Energy Impacts of Human Health and Wellness Recommendations
Considering Daylight and Electric Light

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Energy Impacts of Human Health and Wellness Recommendations Considering Daylight and Electric Light

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1. Introduction

In a previous investigation by Safranek and others (2020), an office and a classroom were simulated to investigate the potential energy impacts of circadian lighting recommendations in building standards such as WELL v2 Q2 2019. The simulations were focused on the ability of electric lighting to meet recommended levels of equivalent melanopic lux (EML, units of m-lux) and circadian stimulus (CS, unitless) and estimated that lighting energy use may increase by at least 10%, and in some cases by 100%, due to increased luminaire outputs and the corresponding increases in luminaire power. A key takeaway was the need to consider daylight in future evaluations, as it may contribute to levels of EML and CS, allowing for reduced luminaire output and corresponding energy use.

The latest guidance included in WELL v2, Q1 2022 indicates 100% of workstations in regularly occupied spaces are required to receive least 275 m-lx for 4 or more hours per day to achieve 3 points toward WELL certification. For projects that meet the WELL definition of “enhanced daylight”, electric lighting must provide at least 180 m-lx; this assumes that daylight will provide the remaining 95 m-lx. There is a lower EML threshold (150 m-lx) included in WELL v2, Q1 2022 for 1 point toward WELL certification but it will not be considered in this analysis.

Field investigations of daylight availability in real-world architectural environments indicate that building occupants may not receive the recommended thresholds for circadian lighting metrics from daylight alone depending on their location and viewing direction within the space (Figueiro et al., 2017; Konis, 2018). The ability to conduct annual spectral simulations of daylight to investigate these findings is currently limited because existing simulation tools allow for either point-in-time spectral simulations of daylight or annual daylight simulation without sky spectrum being considered. Additionally, data describing the variation of daylight spectra throughout the day and year is currently limited to a few locations in the United States.

The goal of this current evaluation is to estimate the potential energy impacts of existing circadian lighting recommendations considering electric lighting and daylight. Towards this goal, a spectral simulation workflow was created for estimating the contributions of electric light sources and annual daylight, relying on measured spectra. The simulation workflow was used to estimate illuminance, EML, and electrical energy use for an open-plan office space.

2. Methods

A simulation workflow was established for meeting the EML recommendations of 275 m-lx published in WELL v2, Q1 2022 (WELL 2022)[1] with daylight and electric lighting while also minimizing the potential energy impacts. Ladybug and Honeybee (Ladybug Tools, 2022) software components were used within the Grasshopper visual scripting environment to simulate daylight for every day of the year. For these simulations, daylight was treated as an equal energy light source and the spectral reflectance of room surfaces was simplified into three bins. Horizontal and vertical illuminances from daylight alone were calculated at each workstation. Vertical illuminance was converted to EML by multiplying illuminance by the melanopic to photopic ratio (M/P) of the spectrum received at the calculation point for the corresponding hour, as explained in the following section.

Adaptive Lighting for Alertness (ALFA) was used to simulate electric lighting and surfaces in 81 spectral bins, allowing for a more detailed representation of LED spectral power distributions

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[1] Corresponding melanopic equivalent daylight illuminance (m-EDI) threshold values are also listed in WELL v2, Q1 2022. EML can be converted to m-EDI using a scalar multiplier: EML = 1.103 x m-EDI.

(SPDs) and surface reflectance distributions (SRDs). Luminaires were simulated at 100% lumen output to estimate the maximum illuminance and EML from the electric lighting. Illuminance and EML values for daylight and electric lighting were combined each hour and a custom MATLAB script was used to determine the dim-level of all luminaires in 1% increments to maintain 275 m-lx for occupants at all workstations.

Daily electric lighting schedules, like that presented in Figure 1, were output from MATLAB and indicated the lumen output and input power needed to meet recommended horizontal illuminance or EML thresholds for every hour of the year. These schedules were then used to estimate energy consumption for the electric lighting system using two control scenarios: meeting 275-m-lx at all workstations for a 10-hour duration between 8 a.m. and 5 p.m. versus meeting the 275 m-lx at all workstations for a 4-hour duration and otherwise reducing the lumen output to a level meeting Illuminating Engineering Society's (IES) recommendations for average horizontal illuminance.

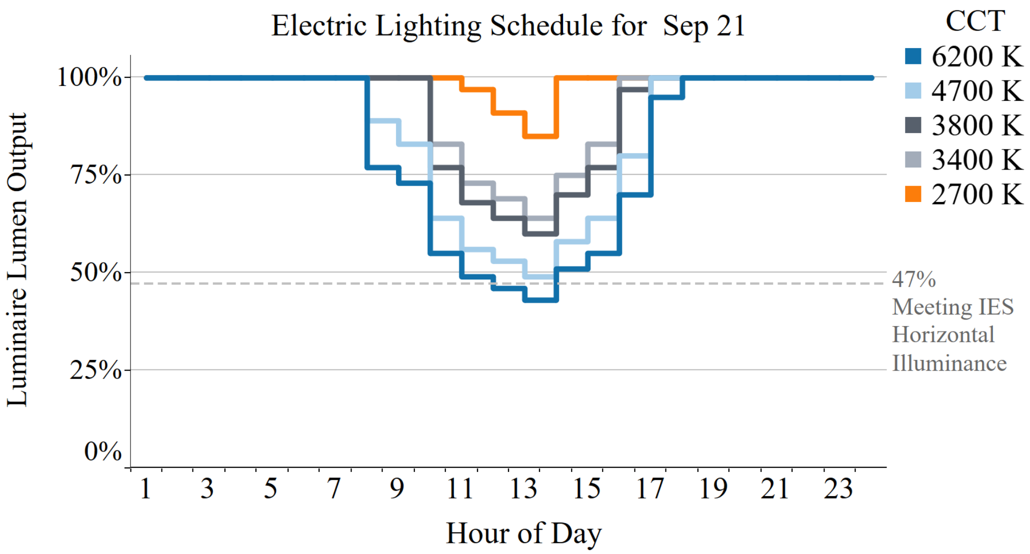


Figure 1. Example of an electric lighting schedule for meeting 275 m-lx at all workstations for one day. Electric lighting is dimmed based on daylight availability to the minimum luminaire lumen output needed to meet the EML threshold. The grey dashed line indicates the lumen output needed to meet IES horizontal illuminance only.

2.1 Simulating Daylight Spectra

Calculating EML requires some knowledge of the light source SPD, however, measured data describing the spectrum of daylight throughout the year are limited to only a few locations in the United States. For this analysis, a method was established for estimating the EML contributions from daylight using spectral measurements captured by the National Renewable Energy Laboratory (NREL). A spectrophotometer, managed and maintained by NREL (Andreas & Stoffel, 1981), collects spectral data of the sky dome in Golden, CO, in 1-nm increments every 5 minutes throughout the year. Measurements from 2018 were used to create an hourly schedule of sky spectra for times from 8 a.m. to 5 p.m. The M/P ratios were then calculated for each hour using the method outlined by WELL (2022).

Figure 1 plots the hourly distribution of daylight M/P values in 2018 from 8 a.m. to 5 p.m. Average M/P for the year is 1.05, although there is deviation from this average value, particularly in the evening hours. Interior daylight illuminance values are multiplied by the M/P value for each hour, providing an estimate of the EML contributions from daylight.

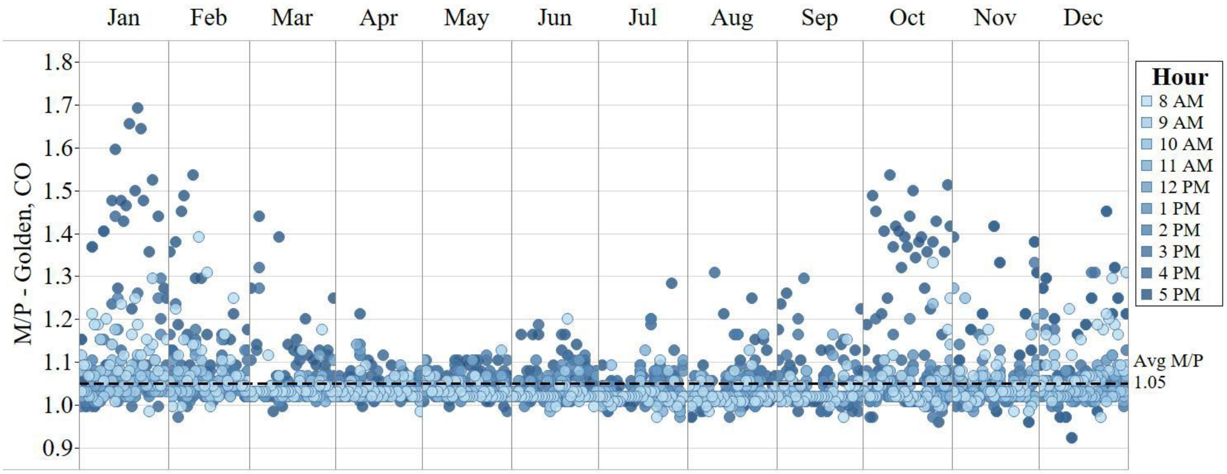


Figure 2. Hourly M/P ratios for Golden, CO from 8 a.m. through 5 p.m.

2.2 Model Parameters

A 2060-ft^2 open plan office with 40 workstations, shown in Figure 3, was used for lighting simulations; this model is the same as that used in previous investigations by Safranek and others (2020). The south-facing wall of the office has floor-to-ceiling windows with a window-to-wall ratio of 90%. Calculation points for simulating horizontal and vertical illuminance were created at each workstation at 2.5 ft and 4 ft above the floor, respectively. Vertical calculation points represent the field of view of a person seated at the workstation and facing toward the monitor. Computer monitors were modeled but were not considered to be sources of light for this analysis. While glare from daylight was estimated for the vertical viewing positions, shading was not considered.

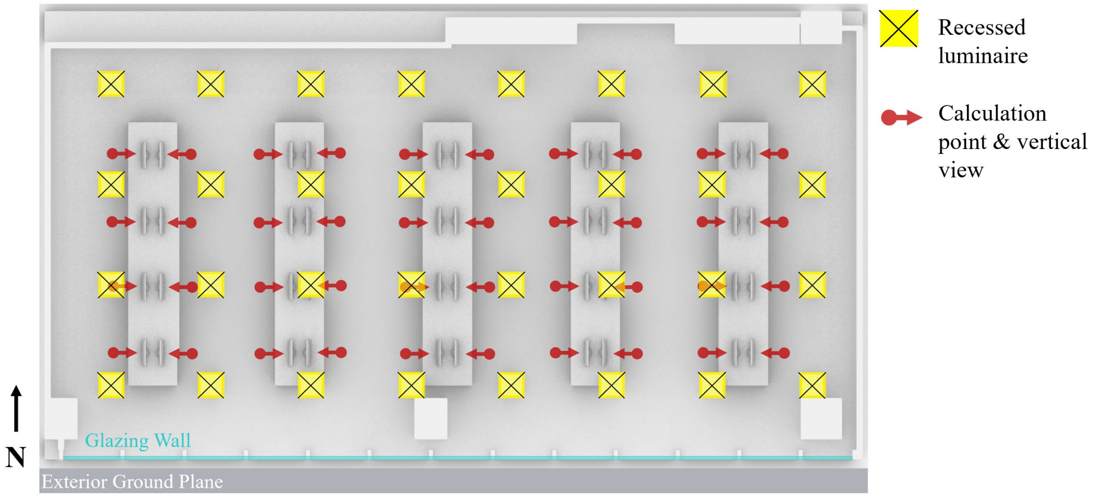
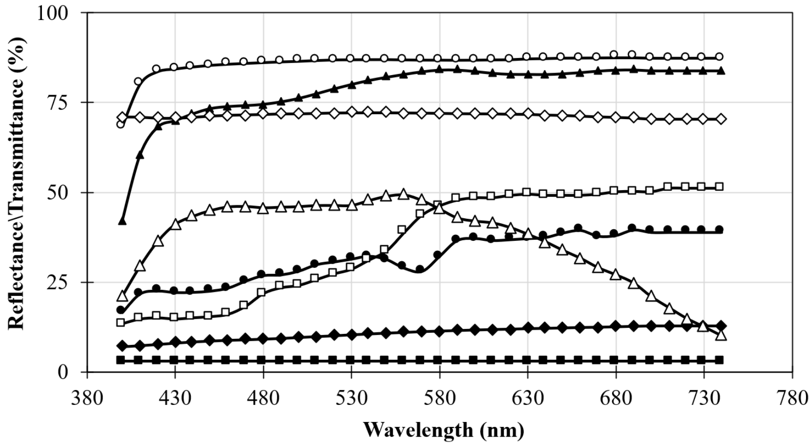


Figure 3. Plan view of model showing locations of luminaires, desks, and computer monitors.

Overall, the materials and luminaires used in the model represent those typically used in office spaces. Many of the SRDs included were measured using a Konica Minolta CM-700D portable spectrometer, supplemented with SRDs from the ALFA library. The average reflectance values and full SRDs are shown in Figure 4.



Surface Material	Average
—○—White Ceiling Tile	86%
—▲—White Wall Paint	78%
—◇—Silver Window Frame	71%
—●—Flooring - Dark Grey	32%
—□—Blonde Wood	36%
—■—Monitors	3%
—◆—Exterior Ground Plane	10%
—△—Glazing	37%

Figure 4. Spectral reflectance distributions for surfaces and spectral transmittance distribution for glazing. Average reflectance and transmittance from 400-740 nm are tabulated on the right.

Thirty-two white-tunable 2 by 2 ft light-emitting diode (LED) luminaires were modeled 8 ft on center. Colorimetric and electrical data for the luminaires were supplied from photometric testing of one luminaire sample in an integrating sphere at Pacific Northwest National Laboratory's Lighting Metrology Laboratory in Richland, WA. Five SPDs, with CCTs ranging from nominally 2700 to 6200 K, were selected from the test data to represent the range of settings available for the luminaires. These SPDs are plotted in Figure 5 and the CCT values will be used to reference the corresponding SPDs throughout this paper. The maximum power draw of the luminaire averaged 40.5 W for all CCT conditions with a linear relationship between lumen output and luminaire power during dimming. CCT did not affect the lumen output or luminaire power for this luminaire. ALFA simulations where the lumen output was adjusted to less than 100% also assumed a linear relationship between lumen output and resulting illuminance at calculation points. A light loss factor was not considered for the luminaires.

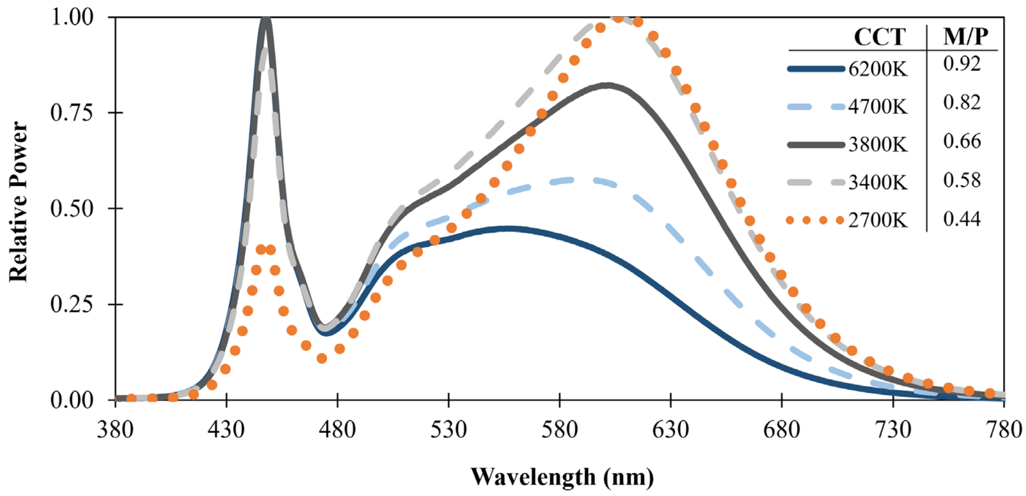


Figure 5. Relative spectral power distributions and M/P values of electric light sources.

3. Results

Table 1 presents estimates of average lumen output and the annual energy required to meet the WELL v2, Q1 2022 EML threshold of 275 m-lx for the 10-hour and 4-hour scenarios. A baseline condition is also included, indicating the lumen output and energy required to meet IES average horizontal illuminance recommendations (300 lx) with electric lighting only. This baseline condition can be achieved with an average luminaire lumen output of 47%, requiring 2223 kWh annually; however, only 2% of the hours between 8 a.m. and 5 p.m. meet 275 m-lx at all workstations. By increasing luminaire lumen output or the CCT of the luminaires, it is possible to increase the number of hours meeting the EML threshold. For example, 93% of the hours between 8 a.m. and 5 p.m. can be met with the 6200 K condition operating at an average lumen output of 68% throughout the year. In doing so, the annual energy also increases by 990 kWh to 3213 kWh total.

Table 1. Summary of annual daylight and electric lighting simulations for meeting WELL v2, Q1 2022 EML threshold (275 m-lx) for a 10-hour and 4-hour duration. The lumen output and energy required to meet IES horizontal illuminance recommendations with electric lighting only is included as the baseline lighting condition.

	10-hr Scenario (8 a.m. to 6 p.m.)				4-hr Scenario (9 a.m. to 1 p.m.)			
Lighting Condition	Avg. Lumen Output (%)†	Hrs Meeting 275 m-lx (%)‡	Annual Energy (kWh)	Increase from Baseline (kWh, %)	Avg. Lumen Output (%)†	Hrs Meeting 275 m-lx (%)‡	Annual Energy (kWh)	Increase from Baseline (kWh, %)
Baseline: IES Avg. E_h Only	47	2	2223	---	47	5	2223	---
2700 K	92	20	4355	2132, 96	61	38	2897	674, 30
3400 K	87	42	4109	1886, 85	58	67	2744	521, 23
3800 K	84	53	3994	1771, 80	57	77	2688	465, 21
4700 K	76	79	3584	1361, 61	53	91	2506	283, 13
6200 K	68	93	3213	990, 45	50	100	2368	145, 7

† Average lumen output throughout the year calculated from hourly dimming schedules to maintain 275 m-lx at the eye for all workstations.

‡ The annual number of hours meeting 275 m-lx for all workstations.

Currently, WELL v2, Q1 2022 recommends that EML thresholds be met for four hours, beginning by noon. With an advanced lighting control system, light levels can be increased for 4 hours and otherwise dimmed to light levels designed to meet horizontal illuminance levels recommended by IES. The simulations of daylight identified the 4-hour period from 11 a.m. to 3 p.m. as having the greatest daylight availability throughout the year, requiring the least amount of supplemental light to meet EML thresholds recommended by WELL. Meeting 275 m-lx during this 4-hour period resulted in an annual energy usage of 2368 kWh to 2897 kWh, depending on the CCT condition of the electric lighting system. The proposed 4-hour control scenarios offer additional energy savings beyond those possible through the 10-hour scenarios including daylight dimming.

4. Discussion and Conclusions

While daylight did allow for reductions in electrical lighting energy usage, this analysis demonstrates the need for more integrated approach to meeting EML goals. With daylight and electric light, it was only possible to achieve 275 m-lx at every workstation with the 4-hour scenario and a CCT of 6200 K; however, the 3400 K and 3800 K lighting conditions may be more typical in office applications. In the case of the 3800 K lighting condition, meeting the EML threshold at all workstations was possible for roughly 50% of the hours between 8 a.m. to 5 p.m. with an 80% increase in annual energy compared to a lighting condition designed to meet IES recommendations.

4.1 EML Levels from Daylight

The current recommendations in WELL v2, Q1 2022 indicate that a total of at least 275 m-lx should be provided at every workstation by electric lighting or a minimum of 180 m-lx provided by electric lighting assuming that the remaining 95 m-lx will be met by daylight. Variables such as daylight availability, occupant view direction, furniture layout, and potential for glare will all affect the EML contributions from daylight.

Figure 7 shows hours when daylight will not provide the expected 95 m-lx at one or more workstations. These hours are colored orange and account for 58% of the daytime hours throughout the year. There are also instances throughout the year where some workstations will be subject to high levels of vertical illuminance, which may result in intolerable levels of glare. Maximum vertical illuminance for all workstations, per hour, were used to calculate the simplified daylight glare probability [DGPs, (Weinold, 2009)]; DGP values are summarized in Table 2. Hours where one or more workstations have DGP values greater than 0.45 (intolerable levels of glare) are colored yellow in Figure 7. These hours indicate instances when shades might need to be deployed or occupant view direction might be adjusted to avoid glare. The adjustment of one shade may lower the EML for one or more workstations, and EML will also decrease as an occupant's view shifts away from the window. Combining hours with insufficient daylight and hours with intolerable DGPs, 71% of the hours from 8 a.m. through 5 p.m. fail to meet 95 m-lx at one or more workstations without introducing intolerable levels of glare.

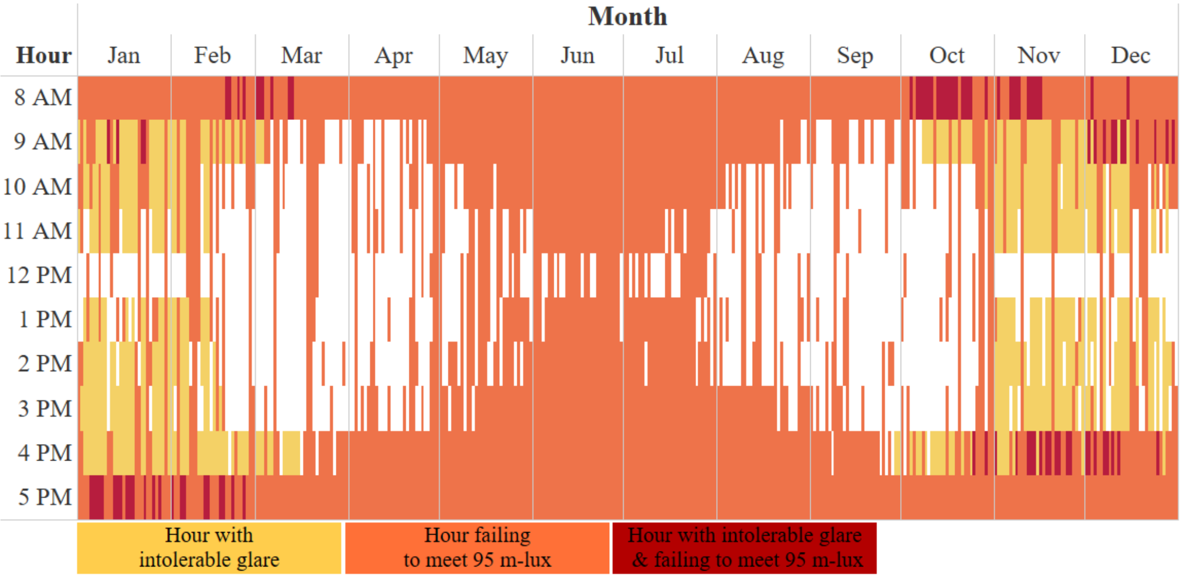


Figure 6. Daytime hours throughout the year where daylight may not be sufficient to meet WELL v2, Q1 2022 recommended levels of EML.

Table 2. DGPs results for daytime hours. Vertical illuminance is used to determine hours that may experience glare from daylight from 8 a.m. through 5 p.m.

Glare Rating	DGP Value	Number of Hours
Imperceptible	< 0.35	2859 (78%)
Perceptible	0.35 – 0.40	154 (4%)
Disturbing	0.40 – 0.45	65 (2%)
Intolerable	> 0.45	572 (16%)

4.2 Limitations

Several simplifying assumptions were used during the simulation and analysis of the results presented in this paper. High-resolution spectral sky data, like that collected by NREL, is currently limited to only a couple of locations in the United States. Existing software tools are limited in their ability to simulate spectral sky data annually. The method for estimating EML from daylight does not account for any shifts in the spectrum possible as daylight passes through glazing materials or inter-reflects between room surfaces.

Additionally, the office model used for these simulations has large south-facing windows in a relatively sunny climate. Estimates of vertical illuminance, EML, and glare will change if the building location, building orientation, or glazing properties are changed. This analysis did not consider zonal control of the electric lighting system, which may allow for additional energy savings through separate control of the luminaires closest to the window.

5. References

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