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Abstract

This paper focuses on performance variations associated with lamp geometry and distribution in portable table luminaires. If correctly retrofit with compact fluorescent lamps (CFLs), these high use fixtures produce significant energy savings, but if misused, these products could instead generate consumer dissatisfaction with CFLs. It is our assertion that the lumen distribution of the light source within the luminaires plays a critical role in total light output, fixture efficiency and efficacy, and, perhaps most importantly, perceived brightness. We studied nearly 30 different integral (screw-based) CFLs available on the market today in search of a lamp, or group of lamps, which work best in portable table luminaires. Our findings conclusively indicate that horizontally oriented CFLs outperform all other types of CFLs in nearly every aspect.

Introduction

Energy-efficient residential lighting has the potential to produce dramatic savings. While retrofits in commercial spaces typically replace old fluorescent technology with new fluorescent technology with efficacy improvements of 20%-30%, residential retrofits replace incandescent lamps with fluorescent lamps for a 400% increase in efficacy. While this market is not as large as the commercial one, the four fold efficacy improvement presents a dramatic energy savings potential.

User surveys indicate that high-use luminaires, such as table lamps, account for a large portion of the energy used for residential lighting. It has been estimated that 30% of the fixtures in homes account for 75% of the lighting energy consumed.[1] Targeting these high-use residential fixtures for compact fluorescent lamp (CFL) replacement can potentially produce dramatic energy savings.

In order to transform the table lamp market from incandescents to CFLs, we need to address several important technical factors including perceived brightness, light distribution, user satisfaction and power quality. CFLs are very different than standard A-Lamps in many ways, and these differences, when not accounted for, can produce undesirable effects leading to rejection by consumers and a failure to achieve desired load reductions by utility sponsors.

Previous studies have focused on the high-use table and compared the difference in the output of that standard A-Lamp to a few standard CFLs.[2] This study presents much more comprehensive information on the operation of all types of integral CFLs in table lamps in search of the most appropriate CFL for retrofits. The data presented in this paper will hopefully help aid in the development of new table lamps optimized for the CFL, as well as identify integral CFLs for use in existing table lamps while we wait for the new dedicated fixtures to capture a significant market share. [3]

Experimental Procedure

Nearly 30 different CFLs were used in this study including vertical, horizontal, and globe CFLs with wattages from 7 W to 38 W. All bare lamps where first measured in our 2.0 m (80 inch) integrating sphere while operating base-up (to minimize thermal losses) as recommend by IES standards. These tests yielded bare lamp total lumen and efficacy values. Sphere temperature was maintained at 22°C ± 0.4°C (72°F±1°F). While the effect on lamp output and input power is minimal, all testing was performed at this temperature rather than the standard 25°C (77°F) because 22°C ± 0.4°C (72°F±1°F) is more typical of residential temperature.

These lamps were then measured in our swing-arm goniophotometer in a standard table lamp (black, reflectance = 4.4%, total height = 82 cm (32”), socket height = 59 cm (23”), cutoff angle = 10°) with a conical shade (white, reflectance = 51.9%, height = 25.5 cm (10”), minor diameter = 15 cm (6”), major diameter = 51 cm (20”), shade angle = 35°). Room temperature was maintained at 22°C ± 0.4°C (72°F±1°F) to correspond to integrating sphere tests and the CFLs were operated base down allowing both fixture and thermal losses to be included in fixture efficiency calculations. The goniometer yielded detailed candlepower plots, zonal and total lumen information, and fixture efficacy for the portable table luminaires. Rotational symmetry of the lamp was carefully considered during goniometer testing (i.e., a bisymmetrical lamp was rotated 180 degrees in the photo-goniometer). Power quality information was also gathered during experimentation with Xitron power analysis equipment.

By normalizing goniometric results (i.e. scaling the candlepower plots) of various sources to a standard wattage, the distribution of sources with different lumen packages can be more fairly compared to each other. We picked a “typical” CFL power of 20 W as our normalization constants. Normalization to a wattage was chosen over normalization to a standard lumen value because it allows us to consider lamp efficacy in our comparisons. For example, a standard A-lamp may have a favorable lumen distribution in a table lamp compared to many CFL lamps by lumen output only. However, the low efficacy of A-lamps makes them a very poor choice in our study of energy efficient lighting.

Lamps were categorized by geometry because this affects lumen distribution so dramatically. In theory, two quad tube CFLs of different wattages should have very similar normalized candlepower information, because they are very similar in shape. However, a quad tube CFL and a circline CFL have very different geometries and thus different candlepower data.

Results

The normalized candlepower data is generated by multiplying the goniometric information at each point by the ratio of the constant to the measured value. For example, to normalize a 23 W source to a 20 W constant, candlepower readings are multiplied by 20÷23, or 0.870. Because power varies fairly linearly with lumen output (i.e. efficacy is constant), normalization by wattage is possible. **Table 1** presents the average candlepower data for three types of CFLs (horizontally oriented, vertically oriented and globe CFLs) as well as that average candlepower data normalized to 20 W. Interesting results from these experiment are seen when we create candlepower plots of this data, as is done in **Figure 1**.

Table 1. Average Candlepower Data for 8 Horizontal, 17 Vertical and 4 Globe CFLs

Degrees from nadir	Average Intensities (cd)			Average Intensities Normalized for 20 Watts (cd)		
	Horizontal	Vertical	Globe	Horizontal	Vertical	Globe
0	116	95.0	81.1	111	107	94.7
5	157	100	87.8	150	113	102
15	213	115	104	204	129	121
25	212	123	109	203	139	127
35	193	121	104	185	136	121
45	170	120	102	162	135	119
55	120	98.7	83.8	115	111	97.8
65	61.8	42.5	35.2	59.1	47.8	41.1
75	29.9	25.4	22.6	28.6	28.5	26.3
85	28.1	24.8	23.1	26.9	27.9	26.9
95	35.7	30.8	29.6	34.1	34.6	34.5
105	45.6	39.4	37.5	43.6	44.4	43.8
115	53.5	46.1	43.2	51.1	51.9	50.5
125	61.5	50.8	47.1	58.8	57.1	55.0
135	69.1	56.8	50.8	66.1	63.9	59.3
145	84.9	71.7	71.9	81.2	80.7	84.0
155	106	82.3	90.9	102	92.6	106
165	114	75.4	95.3	109	84.8	111
175	116	68.4	97.2	111	77.0	113
180	118	70.4	102	113	79.3	119

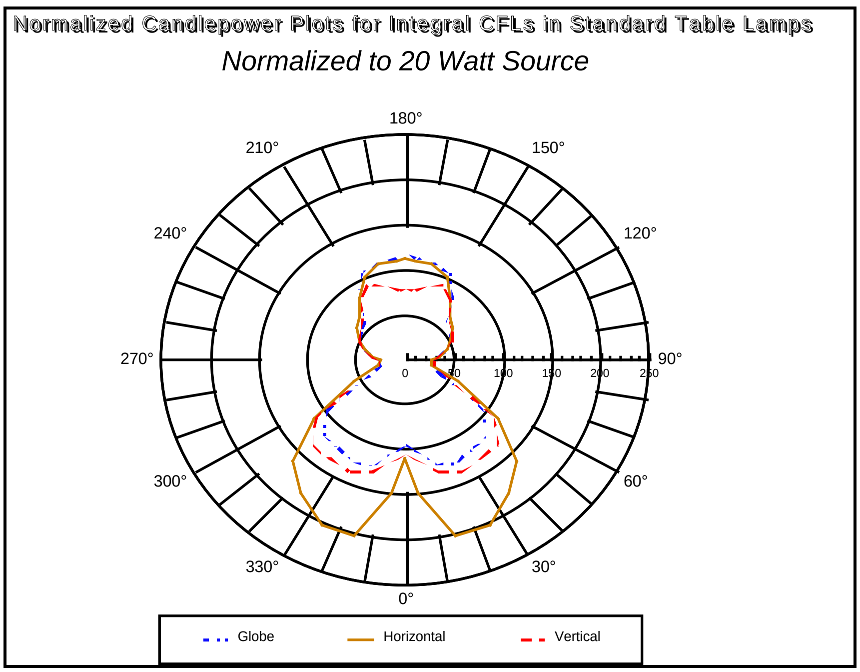

Figure 1. This plot shows a summary of 4 Globe, 8 Horizontal, and 17 Vertical CFLs that were normalized to a 20 W source and then averaged with all other lamps of their type.

When comparing candlepower plots, several distribution effects must be considered. The most critical angles are those below the shade (**Figure 1**, 0° to 60°) because the light output from this area illuminates the task plane. The light detected in the area covered by the shade (60° to 150°) provides minimal ambient lighting and is not usable as task lighting. The light exiting through the top aperture of the shade (150°-180°) provides ambient lighting.

The results displayed in **Figure 1** agree with our hypothesis. We can see that the globe and horizontal sources generate more light than verticals at near zenith angles, the horizontal sources yield the most light at nadir angles, and all three sources yield similar output in the shade region. The globe lamps produce a significant amount of light out the top of the shade because of their fairly large solid angle, or "footprint" near zenith (unlike the vertical sources). Yet the source is small enough and centered in the fixture so that much of the light comes out the top aperture of the shade without reflection (unlike the horizontal source). These optical advantages are somewhat tempered by the losses incurred because of the lower efficacy associated with its plastic diffuser.

The horizontal sources yield significantly more light out the bottom aperture of the shade. They concentrate their illumination vertically and most extend radially out around the center of the fixture circumventing light blockage due to the fixture base. A surprising result, shown vividly in **Figure 1**, is the fact that vertical CFLs do not produce a more significant amount of light in the area covered by the shade. Since the vertical CFLs' light is sent primarily in the horizontal direction, we might expect it to produce a much brighter shade, but this is not what was found. Instead we found that shade brightness was nearly equal for all three lamp types.

As a double check of the validity of using far-field goniometric results to comment on table lamp task plane illuminance, we conducted a set of simple illuminance experiments.[4] First we selected the one horizontal and two vertical CFLs whose intensities most closely matched those of the average intensities of their group at each angle. Next, these lamps were placed in the same table lamp as was used for all goniometric tests, and we took task plane illuminance readings at a series of distances that corresponded to the angles measured in the goniometer. These values were then normalized to 20 W (using the same method as above) to avoid unfair comparisons. The results, as shown in **Figure 2**, correspond quite well. The horizontal lamp produced much greater task illuminance than either of the vertical CFLs. Additionally, we can see that the more compact triple tube lamp produces more task plane light than the quad, which casts most of its flux horizontally.

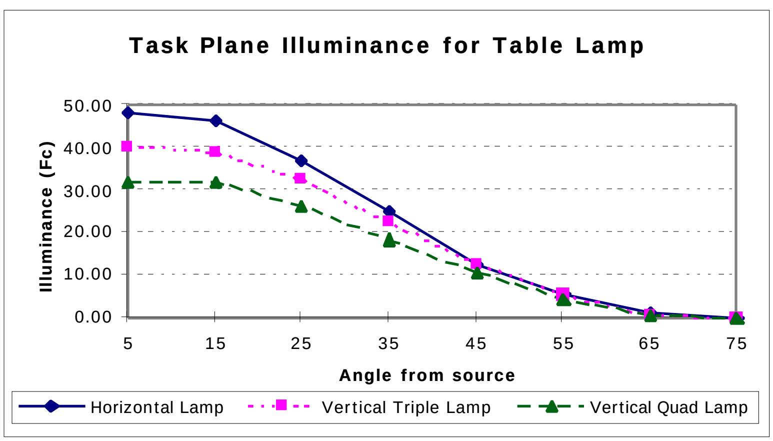

Figure 2. Task plane illuminance was greater for a typical horizontal source than it was for typical vertical CFL sources. All three sources were normalized to a 20 W CFL source.

It is useful to look at these CFLs in ways other than their distributional effects. One important indicator is the fixture efficiency. Fixture efficiency is easily found by comparing the bare bulb lumens of the source with the fixture lumens. Both fixture losses and thermal losses from base down operation are accounted for here. This yields quantitative insight into the performance of sources of different geometries. Another important metric is the fixture efficacy, which is in some ways "the bottom line" analysis showing exactly how many lumens are escaping the fixture per Watt input. Efficacy is also highly dependent on the source's distribution and fixture efficiency.

Table 2 presents the average data in a variety of categories for the three CFL groups we have been analyzing. Appendix A provides similar data for each lamp tested and group maximums and minimums. **Figures 3 through 5** graphically represent selected data from **Table 2** and reiterate many of the distributional effects discussed earlier. These graphs focus on the horizontal and vertical CFLs only because comparisons between the two provide the greatest insight and they are much more common than globe CFLs.

Table 2. Average Data for 8 Horizontal, 17 Vertical and 4 Globe CFLs

	Average Horizontal	Average Vertical	Average Globe
Power (Watts)	20.92	17.77	17.13
Fixture Lumens	1197	924	723
Bare Lamp Lumens	1317	1140	821
Fixture Efficacy	56.51	50.51	42.17
Bare Lamp Efficacy	62.24	62.54	48.07
Fixture Efficiency	90.74%	81.23%	88.00%
% Lumens Above Shade	8.85	8.54	11.02
% Lumens Into Shade	40.51	45.46	45.73
% Lumens Below Shade	50.64	46.00	43.25

Figure 3 shows the substantial losses the average vertical CFLs suffer as compared to the average horizontal CFLs. The average fixture efficiency of the horizontal sources was over 90% while the vertical sources yielded average efficiencies of 81%. While some of the vertical CFLs' losses were due to thermal effects from a base down operation, the vast majority was caused by their light being sent into the partially absorbing shade.

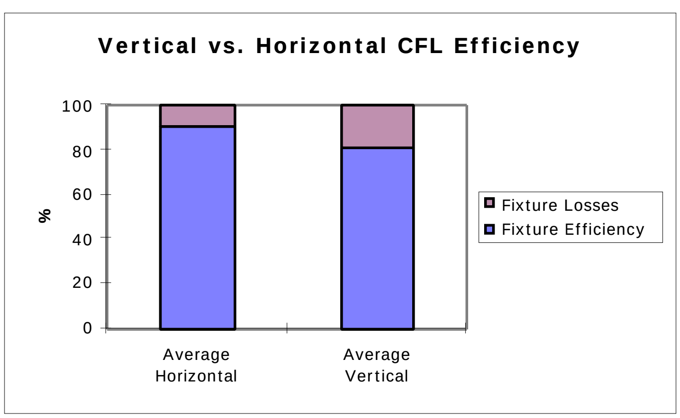

Figure 3. Average Horizontal CFLs suffer less fixture losses than average vertical CFLs in table lamps.

Figure 4 summarizes the averaged efficacy data for the vertical and horizontal CFLs. While bare bulb vertical CFLs had a slightly higher efficacy, the horizontal lamps had a significantly higher fixture efficacy caused by the differences in fixture efficiency as seen in **Figure 4**.

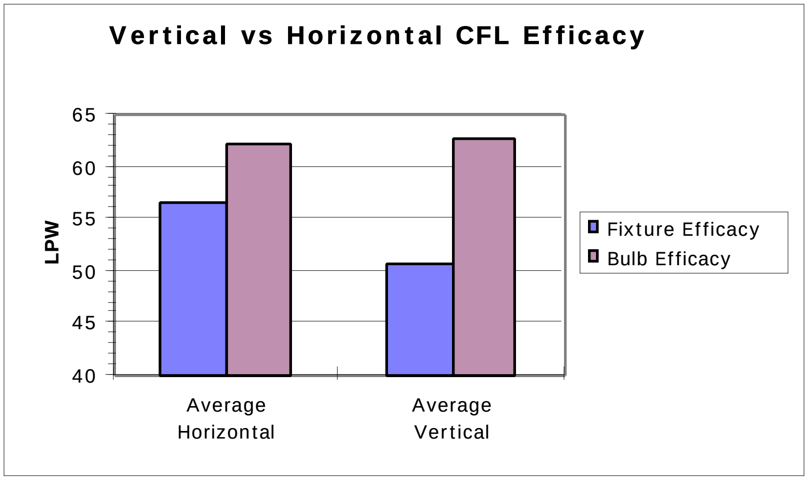

Figure 4. Fixture losses of vertical CFLs more than canceled their slightly higher bulb efficacy yielding fixture efficacies of 50.5 LPW for vertical and 56.5 LPW for horizontal sources.

Figure 5 more clearly demonstrates some of the findings in the previously discussed normalized candlepower plots and explains the differences found in the fixture efficiencies. The vertical lamps suffered greater shade losses because much more of their light was sent into the shade and was absorbed. Most of the light from the horizontal sources exited the fixture above or below the shade, without being reflected or absorbed by the shade.

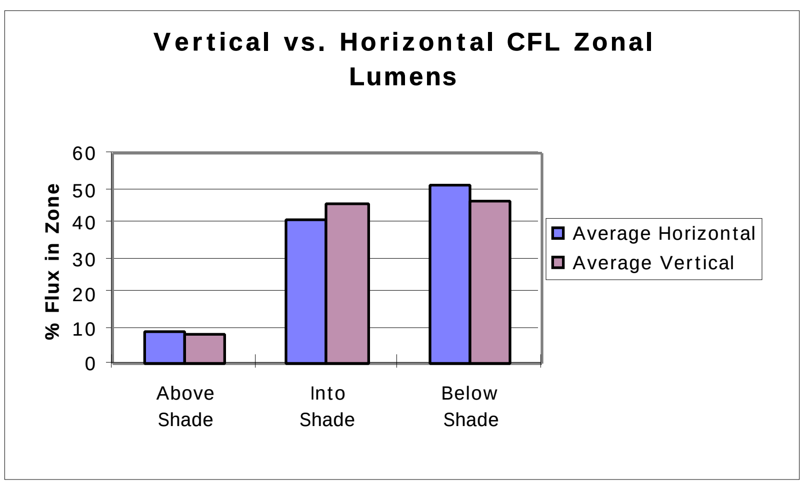

Figure 5. Vertical CFLs have lower fixture efficiencies because they send more flux into the 60°-150° shade zone.

Conclusions

Horizontal CFLs have been shown to out perform other types of CFLs in table lamps in nearly every way. They increase light intensity at the critical regions of above and below the shade by 40%-50% as compared to standard vertical CFLs, while not noticeably decreasing shade brightness. While new CFL designs are starting to reach the market (notably, spiral CFLs meant to mimic the distribution of A-Lamps) it is our conclusion that we need not look any further than the currently readily available horizontal CFLs. The next step in optimizing CFL performance for table lamps should be in the production of dedicated fixtures with horizontal lamps. These new pin based fixtures will be optically optimized with a specified lamp height and shade size appropriate for the new sources. These new fixtures will improve performance even more and further ensure consumer acceptance and energy savings.

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