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Preface

The U.S. Department of Energy (DOE) CALiPER program has been purchasing and testing general illumination solid-state lighting (SSL) products since 2006. CALiPER relies on standardized photometric testing (following the Illuminating Engineering Society of North America [IES] approved method LM-79-08) conducted by accredited, independent laboratories. Results from CALiPER testing are available to the public via detailed reports for each product or through summary reports, which assemble data from several product tests and provide comparative analyses. Increasingly, CALiPER investigations also rely on new test procedures that are not industry standards; these experiments provide data that is essential for understanding the most current issues facing the SSL industry.

It is not possible for CALiPER to test every SSL product on the market, especially given the rapidly growing variety of products and changing performance characteristics. Instead, CALiPER focuses on specific groups of products that are relevant to important issues being investigated. The products are selected with the intent of capturing the current state of the market at a given point in time, representing a broad range of performance characteristics. However, the selection does not represent a statistical sample of all available products in the identified group. All selected products are shown as currently available on the manufacturer’s webpage at the time of purchase.

CALiPER purchases products through standard distribution channels, acting in a similar manner to a typical specifier. CALiPER does not accept or purchase samples directly from manufacturer’s to ensure all tested products are representative of a typical manufacturing run and not hand-picked for superior performance. CALiPER cannot control for the age of products in the distribution system, or account for any differences in products that carry the same model number.

Selecting, purchasing, documenting, and testing products can take considerable time. Some products described in CALiPER reports may no longer be sold or may have been updated since the time of purchase. However, each CALiPER dataset represents a snapshot of product performance at a given time, with comparisons only between products that were available at the same time. Further, CALiPER reports seek to investigate market trends and performance relative to benchmarks, rather than as a measure of the suitability of any specific lamp model. Thus, the results should not be taken as a referendum on any product line or manufacturer. Especially given the rapid development cycle for LED products, specifiers and purchasers should always seek current information from manufacturers when evaluating products.

To provide further context, CALiPER test results may be compared to data from LED Lighting Facts, ENERGY STAR® performance criteria, technical requirements for the DesignLights Consortium® (DLC) Qualified Products

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1 IES LM-79-08, Approved Method for the Electrical and Photometric Measurements of Solid-State Lighting Products, covers LED-based SSL products with control electronics and heat sinks incorporated. For more information, visit http://www.iesna.org/.
2 CALiPER only uses independent testing laboratories with LM-79-08 accreditation that includes proficiency testing, such as that available through the National Voluntary Laboratory Accreditation Program (NVLAP).
3 CALiPER summary reports are available at http://www.ssl.energy.gov/reports.html. Detailed test reports for individual products can be obtained from http://www.ssl.energy.gov/search.html.
4 LED Lighting Facts® is a program of the U.S. Department of Energy that showcases LED products for general illumination from manufacturers who commit to testing products and reporting performance results according to industry standards. The DOE LED Lighting Facts program is separate from the Lighting Facts label required by the Federal Trade Commission (FTC). For more information, see http://www.lightingfacts.com.
5 ENERGY STAR is a federal program promoting energy efficiency. For more information, visit http://www.energystar.gov.
List (QPL),\(^6\) or other established benchmarks. CALiPER also tries to purchase conventional (i.e., non-SSL) products for comparison, but because the primary focus is SSL, the program can only test a limited number.

It is important for buyers and specifiers to reduce risk by learning how to compare products and by considering every potential SSL purchase carefully. CALiPER test results are a valuable resource, providing photometric data for anonymously purchased products as well as objective analysis and comparative insights. However, photometric testing alone is not enough to fully characterize a product—quality, reliability, controllability, physical attributes, warranty, compatibility, and many other facets should also be considered carefully. In the end, the best product is the one that best meets the needs of the specific application.

For more information on the DOE SSL program, please visit http://www.ssl.energy.gov.

\(^6\) The DesignLights Consortium Qualified Products List is used by member utilities and energy-efficiency programs to screen SSL products for rebate program eligibility. For more information, visit http://www.designlights.org/.
Outline of CALiPER Reports on Linear (T8) LED Lamps

This report is part of a series of investigations performed by the CALiPER program on linear LED lamps. Each report in the series covers the performance of up to 31 linear LED lamps, which were purchased in late 2012 or 2013. Summaries of the evaluations covered in each report are as follows:

Application Summary Report 21: Linear (T8) LED Lamps (March 2014)\(^7\)
This report focused on the bare-lamp performance of 31 linear LED lamps intended as alternatives to T8 fluorescent lamps. Data obtained in accordance with IES LM-79-08 indicated that the mean efficacy of the group was slightly higher than that of fluorescent lamps (with ballast), but that lumen output was often lower. The color quality of the linear LED lamps varied substantially, with many of the products having worse color quality than a typical fluorescent T8 lamp (e.g., CRI less than 80). One important finding was the range in luminous intensity distribution, with clear-optic lamps all having a beam angle less than 120°, and diffuse-optic lamps all having a beam angle above 126°. None of the lamps had an omnidirectional luminous intensity distribution similar to that of a linear fluorescent lamp.

Report 21.1: Linear (T8) LED Lamps in a 2×4 K12-Lensed Troffer (April 2014)\(^8\)
This report focused on the performance of the 31 linear LED lamps operated in a typical troffer with a K12 prismatic lens. In general, luminaire efficacy was strongly dictated by lamp efficacy, but the optical system of the luminaire substantially reduced the differences between the luminous intensity distributions of the lamps. While the distributions in the luminaire were similar, the differences remained large enough that workplane illuminance uniformity could be reduced if linear LED lamps with a narrow distribution were used. At the same time, linear LED lamps with a narrower distribution resulted in slightly higher luminaire efficiency.

Report 21.2: Linear (T8) LED Lamp Performance in Five Types of Recessed Troffers
Although lensed troffers are numerous, there are many other types of optical systems as well. This report looked at the performance of three linear (T8) LED lamps—chosen primarily based on their luminous intensity distributions (narrow, medium, and wide beam angles)—as well as a benchmark fluorescent lamp in five different troffer types. Also included are the results of a subjective evaluation. Results show that linear (T8) LED lamps can improve luminaire efficiency in K12-lensed and parabolic-louvered troffers, effect little change in volumetric and high-performance diffuse-lensed type luminaires, but reduce efficiency in recessed indirect troffers. These changes can be accompanied by visual appearance and visual comfort consequences, especially when LED lamps with clear lenses and narrow distributions are installed. Linear (T8) LED lamps with diffuse apertures exhibited wider beam angles, performed more similarly to fluorescent lamps, and received better ratings from observers. Guidance is provided on which luminaires are the best candidates for retrofitting with linear (T8) LED lamps.

Report 21.3: Cost-effectiveness of Linear (T8) LED Lamps (Pending)
Meeting performance expectations is important for driving adoption of linear LED lamps, but cost-effectiveness may be an overriding factor in many cases. Linear LED lamps cost more initially than fluorescent lamps, but energy and maintenance savings may mean that the life-cycle cost is lower.

\(^7\) Available at: http://www1.eere.energy.gov/buildings/ssl/application-troffer.html
\(^8\) Available at: http://www1.eere.energy.gov/buildings/ssl/application-troffer.html
This report will describe calculations of cost effectiveness based on tiers for lamp cost, electric rate, and annual hours of use. These calculations will be useful for users with a wide range of applications.

In addition to these four technical reports, CALiPER will offer a concise guidance document that describes the findings of these studies and provides practical advice to manufacturers, specifiers, and consumers. As always, the applicability of general guidance to any specific application may vary. Further, the LED market is rapidly changing, meaning today’s conclusions may or may not apply to products in the future. The performance and effectiveness of every lighting system should be evaluated on its own merits.
1 Background

As LEDs have evolved in the architectural lighting market, integral LED lamps have become obvious options for replacing low-efficacy halogen lamps. However, many LED manufacturers are now targeting T8 fluorescent (FL) lamps, which in their premium form already boast efficacy of greater than 90 lm/W, excellent lumen maintenance, and long life of up to 80,000 hours when paired with well-engineered electronic ballasts. Are linear LED lamps (also called T8 LEDs or T8 LED replacement lamps) ready to compete with an incumbent technology that is familiar, efficient, interchangeable, and cost-effective?

Linear LED lamps are increasingly considered by electricians and facility managers as obvious energy-efficient replacements for the linear fluorescent lamp. Linear LED lamps are often promoted by manufacturers and sales agents as an easy retrofit option, with only minor retrofit labor needed, equivalent lighting performance to fluorescent, dramatic energy savings and resulting return on investment, and/or almost negligible relamping costs because of long life. The CALiPER Series 21 reports address the following questions:

1. Are the aforementioned claims of ease of use and economic benefit legitimate?
2. Are all linear LED lamps the same? If not, how are they different?
3. Are linear LED lamps interchangeable?
4. Are there any ongoing concerns about safety?
5. Do all linear LED lamps work equally well in all common troffer types?
6. Once mounted inside a troffer, how does a linear LED lamp affect the luminaire light distribution, the appearance of the troffer, the light output, and the luminaire’s resulting energy and efficacy performance?
7. What criteria should the contractor, owner, or specifier use to specify and order the best type of linear LED lamp for their application?

The first report in this series, CALiPER Application Summary Report 21, addressed the first four questions, covering the basic photometric performance of 31 linear LED lamps. The key findings were that the mean efficacy of the group was slightly higher than for fluorescent lamps (with ballast), but that lumen output was often lower (Table 1). For example, the linear LED lamps on average emitted only 70% to 80% of the rated lamp lumens of typical (full-wattage) F32T8 lamps—and less than energy-saving versions of T8 fluorescent lamps (e.g., F28T8). Another important finding was the range in luminous intensity distribution, with clear-optic lamps all

<table>
<thead>
<tr>
<th>Lamp Type</th>
<th>Initial Output (lm)</th>
<th>Total Input Power (W)</th>
<th>Efficacy (lm/W)</th>
</tr>
</thead>
<tbody>
<tr>
<td>LED¹</td>
<td>Min</td>
<td>1,357</td>
<td>11.5</td>
</tr>
<tr>
<td></td>
<td>Mean</td>
<td>1,790</td>
<td>19.2</td>
</tr>
<tr>
<td></td>
<td>Max</td>
<td>3,126</td>
<td>28.6</td>
</tr>
<tr>
<td>FL</td>
<td>BK13-30 (F28T8XL/841/ECO)²</td>
<td>2,193</td>
<td>24.4</td>
</tr>
<tr>
<td>FL</td>
<td>Typical F32T8/841³</td>
<td>2,567</td>
<td>27.5</td>
</tr>
</tbody>
</table>

1. Statistics of CALiPER Series 21 linear LED lamps (31 tested)
2. Includes 0.87 ballast factor (rated 28 W lamp values: 2,675 lm; 96 lm/W)
3. Values estimated from manufacturer catalog data with a 0.87 ballast factor applied (rated 32 W lamp values with high efficiency instant-start ballast: 2,950 lm; 92 lm/W). This is not CALiPER test data.
having a beam angle less than 120°, and diffuse-optic lamps all having a beam angle above 126°. As seen in Figure 1, none of the lamps had an omnidirectional luminous intensity distribution similar to that of a linear fluorescent lamp. Additionally, the color quality of the 31 linear LED lamps varied substantially, with many of the products having worse color quality than a typical fluorescent T8 lamp (e.g., CRI less than 80).

The report also showed that manufacturer claims are often inaccurate. CALiPER’s independent product testing showed that approximately half of the products varied by more than 10% from their claimed output (lm), input power (W), and/or efficacy (lm/W). Claimed beam angles were frequently more than 10% different from the measured value, indicating that beam angle may be a widely misunderstood metric.

Another important finding was the large number of wiring configurations exhibited by different LED lamp types, which brings up questions of interchangeability and safety.

The second report in this series, CALiPER Report 21.1, covered the photometric performance of the same 31 linear LED lamps installed in a K12 prismatic lensed troffer. In general, luminaire efficacy was strongly dictated by lamp efficacy, but the optical system of the luminaire substantially reduced the differences between the luminous intensity distributions of the lamps. While the distributions in the luminaire were similar, the differences remained large enough that workplane illuminance uniformity might be reduced if linear LED lamps with a narrow distribution were used. At the same time, linear LED lamps with a narrower distribution resulted in slightly higher luminaire efficiency.

This report, CALiPER Report 21.2, discusses the photometric performance of four lamp types in five troffer types, examining how three linear LED lamps with different luminous intensity distributions and one fluorescent

![Figure 1](image.png)

**Figure 1.** Relative luminous intensity distribution for all of the Series 21 products. The fluorescent benchmark product (BK13-30) is shown in black and has similar intensity in all directions perpendicular to the length of the lamp. The linear LED lamps are far more directional, but tend to cluster as a narrower light distribution if the face of the lamp is clear, or as a wider distribution if the face of the lamp is diffuse.
benchmark product affect luminaire efficacy, efficiency, and luminous intensity distribution (also known as photometric distribution). The luminous intensity distributions of the four lamps are shown in Figure 2. In addition to analyzing photometric reports, a subjective evaluation was performed in a full-scale mockup installation to get feedback on visual appearance and visual comfort from the lamp and luminaire combinations.

**Questions for this CALiPER Study**
This portion of the Series 21 CALiPER investigations was intended to address the following questions:

1. Given that linear LED lamps have different luminous intensity distributions, how does the change in bare-lamp performance affect the overall performance of luminaires in which linear LED lamps are installed?
2. Is the change in performance from linear LED lamps the same for five different types of recessed 2×4, 2-lamp fluorescent luminaires?
3. How do the appearance and visual comfort of the combinations of LED lamp and luminaire compare to the appearance and visual comfort of the incumbent fluorescent?

![Figure 2. Relative luminous intensity distribution of the four Series 21 products that are the focus of this report.](image)

The three linear LED lamps selected for examination in five typical troffer types are marked in purple (13-03, a clear aperture tube with narrow distribution), in blue (13-27, a diffuse aperture tube with distribution in the middle of the range), and in orange (13-20, a diffuse aperture tube with wide distribution). Note that the small black circles mark the angle of half of the beam angle, which is double the vertical angle where intensity is 50% of the maximum.
2 Methods

This CALiPER investigation involved products selected in late 2012 through 2013, with final analysis carried out in March 2014. The evaluation event with observers was held in January 2014. It is acknowledged that the products used in this evaluation may have been replaced with a newer product and may no longer be sold. However, that does not diminish the broader relevance of the findings. In fact, the lamps were selected as representative based on their performance attributes (e.g., luminous intensity distribution), and the evaluation was not intended as a measure of the suitability of any specific lamp model.

Lamp Selection

The data presented in CALiPER Application Summary Report 21 indicated that the efficacy of many (not most) of the LED lamps exceeded or was equivalent to that of T8 fluorescent lamps, but none matched the luminous intensity distribution of the omnidirectional fluorescent lamps. The physical appearance of the LED lamps can be one clue to their differing optical performance. Most linear LED lamps have a 180° aperture, as the back side of the lamp is opaque because it either contains the driver or other electronics, or because it contains aluminum or plastic elements for heat management. This usually limits the light emission to one direction, although some lamps have optics that redirect a small amount of light toward the back side of the lamp. The front face of the lamp may be clear plastic or plastic with a light striation to obscure the view of the array of LEDs behind the plastic. These lamps generally produce a narrow distribution, with a lamp beam angle of roughly 105° to 125° (the left-most diagram in Figure 3). Other lamps have heavier frosting or diffusion to more closely simulate the distribution of the fluorescent lamp—although it is still substantially different—and, depending on the material used, can produce a beam angle of roughly 125° to 160° (the middle two diagrams in Figure 3).

CALiPER Series 21 includes a total of 31 linear LED lamps. This study used three of those products, chosen to represent the range of luminous intensity distributions (Figure 3), as well as the benchmark F28T8 fluorescent lamp. The lamps included:

- 13-03: Linear LED with a clear 180° aperture and narrow measured beam angle of 105° (no claimed beam angle)
- 13-27: Linear LED with a diffuse 180° aperture and medium measured beam angle of 133° (145° claimed beam angle)
- 13-20: Linear LED with a diffuse 240° aperture and wide measured beam angle of 160° (340° claimed beam angle)
- BK13-30: Fluorescent benchmark (diffuse) with a 360° (omnidirectional) emission, operated on instant-start electronic ballast (0.87 ballast factor).

The bare-lamp performance of these four products is shown in Table 2. The bare-lamp data provides the measurements of one lamp, with the same system configuration as occurred in the troffer; for the benchmark fluorescent lamp, that means two lamps were connected to the ballast while only one lamp was photometered. The make and model of each product are listed in Appendix A.

In this report, the LED lamps are referred to as the narrow LED, medium LED, and wide LED; however, such distinctions are not part of manufacturer literature. Further, CALiPER Application Summary Report 21 indicates that the majority of currently available linear LED lamps are most readily divided into two groups based on their aperture finish: clear or diffuse. In seeking an appropriate lamp, this may be the best way to differentiate lamps, since CALiPER found that many manufacturers did not report any information about the distribution, and those that did often confused metrics like beam angle with the emitting aperture of the lamp.

Table 2. Results of CALiPER tests for the three Report 21.2 linear LED lamps and the fluorescent benchmark (BK13-30).

<table>
<thead>
<tr>
<th>DOE CALiPER Test ID</th>
<th>Aperture Finish</th>
<th>Distribution Descriptor(^2)</th>
<th>Beam Angle (90°)</th>
<th>Initial Output (lm)</th>
<th>Total Input Power (W)</th>
<th>Efficacy (lm/W)</th>
<th>CRI</th>
<th>CCT (K)</th>
</tr>
</thead>
<tbody>
<tr>
<td>13-03</td>
<td>Clear (lightly frosted)</td>
<td>Narrow</td>
<td>105</td>
<td>1,607</td>
<td>18.3</td>
<td>88</td>
<td>84</td>
<td>3963</td>
</tr>
<tr>
<td>13-27</td>
<td>Diffuse</td>
<td>Medium</td>
<td>133</td>
<td>1,844</td>
<td>22.5</td>
<td>82</td>
<td>72</td>
<td>4099</td>
</tr>
<tr>
<td>13-20</td>
<td>Diffuse</td>
<td>Wide</td>
<td>160</td>
<td>1,973</td>
<td>19.6</td>
<td>101</td>
<td>90</td>
<td>6035</td>
</tr>
<tr>
<td>BK13-30(^1)</td>
<td>N/A</td>
<td>Omni</td>
<td>N/A</td>
<td>2,193</td>
<td>24.4</td>
<td>90</td>
<td>84</td>
<td>3893</td>
</tr>
</tbody>
</table>

1. Data for one of two premium, energy-efficient 28 W fluorescent T8 lamps operated on a high-efficiency instant-start electronic ballast (normal Ballast Factor of 0.87), similar to those eligible for incentives in many electric utility rebate programs across the U.S. Rated lamp wattage and lumen output are 28 W and 2,675 lumens.
2. These nominal descriptors are used in this report to differentiate the three LED lamps evaluated. They do not correspond to an identifiable product attribute during specification.

**Luminaire Selection**

In order to explore the performance of linear LED products in use in widespread office, classroom, and healthcare applications, five common two-lamp, 2×4 troffer types were identified, all of which were designed for mounting in a 9’-high acoustical tile/T-bar ceiling. Two-lamp troffers were selected in recognition that existing office, classroom, and healthcare installations are using two-lamp units more commonly in response to pressure from energy codes and due to concern about the use of computer screens and smart devices in interior spaces with high ambient lighting. Also, it is now common for facility managers to request delamping or disconnecting of one or two lamps when three- and four-lamp troffers are remodeled for energy savings. The five troffers selected were:

1. **K12 Lensed**: Troffer with pattern 12 prismatic lens
2. **Recessed Indirect**: Troffer also known as perforated metal basket
3. **Parabolic**: Troffer with 3”-deep 12-cell semi-specular aluminum parabolic louver
4. **Volumetric**: High-efficiency troffer with two linear rounded diffusers to help distribute light to upper wall surfaces
5. **High Performance**: Troffer with angled diffusers and linear metal details

See Appendix B for a list of the troffer manufacturer names, model numbers, and basic photometric characteristics (using fluorescent lamps). Appendix C provides full specification sheets for each troffer product. Throughout this report, the troffers are referred to using the name shown in italics.

All of the linear LED lamps, fluorescent lamps, and troffer luminaires were ordered through electrical distributors and websites. The products and their arrival condition were documented once received by the CALiPER team at the Pacific Northwest National Laboratory (PNNL). One sample of each troffer type was wired with the specified instant-start electronic ballast, and the other three were wired to provide AC mains power for the linear LED lamps. In total, there were 20 different lamp-luminaire combinations.

After being configured, the products were shipped to an independent testing lab for photometric testing according to LM-79-08, then shipped directly to the evaluation host site—the PNNL mockup facility in Fairview, Oregon.

**Photometric Testing**

One sample of each of the 20 lamp-luminaire combinations was tested using a goniophotometer. The LED products were tested using absolute photometry, according to LM-79-08. Each of the products tested in this report was also photometered as a bare lamp; results for that testing are available in CALiPER Application Report 21. While CALiPER typically tests all benchmarks using absolute photometry, the data for these five product configurations were calculated using the absolute photometry of the bare-lamp-and-ballast combination along with a relative-photometry test of the lamps in the luminaire. The resulting data, prorated for the absolute lumens of the bare lamps, provides a good approximation of an absolute photometry test, and was necessary because the original testing was inadvertently performed using relative photometry.

Among other results, the complete set of photometric testing provided data for luminaire lumen output, efficiency, efficacy, and luminous intensity distribution. These results were used to compare the performance of the 20 lamp-luminaire combinations—relative to bare-lamp performance—and to determine those that work well and those that should be avoided. Photographs of each lamp-and-luminaire combination are shown in Figure 4.

**The Mockup Office Installation**

The 20 luminaires were installed in a 47’-by-16’ room with a 9’ acoustical tile ceiling at PNNL’s lighting mockup facility. The luminaires were all equipped with interfaces for the Encelium Energy Management System™ (EMS) and could be wired for individual or group switching during the evaluation process. The luminaire layout clustered together five different troffers containing lamps of the same type, for a total of four clusters (Figure 5). Each cluster was spaced 10’ on center so that identical troffer types could be switched on together with a spacing commonly seen in office and classroom installations.

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9 An absolute test of the lamp-luminaire system was approximated by multiplying the absolute photometry values for the bare-lamp system by the luminaire efficiency reported for the relative photometry test. Likewise, the luminous intensity distribution could be scaled by the ratio of the absolute photometry bare-lamp test lumens to the rated lumens used to scale the relative photometry file. This method accounts for thermal and optical effects in the same manner as absolute photometry, but eliminates the adjustment in total output made by the photometric laboratory when the relative photometry data were reported.
Figure 4. Photographs of all 20 lamp-and-luminaire combinations.
Two movable sheetrock partitions were created so that observers could position the “wall” at a typical distance from the luminaire. This allowed evaluation of the pattern of light created by each luminaire on vertical surfaces. Ceiling tile reflectance was approximately 80%, wall reflectance 70% (nominally off-white paint), and floor reflectance 30% (unfinished concrete). Several movable chairs were located in the space, and observers were encouraged to view luminaires from both a standing and a sitting position, as they would use the space.

**Observers and Evaluation Process**

In January 2014, 24 facility managers, energy engineers, and lighting industry professionals were invited to observe installed luminaires and complete questionnaires about glare and appearance. The individuals were invited through Portland sections of the Illuminating Engineering Society (IES) and the Association of Professional Energy Managers (APEM). Figure 6 shows the observers in action.

All of the troffers were illuminated when the observers initially entered the space. Subsequently, the evaluators were shown four troffers of a single type (such as Parabolic or Volumetric luminaires) at a time, and these were lamped with the narrow LED, medium LED, wide LED, or fluorescent lamps. They were not told which lamp was located in which luminaire, although if they were knowledgeable about lighting products it may have been obvious looking directly at the lamp between blades of the louvers when the Parabolic troffers were shown. The order in which luminaires were evaluated was as follows:

1. Parabolic
2. Recessed Indirect
3. High Performance
4. Volumetric
5. K12 Lens

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**Figure 5.** Reflected ceiling plan of PNNL lighting mockup facility, showing the layout of five troffer types lamped with four types of fluorescent or LED lamps. Each color represents a troffer type; each group of five troffers was lamped with a different lamp.
Observers were asked to complete their questionnaires without talking to others, in order to minimize the sharing of knowledge or prejudicial opinions, and they were asked to answer all questions (the instruction page and one of five questionnaire response pages can be seen in Appendix D). Once the observers had seen all five groups of troffers and completed their evaluations, the forms were collected and there was an open discussion of what they had seen, what they had learned, and what qualities were important to convey to a facility manager, specifier, and user.

**Data Analysis**

The data were collated and analyzed from January to March 2014. Additional on-site luminaire luminance measurements were collected post-hoc in order to help identify metrics that might explain the observers’ choices.
3 Results and Analysis

Photometric Comparison
Table 3 and Figure 7 provide photometric data for the 20 lamp-luminaire combinations. The system properties are a result of both the lamp and the luminaire performance, and there are some interactive effects; that is, some specific combinations perform worse than one would expect based on the lamp type and luminaire type.

Luminaire Lumen Output
For a given troffer type, lumen output from the luminaires was generally dependent on the lumen output of the bare lamps. Bare-lamp lumens ranged from 10% to 27% lower than the fluorescent bare-lamp lumens, with the rank order of luminaire lumen output following the same trend. However, some luminaires emitted fewer lumens than expected based on the bare-lamp lumens alone, and others slightly more. For example, the

<table>
<thead>
<tr>
<th>Luminaire Type</th>
<th>Lamp Type (CALIPER ID)</th>
<th>Beam Angle (90°)</th>
<th>Input Power (W)</th>
<th>Lamp Output (lm)</th>
<th>Luminaire Output (lm)</th>
<th>Luminaire Efficiency (%)</th>
<th>Luminous Efficacy (lm/W)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bare Lamp</td>
<td>LED Narrow (13-03)</td>
<td>105</td>
<td>18.3</td>
<td>1,607</td>
<td>-</td>
<td>-</td>
<td>87.8</td>
</tr>
<tr>
<td></td>
<td>LED Medium (13-27)</td>
<td>133</td>
<td>22.5</td>
<td>1,844</td>
<td>-</td>
<td>-</td>
<td>82.0</td>
</tr>
<tr>
<td></td>
<td>LED Wide (13-20)</td>
<td>160</td>
<td>19.6</td>
<td>1,973</td>
<td>-</td>
<td>-</td>
<td>100.7</td>
</tr>
<tr>
<td></td>
<td>FL (BK13-30)</td>
<td>N/A</td>
<td>24.4</td>
<td>2,193</td>
<td>-</td>
<td>-</td>
<td>89.9</td>
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<tr>
<td>K12 Lens</td>
<td>LED Narrow (13-03)</td>
<td>92</td>
<td>36.4</td>
<td>3,214</td>
<td>2,701</td>
<td>84%</td>
<td>74.2</td>
</tr>
<tr>
<td></td>
<td>LED Medium (13-27)</td>
<td>101</td>
<td>44.6</td>
<td>3,688</td>
<td>2,928</td>
<td>79%</td>
<td>65.7</td>
</tr>
<tr>
<td></td>
<td>LED Wide (13-20)</td>
<td>103</td>
<td>39.0</td>
<td>3,946</td>
<td>3,212</td>
<td>81%</td>
<td>82.4</td>
</tr>
<tr>
<td></td>
<td>FL (BK13-30)</td>
<td>107</td>
<td>50.7</td>
<td>4,386</td>
<td>3,299</td>
<td>75%</td>
<td>65.1</td>
</tr>
<tr>
<td>Recessed Indirect</td>
<td>LED Narrow (13-03)</td>
<td>133</td>
<td>36.4</td>
<td>3,214</td>
<td>1,817</td>
<td>57%</td>
<td>49.9</td>
</tr>
<tr>
<td></td>
<td>LED Medium (13-27)</td>
<td>126</td>
<td>44.5</td>
<td>3,688</td>
<td>2,073</td>
<td>56%</td>
<td>46.6</td>
</tr>
<tr>
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<td>LED Wide (13-20)</td>
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<td>64%</td>
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</tr>
<tr>
<td></td>
<td>FL (BK13-30)</td>
<td>123</td>
<td>51.8</td>
<td>4,386</td>
<td>2,988</td>
<td>68%</td>
<td>57.7</td>
</tr>
<tr>
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<td>LED Narrow (13-03)</td>
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<td>36.5</td>
<td>3,214</td>
<td>2,729</td>
<td>85%</td>
<td>74.8</td>
</tr>
<tr>
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<td>2,943</td>
<td>80%</td>
<td>65.8</td>
</tr>
<tr>
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<td>-1</td>
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<td>3,946</td>
<td>3,206</td>
<td>81%</td>
<td>82.0</td>
</tr>
<tr>
<td></td>
<td>FL (BK13-30)</td>
<td>-1</td>
<td>51.4</td>
<td>4,386</td>
<td>3,229</td>
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</tr>
<tr>
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<td>2,598</td>
<td>81%</td>
<td>71.6</td>
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<tr>
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<td>LED Medium (13-27)</td>
<td>130</td>
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<td>3,688</td>
<td>2,895</td>
<td>78%</td>
<td>65.1</td>
</tr>
<tr>
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<td>129</td>
<td>39.0</td>
<td>3,946</td>
<td>3,239</td>
<td>82%</td>
<td>83.1</td>
</tr>
<tr>
<td></td>
<td>FL (BK13-30)</td>
<td>132</td>
<td>51.4</td>
<td>4,386</td>
<td>3,544</td>
<td>81%</td>
<td>68.9</td>
</tr>
<tr>
<td>High Performance</td>
<td>LED Narrow (13-03)</td>
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<td>36.4</td>
<td>3,214</td>
<td>2,641</td>
<td>82%</td>
<td>72.6</td>
</tr>
<tr>
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<td>LED Medium (13-27)</td>
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<td>3,688</td>
<td>2,926</td>
<td>79%</td>
<td>65.6</td>
</tr>
<tr>
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<td>LED Wide (13-20)</td>
<td>114</td>
<td>39.0</td>
<td>3,946</td>
<td>3,327</td>
<td>84%</td>
<td>85.3</td>
</tr>
<tr>
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<td>FL (BK13-30)</td>
<td>117</td>
<td>51.9</td>
<td>4,386</td>
<td>3,755</td>
<td>86%</td>
<td>72.4</td>
</tr>
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</table>

1. Beam angle could not be accurately calculated for the luminous intensity distribution produced by the Parabolic luminaire.
Figure 7. Polar plots in the 90° plane for each combination of lamp and luminaire, illustrating differences in light distribution from the luminaires. Several luminaires exhibited asymmetrical distributions, and it is not clear whether the LED lamps, the sockets, or the luminaire itself was the cause.
Recessed Indirect luminaire with LED lamps ranged from 15% to 39% lower lumens than the fluorescent (depending on the exact type of LED lamp installed); conversely, the K12 Lens troffer with linear LED lamps ranged from 3% to 18% lower in lumen output. Thus, it can be concluded that the luminaire type affects total lumen output beyond differences in bare-lamp lumens; this effect occurs primarily because the LED lamps have different luminous intensity distributions, which may work more or less effectively with different luminaire optical systems.

Despite the effect of luminaire type on total lumen output, one lesson from this study is that it is important to pay attention to the lumen output of the linear LED lamp. For the three LED lamp types evaluated in this study, the effect of the luminaire was less than the difference in bare-lamp output. Further, none of the LED lamps was able to make up for its lower bare-lamp lumens and result in equivalent luminaire lumens. Any remaining discrepancy in luminaire lumen output must be made up through a change in light distribution that moves the light to the surfaces of greater interest; otherwise, illumination levels will be reduced, which may or may not be acceptable.

**Luminaire Efficiency**

Luminaire efficiency is determined by photometering the bare lamp outside of the luminaire, then installing the lamp inside the luminaire and measuring again. Luminaire efficiency is then a ratio of luminaire lumens to lamp lumens—it is a characterization of the “luminaire effect” previously discussed. This metric ignores the efficacy (lm/W) of the specific lamp; it simply communicates how efficiently the luminous intensity distribution of a lamp works together with the optical system of a luminaire. A higher percentage means more light exits the luminaire. Luminaire efficiency does not indicate the effectiveness of the emitted light distribution.

In the K12 Lens and Parabolic Louver troffers, the LED lamps improved the luminaire efficiency between 6% and 12% or 8% and 15%, respectively, compared to the fluorescent benchmark test results. The efficiency of the Volumetric luminaire was nearly unaffected by the linear LED lamps, with a maximum decrease of 3% and a maximum increase of 2% versus the fluorescent benchmark. The remaining two luminaire types showed a reduction in efficiency: the Recessed Indirect luminaire decreased between 6% and 18% compared to the same troffer lamped with the benchmark fluorescent lamp, and the efficiency of the High Performance troffer dropped between 2% and 7%, depending on the specific LED lamp.

As graphed in Figure 8, no specific LED lamp type (and corresponding luminous intensity distribution) resulted consistently in the greatest increase or decrease in luminaire efficiency across the five troffer types. It can be concluded that it is necessary to know what luminaire is being retrofitted before anticipating luminaire efficiency changes. Luminaire efficiency may rise, fall, or remain very similar depending on the combination of the lamp type and optical system of the luminaire.

Figure 8 also demonstrates that for all troffer types except the Recessed Indirect, the range in luminaire efficiency was much smaller for all three of the LED lamp types than for the fluorescent benchmark; whereas the range in efficiency for those four troffer types was greater than 10% using the fluorescent benchmark lamp, it was less than 5% for the three LED lamp types. Across all lamp types, the variation in luminaire efficiency for the four troffer types other than Recessed Indirect was just 7%. Uniquely, the luminaire efficiency of the Recessed Indirect troffer was the lowest for each lamp in any of the troffers, and it appears to be affected the most by narrower luminous intensity distributions.

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10 The reported changes are calculated as a percent improvement over the efficiency of the fluorescent-lamped version of the same luminaire. This is not the absolute difference in measured luminaire efficiency.
Another important note about luminaire efficiency is the role of ambient temperature on the performance of both LED and fluorescent lamps. When operated in a luminaire, the ambient temperature is higher than the 25°C maintained for a bare-lamp test according to LM-79. This may affect the output of lamps to varying degrees, although it was not explicitly measured by CALiPER for this investigation. Thermal effects do factor into luminaire efficiency calculations.

**Luminaire Efficacy**

Luminaire efficacy is the lumens delivered by the luminaire as lamped, divided by the system input power (Watts). It is an important metric, because it integrates the bare-lamp efficacy with the luminaire efficiency. Ultimately, luminaire efficacy is a more important indicator of system performance and energy use than luminaire efficiency. Figure 9 shows the luminaire efficacy for each lamp-luminaire combination.

As with luminaire lumen output, luminaire efficacy is dependent on bare-lamp efficacy, but is affected somewhat by changes in luminaire efficiency. Considering only the LED lamps, the rank order of efficacy for the lamp types within any luminaire type was the same as the rank order for bare-lamp efficacy. In other words, the changes in luminaire efficiency (no more than 7% within any luminaire type) were less than the differences in bare-lamp efficacy (all greater than 7%) for the three lamps included in this study. Nonetheless, compared to the fluorescent benchmark, all LED lamp types in the K12 Lens and Parabolic troffers resulted in higher luminaire efficacies, despite two of the three lamps having lower bare-lamp efficacies. This corresponds to the fact that the K12 Lens and Parabolic luminaires always had higher luminaire efficiencies when lamped with the LED lamps, but the other luminaire types did not. The conclusion is that K12 Lens and Parabolic troffers are the most favorable to LED lamps based only on efficacy considerations (i.e., ignoring appearance and luminous intensity distribution); used in those two troffer types, bare LED lamps with efficacies as much as 10% lower than an existing fluorescent lamp—depending on the exact luminous intensity distribution—may result in a higher total luminaire efficacy. For the other three luminaire types—Recessed Indirect, Volumetric, and High Performance—

![Luminaire efficiency (%) by lamp and troffer type.](image)

**Figure 8.** Luminaire efficiency (%) by lamp and troffer type.
the efficacy of the bare LED lamp must be at least as high as the fluorescent lamp if higher system efficacy is a goal.

**Luminaire Luminous Intensity Distribution**
The different luminous intensity distribution of a linear LED lamp compared to a linear fluorescent lamp affects the luminous intensity distribution of some troffers in which it is installed, but not others. As a rough approximation of distribution width, CALiPER calculated the beam angle of the luminaire, or the total angle between the points at which the intensity drops to a 50% of the nadir value, in the 90° plane. The luminaire beam angles are listed in Table 3. Polar plots of the luminous intensity distribution in the 90° plane (across the lamps) for all combinations of lamps and luminaires are shown in Figure 7.

Figures 10 through 14 show relative luminous intensity distributions for each lamp-luminaire combination in the 90° plane (across the lamps), with each figure representing one luminaire type. It is important to understand that these are relative plots, with the maximum value normalized to 100% for each plot. In Figure 9, for example, it may appear that the LED-lamped K12 Lens troffers have lower intensity at all vertical angles, when in fact they would have greater luminous intensity at nadir if lumen output were equivalent. The plots can be interpreted as follows:

- For the **K12 Lens** troffer (Figure 10), the narrower LED lamps resulted in relatively more light being directed straight down, with relatively less light between vertical angles of 20° to 60°. As demonstrated in CALiPER Report 21.1 for the full collection of Series 21 linear LED lamps, this results in a reduction in spacing criterion; in a retrofit situation, this could mean less even illumination, and in a new installation, the luminaires may have to be spaced closer together to achieve the same uniformity.
For the Recessed Indirect troffer (Figure 11), all four lamps resulted in very similar luminaire luminous intensity distributions, with the relative emission at any given angle within 10% of each other. The spacing criteria for the luminaires with each lamp type were very similar.

For the Parabolic troffer (Figure 12), lamp distribution had an unpredictable effect on luminaire distribution. Two of the LED lamps had a slightly greater “batwing” effect than the fluorescent-lamped troffer, but the narrowest LED lamp (13-03) substantially reduced the batwing, having relatively higher intensity toward nadir (straight down). In all cases, the LED lamps had a much smaller spacing criterion in the 90°–270° plane, with the fluorescent-lamped luminaire at 1.7, and the LEDs around 1.3.

As with the Recessed Indirect troffer, the lamps had little effect on the luminous intensity distribution of the Volumetric troffers (Figure 13). Relative luminous intensity for the four lamp types was always within about 10%. The spacing criteria for the luminaires with each lamp type were similar.

In the High Performance luminaire (Figure 14), the LED lamps resulted in less intensity toward nadir. As with some other luminaire types, the narrowest LED lamp (clear optic) exhibited the greatest deviation from the fluorescent lamp, whereas the medium and wide LED lamps (both with diffuse optics) performed very similarly. This change enhanced the batwing effect of the luminaire and increased the spacing criteria for the LED-lamped versions compared to the fluorescent version—the only combination where this occurred.

Delivered Illuminance
If lumen output were the same, which lamp’s luminous intensity distribution would result in the highest workplane illuminance? Conversely, if a lamp’s output were a certain percentage lower than a competitor, could it still deliver the same workplane illuminance? Both of these questions require combining the effects of luminaire efficiency and luminaire luminous intensity distribution, both of which are dependent on bare-lamp luminous intensity distribution.
Figure 11. Luminous intensity distribution of the Recessed Indirect troffer with four different lamp types. The distribution of the luminaire was very similar for all lamp types except the narrow LED, which resulted in a slightly wider distribution.

Figure 12. Luminous intensity distribution of the Parabolic troffer with four different lamp types. Note that the narrow LED lamp (13-03) performed differently from the other two LED lamps (13-27 [medium] and 13-20 [wide]). Linear LED lamps emit little light upward, especially those with clear apertures (e.g., the narrow LED); consequently, the light distribution patterns changed compared to the fluorescent benchmark. For all three LED lamps, the light distribution became “spikier” and the cutoff sharper at the high end of the distribution. Parabolic louver luminaires usually produce a batwing distribution, so the luminaire beam angle metric does not describe the distributions accurately.
First, it is interesting to examine the effectiveness of the various luminous intensity distributions in delivering workplane illuminance. While a workplane is not always the target for troffer luminaires, it is a common point of comparison. To examine delivered illuminance, a model was built simulating a large room with a 9' ceiling and the luminaires on 8'-by-10' spacing. A calculation grid at 2.5' above the floor was used to calculate the mean, maximum, and minimum illuminance in the 8'-by-10' area between the centers of the luminaires. In general, the
changes in luminous intensity distribution resulted in minimal changes to the delivered illuminance. This was
determined by normalizing the lumen output of each combination to that of the fluorescent luminaire, then
examining the differences in workplane illuminance, which are shown in Figure 15. All of the differences were
less than 5%, with the Parabolic luminaire lamped with the narrow linear LED lamp having the highest delivered
illuminance per lamp lumen.

It is also important to consider the combined effect of luminaire efficiency and luminous intensity distribution,
which is a more holistic evaluation of the effect of a specific lamp on the delivered illuminance from a luminaire.
Figure 16 shows the percentage change in delivered illuminance relative to the bare LED lamp lumens. For
example, the Narrow linear LED lamp (13-03) resulted in 16% higher average workplane illuminance than if a
fluorescent troffer having the same lamp lumens were used. Figure 16 further illustrates that the best fit for

![Figure 15](image15.png)

**Figure 15.** Change in delivered workplane illuminance due to differences in luminous intensity distribution for the LED lamps relative to the fluorescent benchmark. The LED lamps resulted in a slightly greater percentage of the luminaire lumens reaching the workplane for the K12 and Parabolic luminaires. The difference was negligible for the other luminaire types.

![Figure 16](image16.png)

**Figure 16.** Change in delivered workplane illuminance due to differences in luminaire efficiency and luminous intensity for the LED lamps relative to the fluorescent benchmark. If the linear (T8) LED lamps emitted the same lamp lumens as the baseline 28 W fluorescent lamp, the LED and K12 Lens and LED and Parabolic combinations would result in higher average workplane illuminance, whereas the LED and Recessed Indirect combinations would result in lower average illuminance. The combinations with Volumetric and High Performance luminaires were about the same for LED and fluorescent lamps.
linear LED lamps—when only workplane lighting is a concern—are the K12 Lens and Parabolic troffers. Recessed Indirect troffers should generally be avoided.

While some combinations of linear LED lamps and luminaires improved the percentage of bare-lamp lumens delivered to the workplane, they did not improve workplane illuminance uniformity. In all cases, the uniformity ratios for the LED-lamped versions of a given troffer type were either very similar to or worse than they were for the fluorescent-lamped troffers. The worst scenario was for the High Performance troffer with the narrow LED lamp, which had an average-to-minimum ratio of 1.25, compared to a ratio of 1.07 for the fluorescent-lamped version of the same troffer. While neither case would necessarily be problematic, the difference is worth noting.

**Subjective Evaluation**

Questionnaire responses from 24 facility managers, energy specialists, and lighting industry professionals were tabulated and analyzed. A review of responses from both groups revealed no apparent differences, so the responses from lighting-knowledgeable participants and those less familiar with lighting technologies and techniques were combined. Given the sample size and procedures, no tests of statistical significance were performed. Photographs of the 20 lamp-and-luminaire combinations are shown in Figure 5.

Observers were asked to rank, from best to worst, the visual appearance and visual comfort of the four troffers with different lamping. Figure 17 compares the sum of the rank responses to get a sense of most-appreciated (high sum) and least-appreciated (low sum) combinations of lamp and luminaire. The data was normalized to account for differences in the number of observer responses when necessary; however, nearly all observers responded to each question.

In addition to asking observers to rank the options from most- to least-preferred for appearance and comfort,
the questionnaire asked observers to rate each luminaire’s acceptability for building projects. This was intended to acknowledge that although an observer may prefer one type of troffer over another, both may be acceptable for use in many applications. Figure 18 illustrates the number of observers finding the luminaire-and-lamp combination to be acceptable, again normalized to adjust for non-responses.

The responses to questions on visual comfort ranking and acceptability were compared to maximum spot luminances (shown in Table 4) which were measured at a steep angle of 10° from vertical (to simulate observers sensing glare from overhead) and at an angle of 35° from vertical (to simulate observers sensing direct glare from luminaires in the visual field). Maximum luminances measured from the steep angle were correlated with comfort ratings, except for the Parabolic troffer, where the LEDs of the narrow LED lamp (which had a clear aperture) were directly visible between the blades of the parabolic louver (Figure 19). There are two possible explanations for this exception. The first is that measuring the maximum luminance of the LED chip visible through the clear aperture was difficult and uncertain, even with a 1/3° capture angle on the luminance meter; as a result, the measured value may have been underreported, because it was diluted by the low-luminance surroundings. A second explanation may be that the direct view of the LED may have amplified the observer’s discomfort response.

Although the responses from the observers were not subjected to intense statistical rigor, it is possible to make some observations about the performance of the lamp-and-luminaire combinations:

- Fluorescent-lamped troffers were always preferred for appearance and comfort, compared to the same troffer lamped with any of the linear LED lamps. However, both of the LED products with a diffuse aperture—the medium LED and wide LED—were generally rated as acceptable.

![Figure 18. Observer acceptability rating of troffers. The percentage of observers rating as acceptable the appearance and visual comfort for all combinations of lamps and luminaires (higher = more acceptable, low = less acceptable).](image-url)
Except for the Parabolic luminaire, maximum luminaire luminances measured from 10° vertical were correlated with comfort ratings, and might be a simple method for predicting human response to glare.

The narrow LED lamp (which had a clear aperture) produced the worst ratings on all appearance questions, irrespective of luminaire type.

The narrow LED lamp produced the worst ratings on comfort, except when used in the Volumetric luminaire, where the luminaire optics almost completely obscured the visible differences among the LED lamps.

Observers consistently rated the fluorescent-lamped version of each luminaire as having the most acceptable appearance, and the narrow LED-lamped version as having the least acceptable appearance.

The visual appearance difference between the fluorescent and narrow LED lamps was the greatest in the Parabolic Louver and K12 Lens troffers. When these luminaires were lamped with fluorescent lamps, observers almost unanimously rated the luminaires acceptable for a building project, with over 75% giving them the highest rating. Conversely, over 65% of participants gave the luminaires an unacceptable rating when the luminaires were lamped with the narrow LED lamps, with over 70% giving the lowest ranking.

### Table 4. Maximum spot luminance measurements and observer comfort ratings for each lamp-and-luminaire combination. Note the similarity between the rank order of the 10° luminance measurements and the rank order of the comfort ratings.

<table>
<thead>
<tr>
<th>Troffer Type</th>
<th>Lamp Type</th>
<th>Measured Luminance (cd/m²)</th>
<th>Measured Luminance Order (1=best, 4=worst)</th>
<th>Order of Observer Comfort Ratings¹ (1=best, 4=worst)</th>
</tr>
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<tbody>
<tr>
<td></td>
<td></td>
<td>10°</td>
<td>35°</td>
<td>10°</td>
</tr>
<tr>
<td>K12 Lens</td>
<td>LED Narrow (13-03)</td>
<td>13,840</td>
<td>7,720</td>
<td>4</td>
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<tr>
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<td>LED Medium (13-27)</td>
<td>8,820</td>
<td>6,687</td>
<td>2</td>
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<tr>
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<td>LED Wide (13-20)</td>
<td>9,110</td>
<td>5,911</td>
<td>3</td>
</tr>
<tr>
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<td>FL (BK13-30)</td>
<td>4,749</td>
<td>4,126</td>
<td>1</td>
</tr>
<tr>
<td>Recessed Indirect</td>
<td>LED Narrow (13-03)</td>
<td>2,421</td>
<td>2,630</td>
<td>4</td>
</tr>
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<td>2,148</td>
<td>2</td>
</tr>
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<td>LED Wide (13-20)</td>
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<td>2,312</td>
<td>3</td>
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<td></td>
<td>FL (BK13-30)</td>
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<td>2,259</td>
<td>1</td>
</tr>
<tr>
<td>Parabolic</td>
<td>LED Narrow (13-03)</td>
<td>13,130</td>
<td>5,329</td>
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<td>FL (BK13-30)</td>
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<td>4,693</td>
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<td>FL (BK13-30)</td>
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<td>High Performance</td>
<td>LED Narrow (13-03)</td>
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<td>13,520</td>
<td>4</td>
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<td>LED Medium (13-27)</td>
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<td>8,815</td>
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<td>10,510</td>
<td>3</td>
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<tr>
<td></td>
<td>FL (BK13-30)</td>
<td>6,201</td>
<td>5,856</td>
<td>1</td>
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</table>

1. In three instances, the comfort or acceptability rating was tied.
Figure 19. Correlation between spot luminance measurements at 10° from nadir (top) and 35° from nadir (bottom) versus the sum of observers’ ranks for comfort. For all but the Parabolic troffer, the rankings were highly correlated with the luminance data, especially to the measurement at 10°.
4 Conclusions

This CALiPER report examined performance of linear LED lamps in five different types of fluorescent troffers. Based on both photometric testing and observer responses, LED lamps may work well in some troffers but poorly in others. Table 5 provides a summary of the key findings. Lessons include:

- **Linear LED lamp-and-luminaire combinations generally performed more like fluorescent-lamped luminaires when the lamps exhibited a diffuse finish on the aperture, and consequently had a wider distribution and larger beam angle.** Observers preferred the appearance of the luminaires with these lamps (medium and wide) over the one with the narrow LED lamps and found them less glaring, although the appearance and visual comfort of the fluorescent-lamped luminaires were still regarded as best.

- **Volumetric and High Performance troffers are good candidates for using linear LED lamps.** Of the five luminaire types, linear LED lamps resulted in a light distribution that was most similar to the fluorescent benchmark in the Volumetric troffer. Luminaire efficiency was generally unchanged, and the physical appearance was not dramatically altered by the more-directional LED lamps, making this troffer type the best candidate for an LED lamp retrofit—assuming improved bare-lamp performance. Similarly, the High Performance troffer with LED lamps exhibited a comparable photometric distribution—more so with diffuse-aperture linear LED lamps—and the efficiency and appearance were only minimally affected. If linear LED lamp efficacy exceeds that of fluorescent and lumen output is sufficient, this troffer type may also be a good candidate for retrofit.

- **K12 Lens and Parabolic troffers may be candidates for using linear LED lamps in some applications.** These two luminaire types saw higher luminaire efficiency with the linear LED lamps than the fluorescent benchmark, but appearance was considerably altered by the more directional linear LED lamps. This led to a greater glare response from observers. Also, the light distribution from K12 Lens troffers was narrowed, which may lead to more-uneven workplane lighting in some applications. With linear LED lamps, the Parabolic luminaires were more glaring and the luminous intensity distribution was spikier. Linear LED lamps with lumen output and efficacy at least 90% of that of a T8 fluorescent lamp could be used with caution in these luminaires; although they may be advantageous from an energy-use perspective, lighting quality may be reduced. To achieve energy savings and a reasonable payback, efficacy should be substantially higher than that of a T8 fluorescent lamp.

- **Recessed Indirect troffers are generally less compatible with linear LED lamps.** Linear LED lamps are not recommended for use in Recessed Indirect luminaires, because the directionality of the LED lamps may substantially reduce the efficiency of the luminaire optics. Linear LED lamps can only compete with fluorescent lamps in this luminaire type if their bare-lamp efficacy exceeds that of fluorescent by at least 5% and if the lamp lumen output is equivalent. Linear LED and fluorescent lamps resulted in similar luminous intensity distributions in Recessed Indirect troffers.

- **Manufacturers frequently misidentify beam angles.** The five troffer types were equipped with fluorescent lamps, plus three selected linear LED lamps that represented a narrow, medium, and wide distribution as best as this could be identified from the manufacturers’ technical information. This report provides guidance on selecting appropriate linear LED lamps for specific troffer types, but that guidance is difficult to apply unless manufacturers report accurate distribution information (e.g., beam angle) about their linear LED products. It became clear to the CALiPER team that manufacturers frequently misidentified the beam angle of their lamps, often confusing the aperture angle with beam...
Table 5. Summary of CALiPER results and observer responses for linear (T8) LED lamp performance compared to the CALiPER benchmark F28T8 fluorescent lamp.

<table>
<thead>
<tr>
<th>Distribution</th>
<th>Visual Appearance</th>
<th>Luminaire Efficiency</th>
<th>Efficacy</th>
<th>Light Output</th>
<th>Observers' Comments</th>
<th>Conclusions</th>
</tr>
</thead>
<tbody>
<tr>
<td>CALiPER R21: Full set of 31 linear LED lamps</td>
<td>Not omnidirectional, 105–160° beam angle</td>
<td>Not Applicable</td>
<td>Not Applicable</td>
<td>66–143 lm/W (90 lm/W for fluorescent benchmark)</td>
<td>1,357–3,126 lm (2,193 lm for fluorescent benchmark)</td>
<td>Not Applicable</td>
</tr>
<tr>
<td>CALiPER R21.2: Subset of 3 linear LED lamps</td>
<td>Not omnidirectional, 105–160° beam angle</td>
<td>Not Applicable</td>
<td>Not Applicable</td>
<td>82–101 lm/W (90 lm/W for fluorescent benchmark)</td>
<td>1,607–1,973 lm (2,193 lm for fluorescent benchmark)</td>
<td>Not Applicable</td>
</tr>
<tr>
<td><strong>K12 Lens</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>The beam angle of the luminaire with all types of linear LED lamps was 4° to 15° smaller than with fluorescent lamps.</td>
<td>Linear LED lamps, especially those with a narrow distribution, resulted in a more striped appearance.</td>
<td>5% to 12% higher (relative) for all linear LED lamp types; better for narrow (clear) lamps.</td>
<td>Depends on lamp efficacy; linear LED lamps proportionally higher due to increases in luminaire efficiency.</td>
<td>Depends on lamp lumens; linear LED lamps proportionally higher due to increases in luminaire efficiency.</td>
<td>Fluorescent preferred for glare and appearance; wide (diffuse) linear LED lamps provided best appearance and comfort among LED options.</td>
</tr>
<tr>
<td><strong>Recessed Indirect</strong></td>
<td>Medium and wide (diffuse) LED lamps resulted in performance similar to fluorescent; the narrow (clear) LED lamps resulted in a wider beam angle (by 10°).</td>
<td>The pattern of light on the upper reflector changed with the width of the distribution.</td>
<td>3% to 18% lower (relative) for linear LED lamps, depending on the type; worse for narrow (clear) lamps.</td>
<td>Depends on lamp efficacy; linear LED lamps proportionally lower due to decreases in luminaire efficiency.</td>
<td>Depends on lamp lumens; linear LED lamps proportionally lower due to decreases in luminaire efficiency.</td>
<td>Fluorescent preferred for glare and appearance.</td>
</tr>
<tr>
<td><strong>Parabolic</strong></td>
<td>With the LED lamps, the luminaire had a “spikier” batwing distribution, with sharper cutoff of light at high angles; this resulted in darker areas at the top of walls.</td>
<td>With narrower distributions, the upper reflector became dark; the linear LED lamp face was perceived as brighter.</td>
<td>8% to 15% higher (relative) for linear LED lamps, depending on the type.</td>
<td>Depends on lamp efficacy; linear LED lamps proportionally higher due to increases in luminaire efficiency.</td>
<td>Depends on lamp lumens; linear LED lamps proportionally higher due to increases in luminaire efficiency.</td>
<td>Linear LED lamps resulted in worse appearance and more glare than fluorescent; narrow (clear) LED lamps were worst among the LED options.</td>
</tr>
<tr>
<td><strong>Volumetric</strong></td>
<td>No appreciable difference</td>
<td>No appreciable difference</td>
<td>No appreciable difference</td>
<td>Proportional to lamp efficacy</td>
<td>Proportional to lamp lumens</td>
<td>Little appearance or glare difference between fluorescent and LED linear lamps.</td>
</tr>
<tr>
<td><strong>High Performance</strong></td>
<td>Wide distribution linear LED lamps resulted in a luminaire distribution more similar to fluorescent; narrow bare-lamp LED distributions resulted in greater difference.</td>
<td>Narrow (clear) linear LED lamps resulted in a somewhat more striped appearance for the diffuser.</td>
<td>2% to 8% lower (relative) for linear LED lamps, depending on the type.</td>
<td>Depends on lamp efficacy; linear LED lamps proportionally lower due to decreases in luminaire efficiency.</td>
<td>Depends on lamp lumens; linear LED lamps proportionally lower due to decreases in luminaire efficiency.</td>
<td>Fluorescent preferred for glare and appearance, but linear LED lamps were acceptable; wide (diffuse) linear LED lamps were the best among the LED options.</td>
</tr>
</tbody>
</table>

**Conclusions**

- Choose a wide-distribution (diffuse aperture) LED lamp for high lumen output (>1,900 lm) and efficacy (>100 lm/W) for comparable or better performance and energy savings. Workplane illuminances may be less uniform at the same spacing.
- Consider using linear LED lamps. An improved fluorescent lamp or ballast, LED retrofit kit, or dedicated LED luminaire are better options unless the linear LED lamp efficacy and lumen output are at least 20% higher than fluorescent.
- Cautiously consider using linear LED lamps. Choose wide distribution (diffuse aperture) LED lamps with high output (> 2,000 lm) and efficacy (>100 lm/W). Workplane uniformity may be reduced at the same spacing and room walls may appear darker. Increased glare is a possibility.
- Definitely consider using linear LED lamps. Choose wide-distribution (diffuse aperture) LED lamps with high lumen output (>1,900 lm) and efficacy (>100 lm/W) for comparable performance and energy savings.
angle, or misunderstanding the traditional definition of beam angle. Absent accurate beam angle data, aperture finish can generally be used to differentiate between lamps with narrower and wider distributions.

- **See mockups before ordering large quantities of linear LED lamps.** Specifiers, facility managers, and end users should be wary of placing large orders for linear LED lamps until they have seen four to eight troffers retrofitted and have feedback on the appearance and visual comfort of the retrofitted troffer, as well as the ease of the electrical change.

- **Consider other alternatives as well.** LED troffer retrofit kits and even premium fluorescent lamps with low-output, high-efficiency ballasts should be considered together with the linear LED lamp options, because they may offer better appearance, comfort, light distribution, or other important performance characteristics.

Linear LED lamps may be good alternatives to T8 fluorescent lamps in some applications. However, this is far from a universal recommendation. So much depends on specific LED product performance, quality, and the troffer in which it will be used, as well as the economic issues of LED lamp cost, cost of retrofit labor, hours of operation, and local electric rates. Best results will be achieved when specifiers, facility managers, and contractors scrutinize the LED product offerings and carefully pair them with appropriate applications.
## Appendix A: Lamp Model Identification

Table A1. Product brand and model identification.

<table>
<thead>
<tr>
<th>DOE CALiPER Test ID</th>
<th>Brand</th>
<th>Model</th>
</tr>
</thead>
<tbody>
<tr>
<td>13-03</td>
<td>Toggled</td>
<td>MK2M-T8-48-UN19ND-4080D2-A1</td>
</tr>
<tr>
<td>13-20</td>
<td>Miracle LED</td>
<td>T8 Cool 48”</td>
</tr>
<tr>
<td>13-27</td>
<td>InnoGreen</td>
<td>IG-220DT8120-20-NW</td>
</tr>
<tr>
<td>BK13-30</td>
<td>Lamp: GE</td>
<td>F28T8XLSGPX41ECO</td>
</tr>
<tr>
<td></td>
<td>Ballast: Philips Advance</td>
<td>IOPA2P32N</td>
</tr>
</tbody>
</table>
## Appendix B: Luminaire Product Identification and Performance Metrics using Fluorescent Lamps

### Table B1. Troffer identification and performance characteristics with fluorescent lamps

<table>
<thead>
<tr>
<th>Product</th>
<th>Manufacturer’s Listed Luminaire Efficiency (%)</th>
<th>CALiPER Luminaire Efficiency (%)</th>
<th>CALiPER Calculated Lumens (BK13-30) (lm)</th>
<th>CALiPER Measured Power (BK13-30) (W)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Two Lamps and Ballast (BK13-30)</td>
<td>-</td>
<td>-</td>
<td>4,386</td>
<td>48.9</td>
</tr>
<tr>
<td><strong>K12 Lens</strong></td>
<td><strong>Columbia 4PS24-232G-A12</strong></td>
<td>87%</td>
<td>3,298</td>
<td>50.7</td>
</tr>
<tr>
<td>Recessed Indirect</td>
<td><strong>Lithonia 2AV-G-232-MDR</strong></td>
<td>68%</td>
<td>2,987</td>
<td>51.8</td>
</tr>
<tr>
<td><strong>Parabolic</strong></td>
<td><strong>Columbia P4D24-232-G-MA26-S</strong></td>
<td>76%</td>
<td>3,228</td>
<td>51.4</td>
</tr>
<tr>
<td><strong>Volumetric</strong></td>
<td><strong>Cooper/Metalux 2AC—232</strong></td>
<td>85%</td>
<td>3,509</td>
<td>51.4</td>
</tr>
<tr>
<td><strong>High Performance</strong></td>
<td><strong>Finelite HPR-A-2x4-DCO-2T8</strong></td>
<td>85%</td>
<td>3,754</td>
<td>51.9</td>
</tr>
</tbody>
</table>

1. Luminaire efficiency does not indicate the optical efficiency of the luminaire, but is a ratio of bare-lamp and in-luminaire performance.
2. An absolute test of each lamp-luminaire system was approximated by multiplying the absolute photometry values for the bare-lamp system by the luminaire efficiency reported for a relative photometry test. This method accounts for thermal and optical effects in the same manner as absolute photometry, but eliminates the adjustment in total output made by the photometric laboratory when the relative photometry data was reported.
Appendix C: Troffer Specification Sheets

Columbia LIGHTING

FEATURES

- 4½" deep fluorescent troffer eliminates lens shadowing
- Lamp-to-lens spacing is over 2'
- Contoured housing maximizes photometric performance with uniform lens brightness
- Mitered corners on door present a clean uninterrupted appearance
- Rolled edge housing on all four sides makes the fixture safer and easier to handle
- Heavy duty door frame enhances appearance from eye level
- Snug door fit eliminates light leaks
- Recessed, surface or cable mount
- UL listed 1998
- Available with exclusive wiHUBB technology preinstalled
  - Peer to peer, self-healing wireless mesh network
  - Integrated control system for 0-10/DC or step dimming, or On/Off

CONSTRUCTION

Housing is constructed of heavy gauge steel, die formed for extra rigidity. Standard flush door is formed steel with mitered corners. Doors are retained by cam action latches, are easily removed without tools, and hinge from either side. Regressed or flush aluminum doors with mitered corners are available. End caps are hinged and screwed to the housing for extra rigidity. Four integral T-bar clips are located in the end caps. Wireway accessible from below for upgrades or maintenance.

BALLAST & ELECTRICAL

All luminaires are completely wired with class “P,” thermally protected, resettable, HPS ballast, sound rated A. Lampholders are medium bi-pin with positive retention. Furnished with an access plate. CEE NEMA Premium compliant.

FINISH

All metal parts processed with a multi-stage phosphate bonding treatment and finished with a high reflectance baked white enamel. For a post painted housing finish suffix catalog number with PAF.

SHELTHING

Standard lens is a 100% prismatic virgin pattern 12. Other shielding may be specified. If desired shielding media is not shown in ordering guide, contact your local Hubbell Lighting representative.

CEILING COMPATIBILITY

Designed for recessed installation in standard inverted tee grid ceilings (G), recessed installation in hard ceilings (G with FK accessory), Surface mount at ceiling plane (SM) or cable mount suspension below ceiling plane (CM). For compatibility with specific ceilings contact your Hubbell Lighting representative.

CERTIFICATION

All luminaires are built to UL 1998 standards and bear appropriate UL and cUL or CSA labels. Damp location labeling is standard. Emergency-equipped fixtures labeled UL 924.

ORDERING INFORMATION

EXAMPLE 4PS24-332G-FSA12-EU-SLL

<table>
<thead>
<tr>
<th>4PS</th>
<th>24</th>
<th>-</th>
<th>-</th>
<th>-</th>
<th>-</th>
</tr>
</thead>
<tbody>
<tr>
<td>MODEL</td>
<td>No. OF LAMPS</td>
<td>CEILING TYPE</td>
<td>SHIELDING</td>
<td>VOLTAGE</td>
<td>OPTIONS</td>
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<tr>
<td>4PS</td>
<td>2</td>
<td>G</td>
<td>4PS24-332G</td>
<td>A12</td>
<td>F0735</td>
</tr>
<tr>
<td>4PS</td>
<td>3</td>
<td>F</td>
<td>-</td>
<td>A15</td>
<td>-</td>
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<td>-</td>
<td>-</td>
<td>M</td>
<td>-</td>
<td>A19</td>
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<td>-</td>
<td>-</td>
<td>SM</td>
<td>-</td>
<td>PC1</td>
<td>-</td>
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<td>-</td>
<td>-</td>
<td>CM</td>
<td>-</td>
<td>PC2</td>
<td>-</td>
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<td>SIZE</td>
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<td>-</td>
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<td>LAMP TYPE</td>
<td>24&quot; x 4'</td>
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<td>DOOR STYLE</td>
<td>FS</td>
<td>2B</td>
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<td>E</td>
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<td></td>
<td>FA</td>
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<td>51 Watt</td>
<td>ELW</td>
<td>F0835</td>
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<td></td>
<td>RA</td>
<td>54</td>
<td>4&quot; or 54&quot; or 51 Watt</td>
<td>JE</td>
<td>FS835</td>
</tr>
<tr>
<td></td>
<td>SFA</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
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<td></td>
<td>SRA</td>
<td>-</td>
<td>-</td>
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<td>-</td>
</tr>
<tr>
<td>ACCESSORIES (ORDER SEPARATELY)</td>
<td>CM4812S3C3XIT</td>
<td>48&quot; Cable Mount Kit for 2&quot; Wide CM ceiling type, 3 Wire Feed Cord</td>
<td>-</td>
<td>-</td>
<td></td>
</tr>
</tbody>
</table>

1 Order hanger accessories separately.

2 Not available with Surface Mount Ceiling Type.

3 In-Fixture Module Kit and 24" overall fixture height at power feed location.

4 Provides end wiring access for continuous row mounting. Contact factory for 3-lamp configurations.

LENSED TROFFERS / 4PS24-2, 4PS24-3
## Photometric Data

### Luminaire Data

<table>
<thead>
<tr>
<th>Luminaire</th>
<th>4PS24-232G-FS12</th>
<th>4PS24-232G-FS12</th>
</tr>
</thead>
<tbody>
<tr>
<td>2' x 4' 2-Lamp White Troffer with Prismatic A12 Acrylic Lens</td>
<td>REL-TP2-SC</td>
<td>REL-TP2-SC</td>
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<tr>
<td>Ballast</td>
<td>0.88</td>
<td>0.88</td>
</tr>
<tr>
<td>Lamp</td>
<td>F32T8</td>
<td>F32T8</td>
</tr>
<tr>
<td>Lumens per Lamp</td>
<td>2900</td>
<td>2900</td>
</tr>
<tr>
<td>Total Input Watts</td>
<td>64</td>
<td>64</td>
</tr>
<tr>
<td>Mounting</td>
<td>Recessed</td>
<td>Recessed</td>
</tr>
<tr>
<td>Shielding Angle</td>
<td>0° = 90° 90° = 90°</td>
<td>0° = 90° 90° = 90°</td>
</tr>
<tr>
<td>Spacing Criteron</td>
<td>0° = 1.22 90° = 1.34</td>
<td>0° = 1.24 90° = 1.31</td>
</tr>
</tbody>
</table>

### Zone Lumen Summary

<table>
<thead>
<tr>
<th>Zone</th>
<th>Lumens</th>
<th>% Lamp</th>
<th>% Fixt.</th>
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</thead>
<tbody>
<tr>
<td>0-30</td>
<td>941</td>
<td>57</td>
<td>33.1</td>
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<td>31-60</td>
<td>2640</td>
<td>45.5</td>
<td>25.6</td>
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<td>61-90</td>
<td>4380</td>
<td>73.8</td>
<td>53.3</td>
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<td>90-120</td>
<td>5078</td>
<td>86.5</td>
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<td>120-150</td>
<td>6240</td>
<td>77.8</td>
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</table>

### Coefficients of Utilization (%)

<table>
<thead>
<tr>
<th>RC</th>
<th>80</th>
<th>70</th>
<th>50</th>
<th>30</th>
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<tbody>
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<td>8</td>
<td>7</td>
<td>6</td>
<td>5</td>
</tr>
</tbody>
</table>

### Indoor Candela Plot

- **RCR** = Recessed Candela Ratio
- **RC** = Effective Ceiling Candela Reflectance
- **RW** = Wall Reflectance

### Energy Data

- **Total Luminaire Efficiency**: 86.5%
- **IESNA RP-1-1988 Compliance**: Noncompliant
- **Comparative Yearly Lighting Energy Cost per 1000 Lumens**: $3.41 based on 3000 hrs. and $0.08 per kWh

### Luminaire Data

<table>
<thead>
<tr>
<th>Luminaire</th>
<th>4PS24-232G-FS12</th>
<th>4PS24-232G-FS12</th>
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<tbody>
<tr>
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<td>REL-TP2-SC</td>
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<td>Mounting</td>
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</tbody>
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<th>Lumens</th>
<th>% Lamp</th>
<th>% Fixt.</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-30</td>
<td>2997</td>
<td>26.4</td>
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<tr>
<td>31-60</td>
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<td>43.1</td>
<td>51.1</td>
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<td>61-90</td>
<td>5226</td>
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<td>90-120</td>
<td>7343</td>
<td>84.4</td>
<td>100.0</td>
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<tr>
<td>120-150</td>
<td>941</td>
<td>57</td>
<td>33.1</td>
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</table>

### Coefficients of Utilization (%)

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<thead>
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<th>70</th>
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<td>3</td>
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<td>5</td>
</tr>
</tbody>
</table>

### Indoor Candela Plot

- **RCR** = Recessed Candela Ratio
- **RC** = Effective Ceiling Candela Reflectance
- **RW** = Wall Reflectance

### Energy Data

- **Total Luminaire Efficiency**: 84.4%
- **IESNA RP-1-1988 Compliance**: Noncompliant
- **Comparative Yearly Lighting Energy Cost per 1000 Lumens**: $3.33 based on 3000 hrs. and $0.08 per kWh

### Dimensional Data

- **2' x 2', 2-Lamp, Lay-In**
- **2' x 3', 2-Lamp, Lay-In**

### Ceiling Compatibility

- **Type G**
  - Side: End
  - **Type M**
  - Side: End
  - **Type F**
  - Overlapping trim conceals edges of ceiling opening. Wing hanger suspension included. 4½" overall fixture height.
  - Flanged cut out dimension for single unit only: 24½" x 48½"
AV
2x2, 2x4

Intended Use
An exceptional general lighting product that performs well in large spaces with high ceilings. Especially suited for open office areas, public indoor spaces, libraries and airport waiting areas.

Construction
The optimum mix of directional and diffused reflected light combines for balanced illumination between task and perimeter walls, enhanced visual comfort and minimized shadows.

Available in 2x2” and 2x4” symmetric distributions for general area lighting applications. End-to-end mounting capability.

Choice of shielding options:
- Matte white polyester powder paint finish
- Reflectors provide uniform light distribution
- Optional diffuse aluminum stepped reflectors available.
- Injection-molded plastic light traps present light

Leaks between shielding and end plates.

Electrical
Ballast disconnect provided standard when required to comply with U.S. and Canada electrical codes.

Listings
UL Listed, CUL Listed, CSA Certified, Canadian Standards. NOM Certified—optional.

Protected by one or more of U.S. Patent Nos.: 5,968,829; 399,186; 611,684; 476,462; 2,712,570; 6,655,601.

Example: 2AV G 3 32 MDR MVOLT GEB105

Series | Trim | Air Function | Number of lamps | Lamp Type | Diffuser | Voltage
-------|------|--------------|-----------------|-----------|----------|--------
2AV | G | Standard | 1 | 14T5 | Metal diffuser, round holes | MDR MVOLT 347 |
3 | Screw slot | A | 1 | 14T5 S4T5SHD | Metal diffuser, round holes | |
Not included.

Ballast configuration
(blank) 1- and 2-lamp ballasts per lithonia Lighting standards.

Ballast
GEB105S | T8 and CF electronic ballast, 0% THD, instant start
GEB105P | T5 electronic ballast, 0% THD, programmed start

Options
- AG | Acrylic filter guard
- GL | Internal fast blow fuse
- APB | Air pattern control blades
- ASR | Aluminum stepped reflector
- EL | Emergency battery pack
- PsF50825 | 6’ prewire, 3/8” B, 10-gauge, 3 wires
- CSA | Meets Canadian standards
- NOM | Meets Mexican standards

Notes
1. Available only with CSA option.
2. Specify voltage.
3. Contact www.lithonia.com for available options.

For additional product information, visit www.lithonia.com.
**Features**

- Nominal 3" deep louver
- Fluorescent, energy efficient light source
- Black reveal with full air handling capabilities
- Matte anodized low iridescent, semi-specular (MA) louner finish virtually eliminates visibility of fingerprints and construction dust
- Shallow housing height
- Lightweight
- Recessed, surface or cable mount
- UL Listed 1598
- Available with exclusive HUBB Technology preinstalled
  - Peer to peer, self-healing wireless mesh network
  - Integrated control system for 0-10VDC or On/Off

**Construction**

Luminous housing and end caps are die formed code gauge cold rolled steel. Louver is formed from Duralouvers® anodized aluminum and secured in open or closed position by die formed steel hinges. Louver hinges from either side. Mechanical light trap prevents light leaks. Latches are finger-tip actuated, positive feed type, fabricated of spring steel, and completely concealed in the block reveal.

**Finish**

Parts are treated with a five stage phosphate bonding process and finished with a high temperature baked white enamel. For post painted housing, suffix catalog number with WP. Regressed slots are flat black. Anodized aluminum Duralouver standard finish is matte anodized low iridescent (MA). Also available low iridescent specular aluminum (LS). For custom finishes see accessories.

**Air Handling**

All supply returns and air extract options are available as a specified option. Directional control vanes and/or extract damper features available. Air extract slots are located out of sight in end caps. See air removal data on reverse.

**Installation**

Access plate is furnished with each luminaire for front wiring access from the plenum. No need to open fixture. Product ships standard with mylar dust cover to eliminate site contamination.

**Certification**

All luminaires are built to UL 1598 standards and bear appropriate IL and CUL or CSA labels. Damp location labeling is standard. Emergency-equipped fixtures labeled UL 924.

---

**Ordering Information**

<table>
<thead>
<tr>
<th>P4D</th>
<th>24</th>
</tr>
</thead>
</table>

**Model**

- P4D Duralouver Parabolic

**No. of Lamps**

- 2 Two
- 3 Three
- 4 Four

**Size**

- 2 x 4

**Accessories**

- FK24 Z x 4 Single Flange Kit
- FCR Flange Kit Row Adapter Brackets
- CM48Y25C3F-KIT 48" Cable Mount Kit for 2 x 4 Wire CM Trim Fixtures, 3 Wire Feed Card

**Ceiling Type**

- G Inverted T-Bar
- SM Surface Mount (static only)
- CM Cable Mount (static only)

For custom finish see accessories.

**Lamp Type**

- 24 T5, T8, 28 Watt
- 32 T8, 32, 38 or 48 Watt
- 54 T8 50 or 51 Watt

**Louver Finish**

- MA Matte Anodized Low Iridescent Semi-Specular Aluminum (end)
- LS Low Iridescent Specular Aluminum
- LD Low Iridescent Semi-Specular

**Air Functions**

- S Static
- AV Air Handling with Supply Vane
- C Combination Supply Vane Extract
- CV Combination Supply Vane Extract
- CD Combination Supply Vane Extract Damper
- CYD Combination Supply Vane Extract Damper
- H Heat Extract
- HD Heat Extract with Damper

**Ballast**

- Electronic T8, Instant Start
- 3-Lamp Electronic T8, Instant Start
- EEP Electronic T8, or T5, Programmed Start
- 3EPI 3-Lamp Electronic T8 or T5, Programmed Start

For custom ballast see option.

**Options**

- G1R First Blow Four
- GMR Slow Blow Fuse
- ELM Emergency Battery Pack
- F0735 3 x 5 T8 T5 Lamps Installed
- F0835 3 x 5 T8 T5 Lamps Installed
- C308 3 Wire Feed Card
- C408 4 Wire Feed Card
- TB Two Bull T-Bat Clips
- TB4 Four Bull T-Bat Clips
- RSF Master Switch w/ Harness
- PAF Paint After Fabrication
- NVC NYC Contractor Union Label
- WIN Hubbell Enabled
- EO End of Row OM/OM only
- INT Intermediate OM/OM only

---

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701 Millennium Blvd, Greenville, SC 29607 / Tel: 864-679.1000 / Website: www.columbialighting.com

Page 1/3 Rev: 10/03/13

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**PHOTOMETRIC DATA**

**LUMINAIRES DATA**

- **Luminaires**: P4D24-232-MA26
- **Parabolic**: 2’ x 4’ Lamp with 2x6 Cell Matte Aluminum Louver
- **Ballast**: B2J211200RH
- **Ballast Factor**: 0.88
- **Lamps**: F32T8
- **Lumens per Lamp**: 2900
- **Watts**: 56
- **Shielding Angle**: θ = 20°, θ + 29°
- **Spacing Criterion**: θ = 1.22, θ + 1.56

**COEFFICIENTS OF UTILIZATION (%)**

<table>
<thead>
<tr>
<th>RC</th>
<th>90</th>
<th>70</th>
<th>50</th>
<th>30</th>
<th>10</th>
<th>0</th>
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</thead>
<tbody>
<tr>
<td>RW</td>
<td>0</td>
<td>30</td>
<td>50</td>
<td>70</td>
<td>90</td>
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<tr>
<td>1</td>
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<td>31</td>
<td>25</td>
<td>20</td>
<td>15</td>
<td>21</td>
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</table>

**RCR** = Room Cavity Ratio
**RC** = Effective Ceiling Cavity Reflectance
**RW** = Wall Reflectance

**ZONAL LUMEN SUMMARY**

<table>
<thead>
<tr>
<th>Zone</th>
<th>Lumens</th>
<th>Lamp</th>
<th>Fixt.</th>
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</thead>
<tbody>
<tr>
<td>0-30</td>
<td>724</td>
<td>205</td>
<td>277</td>
</tr>
<tr>
<td>0-60</td>
<td>3094</td>
<td>678</td>
<td>808</td>
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<td>0-90</td>
<td>4381</td>
<td>75</td>
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<tr>
<td>0-120</td>
<td>4381</td>
<td>75</td>
<td>100</td>
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</table>

**ENERGY DATA**

- **Total Luminaires Efficiency**: 75.5%
- **Luminance Efficacy Rating**: 0.69
- **IESNA RP-1-1993 Compliance**: Noncompliant
- **Comparative Yearly Lighting Energy Cost per 1000 Lumens**: $3.48 based on 3000 hrs.
  and 50 cents per KWH

**AVERAGE LUMINANCE (Candela/sq. ft.)**

<table>
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<tr>
<th>RW</th>
<th>0.0</th>
<th>0.25</th>
<th>0.50</th>
<th>0.75</th>
<th>1.00</th>
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<tbody>
<tr>
<td>0</td>
<td>0.6</td>
<td>2.25</td>
<td>4.50</td>
<td>6.75</td>
<td>9.00</td>
</tr>
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</table>

**RANGE: 0-100%**

**INDOOR CANDELA PLOT**

**DIMENSIONAL DATA**

- **Type G**: For lay-in installation in exposed grid ceilings. Maximum tee widths of 1” and maximum tee heights of 2” allowed.
- **FK24 Flange Kit**: For hard ceiling applications order FK24 flange kit. Flange kit wires directly onto concealeed ceiling opening for a clean, finished appearance.

**CEILING COMPATIBILITY**

- **FKCR**: For flanged fixtures in row configurations, the FKCR adapter bracket kit is required in addition to the FK24 kit. Order one less FKCR than the total number of fixtures in a row.

**NOTE**: All dimensions are in inches; dimensions and specifications are subject to change without notice. Please consult factory or check sample for verification.
DESCRIPTION

The Accord™ redefines fluorescent lighting by improving on aesthetics, comfort and energy savings. The Accord provides the right amount of light while eliminating surface shadows commonly found in parabolics. Therefore, Accord increases the comfort level while providing significant energy savings.

The Accord is the ideal solution for offices, schools, hospitals, retail and other applications.

SPECIFICATION FEATURES

Construction
Shallow 3-1/4" deep housing is die formed of code gauge, prime cold rolled steel. Heavy gauge end plates are securely attached with screws for strength and rigidity and the elimination of gaps. Four auxiliary fixture and suspension points are provided. KOs for continuous row wiring. Large access plate for supply connection.

Electrical* Ballasts are Class "P" and are positively secured. Rotor-lock lampholders ensure positive lamp retention. UL/CUL listed. Suitable for damp locations.

Ballast Access
Ballast can be removed from below without tools.

Finish
Durable cold rolled steel with multistage, iron phosphate pre-treatment and white enamel finish to ensure maximum bonding and rust inhibition.

Reflectors
Reflector has high reflectance baked matte white enamel finish for luminous uniformity.

Shielding
Positively retained frosted acrylic profile lenses provide a soft but effective distribution of light.

Air Return
Optional Air Return model provides air flow through air slots in the housing.

Controls
Fifth Light ballast options are offered for both 0-10V continuous dimming and DALI applications. Combine with energysaving products like occupancy sensors, daylighting controls, and lighting relay panels from Cooper Controls (www.coopercontrol.com) to maximize energy savings.

MOUNTING DATA

LAMP CONFIGURATIONS

NOTE: 2' x 2' and 2' x 4' allow for row mounting (1' x 4' does not support feature)

COOPER LIGHTING
The document contains tables and charts related to photometric data for a lighting product. The tables include data on Candelpower, Coefficients of Utilization, Zonal Lumen Summary, and Luminance Data. The data is presented in a structured format with columns for various parameters such as angle, lumens, and other related values.
# Ordering Information

**Sample Number:** ZC-232-UNV-882-U

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<th>Rating</th>
<th>Blank: Standard</th>
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<th>ATW-SW4= Chicago Rated</th>
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<tr>
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<table>
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<td>Wattage (Length)</td>
<td>32=32W T8 (48)</td>
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<tr>
<td>Shielding</td>
<td>Blank=Frosted Acrylic</td>
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<tr>
<td></td>
<td>SGP=Lens with Square Pattern Insert</td>
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<tr>
<td></td>
<td>RDP=Lamp with Round Pattern Insert</td>
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<tr>
<td>Voltage</td>
<td>UNV=Universal Voltage 120/277</td>
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<tr>
<td>Options</td>
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<td>GM=Double Element Fuse</td>
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</tr>
<tr>
<td></td>
<td>Flex=Flex installed</td>
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</tr>
<tr>
<td></td>
<td>EL=Emergency Installed</td>
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<tr>
<td>Lamps</td>
<td>L005=78 Lamp, 17W and 32W, 3500K</td>
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<tr>
<td></td>
<td>L081=78 Lamp, 17W and 32W, 4300K</td>
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<tr>
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<td>LR050HL=78 Lamp, 30W, 3500K, 3100 Lumens</td>
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<td></td>
<td>LR041HL=78 Lamp, 30W, 4300K, 3100 Lumens</td>
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**Ballast Type**

| E8R _T8 Electronic Instant Start. Total Harmonic Distortion < 10% | E8R _PLUS _T8 Electronic Instant Start. High Ballast Factor >1.13. Total Harmonic Distortion < 20% |
| E8R _T8 Electronic Program Start. Total Harmonic Distortion < 10% | E8R _N_T8 Electronic Instant Start. Normal Ballast Factor 1.0 |
| E8R _H_T8 Electronic Instant Start. High Ballast Factor 1.15-1.2 | E8R _DKA_T8 Electronic Program Start Step Dimming. Ballast Factor .88 |
| E8R _L_T8 Electronic Program Start. Low Ballast Factor .77 | E8R _H_T8 Electronic Program Start. High Ballast Factor 1.15-1.2 |
| E8R _DK_T8 Electronic Program Start. Ballast Factor .88 | E8R _N_T8 Program Rapid Start. Total Harmonic Distortion < 10%. Ballast Factor 0.87 |
| E8R _SLTVB_T8 0-10V Program Rapid Start | E8R _SLTVS_T8 0-10V Spec Grade Program Rapid Start. Total Harmonic Distortion < 10%. Ballast Factor 0.87 |
| E8R _DUALI T8 DALI Ballasts | E8R _SLTVB_T8 DALI Program Rapid Start. Total Harmonic Distortion < 10%. Ballast Factor 1.0 |

**Number of Ballasts**

- 1x1 Ballast
- 2x2 Ballasts

**Accessories**

T3A END E.Q. BRACKET PARTS BAG

**Shipping Information**

<table>
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</thead>
<tbody>
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<td>ZC-232</td>
<td>28 lbs.</td>
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</tbody>
</table>

Visit our web site at www.cooperlighting.com

Customer First Center 1121 Highway 74 South Peachtree City, GA 30269 770.486.4800 FAX 770.486.4801 8/13 ADF080359
FINELITE

High Performance Recessed (HPR) 2x4

DESCRIPTION
HPR is a highly effective recessed luminaire delivering excellent visual comfort and outstanding performance for offices, schools, healthcare, and retail applications. Advanced optical designs make HPR a powerful solution for low-ceiling applications and eliminate the shadows common to other recessed products.

CENTER SHIELDING OPTIONS:
HPR is available with three different center shielding options: a diffuse center optic, a slotted center optic, and a round center optic.

DIMENSIONS / LIGHT ENGINE:
Available in 1, 2, or 3 T8, T5, or T5HO lamps.

INTEGRATED SENSORS:
HPR can be specified with integrated daylight or occupancy sensors.

ORDERING GUIDE
Sample Number: HPR - F - 2x4 - DCO - 1T8 - 277 - SC - C1 - IS.88 - OBO

Finelite Series HPR
Luminaire Styles (A-Angled, F-Flat)
Size (2x4)
Center Optic (DCO-Diffuse, SCO-Slotted, RCO-Round)
Light Engine (1, 2, or 3 T8, T5 or T5HO)
Voltage (120, 277, 347V)
Circuiting (SC-Single Circuit, DC-Dual Circuit, SD-Step Dimming)
Mounting (C1-1 T-Bar, C2-8/16' T-Bar, C3-Screw Slot, DW-Drywall Kit, SM-Surface Mount)
Ballast (IS-Instant Start, PS-Program Start, DL-Dimmer, and specify BF*)
Integrated Sensors (OBO-Daylight, OBO-Occupancy, OBB-Both)
* Standard 0.08 for T8 lamps, 1.0 for T5 or T5HO. Contact factory for available SF's
Contact factory for Master/Satellite and factory-supplied whip options.

Finelite, Inc. • 30500 Whipple Road • Union City, CA 94587-1530 • 510 / 441-1100 • Fax: 510 / 441-1510 • www.finelite.com

Due to continuing product improvements, Finelite reserves the right to change specifications without notice. Please visit www.finelite.com for most current data.
CONSTRUCTION: Fixture assembly constructed using die-formed 20-gauge cold-rolled steel housing and ends. All components are hard-tolled to tolerances of 0.010. Ballast compartment is accessible from below. Optical system retained using hinged door frame assembly to provide easy access to ballast compartment and for re-lamping from below without the need of tools. Seismic brackets are integrated into the fixture assembly. Additional wire entries are positioned on the ends of the housing to allow easy wiring access for the installer.

REFLECTORS: Die-formed 20-gauge cold-rolled steel reflectors are finished in 96 LG high reflectance matte white powder coat paint.

OPTICAL SYSTEM: Optical system components include side lens panels and a center optic element held in place with a frame constructed from die-formed cold-rolled steel. The side lenses are UV-stabilized and impact-resistant frosted virgin acrylic, 0.080" thick. They are either angled toward the center optic or parallel to the ceiling plane.

Available options for the center optic elements:

- **Stated Center Optic**: Die-formed cold-rolled steel panel with 1/16 x 1/2 rectangular hole pattern. Virgin acrylic overlay.
- **Round Center Optic**: Die-formed cold-rolled steel panel with precision-punched 3/32" round hole pattern arranged in staggered formation. Virgin acrylic overlay.

LIGHT ENGINE: Available in 1, 2, or 3 T8, T5, or TSHO lamp cross sections.

BALLAST: UL listed Class P Electronic instant-start ballast <10% THD, 0.80 BF standard for T8 lamps. Electronic program-start ballasts <10% THD, 1.0 BF standard for T5/TSHO lamps. Contact factory for available BF’s. Optional add-ons: program-start ballasts (standard for T5/TSHO), 347V emergency battery packs, dimming or bi-level ballasts (controls by others).

ELECTRICAL: Fixtures and electrical components are ETL listed conforming to UL1598 in the USA, and Canada and ETL listed certified to CAN/CSA C22.2 No. 250.0. In accordance with NEC code 410.73 (G) this luminaire contains an internal ballast disconnect. IC-Rated for all lamping except T5Bi30. Optional Chicago Plenum available. Contact factory.

INTEGRATED SENSORS: Refer to Occupancy Sensor and Daylight Sensor tech sheets for more info.

MOUNTING: Standard flange design works with most lay-in-ceiling types. Integral pryout tabs secure luminaire to ceiling grid from above. Fixture offers 8-in locations for 96-wire on all corners. Consult local code for appropriate tie-wire recommendations. Drywall Kit available. Surface mount version available; refer to separate tech sheet.

AIR RETURN: Refer to the 2x4 or 2x2 Air Return tech sheets for more information.

FEED: 18-gauge white wire.

FINISH: Housing and door assembly painted with 96 LG high reflectance matte white powder coat paint. Available in matte white only.

WIRING: Master / Satellite wiring available. Contact factory for configuration options. Optional switches (with flex connectors) supplied in a max. of 11’ lengths.

WEIGHT: Maximum weight: 2x4 - 33 lbs.
Appendix D: Questionnaire Presented to Observers

Instructions to observers (to be read while all 20 fixtures are switched on):

The CALiPER program is looking at many different types of LED products, to help facility managers, designers, engineers, and energy managers choose good-quality LED products that will perform well, look good, and save significant energy over time. To do this, we spend a lot of time and money sending new LED products to laboratories for detailed photometry. The testing results tell us a lot about lumens-per-watt and color quality and power quality, for example. Unfortunately, there are some things that you can’t learn from photometric testing, and you just have to mount the product in a ceiling and get feedback from folks who are looking at the product in person. This is why we’ve invited you here.

This is a simulated office/classroom/healthcare space with recessed troffers installed. There are four groups of troffers, each with five different troffer types in the group. Some of these groups are lamped with conventional fluorescent T8 lamps, and some with LED tubes. The label for the troffer is on a card on the ceiling next to the troffer itself (A1 or B3, for example). We are going to switch on four identical troffer types at a time and ask you to walk around the room and evaluate the troffers as though you were an occupant or user of the space. Feel free to reposition and sit down in chairs to view the luminaires from a seated position. We’ll ask you to complete the survey questions on both appearance of the four fixtures (including the pattern of light it produces) and glare within about 5 minutes. Then we’ll switch to a different troffer type and ask you to complete the survey again. We’ll do this a total of 5 times.

Some differences are subtle, so please don’t agonize over your responses! Just do your best. I’m going to hurry you along because at the end we want to spend about 10 minutes with you explaining what you are looking at, what the products are, and what the advantages/disadvantages of different kinds of T8 LED lamps are. And, we want you to be out of here before the hour is up!

One note: The fourth group of products uses a lamp that was not available in 4000K color, so the next closest color temperature was selected. Please try to leave color out of your evaluation process. Evaluate just the appearance, glare, acceptability, etc. based on the other factors that are visible (we recognize that is difficult).

Your observations will remain anonymous, but please tell us......

Observer name: ______________________________

Age: _________

Male/Female: _______
**VISUAL APPEARANCE OF LUMINAIRE (TROFFER)**

Walk or sit around the room and view all four troffers, imagining these are being installed in offices or schools or healthcare facilities. Please provide brief comments or observations to help explain your rankings, then indicate whether you consider this an acceptable product. Please ignore color differences.

<table>
<thead>
<tr>
<th>Troffer label</th>
<th>Rank (1=worst 4=best)</th>
<th>Brief comments to explain your answers</th>
<th>Acceptable? (Y or N)</th>
</tr>
</thead>
<tbody>
<tr>
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**VISUAL COMFORT (I.E., RANK OF COMFORT/GLARE) OF LUMINAIRE**

Walk around the room and view all four troffers from a range of positions, from underneath to several steps away from the troffer, imagining these are being installed in offices or schools or healthcare facilities. Also, feel free to sit down as though you were working in the space. You may look at the troffers as you would normally, but don’t stare at them. Please provide brief comments or observations to help explain your rankings, then indicate whether you consider this an acceptable product.

<table>
<thead>
<tr>
<th>Troffer label</th>
<th>Rank (1=worst 4=best)</th>
<th>Brief comments to explain your answers</th>
<th>Acceptable? (Y or N)</th>
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DOE SSL Commercially Available LED Product Evaluation and Reporting Program

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