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ABSTRACT

Extensive development of designs and prototyping of energy efficient torchiere systems using compact fluorescent lamps (CFLs) has lead directly to the production of CFL torchieres by a major US manufacturer. This paper compares the electrical and photometric characteristics of one of the new CFL torchieres to standard tungsten halogen torchieres (halogen uplighters). Power assessments and gonio-photometric data indicate that the new CFL torchiere provides significant energy savings over the standard tungsten halogen torchiere while producing more luminous flux. The energy savings is jointly due to the high source efficacy of the CFLs and the poor performance of the imported halogen lamps.

The paper also presents results from a test site in the student dormitories at Stanford University where a torchiere "lamp swap" program was initiated in which students voluntarily traded their halogen torchieres for CFL torchieres. Out of the 500 torchieres involved in the lamp swap, a random sample of nearly 100 halogen lamps (seasoned in the field and considered to represent a typical population) were collected and photometrically and electrically characterized in the laboratory. These laboratory results indicate that the CFL torchieres use 65 watts to produce 25 percent more light than the 300 W tungsten halogen torchieres they are designed to replace. Additionally, the CFL torchieres have the benefit of a cooler lamp operating temperature, making them safer luminaires.[1,2]

INTRODUCTION

The 300 to 500 W halogen torchiere (halogen uplighter) is ubiquitous in the US and many other countries in residential lighting applications. It is estimated that there are 40 million halogen torchieres in the US at this time, principally in residential applications.[3] The high wattage of these systems has contributed to a very significant increase in residential lighting loads, undermining more than a decade of energy conservation programs aimed at increasing compact fluorescent lamp (CFL) market penetration.[4,5]

Torchieres have also become one of the most prevalent luminaires in college dormitories. It is not unusual to see 80 to 90 percent of college dormitory rooms with a torchiere as the primary light source. Data from the housing units at Stanford University indicate that in some cases 40 to 50 percent of the energy load of a dormitory is from halogen torchieres. Fire safety concerns due to the high operating temperature of the halogen sources and their widespread application has lead many colleges to ban halogen torchieres in their dormitories.

Over the last five years, the United States Department of Energy has supported the Energy Efficient Fixtures Program at Lawrence Berkeley National Laboratory (LBNL) to develop and promote dedicated pin-based CFL fixtures as the next generation of efficient lighting. Dedicated fixtures offer several advantages by assuring the persistence of energy-saving technologies while allowing for luminaire design around the more energy efficient source. This continuing effort concentrates on high wattage applications that see long burning hours and includes downlights, table lamps, exterior luminaires and torchieres.

Developing alternatives to the halogen torchiere represents one of the most important projects due to their high wattage and universal application. This project has concentrated on the development of high-efficacy prototypes using a broad range of CFL sources and electronic ballasts that match (or exceed) the light output and distribution of halogen torchieres. These prototypes offered the manufacturing community early concepts for utilization of both existing and novel, high efficacy sources.

Figure 1. Example of CFL Torchiere being used at Stanford University test site. The luminaires are similar in look to halogen torchieres, but they use 2 fluorescent lamps in a white reflector dish (as seen on right).

This paper describes the performance of a high-efficiency CFL torchiere in comparison to the halogen luminaire it is intended to replace. The CFL torchiere (see **Figure 1**), designed from LBNL prototypes, uses two CFL lamps in combination with a single electronic ballast. This new design increases the torchiere's fixture efficacy from less than 12 lm/W to nearly 65 lm/W. Specialized optics and lamp positioning resulted in a fixture efficiency of approximately 84 percent. This value is fairly high considering the relatively large size of the light sources compared with the fixture. With this efficiency, the prototype exceeds the lumen output of currently marketed 300 W halogen torchieres. This lumen matching capability was considered critical, particularly in the first phases of the market transformation, as to not jeopardize consumer satisfaction with the products.

A demonstration program was conducted at Stanford University using the two lamp fluorescent torchiere in which 500 halogen torchieres belonging to students were voluntarily traded for the new CFL torchieres. A subset (nearly 100) of the halogen light sources from the torchieres the students turned in were collected and brought back to LBNL for measurement. This data was then applied to known torchiere fixture models to obtain information on luminaire distribution and output and yield information on the in-situ electrical and photometric characteristics of halogen torchieres. These results were finally compared to the performance of the CFL torchieres based on the LBNL design. Extensive monitoring continues at Stanford including plug load energy monitoring (baseline and post swap), luminaire burn hours, and user satisfaction.

HALOGEN TORCHIERES

Luminaire Description

A cross-section of halogen torchieres, which ranged in price from US$14 to US$80, were purchased from several retail stores. These luminaires were surprisingly uniform in design, though they were produced by different manufacturers. All torchieres were approximately 1.83 m (6 ft) high and comprised of a heavy base, three connected metal poles and a uplighting dish ranging in diameters from 30 to 43 cm (12 to 17 in) (see **Figure 1**, left). These luminaires included a 300 W halogen lamp, a ceramic lamp holder, a simple dimpled aluminum reflector in a dish, and a dimmer or switch. The main difference between the high and low end torchieres was the appearance and aesthetic quality of the luminaires.

Experimental Procedure

Photometric testing was separated into lamp analysis and luminaire analysis. Prior studies of existing halogen luminaires determined the operating characteristics of typical torchieres (efficiency, distribution, etc.).[6] These fixture studies yielded a model that provides average fixture efficiency data and distributional plots as a function of (1) the lamp lumen output and (2) the source's geometry and optics. Bare lamp data (power, lumen output and efficacy) was collected from a cross-section of lamps obtained from the Stanford test site. This data was categorized (300W, 500W, etc.) and averaged. Because average lamp lumen output data was obtained from geometrically similar sources, it could be used in the fixture model to generate average distributional plots. All photometric testing was conducted on thermally stabilized lamps with room temperature and voltage conditions at 22°C (72°F)± 1°C and at 120 V± 0.1 V.

Data Sampling

A random sampling of nearly 100 halogen lamps was obtained from the Stanford University test site. These lamps represent a wide range of manufacturers, nominal power ratings and prior burn hours. Experimental data from these lamps provides an excellent look at the "typical" characteristics of the halogen lamps currently in the marketplace.

All halogen lamps obtained from the Stanford lamp swap were either rated 300 W (82.8% of total population) or 500 W (17.2%). Because the CFL torchiere was designed to match the performance of the 300 W torchieres, the 500 W lamps were photometrically measured, but not used in the analysis. The 300 W lamps were separated into 2 groups: (1) "Unlabeled", which included all unlabeled and labeled lamps of unknown manufacturers, and (2) "Known", which included all labeled lamps from known manufacturers in Europe, the United States, and Japan.

Lamp Characterization

A 2.0 m (80 in) integrating sphere was utilized to determine bare lamp lumen output and power to calculate lamp efficacy. The bare halogen lamps were operated horizontally (as they are in the torchiere fixtures) in the integrating sphere. A voltage stabilized line without the torchiere dimming circuitry was used for testing.

Luminaire Characterization

As previously discussed, it was deemed impractical and unnecessary to goniometrically characterize each halogen torchiere separately because, while the lamps can vary dramatically from one another, previous studies have demonstrated that the fixture efficiencies and distributions remain largely similar.[7] By placing the average lumen output of nearly 100 lamps into the torchiere fixture model, an average candlepower plot can effectively be produced.

CFL TORCHIERES

Luminaire Description

Several of the CFL torchieres produced for the Stanford University torchiere swap were obtained for testing (see **Figure 1**). They consist of two flat F36 lamps in a reflective white powder-coat painted reflector, lamp connectors, a two lamp ballast located in the dish underneath the reflector, a two-way (high-low-off) switch, and circuitry to run lamps properly at the "low" level (only one lamp on).

Experimental Procedure

Experimental data for the CFL torchieres yielded "laboratory" results as opposed to typical "field" results which were obtained from the halogen lamps aquired from the students. Because these new luminaires have never been installed before, it is not possible to test CFL torchieres that have been in the field for some time as we can with the halogen torchieres. Thus a side-by-side comparison of the halogen torchieres with the CFL torchieres must consider effects of lamp lumen depreciation over the CFL torchiere's life. Typically, lumen depreciation in tungsten-halogen lamps is linear with rated life, reaching a maximum of an 8 percent decay near end of life.[8]

Lamp Characterization

The seasoned and thermally stabilized CFLs were operated horizontally in the integrating sphere (as they are in the fixture) under the same stabilized laboratory conditions previously described for the halogen experiments.

Luminaire Characterization

Complete electrical and photometric data was collected on the seasoned and stabilized lamps in the CFL torchieres using an integrating sphere and a gonio-photometer. The luminaire was operated at both high and low light levels to determine whether the fixture efficiency and candlepower distribution varied with operating level. Input power, total harmonic distortion (THD), power factor (pf) and current crest factor were monitored continuously during goniometric testing by a computer controller linked to a power analyzer. At the completion of the test, the power analyzer data was averaged and recorded.

RESULTS

The halogen lamps obtained from Stanford University were measured for lumen output and input power in the integrating sphere. **Table 1** presents these results broken down into several categories: unlabeled 300 W lamp , known 300 W lamps, all 300 W lamps, and all 500 W lamps.

Table 1. Electrical and Photometric Data on Halogen Lamps from Stanford Dormitories.

Lamp Type	# of Lamps	% Lamps	Nominal Wattage	Measured Wattage	Lumens	lm/W
Unlabeled	60	69.0	300	272.0	3684	13.54
Known	12	13.8	300	304.0	6251	20.56
Total 300 W	72	82.8	300	277.4	4109	14.58
Total 500 W	15	17.2	500	476.5	9372	19.58

Unlabeled lamps were found in 69.0% of the torchieres while, overall, 300 W halogen lamps were found in 72 of 87 (82.8%) of the torchieres. Because the unlabeled lamps are generally much cheaper than known lamps, they not only come in most or all torchieres, but are often used as replacement lamps as well. Unfortunately, these lamps dramatically underperform compared to the known lamps. The unlabeled lamps averaged 3684 lumens compared to 6251 lumens from the known lamps. The known lamp average efficacy of 20.56 lm/W represents more than a 50 percent improvement over the unlabeled average efficacy of 13.54 lm/W. The unlabeled lamps generally operated 10% below their rated power.

Figure 2 presents a bar distribution graph of 300 W lamp data broken into 1 lm/W bins. The first peak on the histogram occurs from 12 to 15 lm/W and is comprised entirely the unlabeled lamps. The second peak occurs at 21 lm/W, slightly higher than the common “catalog” efficacy of halogen lamps of 20 lm/W, and is made up exclusively of the known lamps. Also noteworthy are the lamps with efficacies of 10 lm/W and under. Many of these lamps were heavily blackened on the inside, possibly caused from prolonged operation in a dimmed operation mode.

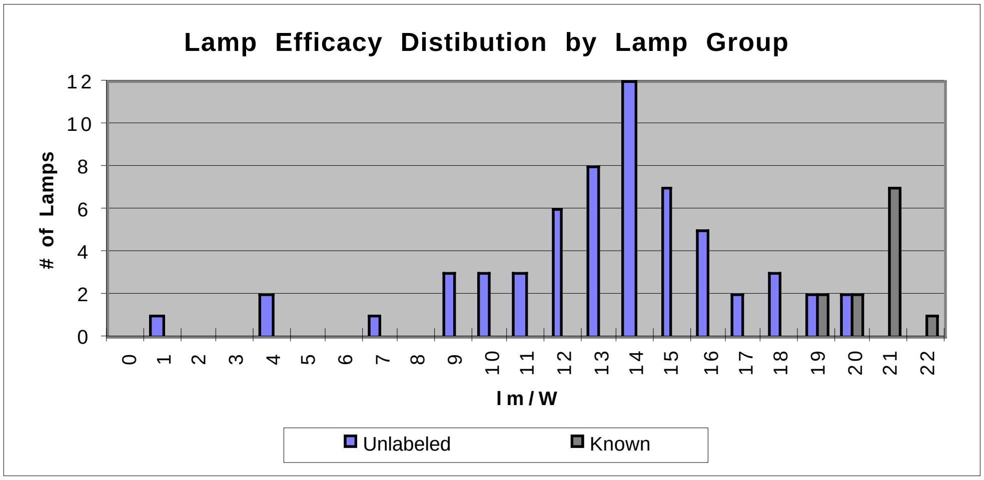

Figure 2. Frequency distribution of halogen lamp efficacy.

Further decreasing the energy efficiency of the halogen lamps is the strong non-linear relationship between efficacy and dimming, as seen in **Figure 3**. This plot, constructed from average data from several halogen lamps, shows that a halogen torchiere operated at 50 percent light output consumes nearly 75 percent of peak power, while at 50 percent peak power the torchiere will produce 20 percent of peak light output.[9]

Luminaire Characterization of Halogen and CFL Torchieres

Table 2 presents lamp and fixture data for the CFL torchiere and the average unlabeled halogen torchiere at full and half power. All CFL data is from integrating sphere and goniometric measurements, while the halogen lamp's power and lumens are found by placing average lamp data in the fixture model, as described in the halogen torchiere experimental procedure section. Fixture efficiency for the halogen torchiere was found to be 88% from prior goniometric testing.

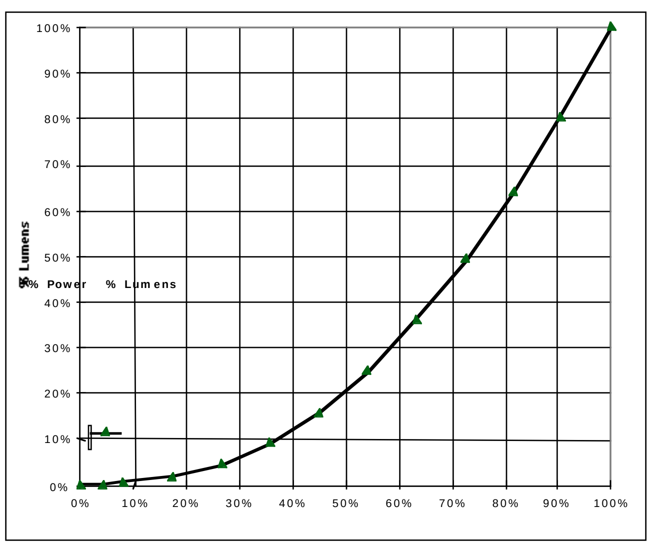

Figure 3. Percent lumen vs. percent power for dimmed halogen sources.

Table 2. Fixture Data from CFL and Halogen Torchieres

	Nominal Wattage	Actual Wattage	Lamp Lumens	Fixture Efficiency	Fixture Lumens	Power Factor	Harmonic Distortion	Fixture Efficacy
CFL - Full	72	64.95	4826	83.7%	4041	0.99	14.33%	62.21
CFL - Half	36	39.12	2565	83.1%	2132	0.95	25.88%	54.50
Halogen - Full	300	272.0	3684	88.0%	3242	0.99	5.37%	11.92
Halogen - Half	150	136.0	739	87.7%	648	0.63	75.41%	4.76

At full power, the CFL torchiere produces 25 percent more lumens than the average 300 W halogen torchiere and has over five times greater efficacy. At half power, the CFL torchiere produces over six times the lumens of the halogen torchiere at half power, with a 13 fold increase in efficacy. While the poor performance of the halogen lamps contributes to this efficacy discrepancy, it should be noted that even if the halogen lamps averaged their “catalog” efficacy of 20 lm/W, there would still be a three to four fold efficacy improvement in going from halogen to CFL torchieres. It should also be noted that the power quality (power factor and harmonic distortion) of the halogen torchiere decays fairly dramatically with dimming, whereas power quality is fairly constant for the CFL torchiere. (The harmonic distortion of the halogen at full power is non-zero because of the presence of the dimmer switch.)

The distribution of the CFL torchiere is best understood when analyzed relative to the halogen torchiere. **Figure 4** gives the averaged candlepower plot for the CFL torchiere and the typical 300 W torchiere at full and half power. While, at full power, the halogen torchiere nearly matches the centerbeam intensity of the CFL torchiere, the halogen torchiere has a much more narrow distribution. This gives the halogen torchiere the look of having a bright “hot spot” over the luminaire, but the CFL torchiere provides greater and more even illuminance throughout the room. At half power, the effects of the decreased efficacy from dimming are quite pronounced, and the CFL torchiere provides significantly more illuminance at all angles.

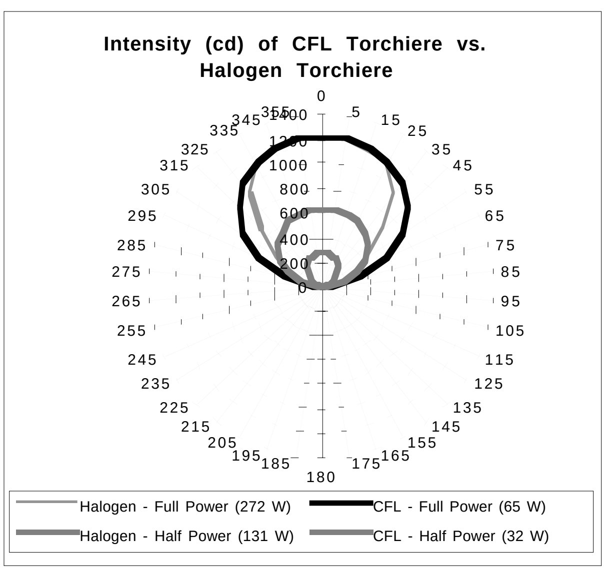

Figure 4. The candlepower distribution of a CFL torchiere vs. Halogen Torchiere

Figure 5 shows standard candlepower plots for the CFL torchiere at full (left) and half (right) power. Because of the diffuse white reflector, the distribution from the torchiere is fairly uniform and does not vary greatly with the orientation of the luminaire. The diffuse reflector also allows for operation in half power mode (one lamp off) without noticeably changing the light distribution.

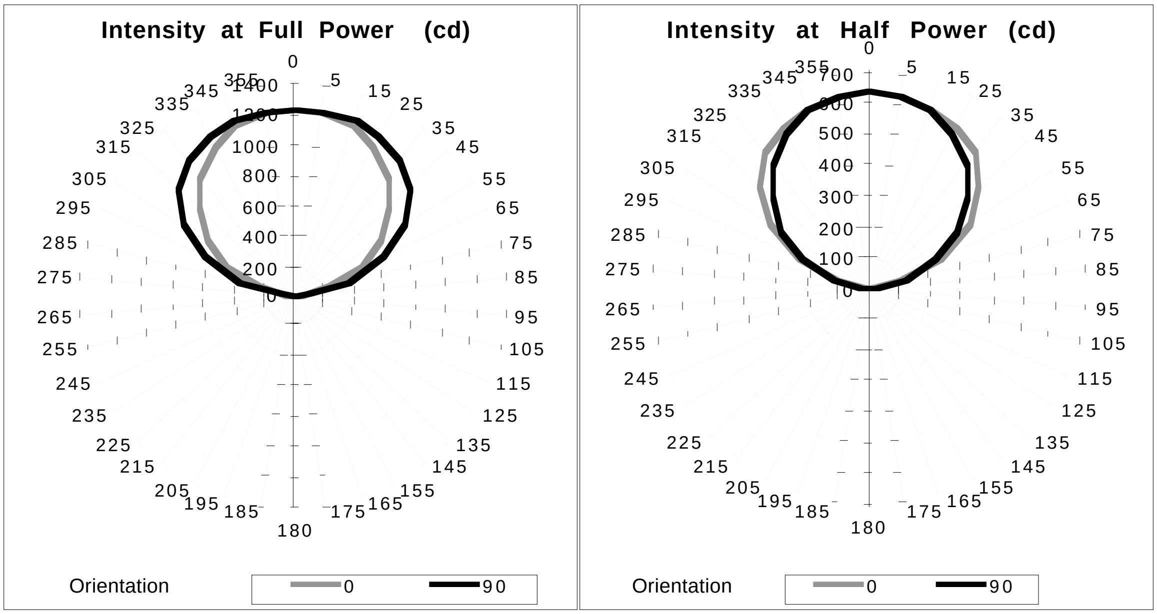

Figure 5. The candlepower distribution of the CFL torchiere at full power (left) and half power (right).

CONCLUSIONS

Experimental photometric and power analysis indicates that the halogen torchiere is a very inefficient energy user. Not only is this incandescent technology three to four times less efficacious than fluorescent lamps, but data from a cross-section of lamps in the field indicate that they are often over 30 percent less efficacious than could be expected based on catalog data. The non-linear dimming control system only adds to the already poor efficacy of this lighting system. The vast quantity of these inefficient luminaires makes them one of the largest lighting efficiency and conservation issues to date.

The LBNL-designed energy efficient CFL torchieres now being manufactured can provide greater light output with significant energy savings. This effort is part of an ongoing research and development program that focuses on market transformation issues and the technical development of energy efficient luminaires for residential applications. Monitoring of energy use, use patterns and user satisfaction continue at the Stanford University test site in order to better understand the market potential and design improvements for this and other energy efficient torchieres.

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