LESSONS IN THE CLASSROOM

Tunable light could potentially improve student learning, increase teacher satisfaction and trim energy use. A recent pilot project explored these benefits

By **Bob Davis and Sarah Safranek**

Innovations in pedagogy and technology have transformed today's classrooms, with students and teachers engaged in learning activities that move far beyond the image of a teacher standing in a cloud of chalk dust at the front of the room. Classroom design has adapted, supporting group work, mobile device use and audiovisual presentations in addition to traditional lecture formats (see "Designing the Active Classroom" in the February 2015 issue of *LD+A*). Tunable LED lighting systems, which provide the ability to vary both the intensity and spectrum of light, are another technology tool for teachers and classroom designers to support today's learning styles and teaching methods.

According to the 2011 U.S. Environmental Protection Agency (EPA) report *Energy Efficiency Programs in K-12 Schools*, energy expenditures in U.S. K-12 schools total about $8 billion annually and represent the second-largest expense to schools, after personnel costs. EPA notes that the $2 billion that could be saved through a 25% reduction in energy costs could be used to hire nearly 36,000 new teachers or purchase 40 million new textbooks.

The growing use of tunable LED lighting systems is being driven by energy and non-energy considerations. First, there's the potential for significant energy savings relative to fluorescent systems and non-dimmable LED lighting systems. These savings can be attributed to the combination of two factors: the higher efficacy of LED systems compared to fluorescent systems, and the dimming capability provided by tunable lighting. Beyond the more efficient technology, in some cases schools are achieving additional savings by reducing classroom illuminances, since many older schools have illuminances that exceed current IES recommendations.

The possible non-energy benefits of tunable LED systems include providing teachers with an additional element of control over the classroom, as dynamic variations in intensity and spectrum may promote learning and student engagement through visual cues that reinforce desired student behaviors. In addition, variations in the spectrum of light may contribute to increased student alertness and concentration. While the scientific evidence for these non-energy benefits is still being explored, the potential positive effects on student learning and teacher satisfaction have made tunable LED systems an intriguing option for schools to explore.

The U.S. Department of Energy (DOE), through its Gateway program, has been studying tunable LED lighting in real-world installations, several of which have involved classroom settings. (Study reports and related resources can be found online at *https://www.energy.gov/eere/ssl/led-color-tunable-products*.) The first classroom study, summarized in the December 2017 issue of *LD+A*, was a trial installation of tunable-white LED lighting systems in three classrooms in the Carrollton-Farmers Branch Independent School District in Carrollton, TX. In this project, DOE collaborated with the school district; the engineering firm of Estes, McClure & Associates; and Acuity Brands Lighting.

The energy savings based on power reduction was found to be 58%, with even deeper savings from dimming and the use of controls. Teachers also reported that the tunable lighting enhanced student engagement in class, and that they used the lighting to provide behavioral cues to the students. For example, one fifth-grade teacher reported regularly using a lighting scene with low CCT and intensity after lunch or recess, as a signal to the students that it was time to settle down and get back to work.

More recently, DOE completed an evaluation of tunable LED lighting in three classrooms in the Folsom Cordova Unified School District (FCUSD) in Folsom, CA, in conjunction with the school district and the Sacramento Municipal Utility District (SMUD). The tunable LED classroom lighting system and controls selected by FCUSD for the trial installation were supplied by Finelite. The classroom lighting system had been developed by Finelite with R&D support through a competitive funding opportunity from the DOE Solid-State Lighting Program; that R&D effort included gathering input from multiple teacher groups for designing the control interface.

The opportunity to gain firsthand experience with tunable LED lighting systems and to explore improving the classroom environment, especially in classrooms for children with autism spectrum disorder (ASD), was of interest to both FCUSD and SMUD. SMUD invited Pacific Northwest National Laboratory to document the energy and photometric performance of the existing and trial lighting systems as part of a Gateway evaluation. The initial Gateway report from this project was published in September 2018, with further analyses reported in a supplement published in March 2019.

System Components. The tunable LED lighting system was installed in August 2017, before the beginning of the FCUSD 2017-2018 school year. One of the three classrooms that received the LED lighting system was used for general-education fifth-graders, and the other two were used for ASD students. In each of the three classrooms, existing two-lamp T8 fluorescent recessed luminaires were replaced with recessed 2-ft by 2-ft white-tunable LED luminaires. Additionally, one 12-ft white-tunable LED wall-wash surface-mounted luminaire was installed above the whiteboard in each classroom.

A wall-mounted, touch-sensitive controller was located at the front of each classroom, adjacent to the whiteboard, and used a DMX512 protocol to communicate with the luminaires (**Figure 1**). The controller offered five preset lighting scene buttons, which varied the light levels, distribution of light to different parts of the classroom and spectral power distribution (SPD). Teachers could depart from the preset scenes using three slider bars, two of which provided continuous 0-100% dimming (one for the general luminaires and one for the whiteboard luminaire) and the third allowing for color tuning rated for 2700K to 6500K across all luminaires (see **Figure 2** for SPDs of several conditions). The touchpad also featured on/off power buttons for the entire system and for the general and whiteboard luminaires separately.

$8 billion
Annual energy costs in U.S. K-12 schools, second only to personnel

Energy Savings. The LED classroom lighting system, if operated at full output, would produce similar illuminances to the existing fluorescent system when operated at full output, and would yield an estimated 46% annual energy savings. However, the fluorescent systems provided average illuminances that were well above the current IES-recommended levels, and for the pilot study the individual teachers established the illuminances they desired for the general setting in each classroom (which in all cases met IES recommendations). SMUD initiated field measurement proce-

Figure 1: The control pad installed near the whiteboard at the front of each classroom. The five scene buttons on the left (beneath the power button) changed the intensity, distribution and spectrum of light based on pre-set programmed conditions. The touch-sensitive slider bar marked "Downlight" provided dimming control of the recessed luminaires used for general room lighting, while the slider bar marked "Whiteboard" provided dimming control of the pendant luminaire used for lighting the whiteboard. The slider bar marked "Color" provided spectral control of all the luminaires in the classroom, with a rated CCT range of 2700K to 6500K.

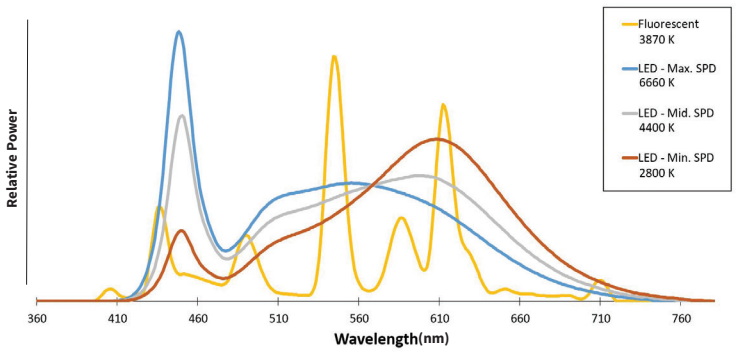

Figure 2: SPDs for three of the color control settings of the LED system and for the existing fluorescent system, measured directly underneath a luminaire installed in a classroom.

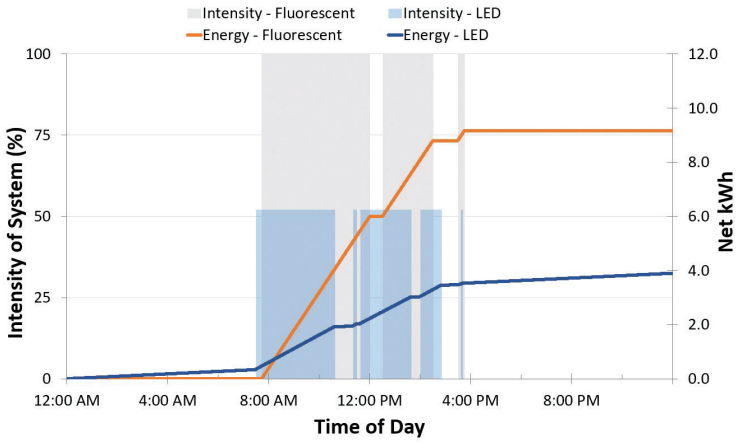

Figure 3: Intensity control settings and resulting energy use for a typical day in one of the classrooms in the pilot study. The resulting energy savings during this day for the LED system relative to the existing fluorescent system was 57%.

dures to document the energy use of the existing and proposed new systems.

Collection of energy data for each of the three classrooms began during the last week of the 2016-2017 school year, while all three classrooms were operating under fluorescent lighting systems, and continued until the conclusion of the 2017-2018 school year. Based on the monitored energy use in the three classrooms, the actual savings during a typical day ranged from 48% to 69%, depending on how the teacher used the controls for both the fluorescent and LED systems. For example, **Figure 3** shows the usage profile and resulting energy use for a typical day in one of the classrooms for ASD students, with 57% energy savings overall.

The actual energy savings throughout an entire school year will be less than what has been estimated in these daily profiles, as the DMX-controlled driver in each LED luminaire has a small power draw when the system is turned off, which is sometimes referred to as "phantom" or "baseline" load. (This is shown in Figure 3, where the LED energy continues to increase even when the intensity setting is at zero.) Baseline power draw with active controls such as DMX, digital addressable lighting interface (DALI), and Power over Ethernet (PoE) needs to be considered to maximize the energy savings potential of tunable LED systems in classrooms. Turning power off completely to the driver would save energy by minimizing the baseline load, but the trade-off might be less control flexibility, more controllers or limitations on deep dimming.

Teachers' Use of Controls. To document the use of the lighting controls for the LED systems, the lighting system manufacturer provided extra hardware and software to enable logging of the teachers' usage of the control pads. Based on these data, it was clear that each of the teachers interacted with the LED lighting system differently, with their individual preferences remaining relatively consistent over the monitoring period. The teachers in the two ASD classrooms utilized the preset buttons and the customizable slider bars regularly, while the teacher in the general education classroom primarily used the default on/off functionality of the lighting system with few other adjustments during the day. **Figure 4** illustrates these differences, showing the amount of time that the lighting system in each classroom was set to different conditions, as a percentage of the total time that the system was powered on. The individual differences between teachers in the use of controls shows the opportunity for customizing the educational setting that tunable LED lighting systems can provide.

The logged control data also provide insight into how the teachers varied both the SPD and output of the LED lighting system. For example, one teacher in an ASD classroom used the "Calm" setting almost daily, at 8:30 a.m. and 1:30 p.m. This preset control changed the CCT setting to 2800K at low illuminance. In a follow-up interview, this teacher (see breakout quote) suggested that the lighting acted as a cue for students to redirect their attention to a new activity, improving their readiness to learn. The logged data also indicate that teachers were not comfortable with a combination

of higher CCT and higher illuminance settings. Throughout the monitoring periods, a press of the "Energize" button (control settings of 5000K and more than 500 lx illuminance) would quickly be followed by adjustments from the color slider or another preset selection; for one classroom, eventually that button was no longer used.

At the conclusion of the 2017-2018 school year, teachers from the participating classrooms were interviewed by SMUD for feedback on the tunable LED lighting system. The teachers considered the preset lighting options particularly beneficial because they allowed for quick interaction with the system. Each teacher commented on using the presets as a way of getting the attention of their students or as a transitional cue between certain activities. Their feedback indicated that the lights were more effective for getting the attention of their students than other previously used methods, such as ringing a bell or talking loudly. Being able to dim the lighting system was reported to be particularly valuable, with the ability to change the color considered a secondary benefit.

Moving forward, small-scale pilot studies such as those from the Carrollton and Folsom schools will help to establish the proof-of-concept for using tunable LED lighting in classrooms, and show the potential effects on energy use and on human responses in these settings. But a broader, more scientific evidence base is needed for a better understanding of the holistic effects these systems can have on teachers, students and the classroom environment. To this end, we are currently exploring collaborative research efforts to study these effects in school districts where tunable systems have been implemented on a broader scale, throughout hundreds of classrooms in multiple schools.

These projects take a long time to establish and then complete, but ultimately they will serve to help educational planners and facility designers continue to evolve their facilities to better support today's educational needs. And a deeper pool of research results can help lighting technology developers provide future lighting solutions that better address the full range of human needs. If you are aware of schools that are implementing innovative lighting solutions, and that are willing to help establish a broader base of research results, the authors welcome your input. ◎

"I absolutely love the lighting. I feel like lighting is something that we might not think about but it can have such a huge impact on [the students'] behavior or academics. If the calm setting really helps them calm down and be more regulated, then they're ready to learn and much more willing to learn."

Teacher of students with autism spectrum disorder in the Folsom Cordova Unified School District

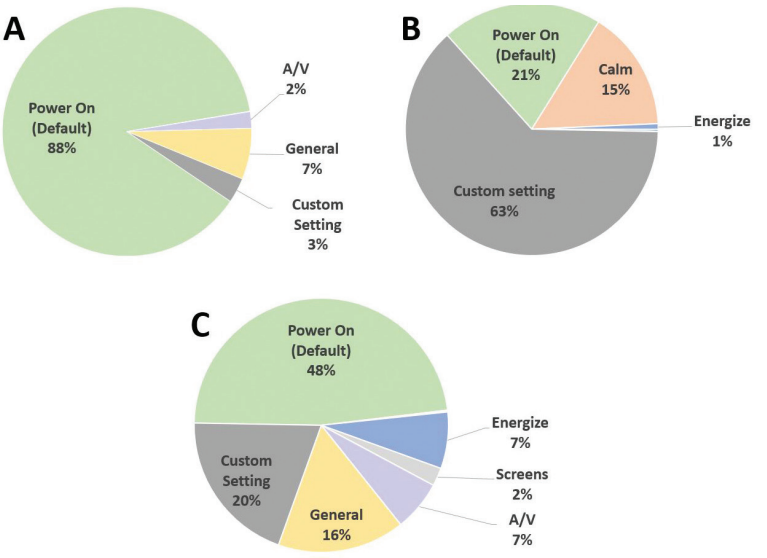

Figure 4: Teacher usage of the lighting controls during the study period, showing the amount of time that the lighting system in each classroom was set to different conditions as a percentage of the total time that the system was powered on. In Classroom A, the teacher primarily used the default lighting condition through the on/off controls. In Classroom B, the teacher often used the slider bars to customize the lighting to the desired condition. In Classroom C, the teacher often used the preset scenes and also used the slider bars.

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