements of Section 401.3.4.2. While it would be ideal if these calculations were included on the plans, this is not standard practice. (The shaded areas of the form indicate information that is to be taken from the plans.) The plans must include a wiring diagram of the type of controls and the fixtures they control. The area of each space can be scaled from the plans.

Compliance must be demonstrated on a space-by-space basis, rather than on an overall basis. Extra lines for additional building spaces are provided on the back.

Lighting Schedule (optional)

While a lighting schedule is not required by the 90.1 Code, it is a highly effective means of consolidating much of the material required for the compliance forms. A well-constructed lighting schedule will address ballast requirements for tandem wiring and high power factor, as well as listing input wattage for each luminaire type. Ideally, the lighting schedule would list all of the following:

- *Fixture ID:* The identification symbol or number used to identify the different luminaires shown on the lighting or reflected ceiling plans.
- *Fixture Description:* A general description of the luminaire, including mounting type, source type, size, and any special instructions, such as mounting height. In practice, the fixture description usually lists a manufacturer and part number.
- *Lamp Quantity and Type:* The quantity and lamp source used in the luminaire.
- *Ballast Type*: Ballast technology type (electronic high frequency, magnetic, hybrid, HID, etc.). An increasingly popular practice used by designers is to include an entire ballast schedule along with the lighting schedule. This allows the designer an easy means of specifying and documenting ballast technology type, power factor, tandem wiring, ballast factor, etc.
- *Input Watts:* The input wattage for each fixture. This value should include ballast losses, which will vary depending on luminaire construction and mounting type. Use the value supplied by the luminaire manufacturer, if possible. If this value is unavailable, the typical input wattages listed in the Reference section of this chapter may be used. The values for input wattage may then be transferred to the Lighting Wattage Worksheet to determine interior and exterior connected lighting power.

PERMIT APPLICANT'S RESPONSIBILITIES

At permit application, the goal of the applicant is to provide all the necessary information to show compliance with the 90.1 Code. If the plans examiner is able to verify compliance with one review, then the permit can be issued and construction started without delay. To assist in submitting the permit application, the applicant should review not only the following information specific to the applicant but also the subsequent two sections that review responsibilities of the plans examiner and the inspector. The following section addresses the two common problems with permit applications: (1) missing information, or (2) incorrect information.

Information may be missing because the applicant was not aware of all of the code requirements or because the required information was located on the specifications but not on the plans. Note that building departments generally approve plans, but not specifications. The Checklist on the back of the Electrical/Lighting Summary Form provides a detailed list of the type of information that needs to be on the plans. This information can then be provided in a number of ways:

- *On the drawings.* Provide wiring diagrams with all electric feeders subdivided by usage; lighting control diagrams indicating type of lighting control and the fixtures/circuits that it controls; tandem ballast wiring of one- and three-lamp fixtures.
- *In schedules.* For instance, list motor horsepower and efficiency on a motor schedule, and total wattage, number of luminaires, and ballast power factor on a lighting fixture schedule.
- *Through notes and call outs.* Indicate the types of lighting controls, operating sequences, and check metering provisions. Note that building owner is to be given operation and maintenance literature and that exterior lighting is to be automatically controlled by a photocell, timeclock or combination of the two.
- *Through supplementary worksheets or calculations.* Provide calculations where required, such as for interior and exterior lighting wattage and for lighting control points. You may include these calculations on the drawings or incorporate as additional columns in the schedule or submit completed worksheets provided with this manual.

Incorrect information may be due to a lack of understanding of the code. More likely, it indicates that the code has changed since the last project. The applicant can use a correction list as a reminder to update the office specifications to avoid receiving this same correction again in the future. Some features to note are:

- Electrical power feeders are to be subdivided by lighting, HVAC, service water heating, elevators and other equipment or systems of more than 20 kW.
- Motors typically will need to be “energy-efficient” class, rather than standard, to comply with minimum efficiency.
- Assuming a reasonable spacing, most one- or two-lamp fluorescent fixtures with energy-efficient lamps and ballasts will comply with the interior lighting power allowance. For three-lamp fixtures, the options are more limited unless electronic ballasts are used. The days of four-lamp fixtures are past. Incandescents can be used sparingly, but compact fluorescents facilitate compliance. Parking garage lighting will need to be more efficient than conventional fluorescent.

- Generally, some type of automatic lighting control (occupancy sensors, programmable timers, photocell dimming) is necessary to provide the minimum number of controls.

PLANS EXAMINER'S RESPONSIBILITIES

The plans examiner must review each permit application for 90.1 Code compliance before a permit is issued. By letting the designer and contractor know what's expected of them early in the process, the building department can help assure that the submitted drawings comply with the code. This helps the inspector to avoid the headache of correcting a contractor who is following drawings that do not meet the code requirements.

The biggest challenge for the plans examiner is often determining where the necessary information is and whether the drawings are complete. The plans examiner should make sure that the applicant includes the Electrical and Lighting Summary and Checklist forms in this manual as part of the submittal package. The information provided on these forms makes the job easier and reduces plan review time.

A complete electrical power and lighting plan review covers all of the requirements in Section 401, but may also include consideration of daylighting area defined in Section 402. For Section 401, first review the responsibilities of the applicant in the previous section to get a general sense of key requirements, then:

- Check that wiring diagrams indicate that electric power feeders are subdivided by usage.
- Look for notes indicating check metering provisions, and that electrical schematics and operations and maintenance literature will be provided to the owner.
- Check that there's a motor schedule with the correct efficiencies, or that exceptions are documented and justified.
- Check that the exterior lighting power allowance on the Lighting Wattage Worksheet is filled out correctly. Note that the facade and other activity areas only include those areas illuminated (not the entire facade or site area).
- Check that the proposed exterior lighting from the Lighting Wattage Worksheet matches the drawings and schedules, and that it includes number of lamps, ballast type, total wattage, etc. Also, note that compliance must be shown for exterior lighting alone, no tradeoffs are allowed with interior lighting.
- Check that the interior lighting power allowance on the Lighting Wattage Worksheet is filled out correctly using either the building space method or the specific space method.
- If the building space method is used, note that the areas are gross lighted areas (GLA) as measured from the interior of perimeter walls (not the gross floor area) and that the wattage allowances are based on the GLA of the entire building (not the GLA of that particular use). Be aware that Table 401.3.2a is not available for all building spaces.
- If the specific space method or LTGSTD is used, note that the areas are areas of the space as measured from the interior of perimeter walls or partitions (again, not the gross area).

- Check that the proposed interior lighting from the Lighting Wattage Worksheet matches the drawings and schedules, and that it includes the number of lamps, ballast type, total wattage, etc. (Tip: the effect of the ballast on total fixture wattage will vary by ballast type. For fluorescent lamps with magnetic ballasts, this may mean a total that is 1.1 times the lamp wattage. For electronic ballasts, the fixture wattage may be the same as or lower than that of the lamps alone.) Make sure that any exceptions are justified. Also, note that interior lighting must comply on its own; no tradeoffs are allowed with exterior lighting.
- If lighting power control credits (LPCC) are taken for automatic controls, check that the controls are shown on the drawings, that they have the features required (readily accessible with temporary override and automatic return to the original schedule for programmable timing controls, etc.), and that they control the number of fixtures claimed.
- Check that the Lighting Controls Worksheet is filled out correctly, that the controls listed equal or exceed the minimum number required, and that they match the drawings. Make sure that any exceptions are justified.
- Check that interior lighting controls are accessible from within the space controlled, and that hotel and motel guest rooms have a master switch at the main entry door.
- Check that exterior lighting controls have a photocell and/or timer with the necessary features.
- Check that recessed one-lamp and three-lamp fluorescent fixtures are tandem wired.
- Check that ballasts have a minimum power factor of 90%.

For Section 402:

- If the skylight exemption was taken as part of the building envelope compliance, verify that the necessary automatic daylighting controls are to be installed.
- If the fenestration daylighting option was taken for building envelope compliance, verify that the necessary automatic daylighting controls are to be installed.

Remember that good plan review is important. It’s much easier to change a number on a drawing than to remove equipment after it has already been installed.

FIELD INSPECTOR'S RESPONSIBILITIES

The inspector's task is to make sure that the project is constructed in accordance with the approved plans. Be aware that a number of requirements will vary from project to project. Consequently, while some requirements may be learned once, others will necessitate on-site checking of the approved plans.

The primary challenge for the inspector may be educating the contractors about any changes in the code requirements so that installations are performed correctly, not simply the way they may have been routinely done in the past.

For this code, some of the most important items are listed below. As a start, review the responsibilities for the applicant and plans examiner in the previous two sub-sections to get a general sense of key requirements.

Rough Electrical Inspection

The following items should be checked during the rough electrical inspection:

- Verify that electrical feeders are subdivided by usage.
- Verify motor efficiency, if possible. Efficiency ratings are not always listed with nameplate data, so verify that the installed motors match what is listed on the plans or schedules.
- Verify lamp and ballast types. It is important to confirm that the lamps and ballasts are the same as those listed on the drawings and schedules. (Tip: try to look at lamps when they are coming out of the box so it won't be necessary to climb a ladder and disassemble a fixture after it's been installed in the ceiling.) Expect T-8 lamps (the skinny tubes, 1 inch (8/8ths) in diameter) rather than the old T-12 lamps (1-1/2 inches in diameter - 12/8ths).. Expect compact fluorescents in hallways rather than incandescents. Expect something more efficient than incandescents in most of a retail space. Expect metal halide or high pressure sodium in parking garages, and in most high ceiling manufacturing and warehouse spaces.
- Verify number of fixtures and spacing.
- Verify number and type of interior lighting controls. Assume that there is a local control required in each space. Assume that some type of automatic lighting control is required unless there is one manual control for every task location or group of tasks. Assume that automatic daylighting controls are required for lighting fixtures around skylights.
- Verify type of automatic exterior lighting controls. Expect photocell or look for timer with scheduling capabilities and four- hour battery backup.
- Verify tandem wiring of one- and three-lamp ballasts.
- Inform contractor of any missing items or corrections to be made.

Final Inspection

Check the following items during the final inspection:

- Verify that problems or unresolved issues noted at the rough-in inspection have been addressed.

- Verify that subdivided feeder have provisions for portable or permanent check metering.
- Verify that the contractor has provided the building owner with a schematic of the electrical systems.
- Verify automatic controls for exterior lighting. Expect a photocell or look for a timer with scheduling capabilities and four-hour battery backup.
- Verify exempt exterior and interior exempt lighting fixtures, if applicable
- Verify lighting systems exempt from control requirements
- Verify installation of all required lighting controls
- Verify accessibility of all manual controls
- Verify operation of automatic lighting controls, if used.

An inspector's ongoing challenge is responding to change orders during construction. The call is easy if a more efficient piece of equipment is being substituted for a less efficient one. For instance, it is acceptable to substitute a 92% efficient motor if the drawings specify only 91%. Also, a lamp and ballast combination rated at 64 watts is an improvement over a 67-watt combination, provided that the number of fixtures isn't increased and that the substituted ballast doesn't affect any automatic controls.

A more difficult change order is one that reduces efficiency. For example, if the proposed substitute motor is only 89% efficient but meets the code minimum for this size motor, the inspector needs to check with the plans examiner to make sure that no tradeoffs were made that would have required a higher efficiency motor. Similarly, if a 69-watt lamp and ballast combination is substituted for one with 64 watts, the inspector must definitely check with the plans examiner. In this case, compliance is based on a calculation of the total installed wattage which will vary based on the fixture wattage and the number of fixtures. Whenever there are significant changes, the inspector is expected to request that the applicant submit revised plans so that the plans examiner can verify compliance and assure that there is a correct record on file in the building department.

An even tougher case is when the contractor has already installed noncomplying equipment without checking with the inspector. The inspector should be quite strict for several reasons. First, since most contracts are awarded on a cost-competitive basis, the low bid company might win the job and then make its profit by installing non-complying equipment. This would be unfair to the higher-bid contractors. Second, a lenient inspector's job will be more difficult in the future. A non-complying contractor who skates by will most likely have additional requests for future projects. In addition, other contractors will also begin to ask for special treatment. Self-policing, which works well if everyone is being treated fairly, will begin to decline.

Finally, there is the situation when the approved plans do not contain all of the code requirements. If information or notes are missing from the plans, the inspector can, for instance, simply direct the contractor to make the necessary changes in the field; i.e. tandem-wire ballasts or provide a minimum of lighting controls in each space. The inspector's job is more difficult, however, if the drawings contain information that is wrong. Perhaps the inspector notices that the efficiency of the installed motor is too low and informs the contractor. The contractor responds that they are following the approved plans and indeed they are. The inspector, as the representative of the building official, is clearly authorized to require that the contractor build the project to code. (If necessary the inspector can show the contractor the building department note which says “approved subject to errors and omissions.) In this case, it seems appropriate for the inspector to inform the plans examiner of the problem and ask the plans examiner to help solve the problem. The plans examiner may be able to suggest improvements in other areas that would compensate for this shortfall. It is important for the plans examiner and inspector to appreciate the challenges of each others’ work and the benefits of a team effort.

Case Study – Office Building

The following case study demonstrates the recommended procedure for documenting compliance to the requirements listed in Section 401 of the 90.1 Code. Items that must be documented on the compliance forms include electrical system requirements, electric motor efficiency, interior and exterior lighting allowances, lighting controls and ballasts for fluorescent and high intensity discharge lamps.

This case study includes filled out versions of the summary form and the two lighting worksheets that are described in the Compliance and Enforcement section of this chapter. For demonstration purposes, the case study uses both the building space method and the specific space method to determine interior lighting power allowance (ILPA). The 90.1 Code allows either of these methods to be used. The following additional documents are included in Appendix B as part of this case study:

- Electrical Distribution Plans - pages B-5 and B-6 (E-1 and E-4): Used to show compliance with requirements for check metering and electrical schematics.
- Lighting Schedule (included with explanatory text. See Table 401F): Shows luminaire type, including information about lamps, ballasts, and input wattages; used to determine interior and exterior lighting power; also demonstrates compliance with ballast requirements addressing power factor and tandem wiring, and lists all luminaires that are exempt from the lighting wattage and control requirements.
- Reflected Ceiling Plan - page B-4: Shows layout and distribution of the interior lighting fixtures; used with lighting schedule to calculate total interior lighting power; also used to determine ILPA with the specific space method.
- Site Plan - page B-5 (E-1): Shows layout of exterior lighting fixtures; used with lighting schedule to calculate exterior connected lighting power.

Under most circumstances, Section 401 compliance documentation would also include a motor schedule to demonstrate compliance with minimum efficiency requirements for electric motors. However, in this case study, motor requirements are addressed in Section 403.

BUILDING DESCRIPTION

This case study building is a new office facility that will be constructed in Chattanooga, Tennessee in the immediate future. The majority of the building is open plan partitioned office areas. The plan includes skylights and perimeter windows that will introduce ample amounts of daylight into the space. The electrical engineer and lighting designer for the project have specified state-of-the-art high efficiency lighting components in their design, including T-8 lamps, electronic high frequency dimming ballasts, high efficiency fluorescent luminaires, daylighting controls, and occupancy sensors.

RECOMMENDED PROCEDURE

This section discusses the procedure that was used to fill out the Electrical Systems Summary, Lighting Wattage Worksheet and Lighting Controls Worksheet for the case study office building. The two lighting worksheets must be completed prior to filling out the Summary form.

Lighting Schedule

To facilitate the calculation of both interior and exterior lighting power, the applicant has included a lighting schedule (reproduced below), with the compliance documentation. In addition to listing the input wattages that will be used on the Lighting Wattage Worksheet, the schedule lists information about ballasts that may be used to demonstrate compliance with Sections 401.3.5.1 and 401.3.5.2 of the 90.1 Code.

This lighting schedule is not limited to assisting in the calculation of interior and exterior lighting power. Luminaires that are excepted from the requirements are listed as "exempt" in the input wattage column. The schedule also addresses the ballast requirements by noting luminaires that require tandem ballasting (Section 401.3.5.1), and by specifying that all ballasts shall be high power factor (Section 401.3.5.2).

Table 401F Lighting Schedule – Office Building

Fixture ID	Fixture Type	Lamp Quality & Type	Ballast Type (1)	Input Watts (2), (3)
B	4' Pendant-Mounted Parabolic Fluorescent. Direct/Indirect	1-F32T8/735	Electronic Dimming	31
B1	Same As Type B, But 2 Tandem-Wired Fixtures With 1 Ballast	2-F32T8/735	Electronic Dimming	61
D	Recessed 8" Fluorescent Downlight With Alzak Reflector	2-CFQ26W/835	Electronic	46
D1	Recessed 7" Fluorescent Downlight With Alzak Reflector	1-CFQ18W/835	Electronic	17
F1	1'x4' Recessed Fluorescent With 8-Cell Parabolic	1-F32T8/735	Electronic Dimming	30
F1A	Same As Type F1, But 2 Tandem-Wired Fixtures With 1 Ballast	2-F32T8/735	Electronic Dimming	59
F2	2'x4' Recessed Fluorescent With 16-Cell Parabolic Louver	2-F32T8/735	Electronic Dimming	59
F2A	20"x4' Recessed Fluorescent With 16-Cell Parabolic Louver	2-F32T8/735	Electronic Dimming	59
G	Pendant-Mounted 4' Industrial Fluorescent. With Specular Reflector	1-F32T8/735	Electronic Dimming	31
G1	Same As Type G, But 2-Tandem Wired Fixtures With 1 Ballast	2-F32T8/735	Electronic Dimming	61
H	Wall-Mounted Square 4" x 4' Fluorescent With Prismatic Lens	1-F32T8/735	Electronic Dimming	30
J	8' Pendant-Mounted Parabolic Fluorescent. Direct/Indirect	2-F32T8/735	Electronic Dimming	61
K	Pole Top HID With IES Type III Horizontal Distribution & 15' Pole	1-S150	HID	188
K1	Pole Top HID With IES Type V Vertical Distribution & 15' Pole	1-S150	HID	188
K2	Pole Top HID With IES Type IV Forward Distribution & 15' Pole	1-S150	HID	188
K3	2 Arm-Mounted HIDs With Type V Distribution & 15' Pole	2-S150	HID	376
L	Surface-Mounted 4' Enclosed Fluorescent. Wrap Around	2-F32T8/735	Electronic Dimming	59
M	1'x4' Recessed Prismatic Fluorescent With Specular Reflector	1-F32T8/735	Electronic Dimming	30
M1	Same As Type M, But 2-Tandem Wired Fixtures With 1 Ballast	2-F32T8/735	Electronic Dimming	59
N	4' Wall-Mounted Parabolic Fluorescent Direct-Indirect	1-F32T8/735	Electronic Dimming	31
P	4' Surface-Mounted Undercabinet Task Light	1-F32T8/735	Electronic Dimming	30
Q	Ceiling Mounted Battery-Operated Emergency Light With Dual Heads	2-7.2W PAR36	N/A	Exempt
Q1	Same As Type Q, But Recessed In Wall @ 10' A.F.F.	2-7.2W PAR36	N/A	Exempt
X	Battery-Operated LED Exit Sign With Universal Mounting Plate	LED	N/A	Exempt

Notes:
1. All ballasts shall be high power factor.
2. Input watts include ballast losses and are taken from the default wattage tables listed in Section 401 of the 90.1 Code Compliance Manual (this document).
3. Input wattages for fixtures using dimming ballasts are for full light output.

Lighting Wattage Worksheet

Once the lighting schedule has been completed, it is relatively easy to fill out the Lighting Wattage Worksheet. There are four steps in the process:

1. Calculate the Exterior Lighting Power Allowance (ELPA).
2. Calculate the proposed exterior Connected Lighting Power (CLP).
3. Calculate the Interior Lighting Power Allowance (ILPA), using either the building space method or specific space method.
4. Calculate the proposed interior Connected Lighting Power (CLP).

These steps are discussed in detail below, using the case study building as an example. It is important to note that although the applicant need choose only one method of determining ILPA, both the building space and specific space methods are shown in the case study, meaning that page 2 of the Lighting Wattage Worksheet has been filled out twice to show both methods of calculating ILPA.

Exterior Lighting Power Allowance

The exterior lighting power allowance is calculated using Table 401C, along with the plan sheet that shows exterior lighting (typically an electrical site plan). Simply follow page 3 of the Lighting Power Worksheet to determine the allowance.

The case study building has only five areas where the ELPA must be calculated. The ELPA calculation is shown on page 1 of the Lighting Wattage Worksheet, and the five areas and their associated ELPAs are described below.

- The 39,765 ft^2 parking lot earns a higher allowance (0.18W/ft^2) as a public lot. The plans examiner should confirm that the parking area qualifies as a *public* lot. This is determined by whether the lot will be used by visitors, as well as employees.
- The walkways listed on the worksheet lead from the parking lot to an employee entrance at the side of the building. Since they are intended for employee use they count as *private* areas, and receive a lower allowance (0.1W/ft^2) than would similar areas intended for general public use.
- The employee entrance to the facility is defined by the code as an *exit*. Regardless of whether or not it has a canopy, it receives an allowance of 25W/linear ft of door opening, which is defined as the width of the door, or 6 ft.
- The drive-through covered area in front of the building is listed as a vehicle inspection area, used primarily during the day. Nevertheless, it qualifies as a non-manufacturing work area, receiving an allowance of 0.20 W/$ft^{2.}$
- The main entry of the building is covered. As such, it is classified as a light traffic (typical of office buildings) canopied entrance.

Calculating the above exterior areas of the building yields a total ELPA of 9,094 watts. The next step is to determine the proposed exterior connected lighting power. If this value does not exceed 9,090 watts, the project will comply with the requirement for exterior lighting power.

Exterior Connected Lighting Power

The proposed exterior connected lighting power for the case study building is determined by using the lighting schedule along with the electrical site plan page B-5 (E-1). Exterior CLP is equal to the sum of the input wattages of all exterior luminaires. It is very important that the plan checker review the applicant's input wattages to insure that they are accurate within an acceptable margin of error. See the Reference section of this chapter for input wattage defaults for most common lamp and ballast combinations. These may be used if manufacturer data are unavailable, or if the input wattages listed on the Lighting Wattage Worksheet or other lighting documents appear inaccurate.

As shown on page 1 of the Lighting Wattage Worksheet, the total proposed exterior CLP for the case study building is only 3,616 watts. As such, the exterior lighting power is well under the ELPA, and the building easily complies with the exterior lighting power requirement.

ILPA Calculation -- Building Space Method

The top part of Page 2 of the Lighting Wattage Worksheet demonstrates the ILPA calculation using the building space method. The first step in calculating ILPA, or in checking the calculation, is to determine whether or not 10% or more of the building is intended for multiple space activities. If so, each building space activity must be calculated separately. The building official should note that the case study building is entirely intended for office use and directly related facilities. As such, the office allowance may be taken for the entire building.

Using the building floor plans, the gross lighted area of the building is determined to be 15,127 ft^2. Recall that the gross lighted area of the building is measured from the inside of all perimeter exterior walls and includes any interior partitions. Using Table 401.3.2a, an office building of 10,001 to 25,000 ft^2 is allotted an ILPA of 1.72 W/ft^2. Therefore, multiplying the gross lighted area by the allotment yields an ILPA of 26,018 watts for the entire building. If the proposed interior connected lighting power (CLP) does not exceed the ILPA, the building will comply with the interior lighting requirement.

ILPA Calculation -- Specific Space Method

The bottom part of Page 2 of the Lighting Wattage Workshop demonstrates the specific space approach to determining ILPA. Calculating ILPA with this method is more time consuming than the building space approach, yet it nearly always yields a more generous allowance.

Using the specific space method requires the applicant to separate building spaces by activity, ceiling height, and area of the space. The worksheet requires that for each space the following values be recorded:

- *Allowed Power (W/ft^2):* refers to the unit interior power allowance listed for the space type in Tables 401.3.2b, c, and d. This value is recorded in column F of the worksheet. The plan checker should verify that the appropriate value is entered.

- *Area (ft^2):* refers to the area of the space (not the gross lighted area). It is limited to the measurement from the inside surface of the perimeter walls or partitions and does not include the thickness of partitions within the space. The area is recorded in column G of the worksheet.
- *Area Factor*: accounts for the geometry of the space and is determined by using either Figure 401.3.2e or the Area Factor Formula. The area factor is recorded in Column H of the worksheet. The maximum value is subject to the restrictions listed in the footnotes of Tables 401.3.2b, c, and d.
- *Number of Similar Spaces:* provides the applicant with an area to record multiples of the same space. All like spaces must be identical in terms of unit interior lighting power allowance, area and area factor. This value is recorded in Column I of the worksheet.

The allowed lighting power for each space is the product of Columns F, G, H, and I in the worksheets. The sum of the resultant allowed watts, recorded in Column J, is the ILPA for the building.

The specific space ILPA calculation of the case study building, listed at the bottom of page 2 of the lighting wattage worksheet yields a total ILPA of 28,293 watts. Note that this ILPA is more than 2,000 watts higher than the ILPA calculated with the building space method.

All unit ILPA values listed in the specific space ILPA calculation are taken from Table 401.3.2.b. Please note the following important points:

- All office spaces are classified as *Office Category 1* with reading, typing, and filing tasks. Although this is a partitioned office building, all partitions are lower than 4.5 ft below the ceiling.
- The area factor for Office Category 1 may not exceed 1.55. See Footnote “e” of Table 401.3.2b
- All corridors are assigned an area factor of 1.0, complying with Footnote “c” of Table 401.3.2b.
- The lunchroom is classified as *Recreation/Lounge* space. This space is intended to provide employees with an area to take breaks and eat lunch. Since there are no commercial type food preparation facilities on the premises this area may not be classified as any of the food service spaces listed in Table 401.3.2b.
- Storage spaces in the building are classified as *Active Storage, Fine*. This category is applies to storage of office materials, forms, and related items.
- Training areas are considered to be *Classroom/Lecture Hall* spaces.
- As shown in the reflected ceiling plans, the conference rooms do not qualify as multi-function spaces having supplementary, independently controlled lighting systems. As such, they do not receive the 1.5 power adjustment factor listed in Footnote “b” of Table 401.3.2b for applicable spaces.

The next step in filling out the Lighting Wattage Worksheet is to calculate the proposed interior connected lighting power (CLP). The building will comply with the interior lighting power requirements if the proposed interior CLP does not exceed the ILPA, as calculated using *either* the building space or specific space method.

Interior Connected Lighting Power (CLP)

The interior connected lighting power is calculated on page 3 of the Lighting Wattage Worksheet by using a lighting schedule along with either a reflected ceiling plan or a lighting plan showing the distribution of fixtures in the building. Since the lighting schedule should include input wattages for each fixture type, simply count the quantity of each fixture type shown on the plans. This should be done for each building location.

It is important that the plan checker verify that the input wattage listed for each fixture type is appropriate. The fixture description column of the worksheet will list either a manufacturer's part number or a description that allows the plan checker to make a reasonable estimate of input wattage. As with the procedure for calculating exterior CLP, the tables listed in the reference section of this chapter may be helpful in determining accurate estimates of fixture input wattages.

Multiplying the number of fixtures times the fixture input wattage will yield the proposed watts for each building location. The sum of the proposed wattages is the interior connected lighting power. If the CLP is less than or equal to the ILPA, as determined by either the building space or specific space method, then the interior lighting power complies. If not, the building may still comply once lighting power control credits are applied to the CLP.

As shown on Page 3 of the Lighting Wattage Worksheet, the calculated CLP for the case study building is only 9,956 watts, and therefore complies with the interior lighting power requirement (regardless of the ILPA calculation method used). There is no need to calculate the optional lighting control credits.

Note that three fixture types (Types Q, Q1 and X) on the lighting schedule for the case study building are excepted from the CLP calculation. Fixture types Q and Q1 are emergency lights that activate only in the event of a building power failure. As such, they fall into the exception categories listed in Section 401.3.2. Fixture Type X is a battery-operated exit light that is not part of the building's electrical system.

Adjusted Lighting Power (ALP)

It is anticipated that many projects will not comply with the interior CLP requirement without applying lighting control credits for the use of automatic controls. If this is the case, the applicant must either redesign the lighting, or calculate the Adjusted Lighting Power by filling out columns H, I, and J of the Lighting Wattage Worksheet.

If the ALP calculation is performed, it is important that all fixtures are separated according to whether or not they are controlled by an automatic device. It is not acceptable to apply a power adjustment factor (PAF) to a building space having manual controls. The PAF may only be applied to circuits that are entirely controlled by automatic devices.

PAFs are listed in Table 401.3.3 according to control type. The connected lighting power is adjusted by multiplying the CLP of automatically-controlled fixtures, times the applicable PAF. This result is then subtracted from the CLP to calculate the adjusted lighting power. The ALP is recorded in Column J. If no credit is taken, the ALP is equal to the CLP. Summing the values of Column J yields the total ALP, which must not exceed the ILPA, as calculated by either method.

Lighting Controls Worksheet

The next step in the documentation procedure is to calculate both the required number of manual lighting controls and the proposed number of equivalent controls in the building. The calculations should be done on the Lighting Controls Worksheet. Documents needed to perform the controls calculations include a floor plan and an electrical or lighting plan showing the layout and distribution of all light switches and automatic control devices such as occupancy sensors and daylighting controls.

Required Number of Manual Controls

The are two steps in the procedure for calculating the required number of lighting controls. First, recall that each building space enclosed by walls or ceiling-high partitions must have at least one manual control *or its equivalent*. In addition, any separate space with more than 1,500 watts of lighting must have an additional manual control or equivalent for each 1,500 watts (rounded up) in excess of 1,500. For example, a large office space with 4,000 watts of lighting would require three manual controls or equivalents.

The second step in the calculation for the required number of lighting controls is the inclusion a separate manual control or equivalent for each task location or group of locations within an area of 450 ft^2 or less in the larger space. For example, a private office with a desk would require an additional manual control or equivalent to account for the work task at the desk.

The left side of page 1 of the Lighting Controls Worksheet lists the required number of manual lighting controls for the case study office building. Note that each room number is broken down by area and additional tasks within the area. Altogether, the building requires 25 manual controls for separate spaces and an additional 27 controls to account for additional task areas of 450 ft^2 or less. Atypical building spaces are listed below.

- Room numbers 101, 126, and 127 are exempt from the minimum manual control requirements, because they must be controlled as a whole. Room 101 is the entry foyer, and rooms 126 and 127 are lobby/reception areas.
- Room 116 is a small unlighted closet, The control requirements do not apply.
- Room 102 is a large open office area with 2,645 watts of lighting. There are six separate groups of work stations (<450 ft^2) within the space. Therefore, the room requires eight manual controls: two for the 2,606 watts of lighting, and six additional controls to account for each group of tasks.
- Room 103 is similar to Room 102, only larger. It requires two manual controls for its 2,645 watts of connected lighting, and one control for each of the eight task areas located within.
- Storage spaces, rest rooms, and similar areas require only one manual control, as no significant visual tasks occur over a prolonged period of time in these spaces.
- Rooms 106 and 110 are conference rooms with two tasks each (tabletop reading and wall display). As such, they require a total of three manual controls.

Equivalent Number of Manual Controls

The calculation for the equivalent number of manual controls should be done on the right side of the Lighting Controls Worksheet. If the number of equivalent manual controls is greater than or equal to the number of required manual controls, the building complies with the manual control requirement.

The 90.1 Code allows automatic lighting control devices to count as more than one manual control: occupancy sensors count as two equivalent manual controls; automatic dimming controls count as three equivalent manual controls; etc. The case study office building uses several automatic lighting controls. The designers have specified dimming ballasts with daylighting controls and occupancy sensor overrides in most of the building areas. The building's 42 occupancy sensors and 16 daylighting controllers are equal to 134 manual controls – well over the calculated requirement of 51 manual controls. The project easily complies with the manual control requirements.

Electric Systems Summary Form

Once the Lighting Wattage Worksheet and the Lighting Controls Worksheets have been completed, the final step in the electrical documentation process is to fill in the Electric Systems Summary sheet. Most of the work has already been done on the Lighting Worksheets, so it is mostly a process of transferring calculations from the worksheets and listing reference points. Nevertheless it is important that this form be filled out as completely and as accurately as possible to facilitate the compliance process. The building official should not accept the form until it has been completed in full.

The Electric Systems Summary is organized to follow the sequence of the requirements listed in Section 401 of the 90.1 Code. All the requirements for electrical distribution, electric motor efficiency, interior and exterior lighting power, lighting controls, and ballasts must be addressed. The form is organized so that the applicant must provide a written response to each code requirement. Most of the entries made by the applicant will be simple yes/no responses, followed by a reference that shows where the information may be verified. Blank areas indicate that additional information is required.

The remainder of this section discusses the procedure for filling out the Electric Systems Summary form, using the case study office building as an example.

401.1 Electrical Distribution System

There are two portions to the section on the electrical distribution system. First, the check metering provisions must be addressed by circling the applicable yes/no value for feeder division and referencing the area on the plans where this information may be found. In the case study building, the feeders are divided by usage, as indicated on page B-6 (E-4) of the electrical plans. Note that page B-6 (E-4) contains panel schedules listing distribution layout of each of the building's six subpanels. This provides the inspector with an easy means of checking off the submetering requirements.

The second portion of the electrical distribution system section asks for the location of the electrical schematic. In the case study building this information is noted on page B-5 (E-1) of the electrical drawings in the form of a single-line diagram.

401.2 Electric Motor Efficiency

This section of the Summary form requires the applicant to note the location of the documents listing electric motor efficiency (typically in the form of a motor schedule). The applicant should also note exceptions in the form of multispeed motors or motors included in the HVAC requirements of Section 403. In the example, note that the applicant has indicated that the motor efficiency requirements are shown in the mechanical plans, meaning that the requirements of Section 403 are in effect. It is important that the plan checker verify this notation.

401.3 Lighting Power Allowance

This section requires transferring calculated values for interior and exterior connected lighting power from the Lighting Wattage Worksheet. The reference location should be the Lighting Wattage Worksheet (note: it is the inspector's duty to confirm that the connected interior and exterior lighting power complies with the respective allowances.) It is important to verify that the exterior and interior allowances and connected lighting power correspond with the values calculated on the Lighting Wattage Worksheet.

This section of the Summary form should also note any lighting equipment that is exempt from the lighting power calculations. Note that with the case study building, an exemption is listed for normally off emergency lighting, and that the reference location for this information is the lighting schedule.

If lighting control credits are used to aid compliance, they should be noted at the end of this section.

401.3.4 Lighting Controls

There are several entries to be completed in the lighting control section of the Electric Systems Summary. First, the applicant must note the proposed number of controls, using the value calculated on the Lighting Controls Worksheet for equivalent number of manual controls. Once again, the plans examiner must verify that the calculation for the number of required manual controls is accurate.

This section also provides a place to note exceptions to the manual control requirements. In the case study building note that exceptions circled include occupancy sensors, automatic dimming, and spaces controlled as a whole, and that these exceptions are noted on the Lighting Controls Worksheet.

The applicant must also use this section of the Electric Systems Summary to account for control accessibility and exceptions. The case study building has an exemption based on the use of automatic control devices.

Finally, this section must show that the exterior lighting meets the requirement for automatic controls. The reference showing the plan location of this requirement is important, as both the plans examiner and the building inspector will need to verify that the control device is either a photocell, automatic time scheduler, or combination device. In the case study building, the exterior lighting reference is to the electrical site plan shown on page B-5 (E-1).

401.3.5 Ballasts

This section should note the location of documentation indicating the use of high power factor ballasts and tandem wiring for applicable one- and three-lamp luminaires. In the case study building, this information is located on the lighting schedule.

If dimming ballasts and/or ballasts for compact fluorescent lamps, circline lamps, or low wattage HID lamps are used for the project, they should also be noted in this section. Note that the case study building has both dimming and compact fluorescent ballasts listed on the lighting schedule.

ADDITIONAL ITEM TO NOTE

The final step in completing the Electric Systems Summary is to verify that the worksheets for lighting wattage and controls have been completed and included with the summary form. The applicant should also note on the last line of the summary form whether or not LTGSTD output has been used for any of the calculations. If so, the printout must be included with the summary form.

Figure 401F Office Case Study Electric Systems Summary Form

Figure 401G Office Case Study Lighting Wattage Worksheet (1 of 3)

Figure 401G Office Case Study Lighting Wattage Worksheet (continued) (2 of 3)

Figure 401G Office Case Study Lighting Wattage Worksheet (continued) (2 of 3)

Figure 401G Office Case Study Lighting Wattage Worksheet (continued) (2 of 3)

Figure 401G Office Case Study Lighting Wattage Worksheet (continued) (3 of 3)

Figure 401H Office Case Study Lighting Controls Worksheet (1 of 2)

Figure 401H Office Case Study Lighting Controls Worksheet (continued) (2 of 2)

Case Study – Restaurant

BUILDING DESCRIPTION

This case study is a new restaurant building to be constructed in the immediate future in Columbus, Ohio. Approximately half of the floor space consists of dining rooms, bar areas, and other spaces intended for customer use. The remainder of the facility consists of kitchen and food preparation areas, as well as other work areas used by employees.

Exterior Lighting

The restaurant will be located in an existing shopping center. All parking lot lighting is already in place, and does not need to be considered in the calculations. However, several exterior fixtures are included in the lighting design for the building. Fixtures types include decorative wall lights, security lights, and landscape lights. Exterior fixture distribution is shown on the lighting plan, page
B-5 (E-1). Fixture types and descriptions are shown on the lighting schedule listed below. All exterior lights are controlled by a photocell mounted on the roof of the building.

Interior Lighting

The lighting design calls for a large number of incandescent fixtures in the public areas, with the intent of providing a warm and inviting atmosphere for patrons of the facility. Most of the incandescent sources are controlled with manual or preset dimming systems.

Employee work areas are lighted with fluorescent fixtures equipped with T-12 lamps (energy saving type) and magnetic ballasts. All lighting systems in these areas are controlled with manual on-off switches.

All light fixtures are described in the lighting schedule shown below. The input wattage tables in the Reference section of this chapter should be used to fill in blank spaces in the lighting schedule. Using the schedule along with the enclosed lighting plan will provide all the information required to complete the following compliance documentation items:

- Lighting Wattage Worksheet
- Lighting Controls Worksheet
- Lighting portion of the Electric Systems Summary

(Assume that the building meets the requirements for the electrical distribution system and electric motors).

Table 401G Lighting Schedule – Restaurant

Fixture		**Lamp Qty. &**	**Ballast**	**Input**
ID	Description	Description	Type	Watts
A	Recessed 2x4 Fluorescent Grid Troffer w/Prismatic Diffuser	3-34W F40T12/ES	Magnetic EE	
AX	Same as Type A Except w/Integral Battery Back-Up	3-34W F40T12/ES	Magnetic EE	
AX1	Same as Type A Except w/ Flange Mounting	3-34W F40T12/ES	Magnetic EE	
B	33" Fluorescent Undercabinet Light w/Integral Switch	1-F13T5/1-F8T5	Magnetic EE	27
C	Recessed 6" Incandescent Downlight w/Gold Reflector	1-75W HPAR 30	N/A	75
D	Recessed 4" Incandescent Downlight w/Gold Reflector	1-50W HPAR 20	N/A	50
E	Pendant-Mounted Incandescent Decorative Chandelier	1-60W G40 Silver	N/A	60
F	Surface-Mounted 1x4 Fluorescent Wrap Around	2-34W F40T12/ES	Magnetic EE	
G	Low-Voltage Incandescent Track Light, Black Finish	1-50W MR16	N/A	50
G1	Same as Type G, Except White Finish	1-50W MR16	N/A	50
H	Pendant-Mounted Incandescent Decorative Chandelier	1-150W G40	N/A	150
J	Low Voltage Incandescent Track Light, Black Finish	1-20W MR16	N/A	20
J1	Same as Type J, Except White Finish	1-20W MR16	N/A	20
K	Wall-Mounted Incandescent Exterior Cylinder	1-45W HPAR38	N/A	45
L	Wall-Mounted Incandescent Exterior Cylinder	1-90W HPAR38	N/A	90
M	4 ft. 2-Lamp Fluorescent Open Strip	2-34W F40T12/ES	Magnetic EE	
N	Recessed Emergency Light w/Integral Battery Pack	1-10W T2 Bipin	N/A	EXEMPT
P	Recessed Incandescent Wall Washer w/Black Baffle	1-75W HPAR	N/A	75
Q	Wall-Mounted Emergency Light Head	1-7.2W/6V Seal Beam	N/A	EXEMPT
Q2	Wall-Mounted Emergency Battery Cabinet for Type Q	N/A	N/A	EXEMPT
R	Surface-Mounted Fluorescent Drum Light w/Diffuser	2-CFQ/26W	Magnetic EE	
T	Incandescent Porcelain "Keyless" Lamp Holder	1-60W A19	N/A	60
U	Surface-Mounted Incandescent Picture Light	1-25W T10	N/A	25
W	Wall-Mounted Incandescent Exterior Cylinder	1-45W HPAR38	N/A	45
AA	Grade-Mounted Incandescent Landscape Light	1-90W HPAR38	N/A	90

Reference

The first-time or occasional user of the 90.1 Code may be unfamiliar with some of the terms that are found in Section 401. Most of these terms are defined in Section 201 of the Code, but may still be lacking in clarity. This section is included to provide additional helpful information regarding terminology that is used when describing compliance for electrical and lighting systems.

GROSS LIGHTED AREA

Gross lighted area (GLA) is used in the building space method of determining interior lighting power allowance (ILPA). The gross lighted area of the building is defined as the sum of the total lighted areas of a building measured from the *inside* surface of the perimeter exterior walls for each floor of the building. The GLA does not include the thickness of the exterior partitions, but it does include the area of interior partitions within the building. Because the GLA does not include the exterior wall thickness, it is different from the gross area of the building. Exempt retail display windows are excluded from the GLA measurement. The GLA is measured from the *interior side* of the enclosed display windows.

AREA OF THE SPACE

The area of the space (A) is used with the specific space method of calculating ILPA. It is defined as the horizontal lighted area of a given space measured at the height of the working surface, from the inside of the perimeter walls or partitions. It is important to note that this definition *excludes* the thickness of any interior partitions from the calculations and requires that only horizontal areas be included. This is the primary difference between the area of the space and the gross lighted area (GLA). A given building's GLA will always be higher than the sum of the areas of the spaces. Another notable difference between these two measures is that while the GLA is calculated for an entire building, the area of the space must be calculated for each building space.

TASK LOCATIONS AND MANUAL CONTROLS

The 90.1 Code specifically requires that each task location occupying an area of 450 ft^2 in a building be supplied with one manual control (or equivalent) in addition to the control required for the space as a whole. A task location is defined by the 90.1 Code as an area within a given building space where significant visual functions are performed and where lighting is required above and beyond that required for general ambient use. The interpretation of what constitutes a significant visual function requires some judgment. The key element is the degree of visual acuity required to perform the task with accuracy. For example, any visual activity involving paper tasks, such as reading, writing, or computer work, requires a relatively high amount of visual accuracy if the task is to be performed accurately. Therefore, these tasks can be considered significant. Similarly, operation of machinery or equipment is a significant visual function. Using rest room facilities, on the other hand, would not qualify as a significant visual function.

One means of determining whether or not a building space or activity may be associated with significant visual tasks is to refer the *Lighting Handbook (8th ed.),* published by the Illuminating Engineering Society (IES). The *Handbook* lists recommended illuminance[2] levels for nearly every type of activity that can occur in a commercial workspace. Each activity is assigned a letter value corresponding to an optimal recommended lighting level category. Any activity that is assigned a level of "D" or above may be considered to be what the 90.1 Code defines as a significant visual task, meaning that it qualifies as a task location requiring an additional manual control or equivalent.

The following table summarizes the categories used by the IES to determine recommended lighting levels, and may, in turn be useful for defining building spaces that qualify as task locations requiring additional controls.

Table 401H IES Illuminance Categories for Generic Types of Interior Activities

Type of Activity	Category	Reference on Work Plane
Public spaces with dark surroundings	A	General lighting throughout spaces
Simple orientation for short, temporary visits	B	
Working spaces where visual tasks are only occasionally performed	C	
Performance of visual tasks of high contrast or large size	D	Illuminance on Task
Performance of visual tasks of medium contrast or small size	E	
Performance of visual tasks of low contrast or very small size	F	
Performance of visual tasks of low contrast and very small size over a prolonged period of time	G	Illuminance on task, obtained by a combination of general and local (supplementary) lighting
Performance of very prolonged and exacting visual task	H	
Performance of very special visual tasks of extremely low contrast and small size	I	

Source: Illuminating Engineering Society of North America: *Lighting Handbook (8th ed.)*, 1993

[2] Illuminance is defined as the density of luminous flux incident on a surface. It is measured in either lux or footcandles (fc) and refers to the overall amount of light on the surface per measurement unit.

BALLASTS

Lamp ballasts are used with all discharge lamps, including fluorescent, mercury vapor, metal halide, and high and low pressure sodium. Unlike incandescent lamps, which use electric current to heat a tungsten filament until it produces visible light, discharge lamps pass an electric arc across electrodes sealed in a gas-filled tube, ionizing the gas and releasing electrons. For proper lamp operation, the electric arc must be maintained at a very specific voltage and current. The ballast serves this function. In some cases, the ballast also provides the voltage that starts the arc.

Efficacy

It is important to understand that lighting energy efficiency is, in large part, determined by the interaction between lamps and ballasts. *Efficacy*, defined as the ratio of light output to watts input, is a term commonly used to describe the lighting energy efficiency of a lamp-ballast system. There are essentially three ways to improve the efficacy of a lamp-ballast system:

1. Reduce ballast losses
2. Reduce losses created by constantly heating lamp electrodes
3. Operate lamps at high frequency

All three of these methods involve the ballast component of the system. Newer ballast products exploit one or more of these techniques to increase lamp-ballast system efficacy. The 90.1 Code addresses the first technique by requiring tandem wiring of one-lamp and three-lamp fluorescent fixtures. Ballast losses are reduced by using a single ballast to drive three or four lamps, instead of one or two. Ballast losses are also reduced by using copper (as opposed to aluminum) windings and high-grade magnetic components in electromagnetic ballasts, and by quality circuit design in electronic high-frequency ballasts. Some electromagnetic ballasts are able to shut off the voltage to fluorescent lamp electrodes once the lamp has started, thus increasing efficacy. High-frequency operation of fluorescent lamps offers the greatest increase in system efficacy, and is performed by electronic ballasts, discussed in the next section.

Electronic Ballasts

Electronic high-frequency ballasts represent relatively recent advances in technology that have created tremendous opportunities for improved lamp performance, increased energy efficiency, and enhanced design flexibility. Electronic ballasts take incoming 60 Hz power and convert it to high-frequency AC. Electronic ballasts are more efficient than magnetic ballasts in converting input power into optimal lamp power. For example, operating fluorescent lamps at high frequency increases lamp-ballast system efficacy by 15% to 20%. Electronic ballasts also offer the following additional advantages over magnetic ballasts:

- With high intensity discharge (HID) lamps, electronic ballasts offer relatively precise management of the lamp's arc tube wattage, usually resulting in longer lamp life and more consistent color.
- Electronic ballasts are much quieter than magnetic ballasts.

- Electronic ballasts reduce fluorescent lamp flicker to a level that is essentially unperceivable.
- Electronic ballasts are readily available to operate three or four lamps, reducing tandem wiring requirements, as well as labor costs for installation and field wiring.
- An increasing number of sophisticated lighting control components are now available for electronic ballasts with dimming and/or light level switching capabilities. This has enhanced the availability and flexibility of lighting control strategies for designers.

Power Factor

The 90.1 Code requires that fluorescent and HID lamp ballasts have a power factor of at least 90%. Power factor is a measure of how effectively an electrical component can convert current supplied by the utility into actual usable power used by an electrical device, such as a lamp. In all inductive (non-resistive) electrical loads, including fluorescent and other discharge lamps, motors, and transformers, a fraction of the input power to the device is used to sustain an electromagnetic field. This is known as reactive power. The remainder of the input power, known as working power, is used to operate the device. Working power is measured in kilowatts (kW). It is relatively constant (i.e. it does not fluctuate much) and can be easily read on a wattmeter or similar device. Unlike working power, reactive power circulates between the source of electricity and the load, placing a heavier drain on both the generator and the distribution system.

Added together, working power and reactive power determine apparent power, measured in kilovolt-amperes (kVA). Power factor describes the ratio of working power to apparent power, determined by:

$$\text{Power Factor (PF)} = \frac{\text{Working Power (kW)}}{\text{Apparent Power (kVA)}}$$

What is especially important about power factor is that kVA is a measure of how much current the utility must deliver to the electrical system. As an example, consider a fluorescent lighting system consisting of 150 three-lamp lensed troffers equipped with energy saving lamps and normal power factor (< 90%) ballasts. Each luminaire uses 134 watts (1.34 kW) of input power. If the typical ballast power factor of the lighting load is 80%, the lighting system will have apparent power of (150 x 1.34/.8 kW), or 251 kVA, which is 20% more current than would be required with an optimal power factor of 1.0. The utility must supply the extra power, even though it is performing no useful function.

Power factor problems are mostly nonexistent in modern discharge lighting systems. Electronic fluorescent lamp ballasts for 4 ft lamps, for instance, typically have a power factor exceeding 99%. About the only remaining new lamp ballasts available with normal power factor ballasts (<90%) are those used with compact fluorescent lamps. The 90.1 Code exempts these products from the ballast requirement, as they typically draw only a very small portion of a building's overall power requirements. Nevertheless, high power factor (HPF) ballasts are readily available, at a reasonable cost premium, for all compact fluorescent lamps, and designers are encouraged to use them in their specifications.

LIGHTING ENERGY COSTS

At the beginning of this chapter it was noted that lighting accounts for about 40% of all commercial building energy consumption in the United States. Lighting is also expensive, particularly in areas where utilities assess peak demand charges for afternoon electric use. For example, the cost of lighting a 10,000 ft^2 office building with connected lighting power of 20,000 watts (2 W/ft^2) ranges from $3,500 to more than $7,000 per year, not including air conditioning and environmental costs[3].

The cost of lighting may be loosely defined as:

Lighting Cost = Lighting Power (kW) x Time of Use (hrs) x Average Cost of Electricity

In addition to saving energy, compliance with the lighting requirements in the 90.1 Code encourages reduced lighting costs in commercial buildings. The Code requirements affect lighting energy costs in two ways:

1. Lighting power (kW) is reduced through the requirements for interior and exterior lighting power:
2. Lighting time of use is reduced through the lighting control requirements and through the encouragement of the use of automatic lighting controls. Some types of control devices, such as daylighting controls, also reduce both lighting power and the average cost of electricity.

These two components in the lighting cost equation are discussed in more detail in the remainder of this section.

Lighting Power

Calculating the connected lighting power (CLP) to determine compliance with both the interior and exterior lighting power requirements necessitates determining the input wattage used by all light fixtures on the project. It is crucial to establish that, except for incandescent sources, fixture input wattage is not the same thing as lamp wattage. Input wattage for all discharge sources is determined by the interaction between lamps, ballast, and fixture construction. As noted in the previous section, lighting efficacy is determined by the ratio of light output to input wattage. A high-efficacy system uses less input wattage to produce the same amount of light as a lower efficacy system. However, the two components of efficacy – input wattage and light output – are both affected by the ambient temperature in which they operate.

The light output and input wattage ratings listed in lamp manufacturer catalogs are determined under very specific laboratory conditions: operated by a “reference ballast” in free air at a temperature of 25°C (77°F). What researchers and fixture manufacturers have discovered, however, is that lamps behave quite differently when they are inside a light fixture. Light fixtures are hot places, particularly if they are enclosed, located in a plenum, or otherwise poorly ventilated. Temperatures that exceed 25°C (77°F) reduce both the rated light output of the lamp and fixture input wattage.

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[3] When incremental costing is used to assess equipment options in new buildings, lighting measures usually exceed all other types of building improvements, showing rapid (often < 1 year) payback and impressive life-cycle cost savings.

For these reasons, it is important that input wattage be determined, if possible, by using data supplied by the lighting fixture or ballast manufacturer. The default wattage tables in the following pages are included in this document to supply a source of information when manufacturer data is missing or unknown. While manufacturer data is preferred when determining connected lighting power, the data listed herein will suffice, provided the values are used prudently. Users of these wattage values are encouraged to view the following notes on interpreting the table values:

- ANSI values listed for fluorescent systems assume open air operation of lamps at 25° C (77° F). Open suspended luminaires and heat extract type recessed troffers will have similar input values.
- Input wattage values for enclosed lamps are generally less than they are under ANSI conditions. It is important to note that while input wattage is reduced in enclosed luminaires, so is light output. Partial listings for enclosed lamps are shown when available (fluorescent systems only). These values are for static (no heat extract) lensed luminaires recessed into acoustical tile ceilings.
- ANSI input wattages listed for electronically-ballasted rapid start and instant start systems represent averages taken from manufacturer catalogs. Input wattage values for these products vary considerably due to the availability of a variety of different ballast factors from manufacturers. High ballast factor ballasts require more input watts than low ballast factor ballasts, but they produce more light output from the same lamps. The reverse is true for low-wattage reduced output electronic ballasts.

Table 401I Typical Lighting Power for Magnetically-Ballasted Fluorescent Lamp-Ballast Systems (watts)

Lamp/Ballast Combination	**4 Lamps 2 Ballasts**		**3 Lamps 2 Ballasts**		**3 Lamps Tandem-Wired Ballasts**		**2 Lamps 1 Ballast**	
	ANSI	**Enclosed**	**ANSI**	**Enclosed**	**ANSI**	**Enclosed**	**ANSI**	**Enclosed**
Standard Magnetic Energy Saving Ballasts								
31-watt FB31T8			105	97	104	96	69	64
32-watt F32T8	140	129	106	98	105	97	70	65
34-watt F40T12/ES	144	137	112	107	108	103	72	68
40-watt F40T12	176	160	134	121	129	117	88	80
40-watt FB40T12			134	121	129	117	86	78
40-watt F40T5 Twin Tube			130	120			86	79
60-watt F96T12/ES Slimline							123	
75-watt F96T12 Slimline							158	
95-watt F96T12/High Output/ES							199	
110-Watt F96T12/High Output/ES							237	

Notes:
Data listed is for standard energy efficient magnetic ballasts.
Values listed for 3-lamp systems with 2 magnetic ballasts have 1 single-lamp ballast and 1-double-lamp ballast.

Table 401J Typical Lighting PowerElectronically-Ballasted Rapid Start Fluorescent for Electronically-Ballasted Rapid Start Fluorescent Lamp-Ballast Systems (watts)

Lamp/Ballast Combination	**4 Lamps, 1 Ballast**		**3 Lamps, 1 Ballast**		**2 Lamps, 1 Ballast**		**1-Lamp 1 Ballast**	
	ANSI	**Enclosed**	**ANSI**	**Enclosed**	**ANSI**	**Enclosed**	**ANSI**	**Enclosed**
265 mA T-8 Lamps								
17-watt F17T8					34	33	16	15
25-watt F25T8			66	63	46	44	23	22
32-watt F32T8	120	116	90	87	61	59	31	30
40-watt F40T8			108		73	71	39	
T-12 and T-10 Lamps								
25-watt F30T12/ES			77		49	47	27	25
30-watt F30T12			87		59	57	32	30
34-watt F40T12/ES	117		90	87	62	60	31	30
40-watt F40T10			109	106	73	71	39	38
40-watt F40T12	140		106	103	72	70	38	36
40-watt FB40T12			100	93	67	62		
85-watt F72T12 High Output					164		82	
95-watt F96T12/HO/ES					170			
110-Watt F96T12/HO					201			
Twin Tube Biax Lamps								
36-watt FT36T5 Twin Tube			106		72		37	
39-watt FT39T5 Twin Tube			104		70		37	
40-watt FT40T5 Twin Tube				69	67		37	
50-watt FT50T5 Twin Tube			125		106		54	

Notes:

Data listed represents averages of rapid start products available in 1994 from established manufacturers of electronic ballasts. Actual input wattages for these systems may be tuned by using specific products, and will differ from these values.

Systems shown have minimum 0.85 ballast factor

Table 401K Typical Lighting PowerElectronically-Ballasted Instant Start Fluorescent for Electronically-Ballasted Instant Start Fluorescent Lamp-Ballast Systems (watts)

Lamp/Ballast Combination	**4 Lamps, 1 Ballast**		**3 Lamps, 1 Ballast**		**2 Lamps, 1 Ballast**		**1-Lamp 1 Ballast**	
	ANSI	Enclosed	ANSI	Enclosed	ANSI	Enclosed	ANSI	Enclosed
265 mA T-8 Lamps								
17-watt F17T8	62	60	50	49	34	32	18	17
25-watt F25T8	87	85	68	67	48	46	28	27
31-watt FB31T8			88	79	61	55	31	30
32-watt F32T8	110	104	89	88	61	57	33	31
36-watt F36T8	150		112		78			
55-watt F96T8					110			
T-12 Slimline Lamps								
55-watt F72T12 Slimline					109			
60-watt F96T12 Slimline/ES					110		72	
75-watt F96T12 Slimline					135		85	
Twin Tube Biax Lamps								
39-watt FT39T5					64		42	
40-watt FT40T5			103		72		43	
55-watt FT55T5 Twin Tube						115		

Notes:

Data listed represents averages of rapid start products available in 1994 from established manufacturers of electronic ballasts. Actual input wattages for these systems may be tuned by using specific products, and will differ from these values.

Systems shown have minimum 0.85 ballast factor

Table 401L Typical Lighting Power for Electronically-Ballasted Low Wattage Reduced Output Fluorescent Lamp-Ballast Systems

Lamp/Ballast Combination	**4 Lamps, 1 Ballast**		**3 Lamps, 1 Ballast**		**2 Lamps, 1 Ballast**		**1-Lamp 1 Ballast**	
	ANSI Watts	Ballast Factor	ANSI Watts	Ballast Factor	ANSI Watts	Ballast Factor	ANSI Watts	Ballast Factor
17-watt F17T8	54 (RS)	0.77			27 (RS)	0.77	14 (RS)	0.77
25-watt F25T8	80 (IS)	0.82			41 (RS)	0.77	21 (RS)	0.77
	79 (RS)	0.77						
32-watt F32T8	99 (IS)	0.79	79 (IS)	0.82	54 (IS)	0.82	28 (RS)	0.77
	101 (RS)	0.77	78 (RS)	0.75	55 (RS)	0.79		
34-watt F40T12/ES	117	0.83	85	0.83	61	0.83	31	0.82
39-watt F39T5 Twin Tube			73 (IS)	0.63	52 (IS)	0.64		
40-watt F40T5 Twin Tube					60 (RS)	0.7		
40-watt F40T8			69 (IS)	0.8	66(IS)	0.82		
					69 (RS)	0.80		
40-watt F40T12			85	0	61	0.73	57	
40-watt F40T10					72	0.84	37	0.84
59-watt F96T8					105	0.83		
85-watt F72T12/HO					160	0.80		
110-watt F96T12						190	0.8	

Notes

All systems with ballast factor of < 0.85

RS = rapid start operation

IS = instant start operation

Ballast factor listed is typical for the average input wattage given for all available products. Note that reducing the ballast factor decreases light output in addition to reducing input wattage.

Table 401M Typical Lighting PowerCompact Fluorescent Lamps for Compact Fluorescent Lamps

Lamp Type	**Ballast Type**	**Input Watts**
5-watt twin-tube	Reactor preheat	9
7-watt twin-tube	Reactor preheat	11
9-watt twin-tube	Reactor preheat	13
13-watt twin-tube	Reactor preheat	17
9-watt quad-tube	Reactor preheat	13
13-watt quad-tube	Reactor preheat	17
10-watt quad-tube	Autotransformer preheat	16
	reactor preheat	13
13-watt quad-tube	Autotransformer preheat	18
	reactor preheat	16
15-watt quad-tube	Reactor preheat	20
18-watt quad-tube	Autotransformer preheat	25
	reactor preheat	22
18-20-watt twin-tube	370 mA preheat or rapid start	22
18-watt twin-tube	270 mA rapid-start	23
	265 mA electronic IS	17
20-watt quad-tube	Reactor preheat	27
24-27-watt twin-tube	340 mA rapid-start	32
	265 mA electronic IS	21
26-watt quad-tube	Autotransformer preheat	37
	Reactor preheat HPF	33
	Electronic HPF	23
27-watt quad-tube	Reactor preheat	34

Table 401N Typical Lighting Power for High Intensity Discharge Lamps

Lamp Watts	Ballast Watts	Fixture Input Watts
Mercury Vapor Lamps		
75	15	90
100	18	118
175	25	200
250	35	285
400	50	450
1,000	75	1,075
Metal Halide Lamps		
32	6	38
50	13	63
70	18	88
100	25	125
175	35	210
250	42	292
400	55	455
1,000	70	1,070
High Pressure Sodium Lamps		
35	8	43
50	13	63
70	18	88
100	30	130
150	38	188
250	50	300
400	65	465
1,000	90	1,090

Notes:
Source: Pacific Gas & Electric
Figures listed represent average values taken from OSRAM-SYLVANIA, Philips, and General Electric lamp catalogs.

LIGHTING CONTROLS

The 90.1 Code allows applicants to adjust the interior CLP to account for the use of automatic lighting controls. High efficiency lighting components, such as T-8 fluorescent lamps and electronic high frequency ballasts, make a significant impact on lighting energy and its associated costs by reducing the kW required to light buildings. Lighting controls, on the other hand, affect lighting energy by directly reducing lighting's time of use. Some lighting control techniques, such as using photocell controls in daylighted building spaces, not only reduce lighting time of use, but also decrease lighting power, and may even reduce the average cost of electricity by eliminating some lighting kW during peak demand periods. For these reasons it is easy to see why the 90.1 Code assigns optional power adjustment factors (PAFs), thus encouraging the use of automatic controls.

Stepped Lighting Control

There are two ways to control lighting systems: by switching and by dimming. When switching systems are used with entire circuits of lights, as opposed to individual light fixtures, the control protocol is usually described in terms of steps, with each numerical "step" referring to a percentage of full lighting power. One of the steps in a stepped scheme is all lights off, and a second level is all lights on. Thus, a 3-step lighting control scheme would offer three levels of lighting control: all lights off; half the lights off; and all lights on[4].

The 90.1 Code classifies two types of switching controls in Table 401.3.3:

- *On/Off* (two-step) controls are eligible for PAFs only when combined with one or more additional automatic controls, such as daylighting control or occupancy sensing.
- *Multiple-Step Dimming* refers to all other stepped controls. They qualify for PAFs either alone or in combination with other devices.

Stepped lighting control systems may be designed to switch either individual fixtures, individual ballasts within fixtures, or both. The control scheme is determined by the design of the electrical circuiting. Typically, a control device in the form of a photocell, occupancy sensor, or time clock sends a signal to a signal processor. The processor then switches individual relays or contactors that control lighting circuits.

The major advantage of stepped lighting control systems is that they are a relatively inexpensive approach to automatic lighting control of large individual spaces. Their primary drawback, however, is that they can be very distracting to occupants in a space. The change in the appearance of the space is pronounced and abrupt, and often, there is an audible *snap* as the relays switch. Generally, this problem is limited to cases when stepped switching is combined with photosensors as part of a daylighting control system.

Stepped controls also limit the flexibility of the design, in terms of offering only preset lighting levels. By contrast, continuous dimming systems are able to tune the light levels in response to a preset design criterion.

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[4] A three-step scheme is also referred to as a "0%-50%-100%" scheme.

Continuous Dimming Controls

Continuous dimming control systems are designed to adjust electric lighting in a space to maintain a preset lighting level. Typically, these systems include a photocell to monitor lighting levels, a signal processor, and electronic dimming ballasts, which alter the current to the lamps in response to the signal coming from the processor. Continuous dimming is a fluid, dynamic means of light control: ambient light is constantly monitored, and lamp output is adjusted accordingly.

Properly designed and maintained continuous dimming systems offer several advantages over stepped controls:

- There are no distracting and abrupt changes in lighting levels to distract the occupants of the space.
- Appropriate lighting levels, with respect to visual task requirements, are maintained in the space at all times.
- There is a much greater range of electric light level available. Some ballasts can dim lamps down to 1% of full output.

The primary disadvantage of continuous dimming is its cost. Each light fixture must have a dimming ballast. This requires a significant cost premium above the regular fixture cost. In some cases – particularly with HID ballasts – the additional cost for a dimming ballast can more than double the first cost of the entire fixture. In addition, some electronic dimming ballasts have been known to be received notoriety for being unreliable. Generally this is because these are relatively new products, and manufacturing quality control practice is only now beginning to catch up with the technology. This situation is likely to improve in the immediate future.

Types of Controls

The 90.1 Code assigns power adjustment factors (PAFs) to credit the use of automatic controls that use one or more of several different approaches to control electric lighting. Lighting controls that receive PAFs use stepped switching or dimming, as discussed previously, in combination with one or more of the following designs:

- *Programmable Timing:* Using a time scheduling device to switch lighting systems on or off according to predetermined schedules.
- *Occupancy Sensing* lighting control:: Adjusting lights in response to the presence or absence of people in the space.
- *Daylighting:* Switching or dimming electric lights in response to the presence or absence of daylight illumination in the space.
- *Lumen Maintenance:* Gradually adjusting electric light levels over time to correspond with the depreciation of light output from aging lamps.

The control hardware and design approaches used with these strategies is discussed in more detail below.

Programmable Timing

Programmable timing, also known as automatic time scheduling, is the oldest form of automatic lighting control. Time scheduling manages the on and off times of a building's lighting systems. Scheduling systems function by turning off all or some of the lights when a building space is unoccupied. In the most basic time scheduling scheme, a time clock switches lighting circuits on or off based on programmable schedules. For example, exterior lighting is usually switched on to correspond to sundown, and is switched off again at daybreak. By contrast, time scheduling of interior lighting systems is, for the most part, based on occupancy schedules. In some cases, time clocks are used to energize additional lighting control systems, such as daylighting controls, which are held off during unoccupied periods.

Time scheduling systems employ the following components:

- A *central processor*, is usually capable of controlling several output channels, each of which may be assigned to one or more lighting circuits.
- *Relays* are series-wired to lighting control zones, and are controlled by the central processor.
- *Overrides* are required to accommodate individuals who use the space during scheduled off hours. Individuals can activate manual switches or telephone overrides to regain temporary control of the lights in a given space.

In most cases, Class II (low voltage) wiring links all the components in the system, and the system uses a flashing warning system to let individuals know that the lights are going off. This allows occupants either to vacate the space, or activate an override to keep the lights on.

The crucial component in any time scheduling system is the programmable central processor, which is essentially a multiple circuit controller. The central processor can be programmed by building maintenance personnel to schedule on and off loads on each of its output channels. If desired, several different on-off sequences may be programmed on each channel.

A central processor typically consist of the following components:

- A programmable microprocessor with electronic clock is capable of separately scheduling weekday, weekend, and holiday operation. Astronomical time-keeping ability means that the processor is able to make seasonal and daylight savings adjustments[5]. Typically, the processor has a built-in battery backup so that the programmed schedule remains in memory during power outages. The processor is usually able to "sweep" at regular intervals during its off hours. The processor remembers when overrides have been employed to keep lights on in any particular area; the processor will then repeat the operation to turn off the lights.
- Switch inputs allow occupants to override the shutoff function of the processor. Usually the switches and wiring to the controller are low voltage. Inputs may also be wired to photocells or occupancy sensors for additional flexibility.

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[5] The power of the microchip now allows for one-time programming of all 365 days in the year.

- Output channels are required for each lighting control zone. Sophisticated designs sometimes provide two or more outputs for each control zone. This allows for stepped control of the zone. In some systems, output channels can be designed to provide a variable signal, allowing for dimming applications. These are of considerable expense, however, since each dimming channel requires a digital-to-analog signal converter.

Generally, time scheduling is the most effective way to save lighting energy when occupancy patterns are relatively regular or when lighting operating hours are easy to predict. Exterior lighting control is the best example of this type of application.

Occupancy Sensors

Occupancy sensors are automatic scheduling devices that detect motion and turn lights on and/or off accordingly. Most devices can be calibrated for sensitivity and for the length-of-time delay between the last detected occupancy and extinguishing of the lights. The most energy-efficient occupancy sensors require that the user manually switch on the lights when entering a controlled zone (the "lights off" function is still automatic).

Occupancy sensor systems typically consist of a motion detector, a control unit, and a relay. Usually, two or more of the components are integrated into one package. Most systems also require a power supply in the form of a transformer, which steps down the building voltage to 24V. The detector collects information, then sends it to the controller, where it is processed. Output from the controller activates the relay, which in turn switches the light circuit.

There are two major types of occupancy controls used to detect motion:

- *Wallbox* units are designed to fit into a standard wall switch box and operate on the building voltage (i.e. a separate power supply is not required). They are excellent, inexpensive replacements for standard wall switches. Their main limitation is that they are relatively short-ranged.
- *Wall and Ceiling* units typically contain an integrated sensor/controller unit wired (Class II) to a switchpack containing the relay and power supply. They are by far the more popular type of the two and have very few application limitations.

Occupancy sensing lighting controls represent a refinement of the motion detection technology developed in the early 1970s to detect intruders for residential and commercial security applications. With lighting control, two different means of detecting occupancy are used:

- *Passive Infrared (PIR) sensors* perceive and respond to the heat patterns of motion. The body-heat patterns of humans in the infrared range can be detected fairly easily relative to other forms of heat. This same technology is used in most residential and commercial security systems. The chief advantage of PIR sensors is that they are relatively inexpensive and reliable. They very rarely false trigger by responding to non-occupant motion in a space. The major limitation to PIR sensors is that they are strictly line-of-sight devices, unable to see around corners or partitions.
- *Ultrasound (US) detectors* radiate ultrasonic waves into a space, then read the frequency of the reflected waves. Motion causes a slight shift in frequency,

which the detector interprets as occupancy. They are more sensitive than PIR sensors, which is both an advantage and a disadvantage. They are often used very effectively in partitioned spaces, but are also more prone to false triggering due to their sensitivity to air movement. Proper design and installation minimizes this potential problem.

Most occupancy sensor manufacturers also offer products that integrate both PIR and US technology into one package. Typically these are designed to avoid false triggering by holding the lights off unless both detectors sense motion in the space.

It is difficult to generalize about the amount of lighting savings attributable to the use of occupancy sensors. All applications are different, and actual savings depend on occupancy patterns, lighting schedules, employee habits, and many other factors. They are most effective in building spaces where occupancy is sporadic or unpredictable and in spaces, such as storage areas, where the lights are likely to be left on inadvertently. Typical savings range from 10%, in large open offices, to 60%, in some warehouse applications.

Despite the unpredictability of the savings obtained with occupancy sensor lighting control, it is a control strategy that consistently pays off in terms of its cost benefit. In many cases, occupancy sensors pay for themselves in less than a year.

Daylighting

Daylighting control may be defined as the practice of automatically lowering electric light levels as the amount of daylight increases. Conversely, as available daylight diminishes, electric light levels are increased to maintain the same lighting levels. The availability of daylight in a building is a function of building site location and orientation, fenestration, and surface treatments. As such, it is very important component of energy-efficient architecture. For this reason, the reader is encouraged to read through Chapter 402 of this manual for additional information about daylighting.

Several components comprise a daylighting control system:

- A *photocell* or *photosensor* measures the light level, either within the work space at the visual task, or in a separate area that receives an independent source of daylight. The photocell generates an electric signal in proportion to the intensity of the light that strikes its surface. Photocells that measure illuminance within the work space are part of a *closed-loop* control system, as they are designed to monitor the actual space that they control. *Open-loop* systems, by contrast are designed so that the only thing they monitor is a source of daylight. In an open-loop system, the photocell is less likely to be influenced by the electric lights, building surfaces or shadows.

- A *processor* interprets the incoming signal from the photocell and uses an algorithm to convert it into a command signal that is sent to a dimming unit or switching device. In some cases, the processor is integrated with the photocell, while in others it is a separate unit, usually located at or near the lighting control panel. The processor includes calibration controls to set the minimum light level.

- A *dimming unit* varies the output of the electric lights by altering the amount of input power going to the lamps. Alternatively, a relay or contactor will respond to the signal from the processor by switching a lighting circuit on or off.

There are three types of daylighting control strategies:

- Large zone continuous-dimming daylighting systems use expensive, heavy-duty light-level controllers designed to dim fluorescent lamps with standard non-dimming ballasts over a range from full (100%) output, down to as low as 15%. The photocell monitors ambient light, and the control processor attempts to maintain a predetermined minimum level based on input from that photocell. This is a relatively old daylighting technique that is relatively rare in new construction applications.
- Small-zone continuous-dimming daylighting systems use either a single, smaller light-level controller for each room, or a low-voltage, photocell-driven bank of electronic dimming ballasts to control the electric light level in the space. With the latter technique, all processing is handled by the photocell.
- Stepped daylighting is the most cost effective of all daylighting systems. A simple application is manually to switch lamps or luminaires near the window separately from lights near the inner wall. More sophisticated solutions include the use of multilevel ballasts. A potential problem with stepped daylighting strategies is occupant distraction and irritation caused by repeated/sudden changes in light levels (cycling). This problem is eased somewhat by programming a *deadband* into the photocell-control loop. This deadband creates different setpoint levels for on and off switching. For example, while the lights may switch off when an illuminance level of 700 lux (70 fc) is detected, they will not switch back on until illuminance drops to a much lower level of 350 lux (35 fc), for instance. This reduces or eliminates continual on-off cycling of the lighting system. Despite the potential problems inherent in stepped daylighting strategies, they remain useful because of their relatively low cost.

Properly designed and maintained daylighting controls are among the most significant and cost-effective strategies available for controlling electric lighting. Energy savings can exceed 50% in some applications, and the impact on the cost of lighting a building is usually immediate and substantial. Since the maximum daylight availability typically corresponds with a utility's peak demand curve, saving lighting energy during this period maximizes cost savings. The major disadvantages to using daylighting is that it requires careful calibration and regular maintenance. In addition, if dimming ballasts are used, the cost premiums are substantial.

Lumen Maintenance Controls

Lumen maintenance is based on the fact that most lighting systems are deliberately designed so that the target lighting levels are produced at the end of the maintenance cycle, when lamp output has depreciated and fixtures are dirty. Like daylighting, lumen maintenance relies on a photoelectrically-linked lighting system. Lumen maintenance controls reduce the light output of the fixtures at the beginning of the maintenance cycle and gradually increase output as lamps age and fixtures accumulate dirt. The reduction of light output at the beginning of the cycle is performed by reducing fixture input watts, thus saving energy.

Lumen maintenance systems use equipment similar to continuous daylighting systems. The photocell is always mounted so that it monitors the light level at the task (closed loop system). When the photocell detects the gradual drop in light output, the control system automatically increases input power to compensate.

Because of the similarity of lumen maintenance control approaches to those used for daylighting, it is sometimes practical to link the two strategies.

Depending on building use, lumen maintenance can save about 15% of the lighting energy for any prudently designed and maintained lighting system. The best candidates for lumen maintenance are large areas, such as assembly and shop areas, that have a highly-depreciating lighting system with a final light loss factor below 0.70.

Lumen maintenance strategies are relatively rare, unless they are combined with daylighting. Used alone, lumen maintenance controls are expensive, due to the required used of dimming ballasts. The savings gained by their use rarely justifies the expense, unless a daylighting control scheme is also in place.