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CALiPER

Report 21.2:

Linear (T8) LED Lamp Performance in Five Types of Recessed Troffers

May 2014

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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[1]) conducted by accredited, independent laboratories.[2] 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.[3] 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,[4] ENERGY STAR® performance criteria,[5] 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.

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[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 1. Performance comparison of two baseline fluorescent lamps with the minimum, mean, and maximum values of the 31 LED lamps tested for the CALiPER Series 21 reports. The baseline fluorescent lamps are F28T8 (BK13-30) and an F32T8/841 lamp estimated from manufacturer's data.

Lamp Type		Initial Output (lm)	Total Input Power (W)	Efficacy (lm/W)
	Min	1,357	11.5	66
LED[1]	Mean	1,790	19.2	94
	Max	3,126	28.6	143
FL	BK13-30 (F28T8XL/841/ECO)[2]	2,193	24.4	90
FL	Typical F32T8/841[3]	2,567	27.5	89

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

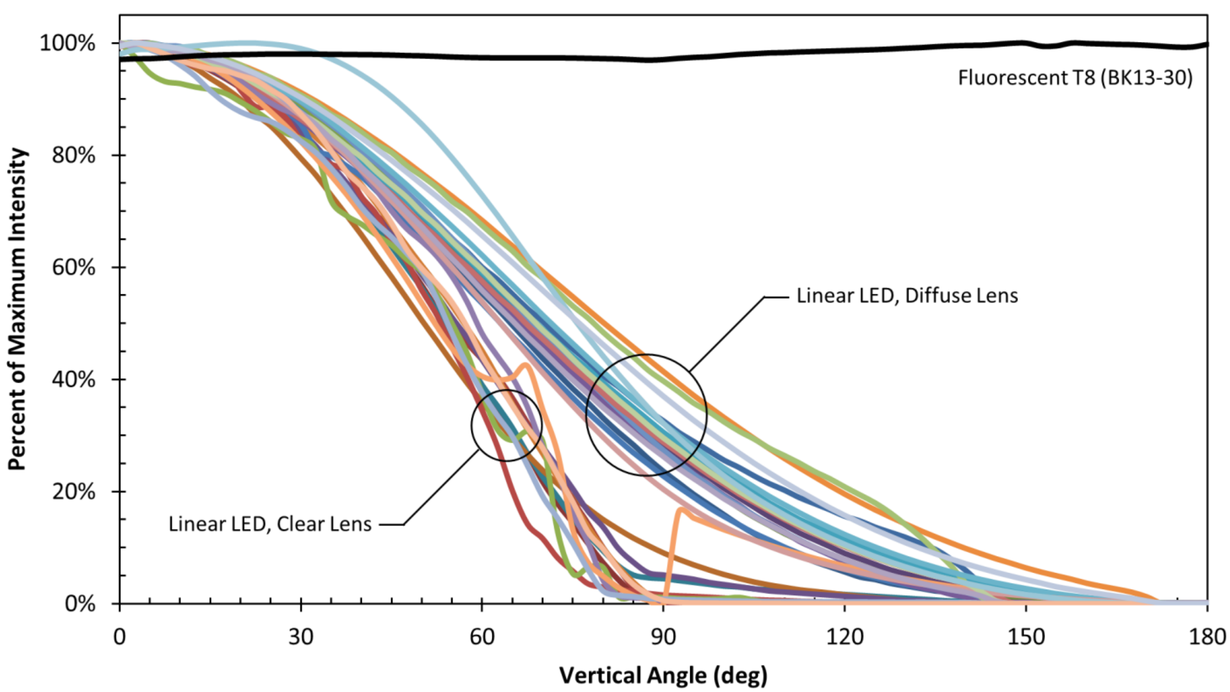


Figure 1. Relative luminous intensity distribution for all of the Series 21 products. The fluorescent benchmark product (BK13-30) is shown in black and has similar intensity in all directions perpendicular to the length of the lamp. The linear LED lamps are far more directional, but tend to cluster as 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?

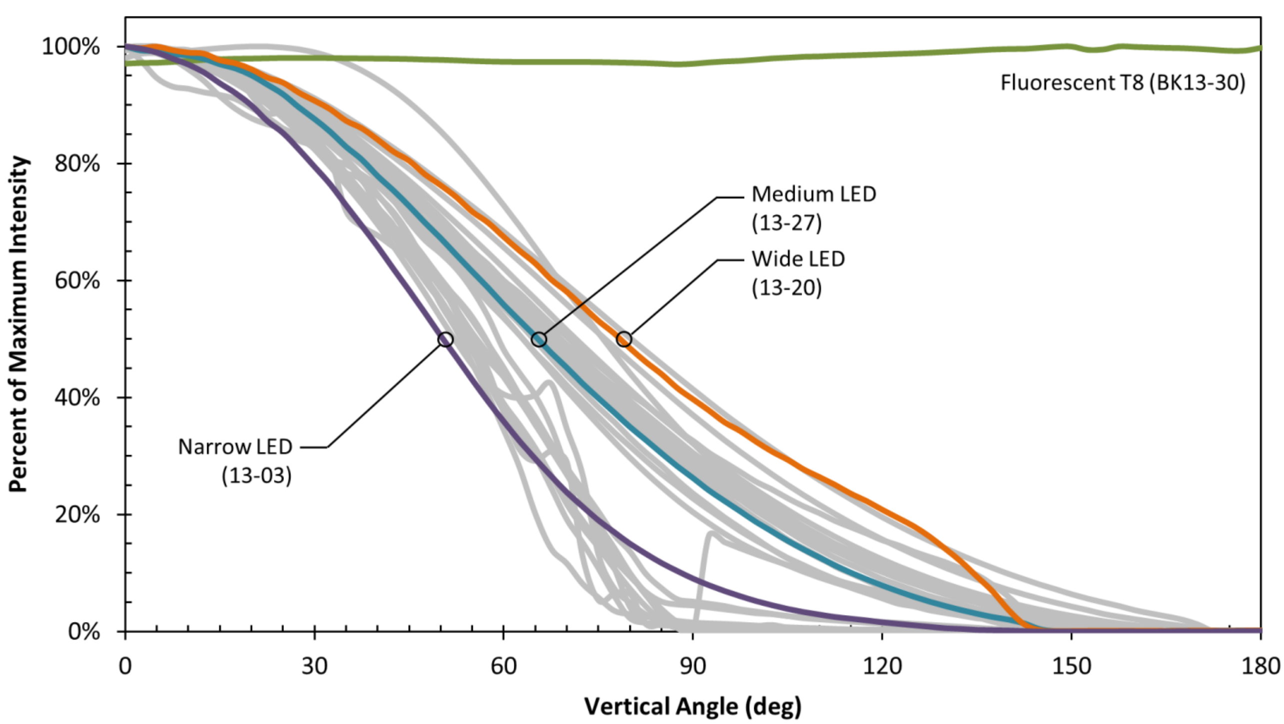


Figure 2. Relative luminous intensity distribution of the four Series 21 products that are the focus of this report. The three linear LED lamps selected for examination in five typical troffer types are marked in purple (13-03, a clear aperture tube with narrow distribution), in blue (13-27, a diffuse 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).

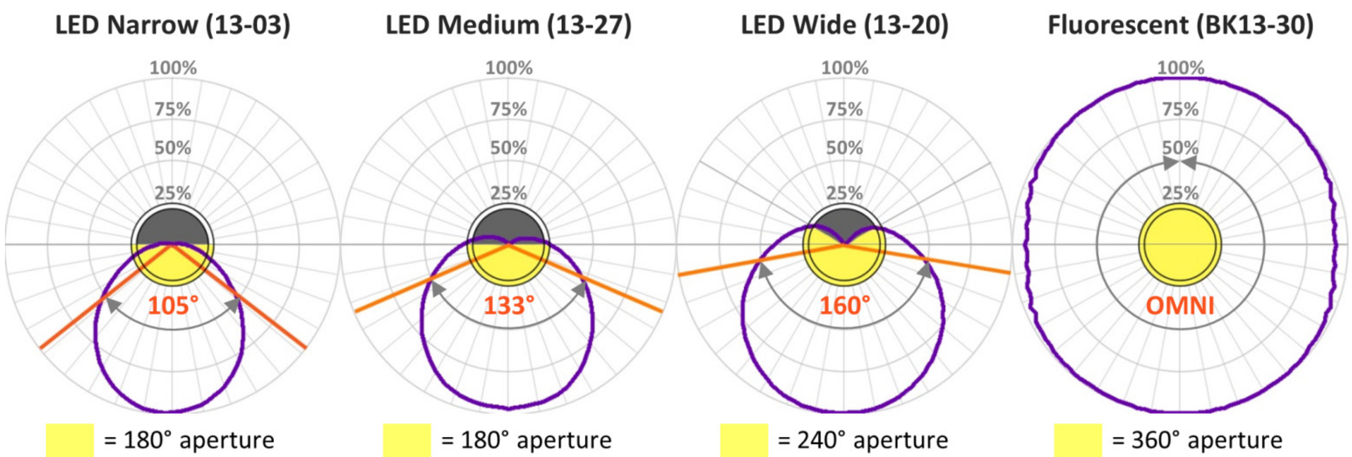


Figure 3. Aperture angle and beam angle of Report 21.2 LED and fluorescent lamp products. The aperture angle for the wide distribution LED lamp (13-20) is approximate, because the diffuser wraps around the edge of the opaque interior surface. The yellow indicates the front of the lamp and thus the direction of emitted light, whereas the gray indicates the back of the lamp.

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).

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

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.[9] 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.

[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.

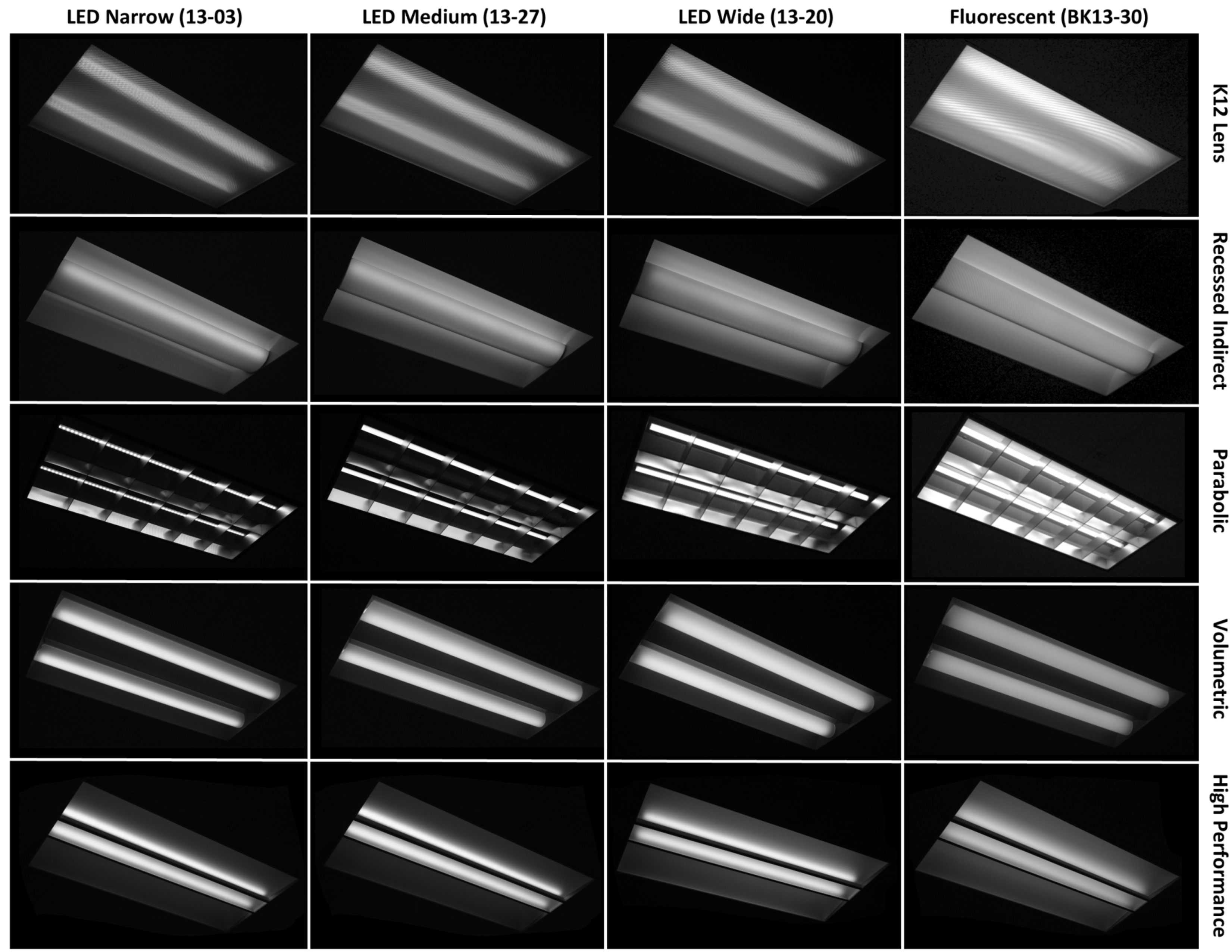


Figure 4. Photographs of all 20 lamp-and-luminaire combinations.

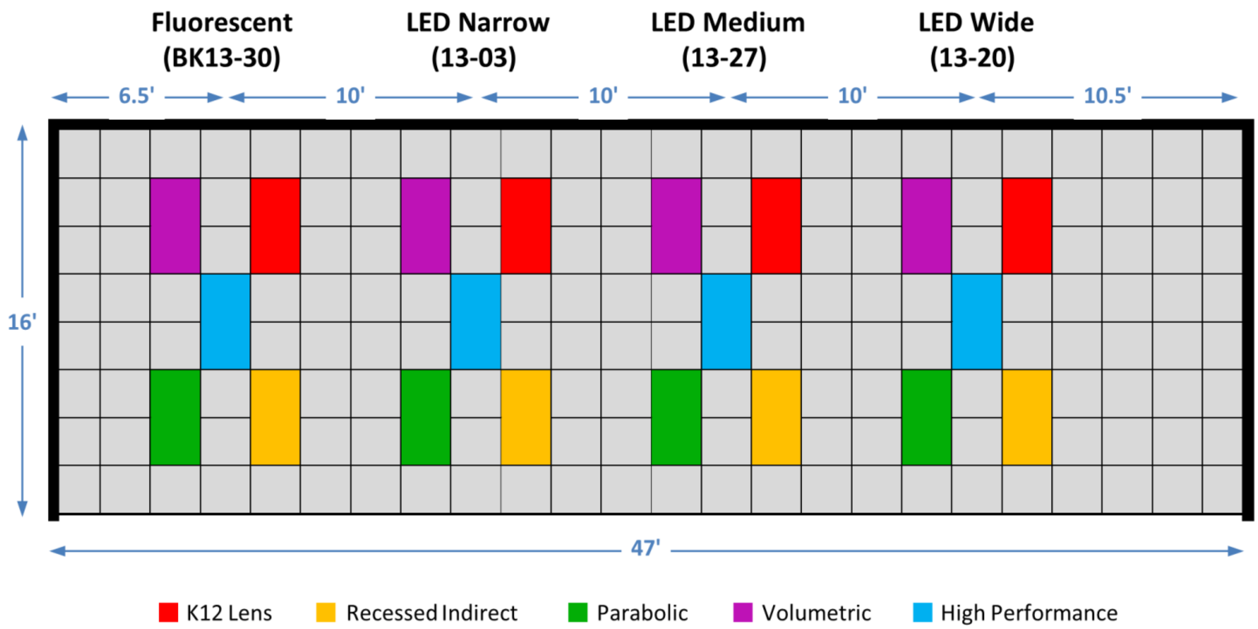


Figure 5. Reflected ceiling plan of PNNL lighting mockup facility, showing the layout of five troffer types lamped with four types of fluorescent or LED lamps. Each color represents a troffer type; each group of five troffers was lamped with a different lamp.

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

Figure 6. Observers from APEM and IES sections observing troffers lamped with fluorescent or LED lamps.

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 3. Summary data for bare-lamp and in-luminaire testing.

Luminaire Type	Lamp Type (CALiPER ID)	Beam Angle (90°)	Input Power (W)	Lamp Output (lm)	Luminaire Output (lm)	Luminaire Efficiency (%)	Luminous Efficacy (lm/W)
Bare Lamp	LED Narrow (13-03)	105	18.3	1,607	-	-	87.8
	LED Medium (13-27)	133	22.5	1,844	-	-	82.0
	LED Wide (13-20)	160	19.6	1,973	-	-	100.7
	FL (BK13-30)	N/A	24.4	2,193	-	-	89.9
K12 Lens	LED Narrow (13-03)	92	36.4	3,214	2,701	84%	74.2
	LED Medium (13-27)	101	44.6	3,688	2,928	79%	65.7
	LED Wide (13-20)	103	39.0	3,946	3,212	81%	82.4
	FL (BK13-30)	107	50.7	4,386	3,299	75%	65.1
Recessed Indirect	LED Narrow (13-03)	133	36.4	3,214	1,817	57%	49.9
	LED Medium (13-27)	126	44.5	3,688	2,073	56%	46.6
	LED Wide (13-20)	124	38.9	3,946	2,527	64%	65.0
	FL (BK13-30)	123	51.8	4,386	2,988	68%	57.7
Parabolic	LED Narrow (13-03)	-[1]	36.5	3,214	2,729	85%	74.8
	LED Medium (13-27)	-[1]	44.7	3,688	2,943	80%	65.8
	LED Wide (13-20)	-[1]	39.1	3,946	3,206	81%	82.0
	FL (BK13-30)	-[1]	51.4	4,386	3,229	74%	62.8
Volumetric	LED Narrow (13-03)	126	36.3	3,214	2,598	81%	71.6
	LED Medium (13-27)	130	44.5	3,688	2,895	78%	65.1
	LED Wide (13-20)	129	39.0	3,946	3,239	82%	83.1
	FL (BK13-30)	132	51.4	4,386	3,544	81%	68.9
High Performance	LED Narrow (13-03)	108	36.4	3,214	2,641	82%	72.6
	LED Medium (13-27)	115	44.6	3,688	2,926	79%	65.6
	LED Wide (13-20)	114	39.0	3,946	3,327	84%	85.3
	FL (BK13-30)	117	51.9	4,386	3,755	86%	72.4

1. Beam angle could not be accurately calculated for the luminous intensity distribution produced by the Parabolic luminaire.

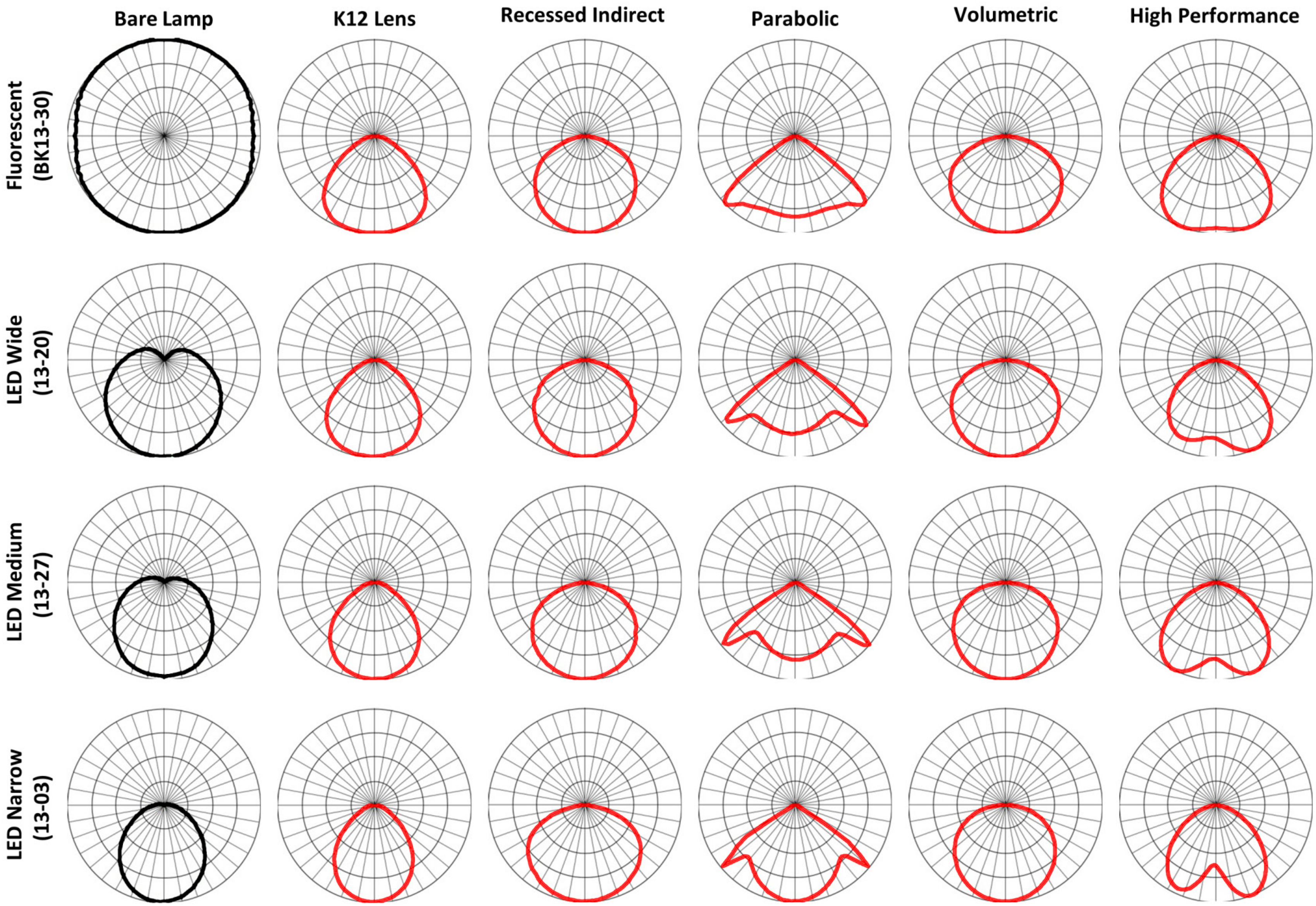


Figure 7. Polar plots in the 90° plane for each combination of lamp and luminaire, illustrating differences in light distribution from the luminaires. Several luminaires exhibited asymmetrical distributions, and it is not clear whether the LED lamps, the sockets, or the luminaire itself was the cause.

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.[10] 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.

[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.

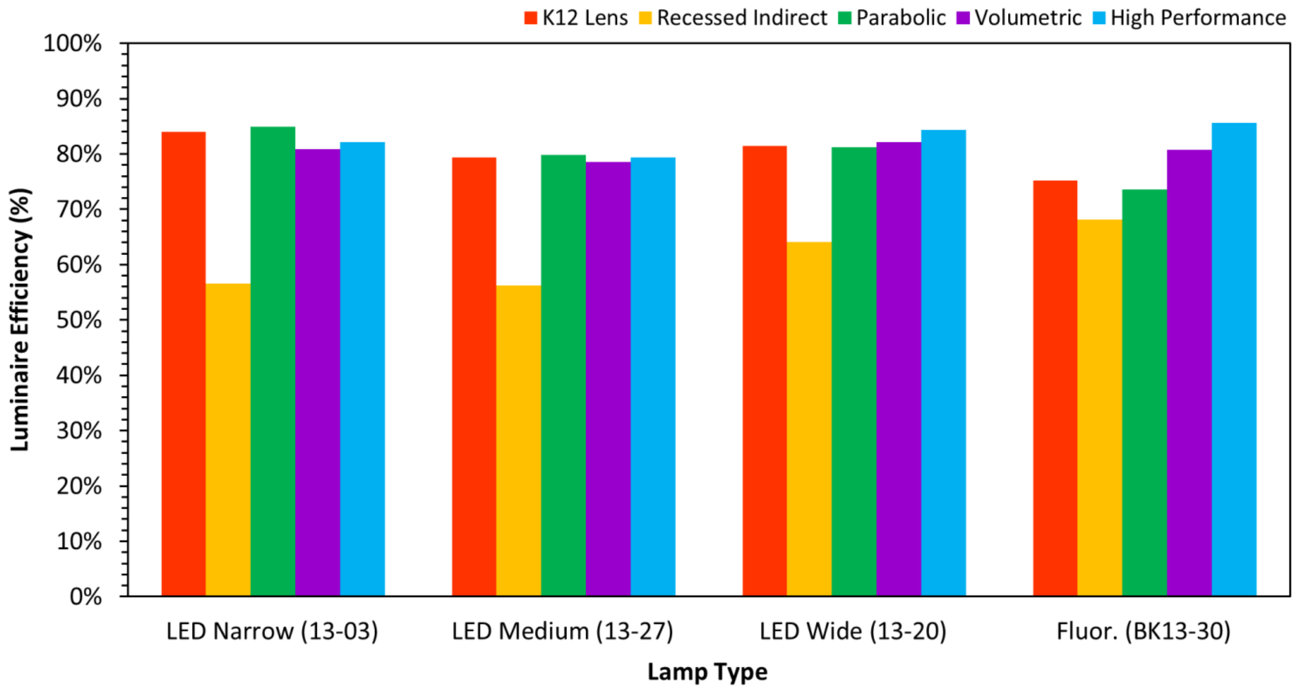


Figure 8. Luminaire efficiency (%) by lamp and troffer type.

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—

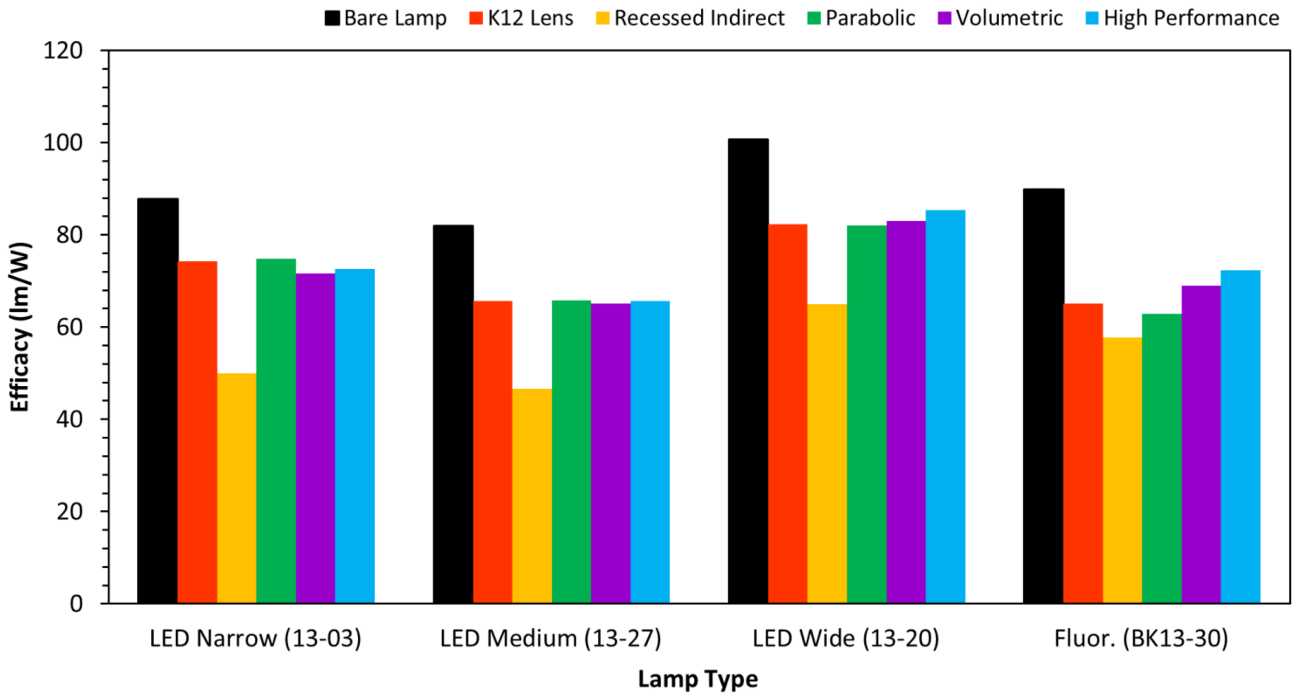


Figure 9. Bare lamp and luminaire efficacy, by lamp and troffer type.

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.

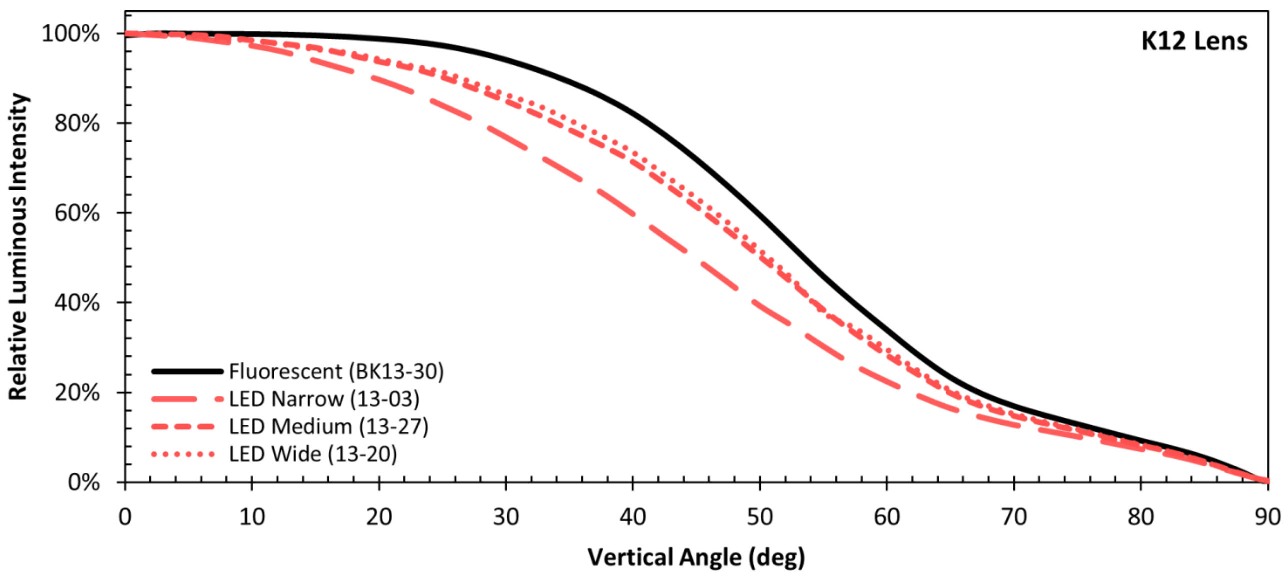


Figure 10. Luminous intensity distribution of the K12 Lens troffer with four different lamp types. The LED lamps result in a narrower luminous intensity distribution from the luminaire, with the beam angle between 4° and 15° smaller than the fluorescent benchmark. The narrow LED lamp (13-03) produces the narrowest distribution of the LED options, and the wide LED lamp (13-20) produces the widest.

- 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.

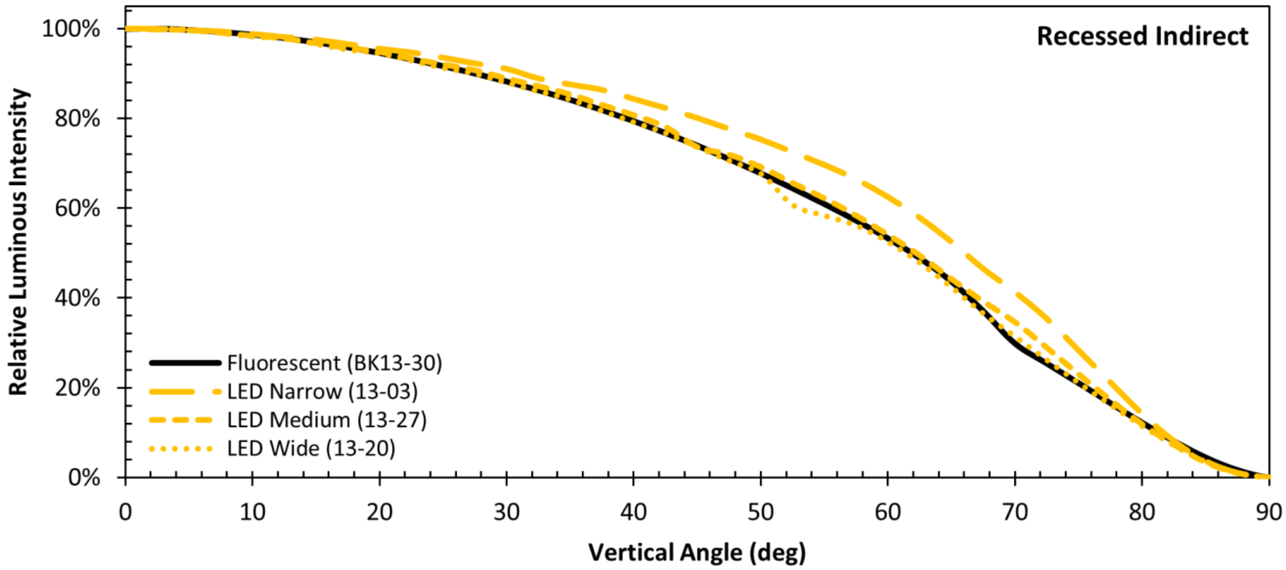


Figure 11. Luminous intensity distribution of the Recessed Indirect troffer with four different lamp types. The distribution of the luminaire was very similar for all lamp types except the narrow LED, which resulted in a slightly wider distribution.

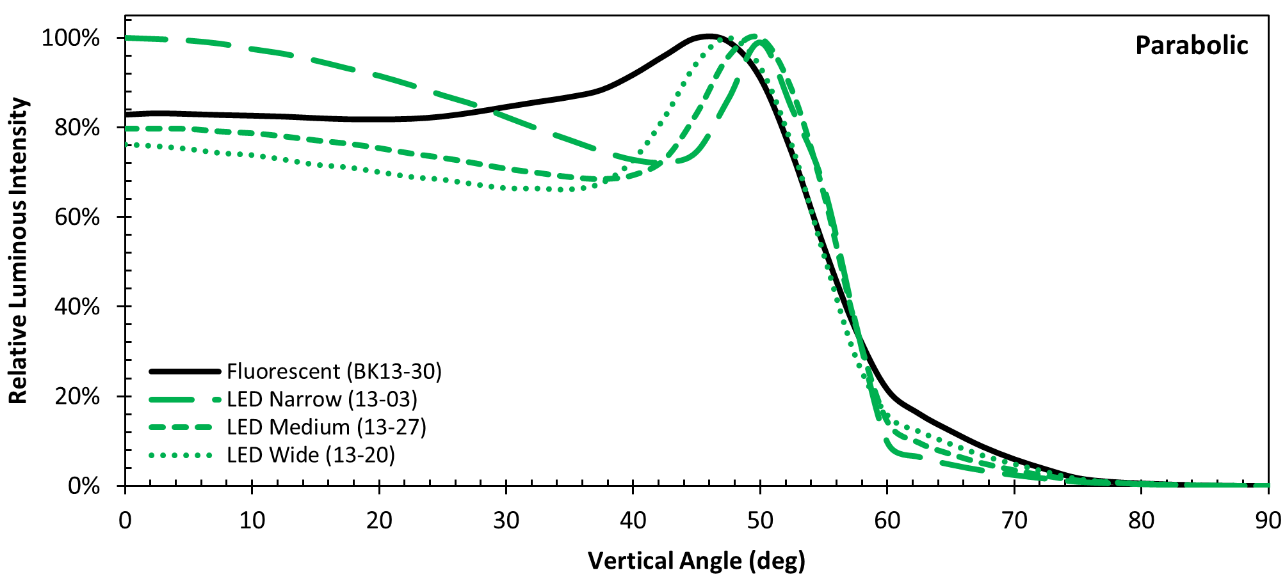


Figure 12. Luminous intensity distribution of the Parabolic troffer with four different lamp types. Note that the narrow LED lamp (13-03) performed differently from the other two LED lamps (13-27 [medium] and 13-20 [wide]). Linear LED lamps emit little light upward, especially those with clear apertures (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.

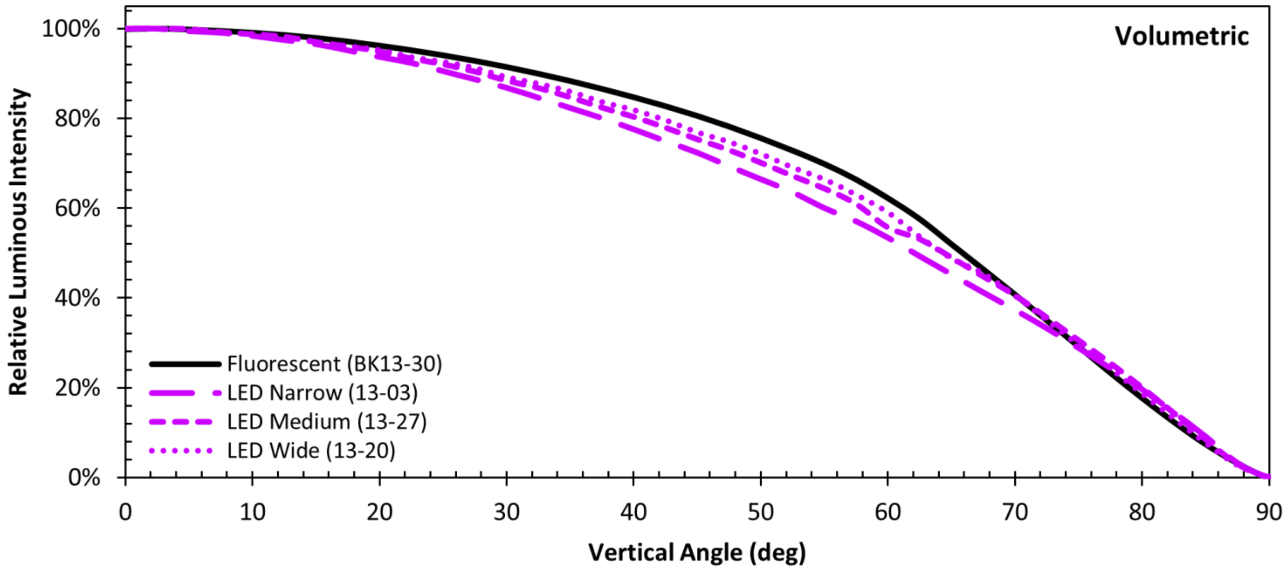


Figure 13. Luminous intensity distribution of the Volumetric troffer with four different lamp types. There was little difference in the distribution of the luminaire because of the different lamp types.

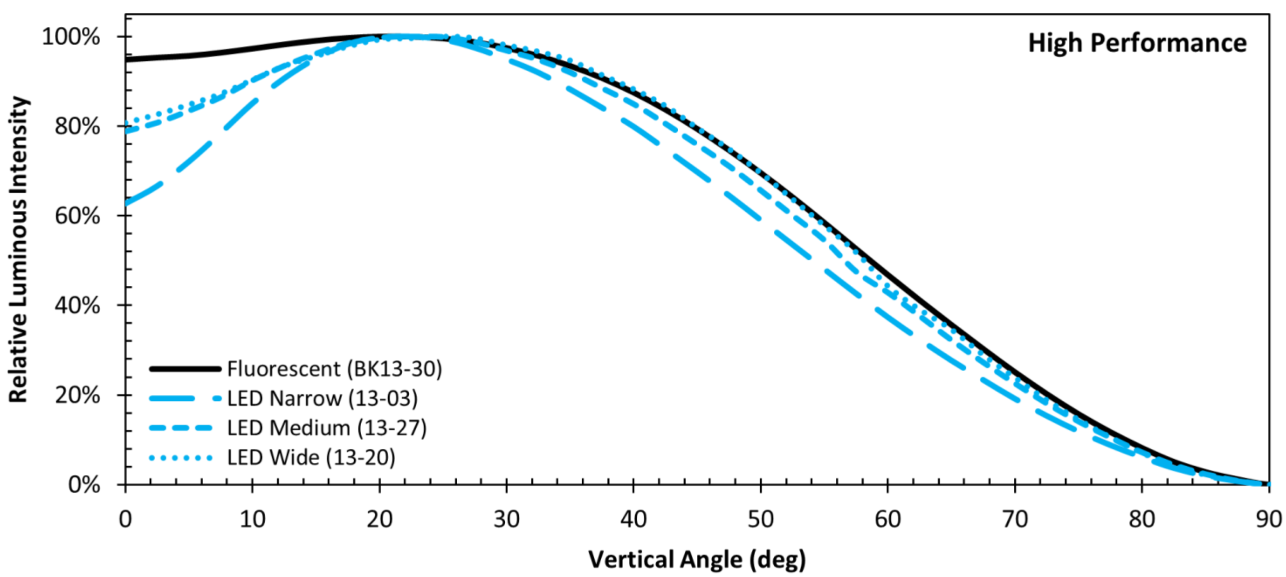


Figure 14. Luminous intensity distribution of the High Performance troffer with four different lamp types. All of the LED lamps resulted in relatively lower intensity at nadir, with the narrow lamp (13-03) producing the most dramatic difference. This may be partially due to the lamps being located directly above the linear metal details, which may have blocked the light from the already-narrower distribution lamps.

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

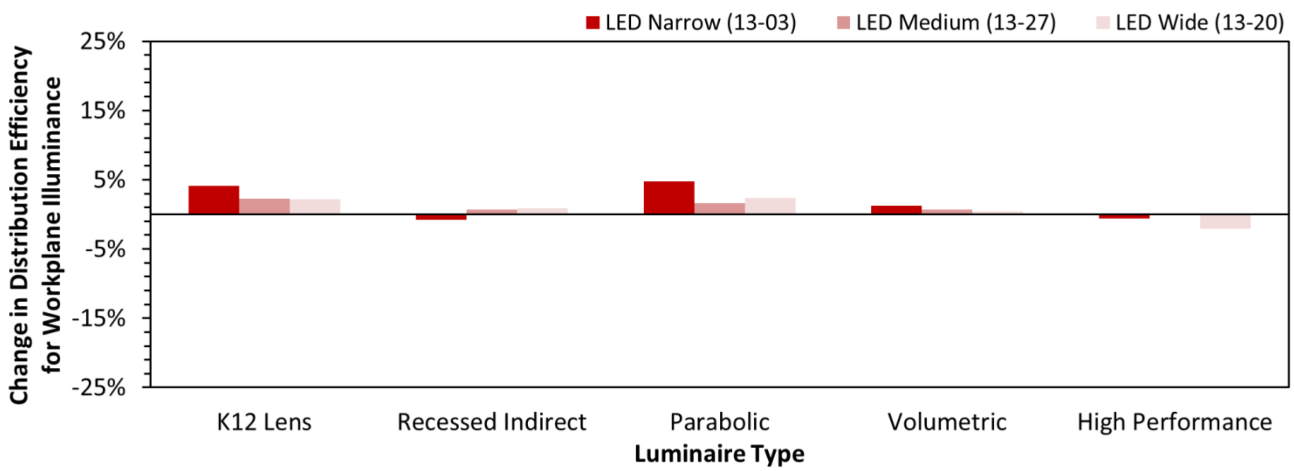


Figure 15. Change in delivered workplane illuminance due to differences in luminous intensity distribution for the LED lamps relative to the fluorescent benchmark. The LED lamps resulted in a slightly greater percentage of the luminaire lumens reaching the workplane for the K12 and Parabolic luminaires.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

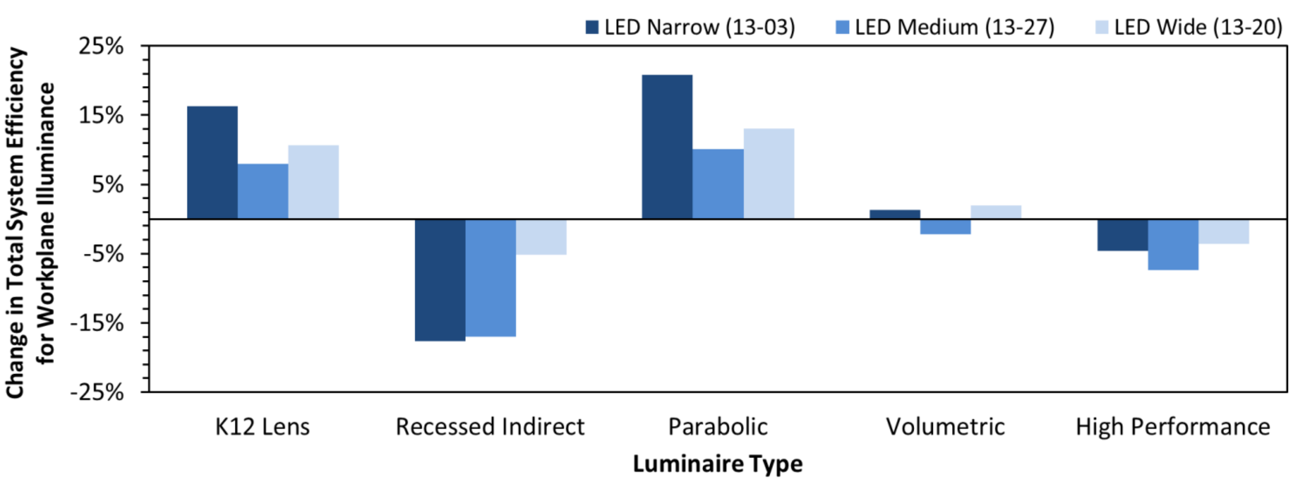


Figure 16. Change in delivered workplane illuminance due to differences in luminaire efficiency and luminous intensity for the LED lamps relative to the fluorescent benchmark. If the linear (T8) LED lamps emitted the same lamp lumens as the baseline 28 W fluorescent lamp, the LED and K12 Lens and LED 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,

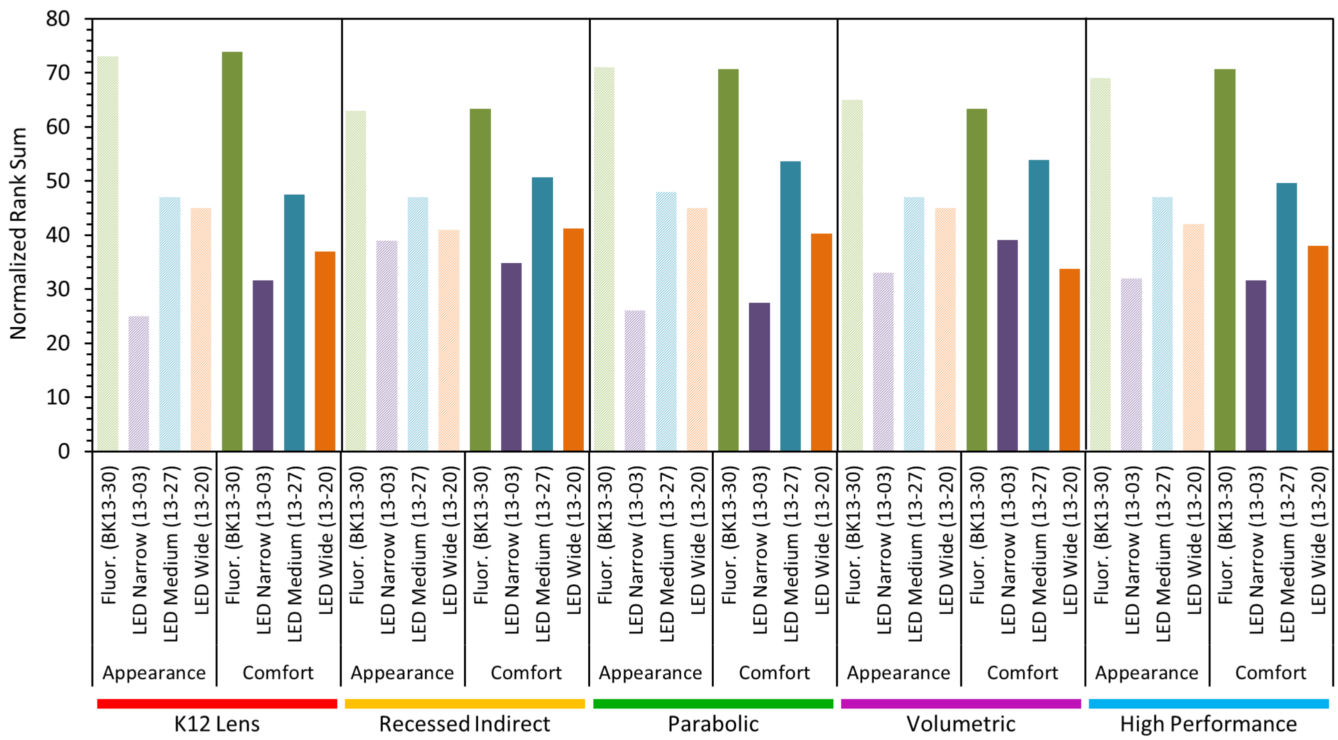


Figure 17. Sum of observers' rankings for the appearance and comfort of each combination of lamp and troffer (high = most -preferred, low = least-preferred).

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.

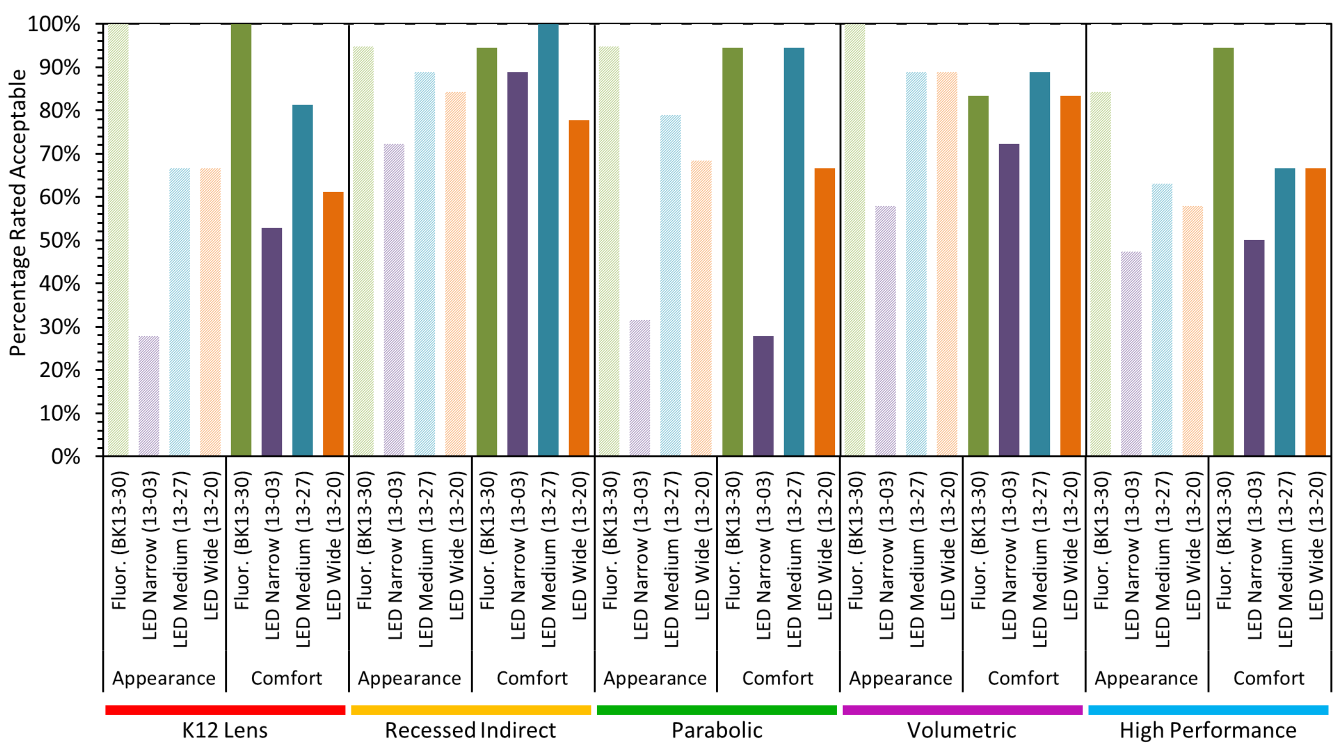


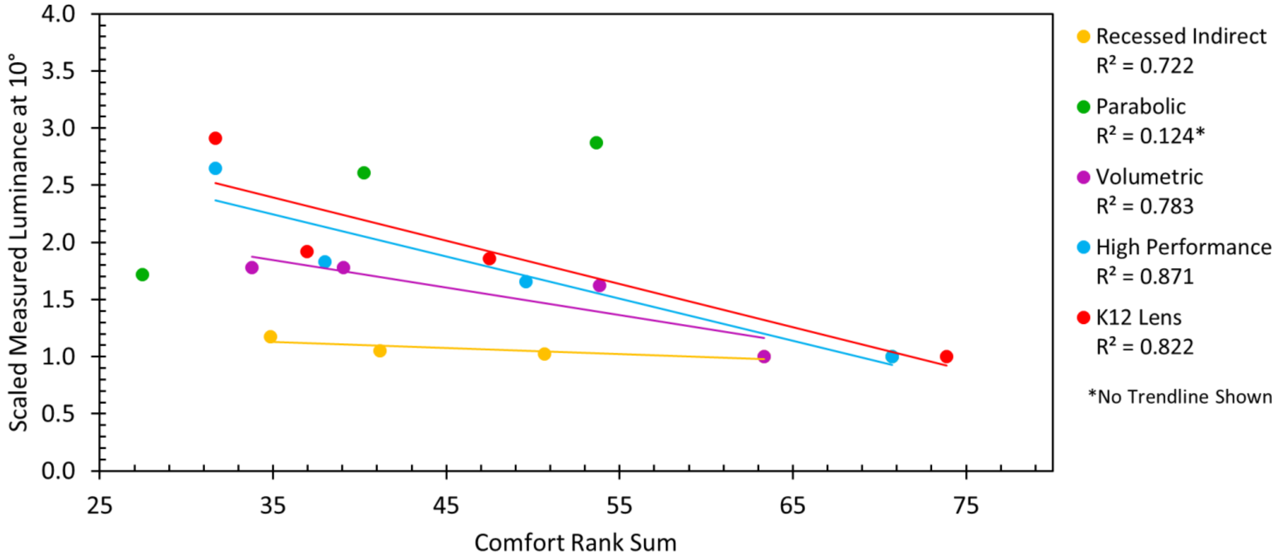
Figure 18. Observer acceptability rating of troffers. The percentage of observers rating as acceptable the appearance and visual comfort for all combinations of lamps and luminaires (higher = more acceptable, low = less acceptable).

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.

Troffer Type	Lamp Type	Measured Luminance (cd/m^2)		Measured Luminance Order (1=best, 4=worst)		Order of Observer Comfort Ratings[1] (1=best, 4=worst)	
		10°	35°	10°	35°	Rank	Accept.
K12 Lens	**LED Narrow (13-03)**	13,840	7,720	4	4	4	4
	LED Medium (13-27)	8,820	6,687	2	3	2	2
	LED Wide (13-20)	9,110	5,911	3	2	3	3
	FL (BK13-30)	4,749	4,126	1	1	1	1
Recessed Indirect	**LED Narrow (13-03)**	2,421	2,630	4	4	4	3
	LED Medium (13-27)	2,111	2,148	2	1	2	1
	LED Wide (13-20)	2,164	2,312	3	3	3	4
	FL (BK13-30)	2,060	2,259	1	2	1	2
Parabolic	**LED Narrow (13-03)**	13,130	5,329	2	1	4	4
	LED Medium (13-27)	21,930	16,930	4	4	2	1
	LED Wide (13-20)	19,900	16,840	3	3	3	3
	FL (BK13-30)	7,632	8,413	1	2	1	1
Volumetric	**LED Narrow (13-03)**	5,138	4,931	3	4	3	4
	LED Medium (13-27)	4,683	4,484	2	2	2	1
	LED Wide (13-20)	5,138	4,693	3	3	4	2
	FL (BK13-30)	2,890	3,043	1	1	1	2
High Performance	**LED Narrow (13-03)**	16,410	13,520	4	4	4	4
	LED Medium (13-27)	10,260	8,815	2	2	2	2
	LED Wide (13-20)	11,350	10,510	3	3	3	2
	FL (BK13-30)	6,201	5,856	1	1	1	1

1. In three instances, the comfort or acceptability rating was tied.

- 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.



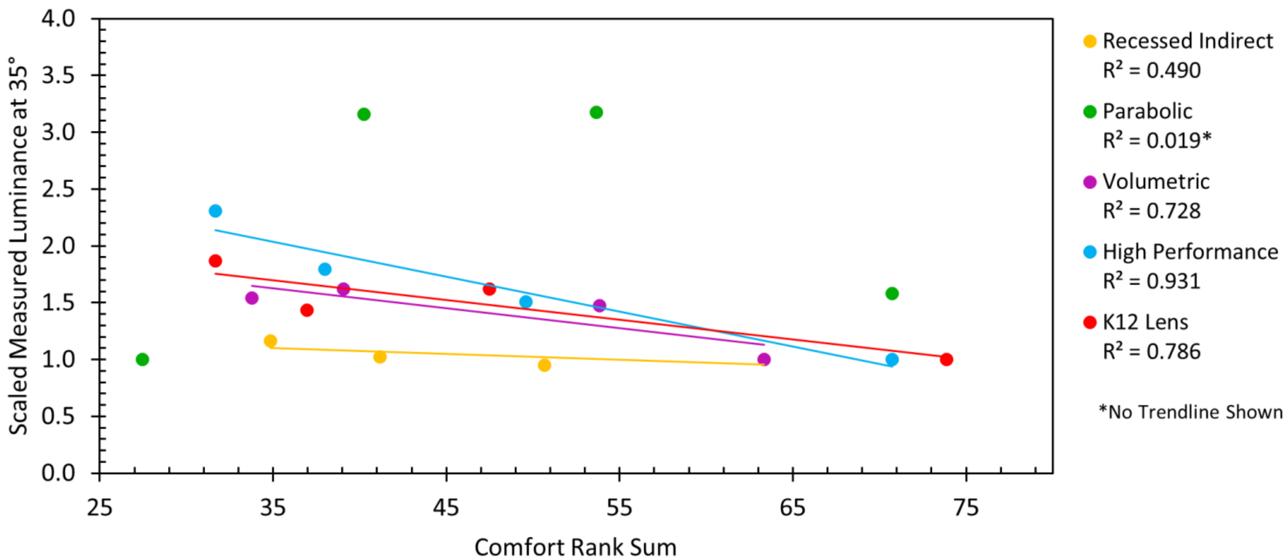


Figure 19. Correlation between spot luminance measurements at 10° from nadir (top) and 35° from nadir (bottom) versus the sum of observers' ranks for comfort. For all but the Parabolic troffer, the rankings were highly correlated with the luminance data, especially to the measurement at 10°.

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.

	Distribution	Visual Appearance	Luminaire Efficiency	Efficacy	Light Output	Observers' Comments	Conclusions
CALiPER R21: Full set of 31 linear LED lamps	Not omnidirectional, 105–160° beam angle	Not Applicable	Not Applicable	66–143 lm/W (90 lm/W for fluorescent benchmark)	1,357–3,126 lm (2,193 lm for fluorescent benchmark)	Not Applicable	Linear LED performance is often appreciably different from fluorescent; efficacy and lumen output could be higher or lower.
CALiPER R21.2: Subset of 3 linear LED lamps	Not omnidirectional, 105–160° beam angle	Not Applicable	Not Applicable	82–101 lm/W (90 lm/W for fluorescent benchmark)	1,607–1,973 lm (2,193 lm for fluorescent benchmark)	Not Applicable	Linear LED performance is often appreciably different from the fluorescent benchmark. For these three lamps, the lumen output was lower than for the fluorescent benchmark.
K12 Lens	The beam angle of the luminaire with all types of linear LED lamps was 4° to 15° smaller than with fluorescent lamps.	Linear LED lamps, especially those with a narrow distribution, resulted in a more striped appearance.	5% to 12% higher (relative) for all linear LED lamp types; better for narrow (clear) lamps.	Depends on lamp efficacy; linear LED lamps proportionally higher due to increases in luminaire efficiency.	Depends on lamp lumens; linear LED lamps proportionally higher due to increases in luminaire efficiency.	Fluorescent preferred for glare and appearance; wide (diffuse) linear LED lamps provided best appearance and comfort among LED options.	**Consider using linear LED lamps.** Choose a wide-distribution (diffuse aperture) LED lamps with high lumen output (>1900 lm) and efficacy (>100 lm/W) for comparable or better performance and energy savings. Workplane illuminances may be less uniform at the same spacing.
Recessed Indirect	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°).	The pattern of light on the upper reflector changed with the width of the distribution.	3% to 18% lower (relative) for linear LED lamps, depending on the type; worse for narrow (clear) lamps.	Depends on lamp efficacy; linear LED lamps proportionally lower due to decreases in luminaire efficiency.	Depends on lamp lumens; linear LED lamps proportionally lower due to decreases in luminaire efficiency.	Fluorescent preferred for glare and appearance.	**Likely do not consider 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.
Parabolic	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.	With narrower distributions, the upper reflector became dark; the linear LED lamp face was perceived as brighter.	8% to 15% higher (relative) for linear LED lamps, depending on the type; better for narrow (clear) lamps.	Depends on lamp efficacy; linear LED lamps proportionally higher due to increases in luminaire efficiency.	Depends on lamp lumens; linear LED lamps proportionally higher due to increases in luminaire efficiency.	Linear LED lamps resulted in worse appearance and more glare than fluorescent; narrow (clear) LED lamps were worst among the LED options.	**Cautiously consider linear LED lamps.** Choose wide distribution (diffuse aperture) LED lamps with high output (> 2,000 lm) and efficacy (>100 lm/W). Workplane illuminance uniformity may be reduced at the same spacing and room walls may appear darker. Increased glare is a possibility.
Volumetric	No appreciable difference	No appreciable difference	No appreciable difference	Proportional to lamp efficacy	Proportional to lamp lumens	Little appearance or glare difference between fluorescent and LED linear lamps.	**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.
High Performance	Wide distribution linear LED lamps resulted in a luminaire distribution more similar to fluorescent; narrow bare-lamp LED distributions resulted in greater difference.	Narrow (clear) linear LED lamps resulted in a somewhat more striped appearance for the diffuser.	2% to 8% lower (relative) for linear LED lamps, depending on the type.	Depends on lamp efficacy; linear LED lamps proportionally lower due to decreases in luminaire efficiency.	Depends on lamp lumens; linear LED lamps proportionally lower due to decreases in luminaire efficiency.	Fluorescent preferred for glare and appearance, but linear LED lamps were acceptable; wide (diffuse) linear LED lamps were the best among the LED options.	**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.

DOE CALiPER Test ID	Brand	Model
13-03	Toggled	MK2M-T8-48-UN19ND-4080D2-A1
13-20	Miracle LED	T8 Cool 48"
13-27	InnoGreen	IG-220DT8120-20-NW
BK13-30	Lamp: GE Ballast: Philips Advance	F28T8XLSPX41ECO IOPA2P32N

Appendix B: Luminaire Product Identification and Performance Metrics using Fluorescent Lamps

Table B1. Troffer identification and performance characteristics with fluorescent lamps

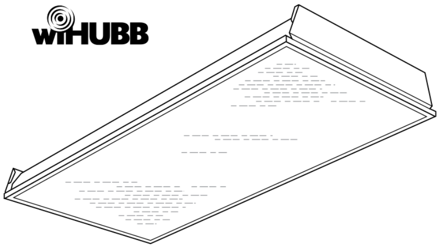
Product	**Manufacturer's Listed Luminaire Efficiency** (%)	**CALiPER Luminaire Efficiency[1]** (%)	**CALiPER Calculated Lumens (BK13-30)[2]** (lm)	**CALiPER Measured Power (BK13-30)** (W)
Two Lamps and Ballast (BK13-30)	-	-	4,386	48.9
K12 Lens Columbia 4PS24-232G-A12	87%	75.2%	3,298	50.7
Recessed Indirect Lithonia 2AV-G-232-MDR	68%	68.1%	2,987	51.8
Parabolic Columbia P4D24-232-G-MA26-S	76%	73.6%	3,228	51.4
Volumetric Cooper/Metalux 2AC—232	85%	80.0%	3,509	51.4
High Performance Finelite HPR-A-2x4-DCO-2T8	85%	85.6%	3,754	51.9

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.

Columbia
LIGHTING

4PS24-2, 4PS24-3

2' × 4' Specification Grade Static Troffer / 2 or 3-Lamp T5, T5HO, T8



Also available with 4 or 6 lamps.

PROJECT INFORMATION

Project Name	Type
Catalog No.	Date

FEATURES

- 4¼" 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 1598
- Available with exclusive wiHUBB technology preinstalled
  – Peer to peer, self-healing wireless mesh network
  – Integrated control system for 0-10VDC 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 also 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, resetting, HPF 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.

SHIELDING

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 1598 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**

4PS 24 – ___ ___ ___ – ___ ___ – ___ ___ – ___

MODEL
- **4PS** Specification Grade Static Troffer

SIZE
- **24** 2' × 4'

NO. OF LAMPS
- **2** Two
- **3** Three

LAMP TYPE
- **28** 4', T5: 28 Watt
- **32** 4', T8: 32, 30, 28 or 25 Watt
- **54** 4', T5HO: 54 or 51 Watt

CEILING TYPE
- **G** Inverted T-bar (std.)
- **F** Overlap Flange (4½" overall fixture height)
- **M** Fit-in Flange (4½" overall fixture height)
- **SM** Surface Mount
- **CM** Cable Mount[1]

DOOR STYLE
- **FS** Flush Steel
- **FA** Flush Aluminum
- **RA** Regressed Aluminum
- **SFA** Silver Flush Aluminum
- **SRA** Silver Regressed Aluminum

SHIELDING
- **A12** Acrylic Prismatic Pattern 12
- **A15** Acrylic Prismatic Pattern 15
- **A19** Acrylic Prismatic Pattern 19
- **PC1** ½" × ½" × ½" Specular Silver Polystyrene Louver
- **PC2** 1½" × 1½" × 1" Specular Silver Polystyrene Louver

For thicker lens, specify - Example: A12125

VOLTAGE
- **U** 120V-277V
- **347** 347V

BALLAST
- **E** Electronic T8, Instant Start
- **ELW** 2-Lamp Electronic T8, 0.77 Ballast Factor, Low Wattage, Instant Start
- **3E** 3-Lamp Electronic T8, Instant Start
- **3ELW** 3-Lamp Electronic T8, 0.77 Ballast Factor, Low Wattage, Instant Start
- **EP** Electronic T5 or T8, Programmed Start
- **3EP** 3-Lamp Electronic T5HO or T8, Programmed Start

For specific ballast vendor, show as option.

OPTIONS
- **F0735** 35K 75 CRI T8 Lamps Installed
- **F0835** 35K 80CRI T8 Lamps Installed
- **F5835** 35K 80CRI T5 Lamps Installed
- **GLR** Fast Blow Fuse
- **EL** Emergency Battery Pack
- **EL5** Emergency Battery Pack, T5 or T5HO
- **PAF** Paint After Fabrication
- **SLL** Spring Loaded Latches
- **MS9** Master/Satellite Pair w/9' Harness
- **NYC** NYC Compliant
- **NYCU** NYC Compliant, Union Label
- **WIH** wiHUBB Enabled[2,3]
- **EOR** End of Row (SM or CM only)[4]
- **INT** Intermediate (SM or CM only)[4]

ACCESSORIES (ORDER SEPARATELY)
- **CM48Y2SC3F-KIT** 48" Cable Mount Kit for 2' Wide CM ceiling type, 3 Wire Feed Cord

[1] Order hanger accessories separately.
[2] Not available with Surface Mount Ceiling Types.
[3] In-Fixture Module Antenna adds 2" to overall fixture height at power feed location.
[4] Provides end wiring access for continuous row mounting. Contact factory for 3-lamp configurations.

4PS24-2, 4PS24-3

2' × 4' Specification Grade Static Troffer / 2 or 3-Lamp T5, T5HO, T8

PHOTOMETRIC DATA

Test **14272** Test Date **4/4/06**

LUMINAIRE DATA

Luminaire	**4PS24-232G-FSA12 4PS Lensed Troffer 2' × 4' 2-Lamp White Troffer with Prismatic A12 Acrylic Lens**
Ballast	**REL-2P32-SC**
Ballast Factor	**0.88**
Lamp	**F32T8**
Lumens per Lamp	**2900**
Total Input Watts	**64**
Mounting	**Recessed**
Shielding Angle	**0° = 90 90° = 90**
Spacing Criterion	**0° = 1.22 90° = 1.34**
Luminous Opening in Feet	**Length: 3.81 Width: 1.81 Height: 0.00**

AVG. LUMINANCE (Candela/Sq. M.)

Average Luminance Angle	0.0	22.5	45.0	67.5	90.0
0	3161	3161	3161	3161	3161
30	3010	3093	3246	3311	3340
40	2765	2836	3007	3132	3197
45	2558	2574	2733	2865	2956
50	2263	2292	2419	2542	2610
55	1992	1989	2068	2158	2242
60	1761	1617	1664	1751	1929
65	1592	1326	1285	1418	1655
70	1524	1273	1141	1323	1538
75	1550	1357	1345	1369	1574
80	1573	1519	1591	1519	1591
85	1755	1701	1773	1684	1701

ZONAL LUMEN SUMMARY

Zone	Lumens	% Lamp	% Fixt.
0-30	1613	27.8	32.1
0-40	2640	45.5	52.6
0-60	4280	73.8	85.3
0-90	5018	86.5	100.0
0-180	5018	86.5	100.0

COEFFICIENTS OF UTILIZATION (%)

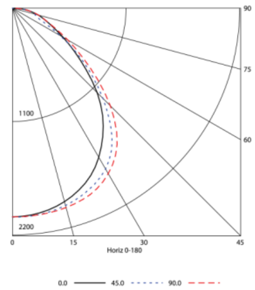
RC	80				70				50			0
RW	70	50	30	10	70	50	30	10	50	30	10	0
RCR 1	91	88	84	93	89	86	83	85	83	80	67	74
2	80	75	70	85	79	74	70	76	72	68	57	63
3	71	65	60	78	70	64	59	68	62	58	49	54
4	64	57	51	72	63	56	51	61	55	50	42	47
5	58	50	45	66	57	50	45	55	49	44	37	41
6	52	45	39	61	51	44	39	50	44	39	32	37
7	47	40	35	57	47	40	35	45	39	35	28	33
8	43	36	32	53	43	36	31	42	36	31	25	29
9	40	33	28	50	39	33	28	39	32	28	23	26
10	37	30	26	47	37	30	26	36	30	26	21	24

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

ENERGY DATA

Total Luminaire Efficiency	**86.5%**
Luminaire Efficacy Rating (LER)	**69**
IESNA RP-1-1993 Compliance	**Noncompliant**
Comparative Yearly Lighting Energy Cost per 1000 Lumens	**$3.48 based on 3000 hrs. and $0.08 per KWH**

INDOOR CANDELA PLOT



Test **14271** Test Date **4/3/06**

LUMINAIRE DATA

Luminaire	**4PS24-332G-FSA12 4PS Lensed Troffer 2 × 4 3-lamp white troffer with prismatic A12 acrylic lens.**
Ballast	**REL-3P32-SC**
Ballast Factor	**0.88**
Lamp	**FO32T8**
Lumens per Lamp	**2900**
Total Input Watts	**87**
Shielding Angle	**0°=90 90°=90**
Spacing Criterion	**0° = 1.24 90° = 1.31**
Luminous Opening in Feet	**Length: 3.81 Width: 1.81 Height: 0.00**

AVG. LUMINANCE (Candela/Sq. M.)

Average Luminance Angle	0.0	22.5	45.0	67.5	90.0
0	4516	4516	4516	4516	4516
30	4354	4445	4569	4643	4655
40	4055	4140	4287	4411	4503
45	3766	3836	4009	4161	4271
50	3400	3480	3640	3803	3878
55	3070	3129	3236	3451	3459
60	2753	2710	2747	3022	3084
65	2415	2212	2168	2493	2619
70	2191	1812	1702	2104	2355
75	2117	1737	1622	2008	2388
80	2256	1924	1933	2202	2481
85	2275	2149	2203	2525	2454

ZONAL LUMEN SUMMARY

Zone	Lumens	% Lamp	% Fixt.
0-30	2297	26.4	31.3
0-40	3754	43.1	51.1
0-60	6226	71.6	84.8
0-90	7343	84.4	100.0
0-180	7343	84.4	100.0

COEFFICIENTS OF UTILIZATION (%)

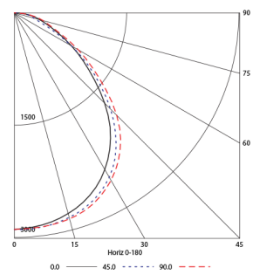
RC	80				70				50			0
RW	70	50	30	10	70	50	30	10	50	30	10	0
RCR 1	92	89	85	82	90	87	84	81	83	81	78	72
2	85	78	73	68	83	77	72	68	74	70	66	61
3	78	69	63	58	76	68	62	57	66	60	56	53
4	72	62	55	50	70	61	54	49	59	53	49	46
5	66	56	48	43	64	55	48	43	53	47	42	40
6	61	50	43	38	60	50	43	38	48	42	37	35
7	57	46	39	34	55	45	38	34	44	38	33	31
8	53	42	35	30	52	41	35	30	40	34	30	28
9	50	39	32	27	48	38	32	27	37	31	27	25
10	46	36	29	25	45	35	29	25	34	29	25	23

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

ENERGY DATA

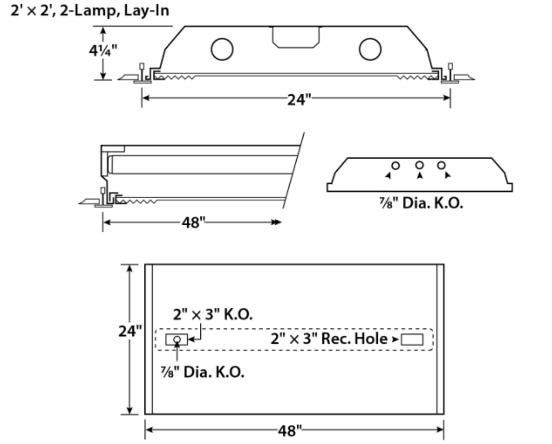
Total Luminaire Efficiency	**84.4%**
Luminaire Efficacy Rating (LER)	**72**
IESNA RP-1-1993 Compliance	**Noncompliant**
Comparative Yearly Lighting Energy Cost per 1000 Lumens	**$3.33 based on 3000 hrs. and $0.08 per KWH**

INDOOR CANDELA PLOT



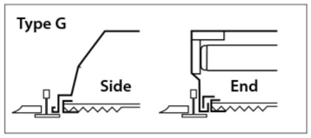
DIMENSIONAL DATA

2' × 2', 2-Lamp, Lay-In



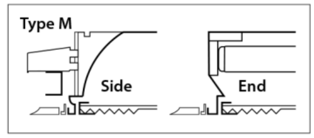
CEILING COMPATIBILITY

Type G



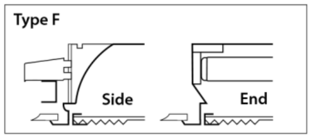
For lay-in installation in exposed grid ceilings. Maximum tee widths of 1" and maximum tee heights of 1½" allowed.

Type M



"Fit-in" style extruded trim aligns with modular tile joint. Fixture is supported from concealed suspension, includes adjustable wing hangers. 4½" overall fixture height.

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: 24⅛" × 48⅛"

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

AV

2'x2', 2'x4'

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

Construction
The optimum mix of directional and diffuse reflected light combine for balanced illumination between task and proximate walls, enhanced visual comfort and minimized shadows.

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

Choice of shielding options.

Matte-white polyester powder paint finished reflectors provide uniform light distribution. Optional diffuse aluminum stepped reflectors available.

Injection-molded plastic light traps prevent light leaks between shielding and end plates.

Electrical
Ballast disconnect provided standard where required to comply with U.S. and Canadian electrical codes.

Listings
UL Listed. CUL Listed or CSA Certified to Canadian standards. NOM Certified – optional.

Protected by one or more of U.S. Patents Nos.: 5,988,829; 399,586; 411,641; 413,402; 2,212,513; 87,513.

ORDERING INFORMATION

For shortest lead times, configure products using **bolded options**.

Example: 2AV G 2 32 MDR MVOLT GEB10IS

Series	Trim	Air function	Number of lamps	Lamp type	Diffuser	Voltage
2AV 2'wide, symmetric distribution	**G** Grid trim	**(blank)** Standard	1	14T5 14W T5 (22")	**MDR** Metal diffuser, round holes	**MVOLT**
	ST Screw slot	A Air supply/return	**2**	17 17W T8 (24")	**SBL** Straight blade louver, round holes	347[1]
			3	24T5HO 24W T5 (22")	MDM Metal diffuser, mini slots	
			Not included.	28T5 28W T5 (46")	ADP Acrylic diffuser, linear prismatic lens	
				32 32W T8 (48")	MDC Metal diffuser, round holes with large center slots	
				54T5HO 54W T5 (46")	MDS Metal solid diffuser	
				CF40 40W TT5 (24")		
				CF50 50W TT5 (24")		

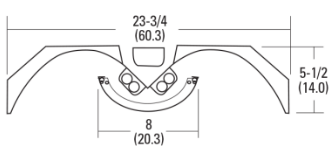
Ballast configuration	Ballast	Options
(blank) 1- and/or 2-lamp ballasts per Lithonia Lighting standards	**GEB10IS** T8 and CF electronic ballast, ≤10% THD, instant start	ALG Acrylic litter guard
1/3 One 3-lamp ballast	**GEB10RS** T8 and CF electronic ballast, ≤10% THD, programmed rapid start	GLR Internal fast-blow fuse[2]
	GEB10PS T5 electronic ballast, ≤10% THD, programmed rapid start	APB Air pattern control blades
		ASR Aluminum stepped reflector
		EL Emergency battery pack[3]
		PWS1836 6' prewire, 3/8" dia., 18-gauge, 3 wires
		CSA Meets Canadian standards
		NOM Meets Mexican standards

ADDITIONAL INFORMATION

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

CONFIGURATIONS				
SERIES	NOMINAL SIZE	NUMBER OF LAMPS	LAMP TYPE	BALLAST
AV	2'x4'	1, 2, 3	28T5, 54T5HO	GEB10PS
AV	2'x4'	1, 2, 3	32	GEB10IS, GEB10RS
AV	2'x2'	1, 2, 3	14T5, 24T5HO	GEB10PS
AV	2'x2'	1, 2, 3	17	GEB10IS, GEB10RS
AV	2'x2'	1, 2, 3	CF40, CF50	GEB10IS, GEB10RS

Drawings are for dimensional detail only and may not represent actual mechanical configuration. Dimensions are shown in inches (centimeters) unless otherwise noted.

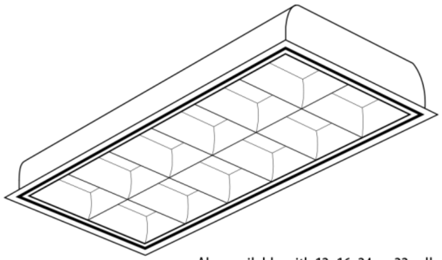


Notes
1 Available only with CSA option.
2 Specify voltage.
3 Consult www.lithonia.com for available options.

Columbia LIGHTING

P4D24

2' × 4' DuraLouver® Parabolic / 2, 3, or 4-Lamp T5, T5HO, T8



Also available with 12, 16, 24, or 32 cells

PROJECT INFORMATION

Project Name ______________________ Type ________

Catalog No. ______________________ Date ________

FEATURES

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

CONSTRUCTION

Luminaire housing and end caps are die formed code gauge cold rolled steel. Louver is formed from DuraLouver® 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 black 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 PAF. Regressed slots are flat black. Anodized aluminum DuraLouver standard finish is matte anodized low iridescent (MA). Also available low-iridescent specular aluminum (LS).

AIR HANDLING

All supply/return and air extract functions 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

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

BALLASTS

Energy efficient, thermally protected, automatic resetting, Class P, high power factor, sound rated A, magnetic or electronic ballasts. CEE NEMA Premium compliant.

ELECTRICAL

Standard class "P", thermally protected, autoresetting HPF ballast, sound rated A. CEE NEMA Premium compliant. All ballast leads extend a minimum of 6" through access location. NEC/CEC-compliant ballast disconnect is standard.

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 1598 standards and bear appropriate UL and cUL or CSA labels. Damp location labeling is standard. Emergency-equipped fixtures labeled UL 924.

ORDERING INFORMATION

EXAMPLE P4D24-232G-MA26-S-EU

P4D 24 – ___ ___ ___ – ___ ___ ___ – ___ – ___ ___ – ___

MODEL

P4D	DuraLouver Parabolic

SIZE

24	2' × 4'

NO. OF LAMPS

2	Two
3	Three
4	Four

LAMP TYPE

28	4', T5: 28 Watt
32	4', T8: 32, 30, 28 or 25 Watt
54	4', T5HO: 54 or 51 Watt

CEILING TYPE

G	Inverted T-bar[1]
SM	Surface Mount (static only)
CM	Cable Mount (static only)[2]

For hard ceilings use flange kit; see accessories.

LOUVER FINISH

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

NO. CELLS CROSSWISE

2	Two
3	Three
4	Four

NO. CELLS LENGTHWISE

6	Six
8	Eight

AIR FUNCTIONS

S	Static[3]
A	Air Handling[3]
AV	Air Handling w/Supply Vanes[3]
C	Combination Supply/Extract[4]
CV	Combination Supply Vanes/ Extract[4]
CD	Combination Supply Extract Dampers[4]
CVD	Combination Supply Vanes Extract Dampers[4]
H	Heat Extract[4]
HD	Heat Extract w/Dampers[4]

BALLAST

E	Electronic T8, Instant Start
3E	3-Lamp Electronic T8, Instant Start
EP	Electronic T5 or T8, Programmed Start
3EP	3-Lamp Electronic T5HO or T8, Programmed Start

For a specific ballast vendor show as option.

VOLTAGE

U	120V-277V
347	347V

OPTIONS

GLR	Fast Blow Fuse
GMF	Slow Blow Fuse
EL	Emergency Battery Pack
F0735	35K 75 CRI T8 Lamps Installed
F0835	35K 80 CRI T8 Lamps Installed
F5835	35K 80 CRI T5 Lamps Installed
C388	3-Wire Flex
C488	4-Wire Flex
TB	Two Bulk T-bar Clips
TB4	Four Bulk T-bar Clips
MS9	Master/Satellite w/9' Harness
PAF	Paint After Fabrication
NYC	NYC Compliant
NYCU	NYC Compliant, Union Label
WIH	wiHUBB Enabled[5,6]
EOR	End of Row (SM/CM only.)[7]
INT	Intermediate (SM/CM only.)[7]

ACCESSORIES

FK24	2' × 4' Single Flange Kit
FKCR	Flange Kit Row Adapter Brackets
CM48Y2SC3F-KIT	48" Cable Mount Kit for 2' Wide CM Trim Fixtures, 3 Wire Feed Cord

[1] For drywall order G ceiling type with FK flange kit accessories.
[2] Order hanger accessories separately.
[3] Fixtures supplied with integral T-bar clips.
[4] Fixtures supplied with two non-integral, screw-type T-bar clips.
[5] In-Fixture module antenna adds 2" to overall fixture height at powerfeed location.
[6] Not available with Surface Mount ceiling type.
[7] Provides end wiring access for continuous row. Contact Hubbell Lighting representative for continuous row 3-lamp fixtures.

Protected by US Patent 6,582,098.
Specifications subject to change without notice.

PHOTOMETRIC DATA

Test **12454** Test Date **3/14/00**

LUMINAIRE DATA

Luminaire	**P4D24-232-MA26** **P4D, Parabolic** **2' X 4' 2 LAMP WITH 2X6 CELL MATTE ALUMINUM LOUVER**
Ballast	**B232I120RH**
Ballast Factor	**0.88**
Lamp	**F32T8**
Lumens per Lamp	**2900**
Watts	**56**
Shielding Angle	**0° = 20 90° = 29**
Spacing Criterion	**0° = 1.22 90° = 1.56**

ZONAL LUMEN SUMMARY

Zone	Lumens	Lamp	Fixt.
0-30	1214	20.9	27.7
0-40	2057	35.5	46.9
0-60	3934	67.8	89.8
0-90	4381	75.5	100.0
0-180	4381	75.5	100.0

ENERGY DATA

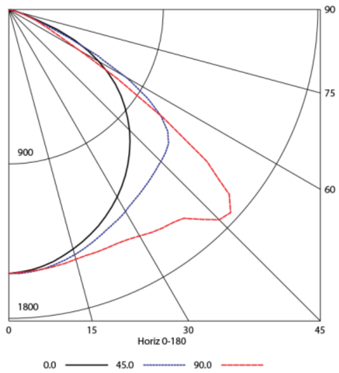
Total Luminaire Efficiency	**75.5%**
Luminaire Efficacy Rating (LER)	**69**
IESNA RP-1-1993 Compliance	**Noncompliant**
Comparative Yearly Lighting Energy Cost per 1000 Lumens	**$3.48 based on 3000 hrs. and $0.08 per KWH**

COEFFICIENTS OF UTILIZATION (%)

RC	80				70				50			0
RW	**70**	**50**	**30**	**10**	**70**	**50**	**30**	**10**	**50**	**30**	**10**	**0**
RCR 1	83	80	78	75	81	79	76	74	76	73	72	66
2	77	71	66	63	75	70	65	62	67	63	60	56
3	70	63	57	53	68	62	56	52	59	55	51	48
4	64	56	49	45	62	55	49	44	53	48	44	41
5	59	50	43	38	57	49	43	38	47	42	38	35
6	54	45	38	33	53	44	38	33	43	37	33	31
7	50	40	34	29	49	40	34	29	39	33	29	27
8	47	37	30	26	46	36	30	26	35	30	26	24
9	44	34	27	23	42	33	27	23	32	27	23	21
10	41	31	25	21	40	30	25	21	30	24	21	19

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

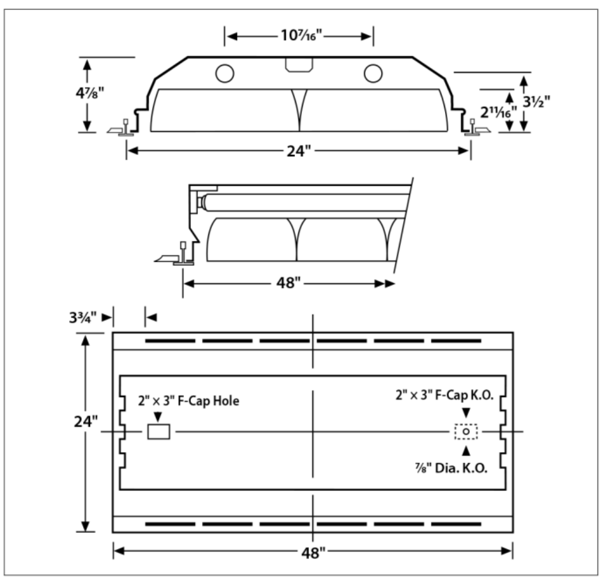
INDOOR CANDELA PLOT



AVG. LUMINANCE (Candela/Sq. M.)

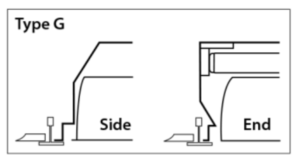
Average Luminance Angle	0.0	22.5	45.0	67.5	90.0
0	2535	2535	2535	2535	2535
30	2402	2446	2587	2785	2901
40	2352	2448	2765	3170	3418
45	2317	2466	2919	3567	4038
50	2264	2479	3116	3886	4299
55	2174	2473	3109	3328	3152
60	1999	2336	2590	1871	1541
65	1647	1866	1518	976	952
70	839	965	695	613	617
75	363	351	325	312	280
80	219	209	171	162	152
85	151	132	114	114	95

DIMENSIONAL DATA

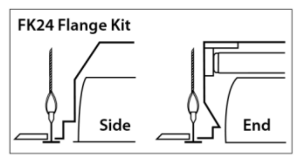


NOTE: All dimensions are in inches; dimensions and specifications are subject to change without notice. Please consult factory or check sample for verification.

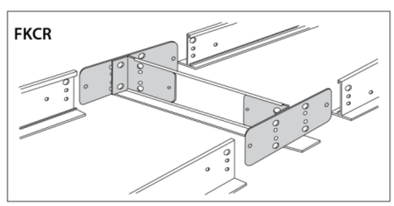
CEILING COMPATIBILITY



For lay-in installation in exposed grid ceilings. Maximum tee widths of 1" and maximum tee heights of 2" allowed.



For hard ceiling applications order FK24 flange kit. Flange kit wires directly into concealed ceiling opening for a clean, finished appearance.



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 row. (Example: Row of two, order (2) FK24 & (1) FKCR)

Row cut out dimensions using FK24s & FKCR adapters:
Width 24⅜", Length [48" × (# in row)] + ⅜". Example: (48" × 2)+ ⅜" = 96⅜"

Flange kit rough in dimensions for single unit only: 24⅜" × 48⅜"

701 Millennium Blvd. Greenville, SC 29607 / Tel **864.678.1000** / Website **www.columbialighting.com**

COOPER LIGHTING - METALUX®

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.

Catalog #		Type
Project		
Comments		Date
Prepared by		

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 end 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 pretreatment 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.

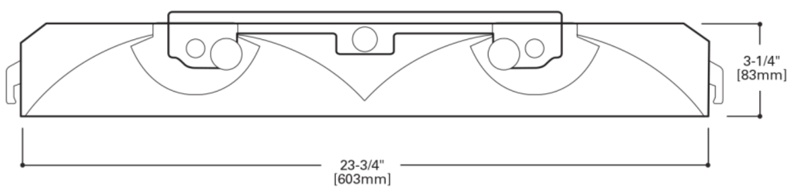
Air Return
Optional Air Return model provides air flow through air slots in the housing.

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.

2AC
232T8

T8 LAMPS

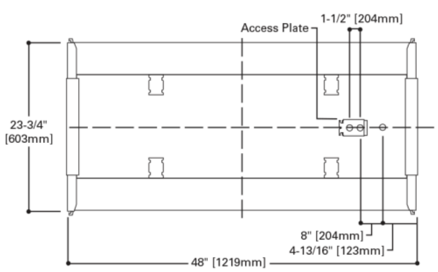
2' x 4' Recessed Troffer Series



accord™ Enhanced Lighting Series

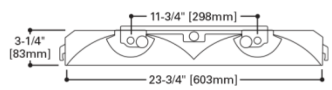
powered by fifthlight technology

MOUNTING DATA



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

LAMP CONFIGURATIONS



ENERGY DATA

Input Watts:

EB Ballast & STD Lamps @ 277V
232 (58)

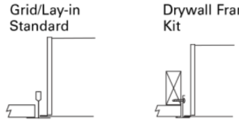
Luminaire Efficacy Rating
LER =FL83 LPW
Catalog Number: 2AC-232

Yearly Cost of 1000 lumens, 3000 hrs at .08 KWH = $2.89

*Reference the lamp/ballast data in the Technical Section for specific lamp/ballast requirements.
**Consult Pre Sales Technical Support.
***See Drywall Frame Kit Accessory

CEILING COMPATIBILITY

G	F	Ceiling Type**	Trim Type
Grid/Lay-in Standard	Drywall Frame Kit	Exposed Grid	G
		Concealed T	G or T
		Slot Grid	G or T
		Flange	***

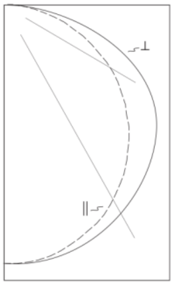


LAMPS CONTAIN MERCURY. DISPOSE ACCORDING TO LOCAL, STATE OR FEDERAL LAWS

LINEAR DISCONNECT
Safe and convenient means of disconnecting power.

COOPER LIGHTING

ADF080359



2AC-232-UNV-EB81

Electronic Ballast

(2) F32T8/835 Lamps
3100 Lumens each

Spacing criterion: (II) 1.3 x mounting height, (⊥) 1.5 x mounting height

Efficiency 85%

Test Report: 241P14200

LER = FL83 LPW

Yearly Cost of 1000 lumens, 3000 hrs at .08 KWH = $2.89

Candlepower

Angle	Along II	45°	Across ⊥
0	1614	1614	1614
5	1607	1612	1618
10	1587	1596	1605
15	1551	1569	1587
20	1502	1531	1558
25	1440	1483	1521
30	1366	1425	1477
35	1280	1358	1425
40	1184	1282	1366
45	1080	1198	1298
50	967	1107	1221
55	848	1007	1134
60	723	899	1022
65	589	783	857
70	452	635	664
75	315	456	465
80	187	280	277
85	81	118	113
90	0	0	0

Coefficients of Utilization

Effective floor cavity reflectance 20%

rc	80%				70%				50%			30%			10%			0%
rw	70	50	30	10	70	50	30	10	50	30	10	50	30	10	50	30	10	0
RCR																		
0	101	101	101	101	99	99	99	99	94	94	94	90	90	90	87	87	87	85
1	92	87	83	80	89	85	82	79	82	79	76	78	76	74	75	73	72	70
2	83	75	69	64	81	74	68	63	71	66	62	68	64	60	65	62	59	57
3	75	66	58	53	73	64	58	52	62	56	51	59	54	50	57	53	49	47
4	69	58	50	44	67	57	49	44	55	48	43	53	47	42	51	46	42	40
5	63	51	43	38	61	50	43	37	49	42	37	47	41	36	45	40	36	34
6	58	46	38	33	56	45	38	32	44	37	32	42	36	32	41	36	31	30
7	54	42	34	29	52	41	34	28	40	33	28	38	32	28	37	32	28	26
8	50	38	30	25	48	37	30	25	36	30	25	35	29	25	34	29	25	23
9	46	35	28	23	45	34	27	23	33	27	22	32	27	22	31	26	22	21
10	44	32	25	21	42	32	25	20	31	25	20	30	24	20	29	24	20	19

Zonal Lumen Summary

Zone	Lumens	%Lamp	%Fixture
0-30	1280	20.6	24.3
0-40	2129	34.3	40.4
0-60	3945	63.6	74.9
0-90	5271	85.0	100.0
0-180	5271	85.0	100.0

Luminance Data

Angle in Deg	Average 0-Deg cd/sm	Average 45-Deg cd/sm	Average 90-Deg cd/sm
45	2188	2427	2630
55	2118	2515	2832
65	1996	2654	2905
75	1743	2524	2574
85	1331	1939	1857

ORDERING INFORMATION

SAMPLE NUMBER: 2AC-232-UNV-EB82-U

Rating
Blank=Standard
NY=New York Rated
ATW-SW4=Chicago Rated

Width
2=2' Width

Series
AC=Accord Series

Type
A=Air (optional)

Number of Lamps (Not included)
2=2 Lamp

Wattage (Length)
32=32W T8 (48")

Shielding
Blank=Frosted Acrylic
SQP=Lens with Square Pattern Insert
RDP=Lens with Round Pattern Insert

Voltage [1]
UNV=Universal Voltage 120-277

Options
GL=Single Element Fuse
GM=Double Element Fuse
Flex=Flex installed
EL=Emergency Installed

Lamps
L8835=T8 Lamp, 17W and 32W, 3500K
L8841=T8 Lamp, 17W and 32W, 4100K
L8835HL=T8 Lamp, 32W, 3500K, 3100 Lumens
L8841HL=T8 Lamp, 32W, 4100K, 3100 Lumens

Ballast Type
EB8_=T8 Electronic Instant Start. Total Harmonic Distortion < 10%
EB8_/PLUS=T8 Electronic Instant Start. High Ballast Factor >1.13. Total Harmonic Distortion < 20%
ER8_=T8 Electronic Program Start. Total Harmonic Distortion < 10%

High Performance T8 Ballasts
HB8_L=T8 Electronic Instant Start. Low Ballast Factor .77
HB8_=T8 Electronic Instant Start. Ballast Factor .88
HB8_N=T8 Electronic Instant Start. Normal Ballast Factor 1.0
HB8_H=T8 Electronic Instant Start. High Ballast Factor 1.15-1.2
HR8_DIM=T8 Electronic Program Start Step Dimming. Ballast Factor .88
HR8_L=T8 Electronic Program Start. Low Ballast Factor .77
HR8_=T8 Electronic Program Start. Ballast Factor .88
HR8_H=T8 Electronic Program Start. High Ballast Factor 1.15-1.2

0-10V Dimming Ballasts [3]
5LTV8_=T8 0-10V Program Rapid Start. Total Harmonic Distortion < 10%. Ballast Factor 0.87
5LTVS8_=T8 0-10V Spec Grade Program Rapid Start. Total Harmonic Distortion < 10%. Ballast Factor 0.87 [4]

Fifth Light DALI Ballasts [2]
5LT8_=T8 DALI Program Rapid Start. Total Harmonic Distortion < 10%. Ballast Factor 1.0

Number of Ballasts
1=1 Ballast
2=2 Ballasts

Packaging
U=Unit Pack
PALC=Job Pack, in carton

NOTES: [1] Products also available in non-US voltages and frequencies for international markets. [2] For a complete listing of Fifthlight Technology products and other solutions from Cooper Controls, visit www.coopercontrol.com. [3] 0-10V ballast do not include DALI feature. Please select DALI ballast for use with Fifth Light system. [4] Specification grade 0-10V dimming ballast are NEMA premium and CEE listed. They are compatible with low mercury and energy saving lamps.

For complete product data, reference the Fluorescent Specification binder. Specifications & dimensions subject to change without notice. Consult your Cooper Lighting Representative for availability and ordering information.

ACCESSORIES

T3A END E.Q. BRACKET PARTS BAG

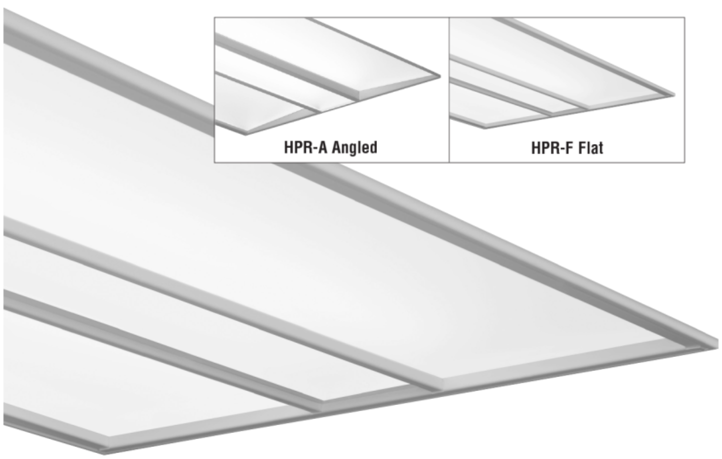
SHIPPING INFORMATION

Catalog No.	Wt.
2AC-232	28 lbs.

BUY AMERICAN ACT OF 2009 COMPLIANT

FINELITE

High Performance Recessed (HPR) 2x4



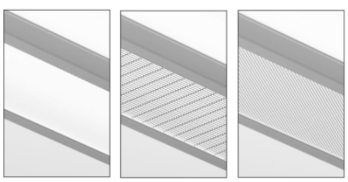
HPR-A Angled | HPR-F Flat

Date	
Project	
Type	
Comments	

DESCRIPTION

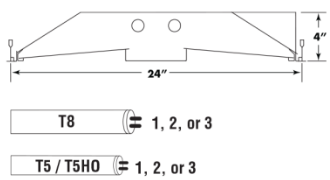
HPR is a highly effective recessed luminaire delivering excellent visual comfort and outstanding performance for offices, schools, healthcare, and retail applications. Advanced optical designs make HPR a powerful solution for low-ceiling applications and eliminate the shadows common to other recessed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

Diffuse (DCO) | Slotted (SCO) | Round (RCO)



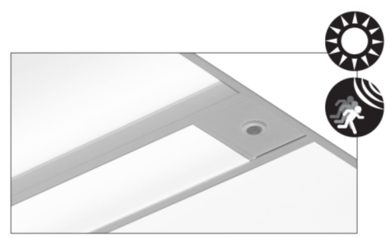
CENTER SHIELDING OPTIONS:

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

HPR - [ ] - [ ] - [ ] - [ ] - [ ] - [ ] - [ ] - [ ] - [ ]

- 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, C2-9/16" T-Bar, C3-Screw Slot, DW-Drywall Kit, SM-Surface Mount)
- Ballast (IS-Instant Start, PS-Program Start, BL-Bi-level, DI-Dimming, and specify BF*)
- Integrated Sensors (OBD-Daylight, OBO-Occupancy, OBB-Both)

** Standard 0.88 for T8 lamps, 1.0 for T5 or T5HO. Contact factory for available BF'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

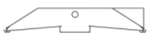
IC - RATED

BUY AMERICAN ACT OF 2009 COMPLIANT

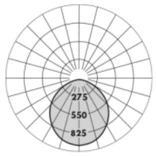
FINELITE

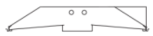
High Performance Recessed (HPR) 2x4

PHOTOMETRY

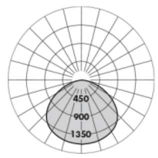


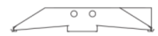
HPR-A: 1 T8-DCO (2x4)
Efficiency: 87.6%
Peak Candela Value: 990@ 0˚
LSI Report: 25411



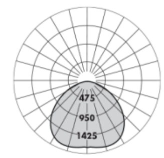


HPR-A: 2 T5-DCO (2x4)
Efficiency: 86.9%
Peak Candela Value: 1548@ 0˚
LSI Report: 25441





HPR-A: 2 T8-DCO (2x4)
Efficiency: 84.8%
Peak Candela Value: 1733@ 20˚
LSI Report: 25417



CANDLEPOWER SUMMARY

	0.0	22.5	45	67.5	90	Flux
0	990	990	990	990	990	
5	988	988	987	985	979	95
10	975	976	974	971	966	
15	953	953	951	948	943	267
20	922	922	917	913	908	
25	880	880	874	869	864	401
30	828	827	821	816	812	
35	765	764	758	756	754	474
40	695	693	687	692	693	
45	617	615	614	623	627	476
50	535	533	535	548	554	
55	451	449	453	467	473	408
60	367	365	370	380	386	
65	287	284	288	293	298	286
70	210	208	207	210	213	
75	139	137	134	135	135	145
80	77	75	71	70	69	
85	29	26	23	20	20	31
90	0	0	0	0	0	

CANDLEPOWER SUMMARY

	0.0	22.5	45	67.5	90	Flux
0	1548	1548	1548	1548	1548	
5	1545	1544	1545	1546	1537	149
10	1522	1525	1531	1536	1531	
15	1485	1492	1505	1517	1515	424
20	1434	1446	1468	1488	1492	
25	1367	1387	1420	1454	1462	653
30	1288	1314	1362	1410	1424	
35	1195	1227	1292	1352	1372	805
40	1093	1130	1208	1276	1300	
45	983	1022	1107	1177	1201	845
50	864	904	987	1053	1074	
55	740	778	852	907	923	750
60	615	646	708	746	757	
65	491	513	558	581	589	542
70	369	383	409	422	426	
75	254	262	272	276	276	286
80	150	150	152	148	145	
85	61	58	52	44	43	65
90	0	0	0	0	0	

CANDLEPOWER SUMMARY

	0.0	22.5	45	67.5	90	Flux
0	1687	1687	1687	1687	1687	
5	1689	1693	1697	1699	1688	164
10	1672	1682	1700	1713	1710	
15	1640	1659	1694	1725	1729	477
20	1595	1623	1677	1723	1733	
25	1533	1570	1644	1702	1715	752
30	1454	1499	1586	1650	1666	
35	1357	1408	1502	1566	1581	927
40	1244	1297	1392	1451	1465	
45	1117	1167	1256	1306	1318	950
50	979	1023	1099	1140	1148	
55	832	868	930	960	963	815
60	683	710	757	773	773	
65	538	555	586	592	591	569
70	398	408	422	421	419	
75	267	271	274	268	266	288
80	151	150	148	140	138	
85	58	56	51	44	43	64
90	0	0	0	0	0	

— Refer to www.finelite.com for additional photometry and product information.

SPECIFICATIONS

CONSTRUCTION: Fixture assembly constructed using die-formed 20-gauge cold-rolled steel housing and ends. All components are hard-tooled 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 entrances 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:

Diffuse Center Optic: UV-stabilized and impact-resistant frosted virgin acrylic. Optional Soft Glow Optic (SGO) available for T8 only.

Slotted 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 T5HO lamp cross sections.

BALLAST: UL listed Class P. Electronic instant-start ballast <10% THD, 0.88 BF standard for T8 lamps. Electronic program-start ballasts <10% THD, 1.0 BF standard for T5/T5HO lamps. Contact factory for available BF's. Optional adders: program-start ballasts (standard for T5/T5HO), 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 3 T5HO. Optional Chicago Plenum available. Contact factory.

Daylight Sensor Occupancy Sensor

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 tie-in locations for tie-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 wire standard.

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 whips (with flex connectors) supplied in a max. of 11' lengths.

WEIGHT: Maximum weight: 2x4 - 33 lbs.

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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.

Troffer label	Rank (1=worst 4=best)	Brief comments to explain your answers	Acceptable? (Y or N)
B1			
B2			
B3			
B4			

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.

Troffer label	Rank (1=worst 4=best)	Brief comments to explain your answers	Acceptable? (Y or N)
B1			
B2			
B3			
B4			

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