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The Circadian Design Balancing Act Lessons from a pandemic-shortened office study

In 2019, a rare opportunity presented itself for lighting designers to specify a lighting system for a field study on dynamic office lighting. With the 2020 exodus of employees from open offices to home offices, the study was halted, but not before many lessons were learned. This column shares the insights gained while designing a code-compliant electric lighting system to meet circadian lighting recommendations with minimal glare and excellent color rendering. Unexpected hurdles made this balancing act even harder.

Cook County initiated this project to further understand how lighting could better support the well-being of its employees and planned to use the results to inform County lighting standards, as well as make a broader contribution to office lighting research. Cook County selected two middle floors of a 37-story office building in downtown Chicago for the study and chose Schuler Shook as the lighting designer, with Pacific Northwest National Laboratory (PNNL) partnering to assist with research.

The two floors had some private offices on the perimeter, but most of the floors were comprised of open offices. The research plan called for several conditions to be compared, so the lighting system had to be flexible enough to meet current IWBI WELL recommendations and UL Design Guideline 24480. Despite floor-to-ceiling windows, daylight in the offices was limited due to adjacent high-rises, so designers planned to rely solely on the electric lighting system with daylight dimming. Another requirement was the ability to vary light level and spectrum throughout the day to meet circadian lighting recommendations while minimizing energy use. With all these requirements the lighting design team knew that this project would require a state-of-the-art tunable lighting system and was eager to find the perfect solution.

The WELL and UL circadian lighting recommendations call for light levels at occupant eye-level that are higher than what is achieved when solely meeting IES recommendations for horizontal work plane illuminance. As a result, Schuler Shook wanted to use a family of multiple white-tunable luminaire types that provided bi-directional (direct and indirect) and asymmetric distributions. The direct component could deliver light on the work plane efficiently, while the indirect and asymmetric distributions could direct light on the ceiling and walls. The ambient component was needed to meet circadian light level recommendations while also meeting IES recommendations for contrast ratios to minimize discomfort glare. Ceiling heights as low as 8 ft required more than the standard Lambertian (cosine) distribution to spread light throughout the office spaces while still meeting the energy code.

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While the intensity of a light source is key to increasing the circadian metric values stipulated by WELL and UL, the spectral characteristics of the source also play an influential role (Safranek et al. 2020). The design team investigated spectrally optimized sources to provide more flexibility in balancing circadian recommendations with energy efficiency while maintaining color and visual quality. To optimize the spectra delivered by the system, the team initially explored tunable lighting systems with three or more channels. While initially optimistic, the designers realized they would have to make a trade-off after tirelessly searching for products. Multi-primary systems that can vary the spectrum independent of chromaticity did not have the optics necessary to create a non-Lambertian distribution. Products with the necessary optical distribution to meet circadian metrics and code only had two primaries, a warm and cool phosphor-converted LED, with chromaticity mid-range deviating considerably from the blackbody locus. Products with two-primaries can have fair color rendering mid-range,

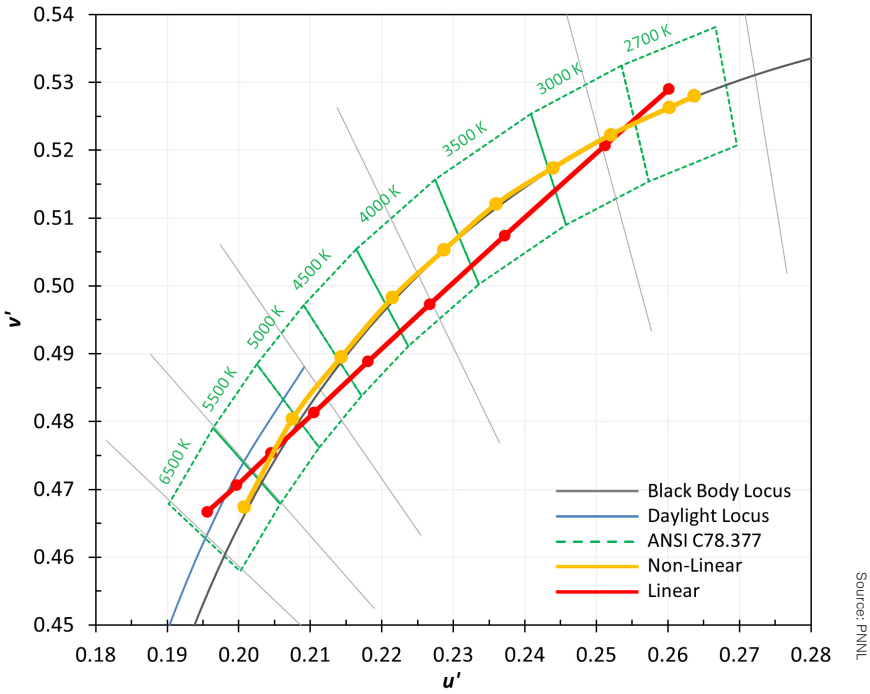

Figure 1. Examples of white-tunable products from prior CALiPER testing. Linear (two-channel) products can only mix to chromaticities directly between the two primaries, whereas products with more than two primaries (multi-channel) can be used to create mixes that can approximately follow the blackbody locus. Deviation from the blackbody locus and color rendering depend on the primaries selected for linear products.

with limited ability to optimize spectra for the recommended circadian metrics (**Figure 1**). As a third option, some lighting products alter source spectra to specifically account for circadian metrics. Unfortunately, these products provide limited spectral flexibility and available optical distributions for these products remained a hurdle, particularly in a linear form factor. Additionally, the criteria for this tunable lighting system included a slow, visible change in the color appearance of the light source throughout the day for biophilic and cueing considerations.

The design team's extensive searching and initial simulations resulted in only one suitable product solution: a 2700K to 6500K two-channel, edge-lit luminaire with an injection-molded optic providing a batwing distribution. Initial simulations by the designers showed that the targeted circadian metric values at the eye could be achieved for most workstations while also meeting IES recommendations for contrast ratios.

For the open-office areas, horizontal illuminance levels ranged between two-to-three times what the designers typically provide based on IES recommendations, with a subsequent increase in energy consumption. For many spaces, the connected lighting power density (LPD) was at or above the base allowance of the IECC-2018 code applicable to the project. Increased vertical surface illumination along with indirect lighting—both needed for an effective and comfortable lighting system—added to the challenge of complying with code, and it was not possible to meet sustainability recommendations such as LEED.

There has been so much talk about tunable lighting, light and health, and circadian lighting recommendations, that it was unexpected to not find one product option that met all the criteria for this project and then to find only one that met most criteria. Due to the pandemic this project was never installed, so the research plan could not be completed, but the completed work highlighted the hurdles through design development. The challenges that come with bidding, installation and commissioning awaited the project. Once installed, the team hoped to better understand how occupants respond to dynamic (and high) light levels and color temperatures since this is a departure from what is typically deemed comfortable and aesthetically pleasing for office electric lighting systems.

Change permeates the current lighting industry—changing metrics, changing recommendations, changing technology and, perhaps even harder to predict, changes in commercial office spaces. While all these changes can be daunting, it is also an exciting time to be exploring the new features and potential of lighting systems.

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