Increasing Market Acceptance of Compact Fluorescent Lamps (CFLs)

Final Project Report

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Table of Contents

Executive Summary

The Lighting Research Center (LRC), in cooperation with the ENERGY STAR® program under the U.S. Environmental Protection Agency and the U.S. Department of Energy, investigated methods of increasing the market acceptance of screwbase compact fluorescent lamps (CFLs). CFLs generally have not sold well, despite their benefits of energy efficiency, long life, and potential cost savings over the lamp life. In 1999, sales of incandescent units totaled 1.15 billion compared with 5.9 million total compact fluorescent units sold (NRDC 1999b). In 2001, the existence of CFLs in residential buildings accounted for only 2% of all light sources (Navigant 2002). The LRC hypothesized that issues of color, warm-up time, life, and light output are major barriers to the acceptance of CFLs by consumers. To test these hypothesis, the LRC performed limited measurements on color variation and warm-up time, and conducted a focus group study to gather information on consumer perceptions and actual experiences with CFLs.

The CFL color measurements showed a wide variation in correlated color temperature (CCT) and chromaticity coordinates, both between manufacturers and within manufacturers' own CFL product lines. This means that from lamp to lamp, a multitude of color differences can be observed, even among lamps labeled with the same CCT.

Tests of warm-up time on 12 ENERGY STAR-brand CFLs showed the average warm-up time (time to reach 80% of stable light output) to be less than 23 seconds, well within the ENERGY STAR guidelines.

The focus group study uncovered consumer knowledge, perceptions, and experiences regarding CFLs and the ENERGY STAR program. Overall, price, size, color consistency, start-up time, and the image of fluorescent technology as a whole are major contributors to the consumer market's reluctance to purchase CFLs. Lamp life and light output of CFLs do not appear to be major issues for consumers.

If CFLs are to gain greater penetration in the home lighting market, they need to provide added performance such as energy efficiency and longer life, without inconveniences such as color inconsistency and poor fit. Education about lighting energy use and the benefits of energy-efficient lamps will be key to greater acceptance. The industry also will need to investigate lamp and ballast sizing, color specification, and better ways of communicating with consumers about product characteristics and performance.

1. Project Background

Screwbase compact fluorescent lamps (CFLs) offer significant rewards including energy efficiency and long lamp life. The ENERGY STAR® program endorses the use of CFLs as a way to save energy, lower electricity bills, and reduce environmental pollution. Given these advantages, however, CFLs have had difficulty gaining broad acceptance among consumers, accounting for only 2% of installed lamps in all residential buildings in the United States (Navigant 2002).

Market research (NRDC 1999a) shows that homeowners base their lighting purchases on the quality, perceived attractiveness, and reliability of the products they buy. If a consumer purchases ENERGY STAR lighting products and these products do not perform reliably, or do not deliver the quality or appearance expected, the consumer will be unlikely to purchase another similar product in the future. This can significantly weaken national and regional market transformation efforts to encourage the use of ENERGY STAR and other energy-saving lighting products.

The U.S. Environmental Protection Agency (EPA) has found that consumers have mixed perceptions of the value of ENERGY STAR CFLs. Anecdotes also have shown that consumers are not satisfied with premature failures and color characteristics of CFLs, particularly color consistency. Standards created to solve some of these issues have not always reflected real-life applications or consumer needs. The Lighting Research Center (LRC), with its expertise and knowledge of this technology, developed a hypothesis identifying the most important barriers to the acceptance of CFLs by the consumer market and the degree of effort (time) required to overcome them. (See Figure 1.)

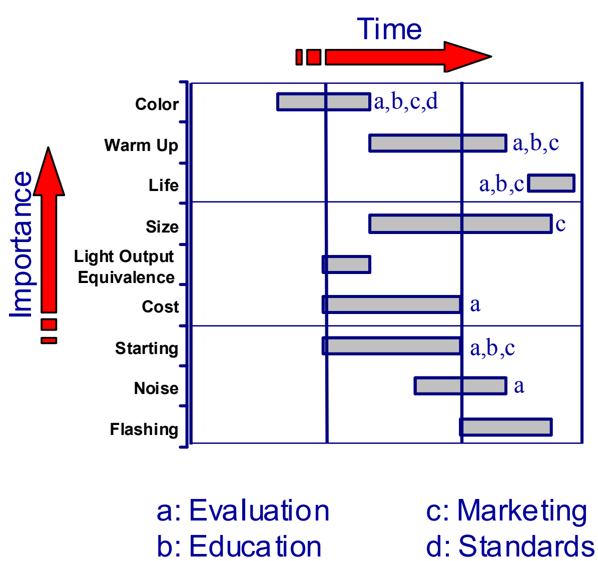

Figure 1: Barriers to consumer acceptance of CFLs, listed in order of importance (bottom to top) with actions needed and relative timeframes for completion.

A nine-block diagram (Figure 1) was used to identify the barriers to acceptance of CFLs. The Y-axis lists the order of importance of each characteristic identified as a possible barrier. The X-axis represents the estimated relative it will take to remove the identified barriers. It is suggested that four types of tasks be used to remove the barriers: (a) evaluation, (b) education, (c) marketing, and/or (d) standards. Ideally, the most important barriers should be removed more quickly (upper-left quadrant), but as shown in Figure 1, this is not always the case. The LRC believes that issues of color, warm-up time, life, and light output all contribute to product rejection by consumers. Lamp size, cost, start time, noise, and flashing also were identified as potential barriers to acceptance.

Working from this analysis, the LRC in conjunction with the U.S. EPA developed this project to evaluate some performance characteristics and overall consumer perceptions of CFLs.

Understanding the barriers to consumer acceptance and developing strategies to overcome them is vital to strengthening consumer confidence in the reliability and quality of ENERGY STAR products. Based on the project findings, this report offers short-term and long-term strategies to improve market penetration of CFLs. By building industry consensus and "buy in" to the strategies, ENERGY STAR and its CFL manufacturing partners will meet goals for energy efficiency, pollution reduction, and sales.

2. Project Goal

The goal of this project was to evaluate the original hypothesis regarding the ranking of potential barriers to consumer acceptance of CFLs and to better understand consumers' concerns and opinions about CFLs.

For this project, the LRC chose to evaluate the following potential barriers:

- Color
- Warm-up time
- Life
- Equivalent light output

Other issues examined in this project included consumer familiarity with incandescent lamps, familiarity with the ENERGY STAR label, buying habits, understanding of CFL life and energy-savings benefits, and CFL costs.

The final goal was to recommend actions to overcome the identified barriers and gain greater consumer acceptance.

In the next phase of this project, the LRC will work with industry and other interested parties to start implementing some of the proposed solutions derived from this first project phase reported here.

3. Research Methodology

Two research tasks were conducted for this project: laboratory measurements and a focus group study (See Figure 2).

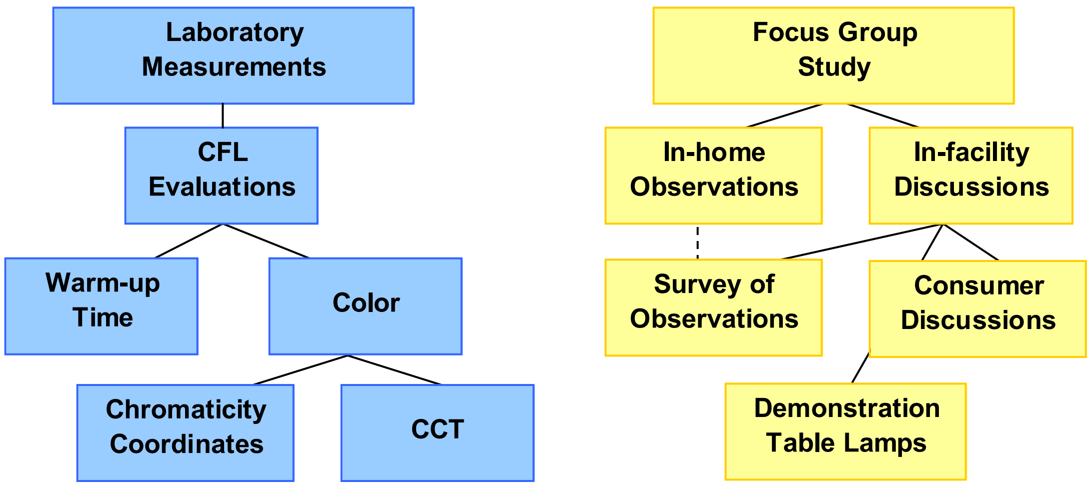

Figure 2: Diagram of research methodology.

The laboratory measurements included evaluations of various CFL products currently on the market. The LRC conducted limited measurements on color variations of CFLs, including chromaticity coordinates and correlated color temperature (CCT). The LRC also conducted limited measurements on warm-up time of various CFLs.

The focus group study was developed and conducted to document consumers' concerns and opinions about CFLs and to verify whether the barriers identified by the LRC matched consumers' opinions. The focus group study included an in-home observation of CFL samples given to participants and an in-facility session in which the participants were brought together in several small groups. The in-facility session included a survey of the participants' in-home observations with their CFL samples, general discussions about CFLs and lighting, and a demonstration of several table lamps.

4. Laboratory Measurements

4.1 Color

4.1.1 Background

The color appearance of incandescent light sources can be described by color temperature, such as 2700 kelvin (K) or 3000 K. CCT is an extension of color temperature to other types of light sources, such as fluorescent lamps and LEDs, which can be more varied in hue than incandescent lamps. CCT is defined as the apparent color of a light source relative to the color appearance of a reference source, usually an incandescent light source (Wyszecki and Stiles 1982), and is measured in units of K. An incandescent lamp has a CCT in the range of 2700 K to 3000 K, while daylight is 5000 K or higher. Since both the mercury discharge and the phosphor coating in a fluorescent lamp contribute to its CCT, the CCT of a fluorescent lamp can range anywhere from 2700 K to 6500 K. In general, CFLs have a CCT of 2700 K to 3000 K to mimic incandescent lamps. CCT, however, does not necessarily relate to human color perception. CCT is a one-dimensional, simplified description of apparent color based on a two-dimensional color metric where colors are quantified by a pair of coordinates in color space, known as chromaticity coordinates. Chromaticity is a more complete way of describing or quantifying color than CCT.

Chromaticity coordinates are calculated from the spectral power distribution of the light source (Figure 3) and plotted in a color space diagram (Figure 4). Light sources with chromaticity coordinates near the center of the blackbody locus appear white. Two light sources with the same CCT can be perceived as being different in color if their chromaticity coordinates are different. This is because each CCT value (e.g., 2700 K) is defined as a line that crosses the blackbody locus, and any pair of chromaticity coordinates that falls on that line will have the same CCT. However, points above the blackbody locus will appear "greenish," while points below the blackbody locus will appear "pinkish" or "purplish." Light sources with the same chromaticity coordinates will always look the same in terms of color, while light sources with different CCT may or may not appear the same.

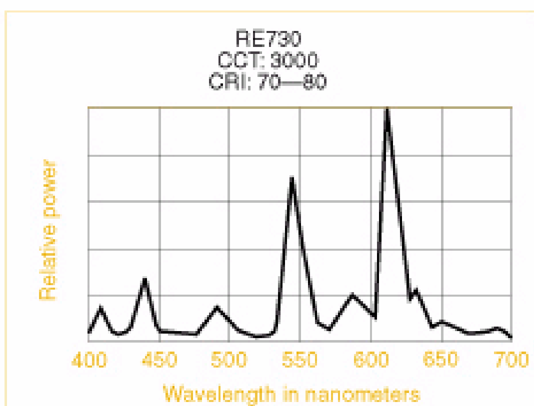

Figure 3: SPD of a light source.

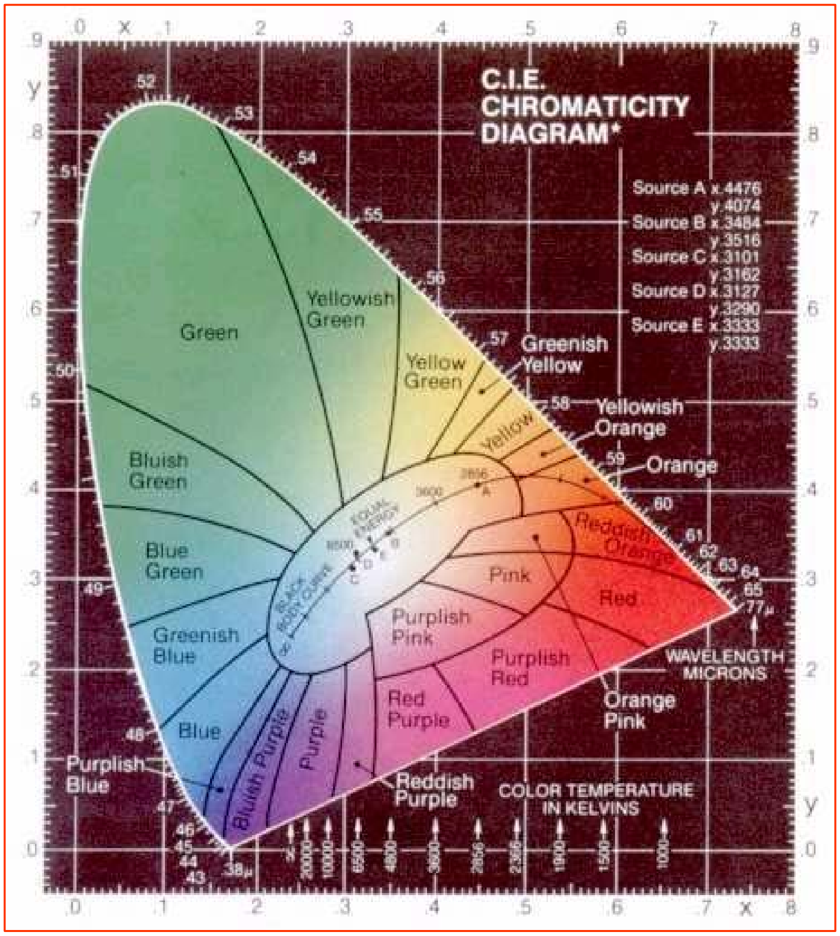

Figure 4: CIE chromaticity diagram.

For the past several years, researchers have conducted studies to better understand how the visual system perceives color differences. The majority of these studies involve color matching under controlled conditions. The most cited study is one conducted by MacAdam in 1942. A common way to communicate discriminability between light sources of different chromaticities is by the use of MacAdam ellipses. He collected thousands of side-by-side color matches to 25 reference light sources distributed throughout chromaticity space. The chromaticity of a fixed stimulus was located in a given straight line in the CIE chromaticity diagram. The standard deviations were calculated using the distance in the chromaticity diagram between the reference point and the variable stimulus. MacAdam's auxiliary experiments on just-noticeable color differences indicated that for the same observer the just-noticeable color difference between the test and the reference light sources are proportional to the corresponding standard deviations of color matching. The just-noticeable color difference was found to be about three times as large as the corresponding standard deviation (Wyszecki and Stiles 1982).

To simplify the data presentation, MacAdam chose to represent the entire set of data for a given reference light graphically by a common shape, ellipses, in chromaticity space. The orientations and sizes of the ellipses varied throughout chromaticity space. Thus, a MacAdam ellipse defines the two-dimensional "just-noticeable color differences" in chromaticity space.

The American National Standards Institute (ANSI) has incorporated the MacAdam ellipse in specifying the chromaticity tolerance for T8, T10, and T12 fluorescent lamps. According to ANSI all T8, T10, and T12 fluorescent lamps produced by manufacturers must be within a 4-step MacAdam ellipse centered on specific chromaticity coordinates (ANSI 1996). The specified coordinates and their associated CCTs are listed in Table 1.

Table 1: Chromaticity specifications from ANSI and IEC.

Lamp Type	x	y
2700 K *	0.463	0.420
3000 K / Warm white	0.440	0.403
3500 K / Warm	0.411	0.393
4100/4000 K / Cool white	0.380	0.380
5000 K	0.346	0.359
6500 K / Daylight	0.313	0.337

*Specification from IEC 60081

4.1.2 Methods

For the color measurements, lamp samples from 12 manufacturers in wattages ranging from 11 W to 29 W were studied. The chromaticity coordinates and CCTs for each product model number, five lamp samples each, were measured. Each of these lamps was seasoned at normal power for 100 hours prior to taking measurements. Figure 5 illustrates the resulting chromaticity coordinates plotted in CIE 1931 color space. CFLs within the shaded area in Figure 5 meet the ENERGY STAR requirements for CCT. Points outside the shaded area can also meet ENERGY STAR specifications if the CCT of these lamps is included on the packaging. The graph also shows two 4-step MacAdam ellipses centered at the chromaticity coordinates for 2700 K and 3000 K in Table 1. Lamps within the two 4-step MacAdam ellipses will meet industry standards for T8, T10, and T12 fluorescent lamps.

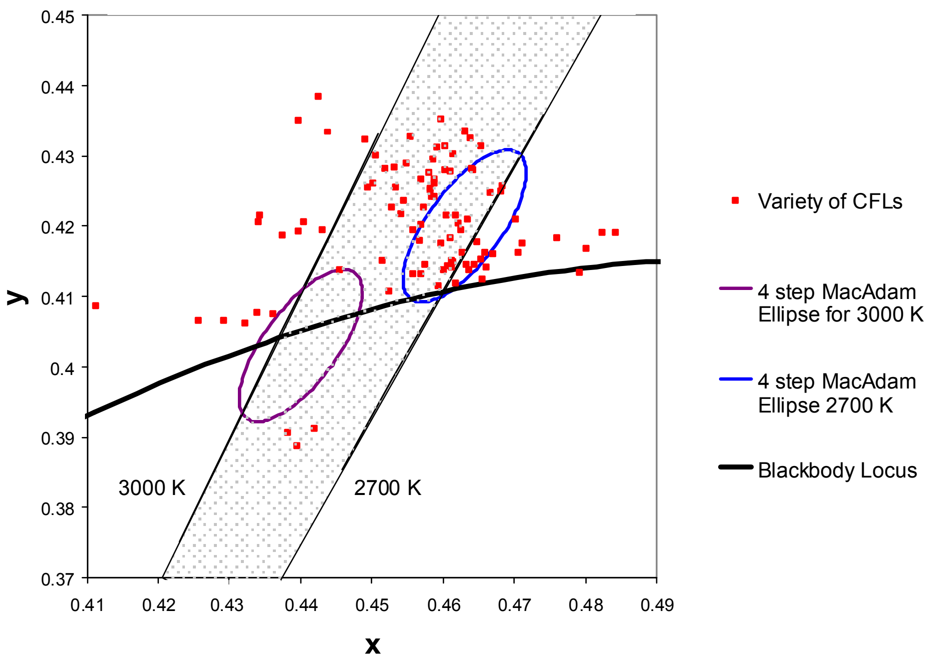

Figure 5: Chromaticity coordinates for some CFLs.

4.1.3 Results

Although these products are rated with a CCT of 2700 K, many of them have chromaticities outside the ENERGY STAR specification and the 2700 K 4-step MacAdam ellipse.

Variations in chromaticity were found to be not only between manufacturers, but often within a single product model number. Figure 6 illustrates the deviation in CCT found for the same lamp models used in Figure 5. Although some products do seem to have only a small variability, this is not necessarily predictive of perceived color consistency because lamps of equal CCT can have different chromaticities.

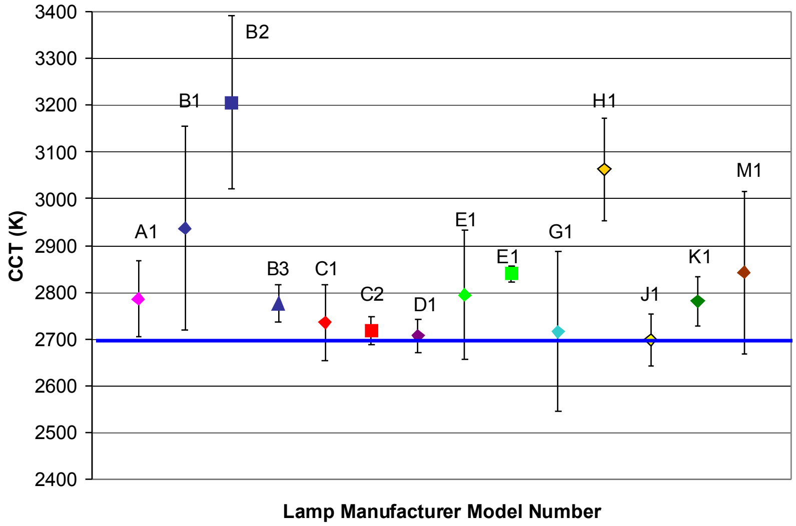

Figure 6: Mean and Standard Deviation of CCTs for 5 lamp samples of each model number. The dark blue line represents a CCT of 2700 K.

4.2 Warm-up Time

4.2.1 Background

ENERGY STAR defines CFL warm-up time (also called run-up time) as the time needed for the lamp to reach 80% of its stable light output after being switched on (ENERGY STAR 2002). Program guidelines for ENERGY STAR CFL manufacturing partners state that CFL warm-up time must be three minutes or less.

All CFL products utilize excited mercury to produce UV radiation, which in turn stimulates the phosphor coating inside the lamp to produce visible light. Light output from a CFL will vary significantly as a function of bulb temperature unless an amalgam is used in place of pure mercury. Thus, a CFL with amalgam will have a more consistent light output under hot and cold bulb conditions than a CFL without amalgam. Unfortunately, the use of amalgam in a CFL will significantly delay the time for the lamp to reach a stable light output. None of the lamps measured in this study incorporated amalgams.

4.2.2 Methods

LRC staff conducted limited measurements of warm-up time on twelve ENERGY STAR-brand CFLs. The lamp samples ranged in rated power from 14 W to 29 W. Five samples of each product model number were tested to obtain an average warm-up time for that model. The measurement system recorded light output and current every second after an initial 10 seconds until the lamp met stability criteria. Light output was determined as stable when it remained within 1% for 8 minutes. Once the light output was stable, photometric measurements were taken. After the photometric measurements were recorded, the light output was measured again to confirm continued stability.

4.2.3 Results

Table 2 shows the average warm-up times for each lamp model to reach 80% of stable light output and times to reach 100% stable light output. The average time for all lamps to reach 80% of stable light output was less than 23 seconds. The slowest warm-up time was 51 seconds, while four lamps reached 80% of stable light output in under 10 seconds. The average time for 100% stable operation was approximately 20 minutes. The longest and shortest times to 100% stable light output were 34 minutes and 13 minutes, respectively.

Table 2: Test Compact Fluorescent Lamp Warm-up Times

Lamp Manufacturer ID	Lamp Operating Power (seconds)	Warm-Up Time to 80% Stable Light Output (seconds)	Warm-up Time to 100% Stable Light Output (minutes)
A1	15	23	19
B1	11	<10	26
B2	15	<10	28
B3	3-way operating at 14 W	44	19
C1	Dimmable lamp at 29 W	51	23
C2	27	26	18
D1	15	23	14
E1	15	16	19
E2	25	<10	18
F1	20	<10	16
G1	15	33	24
H1	3-way operating at 26 W	17	34
J1	15	16	13
K1	15	19	22
L1	14	19	16
M1	23	29	18

4.3. Summary of Laboratory Measurements

The CFL color measurements show a wide variation in chromaticity, and thus, CCT, both between manufacturers and within manufacturers' own CFL product lines. Although CCT can often be found on CFL packaging labels, it is an ambiguous measurement because lamps can have equal CCTs but still be visibly different in color appearance.

The average warm-up time for the measured CFLs is approximately 20 seconds, well within the ENERGY STAR specifications.

5. Focus Group Study

5.1 Study Background and Methodology

The purpose of the focus group study was to learn consumers' opinions of CFLs and compare them to the previously identified barriers to acceptance in the marketplace. Objectives for the focus group study included:

- Understanding consumer knowledge and perceptions of CFLs.
- Documenting specific consumer experiences and reactions with a variety of CFL samples.
- Determining consumer recognition of performance differences between CFLs and incandescent lighting.
- Exploring basic lamp shopping habits and decision processes.
- Understanding consumer knowledge and perceptions of the ENERGY STAR program.

Four separate focus group studies of 10 to 12 participants each (44 total) were conducted July 15-16, 2003, in the New York Capital Region. All of the participants were required to be at least 25 years of age, have experience with CFLs, and have responsibility for paying utility bills and for purchasing lamps. Participants were divided into two categories: 1) those who had used, or currently are using, CFLs in their home and who are satisfied with the lamp's performance; and 2) those who have used CFLs in the past and were dissatisfied, or those who have knowledge of CFLs but have declined to purchase the lamps.

The focus group research was composed of two parts. The first part consisted of an in-home observation that allowed the participants to test and observe CFLs in their own homes for two weeks. The second part consisted of in-facility sessions with other participants and a facilitator. The in-facility sessions included a survey of participants' in-home experiences with the sample CFLs, general discussions about CFLs and lighting, and a demonstration of table lamps using several types of CFLs and an incandescent lamp.

5.2 In-home Observation

5.2.1 Background

For the in-home observation, participants were asked to install three CFL products in their own homes and to provide evaluations of the products through a questionnaire and through an additional in-facility survey and discussion.

5.2.2 Methods

Prior to the group meetings, each participant received three CFLs and was asked to install the lamps in his or her home. Two lamps were 20-watt products with slightly different chromaticities but noticeable differences in color appearance (Lamp A and Lamp B), and the third lamp was a 28-watt product with a slight delay in starting (Lamp C). All samples were ENERGY STAR products (Appendix A). LRC staff seasoned and photometrically measured each lamp sample prior to distribution. The photometry data includes light output, power, current, voltage, warm-up time, chromaticity coordinates, CCT, and Color Renditions Index (CRI). This data are shown in Table 3 and Figure 7.

Table 3: Focus group lamp photometry data

Measurement	Lamp A 20 watts	Lamp B 20 watts	Lamp C 28 watts
Light Output (lumens)	1164 ± 47	1060 ± 63	1476 ±49
Rated Light Output (lumens)	1200	1200	1600
Power (watts)	17.9 ± 0.25	17.8 ± 0.29	24.7 ± 0.37
Current (mAmps)	0.258 ± 0.003	0.275 ± 0.004	0.385 ± 0.005
Voltage (Volts)	120.0 ± 0.007	120.0 ± 0.007	120.0 ± 0.008
Warm-up Time (seconds)	<10	<10	<19
x	0.4534 ± 0.0047	0.4348 ± 0.0020	0.4361 ± 0.0041
y	0.4234 ± 0.0030	0.4128 ± 0.0011	0.4163 ± 0.0027
CCT (K)	2892 ± 59	3106 ± 29	3111 ± 53
CRI	80.3 ± 0.6	79.6 ± 0.5	76.6 ± 0.7

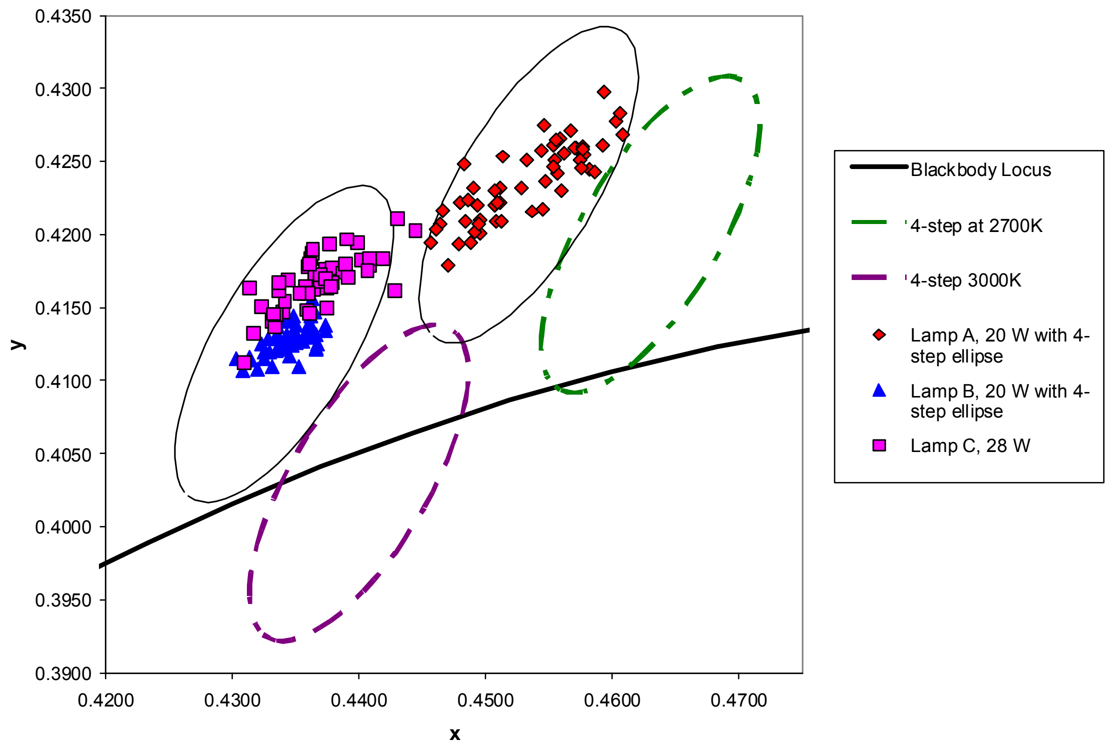

Figure 7: Focus group lamp chromaticity coordinates and associated 4-step MacAdam ellipses.

Participants were instructed to install the lamps indoors in rooms and fixtures they use regularly, and to use the 20-watt lamps in the same room at the same time (Appendix B). Participants were asked to use the lamps for at least two weeks.

Each participant also received a disposable camera and a log sheet questionnaire to document the type of fixture, the placement, and the environmental surroundings of the lamps. The log sheet questionnaire (Appendix C) asked:

- Was the brightness of the lamps satisfactory?
- Was the color of the lamps satisfactory?
- Do lamps A and B appear the same? If not, what is different?

Participants returned the cameras by mail to the LRC prior to the in-facility sessions, and returned the log sheets when they arrived at the session.

5.2.3 Results

Table 4 shows responses to the log sheet questionnaire completed as part of the in-home observation. The table is divided by the two participant groups. “Satisfied” are those participants who have used or currently are using CFLs and are satisfied their performance. “Unsatisfied” are those who have used CFLs in the past and rejected them, or those who have refused to purchase CFLs.

Table 4: Log sheet questionnaire results

Consumer Groups	Was the brightness of the lamps satisfactory?		Was the color of the lamps satisfactory?		Do lamps A and B appear the same?	
	Yes	No	Yes	No	Yes	No
Satisfied	77.8%	22.2%	60.0%	40.0%	21.1%	78.9%
Unsatisfied	66.7%	33.3%	57.1%	42.9%	44.4%	55.6%

The majority of the participants, both "satisfied" and "unsatisfied," were content with the brightness of the sample lamps. The color of the lamps, although different, also appeared to be satisfactory for most, but only by a small margin. Interestingly, when the participants were asked whether the two 20-watt lamps appeared the same, twice as many "unsatisfied" users compared with "satisfied" users thought they were the same. Still, most people did notice the difference, although some attributed the difference to brightness and not just color.

5.3 In-facility Sessions

5.3.1 Background

The in-facility session consisted of a survey of participants' in-home observations of the sample CFLs, general discussions about CFLs and lighting, and a demonstration of table lamps using several types of CFLs and an incandescent lamp. The survey was employed to gather specific data about participants' overall impressions of the CFL samples they tested at home. The purpose of the general discussions portion of the focus group was to learn more about consumers' perceptions of lighting and energy, their perceptions of the ENERGY STAR brand, their knowledge of CFLs and incandescent lamps, and their past experiences with CFLs. In the demonstration of the table lamps, participants were asked to rate and discuss their preferences for each lamp as a way of soliciting additional views on CFLs.

5.3.2 Survey Methods

Participants were asked to complete a written survey during the in-facility session about their in-home experiences with the CFLs. The survey asked participants to recall and rate their overall impressions of the CFL samples through questions about a number of lamp characteristics. The survey was given to the participants near the start of the focus group discussions (Appendix D).

5.3.3 Survey Results

In the survey, participants were asked to choose their top two most important lighting characteristics from the following:

- equivalent light output
- lighting color—warm
- lighting color—cool
- brightness
- start-up

- warm-up to full brightness
- replacement lamp fit
- appearance/looks.

The responses to this question are summarized in Figure 8.

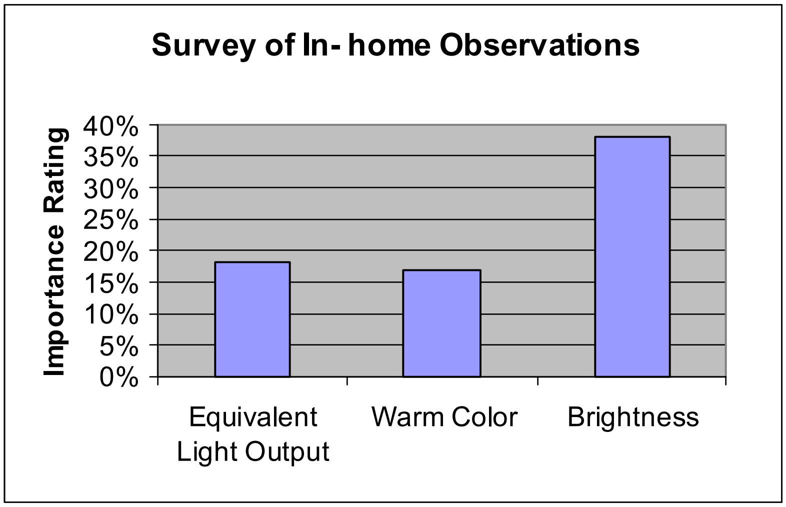

Figure 8: Consumer preferences of lighting characteristics.

As shown in Figure 8, the top lighting characteristic for the 44 participants was brightness. Brightness is defined by the amount of light produced by the lamp. Participants judged a lamp's brightness by a "readability" standard—that is, the ability to read under that lamp. Participant preferences for lighting brightness appeared to vary widely. Bright, white light was generally requested for kitchens, bathrooms, and for reading lights; softer light was desired in bedrooms and living rooms.

The second preferred lighting characteristic was equivalent light output. Equivalent light output can be defined as equaling the perceived light output of the incandescent lamp and the CFL. For example, if a user replaces a 100-watt incandescent lamp with a CFL rated as an equivalent replacement, is the light output perceived to be the same? The consumer may associate "equivalent light output" with whether the light output of the CFL is sufficiently comparable to the light output of the lamp it replaced.

Warm color proved to be the third preference by the participants. Opinions from those participants who noticed the color difference between the lamps were varied. Some had definite inclinations for one color over the other, and some did not like any of the colors. It is important to note here that the survey used the terms "warm" and "cool" to describe the lighting color, which may have not been clearly understood by the participants. The participants' lack of knowledge about these lighting terms was subsequently identified during the focus group discussion.

Figure 9 shows how the 44 participants rated their in-home experiences with the sample CFLs versus their expectations. Overall, the participants found that the lamps performed better than they expected in terms of equivalent light output and brightness—brightness being cited as the most important characteristic by participants, as stated above.

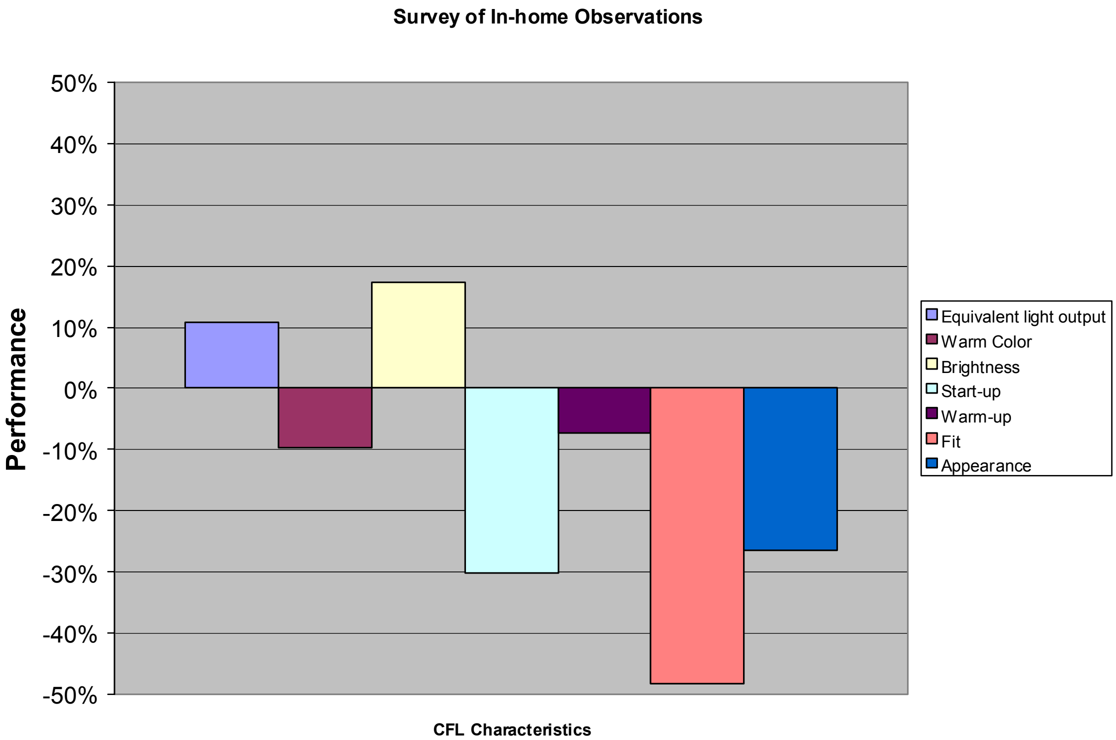

Figure 9: Consumer ratings of CFL performance versus expectation (n = 44).

However, participant preferences were not always based on better performance. One participant described the light from fluorescent lamps as "unfriendly." This phrase was appreciated by several participants as an explanation for their dislike of a lamp, despite good performance. The light output and brightness of the CFL might have been better than the incandescent lamp it replaced, but it was still a fluorescent lamp. Where participants rated CFL brightness as "satisfactory" or "better than expected," they said they did not necessarily prefer that level of brightness for the application of the CFL in their own homes.

Lamp fit was a significant problem for many, which created problems for some participants to use all the samples during the in-home test. Sometimes the length or width of the lamp was the problem, and other times the width of the ballast prevented the use of the lamp in the desired fixtures. Many had aesthetic concerns with lamps that were too long and protruded beyond the shades.

Start-up time was an issue for many people. According to the survey, 30% found that the CFL samples did not start-up as fast as they expected. Many consumers expect an instant start, as with an incandescent lamp. Any small delay may be annoying to them. Most of the participants did notice that the 28-watt lamp (Lamp C) had a slight delay in starting. Current ENERGY STAR specifications require a CFL to come on and stay on within one second.

Warm-up time and lamp appearance also appear to be disappointing characteristics of the lamps. Interestingly, very few people commented on warm-up time during the discussions, and some even expressed pleasant surprise at how fast the CFLs came on compared with previous experiences. It is likely that the subject was not brought up in the in-facility discussions because the participants were comparing the CFLs to older technologies. The appearance of the lamps—the overall looks—seems to be a problem. Again, aesthetic concerns may be an issue here. Some people just did not like the shape or thought CFLs looked "funny."

Some participants said they noticed the intended color variations among the CFLs during the in-home test. Overall, participants had strong opinions and preferences regarding the colors they saw, particularly with the "yellow" CFL. (One of the 20-watt samples appeared "yellow" and the other sample appeared more "white.") Participants were also aware that the lamp shade had an influence on color.

5.3.4 General Discussion Methods

A discussion outline was created using questions presented in a deliberate order (Appendix E). A focus group facilitator led off each question and probed for further information.

5.3.5 General Discussion Results

Participants were very familiar with the ENERGY STAR brand and considered ENERGY STAR ratings and labeling program to be credible. When participants were asked how they knew whether the product they were buying (lamps or other products) was energy-efficient, many referred to the ENERGY STAR label, without previous mention of the program by the group facilitator. Many said they looked for the ENERGY STAR label, especially on major appliances and replacement windows. When asked how they knew the information and promised savings stated by ENERGY STAR were reliable, most said they took the claims as true without further validation. Participants could not identify the sponsor of the ENERGY STAR program or make any link between the program and the EPA or DOE. Some said it was an independent program, others said it was run by product manufacturers, and a few noted that it was a government agency.

Participants showed good awareness of CFLs and their presence in retail stores. When asked what they knew about CFLs, participants responded most frequently that the lamps are "energy saving" and "long lasting." A few also noted a difference in look and shape, a variation in brightness, the expense and recent reduction in price, a delayed start-up, and a cool (thermal) temperature. Participants also stated that they believed the claims of performance, efficiency, and durability noted on the packaging were true. However, very few had actually read any of the information on the CFL packages. Although many packages list the energy savings and potential dollar savings of using a particular CFL, people were unaware of the information on the packages and even asked the facilitator what these values were. Consumers also were not familiar with terms often found on CFL packaging, such as

CCT. Consumers prefer to use terms such as “soft white” and “bright white” on package labels.

Participants were asked for reasons why they did or did not purchase CFLs prior to the focus group study. Purchasers cited a special price offer from the local utility, energy savings, longer life, and use in difficult-to-change areas. Non-purchasers and those who were dissatisfied with previous CFL purchases cited cost as a primary factor. Some also did not like the physical shape or the color of the light. Others expressed a general dislike for fluorescent lighting, as well as experiences with hesitation to come on, flicker, and poor fit of older versions. Few participants have been repeat purchasers, although some are still using CFLs that were obtained several years ago.

In general, participants understood how CFLs differ from incandescent lamps. When asked how long the average incandescent lamp lasts, the general opinion among participants was three months. The group consensus was that CFLs should last from two to four years. All of the participants were aware that CFLs last significantly longer, but they do not keep track of how long they last. Overall, lamp life is not a major concern for consumers. The life marking on the packaging does not mean much, especially since consumers do not pay attention to how long they use a lamp before replacing it. Some participants did comment that they had installed CFLs at least three years ago and they were still working. On the whole, participants did not feel that changing lamps on a regular basis was a chore, except in hard-to-reach places. Most keep a supply of incandescent lamps on hand.

Though many of the participants noted that energy savings and environmental concerns are important factors in their purchases, they do not consider these aspects when purchasing lamps for their homes. They believe that switching off lights will have a greater impact than will the choice of lamp. Most shoppers don’t spend time comparing lamp products and studying the packaging details other than to look for the wattage and color (“soft white” vs. “bright white”). Although the package contains valuable information, consumers do not read the packaging or notice the listed benefits. They tend to buy the same brands and wattages each time without much consideration, although they also say that they spend time customizing their homes’ lighting room by room. Most prefer three-way lamps wherever possible. At a higher initial cost, CFLs compete with the need for other household products, as well as with low-cost, predictable incandescent lamps.

5.3.6 Table Lamp Demonstration Methods

The table lamp demonstration consisted of two 15-watt CFLs of different colors, a three-way CFL with a very slow start-up and warm-up, and a 60-watt incandescent. Each of the four lamps was of a different shape: one color lamp was the shape of a “U” tube; the other color lamp was a spiral; the three-way was a square shape with the harp of the lamp going through the middle as opposed to around the lamp; and the incandescent was a standard A-lamp. The two lamps used for color differences were both 15 watts and of nearly equal CCT. The chromaticity coordinates fell on opposite sides of the blackbody line in x,y color space, causing one lamp to appear “greenish” and the other to appear “pinkish.” The chromaticity coordinates for the demonstration lamps are shown in Table 5. All lamps were installed in identical table luminaires with identical shades. Participants could not see what type of lamp was installed in each luminaire. Luminaires were turned on one at a time for discussion, and then all at once for comparison.

Table 5: Chromaticity and CCT of demonstration lamps

Lamp	x	y	CCT
15 W "Pink" CFL	0.4389	0.3893	2844 K
15 W "Green" CFL	0.4567	0.4259	2862 K
3-way CFL	0.4676	0.4226	2687 K
60 W Incandescent	0.4515	0.4095	2812 K

5.3.7 Table Lamp Demonstration Results

Participants were asked to rank the demonstration lamps in order of preference (first choice, second choice, etc.). Figure 10 illustrates the participants' preferred choices.

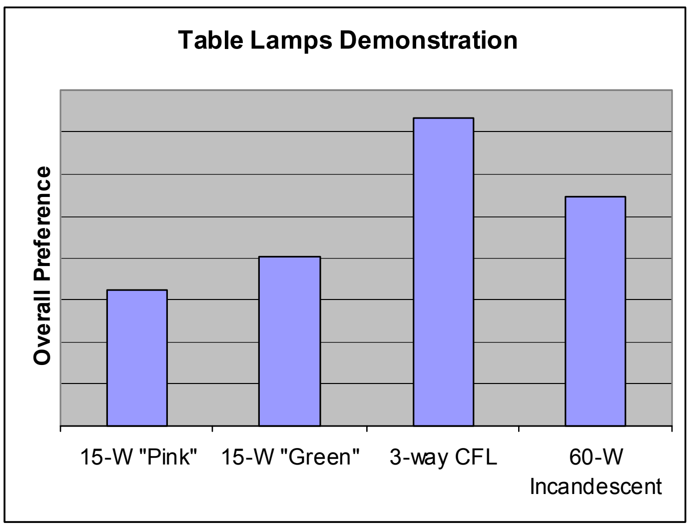

Figure 10: Participant ranking of first choice preference among the demonstration lamps.

Overall, the three-way CFL was the most preferred by a high margin (67% ranked it as their number-one favorite), though many found its start-up hesitation annoying. The color was acceptable to most, the light pattern on the wall was diffuse and without shadows, but the fact that the lamp was a three-way greatly interested people because most did not know that three-way CFLs existed. It is not clear, however, whether the majority chose this lamp as their favorite because it was a three-way or because of the lamp's color, light distribution, and performance characteristics.

The distant second choice favorite among the group was the incandescent lamp. Some considered it brighter while others considered it softer. Some noticed that it cast a green light. During the demonstration, all had assumed that the incandescent was another CFL and were surprised when the shades were removed to expose the bare lamps.

Finally, the "pink" and "green" CFLs scored quite low in preference, probably because of the unfavorable colors and shadows they cast.

During the comparison portion of the exercise, participants made the most comments about color differences. Differences in dispersion of light on the wall were also noticed. Overall, participants could not attribute appearance differences to lamp type (incandescent vs. CFL). This suggests that the group was not previously aware that incandescent lamps have varying colors, nor that a CFL can match or outperform an incandescent lamp's perceived pleasing color. Participants also expressed clear preferences and dislikes for one color or another, but they showed limited consistency. Again, their preferences were dependent on their application such as mood lighting or task lighting.

5.4 Summary of Focus Group Study

Overall, price, size, color consistency, start-up time, and perceptions of fluorescent technology appear to contribute to the consumer market's reluctance to purchase CFLs.

The lack of consumer education about CFLs and their advantages means that consumers will continue to focus on price, a key barrier to acceptance. Though participants in this study were well-aware of the lamps and their potential energy savings and long life, they did not perceive that there was a substantive value from potential energy savings. The focus group facilitator commented: "Sticker shock prevails at retail, and if people don't perceive a high value to the potential energy savings, then the high cost impression remains over the life of the bulb" (Dewine Marketing Resources 2003). Money savings is not a motivator because most homeowners are unaware of their homes' total lighting costs or how much of their electricity bill goes toward lighting. Most consumers believe simply turning lights off will make a bigger impact on energy bills than will the choice of lamp. Consumers require a compelling reason to switch to CFLs, and consumer education beyond what is printed on the packages is needed.

The size and shape of CFLs is a prominent barrier to consumer acceptance. Many of the focus group participants complained that the sample lamps they were given did not fit in the fixtures they had intended to use the lamps in.

Perception of color variations in CFLs also appears to be a major barrier to acceptance in the consumer market. Consumers have distinct color preferences, making predictability and consistency important. Participants expressed frustration with not knowing the color of the CFLs they considered for purchase. However, consumers are unaware of color differences or variations in incandescent lamps. To the consumer, an incandescent package labeled "bright white" will be the same color as the previously purchased "bright white" lamp. Although the preference for the color of the CFL is dependent on the application, consumers still require consistency when purchasing replacement lamps. The facilitator's report noted that "given the general distaste for certain CFL colors, it can be expected that people have an equal distaste for inconsistency in color within the same room" (Dewine Marketing Resources 2003). If consumers are not satisfied with the color of a newly purchased lamp, they will likely return it for a refund. If consumers run into difficulties with finding the right color lamp for their needs, they will not purchase that type of lamp again.

While not discussed in detail by the groups, the survey of the in-home observation revealed that start-up time is an issue. Most participants noted that the 28-watt lamp (Lamp C) did not start immediately. However, they commented on how much faster the lamps came on compared with their previous CFL experiences. Evidently, start-up and warm-up times could still be faster, according to consumer opinion.

Fluorescent technology as a whole has a negative connotation in the minds of many consumers, at least in terms of their usage in homes. Fluorescent lamps are associated with offices, big-box stores, and other buildings that do not conjure up feelings of comfort and home. The word "unfriendly" was mentioned several times as a description for fluorescent lighting.

On the positive side, lamp life and light output were rated favorably by focus group participants.

Lamp life did not appear to be an issue with most of the consumers, probably because many are unclear as to how long lamps last, both incandescent and fluorescent lamps. People tend to believe, however, that fluorescent lamps last longer than incandescent lamps.

Participants found the light output from the sample CFLs and the demonstration CFLs to be satisfactory overall.

6. Conclusions and Recommendations

At the beginning of this study, LRC researchers hypothesized that color, warm-up time, life, and light output were major factors in the consumer rejection of CFLs. Based on the measurements and the consumer research conducted during this project, the LRC found that while color and start-up time do act as barriers, the aspects of cost, size, and the perception of the technology itself were more important. Life and light output do not appear to play as much of a role in the acceptance or rejection of CFLs. On the whole, consumers feel that for the high initial cost CFLs should provide added performance, such as energy efficiency and longer life, without inconveniences, such as color inconsistency or poor fit. Others simply would not use fluorescent lamps in their homes.

Issues that appear to be key barriers to the acceptance of CFLs:

- Initial cost
- Size
- Color

- Start-up and, to a lesser extent, warm-up time
- "Fluorescent" technology itself

Issues that do not seem to be major barriers to the acceptance of CFLs:

- Life
- Light output equivalence (3:1 ratio is satisfactory)

Outlined below are recommended actions to reduce the barriers noted above. These actions include improving manufacturing standards, communication issues, and educational needs. As a trustworthy household name, ENERGY STAR has a perfect opportunity to implement a CFL consumer education program under its auspices. According to the focus group study report, an educational program would "raise the importance and urgency of home lighting as part of homeowners' energy management priorities," especially in light of the recent blackout in the Northeast and past power supply problems in California. However, the success of this program would depend on manufacturers' abilities to improve the performance issues raised by the focus group participants, such as size and color consistency.

Recommended actions

- **Initial cost**
  - Publicize the cost of lighting energy use in homes and the benefits of energy-efficient lamps

- **Size**
  - Investigate the best physical size for typical residential fixtures
  - Develop a new ENERGY STAR metric: Specify lamp and ballast dimensions

- **Color**
  - Need for greater precision in color specification
    - CCT is not a good metric
  - Communication needs to be simplified
    - Avoid using industry jargon
  - Develop a new ENERGY STAR metric: Establish more predictable ways to characterize and "communicate" color

- **Start-up**
  - Set consumer expectations to accept a one-second start-up time

- **Warm-up**
  - Current requirements for a maximum warm-up time of three minutes could be significantly shortened for non-amalgam lamps

- **Reduce "noise" in packaging**
  - Provide more useful information and less "noise" in the packaging to make it simple and predictable for consumers to buy a CFL

- **Find more effective ways to publicize the benefits of energy savings**
    - Provide more compelling arguments for the energy-savings benefits of CFLs. Even though a great amount of publicity is spent on energy savings of fluorescent lamps, consumers still prefer to turn off the lights instead of spending more money on an energy-efficient lamp.

7. Other Activities

Other activities that were undertaken in this contract include:

- Presentation of a seminar on color to EPA, DOE, and ICF Consulting
- Participation in activities to get industry "buy in" – LRC staff attended ENERGY STAR conference in Arizona, March 2003.
- Development of a document for industry with technical recommendations for revisions to ENERGY STAR program requirements for CFLs.

The second phase of this project (not included in this portion of the contract) will involve building industry consensus and "buy in" to the actions listed above. Proposed tasks for this second phase are:

- Work with industry to try to overcome performance and quality issues associated with CFLs
- Work with EPA and DOE to help them review ENERGY STAR performance specifications for lamps and fixtures. The revised performance specifications will incorporate solutions to the main issues identified through the focus groups, data analysis, limited data collection, and industry consensus.

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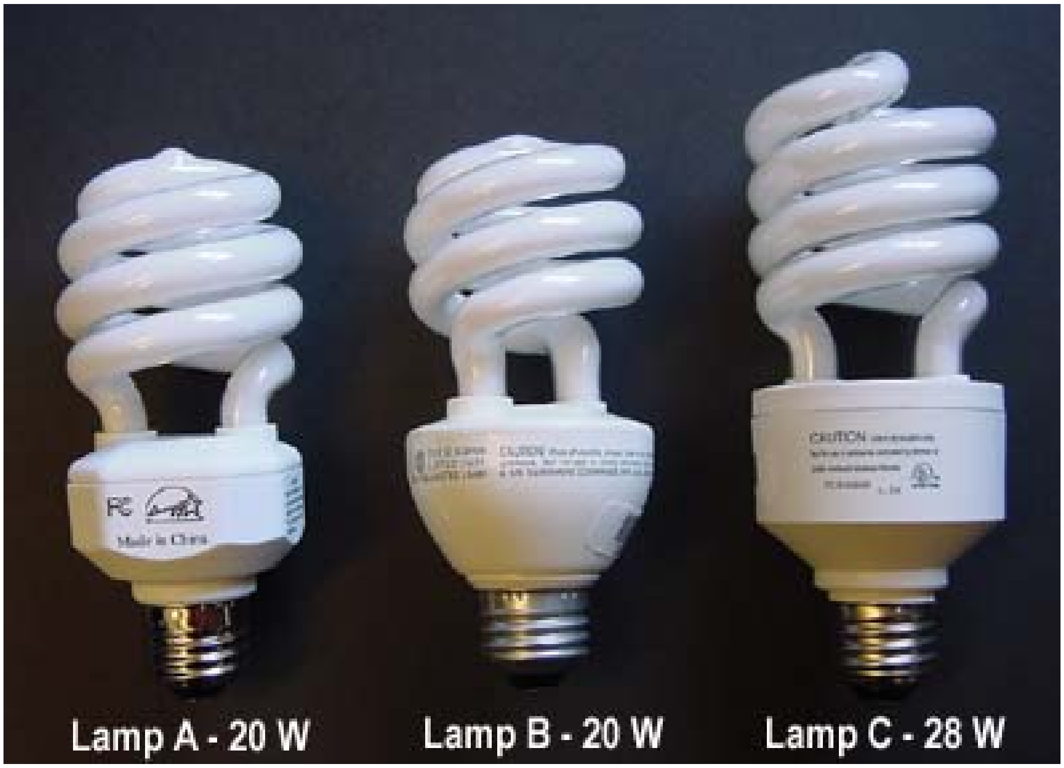
9. Appendices

Appendix A: In-home Observation of CFLs—CFL Samples Given to Participants



Dimensions (inches)	Lamp A	Lamp B	Lamp C
Total Height	5.25	5.25	6.25
Lamp Height	2.75	2.625	3.25
Lamp Width	2.5	2.375	2.5
Ballast Height	2.5	2.625	3
Ballast Width	2	2.375	2.5

Appendix B: In-home Observation of CFLs—Installation Instructions

Instructions for Lamp Study

What you have received:

- 3 Compact fluorescent lamps, each labeled with a bar code number*
- 1 Disposable camera also with a bar code number
- 1 Mail envelope to mail the camera back for film developing
- 1 Light Bulb Log Sheet including a sample

*The bar code numbers are for lamp identification only, and will not be used for participant identification. Please DO NOT REMOVE the labels from the products.

What to do with the lamps

- **These light bulbs are replacements for screwbase incandescent light bulbs.**
- Unplug the lamp fixture from the wall plug before removing or installing any light bulb.
- When installing the compact fluorescent lamp, do not handle the glass tubing of the lamp to avoid possible breakage of the glass. Screw the light bulb in using the plastic base.
    - They can be used on 3-way lamps, but will only work at one setting.
    - Typical uses are in table lamps, floor lamps, and desk lamps. Please DO NOT USE these lamps in fixtures that require the use of ladder to change the light bulb (such as ceiling or suspended fixtures).
    - The Sylvania and the Lightwiz lamps are rated to be equivalent to 75 watt incandescent lamps. The Westinghouse product is rated to be equivalent to a 100-watt incandescent lamp.
- These light bulbs must be used **indoors** and in fixtures that are **not controlled by timers or photo sensors.**
- Please place these light bulbs in rooms and fixtures where they will get used regularly.
- Place at least 2 of the light bulbs in the same room at the same time. Please use the Sylvania light bulb and the Harmony Lightwiz light bulb in the same room. You may move one or both of these to another location after at least 1 week of testing if you desire.
- **Please test the light bulbs for at least 2 weeks.**
- The light bulbs are yours to keep.

What to do with the cameras

- Take pictures of each of the fixtures you will be using for these lamps with the disposable camera provided.
    - **Mail the camera back to the Lighting Research Center in the postage paid envelope provided in your pack.**
    - **We would appreciate receiving the cameras before July 7, 2003.**
    - **Instructions for using the camera are on the camera.**

What to do with the Light Bulb Log Sheet

- Make observations about the lamps after dark.
- Fill in the Light Bulb Log Sheet when you install the light bulbs.

- Fill the second table if you move the light bulbs from one fixture to another, even if it is in the same room. Be sure to write down the lamp bar code numbers.
- Answer the questions at the bottom of the Light Bulb Log Sheet before attending the focus group discussion.
- **Please bring the Light Bulb Log Sheet to focus group discussions.**

If you have any questions or problems with these lamps, please contact Pat Whalen at 383-1661.

Appendix C: In-home Observation of CFLs—Log Sheet Questionnaire

Light Bulb Log Sheet

Date light bulbs are installed: ________________
Camera bar code number: ___________________

Room:		**Room:**
Light bulb bar code number: _______	**Light bulb bar code number:** _______	**Light bulb bar code number:** _______
Fixture description ____**Table Lamp** ____**Floor Lamp** ____**Desk Lamp** ____**Other** _________ **Shade Color**_________	**Fixture description** ____**Table Lamp** ____**Floor Lamp** ____**Desk Lamp** ____**Other** _________ **Shade Color**_________	**Fixture description** ____**Table Lamp** ____**Floor Lamp** ____**Desk Lamp** ____**Other** _________ **Shade Color**_________
Wattage of light bulb replaced:	**Wattage of light bulb replaced:**	**Wattage of light bulb replaced:**

If you have moved the bulbs from one fixture or room to another, please fill out the next table.

Room:		**Room:**
Light bulb bar code number: _______	**Light bulb bar code number:** _______	**Light bulb bar code number:** _______
Fixture description ____**Table Lamp** ____**Floor Lamp** ____**Desk Lamp** ____**Other** _________ **Shade Color**_________	**Fixture description** ____**Table Lamp** ____**Floor Lamp** ____**Desk Lamp** ____**Other** _________ **Shade Color**_________	**Fixture description** ____**Table Lamp** ____**Floor Lamp** ____**Desk Lamp** ____**Other** _________ **Shade Color**_________
Wattage of light bulb replaced:	**Wattage of light bulb replaced:**	**Wattage of light bulb replaced:**

Please answer the following questions after using the light bulbs.

1. For the two lamps used in the same room, do they appear to be the same?
2. If they do not appear the same, what is different about them?
3. Was the brightness of the bulbs satisfactory?
4. Was the color of each of the bulbs satisfactory?

Comments:

Appendix D: In-facility Sessions—Survey

CFL Bulb Performance

	Satisfactory	Better	Not As Well	Didn't Notice
Equivalent Light Output	[ ]	[ ]	[ ]	[ ]
Lighting Color				
Warm	[ ]	[ ]	[ ]	[ ]
Cool	[ ]	[ ]	[ ]	[ ]
Brightness	[ ]	[ ]	[ ]	[ ]
Start-Up	[ ]	[ ]	[ ]	[ ]
Warm-Up to Full Output	[ ]	[ ]	[ ]	[ ]
Replacement Bulb Fit	[ ]	[ ]	[ ]	[ ]
Appearance/looks	[ ]	[ ]	[ ]	[ ]
Daytime	[ ]	[ ]	[ ]	[ ]
Nighttime	[ ]	[ ]	[ ]	[ ]
Other ______________ (please indicate reason)	[ ]	[ ]	[ ]	[ ]
Other ______________ (please indicate reason)	[ ]	[ ]	[ ]	[ ]

Please also CIRCLE the two lighting factors that are most important to you.

Appendix E: In-facility Sessions—Discussion Questions and Outline

Introduction

Thanks for attending – we appreciate your time.
I'm a researcher – not an employee of the sponsor.

Role to moderate discussion – not to defend any position – understand your comments and write a summary report.

Tonight we're here to discuss Compact Fluorescent Lighting – I'll probably call those bulbs CFLs during most of tonight's discussion -- you already started the project a couple of weeks ago when we delivered the CFL bulbs to your home.

My job is to keep the discussion on track and be sure we cover the discussion outline in our limited time – we have a lot to cover. So, we'll try to move quickly.

My questions will focus on your experiences and perceptions with the bulbs and their performance. We are not going to talk about light bulb brands – that's not important to our research project.

"Rules of Engagement"/Etiquette
Relax / informal discussion
Need everyone's participation -- you're a diverse group
Be candid and open
One discussion at a time
(pls. avoid interruptions, side conversations, asking other participants questions)
Speak up for mike and video – for my report reference
Colleagues behind the glass taking my notes
Cell phones/pagers

Start by introducing yourselves …
Name, your occupation
Describe your home and its lighting
What % of your electric bill is for lighting?

- ❑ How many of you … (show of hands)
  - ❑ Pay your household's electric bill?
  - ❑ Buy the light bulbs for your household?
  - ❑ Do both?

- ❑ How many of you make purchases with energy savings or environmental concerns high on your list of important product features?

- ❑ What do we know about Compact Fluorescent Lighting … CFLs? What's different about those bulbs?

- ❑ Before <u>we</u> gave you the CFL bulbs, why did you originally purchase compact fluorescent light bulbs?
  Expectations …
  - Energy efficiency/savings
  - Environmental concern
  - Longer bulb life
  - Better lighting
  - Curiosity/experiment
  - Energy Star® label
  - Other ____________

- ❑ Who recognizes the Energy Star® label? (show of hands)
  What do we know about the Energy Star rating system?
  What Energy Star rated products do you have in your home?
  Does an Energy Star rating influence what you buy?

- ❑ Where did you use the CFL bulbs you previously bought?

- Living room	- Family room	- Bathroom
- Bedroom	- Kitchen	- Dining room
- Table lamp	- Wall fixture	- Nightstand lamp
- Floor lamp	- Desk lamp	- Ceiling fixture

- ❑ Let me ask you to summarize your experiences with the CFL bulbs <u>you</u> had previously purchased?
  - What did you notice?
  - How were they different from the incandescent bulbs?
  - Will you buy again?

- ❑ Did you use the bulbs <u>we provided</u> as we requested?
  - Replaced equivalent wattage incandescent bulbs?
  - In regularly used indoor home areas? No timers?
  - Moved between different lamps/fixtures?
  - Daytime and nighttime?
  - Sent photos? Brought your log sheets with you?

- ❑ Let me ask each of you to briefly summarize your experiences with the CFL bulbs we provided?
  - Where did you use them?

- Living room	- Family room	- Bathroom
- Bedroom	- Kitchen	- Dining room
- Table lamp	- Wall fixture	- Nightstand lamp
- Floor lamp	- Desk lamp	- Ceiling fixture

WORKSHEET

❑ Now I'd like each of you to rate your experiences with
the bulbs we provided in more detail on this worksheet …

Use the check boxes to tell me if you think the CFLs performed as you expected ….

Hand out and Completion of Survey
FLIP CHART -- Drill deeper/poll group in open discussion to probe/understand respondent rationales for likes/dislikes

- Did the two lamps in the same room appear to be the same?
  If not, what was different about them?
  - What did you notice?
  - How were they different from the incandescent bulbs?

❑ What "color" should lighting be?
- White - Yellow/Off-white - Pink - Blue

❑ Let's use the lamps we have here to talk about what you like or don't like about CFL bulbs?

4 lamps – one each fitted with a "pink" CFL, a "yellow" CFL, a slow starter, an incandescent bulb. Turn on two at a time for comparisons and to gauge
acceptance for color and warm-up. Turn on-and-off in response to group's discussion – with and without overhead lights on.

Observe reactions and probe how group perceives the differences for each set.

	The Same	**Better**	**Not As Well**	**Didn't Notice**
Equivalent Light Output	[ ]	[ ]	[ ]	[ ]
Lighting Color				
Warm	[ ]	[ ]	[ ]	[ ]
Cool	[ ]	[ ]	[ ]	[ ]
Brightness	[ ]	[ ]	[ ]	[ ]
Start-Up/Warm up	[ ]	[ ]	[ ]	[ ]
Appearance/looks	[ ]	[ ]	[ ]	[ ]
Sound	[ ]	[ ]	[ ]	[ ]
Flicker	[ ]	[ ]	[ ]	[ ]
Fit	[ ]	[ ]	[ ]	[ ]
Other _______________ (please indicate reason)	[ ]	[ ]	[ ]	[ ]
Other _______________ (please indicate reason)	[ ]	[ ]	[ ]	[ ]

- ❑ Do you know how long your average, traditional incandescent bulbs last?

  - Hours? Months? Years?

- ❑ How long do you think a compact fluorescent bulb should last?
  How do you know or measure if you are getting good or acceptable performance and value from your bulbs?

- ❑ Have you read the packaging for CFL bulbs?
  Probe understanding of terminology …
  CCT – Color Correlated Temperature
  Wattage equivalents
  Lumens

- ❑ Are you likely to purchase a CFL bulb in the future?

  Yes? Why? No? Why?

- ❑ Thanks for your help
  - Please leave your worksheets
  - Pick up the token of our thanks at the desk