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Luminaires for Advanced Lighting in Education

Recipient: RTI International
PO Box 12194
Research Triangle Park, NC 27709-2194

Teaming Partner: Finelite, Inc.
30500 Whipple Road
Union City, CA 94587-1530

Principal Investigator: Dr. J. Lynn Davis

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RTI INTERNATIONAL

2. EXECUTIVE SUMMARY

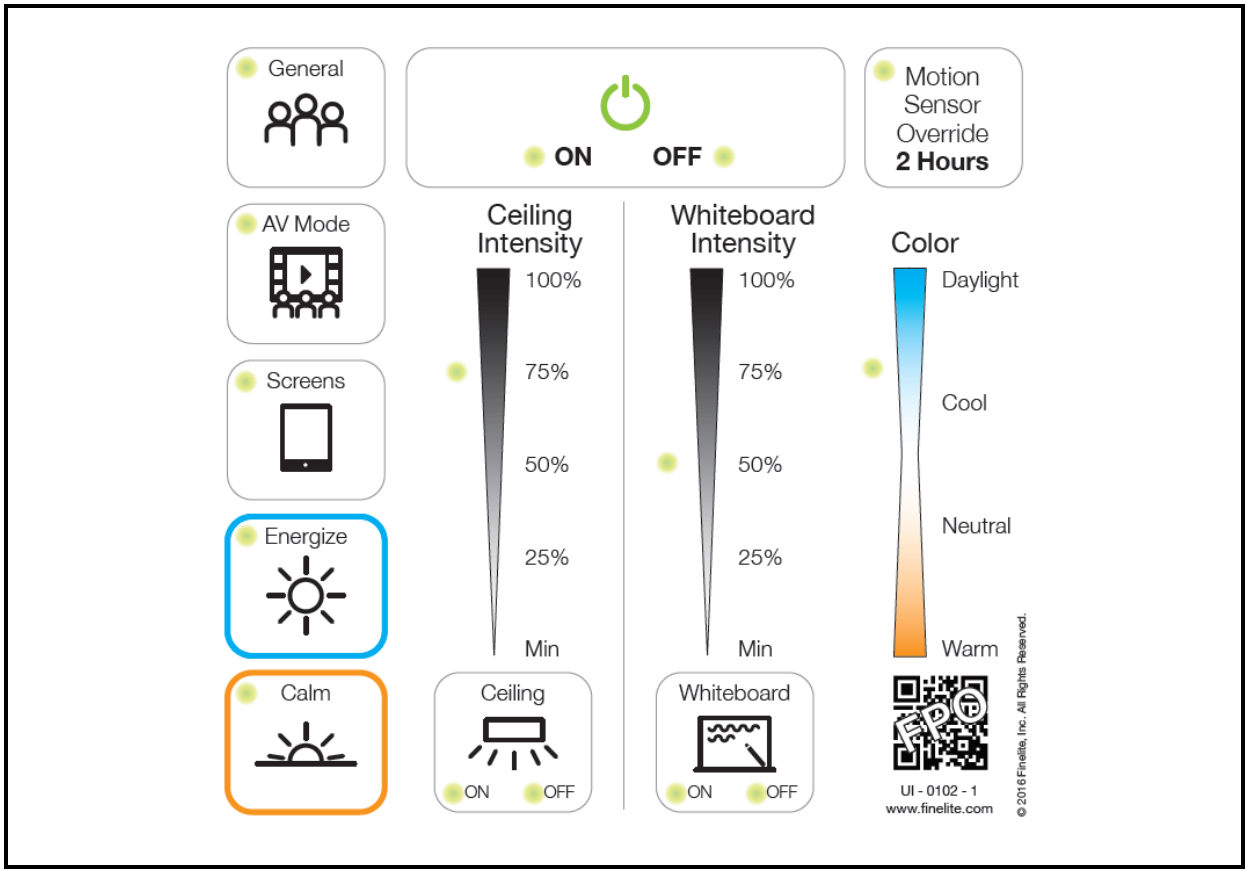
The modern classroom requires multipurpose lighting to accommodate a myriad of educational activities, such as direct instruction; group work; individualized instruction, including computer work; and audiovisual (AV) presentations. For too long, classroom lighting systems have been basic devices with no controls other than an on/off switch, not even dimming. Since the average age of public schools in the United States is 44 years, and the average functional age of these buildings in nearly 20 years [1; 2], the lighting systems of most public schools are minimalistic and outdated. These facts have likely contributed to the high level of dissatisfaction with lighting in public school buildings. A recent survey found that school lighting was rated the most unsatisfactory part of the average facility [2]. Clearly, the lighting technology used in many schools today has robbed teachers of a potentially valuable tool to supplement their teaching skills and benefit their students: the ability to adjust lighting color and illuminance levels to match the educational task at hand.

To overcome this impediment, RTI International and Finelite, Inc., have used funding from the United States Department of Energy (DOE) (through Award DE-EE0007081) to build the Next-Generation Integrated Classroom Lighting System (NICLS). NICLS provides high-efficacy (> 125 lumens per watt [lpw]) lighting, full illuminance control (1% to 100%), and white light tunability (2,700 K to 6,500 K) in a Made-in-the-United States lighting system designed to improve the educational environments of facilities that focus on learners of all ages. This effort culminated in the incorporation of NICLS technology in the DOE Classroom of the Future (COF) demonstration site at Finelite's facility in Union City, CA. This system was designed with the help of teachers for use by educational professionals. A picture of this facility tuned to different colors of white light is shown in **Figure 1.1**.

Figure 1.1 Composite Picture of the Tunable White Lighting (TWL) Capability of NICLS for Educational Facilities

In building this system, more than 80 teachers and school administrators participated in focus groups held at the NICLS technology demonstration site to provide guidance on the use of the advanced lighting technologies in the classroom and the design of the user interface (UI) for the lighting system. These focus group members provided an overwhelmingly positive assessment of the impact of such lighting technology on the learning environment for their students. Teachers of special needs individuals, especially those who are autistic or vision impaired, also pointed out the benefits of the NICLS technology for students with sensory stimulation needs. Together, these focus groups helped to design a UI that is intuitive and simple to use for teachers, students, and substitutes. This UI is designed to accommodate the ability to shift modes quickly because teachers cannot get distracted in the classroom. As shown in **Figure 1.2**, this UI utilizes colors and icons to provide an intuitive, easy-to-use, and inviting appearance. The NICLS UI represents a new paradigm in lighting system controls and is a significant advancement over previous lighting control systems designed for building managers. The focus group members also expressed a strong desire for more information and research on how best to use fully dimmable, tunable light-emitting diode (LED) technology to benefit their students.

Figure 1.2 Intuitive UI Design Developed Exclusively for the NICLS Technology



The extensive research and development program used by RTI and Finelite to develop the NICLS technology started with the identification and acquisition of state-of-the-art mid-power LED technology to provide high luminous efficacy performance to the NICLS platform. The next step was the identification of luminaires that would meet the aggressive goals established for this project by the DOE. In performing this evaluation, more than 100 luminaire designs and options were considered, and those that could not meet the stringent luminous efficacy goals of the project or produced excessive amounts of glare were discarded. In the end, five designs, including direct/indirect pendant luminaires and troffers, were identified that would meet or exceed DOE's performance goals at the end of the project. In independent, third-party testing, the level of performance of the NICLS technology was demonstrated to provide high luminous efficacy (> 125 lpw at all correlated color temperature [CCT] settings) performance in a TWL product that is cost competitive and made in the United States.

Once the NICLS technology demonstration site was completed, a full characterization of the performance of the technology was conducted at the room level. The demonstration site covered over 1,000 ft^2 and contained 12 troffers (2 foot by 2 foot) and five wall wash luminaires for whiteboards. All luminaires in the site have full dimming (100% to 1%) and

TWL capabilities, and the settings of the ceiling luminaires can be varied independent of the whiteboard luminaires, creating a range of scenes for the classroom. The CCT range of the TWL system is continuous from 2,700 K to 6,500 K using a linear tuning algorithm; this range far exceeds that specified by DOE. The system delivers lighting at better than 125 lpw at all CCT values with exceptional color metrics (color rendering index [CRI] > 82, color fidelity metric [R_f] ≥ 81, and color gamut [R_g] ≥ 97 at all CCT values).

At the systems level, the NICLS technology was found to perform exceptionally. With all the luminaires in the NICLS technology demonstration site turned on and set to 100%, the lighting power density (LPD) was only 0.67 watts per square foot (W/ft^2), which is well below the requirements of American Society of Heating, Refrigerating, and Air-Conditioning Engineers 90.1 and California Title 24. Built-in daylight harvesting and occupancy sensors reduce the LPD value even further. At the 100% level for all luminaires, the NICLS technology provides better than 60 foot-candles (fc) at desk height and completely fills the space with even, glare-free lighting. The lighting levels can be cut back to 75% and still provide better than 50 fc at desk height while consuming less than 0.5 W/ft^2. Further dimming levels can be readily achieved with the NICLS technology, and LPD values as low as 0.007 W/ft^2 can be reached (i.e., ceiling and whiteboard luminaires at 10% dimming).

The NICLS system is also designed to be exceptionally robust and will last for 10 years or more during normal use with minimal maintenance. Accelerated stress testing (AST) of the LED modules demonstrated minimal lumen depreciation under these conditions, and the technology can exceed DOE's requirement of better than 85% of the initial luminous flux remaining after 50,000 hours of use. In fact, depending upon the use profile with the NICLS system, the technology can be used for much longer times and still produce more than 85% of the initial luminous flux. The chromaticity shift in the LED boards was also found to be minimal in laboratory testing. While no projections of the operational time necessary to produce a significant color shift (e.g., seven-step chromaticity shift) are possible at this time, the minimal color shifts that were found in accelerated tests reinforce the finding that the NICLS technology will last for 50,000 hours or more with exceptional performance. The robustness of the LED drivers in the NICLS technology was also verified using ASTs developed by RTI, including an operational life test conducted at 75°C and 75% relative humidity. Over 2,500 hours of testing in this environment, minimal changes were found in the drivers chosen for the NICLS technology demonstration site. These findings confirm that the LED drivers in the NICLS platform will exceed DOE's goals of better than 50,000 hours with less than 50% mortality.

This project met or exceeded every goal established by DOE for an advanced lighting system for educational environments, including the following:

- Demonstrating a luminous efficacy value for NICLS luminaires in excess of 125 lpw at all CCT values;

- Demonstrating a TWL range of 2,700 K to 6,500 K while maintaining a CRI of 83 or higher at all values;
- Providing the capability for full-range dimming (100% to 1%) at all CCT values with flicker levels below industry guidelines, such as Institute for Electrical and Electronics Engineer recommended practice P1789, and compatibility with American National Standards Institute C82.77 requirements for luminaires;
- Incorporating daylight and occupancy sensing to provide automatic control of lighting zones to further reduce energy consumption;
- Achieving a rated lifetime on the system exceeding 50,000 hours with a lumen maintenance of at least 85% at 50,000 hours; and
- Creating a teacher-focused UI located at the front of the classroom to operate the lighting system. A smartphone-based UI is also available to accommodate teacher movement in the classroom.

In conclusion, the NICLS technology is an advanced lighting system for educational settings that meets or exceeds all DOE photometric, electrical, and reliability goals for the COF. The NICLS technology has been demonstrated at the classroom level, and the feedback from the dozens of teachers and educational professionals who visited the demonstration site has been overwhelmingly positive. NICLS provides a state-of-the-art lighting environment that adjusts the lighting conditions—both color and illuminance levels—to the needs of students and teachers for the task at hand. Early research has suggested that such lighting conditions will improve not only teacher effectiveness but also a student's ability to concentrate on tasks or calm down and decompress, as needed. The ability of the NICLS technology to tune lighting conditions to the needs of students and teachers applies to both grade school and adult learners.

Ultimately, an investment in advanced lighting systems such as NICLS for the classroom is an investment in the community and its citizens. The energy savings that could be realized by installing the NICLS technology in a classroom are significant, but they represent the tip of the iceberg. The larger long-term gains from advanced solid-state lighting (SSL) systems in the classroom are likely to come from the benefits to the community of having higher-performing schools and better-educated citizens. Given the generally poor perception of lighting quality in public schools, the investment in advanced SSL systems for educational facilities is one that should be seriously considered.