Lighting for Health and Energy Savings: Photometric Calculations

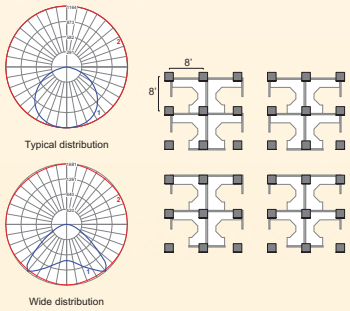
Lighting can help entrain the human circadian system and thereby promote improved health and well-being. However, the light levels required for circadian entrainment in the morning are often higher than those required for visual performance. This has the potential to increase energy use compared to typical LED lighting installations.

This study investigated four strategies for maximizing the ratio of circadian stimulus (CS) delivered at the eye to lighting power density (LPD) from an LED lighting system:

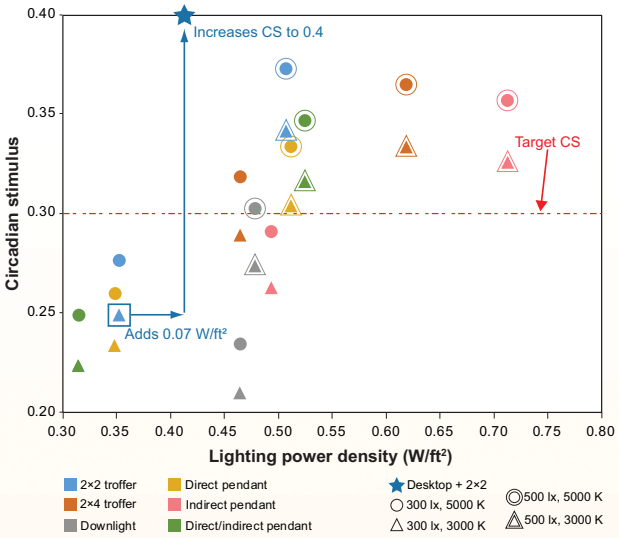
- Intensity distribution: Because light has to reach the back of the observer's eye and lighting standards are based on horizontal illuminance, a higher vertical to horizontal illuminance ratio can increase CS:LPD ratios.
- Spectral power distribution: Because the circadian system is maximally sensitive to short wavelengths, light sources with more short wavelength content can increase CS:LPD ratios.
- Supplemental desktop fixtures: A desktop luminaire delivering narrowband short-wavelength ("blue") light at the eyes increases CS with a minimal increase in energy use.
- CS dosage schedule: Because morning light is important for entrainment, static or tunable-white LED lighting systems can modulate CS delivery and limit energy usage throughout the workday.

Methods

A typical open office space was modelled using photometric simulation software AGi32 to evaluate the CS:LPD ratio of six luminaire types laid out in the space: (1) 2×2 troffer, (2) 2×4 troffer, (3) direct pendant, (4) direct/indirect pendant, (5) indirect pendant, and (6) recessed downlight. The luminaires were operated at two horizontal illuminance levels (300 lx and 500 lx) using two intensity distribution types (typical lambertian, wide) at six CCTs (2700 K, 3000 K, 3500 K, 4000 K, 5000 K, and 6500 K). Additionally, the desktop luminaire was modelled in conjunction with the 2×2 troffer at 300 lx and 3000 K to deliver CS levels of 0.30 and 0.40.



Intensity distribution types used for the 2×2 troffers (on left) and the simulated office space (on right), showing the locations of work stations (white polygons) and the 2×2 troffers (gray squares).



The CS:LPD ratios for all conditions (wide distribution only) examined in this study, showing the effect of adding the desktop luminaire to the 2x2 troffer (300 lx, 3000 K), in the blue square. The arrows show the effect of supplementing the 2×2 troffer with the desktop luminaire delivering narrowband short-wavelength ("blue") light in the morning.

Results

- Of the luminaires that provided the target CS of at least 0.3, 64% of them had a vertical:horizontal illuminance ratio greater than the median value of 0.64. The troffers and pendants with a direct lighting component were the most likely to provide a CS of at least 0.3 with the lowest LPD.
- The average LPD of fixtures providing a CS of at least 0.3 at 5000 K was 5% lower than the LPD of fixtures providing the same CS at 3000 K.
- The supplemental desktop luminaire was the most effective technique for providing CS of at least 0.3 at the eye with the lowest LPD.
- Providing a CS of 0.3 over the entire workday required less energy (3.9 Wh/ft² per day) than providing a high CS of 0.4 in the morning followed by a CS of 0.2 delivered by the 2×2 troffer supplemented by the long-wavelength ("red") desktop luminaire for alertness in the afternoon (4.6 Wh/ft² per day).

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