TECHNICAL REPORT:
CODES AND STANDARDS THAT CAN CONFLICT WITH CIRCADIAN-EFFECTIVE LIGHTING IN GSA BUILDINGS

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BACKGROUND

All physiological and behavioral functions are regulated by a master clock in the suprachiasmatic nuclei (SCN), which is situated in the hypothalamus area of the brain. We normally eat, sleep, work, and play according to the 24-hour time of day. The SCN synchronizes and coordinates these biological functions to the 24-hour day. The master clock in the SCN is directly coupled with the retina and its periodicity is regulated by the light-dark pattern incident on the retina. How the retina converts light into neural signals for the clock is termed circadian phototransduction. The physical light stimulus that is transformed into neural signals projected to the SCN through circadian phototransduction is termed *circadian-effective light*. To mathematically characterize and specify circadian-effective light in architectural applications, it is desirable to have a computational model of circadian phototransduction. To that end, our researchers developed a metric called *circadian stimulus* (CS)[1,2,3] that quantifies the magnitude of the light stimulus for synchronization. The duration and the timing of CS also affect synchronization, so how long and when a person is exposed to light is critical for regulating many physiological and behavioral events, including the timing of the sleep–wake cycle. Empirical data support the inference that daytime light exposure specified in terms of CS ≥ 0.30 will have a positive effect on people in terms of promoting sleep at night, reduced sleepiness during the day, and possible amelioration of depressive symptoms.

Since 2013, the U.S. General Services Administration (GSA) has been working with the Light and Health Research Center (LHRC) to examine the relationship between light, sleep, and well-being in Federal High-Performance Green Buildings[4]. LHRC researchers have evaluated several federal buildings during different seasons by conducting photometric measurements to assess the potential for the application of CS at the appropriate time in the buildings. LHRC researchers utilized light and activity data from occupants who wore a Daysimeter, which is a calibrated, personal light and activity sensor that continuously records and stores these data for a week or more.

The most recent version (2024) of the GSA Facilities Standards for Public Building Service P100[5] (hereafter, P100) establishes requirements for design, construction, and operation of federal civilian buildings, both owned and leased. Recent GSA design projects must follow the requirements of P100 to implement circadian-effective lighting into their designs. The P100 requires that building occupants receive high light levels of CS ≥ 0.3, or 240 equivalent melanopic lux [EML], or 400 photopic lux, as measured on the vertical plane at the eye for at least a 2-hour period each day, preferably during morning hours. This requirement for the provision of circadian effective lighting follows the UL Design Guideline for Promoting Circadian Entrainment with Light for Day-Active People (UL 24480)[6] Updates to the P100 are completed on a 3-year cycle to coordinate with updates to codes and standards to which it refers.

Potential Conflicts with P100 Requirements

As shown in our 2024 design case study,[7] lighting specifiers on GSA project teams face potential conflicts between P100 and several codes, recommended practices, and other design requirements. Conflicts include requirements for lighting power density, lighting energy, lighting controls, and lighting design recommended practices. Because these conflicts can act as barriers to implementing circadian-effective lighting, we have developed recommendations to address them.

The P100 establishes several other requirements for federal construction projects that are relevant here. Solid state (LED) high-efficiency luminaires must meet the requirements of the DesignLights Consortium's Qualified Product List.[8] Furthermore, luminaires must meet the requirements of the Buy American Act,[9] which requires specification of domestically produced construction materials.

Another requirement of the P100 is that new construction and substantial renovations projects must achieve at least a "gold" rating under the U.S. Green Building Council's Leadership in Energy and Environmental Design (LEED)[10] program. Designers working with the LEED program achieve "points" for qualified design features; cumulative points result in a building's LEED rating. While the P100 refers to LEED v4 and v4.1, the most recent version (v5) is publicly available but is still in the process of being ratified at the time of this writing. LEED encourages the use of daylight, and electric light following the efficiency standards described below. LEED also encourages the use of electric lighting with glare control that is stricter than UL 24480 (luminance <6500 cd/m^2).

Energy Code Power Limitations

In the United States, energy code requirements are adopted by individual states based on two key model energy codes that are each updated on three-year cycles. Many states' code documents refer to both the International Energy Conservation Code (IECC)[11] and to ANSI/ASHRAE/IES Standard 90.1.[12] The P100 refers to both the international codes developed by the International Code Council and ASHRAE Standard 90.1. The most recent version of IECC is dated 2024. Because the 2025 version of Standard 90.1 is still in the process of being finalized, this report will refer to the 2022 version that is publicly available at the time of this writing. Although federal buildings are exempt from meeting California's Title 24 energy code, we have included Title 24 in our analysis because it is one of the strictest state energy codes, and often a harbinger of future energy code efforts.

Both IECC and ASHRAE 90.1 model energy codes establish lighting power density (LPD) limits for the total connected electric load of a lighting system. Lighting specifiers can follow either prescriptive ("Building Area Method") or performance ("Space-by-Space Method") compliance paths analyzing the number of lighting watts per square foot. These LPD limits vary depending on building type or space type. As shown in Table 1, the model energy codes limit lighting power densities in offices to 0.56-0.73 W/ft^2. For example, if using the Space-by-Space compliance path, total connected power for lighting in a hypothetical 1000 ft^2 open plan office space would be limited to 560 watts. Scaled by area, lighting power for a hypothetical open plan office with 2000 ft^2 of space would be limited to 1120 W.

Table 1. Maximum lighting power density (W/ft^2) limits for offices

IECC 2024		ASHRAE 90.1 2022				California Title 24 (2022)		
Building Area Method	Space-by-space Method (SxS)		Building Area Method	Space-by-space Method	P100 (70% of ASHRAE 90.1 SxS)		Building Area Method	Space-by-space Method
0.62	0.73 ("Enclosed")	<150 ft^2	0.62	0.73	0.511	<250 ft^2	0.6	0.65
		150-300 ft^2		0.66	0.462			
	0.56 ("Open")	>300 ft^2		0.56	0.392	>250 ft^2		0.6

The P100 restricts LPDs more than required by the most-strict model energy codes, and even more than California's Title 24[13] energy code. As shown in Table 1, the P100 requires that lighting power density for GSA projects must be 30% lower than allowed by ASHRAE 90.1-2022 Space-by-Space method (if it is life cycle cost-effective). In the hypothetical example of a 1000 ft^2 open plan office, lighting would only be allowed a connected power of 392 watts. This limit could make it extremely challenging for lighting specifiers to provide circadian-effective lighting.

As shown in Table 2, energy codes do provide a possible opportunity for augmenting light levels for circadian-effective lighting: furniture-mounted supplemental "task" lighting is either exempt (as in IECC) or has additional lighting power density allowance (ASHRAE and California Title 24). ASHRAE (Table 9.5.2.3) provides additional lighting power allowance for open office, workstation-specific luminaires of 0.25 W/ft^2, provided the lighting is equipped with a sensor for the single occupant and dimming capability over a minimum of 2 minutes, and, interestingly, can control downlight separately from uplight. Furthermore, if the workstation occupant can adjust their own light levels (via handheld device, app, etc.) in their individual workstation, additional lighting power allowance is increased by 0.3 W/ft^2. So, in principle, the lighting power density as a whole can be nearly 1 W/ft^2.

Table 2. Furniture-mounted or task lighting may have an additional lighting power density allowance or may be excluded from lighting power density limits.

IECC 2024	ASHRAE 90.1-2022	California T24 2022
"Task" exempt if auto-shutoff controls	Additional 0.25-0.3 W/ft^2 if controlled separately	May be exempt, or may have additional LPD allowance, depending on hardwired and controls status

With current ASHRAE 90.1 wording, if furniture-integrated circadian-effective lighting is considered the "downlight component" it may be eligible for this provision. Depending on the definition of "task" lighting according to the authority having jurisdiction (AHJ), this exclusion could provide an avenue for localized desktop, or furniture-integrated circadian-effective lighting in addition to general, ambient lighting in the ceiling. Specifiers attempting to use furniture integrated lighting to meet circadian needs would benefit from clarification about its eligibility for additional lighting power allowance when used for circadian needs, or they may be forced to exclude circadian-effective lighting from their designs.

A dedicated layer of light positioned close to the occupant at the desktop level ("local lighting") could be an energy efficient solution to the need for increased light during morning hours to meet the recommendations included in the UL 24480 guideline. We have found that such solutions can be generated for <0.25-0.3 W/ft^2 as permitted by ASHRAE 90.1. Due to a lack of commercial availability in the 2010s, we developed portable local solutions for several GSA research projects[14,15,16] (Figure 1); if these were built today, their power demand would range approximately 15-34 W per desk, similar to the lighting power limits specified in ASHRAE 90.1. Assuming one desk per 100 ft^2, this would translate to 0.15-0.34 W/ft^2.

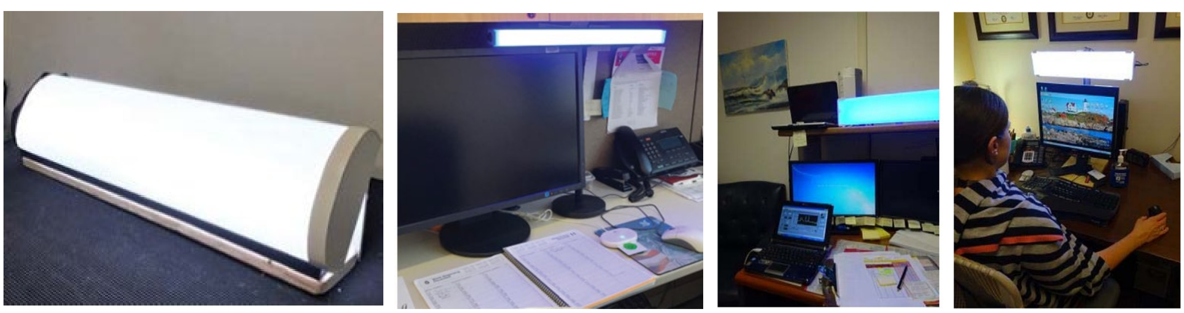

Figure 1. Local lighting examples developed by the lighting researchers for several GSA research projects.

In the example below from 2023[17] (Figure 2), we developed a local solution that used saturated blue light. In addition to high acceptance ratings from the participants, that solution used <10 W per desk. By locating this luminaire <3 feet away from each participant, we were able to meet the circadian-effective lighting criterion while minimizing power demand to stay within code limits. With this type of luminaire, the amount of electric power necessary to achieve circadian stimulus goals would have been approximately three times greater if white light had been used. Assuming 30 W of white light are provided in a 100 ft^2 cubicle, this would translate to 0.3 W/ft^2, similar to the task lighting allowance shown in ASHRAE 90.1-2022. Electric power demand would be halved by developing luminaires that send light in only 180°, rather than the 360° omnidirectional distributions as shown in Figure 2 below.

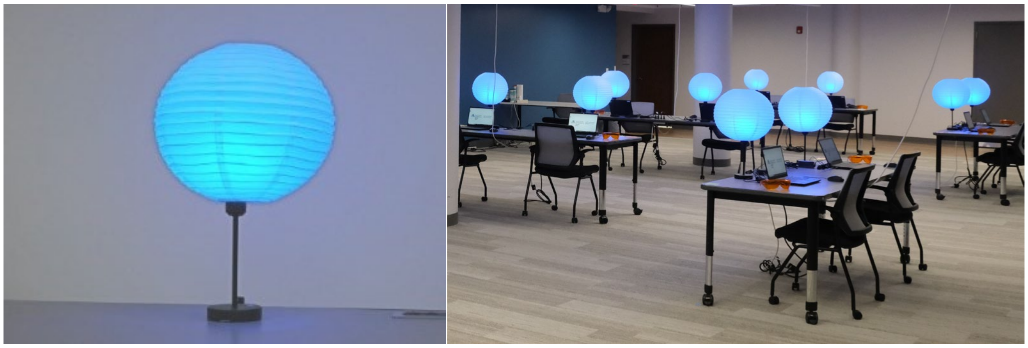

Figure 2. Local lighting solution developed for temporary laboratory research; this solution offered both favorable participant ratings and minimal power demand.

As shown in the renderings below (Figure 3), local solutions could be portable or could be integrated into furniture partitions[18].

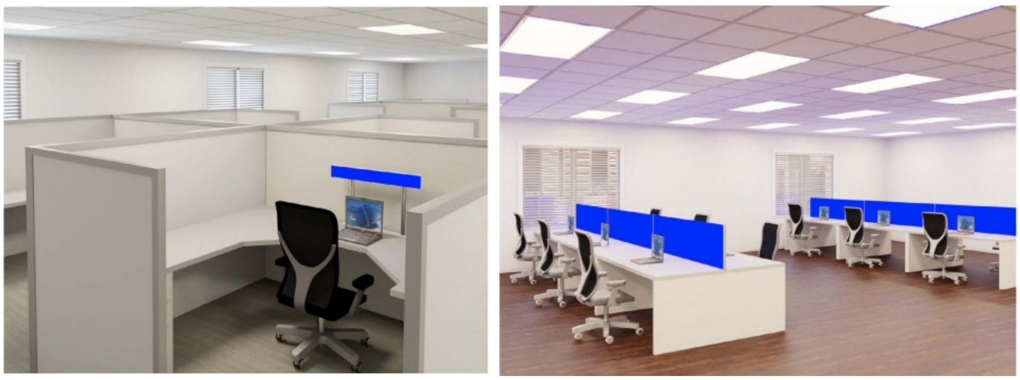

Figure 3. Local lighting could be portable (left) or integrated into furniture partitions (right).

Electric power demand should be minimized by locating the luminaire near the occupant's eyes (1.5-3 ft distance). Therefore, in a number of designs the most energy efficient way to deliver circadian-effective light levels while meeting the P100 requirements (UL 24480) would be through furniture-integrated or portable, local lighting solutions. Lighting controls would need to be integrated into these local lighting solutions to meet the requirements to automatically turn off when occupants were not present.

Importantly, local lighting solutions are not widely available, and those that are available may not meet other luminaire selection requirements (i.e., DesignLights Consortium's Qualified Product List and Buy American Act). Products meeting the requirements for circadian-effective light output, lighting controls, and luminaire selection are not currently marketed as such in the United States, but a luminaire could be specified to enable a manufacturer to respond.

Recommendations: GSA could encourage energy code committees to clarify that portable or furniture-integrated local lighting for the purpose of circadian stimulation is eligible for an additional LPD allowance, as specified for task lighting in ASHRAE 90.1. GSA could encourage American lighting manufacturers to develop products that meet the need for local circadian lighting solutions with minimal additional electric power demand.

It should be noted that although local lighting is an excellent solution for providing circadian-effective lighting, there are many spaces such as classrooms, laboratories, and receiving and sorting facilities, to name a few, where it would be difficult and/or impractical to provide local lighting. In these cases, the provision of circadian-effective lighting may be limited to ceiling-integrated or ceiling-mounted luminaires. As stated above, it is often difficult to provide circadian-effective lighting from ceiling luminaires alone, within the LPD limits prescribed by model energy codes (ASHRAE 90.1, IECC, and California's Title 24).

Recommendation: Energy code committees could develop an additional LPD allowance for circadian-effective lighting if the lighting systems can only be operated during morning hours. This would support the provision of circadian-effective lighting in spaces where it is documented that local lighting solutions are not possible. This additional circadian allowance could be controlled/limited by automated occupancy and photosensing controls already required by existing energy codes (see below).

Lighting Controls Requirements

In addition to their limits on connected lighting load, energy codes also require the installation of automated lighting control devices and/or systems that dim and/or turn off the electric power for lighting in response to changing conditions such as daylight and occupancy. These requirements can conflict with the need to maintain light levels for circadian-effective lighting.

Daylight Sensing

ASHRAE 90.1, IECC, and California's Title 24 energy codes require the installation of automated photosensor lighting controls that dim or turn off electric lighting in most daylighted spaces as a means of reducing lighting energy use. These model energy codes require that photosensors dim the electric lighting in response to daylight, to maintain a target illuminance (typically 300 lx, horizontal, on the work plane). However, this setpoint would very likely result in inadequate circadian-effective light levels, as recommended in P100 (UL 24480). It would be helpful if photosensor controls could be overridden during the morning hours to meet the design criterion. Outside that time period, the setpoint could step down to 300 lx for the remainder of the workday.

It should also be noted that one cannot rely on daylight due to changes in season, weather, obstructions, and other geometry concerns for reliable circadian-effective exposures. Electric lighting is almost always needed.

Recommendation: GSA could encourage energy code committees to allow photosensor lighting controls to maintain higher, circadian-effective light levels for at least a 2-hour period during morning hours in spaces with typical daytime work schedules. GSA could collaborate with lighting controls manufacturers to enable time-of-day features with photosensor controls.

Motion Sensing

The use of motion sensing (also known as "occupant" or "vacancy" sensing) controls is required by model energy codes (ASHRAE 90.1, IECC) and California Title 24. For open plan spaces, sensors must dim the lights by 80-100% of full output after 20 minutes of vacancy. For private offices, sensor-controlled wall switches must either be manually turned back on upon re-entry ("manual-on"), or they must limit electric power to luminaires to no more than 50% output ("partial-on") upon re-entry. With partial-on wall switches, the occupant must manually use their wall switch to activate 100% power.

If all lighting is controlled by partial-on controls, this will likely result in occupants not receiving their circadian-effective dose of light in the morning. Partial-on controls typically operate in a simple, stand-alone capacity and thus lack internal time clocks that could be used to override partial-on functions during morning hours. In these situations, local lighting on the desk or integrated into furnishings, controlled separately from the wall switch, could enable continuity of circadian-effective light exposures.

In open plan spaces, assuming the sensors do not erroneously turn off lighting when the space is occupied, occupants working near the periphery of each control zone may receive light contribution from both zones. Thus, by dimming or extinguishing lighting in one of the spaces, the provision of circadian-effective lighting may be compromised. In such conditions, local lighting at the desk or integrated into furniture would enable continuity of circadian light exposure.

Recommendations: GSA could encourage the specification of local lighting at the desk or integrated into furniture. This light would be controlled by its own occupancy sensor and would come on to automatically meet the circadian criterion upon sensing motion. Alternatively, GSA could allow motion sensing controls to be overridden by the occupant for a 2-hour period during morning hours within the area controlled by the sensor.

Multi-level Dimming

Model energy codes require multi-level dimming controls for general (ceiling-mounted) lighting in several spaces relevant to GSA (e.g., offices, conference/multipurpose/meeting rooms, laboratory, lounge/break rooms). Manual controls must be able to dim lights to 10% of full output; however, manually dimmed lights may remain dimmed for all subsequent users of the space, until another occupant adjusts the dimmer again. Manual dimmers should revert to preset circadian-effective light levels after manual override. However, these systems often do not have time clock functions.

If the space is intended to have circadian-effective lighting, designers should specify an additional circadian-effective layer of light, controlled separately from multi-level dimming for the general lighting in the space. Building systems documentation should discourage the occupants from using dimming features in the morning for circuits that provide circadian lighting, except for temporary needs (e.g., viewing audio-visual materials).

Recommendations: GSA could have a discussion with the lighting designers so that they consider providing an additional circadian-effective layer of light that is controlled separately from multi-level dimming of general lighting in the space. Alternatively, dimming controls could be programmed to always revert back to the circadian criterion light output after manual override.

Automatic Receptacle Control

Model energy codes require automatic receptacle control, meaning that at least 50% of power outlets in spaces relevant to GSA (enclosed/private offices, individual workstations, etc.) must have a time-of-day or occupant sensor control to shut off the receptacle within 20 minutes of vacancy. Manual override is only permitted for up to 2 hours. If portable, plug-in luminaires are used for circadian entrainment, these may be plugged into sensor-controlled outlets. Poor sensor placement may result in false-offs. In that case the occupant must either wave their hands to turn on their circadian-effective local light again, or they could use the 2-hour override feature, or they could simply plug the light into a non-switched outlet.

Recommendations: To minimize energy waste when a desk is vacant, GSA could advise facility managers to use switched outlets to power portable local lighting. To minimize occupant annoyance, sensors controlling automatic receptacles should be located so that they can properly sense relevant occupancy patterns.

High-end Trim

High-end trim allows a facility manager to power demand (and therefore light output) of hardwired lighting to less than maximum levels.[19] High-end trim functions can be used with “task tuning” features that maintain light output over the life of the lighting system by gradually increasing the maximum setpoint to compensate for eventual degradation in system light output.

In addition to mandatory energy efficiency requirements, model energy codes (ASHRAE 90.1 and IECC) have established an energy “credit” system; specifiers can choose which additional efficiency measures to target based on the attributes of the project. High-end trim lighting controls are one of the systems eligible for these credits.

The challenge with high-end trim systems being used with circadian-effective lighting is that high-end trim is typically applied continuously, without regard to time of day. High-end trim controls should incorporate time-of-day functions to enable a different setpoint during morning hours than the rest of the day. Alternatively, it would be simpler if designers exclude circadian-effective lighting from circuits controlled by high-end trim functions. Building systems documentation should discourage the use of dimming features in the morning for circuits providing circadian lighting.

Recommendations: GSA could collaborate with lighting controls manufacturers to enable time-of-day features with high-end trim controls. Lighting designers should exclude circadian-effective lighting from circuits controlled by high-end trim features. The design team should promote documentation that discourages morning dimming on circadian lighting circuits.

Demand-Responsive Controls

Demand responsive lighting controls, also known as load management controls, are another lighting feature that can be eligible in the flexible prescriptive energy credits evaluation. To earn energy credits, demand-responsive controls must automatically respond to a signal in times of peak electricity demand to reduce lighting power demand by at least 20%. If high-end trim is also in use, lighting power must be reduced by an additional 20% below the high-end trim setpoint. While demand-responsive controls can gradually dim, they must complete the 20% reduction setpoint within no more than 15 minutes, in at least 75% of project area, during building peak load.

As of 2025, in much of the USA and for most seasons of the year, daily peak utility demand typically occurs in the evening, not during core business hours.[20] However, weather extremes (heat waves, prolonged arctic air blasts) create electrical grid emergencies that could result in demand responsive control reductions during normal business hours.

Dimming by 20%, especially if sporadic and infrequent, is not likely to undermine occupants' circadian regulation. While facility managers may have the option of programming more-aggressive demand-response dim settings that could be disruptive, they are unlikely to risk annoying their occupants. Nonetheless, building systems documentation should discourage the use of dimming features in the morning for circuits providing circadian lighting.

Recommendation: The electrical engineer or the lighting designer should exclude circadian lighting circuits from demand-responsive control functions if those functions are expected to be used on a daily basis. They should create handover documentation for demand-response controls that emphasizes the intent to provide circadian-effective, high output light in the mornings for circadian needs.

DESIGN RECOMMENDED PRACTICES

Numerous recommended practices issued by professional organizations and associations such as the Illuminating Engineering Society (IES), the U.S. Green Buildings Council (USGBC), and others can conflict with the recommendations of design guidelines for the implementation of circadian effective lighting, such as UL 24480. Most of these recommendations consider only the light needed for visual tasks and not light the needed for circadian entrainment. It should always be remembered that these recommendations reflect the needs of their members and not necessarily the public.

For example, the IES[21] recommends that offices be provided with an average of 300 ± 30 lx on the horizontal work plane and 75 lx on the vertical plane (i.e., at the eye). For reasons that are unclear, they advise against exceeding those levels by more than 10%, which for vertical illuminance would translate to 82.5 lx. This IES recommendation is more than four times lower than what UL 24480 advises and P100 requires for circadian-effective lighting for day-active personnel. Design teams are left to sort out which guideline requirements they should follow.

The IES, and by extension P100, further recommend limiting the ratio of the amount of light emitted by a surface ("luminance") compared to its surroundings. The IES's recommended luminance ratio between a task and immediate surroundings is 3:1, and between task and remote surfaces is 10:1. This recommendation may complicate efforts to locate circadian task lighting at the desktop.

A further conflict comes when the recommendations of these visual lighting design guidelines are incorporated into lighting performance requirements issued to design teams by building owners and developers, sometimes incorrectly (e.g., interpreting minimum visual light level requirements as maximum, requiring minimum light levels to be provided only from hard-wired, ceiling-mounted luminaires). This leads to conflicts with the requirements and design strategies for implementing circadian-effective lighting. These conflicts not only affect designers on the team but also commissioning agents who are tasked with ensuring that installed lighting meets all codes, standards, and performance requirements, often before furniture or localized lighting is even installed.

Recommendations: GSA could develop educational materials advising commissioning agents about the intention of circadian lighting to support healthy occupants while being cognizant of energy and sustainability.

ADDITIONAL PRACTICAL CONSIDERATIONS

In addition to codes and standards, lighting specifiers must also balance other practical considerations. In particular, budget and schedule limitations can exert an overarching influence on the design process.

It should be noted that committees who develop these model codes and design standards have focused goals (e.g., energy efficiency, carbon reduction, promotion of quality lighting products) that do not prioritize the circadian health of the individual occupants.

For GSA projects in which it is not life-cycle cost-effective for certain features to meet some of the P100 requirements listed above, there is an appeals process. This appeals process could be expanded to include additional allowances for circadian-effective layers of light, for restricted hours of the day.

Recommendation: Lighting designers should seek appeals from appropriate GSA personnel when guidelines and recommendations required by the P100 facilities standard conflict with the need to provide circadian-effective lighting.

SUMMARY OF RECOMMENDATIONS

While energy codes and industry recommendations are important to drive improvements in the built environment, GSA should serve the broader objectives for a successful, occupied building. This includes operation, rather than power density, and user-friendly controls that do not compromise their productivity or, in this case, circadian entrainment.

GSA could encourage committees tasked with revising these recommended practice documents to address both visual and circadian lighting requirements; in the interim, the GSA appeals process could include promotion of circadian-effective features.

While acknowledging the important mission of energy codes, GSA could encourage code- and standard-writing committees to broaden their mission to include the circadian needs of the occupants. This may include confirmation that circadian-effective local lighting is eligible for existing task lighting power allowances. This may also include provision of additional power density allowances for ceiling-mounted lighting, provided these features employ automated controls to limit hours of use to the morning.

GSA could collaborate with controls and lighting manufacturers to encourage development of American products and technologies that support circadian-effective design. In particular, to minimize lighting power density, lighting solutions designed for use in close proximity to occupants should be developed. Controls such as daylight photosensors, partial-on sensors, high-end trim, and multi-level controls should be developed that meet circadian-effective criteria in the morning, then revert to conventional functions the rest of the day.

Once products are available, designers should provide a layer of circadian-effective light that is controlled separately from the general lighting. This circadian layer of light could be designed to be switched on manually by building occupants (when needed for task purposes) or be controlled by an occupancy sensor that could be programmed to automatically turn on only during morning hours.

Documentation for completed projects should discourage the dimming of luminaires used for circadian effect during core morning hours, when those spaces are occupied. Educational materials should advise commissioning agents and facilities managers to maintain the functionality of circadian-effective lighting design features.

Credits

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