Two That Are Tunable

DOE's Gateway program investigates tunable lighting in both a medical and classroom setting

BY JAMES BRODRICK

There's considerable interest in manipulating the spectral content of light for reasons ranging from improving spectral efficiency and preference, to enhancing our mood, productivity and health. The science to support potential productivity and health benefits is still at an early stage, yet has led to commercial interest in tunable LED lighting systems, in which both the spectral power distribution (SPD) and intensity are adjustable. The U.S. Department of Energy's (DOE) Gateway program recently completed two evaluations of such systems. The objective was to highlight some of the challenges involved in specifying, installing, commissioning and using them, and the challenges of predicting and evaluating their non-energy benefits as well as their energy performance.

The change in SPD and intensity occurred throughout the day. The left shows the initial night scene, and the right shows the afternoon scene. The downlights were originally programmed to stay on all night (as shown here), but were later reprogrammed to turn off at night, as preferred by the nursing staff.

VIEW OF DINING/ACTIVITY AREA FROM NURSE STATION

A MEDICAL BEHAVIORAL HEALTH UNIT

Seattle's new Swedish Medical Behavioral Health Unit (BHU) serves adult patients with mental-health conditions. The 22-bed, 14,911-sq ft BHU required the renovation of two floors in one wing of an existing hospital. The design sought to compensate for the differences between the old BHU (with dedicated outdoor space and skylights) and the new one (with no windows in the dining/activity space) by leveraging biophilic design tenets. The new BHU incorporates color-tunable luminaires in common areas, and the lighting system employs advanced controls for dimming and color tuning, with the goal of providing a better environment for staff and patients.

ZGF Architects designed the new BHU and invited DOE's Gateway program to document the performance of the LED lighting systems—the first DOE documentation of a color-tunable system specified and installed by building-industry professionals as part of a large-scale renovation project. The lighting system for the new BHU's corridors and dining/activity space was designed to operate according to a daily schedule developed by the ZGF team, including a change in the SPD of the downlights and coves throughout the day. The CCT ranged from 2400K at night to 6000K midday, aligning with the daily color variation of the sky. The intensity level also varied, with lower levels of light through the evening and night, and higher levels in the morning and early afternoon.

GOAL ASSESSMENT

The project provided an opportunity to document both possible benefits and concerns in the design, installation and operation of tunable LED lighting systems in a healthcare application. The findings show that tunable LED systems can provide significant energy savings, but may increase energy use depending on the lighting system and application. For this application, where biophilic and circadian design goals required a tunable lighting system with the ability to vary both spectrum and intensity, the reduced intensity levels from the downlights specified for long periods enabled estimated annual energy savings of 41 percent relative to a non-tunable downlight system with the same number of luminaires.

However, the findings also show that achieving design goals related to circadian and other biological and behavioral effects of lighting sometimes requires higher illuminances than those recommended for visual tasks, and consequently may increase energy use during the hours when those high illuminances are needed. In this project, 74 percent of the estimated annual energy use of the tunable lighting system occurred during the six hours each day when the control settings were based on achieving the desired circadian stimulus. Relative to a non-tunable system designed to only meet illuminance criteria for the visual tasks, this tunable system increased estimated annual energy usage by 19 percent.

Allowing the building occupant some degree of manual control can increase energy savings. The original specification for the downlight system that was initially programmed into the automatic controls kept the downlights on at a dimmed level at night. But the nursing staff decided to manually turn off the downlights at night, after observing that adequate lighting was provided by the cove system. This reduced energy use and was then programmed into the automatic controls.

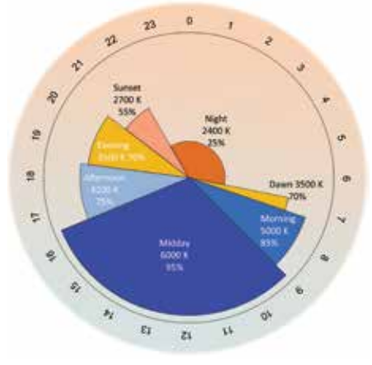
COMMISSIONING

Commissioning of tunable systems remains a challenge. Field commissioning today is often completed by establishing scene settings based on control settings and/or visual assessment, rather than by confirmation with measured data. For this project, the initial commissioning didn't provide the desired range of chromaticities or illuminances, which were only achieved through a careful second phase of commissioning, where chromaticity and illuminance were measured and adjusted for each scene, and then a third phase that was necessary to achieve the desired smooth transitions between the scenes. Without these additional commissioning phases, the energy savings realized would have been much less, and the desired biophilic and circadian goals would not have been achieved.

Developing a detailed specification of the desired control sequences and outcomes early in the design process can help identify potential shortcomings with the specified control solution, and can make the commissioning process more efficient. Although the initial control specification for this project was more detailed than usual, the resulting iterations in commissioning, measurement, calculation and system adjustments revealed the need for even greater specificity in the initial specification. Defining these details as early as possible can highlight the expected level of interoperability between different manufacturers' products, the need for early identification of eye positions and viewing directions for characterizing possible circadian effects, and the increased level of measurement and care required during commissioning.

NON-LIGHTING BENEFITS

Estimating and measuring the SPD at expected eye locations is important for implementing circadian design goals, but there's currently no easy way to estimate the effects at possible eye positions in an architectural space. Common practice for estimating circadian effects of lighting during design includes calculating the illuminance at the eye and then using the rated SPD of the luminaire to calculate related circadian metrics. But this project demonstrated that the actual SPDs at eye locations vary based on position, viewing direction, architectural surfaces, furnishings and location of luminaires. Since any biological effects depend on the SPD at the eye, new techniques are needed to predict the SPDs at different eye locations during design, and then SPDs can be measured and verified during commissioning.



INITIAL DAILY SCHEDULE FOR THE SPD AND INTENSITY-LEVEL CONTROL SETTING

The downlights and coves in the dining/activity area and the coves in the corridors initially changed according to this schedule, which was later revised to smooth the transitions based on user input.

Scientific evidence continues to emerge relating the medical effects of tunable lighting to proposed lighting metrics, but none of the metrics have been formally adopted for use in lighting practice. While there's a growing body of literature on the benefits of biophilic design and the circadian effects of light, and several new lighting metrics have been developed and used in some studies, evidence on the medical effects of these techniques and metrics is very limited and hasn't yet been widely accepted within the medical community. Furthermore, the emerging metrics are still being revised and defined, and none have been adopted by standards-setting organizations.

For more details, download the full report at *https://energy.gov/eere/ssl/downloads/tunable-lighting-medical-behavioral-health-unit*.

New tunable lighting in a classroom: The four SPD settings are shown in clockwise order, beginning with the upper left photo: 3000K (Reading), 3500K (Testing), 4200K (General) and 5000K (Energy). All luminaires were on at full light output for the photograph.

Photos courtesy of Acuity Brands Lighting

THREE GRADE-SCHOOL CLASSROOMS

School districts have shown interest in how tunable lighting can potentially enhance the classroom experience while reducing lighting energy use. One, the Carrollton-Farmers Branch Independent School District in Carrollton, TX, invited DOE to conduct a Gateway evaluation of a trial installation of tunable-white LED lighting systems in three school settings: a fifth-grade math and science classroom at Dale B. Davis Elementary School, a fourth-grade reading and language arts classroom at Sheffield Elementary School, and an eighth-grade science laboratory at Charles M. Blalack Middle School.

Estes, McClure & Associates designed the lighting system in collaboration with the manufacturer (Acuity Brands Lighting). Apart from energy savings, the school district's objectives for the trial installation included assessing the potential for tunable lighting to enhance teacher engagement with students and improve student performance.

The LED lighting systems were installed in August 2016, just before the start of the school year. Each incumbent recessed fluorescent luminaire was replaced with a 2-ft by 4-ft Lithonia Lighting BLT Series Tunable White LED luminaire from Acuity. The LED luminaires offer tunable white lighting with a CCT range of 3000K-5000K. The 4,800-lumen light-output option was specified for the classrooms, resulting in a rated light output of 4,600-5,000 lumens and input power of 34-45 watts at full output. The luminaires were specified with a curved diffuser with linear prisms and with an nLight nTune control interface.

The lighting control system provided the ability to vary the SPD across four preset conditions, associated with nominal CCTs of 3000K, 3500K, 4200K and 5000K. There were also preset scene controls to vary the on/off status and dimming level of different luminaire zones within the room, to better support classroom functions such as audiovisual presentations and student speeches.

The reduction in input power for the tunable-white LED lighting system was estimated to be 58 percent relative to the incumbent fluorescent system. This reduction is attributable to the higher efficacy of the LED luminaires and a reduction in illuminances, which previously exceeded IES-recommended levels. Dimming—which was incorporated into the scene controls and also enabled by separate dimming controls—furthered the energy savings in each classroom. While the individual teacher's usage of the controls varied widely as recorded by the monitoring system, in each case the lighting consistently operated with all or some of the luminaires turned off or dimmed for portions of the school day.

The LED lighting systems were installed and commissioned with very few difficulties, and any issues with initial performance were quickly resolved. The three teachers used the scene controls regularly during the school day but used the SPD controls infrequently. As was the case with the incumbent fluorescent systems, illuminance levels in the classrooms at maximum output met or exceeded IES recommendations for the typical visual tasks with the new LED systems. Color consistency for the tunable-white LED luminaires was very good, even over the dimming range, with only minor variations in CCT and D_{uv}.

TEACHERS' PERSPECTIVE

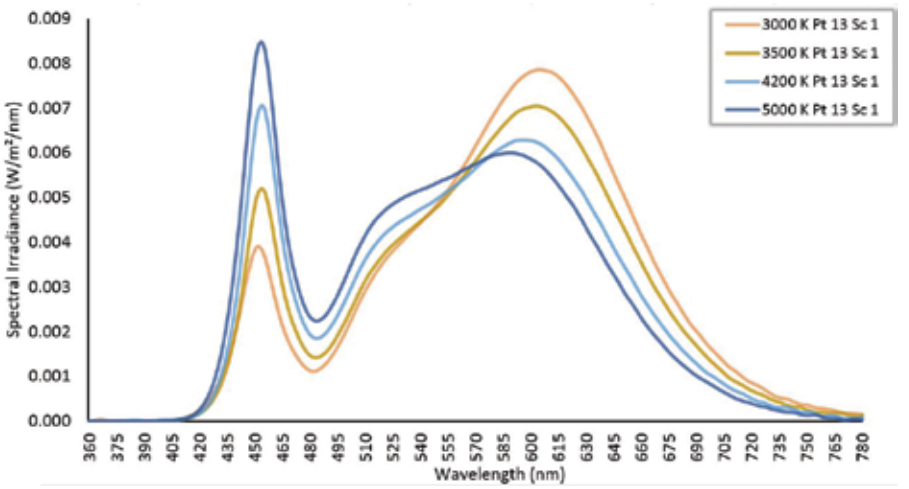
The two teachers interviewed by DOE appreciated the ability to tailor the lighting to different classroom needs, and felt that the lighting and controls allowed the students to be engaged in choosing the settings for various classroom activities. Both teachers stated that the lighting system improved the overall learning environment.

Although most teachers are unfamiliar with CCT and other lighting metrics related to color quality, labeling lighting control settings with familiar terms may provide barriers to full usage of the controls. In this project, labels such as "Reading," "Testing," and "Energy" tended to be interpreted too narrowly by the teachers, who didn't seem to use those control settings for classroom functions that didn't match the labels, although the reasoning for the labels had been explained. The "General" control setting served as the default.

The control locations for this project were constrained by the existing wiring. Where the control locations were more easily accessed by the teacher, the settings (specifically, the dimming level) were varied more regularly, as recorded by the monitoring system.

BEYOND ENERGY SAVINGS

Energy savings from tunable classroom systems result from the switching and dimming functionality of the scene control settings and the manual dimming controls; the ability to vary the color temperature doesn't necessarily provide additional energy savings. Because color-tunable systems are at present more costly than fixed-color LED



SPD for the four control settings, measured at a point in the middle of the classroom between two luminaires, with the meter at seated eye height aimed toward the front of the classroom and the luminaires at 100% output.

Image courtesy of Acuity Brands Lighting

Control station installed in each of the classrooms. The left controller provides SPD control, and the right controller provides light-output control.

systems (which can still provide full scene and dimming control), an economic argument for color-tunable systems can't be based on energy alone. As with other classroom upgrades, the justification for color-tunable lighting systems needs to include non-energy benefits related to a better learning and working environment, possibly linked to student learning outcomes, teacher satisfaction and retention, and human-health impacts. The difficulty in documenting and assigning economic value to these potential non-energy benefits poses a major challenge for color-tunable lighting systems in classrooms and other applications.

The combination of spectral tuning and dimming in the classrooms provides greater opportunity to vary lighting parameters that may affect circadian and behavioral responses for students, teachers and other users, relative to the fluorescent systems. While documenting these circadian and behavioral effects was beyond the scope of this project, the tunable LED systems may be adaptable to reinforce the desired outcomes, should scientific consensus emerge that supports specific SPD and intensity settings for related effects.

For more details, download the full report at *https://energy.gov/eere/ssl/downloads/tuning-light-classrooms*. ☐

CONSIDERATIONS FOR BOTH PROJECTS

- Energy usage
- Commissioning
- Non-illumination benefits
- Operator (nurse and teacher) perspective

THE AUTHOR

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