Manufacturers of Light Bulbs

FEIT ELECTRIC COMPANY
4901 Gregg Road
Pico Rivera, CA 90660
(562) 463-BULB (2852)
(800) 543-FEIT (3348)
Fax: (562) 908-6360
E-mail: info@feit.com
www.feit.com

October 24, 2012

Via Email: docket@energy.ca.gov
Gary.flamm@energy.ca.gov

California Energy Commission
Dockets Office, MS-4
1516 Ninth Street
Sacramento, CA 95814-5512

Subject: Re: Docket No. 12-BSTD-03
Comments Proposed Voluntary
California Quality Light-Emitting Diode (LED) Lamp Specification
CEC-400-2012-016-SD

Dear California Energy Commission,

Feit Electric appreciated the opportunity to comment at the recent meeting on October 11, 2012 regarding the proposed voluntary California Quality Light-Emitting Diode Lamp Specification.

As with the "Super CFL" specification proposed for implementation within the state of California several years ago, it is our opinion that any specification changes required for full participation in the residential consumer market including fair & equal evaluation of products within the retailer and/or utility incentive programs must be based on not only specific individuals and utility company desired specifications within the state of California but the mass production cost efficiency benefits to all consumers nationally and in the state of California. Any "California Only" performance specification that is not required to meet the Energy Star national specification will require custom manufacturing resulting in higher cost for California consumers compared to consumers outside of CA until such time and/or if the exclusive CA specifications are adopted nationally. It is our opinion that the specifications referenced below are not justified to overcome "Market Barriers" to the adoption of LED lamps in CA, will not become the national performance specification for LED lamps, and/or are based on the new ES V1.0 Draft LED specification that has not yet been approved. The result will be a defacto higher tax on CA consumers purchasing LED lamps and decreased sales of energy efficient LED lamps in the state.

As it is understood by Feit Electric, the intent of the proposed voluntary specification is to prevent and/or remove "Market Barriers" believed to exist that are related to specific LED light bulb product performance that result in the non-adoption of LED light bulbs by consumers in the CA residential market.

The information contained herein is intended to support Feit Electric's opinion based on supported facts that certain proposed product performance specification changes proposed within the voluntary specification would be detrimental to the current success in the consumer adoption of LED light bulbs and strong sales in the residential market place serviced fundamentally by the retail stores throughout the state of California. Furthermore, it is with an abundance of sales information, feedback from retailers & consumers, and overall experience, that supports the fact that the "High cost of LED bulbs meeting the current Energy Star performance Specification" is the #1 "Market Barrier" for the adoption of LED light bulbs in California and the US.

Example: Feit Electric is in a unique exclusive position to have been supplying continuously to the retailer market Energy Star listed Omni-directional LED lamps over time. Given we have provided the same retailers this lamp at gradually reduced cost resulting in gradually reduced retail price points, we are able to evaluate POS sales and our ship reports to confirm that sales have increased ten (10) fold since the retail price point fell below $20 (we will make confidential sales data available on an individual basis). Furthermore, given our retailer partners and ourselves monitor consumer return % and this rate is below 1%, and the fact that we know historically that consumers will take the time to return items with retail prices >$10.00, we can conclude that the current Energy Star specifications are meetings and/or exceeding consumer performance expectations while market demand is resulting in lower retail prices.

It is Feit Electric's opinion that these proposed specific enhanced specification changes are not measurable and verifiable as a "Market Barrier" to the residential consumer adoption of LED light bulbs but instead would be relevant product performance specification considerations within the commercial market for non-residential consumers based on "Lighting Specifiers" lighting parameter requirements specific to the "Project" in the commercial market sector.

In addition to all cited studies within the document herein, the following is a summary of credible facts as a basis for this opinion:

- Feit Electric is one (1) of the largest suppliers of CFL and LED light bulbs to retailers in CA
- Feit Electric conceives, designs and manufacturers its LED light bulbs
- Feit Electric uses consumer feed back as well as retailer POS sales data, return data and actual product returns to determine the reason for product returns that contribute to determining potential "Market Barriers" for CFL & LED light bulbs
- Feit Electric uses ANSI, UL and the EPA Energy Star LED light bulb standards, LM-79 and LM-80, as a product design and performance specification guide in developing LED light bulbs produced for the residential market in CA
- The LED light bulb product development time cycle beginning with product design performance characteristic requirements including UL, ES LM-79 & LM-80 testing requirements to availability on retailers shelf is 18 months.
- Feit Electric was not one (1) of the three (3) manufacturers that participated beginning approximately 18 months ago in the development of the draft or final Proposed Voluntary California Quality Light-Emitting Diode (LED) Lamp Specification.
- Feit Electric was not aware of the proposed changes in product specifications within this voluntary specification until September of 2012

Feit Electric would like to be on the record as requesting from this committee the specific consumer complaint data this draft committee used to formulate the exact CRI specification and Color Quality/Consistency ellipse proposed performance requirements within the Proposed Voluntary California Quality Light-Emitting Diode (LED) Lamp Specification. It would be assumed that this data clearly shows when evaluating existing Energy Star approved LED light bulbs, consumers specified their dissatisfaction with differentiating different shades of red colors and found that when comparing two (2) existing Energy Star approved LED light bulbs side by side, the consumer indicated a noticeable difference in color appearance between the two (2) lamps that could then be associated with changing from a 7-step Macadam ellipse to a 4-step Macadam ellipse

Disputed: LED California Quality Light-Emitting Diode (LED) Lamp Specifications

Color Rending Index (CRI)

Proposed Change - Increase from 80 CRI R9>0 to 90 CRI R9>0
Recommended Change - Remains 80 CRI R9>0

Support for Recommendation

Color quality involves both color rendering index (CRI) and color temperature (CCT). Residential consumers consider color quality as the color temperature of the light they see in residential settings which are predominantly for the purpose of reading, writing, cooking, in the bathroom and for conducting normal household functions along with general ambiance indoors and outdoors. Residential applications are different than commercial applications. A CRI of 80 with a R9>0 is not distinguishable from a CRI of 90 with a R9>0 in general residential settings so as long as the CCT is the same for 2 lamps being compared. However, a commercial application such as in a museum, grocery store, restaurant, or a high end clothing store where food safety and preciseness in color interpretation is desired and/or necessary could involve a lighting specifier determining that a 90 CRI is desirable.

The early non-dimmable CFL's and today's dimmable CFL's did not have good color consistency over the life of the lamp. This has resulted in changing CCT's over the life of the product noticeable by the residential consumer leading to dis-satisfaction. The consumer is able to distinguish 3000K from 3500K. As such, we believe that given CFL's have had a CRI of 80 and published reports have indicated a dis-satisfaction with color quality by consumers, the committee drafting this specification has determined that the LED specification for CRI should be increased from 80 to 90. Unlike the CFL performance, the committee is not factoring into its considerations the color consistency of LED lamps over time compared to CFL's including when dimming. In fact, it has been a request by consumers and retailers for LED lamps to be designed in such a way that the LED bulb when dimmed provide the same color shift as an incandescent given their familiarity with the incandescent color shift when dimmed.

Color quality referenced in the various publications regarding the "Market Barriers" for the positive adoption of LED's emphasizes CCT specifically, and does not emphasize CRI. (Example reference: KEMA California LED Lamp Market Characterization Report pgs 3-31 thru 3/34). This was a study focused on potential "Market Barriers" for the residential market in CA. The "Market Barriers" listed in the order presented were as follows:

An example of CCT being emphasized more importantly than CRI was published in the "Demonstration Assessment of Light-Emitting Diode (LED) Retrofit Lamps Host Site: InterContinental Hotel, San Francisco, California page 29." It states, " Look for lamps with a Correlated Color Temperature (CCT) of 2700 to 3000K, and Color Rendering Index (CRI) value greater than 80 with an R9 value >50, or Color Quality Scale (CQS) value greater than 85. Look closely at color appearance of important objects and finishes in the space with the selected lamps. Your eyes are more reliable than color metrics alone."

Both of these publications were focused on the importance of color quality in commercial applications and yet still emphasized the importance of CCT vs. CRI.

<u>Efficacy and the Environment</u>

Beyond the consumer and market aspects of what the eye perceives under different CRI values, is the negative impact of increasing the CRI from 80 to 90 on the lamp systems efficacy and the end result on the environment.

According to a leading chip manufacturer, Cree, as indicated on one (1) specific product specification, increasing the CRI from 80 to 90 will reduce the efficacy by 18% for a given chip. (See attached, Cree specification sheet, X-Lamp X-PG LED's, 80-CRI White 2600K-4300K vs. 90-CRI White 2600K-4300K).

The reduction by 18% in lumens for existing Energy Star listed LED light bulbs currently available on retailers' shelves in CA will lead to both retailer/manufacturer consumer perception problems as well as overall consumer confusion. The new FTC labeling requirements as a part of the 2007 EPACT federal legislation emphasizes using "Lumens" and not "Watts" as a measurement for light output. Energy Star packaging carries the educational motto "Look for the lamp with the highest lumens and the lowest watts".

Example: Implementing a change from 80 to 90 CRI will result in a currently Energy Star listed BR30 LED floodlight with a stated lumen rating of 750 lumens on the packaging being reduced to 600 lumens in order to maintain the current cost required by the retailers to prevent unacceptable financial markdowns and higher retail prices. The result would be a major product perception problem for both the retailer and manufacturer in the state of CA as well as consumer dissatisfaction resulting from the reduced lumen output. Light Output was the #2 "Market Barrier" for the adoption of CFL's. A typical CFL R30 floodlight provides between 580-650 lumens whereas the current Energy Star listed LED BR30 provides 750 lumens addressing this previous "Market Barrier" associated with CFL's.

Given the ultimate objective for the adoption of energy efficient-long life LED light bulbs is to save energy, and accepting the fact that currently 98% of all LED light bulbs that are listed on the DOE Lighting Facts Label data base and Energy Star listed, operate with a CRI <90, it can be deduced that all LED bulbs currently being marketed on retailers' shelves in CA will use 18% more energy should this specification be changed. This statement contradicts the impression provided in the Proposed Voluntary California Quality LED Lamp Specification, page 23 of 56 which states "As of May 30, 2012, the U. S. Department of Energy's SSL Lighting Facts product database contained 123 replacement lamp products with a CRI of 90 or better. Because the LED market already includes a large number of products with high CRI, and because color quality has been identified as a key opportunity for improvement, the proposed Specification includes a minimum requirement for color rendering index."

The fact is only one (1) of the 123 lamps cited above would meet all of the CA proposed specifications and be Energy Star approved. This lamp is available and retails for over $100.00 on Amazon. Given that products promoted within the utility incentive program must be Energy Star listed, it would not be prudent to base the future of promotional programs on the hope that additional products are developed and made available on retailers' shelves in the immediate future.

Additionally, as there is an accepted correlation between the power produced at a power plant and the carbon released in the atmosphere, the additional 18% increase in energy would result in additional pollution into the environment circumventing the efficiency gains made in the last several years thru the installation of existing Energy Star listed LED lamps.

Power Factor (PF)

Proposed Change	-	Increase from 0.70 to 0.90 Current ES and new Draft Specification Requires the following: >0.7 – residential applications >0.9 - commercial applications
Recommended Change	-	Remains at current ES specification levels

Support for Recommendation

The California Compact Committee formed in 1998 included manufacturers of CFL's and all IOU's in the state of CA including SMUD & LADWP. The purpose of the committee was to work together for the adoption of CFL's within the residential consumer market. At this time, SDG&E with Bob Gillespie leading the utility company perspective, the utility companies were advocating all CFL's be redesigned to achieve a 0.9 PF. Given the Energy Star CFL specification was not yet in existence, there was no national specification for which all CFL performance characteristics could be based. The PF's for CFL's averaged 0.4-0.7 except for dimmable CFL's which achieved a PF of 0.9.

Given the cost associated with redesigning all CFL's to meet this requirement, including the added cost to the product, would have resulted in a higher retail price on the shelf, the industry represented by NEMA conducted an evaluation of the impact of CFL's with different PF ratings on the utility grid.

See report "LSD 8-1999, *A NEMA Lighting Systems Division Document, Power* Quality Implications Of Compact Fluorescent Lamps In Residences"

As the report showed the inherit inductive load on the grid, the capacitive lagging voltage of CFL's, and the minimal current draw from CFL's, there was a compelling argument that the higher product cost to the redesigned CFL's and resulting "Market Barrier" to customer acceptance based on the already high cost compared to incandescent bulbs, outweighed the benefit of a higher power factor to the utility companies grid.

Feit Electric proposes that the current and/or new draft ES specifications be utilized based on the following facts:

- The effect of low wattage/current energy saving bulbs including CFL's and LED's on the utility grid has not changed since the thorough PF impact study was first conducted in 1999 thru NEMA
- Commercial 3-phase power systems have different operating characteristics than residential single phase power systems justified thru the ES PF specification differentiating residential and commercial PF specification requirements
- LED light bulbs utilizing chip based dimming drivers incorporate a high power factor >0.9. As the residential consumer market serviced by retailers is evolving quickly from non-dimmable to dimmable LED light bulbs thru a normal evolving transition and taking into account the 18 month from conception development to shelf time frame, an immediate specification change is not required. Current product development trends indicate that +90% of all LED light bulbs on the shelf in CA will provide a >0.9 PF within the next 24 months.
- Current LED bulb products meeting the ES PF specification requirements would require a complete redesign with new driver design requiring new UL and Energy Star submissions of all products. Products on the shelf would require a new model # to comply with compliance submittals resulting in significant cost to replace all products on the shelf with the new items.
- Product cost would increase a min of $0.80-$2.00 resulting in an additional $1.60-$4.00 retail price increase to the consumer as a result of the additional electronic components necessary to meet the higher power factor. This retail price increase will contribute to further impeding the adoption of the LED bulbs given that "High Prices" is the #1 market barrier in the consumer market today for adoption of LED light bulbs.

Beam Angle

Current ES Spec - Not defined
Proposed Change - Beam Angle shall be between 50-90 degrees

Recommended Change - Beam Angle shall be between 50-110 degrees

Support for Recommendation

Establishing the desired maximum allowed beam angle for LED floodlights at 110 degrees vs. the proposed 90 degrees will prevent the complete redesign of existing Energy Star listed LED floodlight lamps without the need for costly secondary optics.

The majority of LED BR30 lamps are providing a beam angle between 110-125 degrees. The current proposed beam angle specification within the Proposed Voluntary California Quality LED Specification is 50-90. Whereas Par 20/30 & 38 LED spotlight light bulbs are using secondary optics to control the beam angle increasing the product cost up to 30% over the comparable R or BR floodlight, the majority of LED BR30 do not use the same type of secondary optics used in the Par LED lamps saving cost and enabling the BR30 LED lamp retail price to be between 40-60% less than their Par spotlight configurations.

Current BR 30 incandescent and ES Halogen lamps provide a nominal beam angle between 75-100 degrees (ref. Caliper Summary Report 2009, pg 23). Additionally, it should be taken into account based with incandescent halogen & incandescent BR30 lamps:

"Because of variability in the manufacturing process, beam angles for blown glass lamp types (R, BR, and ER) are assigned a tolerance of ±12°. For example, the 25° lamp classification can include lamps having a beam angle between 13° and 37°. The more precise pressed glass lamps (e.g., PAR) have smaller tolerances that vary based on the nominal beam angle. Importantly, even lamps having the same numerical classification can produce patterns of light that appear substantially different." (ref: page 6 of 26 Caliper Application Summary Report 16: LED BR30 and R30 Lamps, July 2012)

Current BR30 CFL lamps provide a nominal beam angle between 120-135 degrees (ref. Caliper Application Summary Report 16: LED BR30 and R30 Lamps, July 2012)

Citing the same Caliper Application Summary Report 16 on page 19 of 26, "Although the results from this series of testing were encouraging, there is room for LED BR30/R30 lamps to improve and gain a larger market share. As with other directional lamps, it would be beneficial if more manufacturers offered a range of products (e.g., lumen packages, distributions) using a single form factor, allowing designers and specifiers to meet the demands of various applications. Another current concern is cost; on average, the Series 16 LED BR30/R30 lamps were several times more expensive than incandescent or CFL reflector lamps. In residential applications, where BR30/R30 lamps are most commonly used, economic justification is especially unlikely."

The 110 degree maximum beam angle is a full 16% narrower than the average nominal beam angle of CFL floodlights providing an advantage over the wider CFL beam angle. As stated in the above paragraph, having different lumen distribution options between the various lamp technologies allows designers and specifiers to meet the demands of various applications.

As also referenced in the Caliper report, it is the cost of the LED floodlight lamps which is the major concern and again the #1 "Market Barrier" to the adoption of the LED lamps. This flexibility in adjusting the upper limit of the beam angle with minimize cost increases so as not to impede the current positive market adoption of the LED BR30 floodlight in the market.

Proceeding with the 90 degree maximum beam angle requirement will require a major redesign of the existing LED products. As indicated within the comments regarding Power Factor, taking into account the product design, regulatory approvals & testing and in fairness of all participants not involved in the development of the draft specifications, any change to the beam angle specification should require a min of eighteen (18) months for implementation from the time of any specification finalization.

<u>Specification Scope and Lamp Classification</u>

Current ES Spec - Decorative SSL Lamps include B, BA, C, CA, F, and G (per ANSI C79.1-2002)
Proposed Change - Remove G from the decorative category creating a separate omni-directional specification requirement for Globe. Remove the designation "Decorative lamps shall not qualify as California Quality LED lamps"
Recommended Change - Retain "G" style globes within the decorative classification
Include decorative lamps within the California Quality LED lamp designation

<u>Support for Recommendation</u>

As referenced in many publications including "Residential Lighting Technologies in the United States: An Assessment of Programs, Policies, and Practices, Katherine Johnson on behalf of Intermountain Energy July 18, 2004 within "Current barriers to energy efficient technologies, page 27 of 56".

"Poor Versatility
CFLs are also not as versatile as standard incandescent lamps. The literature review found that in all three studies on CFL perceptions, these lamps were not viewed as a comparable replacement to standard bulbs. This was especially true in applications that required either decorative or specialty bulbs, or required instant on capability (Kates, et al, 2003; Rubinstein et al, 1998).
For example, CFLs may require a full minute to reach 90 percent of its brightness when first energized and usually at least ten seconds before reaching 50 percent of full brightness. This makes CFLs unsuitable for applications such as bathrooms or bedrooms, where instant on is required. Thus, many residential customers have returned to incandescent lamps because the CFLs were unsuited to their needs (Rubinstein, 1998).

Similarly, CFLs are not good replacements in dimmer applications. Most of residential dimming controls are designed for incandescent lamps and will not work properly with CFLS. This lack of versatility is estimated to exclude 30 percent of all lighting sockets in the US, according to Rubinstein (1998)."

Specialty CFL's are the slowest growing CFL market category based on the above performance of decorative CFL's as compared to the incandescent bulbs that the LED lamps are designed to replace.

The current ES labeled LED decorative lamps address each of the performance limitations referenced above as a "Market Barrier". Specifically, the current ES approved lamps provide instant-on, instant full brightness and provide full range dimming options. Additionally, given the lower lumen requirements of the decorative incandescent bulbs, the cost associated with producing lower lumen LED lamps is substantially less than their A, Par, R & BR counterparts requiring substantially higher lumens.

Sales today of the existing LED decorative lamps is higher in unit volume than any of the other LED lamp configurations based on the affordable cost, lower cost delta difference with the equivalent covered CFL lamp, and performance characteristics overcoming the CFL barrier in décor applications.

Less incandescent décor light bulbs have been replaced by energy efficient CFL option than any of the other incandescent lamp configurations including A, Par, R & BR lamps. This provides the most substantial opportunity for CA to promote the adoption of a lamp configuration that is the lowest hanging fruit for energy savings and environmental benefits.

Up until this proposed voluntary specification, the LED décor lamps have not been promoted within the CA utility incentive programs as a result of inconclusive and negative net to gross energy savings data provided under the DEER program used to designate energy efficient technologies and specific lamp styles for inclusion in CA residential utility incentive programs.

This data fails to consider the multiple bulb fixture applications for which decorative incandescent lamps are used including chandelier, lanterns, pendants & ceiling fans.

Requiring that all decorative LED lamps meet the same omni-directional lumen distribution requirements as the omni-directional "A" style lamps should not be required given décor lamps are not promoted or used for use in table lamp applications in single bulb table lamp fixtures. Additionally, the ANSI lamp dimensional requirements and overall product aesthetic requirements create product design and production obstacles that the larger “A” style LED omni-directional lamps do not require due to the non-decorative application focus and larger ANSI dimensional flexibility.

Decorative incandescent lamps and the current ES decorative LED lamps are promoted are primarily used for accent lighting where the decorative effect of the light bulb is based on the type of fixture the light bulb is used.

<u>Color Appearance/Color Consistency</u>

Current ES Spec	- LED lamps shall fall within a 7-step Macadam ellipse of the 2700K or 3000K points on the Planckian Locus
Color Appearance Proposed Change	- LED lamps shall fall within a 4-step Macadam ellipse of the 2700K or 3000K points on the Planckian Locus
Color Consistency Proposed Change	- LED lamps of the same model shall fall within a 2-step Macadam ellipse of the average chromaticity of the tested sample

Recommended Change - Retain current ES specification

<u>Support for Recommendation</u>

The same request to adjust color consistency from a 7-step Macadam ellipse to 4-step Macadam ellipse occurred in the Energy Star V.2 Draft Specification. As a result of information provided by LED chip manufacturers and LED lamp manufacturers regarding the resulting cost increases, the color consistency specification was not changed and remains as a 7-step Macadam ellipse.

Increased cost as a result of tighter binning with the LED’s will result in unnecessary costs increases that cannot be offset without a national adoption of the same specification requirement.

Conclusion:

We appreciate the opportunity to provide these comments using our 34 years experience in the manufacturing and marketing of incandescent, halogen, CFL and LED light bulbs.

We believe this project was justified given the inception was prior to the completion and adoption of the national Energy Star performance specification; however, as the national specification exists, has a new draft in review, and the industry as a whole is utilizing this specification for all future product development looking out 2-3 years, any specification changes being considered should be relegated to the commercial market place and/or be included for future consideration in future Energy Star integral LED specification drafts.

Our objective is same as all involved in this committee which is to provide energy efficient-long life-quality performance based LED lamps at an affordable price that the California consumer will accept creating the gradual adoption of this new technology.

We have been a part of this equation for many years and appreciate your consideration of the facts we have presented.

Please contact me at (562) 463-BULB (2852) should you have any comments or questions.

Thank you

Best Regards

Aaron Feit
President and CEO, Feit Electric

Table 3-13
U.S. Reflector Lamp Installed Base, 2010

Lamp Style		Number of Lamps (000's)		
	Percentage	Residential	Commercial	Total Lamps
PAR20 (halogen)	*9.8%*	*33,900*	*19,300*	*53,200*
PAR30 (halogen)	*11.1%*	*38,700*	*20,200*	*58,900*
PAR38 (halogen)	*16.8%*	*60,800*	*28,900*	*89,700*
BR30 (incandescent)	*37.9%*	*180,000*	*21,800*	*202,000*
BR40 (incandescent)	*8.2%*	*38,800*	*4,700*	*43,500*
R20 (incandescent)	*10.0%*	*48,300*	*5,010*	*53,300*
CFL Reflector	*6.0%*	*32,000*	*-*	*32,000*
LED Reflector	*0.2%*	*-*	*900*	*900*
Total	**100%**	**433,000**	**101,000**	**534,000**

Source: Navigant Consulting, 2011.

3.5.2 California

During 2008 and 2009, field researchers conducted comprehensive inventories of lamps installed in more than 63,000 light sockets in 1,200 California households as part of the Residential Lighting Metering Study.[53] KEMA, Inc. conducted the Metering Study as part of an evaluation of the California investor-owned utilities' 2006-2008 Upstream Lighting Program.[54] Results suggest that less than one percent of residential light sockets in California were filled with LED lamps as of 2008-2009.While it is acknowledged that data from 2008-09 is quite old in relation to the rapidly changing LED market, this is the only data currently available on the installed base of lamps in California. This data will be updated in late 2012 or early 2013 as part of the California Lighting and Appliance Saturation Survey (CLASS).

3.6 Market Barriers

Based on findings from the literature review and interviews with representatives of LED lamp suppliers and LED market experts, DNV KEMA researchers compiled a list of the primary barriers for LED lamp adoption by consumers. While the literature review sources addressed

[53] *KEMA, Inc., PA Consulting Group, Jai J. Mitchell Analytics, The Cadmus Group, and Itron, 2010b.*
[54] *KEMA, Inc., PA Consulting Group, Jai J. Mitchell Analytics, The Cadmus Group, and Itron, 2010a.*

several other barriers, researchers focused on the four most prevalent barriers in these sources, including:

- *High first cost;*
- *Low lumen output;*
- *Performance issues; and*
- *Lack of education.*

3.6.1 High First Cost

Among the barriers identified for LED lamps, high first cost was most frequently cited by literature review sources as the largest obstacle to LED lamp adoption by consumers. This perspective was reiterated participants in the in-depth interviews with LED market actors conducted in early 2012, including 9 of the 12 manufacturers and all 15 of the retailers we interviewed (brick-and-mortar and online). In a 2011 report, DOE documented retail prices of LED lamps were around $36 on average, roughly 30 times higher than the initial cost of incandescent lamps and 9 times higher than the initial cost of CFLs.[55] Retail pricing of LED lamps observed during the Fall 2011 California Retail Store Shelf Survey also suggest that high first cost of LEDs presents a significant barrier to consumer adoption with the average cost of LED A-lamps, the most common household replacement lamp style, over three times more expensive than non-discounted CFLs and almost ten times more expensive than discounted CFL and incandescent A-lamps.

3.6.2 Low Lumen Output

Currently, high-lumen LED lamp options are limited in the market and LED equivalents do not exist for some common high-lumen lamps, presenting a barrier to widespread LED adoption. With the current level of lumen output available, LEDs are not able to compete in the markets for 1,100 lumen and 1,600 lumen replacement lamps (roughly equivalent to standard 75 watt and 100 watt incandescent lamps, respectively). Figure 3-12 shows the trends in lumen output improvements over the past year and an average of 650 lumens for LED lamps in 2011 based

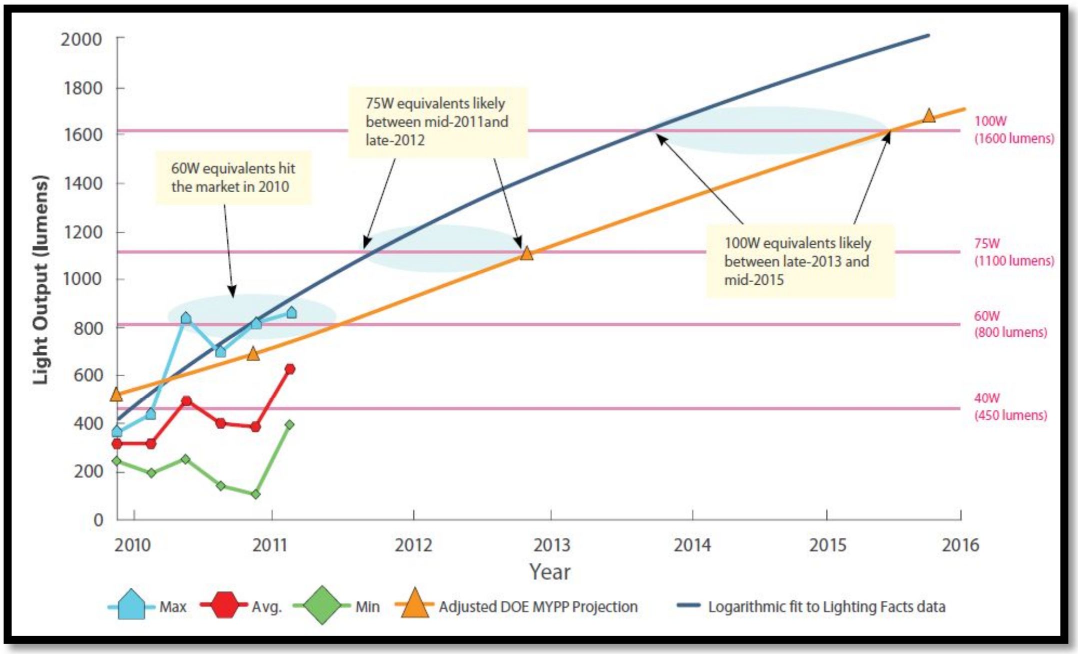
---

[55] Bardsley Consulting, Navigant Consulting, Radcliffe Advisors, SB consulting, SSLS, Inc., 2011a. Section 3.5.

on DOE data.[56] According to DOE projections, LED lamps will begin to enter the 75 watt equivalency (1,100 lumens) market in 2012 and the 100 watt equivalency (1,600 lumens) market between 2013 and 2015.[57]

Both DOE and industry analysts expect lumen output to improve over time. This continuous upward trend is likely to be driven by upcoming lighting standards for manufacturers and improvements in LED technology. By 2015, it is likely that the lumen output barrier will be significantly reduced and the diversity in LED lumens will have increased.

Figure 3-12
Non-Directional LED Lamp Performance Trends and Projections, 2011



Source: D&R International, 2011a.

3.6.3 Performance Issues

The literature review revealed a number of sources that discussed poor performance claims, and most of these sources cited analyses conducted by DOE's Commercially Available LED

[56] D&R International, 2011a. Page 11.
*[57] **Ibid.***

Product Evaluation and Reporting (CALiPER) program.[58] *Since 2006, the U.S. DOE has conducted at least two rounds annually of CALiPER studies and tests of SSL products to verify product claims in the LED replacement lamp market. The purpose of these efforts is to avoid duplicating some of the poor consumer experiences encountered during the introductory stages of CFLs to the consumer market – such as exaggerated manufacturer lifetime claims, flickering, poor color, and so on -- which are widely cited as having had negative effects on the rate of CFL adoption.*[59]

Through the process of evaluating SSL products, the CALiPER program found that a number of LED lamp performance claims were inaccurate, and that consistency at the manufacturing and retail levels can vary widely. Our analyses identified three major categories that were evaluated by CALiPER[60] *where inconsistent product information was provided to consumers, including:*

- **Lumen output.** *Few products met or came close to their claimed lumen output. For almost all lamp styles, less than 50 percent of the lamps tested met the average light output of their claimed incandescent equivalents.*[61] [62]
- **Lamp life.** *Over half of the lamps tested are not expected to meet manufacturer-claimed lifetimes*[63]
- **Correlated Color Temperature (CCT).** *Of the packaging claims tested (primarily rated lumens, CCT, and life) many of the measured values for the products were close to, but not completely, accurate. All incandescent equivalency claims were inaccurate.*[64]

---

[58] *Because most sources in the literature review cited this particular source, KEMA relied on DOE CALiPER findings for this subsection.*

[59] *See, e.g., page 2 of Pacific Northwest National Laboratory, 2011.*

[60] *The results of the CALiPER evaluation referenced are based on 33 different LED lamps from 10 different manufacturers purchased from 8 different retail stores in June and August of 2010.*

[61] *2 of 5 A-lamps tested almost met incandescent equivalents, 1 of 4 B-10 lamps met claims, 4 of 11 MR16/PAR16 lamps came close to meeting claims, 0 of 4 PAR20 SSL lamps met claims, 3 of 7 SSL PAR30 came close to meeting claims.*

[62] *Pacific Northwest National Laboratory, 2011. Page 3.*

[63] ***Ibid.***

[64] ***Ibid.***

6.0 Lessons Learned

6.1 Don’t Buy LED Replacement Lamps Sight Unseen

Qualitative and quantitative characteristics of LED products vary widely. Allocate time and expertise to see, handle, mock up, and test potential replacement lamps in the specific luminaires and spaces before committing to large retrofit projects.

6.2 Color

LED MR-16 replacement lamps are now available with a spectral power distribution that is extremely close to the incumbent halogen lamps in its color appearance and color rendering properties. Look for lamps with a Correlated Color Temperature (CCT) of 2700 to 3000K, and Color Rendering Index (CRI) value greater than 80 with an R9 value >50, or Color Quality Scale (CQS) value greater than 85. Look closely at color appearance of important objects and finishes in the space with the selected lamps. Your eyes are more reliable than color metrics alone.

6.3 Test in Place

Test color acceptability, flicker, size and characteristics of the emitted beam of light, as well as compatibility with installed transformers and dimmers. (In many MR16 luminaires, a magnetic transformer may be compatible with more LED replacement lamps than an electronic transformer.) Get a 3 to 5-year warranty on life, light output, and color characteristics. Local electric utilities and ENERGY STAR® specifications may provide additional guidance on product selection.

6.4 LEDs can be Economically Viable

Good-quality LED replacement lamps can be economically viable in spite of their high initial cost. Consider them when:

- *Electric rates are higher than average (e.g., greater than $0.11/kWh melded rate)*
- *Labor costs for relamping are high because of hard-to-reach locations, areas where skilled labor is costly, the need for access outside of normal work crew hours, access to the space is limited because of special security clearance, clean room requirements, etc.*
- *Hours of operation are extensive (e.g., greater than 40 hours per week).*
- *Utility rebates or incentives are available.*

6.5 Expect Lower Light Output

LED replacement lamp products are improving in light output rapidly. At the time of this project, however, they were only able to replace lower wattage PAR30 and MR16 halogen lamps. If lower light levels are acceptable, then these lamps are candidates for retrofit projects. Similarly, if the existing halogen lamps are dimmed in use, the LED replacement lamp light output may be equivalent when operated at full power. Or, if the room or installation was over-lighted with halogen lamps, LED replacements may correct for over-lighting.

FLUX CHARACTERISTICS (T_J = 25 °C)

The following table provides several base order codes for XLamp XP-G LEDs. It is important to note that the base order codes listed here are a subset of the total available order codes for the product family.

Color	CCT Range		Base Order Codes Min. Luminous Flux @ 350 mA		Calculated Minimum Luminous Flux (lm)*			Order Code
	Min.	Max.	Group	Flux (lm)	700 mA	1.0 A	1.5 A	
Cool White	5000 K	8300 K	R3	122	228	305	406	XPGWHT-L1-0000-00F51
			R4	130	243	325	433	XPGWHT-L1-0000-00G51
			R5	139	260	348	463	XPGWHT-L1-0000-00H51
Outdoor White	3200 K	5300 K	R2	114	213	285	380	XPGWHT-01-0000-00EC2
			R3	122	228	305	406	XPGWHT-01-0000-00FC2
			R4	130	243	325	433	XPGWHT-01-0000-00GC2
Neutral White	3700 K	5300 K	Q5	107	200	268	356	XPGWHT-L1-0000-00DE4
			R2	114	213	285	380	XPGWHT-L1-0000-00EE4
			R3	122	228	305	406	XPGWHT-L1-0000-00FE4
80-CRI White	2600 K	4300 K	Q3	93.9	175	235	313	XPGWHT-H1-0000-00BE7
			Q4	100	187	250	333	XPGWHT-H1-0000-00CE7
			Q5	107	200	268	356	XPGWHT-H1-0000-00DE7
Warm White	2600 K	3700 K	Q3	93.9	175	235	313	XPGWHT-L1-0000-00BE7
			Q4	100	187	250	333	XPGWHT-L1-0000-00CE7
			Q5	107	200	268	356	XPGWHT-L1-0000-00DE7
			R2	114	213	285	380	XPGWHT-L1-0000-00EE7
85-CRI White	2600 K	3200 K	P3	73.9	138	185	246	XPGWHT-P1-0000-008E7
			P4	80.6	151	202	268	XPGWHT-P1-0000-009E7
			Q2	87.4	163	219	291	XPGWHT-P1-0000-00AE7
			Q3	93.9	175	235	313	XPGWHT-P1-0000-00BE7
90-CRI White	2600 K	3200 K	P3	73.9	138	185	246	XPGWHT-U1-0000-008E7
			P4	80.6	151	202	268	XPGWHT-U1-0000-009E7
			Q2	87.4	163	219	291	XPGWHT-U1-0000-00AE7

Notes:

- Cree maintains a tolerance of ±7% on flux and power measurements, ±0.005 on chromaticity (CCx, CCy) measurements and ±2 on CRI measurements.
- Typical CRI for Cool White (5000 K - 8300 K CCT) is 70.
- Typical CRI for Neutral White (3700 K - 5300 K CCT) is 75.
- Typical CRI for Outdoor White (4000 K - 5300 K CCT) is 70.
- Typical CRI for Warm White (2600 K - 3700 K CCT) is 80.
- Minimum CRI for 80-CRI White is 80.
- Minimum CRI for 85-CRI White is 85.
- Minimum CRI for 90-CRI White is 90.
- Calculated flux values are for reference only.

LSD 8-1999

A NEMA Lighting Systems Division Document

Power Quality Implications Of Compact Fluorescent Lamps In Residences

Prepared by

Lamp Section
National Electrical Manufacturers Association
1300 North 17th Street, Suite 1847
Rosslyn, VA 22209
April 16, 1999

Contents

Figures

Power Quality Implications of Compact Fluorescent Lamps in Residences

Overview

There continues to be a growing proliferation of high reliability, low cost electronic products that can represent non-linear loads from a power systems point of view. These products include entertainment devices such as TV's, VCR's, and audio equipment; information technology devices such as PC's, printers, and fax machines; variable speed motor drives for HVAC, and white goods appliances; food preparation and cooking products such as microwaves and cooktops; and lighting products, which include electronic ballasts, compact screw-in fluorescent lamps (CFLs), and other power conversion devices that operate a variety of lamps.

The drivers that have resulted in this proliferation are a direct result of the availability of low cost switch mode devices and control circuitry as well as the benefits that such technology can bring to end users:

- Lower operating costs
- Energy cost savings
- Short economic paybacks, often under two years
- More features, improved performance
- Size and weight reduction
- Improved form factors
- Pollution reduction from fossil fuel generation of electricity

The proliferation of such products results in an increased growth of so-called non-linear loads from a utility point of view. Products with non-linear loads are not new- but it can be argued that we have entered a period where the growth will be unprecedented in all major end-use segments: residential, commercial, and industrial. This growth has led to an increasing concern by some utilities on the effects from such loads on power quality. While some utilities are more concerned than others, it is fair to say that even utilities that are centrist on such issues are spending more effort to instrument their service areas so that they can monitor THD(V) in an attempt to correlate end user and system disturbances with the increase of such loads within their service areas.

While at the highest levels, utilities are concerned with distortion to the voltage waveform that they supply to their customers, they are also concerned with the effects of non-linear loads on their distribution infrastructure, which can include capital equipment and added heating losses within the systems. Some are concerned with disturbances that may occur within the premises of their customers since such customers may attempt to fix the blame for local interaction problems on the power quality as supplied by the utility.

This paper will not go into detail on the fundamentals of the above issues, There are dozens of relatively recent papers that can be referred to for various treatments of this subject from a utility perspective. This paper seeks to put into perspective the subject of CFLs and power quality in a manner that has not been discussed previously, and that will explain why the implications presented by CFLs from a power quality perspective are not as severe as some have postulated.

Scope

This paper will concentrate primarily on the implications of non power factor corrected "screw in" CFLs in residences and on residential power quality. Utilities are often internally conflicted on this issue. The engineering departments tend to be conservative, since they are entrusted with the reliability of the system. Accordingly, they also tend to be risk averse on power quality issues, even when the loads are small and experience indicates that problems have yet to occur with such products as non-power factor corrected CFLs (also called normal power factor by some; but in this paper the terms low power factor or non-power factor corrected will be used interchangeably). This paper presents some recent work that has been done using CFLs in aggregate and with other loads to try to better understand why non- power factor corrected CFL usage has not posed a problem in the last two decades, and particulalry in the last decade when costs have become reasonable and products have made inroads into the residential market place. It is also hoped that this paper will help to justify why utilities should not hesitate to endorse all CFLs, even non-power factor corrected versions over the next several years, as work continues to evaluate and understand aggregate effects..

Benefits of CFLs

A brief review of CFL benefits is helpful to set the stage. CFL's use approximately 25% of the power that would be consumed by an equivalent light out put traditional incandescent lamp. End users and energy advocacy groups realize the savings this can represent in both energy costs and the preservation of natural resources. Such performance provides benefits for utilities who are often looking for ways to reduce connected load or for strategies that can help slow the rise in overall demand. Hence the sometimes conflicted utility dilemma. One department may want to promote low cost, non-PF corrected CFLs at the same time another department cautions against the possible detrimental effects to system power quality.

Since the technology used is fluorescent, which has a much longer innate life than incandescent technology, the CFLs easily achieve rated lifetimes that are 13 times longer in use. This feature alone often convinces the end user to try CFLs in "high usage" applications despite their high initial cost.

As opposed to earlier models, today's CFLs product light outputs equivalent to the most popular incandescent types. Improved color has removed some of the aesthetic objections for residential use, although the size, appearance, and color are still barriers for many residential decision makers, as is initial cost.

Since non- PF corrected CFLs draw about half the RMS current as their full wattage incandescent counterparts, CFL loads reduce current loses that occur throughout the distribution infrastructure, both on the utility side and within the users premesis.

Power Quality Aspects of CFLs

Let us then review *all* the power quality aspects of non-PF corrected CFLs. (This paper concentrates on this category since it is these CFLs that are the lowest in cost and represent the best opportunity for consumer acceptance.)

Efficiency/Energy Savings	Power use reduced to 25% of the equivalent incandescent bulb Reduced "I squared R" distribution losses throughout the electrical infrastructure
Power Factor	Lower than for an incandescent bulb; typically 0.5 for low or non-power factor correced types. Some power factor corrected models range from 0.8 through PF greater than 0.9
Harmonic Currents, THD	Greater than an incandescent lamp; THD(f) for current is typically 150% with some as high as 175%. Harmonic currents are on the order of 15ma per watt. "Low distortion" CFLs have THDs less than 32%, but costs for such system drive up price, increase size, and reduce product performance to some degree.

A Perspective

Given the above, what is the problem? Today's CFLs are more reliable, lower cost, smaller, more attractive, have higher performance than ever before. They have an overall excellent 20 year history in both residences and commercial installations. Manufacturers are aware of no power quality problems either within installations or at the distribution level from such products. Virtually the entire installed base of screw-in CFLs is of the low power factor version (PF approximately 0.5) and with input current THDs in the 150% range.

Yet, these CFLs are still often swept into the general debate on power quality that rages today and are sometimes not endorsed by utilties for incentive programs.

Is this concern justified? The answer is certainly "no" today. There are simply *no* problems that can be attributed to this distributed load throughout residences, even in regions of the country where energy rates are high and where there is reasonable product demand.

Let us review why this is so today, put this in context for the next several years, and then discuss what the implication may be for the future. First we must review how CFLs are actually applied in residences.

Residential CFL Application and Use

Power system engineers are generally familiar with loads that replace equivalent loads even when the technology is upgraded. A more efficient 1/2 HP motor drive still drives a 1/2 HP motor. CFL usage is very different. CFL manufacturers did not design CFLs to use the same energy as the incandescent lamps that they replace. The vast majority of CFLs are designed and used to replace an incandescent lamp at approximately the same *light* level since it is the light level a consumer seeks. Unlike most other non-linear loads, both end users (local environment) and utilities (PCC and back into the distribution system):

- See much lower power consumption per lamp replaced (25% of incandescent wattage).
- See much lower RMS current draw oer lamp replaced, even for low or non-PF corrected CFL products.
- Benefit from reduced I squared R losses
- See only a small increase in harmonic currents (mA/watt)

Power Factor

Let's break down the two most popularly discussed elements of "power quality", namely, PF and harmonic currents/THD for CFLs. It can be shown that even a low PF CFL draws much less total RMS current than the incandescent lamp it replaced. This means that if we only consider PF, a low PF CFL actually has better "power quality" from an RMS current demand perspective than the original incandescent lamp with its 1.0 PF! This is shown dramatically in **Figure 1**. Note that the CFL PF could degrade all the way to 0.3 and still draw less RMS current than the original 100 watt incandescent lamp it replaced.

The only way PF would be an issue would be if CFL manufacturers produced lamps with the same equivalent wattage level as the incandescent lamp it replaced.....however this would provide no user benefit and would not be accepted.

Low PF is not an issue for residential screw-in CFLs.

Harmonic Currents and THD

Screw-in residential CFLs pose no threat to either the utility system or to the local premises environment.

CFLs represent a very, very small portion of the residential lighting load, even in concentrated urban areas. Fewer than 20 million screw-in CFLs are sold annually in the United States, and this includes the commercial sector. The market is not growing at a rapid rate. The largest portion of the CFL market today is represented by the plug in CFL and that is predominately used in dedicated commercial luminaires. True, screw-in CFLs will grow in residences, but relatively slowly, and certainly not in any respect close to the penetration levels that would compete with the literally ***billions*** of incandescent lamps sold into residential households every year.

The average power level of such CFLs sold into residences is approximately 20 -25 watts. This is four time lower than a modern TV or PC. The worst case third harmonic current associated with such a CFL is approximately *200 milliamps*. There is no direct evidence that such harmonic currents circulating within a local residential branch circuit are problematical. Other consumer products have circulated such currents for decades. There is no direct evidence that even aggregate CFLs produce aggregate harmonic currents that have caused problems with local low voltage utility transformers that serve multiple residences, or that such harmonic currents result in unacceptable voltage distortion on either the primary or secondary side of the residential service transformer, or that such CFL harmonic currents from residences cause unacceptable THD(V) levels at locations upstream from the residence.

Supporting Data

Furthermore, the data taken on both a typical commercial branch circuit and at the load center in a typical residence show that the addition of other types of loads commonly found in residences dramatically swamps out or dilutes any possible component of harmonic current provided by the lower power CFLs. See Figures 2, 3, and 4 for typical results. While the specific results will vary with local line impedances and internal residential circuit impedances, the overall effects are indicative of what typically happens today, and helps to explain why such products have not caused problems. (Note, too, that this behavior will be typical of any non-linear load with the same input characteristics of non-PF corrected CFLs. Many non-linear power supplies have this characteristic, such as power supplies for TVs and PCs.)

Figure 2 compares a single CFL and its singular current THD(f), and the effect that can occur when multiple CFLs are applied down stream on a branch circuit. As additional loads were added, of various types, the THD was reduced still further. While the addition of such loads is not predictable, the overall effect is nonetheless real and helps to explain why real world systems have not typically encountered any problems. Since most residential loads are still linear or quasi-linear, and can be relatively large in comparison to CFLs, it is logical that a CFL or even several per household would should not casue any immediate issue in the local environment. The test set up for Figure 2 was a laboratory simulation of a relatively high source impedance presented to a relatively long branch circuit. It can be seen that as even one 250W incandescent load is added to multiple CFLs that the incandescent or linear load predominates. Although one could argue that the harmonic currents are merely being "masked" by the linear load currents, one must consider that any resultant voltage distortion is still in some manner related by a transfer function to the total current THD.

Figure 3 depicts the reduction in THD as other relatively small loads are added in the simulated laboratory environment. A desk fan and incandescent loads are shown by themselves to provide some indication of their their individual linearities.

Figure 4 shows the measured power factor for the same exact combinations of loads presented in Figure 3, and demonstrates the improvement in system PF that occures simultaneously as system THD(i) improves. It should be noted that moderately high aggregate power factors are achieved at moderate THD levels.

Figure 5 depicts the current waveform from one type of screw-in compact fluorescent. It is a relatively classical shaped current waveform for this type of load. Note that as additional identical product loads are added (**Figure 6**), that one cumulative effect is a "filling in" of the current drawn from the branch circuit. This reduces the overall THD and increases the aggregate PF even before additional non-CFL loads are considered. It is very likely that this effect is even more pronounced in the field when multiple non-linear loads from different product designs interact in an aggregate basis.

Figure 7 shows the combined current waveform when ten 23 watt Genura reflector EFLs (a non-electroded version of a CFL) are operated along with a single 250 watt incandescent lamp. Additive aggregate effects for various harmonic currents can be seen in **Figure 8.** Most interesting is the aggregate effect as harmonic order increases. The additive effect is not uniformly linear as harmonic order increases and actually shows an apparent reversal as harmonic order exceeds the ninth harmonic. This data also shows why setting harmonic limits above the 9^{th} or 11^{th} harmonic may turn out to be overly burdensome for many products.

In another set of experiments, aggregate and interactive effects were observed in an actual residence. In this case the measurement point was chosen to present the most pessimistic situation within the residence, directly at the bus bars of the residential load center. It is here that the impedance presented by the power supply is lowest, and is closest to that which would be found at the residential LV side of the local distribution (pole) transformer.

Figure 9 demonstrates that when the THD of the aggregate current is measured directly at the load center, the THD remains constant as additional CFL loads are added. This would be expected since at this point the distribution source impedance is very low. However, even a single typical refrigerator reduces the overall system THD and increases its power factor significantly. Even more interesting is the effect of moving the location of the aggregated CFLs to a more distributed configuration on the first floor. In this configuration, the aggregate THD at the load center is reduced compared to locating the aggregated CFLs directly at the load center. This indicates that distributed effects may represent still another beneficial field mitigation.

Clearly the major conclusion that can be drawn from even this limited series of experiments is that there is significant mitigation that occurs for low powered non-linear distributed loads in residences. Although this testing was concentrated on CFLs, it is exepected that similar effects would be found for TV sets, PCs, audio systems, and other laods that are relatively prolific in total, yet have not directly been the cause of problems up to this point in time.

There is every reason to suspect that effects of the type measured in this paper would also be measured directly at the residence side of the local utility pole transformer as devices cycled on throughout the adjoining residences, although such measurements were not made due to the inherent difficulty and liabilities that could be incurred from such testing.

Models versus Data Monitoring in the Field

Models are useful tools that can sometimes assist in an attempt to understand complex phenomena, but models are not able to, in themselves, adequartely predict the disturbances attributed to small non-linear loads such as CFLs. For such models to be reasonably accurate, the models would need to incorprate the transfer functions that would accurately describe how CFLs act in aggregate fashion, how CFLs interact with other linear and non-linear loads, how CFLs interact under a variety of local impedance situations, and how aggregate local system effects translate to the PCC on both sides of the local LV transformer. While such a model could probably be constructed, it would take a great deal of validation testing with field devices to in fact properly qualify such a model. The use of incomplete models can and probably lead to overly conservative predictions regarding the cumulative effects of low power non linear loads such as CFLs.
Such models should not be relied on as the sole basis for utility policy decisions that deal with approving or endorsing low wattage, low power factor CFLs.

Rather, utilities would do better to spend resources instrumenting residential (and commercial) areas to monitor current and voltage THD in an attempt to correlate any increase in THD levels with either real or perceived customer or utility problems attributed to THD and harmonic current content. Granted, models may be less expensive to operate than a monitoring program, but only field data over time will conclusively demonstrate if there is a problem with harmonic currents.

As a follow on to the kind of initial work performed for this paper, it is suggested that a joint industry/utility series of field tests should be devised that would better quantify the levels and types of mitigation that such aggregate and diverse load factors provide.

Conclusions

Currently available CFLs do not pose a power quality problem for users or utilities. Experience indicates that utilities should not hesitate to fully recommend both low and high power factor screw-in CFLs for residential customers and incentive programs, realizing that most user/consumers will continue to prefer the lower priced non-PF corrected models. Taken together, the benefits of such CFLs strongly outweigh any perceived near term risks from power quality issues. Data presented in this paper underscores why there is very little risk for utilities to endorse such products in the near term.

Both utilities and manufacturers need to stay close to the power quality subject and to work cooperatively to develop future national and international standards that set harmonic and/or PF requirements for products and systems. As the use of non-linear load products continues to grow, and as higher power devices are developed, future potential problems can best be avoided by developing and adopting fair, reasoned, practical requirements for key product sectors, including lighting. There is no compelling argument that can be made for the implementation of immediate, severe harmonic limits from low power distributed non-linear loads. Any requirements applied to products should be based on actual field data, not strictly from models, and implemented in a time phased, trial use and review fashion.

Neither manufacurers, policy makers, utilities, nor mutual customers benefit if real future power quality problems develop in the residential sector.

While such work continues, utilities are advised to accept an interim requirement for low wattage CFLs ($P < 75W$) that would require PF to be equal or greater than 0.5. This sets a minimum PF that has proven historically acceptable and ensures that any new products must at least meet this minimum requirement. Until the national and international work is completed on harmonic limits for North America no THD requirement should be imposed.

Postscript

CFLs in Light Commercial Applications

This white paper specifically deals with the implications of CFLs in residential use. However, many of the conclusions could be applied as well to commercial applications where there is a reasonable mix of linear and non-linear loads or where low PF CFLs would not be expected to be the predominant load. For example, using screw in low power factor CFLs in hotels, motels, and retail stores have not proven to create any power quality issues for users or utilities since the CFL loading tends to relatively small compared to other loads—HVAC (motor loads), additional incandescent and halogen lighting (particularly in commercial establishments), ovens (food preparation), and so forth.

For applications where higher quantities of CFLs would be specified, and where the load would be a higher proportion of the total connected load, it would be expected and recommended that luminaires designed for pin-based (plug-in) CFL lamps and separate ballasts be used rather than screw-in CFLs. Ballasts for such applications, which are designed for heavy commercial use and which are typically supplied with the luminaires (fixtures), are readily available in high PF (PF equal to or greater than 0.9) low THD (less than 32%) versions. In addition, such commercial grade CFL systems generally will provide improved performance and aesthetics since the luminaires are optimized specifically for such systems.

CFL Power Factor Implications - an Example

$$PF = \frac{\text{Power Consumed in Watts}}{\text{Voltage x Current}}$$

$$\left[P = VI \;,\; I = \frac{W}{PF \times V} \right]$$

Compare: P.F. Implication of a 25W CFL, 100W Incandescent Bulb

Voltage (RMS)	Power (Watts)	P.F.	25W CFL Current Draw A (RMS)	100W Inc. Current Draw A (RMS)
120	25	1.0	0.208	0.833
120	25	.9	0.231	
120	25	.8	0.260	
120	25	.7	0.298	
120	25	.6	0.347	
120	25	.5	0.417	
120	25	.4	0.521	
120	25	.3	0.694	
120	25	.2	1.042	
120	25	.1	2.083	

- 25W CFL Draws 0.5A Less Than 1.0 PF 100W Incandescent
- 25W CFL @ 0.6 PF Has Greater "Power Quality" Than 100W A Line

Figure 1

THD From Mixed Loads

Load Combination	THD (I)
1 23W EFL *	170%
11 23W EFLS	143%
11 23W EFLS + 1 250W INC	73%
1 23W EFL & 1 25W HPF CFL	67%
1 23W EFL + 1 25W HPF CFL + 1 95W INC	23%
1 23W EFL + 1 250W INC	13%
1 250W INC	1.5% (Ambient)

Note: * Low P.F., 120V, 23W, 1190 Lumen GENURA EFL

Figure 2

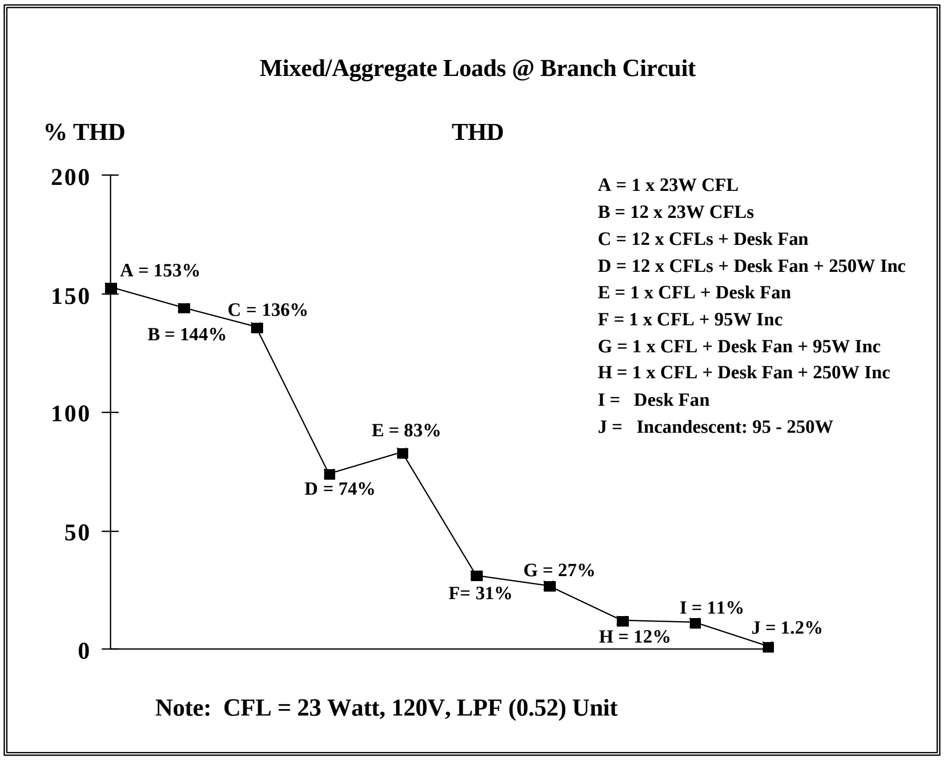


Figure 3

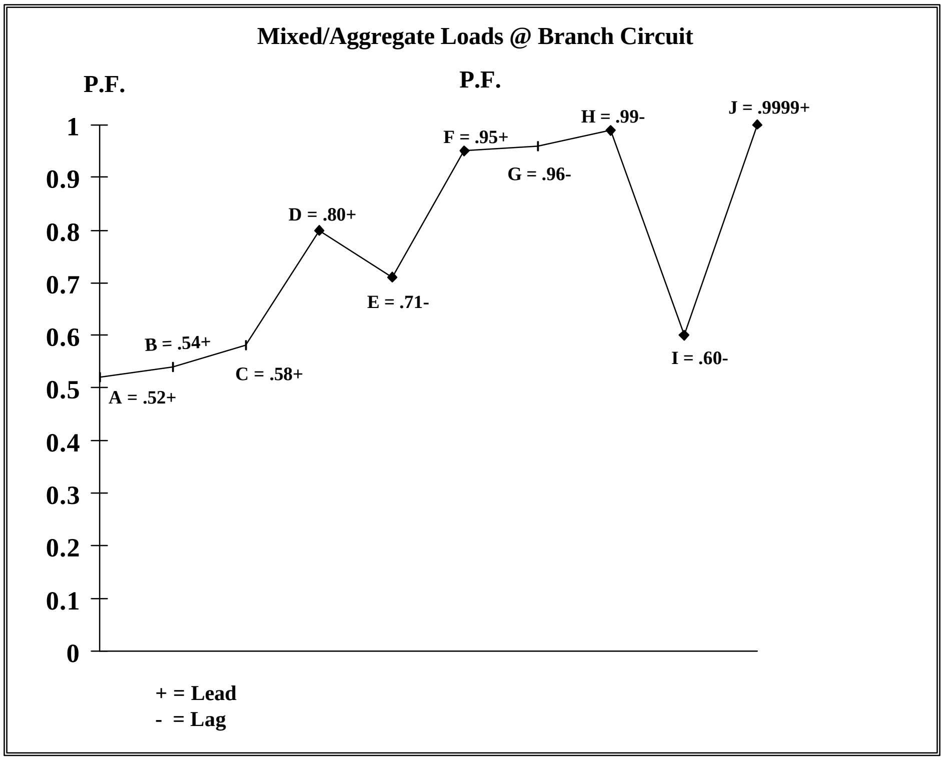


Figure 4

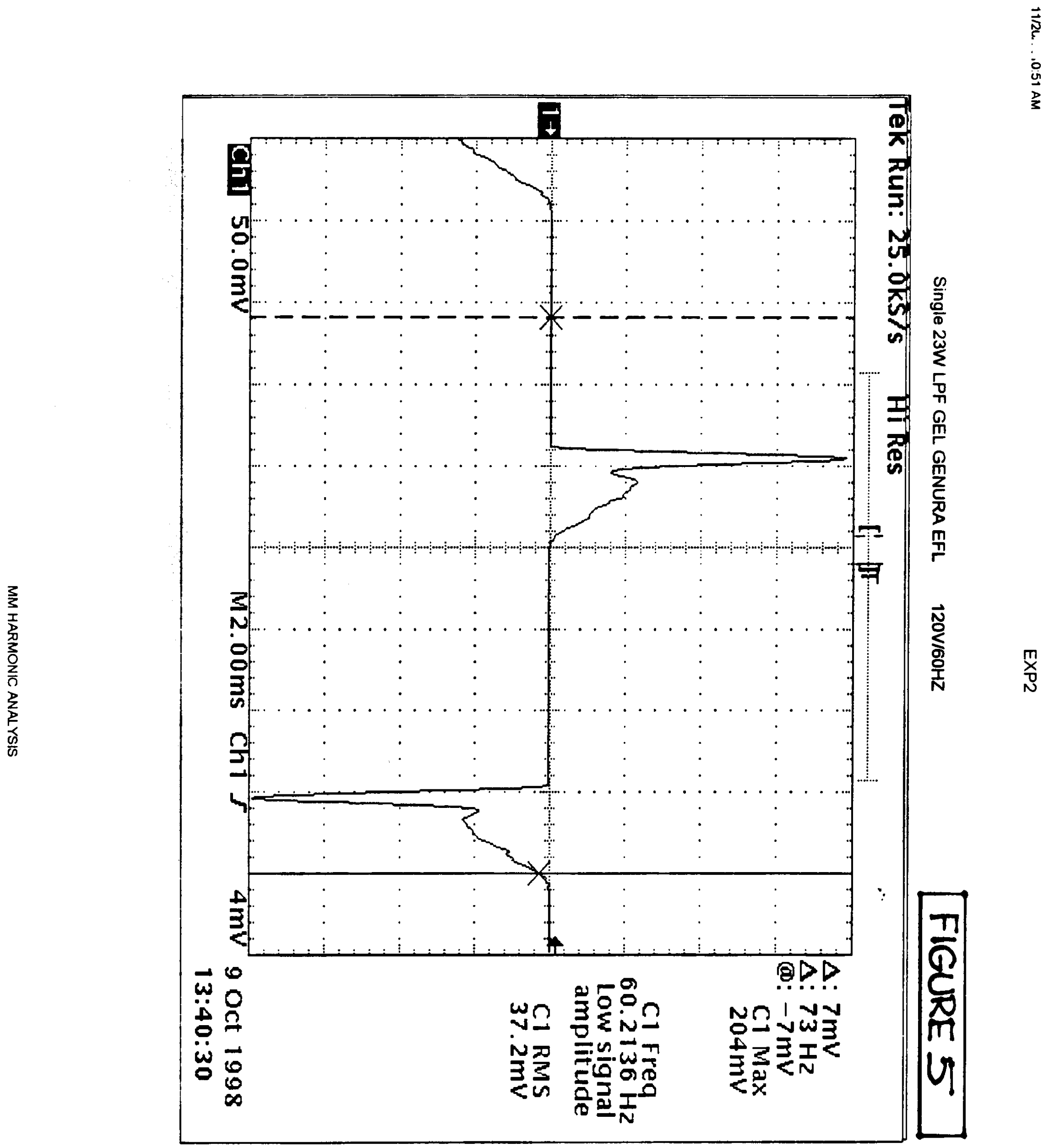


FIGURE 5
EXP2
Single 23W LPF GEL GENURA EFL 120V/60HZ
Tek Run: 25.0kS/s Hi Res
Ch1 50.0mV M2.00ms Ch1 4mV
Δ: 7mV
Δ: 73 Hz
@: -7mV
C1 Max
204mV
C1 Freq
60.2136 Hz
Low signal
amplitude
C1 RMS
37.2mV
9 Oct 1998
13:40:30
MM HARMONIC ANALYSIS

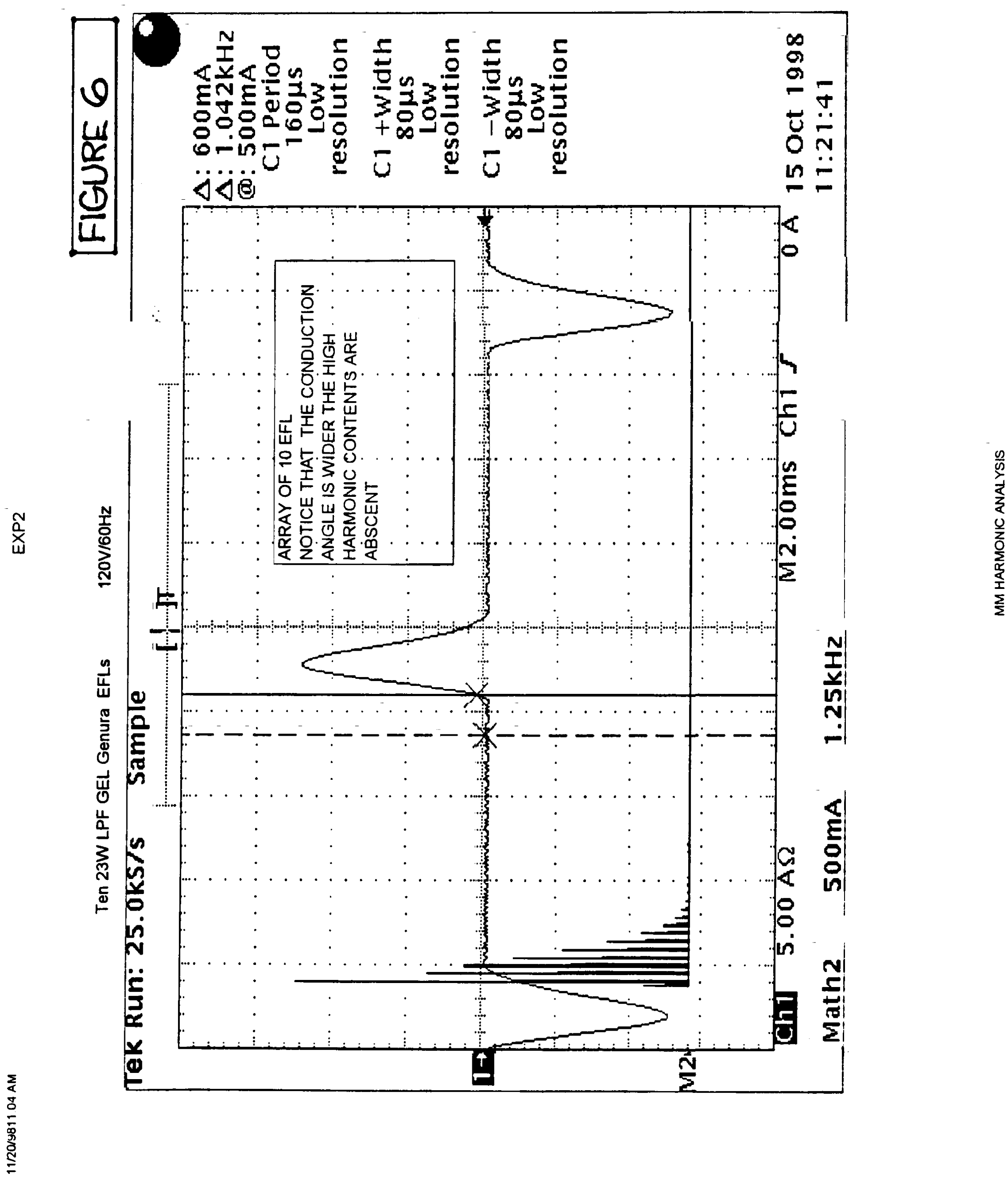


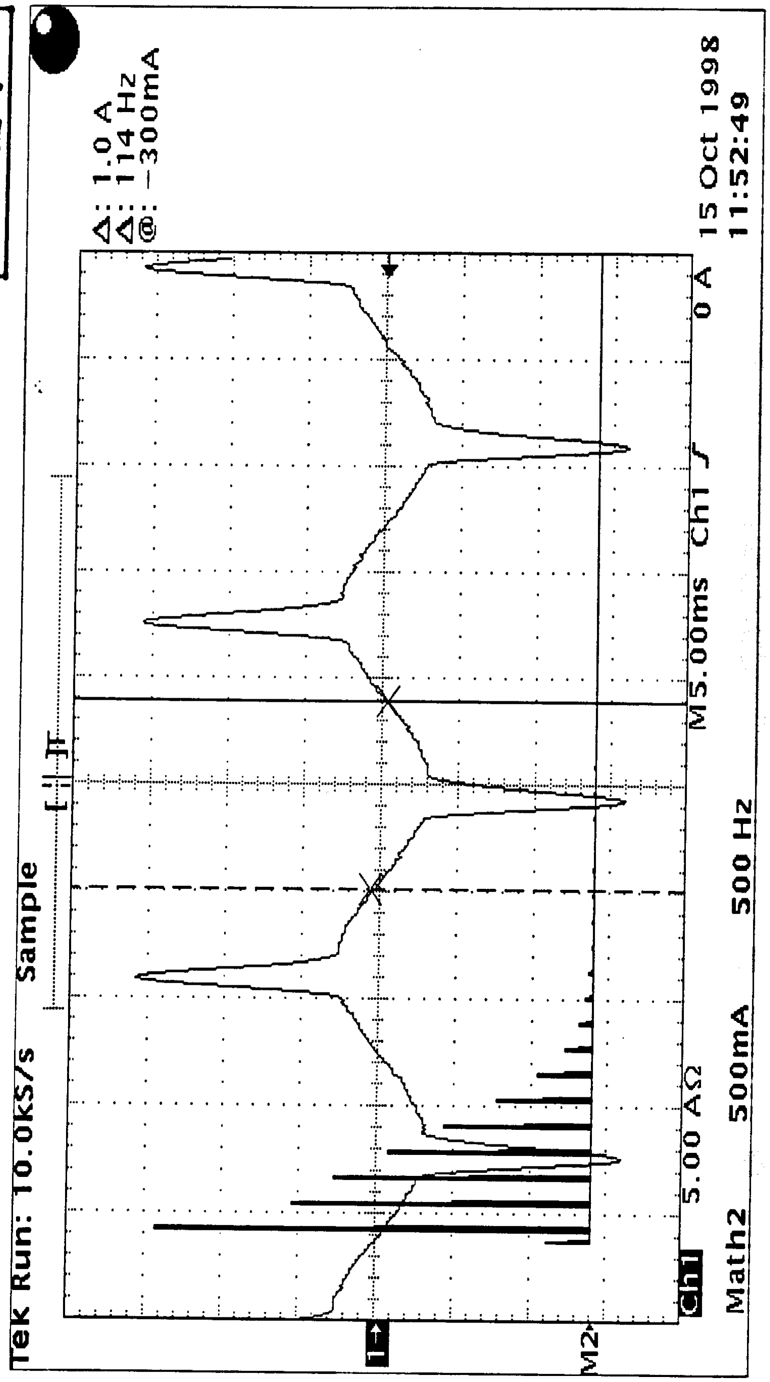
FIGURE 6
EXP2
Ten 23W LPF GEL Genura EFLs
120V/60Hz
Tek Run: 25.0kS/s
Sample
ARRAY OF 10 EFL
NOTICE THAT THE CONDUCTION
ANGLE IS WIDER THE HIGH
HARMONIC CONTENTS ARE
ABSCENT
Δ: 600mA
Δ: 1.042kHz
@: 500mA
C1 Period
160µs
Low
resolution
C1 +Width
80µs
Low
resolution
C1 −Width
80µs
Low
resolution
Ch1 5.00 AΩ
M2.00ms Ch1 ∫ 0 A
Math2 500mA 1.25kHz
M2
15 Oct 1998
11:21:41
11/20/9811 04 AM
MM HARMONIC ANALYSIS

11/20/98 11:18 AM

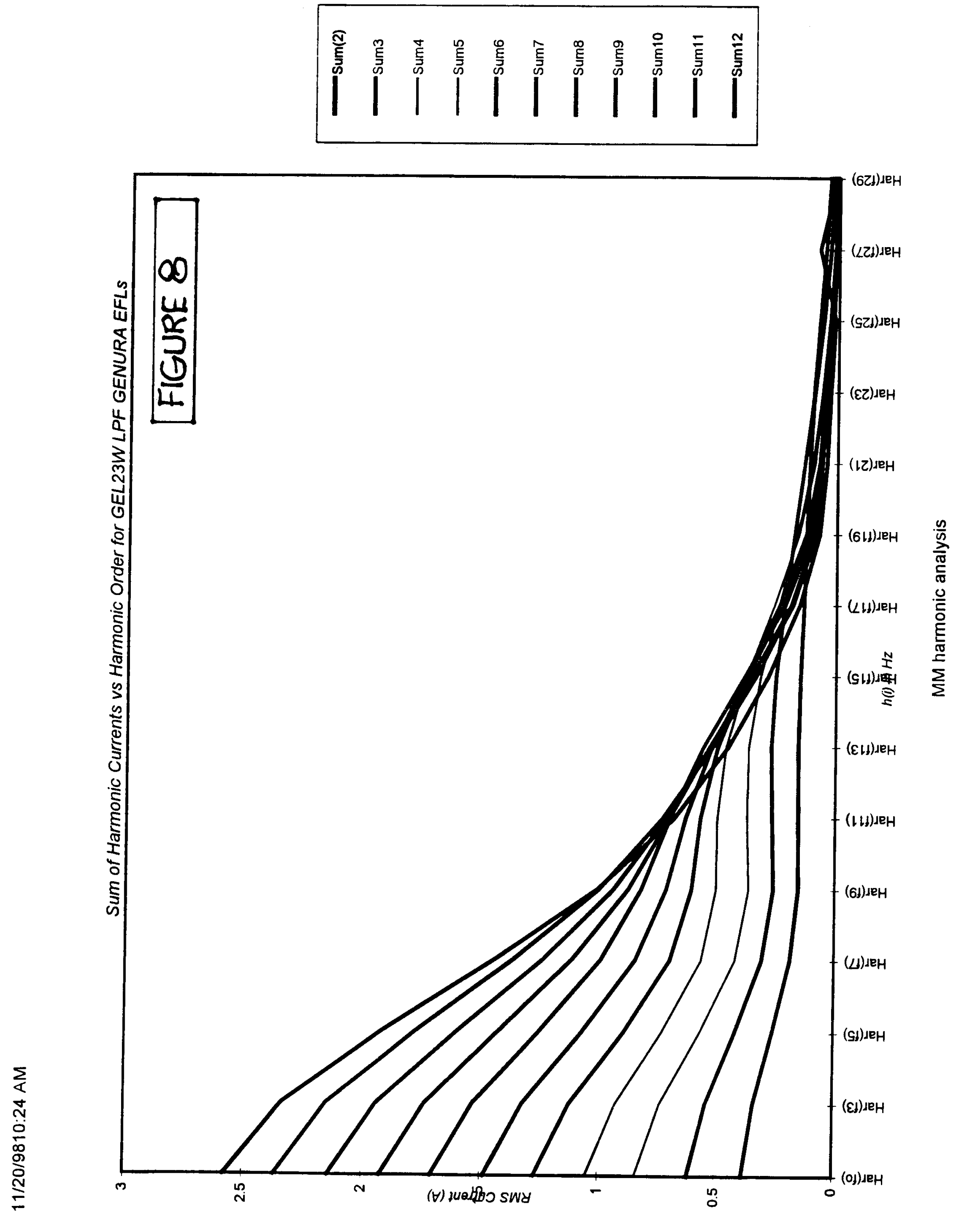
EXP2

Ten 23W LPF GENURA EFLs + 250W Incandescent

FIGURE 7



MM HARMONIC ANALYSIS


11/20/9810:24 AM
Sum of Harmonic Currents vs Harmonic Order for GEL23W LPF GENURA EFLs
FIGURE 8
Sum(2)
Sum3
Sum4
Sum5
Sum6
Sum7
Sum8
Sum9
Sum10
Sum11
Sum12
RMS Current (A)
3
2.5
2
1
0.5
0
Har(fo)
Har(f3)
Har(f5)
Har(f7)
Har(f9)
Har(f11)
Har(f13)
Har(f15)
Har(f17)
Har(f19)
Har(21)
Har(23)
Har(25)
Har(27)
Har(29)
MM harmonic analysis

Typical Lighting Load Characteristics

Aggregate Field Effect Implications and Typical System Mitigation

	% of 60 Hz Fundamental I										PF	THD
Load Control	3	5	7	9	11	13	15	17	19	21		
-1 LPF CFL @ LC	87	68	51	42	40	35	28	23	22	21	.51	153%
-8 LPF CFL @ LC	87	70	55	46	42	38	31	24	19	16	.52	154%
-1 Refrigerator	17	10	6	3	1						.94	21%
-8 LPF CFL 1st Floor Scattered Plus Refrigerator	32	18	10	7	7	7	5	4	3	3	.91	41%
-8 LPF CFLs Only, 1st Floor Scattered Plus Basement Lights	49	26	15	11	11	11	8	6	5	4	.84	62%
+Plus 2 Refrigerators	17	9	6	3	3	3	3	2	2	1	.90	22%
+Plus 1500W Space Heater	11	4	3	2	2						.99	13%
+Plus Clothes Dryer	6	3	2	1							.99	8%

Figure 9

Separately, ANSI C78.21-2003 defines standard lamp classes for PAR, R, BR, and ER lamps; both BR30- and R30-designated lamps must meet the dimensions provided in Figure C78.21-266. Accordingly, they must have an overall length between 4.875 inches and 5.375 inches, and a maximum diameter of approximately 4.25 inches, among other dimensional tolerances. There is no minimum diameter specified.

Classifying the Distribution of Directional Lamps

Directional lamps are commonly specified based on distribution (e.g., beam angle), although BR and R lamps are often specified more loosely than PAR lamps (e.g., simply *flood* or *spot*). Spot lamps typically have a nominal beam angle of 20° or less, whereas flood lamps typically have a nominal beam angle of 25° or more. Figure 1 illustrates the relationship between three descriptors of distribution: center beam candlepower (CBCP), beam angle, and field angle. Complete descriptions of these terms, among others, are included in Appendix A.

To be more specific, directional lamps can be classified with an adjective describing their nominal distribution: very narrow spot (VNSP), narrow spot (NSP), spot (SP), narrow flood (NFL), flood (FL), or wide flood (WFL). However, there is no industry standard defining these descriptors in terms of beam angle, and there is sometimes overlap in the categories across different manufacturers. ANSI C78.379-2006 recommends that distributions are denoted with both the descriptor and the beam angle, which allows the numerical designations to be compared (e.g., FL40 for a flood lamp with a 40° beam angle, or NSP9 for a narrow spot with a 9° beam angle).

Because of variability in the manufacturing process, beam angles for blown glass lamp types (R, BR, and ER) are assigned a tolerance of ±12°. For example, the 25° lamp classification can include lamps having a beam angle between 13° and 37°. The more precise pressed glass lamps (e.g., PAR) have smaller tolerances that vary based on the nominal beam angle. Importantly, even lamps having the same numerical classification can produce patterns of light that appear substantially different. In order to prevent ambiguity, CALiPER does not convert measured beam angles to nominal beam angles.

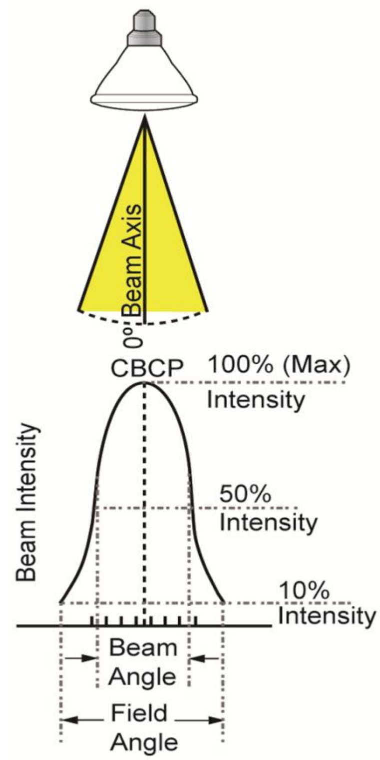


Figure 1. Describing and quantifying the distribution of directional lamps. Beam angle is the point at which the luminous intensity is 50% of its greatest value. Field angle is the point at which the luminous intensity is 10% of its greatest value.

Regulations

Beginning with The Energy Policy Act of 1992 (EPAct 1992), the U.S. Government—specifically DOE—has required directional lamps to meet certain luminous efficacy requirements. EPAct 1992 set the minimum efficacy of some PAR and R lamps, whereas all ER and BR lamps—which at that time were considered niche products with small market share—were excluded. Specifically, the requirements applied to PAR and R lamps with diameters greater than 2.75 inches, having a medium base, and operating near line voltage. The legislation set minimum efficacy levels for wattage bins starting with 40–50 W (10.5 lm/W) and ending with 156–205 W (15.0 lm/W). These minimum efficacies were sufficiently high that it was almost impossible for R lamps to meet the requirements. However, instead of promoting more efficient PAR lamps, the market shifted to the exempted BR and ER lamps.

Distribution of Light

Although there are no specific boundaries, luminous intensity distribution is a fundamental factor in differentiating between directional lamp types, at least for conventional incandescent and halogen products. Thus, it would seem that LED product manufacturers should strive to use product labels that best match performance with that of conventional products. However, this goal is already complicated by CFL reflector lamps, which do not match the luminous intensity distribution of their incandescent counterparts. Unfortunately, this may lead purchasers or specifiers to products that do not perform as expected.

There was substantial variability in the distribution of the Series 16 LED products, with beam angles ranging from 23° to 129°, as shown in Figure 5. Eight of the products performed most similarly to directional CFL lamps, rather

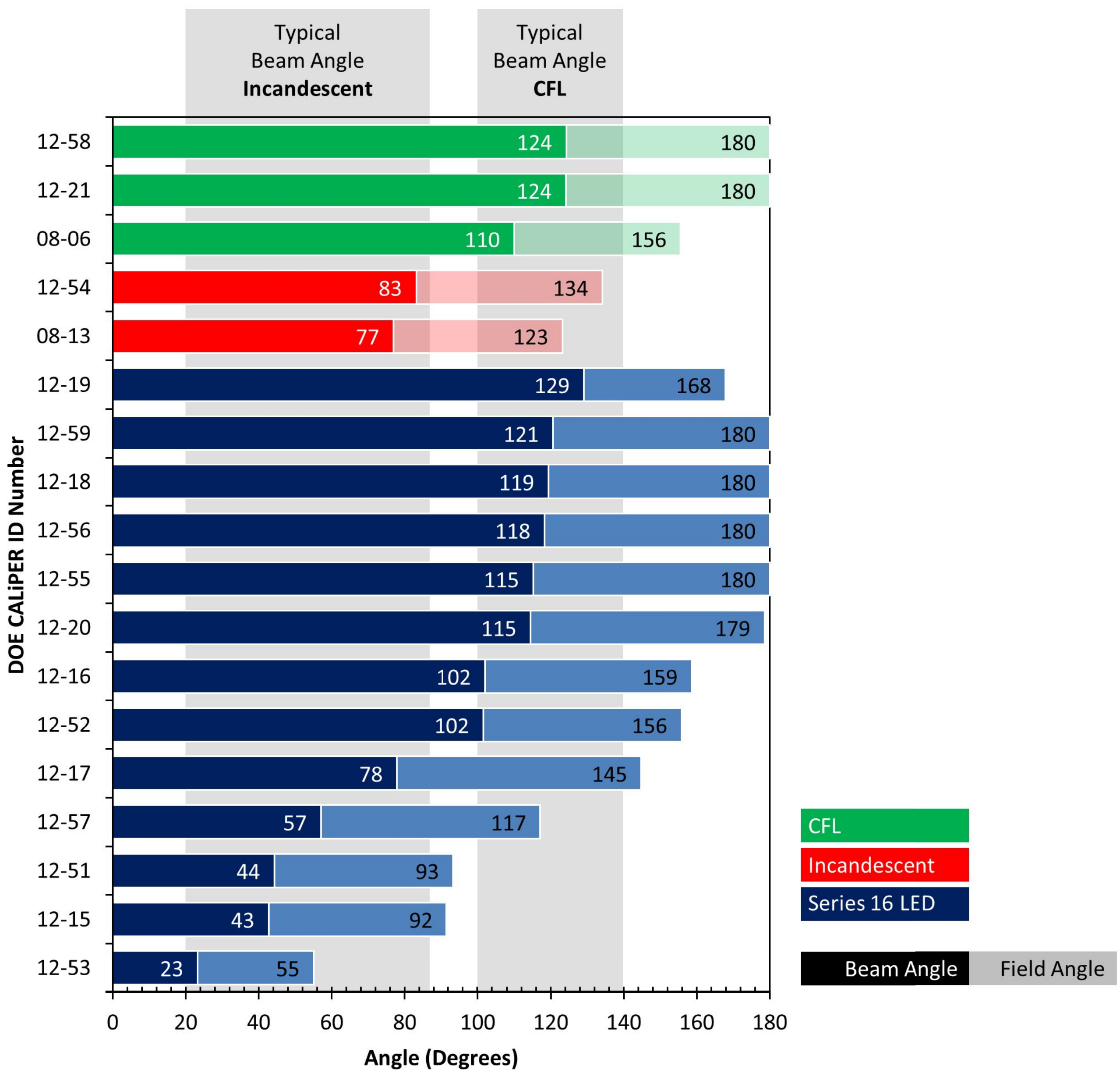


Figure 5. Beam angle and field angle of the Series 16 LED BR30/R30 lamps compared to CALiPER incandescent and CFL BR30/R30 benchmarks. The typical nominal beam angles are based on a review of manufacturer literature as well as CALiPER test data. Many of the Series 16 LED products had distributions similar to CFL reflector lamps rather than incandescent reflector lamps.

6 Conclusions

As tested by CALiPER, the Series 16 LED BR30/R30 lamps showed substantial improvement from earlier tests of similar LED lamps. Many of the Series 16 products would be an effective energy-saving alternative to incandescent BR30 or R30 lamps. Further, the efficacy and color characteristics are similar to or better than directional CFL lamps, yet LED lamps offer a greater variety of luminous intensity distributions. Adding other factors such as dimmability and longer rated lifetime makes LED BR30/R30 lamps the best solution for replacing inefficient and soon-to-be regulated incandescent BR30 and R30 lamps.

The performance of the Series 16 products can be summarized as follows:

- The lumen output of many of the products was equivalent to 65 W or 75 W incandescent BR30/R30 lamps. All of the products emitted between 460 and 860 lumens, which is within the typical range of conventional BR30 and R30 lamps.
- Excluding one product with very high efficacy (91 lm/W), the Series 16 products had luminous efficacies between 51 and 65 lm/W. This is favorable compared to other light source types commonly used in directional lamps, and should continue to rise.
- The Series 16 LED BR30/R30 lamps had luminous intensity distributions ranging from very narrow to very wide. The suitability of these distributions depends on the application, but more than half of the products were more similar to CFL reflector lamps than incandescent BR30/R30 lamps.
- Although there were a few exceptions—two products had a CCT above 5000 K, including one with a CRI less than 80—most of the Series 16 lamps had color quality attributes similar to incandescent lamps.
- The power factor of the Series 16 LED BR30/R30 lamps was considerably better than previously tested LED BR30/R30 lamps, with all but one of the products exceeding the ENERGY STAR minimum requirement.
- Although not specifically examined or measured by CALiPER, the rated lifetime of LED lamps is typically longer than the rated lifetime for incandescent, halogen, or CFL lamps.
- Many of the manufacturer claims were accurate; however, there was a tendency for the lamps to exhibit higher efficacies than reported in the manufacturer's literature.

In terms of lumen output, luminous intensity distribution, and color quality, product 12-17 performed very similarly to incandescent benchmark product 12-54; it also had an efficacy of 62 lm/W compared to 11 lm/W for the benchmark. These two products were from the same manufacturer, and provide a good example of how LED products can be an equivalent replacement for incandescent reflector lamps when properly designed.

Although the results from this series of testing were encouraging, there is room for LED BR30/R30 lamps to improve and gain a larger market share. As with other directional lamps, it would be beneficial if more manufacturers offered a range of products (e.g., lumen packages, distributions) using a single form factor, allowing designers and specifiers to meet the demands of various applications. Another current concern is cost; on average, the Series 16 LED BR30/R30 lamps were several times more expensive than incandescent or CFL reflector lamps. In residential applications, where BR30/R30 lamps are most commonly used, economic justification is especially unlikely.

4. Challenges and Opportunities Offered by Residential Energy Efficient Lighting Technologies

The previous sections described the size and scope of the US residential lighting market. Residential lighting presents a tremendous opportunity for significant and lasting energy savings. However, significant barriers still exist that must be addressed in order to realize that potential. This section focuses on the major barriers to widespread adoption of energy efficient lighting technologies and describes a strategy for realizing this savings potential.

Current Barriers to Energy Efficient Technologies

CFLs are the most widespread energy efficient lighting technology, but these lamps are still disliked by most residential customers. So, the largest barrier to installation remains the lighting technology itself.

The literature review identified several common barriers to CFLs. Unless these barriers are eliminated by improving the technology, CFLs will continue to stay on the fringes in residential lighting applications, just as they have been for the past two decades. Table 12 summarizes the most commonly cited barriers to market acceptance of CFLs.

Table 12: Summary of Market Barriers to CFLs from Literature Review

Market Barrier	**Research Study Supporting that Finding**		
	EPRI, 1994	**Rubinstein, 1998**	**Kates, et al, 2003**
First cost too high.	**X**	**X**	*X*
Do not fit in existing fixture	**X**	**X**	*X*
Poor Appearance/Ugly Lamp	**X**	**X**	*X*
Not versatile: Do not work in some applications including dimmers	**X**	**X**	*X*
Customer resistance and confusion	**X**		*X*
Perceived as dangerous if broken	*X*		

First Cost

As Table 12 shows, initial purchase price remains a major barrier to CFL installations. Even though the average price of CFLs has declined in the past few years, the cost of a CFL bulb is still significantly higher compared to standard incandescent bulbs.

A pricing survey conducted in four Montrose-area locations found that CFL bulbs are consistently priced at 10 times higher than the standard efficiency counterpart. While some incandescent bulbs marketed as “energy misers” are more expensive than a *standard bulb, on average, CFLs are significantly more expensive per bulb compared to standard incandescent bulbs.*

While these prices can be justified when looking at the "lifetime" or payback of a CFL compared to a standard bulb, however as the EPRI research found, "Few customers have *experien*ced noticeable differences in their utility bills as a result of installing CFLs."

Therefore the price-value argument is a difficult one to make for CFLs compared to other energy efficient technologies, where the energy savings are more noticeable. According to Rubinstein (1998), the first-cost barrier effectively eliminates approximately 25 percent of all available lighting sockets (applications).

Even more alarming is that the prevalence of lighting rebate programs has further diluted the value of CFLs to the residential customer. The EPRI report found that "with very few *exceptions, CFLs were installed as a direct result of utility programs which offered direct* monetary incentives." This finding suggests t*hat without utility subsidies, CFLs are unlikely to be routinely installed in most residential lighting applications.*

Installation Cost Comparisons

Figure 8 illustrates the average retail price differences between standard and energy efficient lamps. These average retail prices were based on the prices found in three area stores in the Montrose, Colorado area.

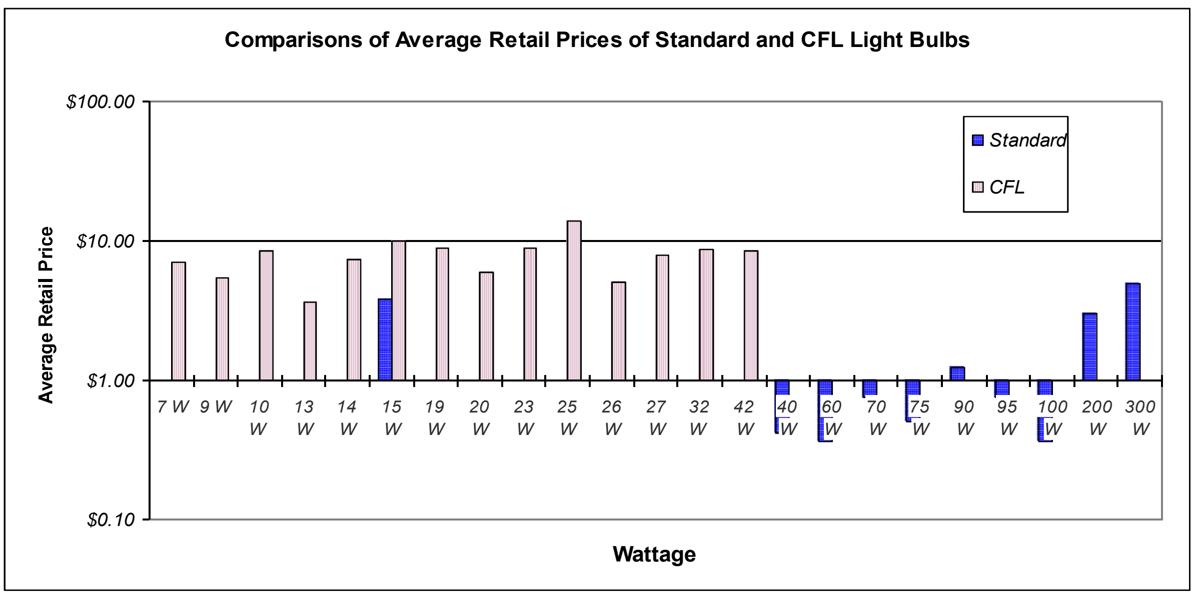


Figure 8: Average Retail Price Differences Between Standard and CFL light bulbs in DMEA's Service Territory

Product Availability

Another major barrier facing DMEA members is the availability of energy efficient lamps. Although three stores in the Montrose, Colorado area offer some energy efficient light bulbs, the overall selection is limited. Given the diverse range of lighting needs in typical homes, it is important therefore to provide customers with a diverse array of energy efficient product offerings.

Fit

CFLs are also not a good fit in many existing fixtures. This poor fit is either due to the interference with the ballast shroud on the fixture cover or because the lamp is too long for the fixture (Rubinstein, 1998). This barrier is estimated to exclude 50 percent of all lighting sockets in the US, according to Rubinstein (1998).

Poor Appearance/Ugly Bulb

CFL bulbs are viewed by many customers as "ugly" because they have an odd shape that *tends not to fit well in the current fixtures. While there have been significant improvements in the overall bulb design by some leading manufacturers, such as TCP, few customers have seen these new more aesthetically-appealing bulbs. This was* illustrated in the EPRI focus group where respondents said that CFLs were "*not as nice* looking" as regular lighting.

Poor Versatility

CFLs are also not as versatile as standard incandescent lamps. The literature review found that in all three studies on CFL perceptions, these lamps were not viewed as a comparable replacement to standard bulbs. This was especially true in applications that required either decorative or specialty bulbs, or required instant on capability (Kates, et al, 2003; Rubinstein et al, 1998).

For example, CFLs may require a full minute to reach 90 percent of its brightness when first energized and usually at least ten seconds before reaching 50 percent of full brightness. This makes CFLs unsuitable for applications such as bathrooms or bedrooms, where instant on is required. Thus, many residential customers have returned to incandescent lamps because the CFLs were unsuited to their needs (Rubinstein, 1998).

Similarly, CFLs are not good replacements in dimmer applications. Most of residential dimming controls are designed for incandescent lamps and will not work properly with CFLS. This lack of versatility is estimated to exclude 30 percent of all lighting sockets in the US, according to Rubinstein (1998).