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An Investigation of the Operational and Design Characteristics of Circadian Lighting Systems

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1. Introduction

This project investigates the operation of a circadian lighting system to gain an understanding of its main design and control characteristics and promote different objectives for its use.

This project identifies pertinent physical and physiological characteristics of lighting and the human response to lighting before exploring current lighting technology through continued literature review. This study concludes with a case study of circadian lighting implemented in an office space and evaluations of success with recommendations for future use.

2. Lighting and Human Characteristics

Defining Light

- *Light* is defined as optical radiation capable of producing a visual sensation in humans. [1]
- *Circadian light* considers the non-visual response in optical irradiance that stimulates the human circadian system. [2]

Spectral Vision

- *Spectral sensitivity* in humans is described by the varied sensitivity of photoreceptors in the eye to spectral composition of light. [2]

Sensitivity Functions

- V(λ) is the developed link between radiometry and photometry, ultimately describing the relationship between perceived illuminance and wavelength for human cone-based (photopic) vision, normalized to 1 at the peak of 555 nm. [2]

Eye-Brain Physiology

- A novel photoreceptor cell in the retina, identified as the *intrinsic photosensitive retinal ganglion cell* (ipRGC), is in part responsible for melatonin suppression influencing circadian response. [3]

Circadian Rhythm Frequency

- Operating on a 24-hour cycle, light and dark both act as a timing device within the SCN, the master clock in the brain. Disruption has negative effects on health. [2]
- Melatonin suppression from ipRGCs for short-wavelength "blue" light is an example of a non-image forming (NIF) response. [4]

CIE – Chromaticity Chart

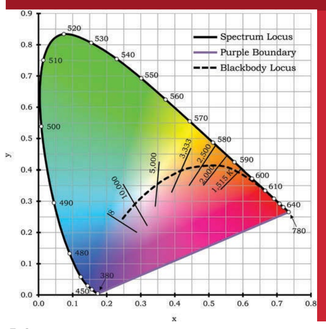

Figure 1. CIE Chromaticity [4]

- X and Y chromaticity coordinates defined within the Spectrum Locus and Purple Boundary
- Blackbody Locus idealized curve for defining CRI and several lines of constant CCT
- Defined boundaries for limitations of color appearance in lighting

3. Current Lighting Technology

- **Correlated Color Temperature** (CCT) in lighting describes the hue of a light source compared to the idealized blackbody radiator, represented on the CIE Color Space [5], visible in **Figure 2.**
- **Color Rendering** Index (CRI) exemplifies the variation between the source and the reference locus through chromaticity coordinates on the CIE Color Space in **Figure 1**. [5]
- A proper melanopic normalization, M(λ), to the human spectral sensitivity function, V(λ), has been achieved through a peak shift to **490nm** [6]
- **Tunable white** and full color-tunable LED products allow users to fine-tune the color spectrum and hue
- Bright illumination with a high "blue" spectral component in the mornings and midday coupled with lower, reduced "blue" content in the evenings mimics the **natural patterns of daylight** [3]

CCT Visual Representation

Figure 2. Correlated Color Temperatures: 2700K, 4000K, 6500K

Photo by Suriyakki/iStock

4. Case Study – UNMC Application

This is related to the installation of novel electric lighting system in an open plan office space located in the 4230 Building at UNMC campus. The office hosts multiple workstations with University staff being the main occupants. **Figure 3** displays the floorplan measurement layout.

This new system, compared to conventional lighting systems, has the added capacity of changing both light intensity and color temperature from the fixtures. This system capability has been found through literature review to have the capacity to promote human satisfaction, alertness, health, and productivity by affecting the occupants' circadian rhythms, a term known as "bio-clock".

With this knowledge, the investigation pertains to system tuning of intensity and color temperature with intent to see a positive response from the occupants within the space. Following literature review, obtaining measurements of the light in the space and then manipulation of the light output of the fixtures can occur. From there, responses can be gathered from occupants using the survey in **Figure 4** to gain a stronger understanding of the relation between the literature and the real life application, with recommendations provided for future use.

UNMC – Processing Methods

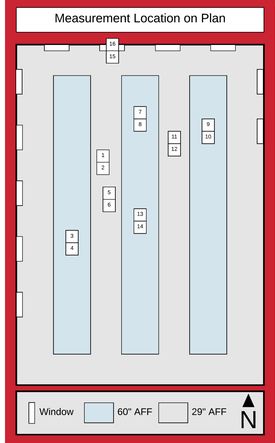

Figure 3. Measurement Plan

- Seen above, this graphic shows where spectral intensity and illuminance measurements were taken

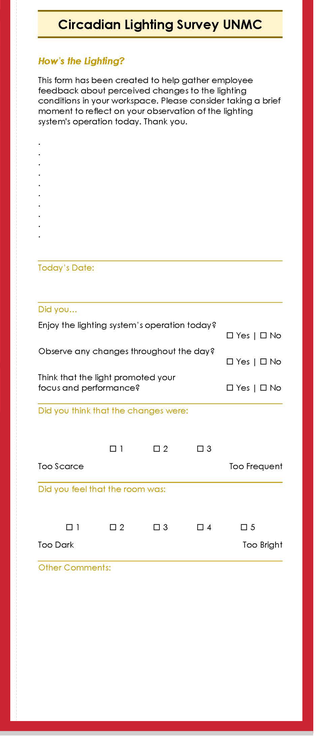

Figure 4. Operational Survey

- Seen right, this document evaluates qualitative response to circadian lighting operation strategy changes within the space

UNMC – Measurement Results

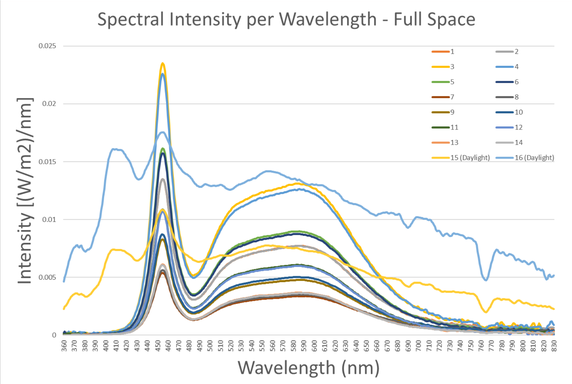

Figure 5. Spectral Intensity curve for each measurement shown in **Figure 3.**

5. Success of Implementation

- Upon completion of initial data collection for spectral intensity and illuminance measurements throughout the space, as seen in **Figure 5,** interruption of the control strategy manipulation by the spread of Covid-19 put a halt on continuation of the case study.
- An understanding of daylight penetration into the space can be leveraged in future work and control strategy implementation pertaining to light intensity through a compiled daylight intensity mapping presented in the report.
- Suggested control strategy for intensity and CCT variation as presented in other literature has been documented and is the next step for continuation of this case study. See **Figure 6.** below.

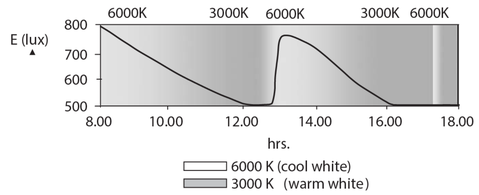

Figure 6. Suggested Illuminance and CCT manipulation for optimal circadian influence throughout the workday [6]

6. Conclusion and Recommendations

Upon completion of this study, a few entities remain unaddressed due to the unforeseen circumstances of the novel coronavirus outbreak. This study was able to successfully identify and review pertinent literature in order to gain a well-rounded understanding of circadian lighting systems and their properties. This knowledge was then applied to the local case study with the UNMC office space primarily through relevant data collection and processing, specifically measuring spectral intensity and illuminance values across the space. Future implementation of control strategy concepts have also been suggested if this investigation is to continue.

The inability to implement the occupant survey as well as the suggested control strategy is less than ideal for the investigation of the value of circadian lighting in modern design. Preliminary measurements of light in the space, with contributions from natural and artificial light sources, are valuable for understanding current state characteristics of the space and for addressing areas of improvement.

From here, observing the interaction between CCT and intensity manipulation related to occupant well-being can pave the way for advanced data analysis. Comparison of measured values to empirical metrics developed for understanding circadian lighting can add to a growing knowledge base of the field, potentially influencing lighting standards and recommendations for design.

Acknowledgements

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