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## **ABSTRACT**

A series of novel energy efficient torchiere systems have been developed using compact fluorescent lamps (CFLs). These systems were studied photometrically and compared with the performance of traditional commercially available tungsten halogen sources. Gonio-photometric data and power assessments indicate that significant lighting energy savings can be obtained by utilizing CFL sources instead of standard tungsten halogen sources. This energy savings is jointly due to the higher source efficacy of the CFLs and the surprisingly poor performance of the imported 300 Watt halogen lamps. Experimental data shows that a 50 to 60 Watt CFL will effectively lumen match a variety of 300 Watt tungsten halogen sources with 5 to 10 times the efficacy. CFL torchieres have additional benefits of higher power quality and cooler lamp operating temperature, making them safer fixtures.<sup>1,2</sup>

## **BACKGROUND**

Currently the American market is seeing a significant increase in sales of imported torchiere systems. These indirect lighting systems use tungsten halogen sources in the 300 to 500 Watt range. There are an estimated 40 million torchieres currently in the US stock with 15 to 18 million units in annual sales.<sup>3</sup> Such wide usage of these systems has resulted in one of the largest increases in US residential lighting energy use and also represents a significant challenge to past and ongoing energy conservation programs throughout the country. Recent studies estimate that halogen torchieres now consume more energy than all of the CFLs are saving in the United States.<sup>4,5</sup>

This is particularly disheartening considering the level of resources federal and state programs have invested to accelerate the penetration of CFL technologies. Furthermore, many utilities throughout the country have sponsored rebate and incentive programs for years to accelerate market transformation with the CFL as one of the most effective conservation technologies. We are currently seeing the complete erosion of the progress associated with many of these demand-side management (DSM) activities.

In order to counter this conservation erosion, it is now necessary to rapidly research and develop energy efficient alternatives to the halogen torchiere fixture using compact fluorescent systems. To this end, a series of torchiere systems using efficient CFL sources were photometrically optimized. These studies are intended to provide information to manufacturers on how to use efficient sources as a replacement for the 300 Watt tungsten halogen source. This effort is part of an ongoing program that focuses on market transformation issues and the technical development of energy efficient fixtures.

## **EXPERIMENTAL PROCEDURE**

Torchiere research included: 1) characterization of existing halogen sources and torchiere fixtures, and 2) prototyping and characterization of energy efficient CFL torchieres. Characterization of the fixtures included standard photometric measurements (candlepower distribution, fixture efficiency) and power analysis (harmonic distortion, power factor). All photometric testing was conducted on

seasoned, thermally stabilized lamps with room temperature and voltage conditions at  $22^{\circ}\text{C} \pm 0.4^{\circ}\text{C}$  ( $72^{\circ}\text{F} \pm 1^{\circ}\text{F}$ ) and at  $120\text{ V} \pm 0.1\text{ V}$ .

A cross-section of halogen torchieres were purchased from several retail chains. These fixtures ranged in price from \$14-\$80 and all included imported 300 W halogen lamps. Several more expensive domestically produced halogen lamps (bulbs) were also purchased and tested.

### ***CFL Fixture Design***

Several CFL prototypes were constructed using the salvaged fixtures from halogen torchieres. These prototypes included CFLs of all shapes and sizes including quads, triples, circlines, F-lamps and 2D lamps. They contained anywhere from one to four lamps and most could operate at multiple output levels.

A conscious effort was taken to make prototypes that could be realistically manufactured. This often required the use of optical reflector materials with reflectances near 90% rather than available, yet prohibitively expensive, 98% reflective materials.

Data from nine of the CFL prototypes is presented here. Prototypes one through five (made with a 43 cm/17 inch dish) and nine (33 cm/13 inch dish) used two, 32 Watt linear quad lamps (or “F-Lamps”) operated with a single electronic ballast. The linear quad lamps were used because they are small and flat with very high efficacy and lumen output. The design of these prototypes resembled the torchiere shown in Figure 1. Only the reflector design, dish size and position of the lamps changed between these prototypes.



Figure 1. Example of a prototype torchiere design. The reflector and lamp configuration shown on the right is similar to the design of prototypes one through five and nine.

The optical reflectors for these prototypes were designed to: 1) hide the ballast, 2) prevent direct flux of one lamp from reaching the other, 3) provide high fixture efficiency with a shallow dish by placing the lamps near the top aperture, and 4) provide an even ceiling pattern during both one and two lamp operation. Prototypes one, three, five, and nine employed white-painted reflectors with reflectances ranging from 81 to 93 percent. Prototypes two and four used specular reflectors ranging in reflectance from 84 to 98 percent.

Prototype six consisted of a 22 Watt circline lamp located inside a 32 Watt circline. This prototype operated with two separate ballasts and a white reflector. Prototype seven used a 38 Watt 2D lamp with a three-way ballast in a specular reflector with a reflectance of 98 percent. Prototype eight utilized two 32 Watt triple lamps operated by two electronic ballasts in a specular reflector with 98 percent reflectance.

### ***Bare Lamp Lumen Output***

A 2 meter (80 inch) integrating sphere was utilized to obtain bare lamp lumen output, power draw and lamp efficacy of the sources.

Halogen: The bare lamps were operated horizontally (as they are in the torchiere fixtures) in the integrating sphere. The lamps were operated on a voltage stabilized line without the torchiere dimming circuits.

CFL: CFLs were operated base up and their ballasts were remote as to not obscure any light. The “base up” lamp orientation yields a more thermally stable lamp operation. This was chosen for bare lamp measurements so that thermal degradation of lumen output in the fixture would register as a decrease in fixture efficiency.

### ***Lumen Output for Dimming***

Halogen: The dimming circuits from a torchiere fixture were removed and added in line with the halogen source in the integrating sphere in order to establish the effect of dimming on source efficacy. Lumen output, total harmonic distortion (THD), and power factor (pf) were recorded at five percent intervals of peak power on several different halogen sources, both domestic and imported. In all dimming experiments, the system was allowed to stabilize for at least 30 minutes between dimming adjustments and measurement.

CFL: CFLs with multi-level ballasts were tested at each level. All testing was performed as described in the “bare lamp lumen output” section above.

### ***Fixture Characterization***

Halogen: Since almost all halogen torchiere fixtures obtained had nearly the same optical geometry (sometimes with very slight differences in the bowl size), the fixture efficiency was only calculated for one fixture. This was done by running a series of tests on a halogen fixture in a computer-controlled swing-arm photo-goniometer (see Figure 2) and comparing the results to those from the halogen lamps previously tested in the integrating sphere. The fixture used contained the same dimming circuit used in the dimming experiments described in the “bare lamp lumen output” section above. During all testing the voltage was stabilized at  $120.0\text{ V} \pm 0.1\text{ V}$  with the dimmer in the “full on” position. The goniometric experiments yielded candlepower distributions and fixture lumen output and, with the previously obtained bare lamp lumens, fixture efficiency.

CFL: Because all CFL torchiere prototypes varied greatly in design, they were each individually tested in the goniometer. The multi-level fixtures were operated at each level to determine whether the fixture efficiency and candlepower distribution varied with operating level.

## ***Power Analysis***

Data on power, THD, pf and current crest factor were monitored continuously during goniometric testing by a computer controller linked to a Xitron power analyzer. At the completion of the test, the power analyzer data was averaged and recorded.

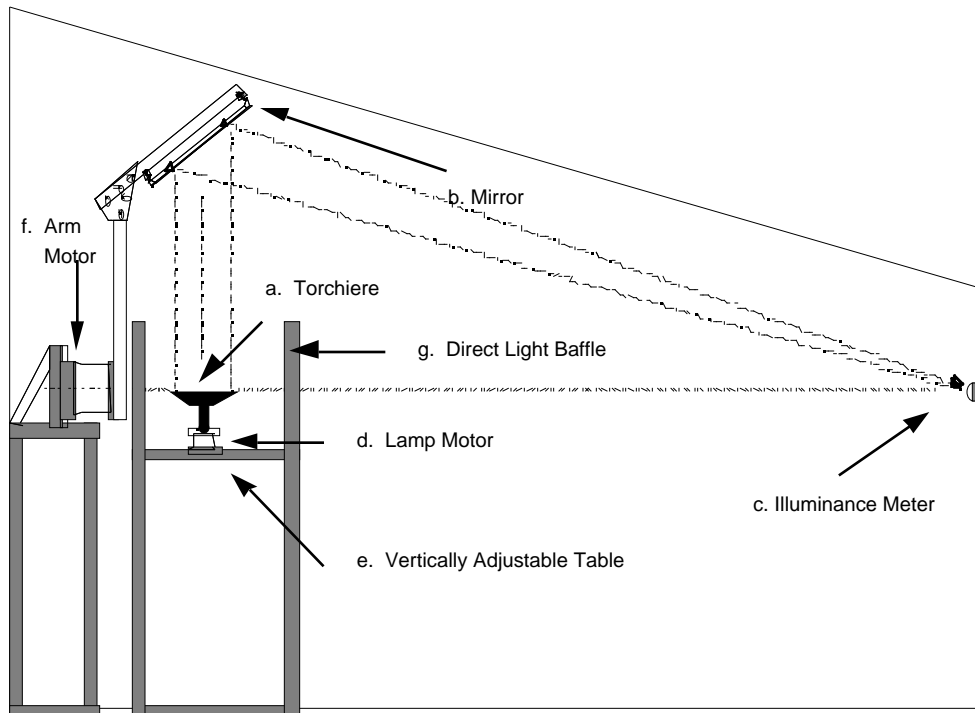


Figure 2. Photo-goniometric Apparatus for Torchiere Testing

## **RESULTS**

### **Halogen Torchieres**

Halogen lamps typically have luminous efficacies near 20 LPW, higher than standard incandescent lamps, due to their hotter filament. While the manufacturers made no efficacy or lumen output claims on the torchieres we purchased, we expected them to have efficacies near this range. We tested the imported halogen lamps that come with the torchieres as well as more expensive, domestically produced lamps.

### ***Efficacy and Lumen Output***

Table 1 shows the power, light output and efficacy data on both the imported and domestically produced halogen lamps. While the import lamps varied dramatically in both light output and power drawn, they were consistently short of the expected efficacy and lumen output. The average efficacy was found to be 11.6 LPW, or more than 40% less than that of major manufacturers and well below the 15-17 LPW of common household incandescents.

Table 1. Power, Lumen Output and Efficacy of Typical Halogen Sources

<b>Import</b>	Power	Lumens	LPW
Lamp 1	272.4	2710	9.949
Lamp 2	307.3	4413	14.36
Lamp 3	250.0	2722	10.88
Lamp 4	262.2	3282	12.52
Lamp 5	262.5	3239	12.34
Lamp 6	249.7	2477	9.920
Lamp 7	260.1	3010	11.57
Lamp 8	259.2	2934	11.32
<b>Average</b>	<b>265.4</b>	<b>3098</b>	<b>11.67</b>
<b>Domestic</b>			
Lamp 1	300.4	5410	18.01
Lamp 2	297.3	5607	18.86
Lamp 3	305.3	5817	19.05
<b>Average</b>	<b>301.0</b>	<b>5611</b>	<b>18.64</b>

***Dimming Effect on Halogen Lamp Efficacy***

The dimmers on torchiere fixtures consist of a circuit which distorts the voltage waveform, affecting both lamp efficacy and power quality. These circuits are largely uniform in design with no noticeable difference in the circuits between the high and low end torchiere models, either in appearance or performance.

Figure 3 shows the effect of dimming on halogen source efficacy (average data for a domestic lamp and an import lamp). As can be seen, dimming has a significant non-linear effect on the lamps. For example, when dimmed to 50% light output, a typical lamp consumed 73% of peak power. Alternatively, a lamp dimmed to 50% maximum power only produced 21% of peak light output.

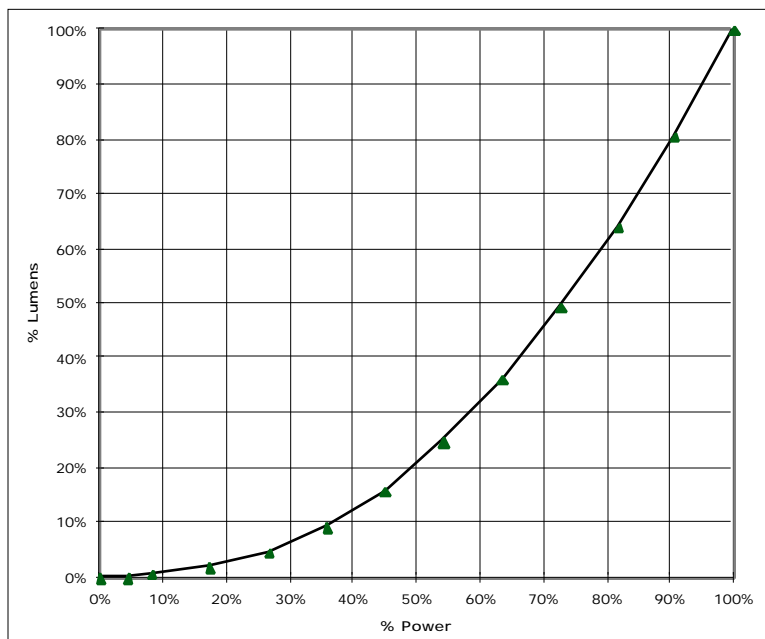


Figure 3. Percent Lumen vs. Percent Power for Dimmed Halogen Sources

### ***Dimming Effect on Halogen Lamp Power Quality***

Efficacy decreases are not the only drawbacks to halogen dimming; power quality declines significantly with dimming. Table 2 shows the effect of dimming on THD and pf.

Table 2. Dimming Effect on Power Quality

<b>Power (%)</b>	<b>Power (Watts)</b>	<b>% THD</b>	<b>PF</b>
100	262.0	5.370	0.9993
95	248.9	20.31	0.9598
90	235.8	27.24	0.9222
85	222.7	33.37	0.8861
80	209.6	39.80	0.8624
75	196.5	45.31	0.8268
70	183.4	50.88	0.7895
65	170.3	56.48	0.7535
60	157.2	63.12	0.7125
55	144.1	69.48	0.6724
50	131.0	75.41	0.6325
45	117.9	82.19	0.5912
40	104.8	89.11	0.548
35	91.7	95.82	0.5004
30	78.6	102.1	0.4529
25	65.5	109.3	0.3997
20	52.4	117.5	0.3458
15	39.3	130.0	0.285
10	26.2	148.4	0.2185
5	13.1	184.1	0.1406

Power quality is a particularly interesting issue when considering the level of concern utility groups have with CFLs that have low pf and high THD. The addition of a large number of these high wattage, low power quality luminaries can have a significant negative impact on a utility.

### ***Fixture Characterization***

Figure 4 shows the candlepower distributions for domestic and imported halogen sources in a typical fixture. These results are averaged data from at least three of each lamp type. The fixture with the domestic lamp has intensities directly above the fixture of nearly 2500 candela, or more than twice that of the import lamps. Obviously because these lamps are of similar geometries and in the same fixture, their candlepower distributions are similar in shape. These fixtures have maximum intensities near apex angles and throw relatively small amounts of direct illumination to lower angles where light would be useful for illuminating far regions of a room.

Table 3 presents the fixture efficiency data for a single torchiere operated with six different halogen sources. The average fixture efficiency of the halogen torchieres is 88.3 percent. Combining this with the source's data from Table 1, the average torchiere with a 300 W import lamp produces 2736 lumens, while one with a domestic lamp produces 4955 lumens.

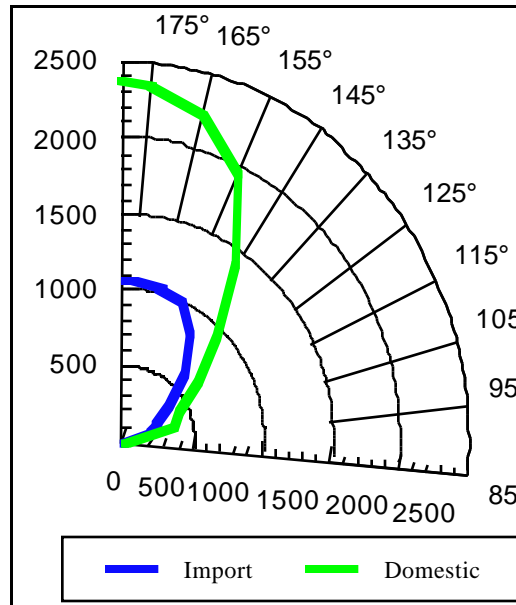


Figure 4. Candlepower Distribution of Halogen Sources in a Torchiera Fixture

Table 3. Fixture Efficiencies of Halogen Torchieres

Import 1	89.5
Import 2	88.5
Import 3	87.3
Import 4	89.6
Domestic 1	86.4
Domestic 2	88.6
Average	88.3

### CFL Torchieres

Numerous CFL torchieres were constructed with a variety of commercially available sources. Torchiera dishes of 33 cm/13 inches (outside diameter) and 43 cm/17 inches were used as the fixture casing. These fixtures were initially designed to lumen match the 300 W import torchieres while attempting to closely mimic their distribution.

#### *Efficacy, Lumen Output, Dimming Effects, and Fixture Efficiency*

Table 4 presents the luminaire lumen output, power, luminaire efficacy and fixture efficiency of 9 unique CFL prototypes. Almost all of these prototypes provide significantly larger lumen packages than the 2736 lumens of the import torchieres, while providing a considerable energy savings. Several of the CFL prototypes even fell within 10 to 20 percent of the lumen output of the high output domestic torchieres. Fixture efficiencies above 90% were obtained in several prototypes. This was possible because of a combination of advanced optics, a shallow dish, a flat CFL source, and a highly reflective (greater than 90 percent) surface finish. It was found that placing the source as high in the fixture as possible, without producing direct lamp image glare, produced the highest efficiencies.

While dimmers were not utilized, no significant effects were found as a result of the fixtures' multi-level switching. Efficacy, THD, and pf were relatively even regardless of light level. Additionally, fixture optics were designed so that light distribution would remain uniform in multi-lamp switching fixtures.



Table 4. Fixture Data for Prototype CFL Torchieres

	Luminaire Output (Lumens)	Input Power (Watts)	Luminaire Efficacy (LPW)	Fixture Efficiency	THD	Power Factor
Prototype 1	3622	61.7	58.8	77.8%	18.37%	0.99
Prototype 2	3993	61.6	64.8	85.7%	18.33%	0.99
Prototype 3	4226	61.6	68.6	90.7%	18.33%	0.99
Prototype 4	4303	61.6	69.8	92.4%	18.37%	0.99
Prototype 5	3943	67.5	58.4	84.6%	13.01%	0.99
Prototype 6	3455	59.0	58.6	90.8%	53.94%	0.97
Prototype 7	2315	38.0	60.9	92.2%	n/a	n/a
Prototype 8	3658	65.4	55.9	94.3%	n/a	n/a
Prototype 9	4005	61.6	65.0	83.6%	4.58%	0.99

### Candlepower Distribution

The prototypes succeeded in lumen matching the halogen torchieres and produced unique candlepower plots as seen in Figure 5. While the prototypes varied greatly from one to the other, in general they produced a much wider distribution than the halogen torchieres. The “hot spot” of the CFL prototypes fell between 1000 and 1300 candela and were able to match the 1000 candela of the import halogen torchieres, but they were no match for the 2400 candela of the domestic lamps. The wider distribution of the prototypes threw much more light into the lower (near horizontal) angles.

While a bright “hot spot” may play an important role in the perception of brightness of the room, it does not necessarily produce appropriate illuminance in a room. This is particularly true across the room from the fixture. The CFL prototypes with their wider distribution likely spread light more effectively through a living space and yield higher illuminance levels throughout the space.

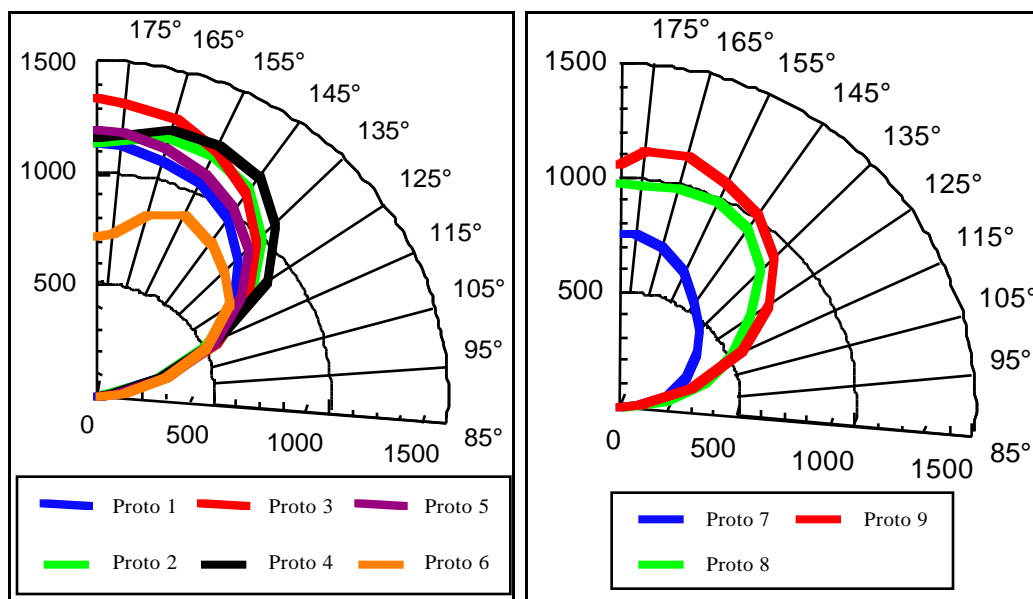


Figure 5. Candlepower Distribution of CFL Prototypes in a 17 inch Torchiere Fixture (left) and a 13 inch Torchiere Fixture (right)

## Energy Use Example During Dimming

Consider an import lamp running at 265.4 W (average) with an efficacy of 11.67 LPW (average) which is dimmed to 50% light output. Suppose this lamp is in a fixture with an efficiency of 88.3% (average) and is placed in a room with ceiling and wall reflectances of 75%. Assuming a typical light ray bounces off the walls and/or ceiling only once (an underestimate), the delivery efficiency from lamp to task plane or floor is  $0.883 \times 0.75$ , or 66%. From Figure 4, at 50% light output the light is using 73% of the power. So the 265.4 W, 11.67 LPW source becomes a 193.7 W, 8.00 LPW fixture with a delivery efficiency of 66%. Thus, this lamp is using nearly 200 W of energy to deliver light at barely 5 LPW.

A 50 W CFL Torchiere with a source efficacy of 65 LPW and a two-level switch is then put into the same room. Assuming the same fixture efficiency (an underestimate), the delivery efficiency from lamp to task plane or floor is again 66%. But now at 50% light output, the lamp only uses 25 W. The CFL lamp delivers light to the task plane for  $65 \text{ LPW} \times .66$ , or 43 LPW, nearly an order of magnitude more efficiently than the halogen torchiere.

## CONCLUSIONS

The experimental photometric and power data indicate that the halogen torchiere is an extremely inefficient energy user. The non-linear dimming control system adds to the already poor efficacy of this lighting system. On a national basis, the sale of halogen torchieres represents one of the largest lighting efficiency and conservation issues to date.

A series of torchiere systems using efficient CFL sources were developed and photometric results indicate that they can provide comparable light output at a fraction of the power. These studies are intended to provide information to manufacturers on how to use efficient sources as a replacement for the 300 Watt tungsten halogen source. This effort is part of an ongoing program that focuses on market transformation issues and the technical development of energy efficient fixtures for residential applications.

## ACKNOWLEDGMENT

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