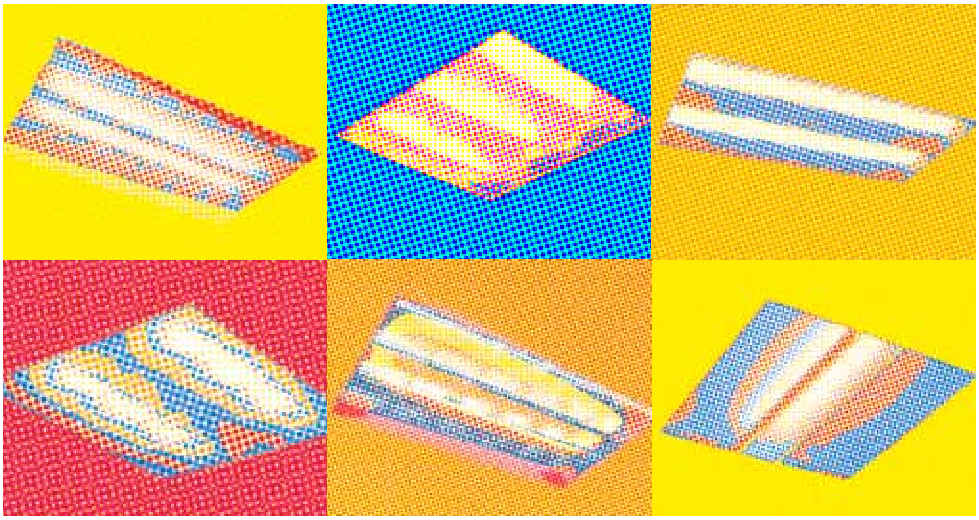

Commercial Ambient LED Lighting: An Emerging Option

The marketplace is teeming with LED replacements for linear fluorescent lamps. To help make sense of it all, a working group of 18 designers and engineers convened in a test facility to size up these products

BY JAMES BRODRICK

For decades now, classrooms and offices in the U.S. have been lighted primarily with fixtures that use linear fluorescent lamps. These fixtures include recessed 2 ft by 4 ft, 2 ft by 2 ft, and 1 ft by 4 ft, as well as linear pendants (both indirect and direct/indirect), chalkboard/whiteboard lights and linear wallwashers. The T8 and T5 fluorescent lamps and electronic ballasts that are used in them comprise a robust, mature technology that, if not exactly well-liked, is at least well-accepted. Maintenance is fairly easy, and although there's a wide range of lamp, ballast, and luminaire types available on the market, there's nevertheless a certain amount of consistency in how these products are installed, as well as in how they work with controls and perform over time. But the rapid advent of solid-state lighting (SSL) has brought with it an increasing number of LED versions of this product type, which are offered as energy-efficient alternatives that also have other potential advantages.

As a result, lighting designers, facility managers, electricians, contractors and end users are all facing big changes in the "Type A recessed fixture"—not only in terms of the lighting plans for new buildings, but also in existing buildings where the lighting needs a facelift. The overall picture can be confusing, to say the least. Some manufacturers offer T8 LED replacement lamps that either are accompanied by a driver to replace the ballast or that include integral drivers. Others offer integral 2 ft by 4 ft and 2 ft by 2 ft luminaires with dedicated LEDs and drivers. Still others offer "kits" to upgrade fluorescent troffers to an LED option—in most cases retaining the fluorescent troffer's housing while replacing the ballast with a driver that powers linear boards of LEDs. Such kits either use the luminaire's existing lens or optical system, or they replace it with a diffusing acrylic panel for a refreshed look.

Some of these LED products use a small number of high-output LEDs, while others use a larger number of medium-output LEDs. And while some mimic the optical performance of their fluorescent counterparts, most simply deliver a cosine (or "blob") distribution that may or may not work in terms of luminaire spacing for ceiling or workplane uniformity, visual comfort or reducing reflected glare on computer screens.

Left: Ceiling of mockup space, showing four sets of 2 ft x 2 ft luminaires spaced on 8 ft x 8 ft centers. Right: Observers evaluating luminaires, using movable wall positioned to show light pattern.

AN EXPLORATORY STUDY

Recognizing the potential for confusion, the U.S. Department of Energy (DOE) conducted an exploratory study through its CALiPER program, aimed at identifying the problems and benefits that lighting designers, specifiers, facility managers and users are likely to encounter as these LED products become increasingly popular in offices and classrooms. The report will be posted online soon at *www.ssl.energy.gov/exploratory.html*.

For the study, 18 lighting designers and facility engineers were convened in September 2012 to compare 24 identical pairs of troffers in a simulated office space. Of the 24 fixture types, three were fluorescent benchmark troffers, five were fluorescent troffers retrofitted with LED tubes, four were troffers with LED non-tube retrofit kits, and 12 were dedicated LED troffers. The products were evaluated for photometric distribution, including direct glare and reflected glare, unifor-

Safety Concerns

There is widespread concern in the lighting industry about the safety and listing of fluorescent troffers that are retrofitted with LED tubes and non-tube kits. After the fluorescent luminaires in the CALiPER study were modified with LED tubes and non-tube retrofit kits, Intertek inspected them to determine how safety certifications might be affected. This provided valuable information about the conditions for preserving Nationally Recognized Testing Laboratory (NRTL) certification and listing of the products.

The most common issue found was a lack of stickers or labels mounted inside the retrofitted troffers, to change responsibility for the product, provide contact information and warn users and maintenance people about the permanent changes made to the luminaire. Of the eight retrofitted troffers inspected, four were missing stickers and a fifth had a label that provided no new contact information for the manufacturer.

There were other issues. In two of the luminaires, it wasn't easy to see how the ground wire was wired. One non-tube retrofit kit had a different manufacturer's name on the instruction sheets from the name on the kit hardware. One kit was installed with self-tapping screws, which aren't allowed because they can pierce a jacketed electrical wire—although it wasn't clear whether these screws were supplied in the kit or provided by the electrician.

One LED tube manufacturer had multiple stickers and markings on its products, with catalog numbers that conflicted with each other. This would pose a problem in reordering. One LED kit utilized LED strips that were screwed directly to the fluorescent troffer housing. Unfortunately, because fluorescent luminaires are temperature-exempt, there's no way to know whether this combination of metal housing and LED is safe, without complete temperature testing of the retrofitted system.

The inspection showed that for over half of the installed tubes and non-tube retrofit kits, an electrical inspector could have disqualified the luminaires due to safety documentation or poor assembly. This doesn't mean the luminaires were unsafe as installed, but it could prompt the inspector to require a site inspection and safety certification by a recognized safety testing body. Manufacturers would be wise to heed this warning in order to avoid costly site certifications.

The four luminaires that were most-favorably rated for reflected glare all had diffuse lenses and seemed to have fairly uniform gradients across the troffer aperture.

mity of light on the task surface and suitability of the light output for the task. The evaluators also considered power quality, flicker, dimming performance, color quality, issues of electrical safety and certification, ease of installation, energy efficiency and life-cycle cost.

The products were ordered in May 2012 and consisted of recessed 2 ft by 2 ft or 2 ft by 4 ft troffer luminaires designed for mounting in a 9-ft acoustical T-bar ceiling (see sidebar). Although 3,500K is a more common CCT for fluorescent luminaires in this country, more LED troffers were available in 4,000K, which consequently became a target criterion for purchasing them, along with a CRI > 80, lumen output of 2,500-6,000 lumens, a power factor > 0.9, and a target spacing criteria minimum of 1.2 in both directions.

Prior to the evaluation, the products were tested for flicker, color and flux at Pacific Northwest National Laboratory and then either sent for LM-79 testing at an independent testing lab or shipped directly to the mockup site at Intertek Testing Laboratory. Those products that were non-tube retrofit kits or LED tube retrofits were installed in either conventional T8 fluorescent K12 lens or mid-grade parabolic louver troffers procured for the study, and the retrofits were performed by a commercial construction electrician, who noted the install time and how easy or difficult it was to do the work. Retrofitted troffers then underwent goniophotometry testing.

SIMULATING REAL-LIFE CONDITIONS

At the mockup facility, the 24 troffer pairs were installed in a 9-ft acoustical ceiling. The layout was designed to space luminaires uniformly within the room, on typical spacings. The 2 ft by 4 ft troffers were spaced on 10-ft centers parallel to the length of the room, and the 2 ft by 2 ft luminaires on 8-ft centers perpendicular to the room. In order for the room to look and function like a real office, four pairs of luminaires were switched together: 2 ft by 4 ft troffers on 8 ft by 10 ft spacing, and 2 ft x 2 ft troffers on 8 ft x 8 ft spacing.

Two movable sheetrock walls were created to enable observers to position them at a typical distance from the luminaire, so that its pattern of light on vertical surfaces could be evaluated. Ceiling tile reflectance was approximately 80 percent, wall reflectance 70 percent (white), and floor reflectance was concrete (approximately 30 percent). Two movable desks were located in the space, with laptop computers and paper tasks for evaluating visibility and reflections. In addition, study participants provided several iPads with highly specular screens, for evaluating reflected glare from the luminaires.

The luminaires were equipped with interfaces for the Encelium dimming system and were wired with 0-10-V control wire. This allowed each luminaire pair to be individually controllable apart from all the other luminaires. The control system was programmed to switch and dim groups of luminaires as needed for the evaluation process and for group viewing.

The observers were divided into groups of six and were presented with four pairs of luminaires illuminated at full output. After being presented with all six groups of luminaires at full output, the observers then saw the same groups of luminaires in dimming mode. At the end of the evaluation session, all observers were brought together to discuss what they had seen, what they had learned and what qualities were important to convey to the specifier and user.

These two LED non-tube retrofit kits were installed in 2 ft x 2 ft fluorescent luminaires and exhibited odd or distracting patterns of light on the lens.

These two fluorescent troffers contained LED T8 replacement tubes and exhibited high luminance contrast, or striping.

NOT WITHOUT ISSUES

Overall, the LED products had a slight edge over their fluorescent counterparts, in terms of efficacy. The efficacy of the fluorescent benchmarks ranged from 54 to 72 lumens per watt, with an average of 65.3. The efficacy of the LED products ranged from 46 to 104 lumens per watt, with an average of 72.9. The non-tube retrofit kits averaged 66.5 lumens per watt, and LED tube products 68.8.

A number of areas of concern about LED troffers were identified (see sidebars). One was color consistency, which varied among the products even though all of them were claimed by their manufacturers to be 4,000K white. Color acceptability of the LED products was related to CRI, with low CRIs leading to poorer ratings and CRIs greater than 85 generally receiving the highest ratings.

There were also concerns about the sharp-edged contrast that was created against the surrounding acoustical ceiling by some of the diffuser-based LED products, which reflected in glossy computer screens. Although many of today's computer screens are matte, glossy screens are still in use, especially with tablets. The study found glare itself to be somewhat of an enigma. All three types of glare were examined: overhead glare, direct (discomfort) glare and reflected glare. And glare was, indeed, an issue for some of the luminaires. Yet, no measured or calculated photometric quantities proved to be reliable predictors of whether glare would be a problem for a given luminaire.

The LED T8 replacement lamps used in the study produced light only in 180 deg and emitted no light from the back side. In parabolic troffers, this resulted in increased contrast between the bright lamp and the unlighted reflector behind it—which would receive plenty of light from an omnidirectional fluorescent tube but doesn't receive any from an LED source. In prismatic lens troffers, it increased the "striping" effect on the lens, owing to the lack of bounced light to the lens surface to

Installation Feedback

CALiPER monitored the installation process for the LED tubes and non-tube retrofit kits in the study, and documented the comments of the contractor who did the work. Here's a sampling of the observations:

Retrofit tubes:

- Instruction sheets referred to sleeving or other bits that were supposed to be included in the kit, but were not.
- Some LED tubes were provided with stickers to be mounted inside the modified luminaire to warn users not to reinstall T8 fluorescent lamps; however, if the instruction sheets made no mention of the label, the electrician didn't think to install them.
- Removing ballasts and rewiring sockets in the existing fixture in order to accommodate the LED tubes was easier to understand, but more work and more time-consuming, than installing an LED non-tube retrofit kit.
- In some troffers, there wasn't enough wire to reach across the fixture once the ballast was cut out. Extra wires had to be added, adding time to the process.
- Two LED tube manufacturers' replacement products had rotatable pins on the socket, for orientation of the lamps inside the troffer. It was very challenging to get these lamps seated and rotated in the fluorescent socket, even before orienting the lamps.

Non-tube Retrofit kits:

- Some non-tube retrofit kits needed to be installed in deeper troffer housings, but it was easy to miss that note on the product cut sheet.
- The kits that directed the installer to throw away the fluorescent tombstones (i.e., sockets) and install bars of LEDs instead of tubes were a lot less labor-intensive than reusing the tombstones.
- One kit provided stranded wire for push connectors, even though solid wire would have been easier to install and would have provided a more secure electrical connection.
- In optics where there was a paper-thickness diffuser provided in addition to the prismatic lens, the instructions weren't clear whether that diffuser was just protective material for shipping, or whether it should have remained in the completed fixture.
- Protective films were provided on some lenses and surfaces to minimize scratching, but instructions suggested removing the film long before the risk of scratching that surface was over.

Manufacturers of LED tubes and non-tube retrofit kits would do well to observe their products being installed in a range of existing troffer types, and improve their products and instruction sheets accordingly to make it easier and more intuitive for the installer, as well as more easily reviewed and approved by the electrical inspector.

even out the light pattern between lamps.

What else did we learn from the CALiPER study? Well, it's clear that LED dedicated troffers are ready to compete with their fluorescent counterparts on an efficacy basis, as shown by the fact that all but one of those that were tested surpassed the fluorescent benchmarks in that regard. Lighting quality factors are of some concern—though no more so for LEDs than for fluorescents. The LED replacement tubes and non-tube retrofit kits, too, performed in the same efficacy range as the fluorescent products, with more lighting quality concerns. All of the troffers produced acceptable uniformity on the workplane, although it's important to note that there were no workstation partitions in the mockup room that could block the spread of light. LED and fluorescent troffers that emitted more than 4,800 lumens were considered to produce too much light for normal office use, given the 9 ft ceiling heights and the luminaire spacing used in the study. Luminaire lumens as low as 2,100 were considered acceptable.

Light distribution on adjacent office walls is a factor that seems to be related to the percent of light emitted from 60 deg to 90 deg. Troffers that emitted more than 10 percent of their lumens in that zone produced better (i.e., higher and "softer") wall patterns. Parabolic louver troffers that were lamped with LED tubes were lower-rated than those lamped with fluorescent lamps, probably because the light from the back side of the tube (the indirect component) helped soften the pattern of light on the adjacent wall.

Strong patterns (e.g., pronounced stripes, swirls, circles) created on lensed fixtures were disliked by the evaluators. The appearance of troffers that contained LED replacement tubes, as well as some non-tube retrofit kits, evoked strong negative reactions, compared with the appearance of dedicated LED or fluorescent troffers. This is a strong warning

Flicker and Dimming

All light sources flicker to some degree, but large variations in light out put can be visible to some people and may affect certain populations even if not visible to them. An issue with fluorescent and high intensity dis charge (HID) luminaires until the advent of high frequency electronic bal lasts in the mid 1990s, flicker has reemerged with the introduction of LED products into the marketplace, in part because the modulation of LED light output over time can be greater than that of fluorescent or HID sources.

Flicker in SSL is a function of the LED driver. Some drivers produce little to no detectable flicker at any level of output, others flicker noticeably at all output levels, while others produce little or no flicker at full output but more pronounced flicker when dimmed. There are four factors that contrib ute to flicker: amplitude modulation of light output (i.e., the peak vs. mini mum light output in a cycle), the average light output in a cycle, the shape or duty cycle of light output during a cycle (or, roughly, how much time the light output is low or off during the cycle) and the frequency.

All luminaires in the CALiPER study were ordered with 0 10 V dim ming ballasts or drivers, if available. Only one of the five LED tube prod ucts was available in dimming versions. Three of the retrofit kits were available in dimming versions, although the fourth was not compatible with the 0 10 V controller and instead was supplied with its own pro prietary digital dimming control.

Dimming performance of the 0 10 V dimmable LED products was about the same as that of the 0 10 V fluorescent, but the stepped dimming pro vided by one dedicated LED troffer product was considered unacceptable for office and classroom applications. Flicker was not an issue for any of the fluorescent or LED troffers operating at full output, nor for the fluores cent troffers when dimmed. However, four of the LED troffers produced moderate to bad flicker when dimmed to low output. This was related to the 100 percent modulation depth and frequency of the dimming driver s pulse width modulation output, but there are no published metrics to help the specifier identify in advance whether a product will exhibit flicker. The observers varied widely in their ability to detect flicker. None were able to reliably detect it when luminaires were at their full output on a dimming controller, but most observers could detect it in the worst offenders when they were in a dimmed state.

The observer ratings were plotted against the Flicker Index and the percent Flicker metrics for the luminaires in dimmed mode. Each of these metrics worked pretty well in explaining the variation in the data, which suggests that one or both of those metrics could be useful for communicat ing flicker performance in manufacturers literature. But the other important takeaway from the data is that even when an LED exhibited high modula tion (i.e., high percent flicker), its acceptability was greater when it oper ated at a very high frequency.

that retrofit products need to be mocked up and visually evaluated before ordering the product for a large installation.

The hope is that the results of this study will not only help lighting designers and engineers specify products that suit the application, but will also help manufacturers improve their product offerings. A copy of the full report will be posted soon at *www.ssl.energy.gov/exploratory.html.* ■

THE AUTHOR

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The Cast of Luminous Characters

The troffers installed for the CALiPER study included:

- Three fluorescent benchmark products: a 2 ft by 2 ft with two T8 U-lamps and a K12 prismatic lens (I); a 2 ft by 2 ft three-lamp troffer with 2 ft T8 lamps and a high-performance diffuser (J); a 2 ft x 4 ft three-lamp troffer with 3 in-deep cell semi-specular 18-cell parabolic louver and 4 ft T8 lamps (K).
- Five 2 ft x 4 ft lensed or parabolic louver troffers retrofitted with T8 LED tubes (A, B, C, D, L; L was a prototype product and was not considered in the final data analysis).
- Four 2 ft by 2 ft lensed troffers retrofitted with LED non-tube kits (E through H).
- Twelve 2 ft by 2 ft or 2 ft by 4 ft dedicated LED troffer products (M through X).