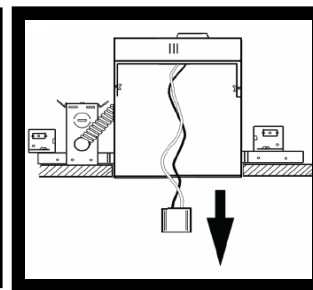
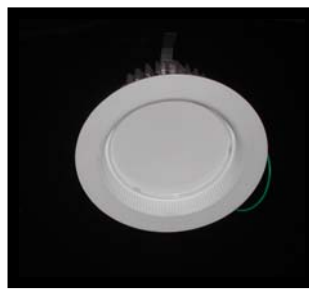
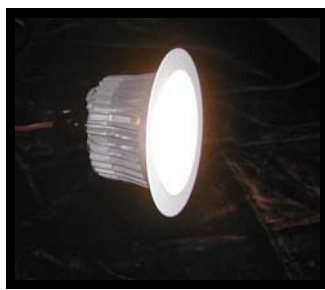


Customer Advanced Technologies Program Technology Evaluation Report



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December 29, 2008

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About the Customer Advanced Technologies Program

SMUD's Customer Advanced Technologies (C.A.T.) program works with customers to encourage the use and evaluation of new or underutilized technologies. The program provides funding for customers in exchange for monitoring rights. Completed demonstration projects include lighting technologies, light emitting diodes (LEDs), indirect/direct evaporative cooling, non-chemical water treatment systems and a wide variety of other technologies.

For more program information, please visit: <http://www.smud.org/education-safety/cat.html>.

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Executive Summary

America has been invaded! Not by Martians, killer bees or the Beatles, this time it is recessed downlights. According to the U.S. Department of Energy (DOE), there are currently over 500 million energy-guzzling recessed downlights installed in U.S. homes. Although recessed downlights provide a clean look and good optical control, most of them waste a lot of energy.

In 2007 LED Lighting Fixtures Inc. (LLF) introduced the LR6 LED module (Figure 1). The LR6 is designed to be an easy retrofit for recessed downlights with incandescent lamps or screw in compact fluorescent lamps. The LR6 delivers a warm, pleasant-looking white light at 54 lumens per watt – more than twice the efficacy of incandescent lamps. It has won several awards including Lighting for Tomorrow's 2007 award for recessed lighting. Since then LLF Inc. has been acquired by Cree Inc. – a major U.S. based LED manufacturer. During 2008 SMUD conducted a research project with thirteen residential customers to test the LR6. Research objectives included:

- Calculate potential energy and cost savings.
- Find out why customers wanted to replace their original lighting systems.
- Determine whether or not customers were able to install the LR6 without hiring an electrical contractor.
- Assess customer satisfaction levels.
- Determine how much customers were willing to pay for the LED downlights.
- Obtain pre and post retrofit illumination measurements.
- Develop and implement a SMUD rebate program if the results of the research project were favorable.



Figure 1: Cree's LR6 LED module is designed as an easy retrofit for incandescent recessed downlights. Source: Cree Inc.

Project Results

- ✓ The LR6 provided higher illumination levels than incandescent lamps and comparable or better levels than compact fluorescent fixtures.
- ✓ Customers who replaced incandescent lamps were able to complete the work without hiring an electrician. Most customers who replaced linear and hard-wired compact fluorescent fixtures hired electrical contractors to complete the work.
- ✓ The top three reasons customers gave for replacing their existing lighting systems were (1) reduce electric bill (2) desire to be "green" or energy efficient, and (3) dissatisfaction with their existing lighting systems.

- ✓ Most of the surveyed customers said they were willing to pay between \$20 and \$40 for LED downlights. Since the current retail price for the LR6 is hovering near \$95, it may face a considerable challenge attaining widespread adoption in the residential market; it is unlikely that most customers are willing to throw a “\$100 light bulb” in their cart while shopping. Unless the cost is reduced considerably, the LR6 will most likely be limited to customers who are remodeling or building new homes. They may also be attractive for residential and commercial customers who have longer hours of use.
- ✓ Overall, customers were very satisfied with the lighting quality provided by the LR6 but experienced some issues and dissatisfaction related to dimming.
- ✓ Compared to 65-Watt BR30 incandescent lamps, the LR6 reduced energy consumption by 82% (approximately 58 kWh per fixture per year). SMUD’s residential customers will save around \$8.70 per year per fixture (average energy rate of \$0.15 per kWh).
- ✓ SMUD is currently working on developing a rebate program for LED downlights.

Introduction

According to a recent report by the U.S. Department of Energy, there are more than 500 million recessed downlights installed in U.S. homes and the number is growing rapidly. In fact, more than 20 million recessed downlights (a.k.a. can lights) are sold in the United States every year¹. Although can lights were originally intended for directional lighting, they have quickly become the lighting system of choice for kitchens, hallways and bathrooms.

Many builders and homeowners choose recessed downlights with incandescent lamps because they are relatively inexpensive, dimmable and provide a sleek architectural look. This is especially true for large custom-built homes. According to the California Lighting Technology Center (CLTC), some larger homes have more than forty can lights² (Figure 2).

In 2005, California implemented tough new energy standards that included lighting efficacy standards for kitchens. This essentially created a new market for residential downlights with compact fluorescent lamps³. However, when given a choice many homebuilders and homeowners still seem to prefer incandescent lamps because they are relatively inexpensive to buy, easy to dim and produce warm pleasant-looking light.

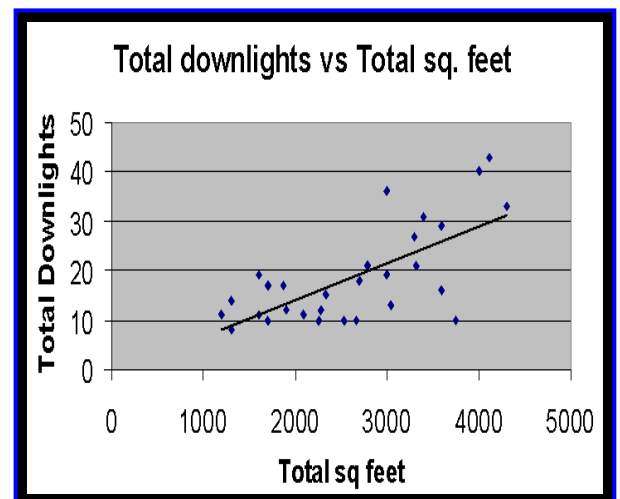


Figure 2: Recently, recessed downlights have become a very popular choice for homebuilders. Some larger homes feature more than forty recessed downlights.
Source: California Lighting Technology Center

¹ “Demonstration Assessment of Light –Emitting Diode (LED) Residential downlights and Undercabinet Lights”; U.S. DOE Solid State Lighting Technology GATEWAY Program

² “Energy Efficient Downlights for California Kitchens” CLTC presentation. March 2004

³ For more information, please download the report “The California Kitchen Lighting System” via SMUD’s website www.smud.org/en/education-safety/Pages/cat.aspx.

The main problem with recessed downlights is that much of the light produced by the lamp is trapped within the fixture and converted to heat. This is especially true for incandescent type "A" lamps as well as many compact fluorescent lamps which emit light in virtually all directions. In fact, depending on the type of lamp and fixture trim used, the amount of wasted light in recessed downlights may be 50% or more. This is a key factor in understanding why LEDs make a lot of sense for can lights. Since the light produced by LEDs is very directional, they have a considerable advantage over other light sources for applications such as recessed downlights.

In the past few years, many LED products have emerged in the market place. Some of these products look very promising while others may not meet the expectations of customers. In other words, there is a lot of junk out there! During 2008 SMUD completed a research project to test a new product designed for recessed downlights: Cree's LR6. The project included thirteen residential customers and focused primarily upon their experiences with the LR6 as well as their overall satisfaction levels. Although thirteen customers are not enough to make accurate statistical predictions about the market, the project did provide some key insights regarding the LR6 and customer expectations.

This report focuses on the potential benefits and valuable lessons learned about using LED lighting for residential downlights. For more detailed information about how LEDs actually work, please download SMUD's 2003 report entitled: "Light Emitting Diode (LED) Lighting Systems" from the Customer Advanced Technologies Web page: www.smud.org/en/education-safety/Pages/cat.aspx.

Technology Overview

Cree's LR6 LED module combines the LEDs, power supply, trim and lens into one package. Most likely, the first thing you will notice about the LR6 is the rather large metal housing. The purpose of the housing is to keep the LEDs cool. This is extremely important since the useful life of an LED is directly related to temperature. Simply put: LEDs hate heat. Recessed cans, especially in residential applications, represent a very challenging environment for LEDs, so an effective thermal management system is absolutely essential. LED products with inadequate thermal management will suffer from poor performance and premature failures. Since all products are not created equal, consumers must be very careful when choosing products.

The LR6 is designed to be an easy retrofit for recessed downlights with incandescent or screw-in compact fluorescent lamps (Figure 3). Although installing the LR6 involves more than just simply screwing it into a socket, many homeowners should be able to replace their incandescent lamps without hiring an electrical contractor (more on this later). The LR6 fits many, but not all, recessed can fixture housings and is dimmable down to about 20%. Fortunately, Cree maintains a list of compatible recessed cans and dimmers on their website: <http://www.creell.com/>.

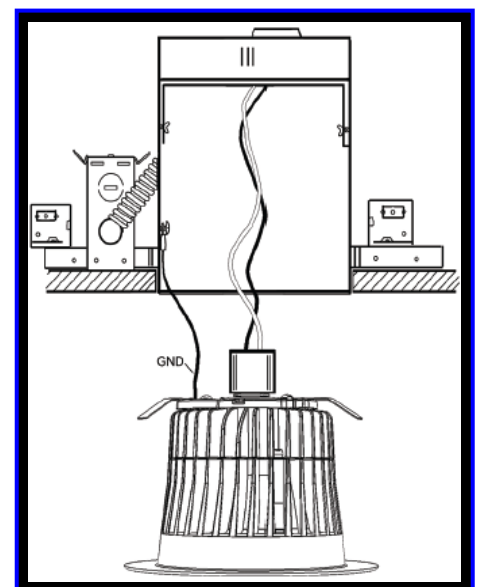


Figure 3: The LR6 LED module is designed to be an easy retrofit for recessed downlights with incandescent or screw-in compact fluorescent lamps.

What makes the LR6 unique is the method in which it produces white light. By combining red and unsaturated yellow LEDs (Figure 4), the LR6 is able to deliver a warm, pleasant appearing light. The output of each LED is regulated via a patented control system which maintains a consistent appearance. According to a recent survey, the appearance of a lamp is very important. In fact, 78% of surveyed consumers who do not purchase compact fluorescent lamps (CFLs) cited the appearance of the light produced by CFLs as one of their main objections.

The LR6 delivers light at 54 lumens per watt (lm/W) – more than twice the efficacy of incandescent lamps. But there is more to the story than the efficacy of the light source: after all many CFLs offer the same efficacy. Why then is it possible to replace a 26 Watt CFL with an 11-Watt LR6 and obtain the same amount of light? The answer to this question can be found by looking at what is known as *system efficacy*.

Since incandescent and compact fluorescent lamps are used in a variety of fixtures, current industry practice is to measure the light output for lamps in an open air environment. For example, the CFL shown below (Figure 5) is rated at 50 lm/W. The problem with using this method is that it does not take into account the fixture (a.k.a. luminaire) losses which may be up to 50% (or even higher in some extreme cases). In this example the system efficacy (delivered light) of the CFL fixture is only 25 lm/W, compared to the LR6 at 54 lm/W.

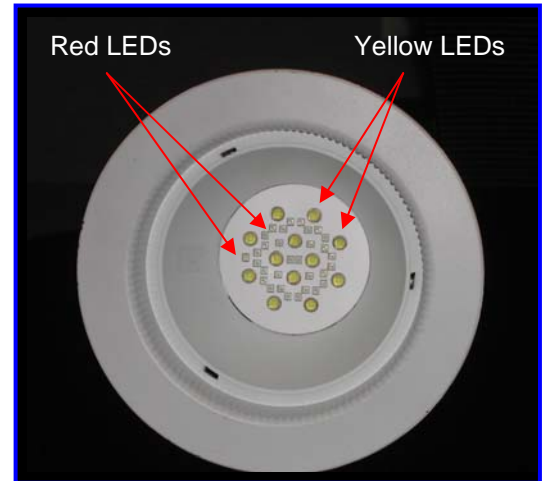
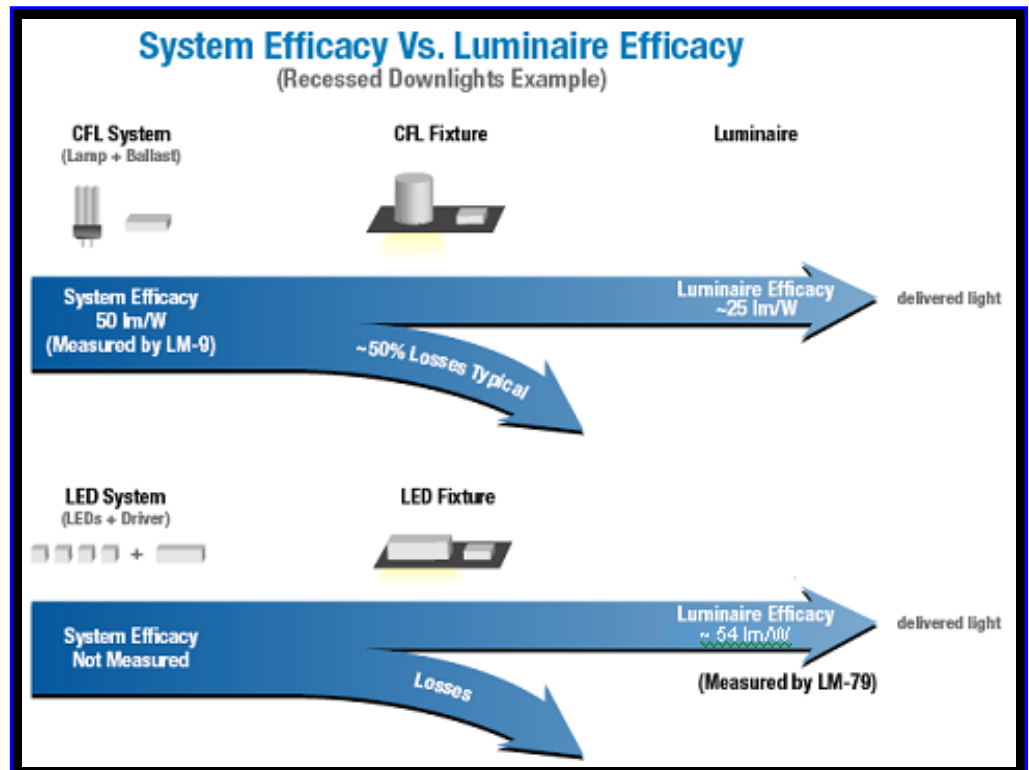


Figure 4: The LR6 uses a combination of red and unsaturated yellow LEDs to produce warm, high-quality light. The output of the LEDs is balanced via patented controls to maintain consistent color and appearance.

Figure 5: When comparing LEDs to other types of lighting systems, it is important to look at the total system efficacy – not just the efficacy of the light source (e.g. CFL). Since the CFL fixture shown in this illustration has losses of 50%, the amount of delivered light is only half of the light produced by the lamp. Because LEDs are highly directional, they may be ideal for applications such as recessed downlights. Source: U.S. Department of Energy.



The Department of Energy (DOE) is using the system efficacy method for evaluating LED fixtures. Unfortunately, since most other types of lighting systems are typically not evaluated in this manner, it can be a little challenging to compare LEDs to other systems.

Based on technical data and laboratory tests conducted by DOE, the LR6 seemed to be a good candidate for replacing incandescent lamps in residential downlight applications. But how would homeowners react to the LR6? Would they be able to install the LR6 themselves or would they need to hire an electrical contractor? To answer these questions, SMUD decided to conduct a field demonstration project.

Field Demonstration Project

Background

During the first half of 2008, SMUD conducted a research project with thirteen residential customers. The main focus of the project was to observe homeowners' experiences with the LR6 as well as their overall satisfaction levels. Since the LR6 is sold as a replacement lamp, SMUD deliberately provided very little technical support. Participants in the study were directed to Cree's website for questions regarding fixture and dimmer compatibility.

The project consisted of two main objectives:

1. Obtain feedback from homeowners regarding the reasons why they chose to replace their existing systems, ease of installing the LR6 and their overall satisfaction levels. To accomplish this objective, all participants were asked to complete a survey. The results of the survey are included as an appendix within this report.
2. Obtain pre and post retrofit illumination measurements and other information needed to determine the technical viability and potential energy savings.

Key Findings

Existing Systems: Homeowners replaced a variety of systems including incandescent lamps, compact fluorescents and 4 ft. fluorescent fixtures. The most popular reasons given for replacing their existing lights were:

- Reduce my electric bill
- Desire to be "green" or energy efficient
- Do not like my existing lights

The first two reasons are not very surprising, after all, who doesn't want to have lower bills and help the environment? What was very interesting is that many homeowners did not like their existing lighting system. Homeowners who replaced incandescent lamps really liked the fact that the LR6 fixtures produce a lot less heat and last longer. Those who replaced compact fluorescent lamps stated that dimming and reliability were important to them. Finally, some

homeowners who replaced 4 ft. fluorescent fixtures had old-fashioned, surface-mounted, wooden light boxes (Figure 6). These systems tend to create deep shadows and make the room feel much smaller. One homeowner said that their old lights made them feel like they were “living in a cave.”

Lessons Learned

This project provided the following insights regarding the LR6:

- Homeowners who replaced incandescent and screw-in compact fluorescent lamps said the LR6 was “easy” or “somewhat easy” to install and did not have to hire an electrician. The only ‘tricky part’ was properly connecting the grounding wire.
- Homeowners that replaced 4 ft. linear fluorescent and hardwired CFL fixtures generally hired electrical contractors to complete the work.
- Homeowners who replaced surface-mounted, wooden, fluorescent light boxes with the LR6 experienced dramatic improvements in lighting quality as well as significant energy savings (Figure 7).
- Almost all homeowners in the study rated the quality of the light provided by the LR6 as “excellent” but expressed some disappointment with the dimming. Originally the product literature for the LR6 simply stated the LED modules were dimmable. In reality the LR6 only dims to about 20% of full output before shutting off. Some homeowners felt that the manufacturer should have stated this fact more clearly. Fortunately Cree has updated the information on their website and product literature.
- Compatible dimmers were not very easy to find; some customers had to special order dimmers through electrical wholesale companies. Fortunately, Cree has plans to expand the number of compatible dimmers in the near future.
- When homeowners were asked the **highest** amount they were willing to pay for the LR6, most indicated between \$20 and \$40 per fixture. However, several customers said that they would be willing to pay more if they were convinced that the LR6 would really last more than ten years, and the dimming was improved.



Figure 6: Most customers who replaced 4 ft. fluorescent fixtures had old-fashioned, surface-mounted, wooden light boxes. These systems tend to create shadows and make the room feel much smaller.



Figure 7: Customers who replaced surface-mounted, wooden, fluorescent light boxes with the LR6 experienced dramatic improvements in lighting quality as well as significant energy savings.

Unfortunately, there is a huge gap between \$40 and the current price of \$95. Even with utility rebates, the LR6 will likely face an uphill battle achieving widespread acceptance as a replacement lamp in the residential market – it is simply too expensive for most customers. The LR6 may be more suitable for home remodeling, new home construction and commercial/institutional installations.

- The LR6 provided more light than all of the original lighting systems and most of the thirteen homeowners were very pleased with the quality and amount of light. Eleven of the thirteen participants said they would recommend the LR6 to a friend but still expressed concerns about the cost.

Energy and Cost Savings Potential

As mentioned earlier in this report, participants in this project replaced a variety of lighting systems with the LR6. Consequently the energy savings for each project varied significantly (Figure 8). However, it is interesting to note that the LR6 retrofit resulted in energy savings for all thirteen sites – even when replacing compact and linear fluorescent systems. One customer reduced their lighting energy consumption by an impressive 88%!

Site #	Old Lighting System			New Lighting System			Savings	
	Type	# Fixtures	Total wattage	Type	# Fixtures	Total wattage	kW	% reduction
1	26W CFL	6	156	LR6	6	72	0.084	54%
2	26W CFL	6	156	LR6	6	72	0.084	54%
3	100W INC	4	400	LR6	4	48	0.352	88%
4	75W INC	7	525	LR6	7	84	0.441	84%
5	26W CFL	9	234	LR6	9	108	0.126	54%
6	2-lamp F40T12	2	184	LR6	4	48	0.136	74%
7	65W INC	6	390	LR6	6	72	0.318	82%
8	50W Halogen	4	200	LR6	4	48	0.152	76%
9	18W CFL	9	162	LR6	9	108	0.054	33%
10	75W INC	8	600	LR6	8	96	0.504	84%
11	2-lamp F40T12	2	184	LR6	6	72	0.112	61%
12	2-lamp F40T12	3	276	LR6	6	72	0.204	74%
13	75W INC	6	450	LR6	6	72	0.378	84%

Figure 8: Although participants in this project replaced a variety of lighting systems, the LR6 produced significant energy savings for all thirteen sites. One customer (Site # 3) reduced their lighting energy consumption by an impressive 88%!

Although customers will undoubtedly replace many different types of lighting systems, the most common scenario for the LR6 will likely be replacing 65 or 75 Watt BR30 incandescent lamps. The calculated total cost of ownership for a 65 Watt BR30 incandescent lamp and the LR6 is shown on the next page:

Life Cycle Energy and Cost Comparison (15 years)

	<u>65 Watt BR30 Incandescent</u>	<u>12 Watt LR6 LED</u>
Energy consumption:	1,067 kWh	197 kWh
Energy costs (@ \$0.15 kWh):	\$160	\$30
Replacement lamp costs:	\$52	\$95
Total cost of ownership:	\$212	\$125

Notes and Assumptions

- Average usage: 3 hours per day, 1,095 hours per year
- Lamp life: incandescents = 1,000 hours, LR6 = 50,000 hours
- Retail cost for 65 Watt BR30 lamps = \$3.50 per lamp. Cost for LR6 = \$95 per fixture
- Although the LR6 is rated for 50,000 hours (45.6 years for residential kitchens), 15 years was chosen for comparative purposes.

Conclusion

Even though at first glance LEDs appear to be a relatively inefficient light source (in terms of raw lumens per watt), their directional nature may make them ideal for applications such as recessed downlights, commercial freezer case lights and outdoor lighting. The future looks even more promising since projections from the U.S. Department of Energy (DOE) state that commercially available white LEDs may achieve efficacies of well over 150 lumens per Watt within the next eight years. If these projections hold true, LEDs may become a contender for virtually all lighting applications (at least as far as efficacy is concerned). In the meantime, challenges for LEDs include:

- **Significantly higher first cost:** LED products such as the LR6 usually cost more than most residential-grade, incandescent and fluorescent recessed fixtures. Although the LR6 looks much more favorable when compared on a life-cycle cost basis, the initial cost will likely be a significant barrier to widespread adoption in cost-sensitive markets such as residential homeowners and production homebuilders. That being said, LEDs may still be an attractive option for commercial and other applications with longer operating hours.
- **Lack of clear performance standards and labeling:** Not all products are created equal. Since LEDs are relatively new to the lighting scene, many of the performance and reliability standards are still under development or are very new. Fortunately, help is on the way since DOE and the Environmental Protection Agency (EPA) recently expanded the Energy Star program to include some solid state lighting (SSL) applications. Furthermore industry standards (e.g. LM79-08 and LM-80) for testing SSL products have been adopted and are gaining momentum. Finally, voluntary programs such as DOE's SSL Quality Advocates, are encouraging manufacturers to

provide clear, consistent, product labeling. However, until these standards and labeling requirements become more established, it is a good idea to ask plenty of questions before purchasing any LED products and avoid “bargain-priced” offerings.

SMUD is currently developing energy efficiency incentives (rebates) for qualifying LED lighting products in applications such as recessed downlights. For more information, please contact SMUD’s Customer Advanced Technologies Program Project Manager at dbisbee@smud.org.

Acknowledgements

We gratefully acknowledge the contributions made from the following:

- ✓ U.S. Department of Energy Solid State Lighting Program <http://www.netl.doe.gov/ssl/>
- ✓ SMUD Customers for their pioneering spirit

Appendix: Homeowner Survey Results

Cree LR6 LED Lighting Questionnaire Results

Number of Respondents: 13

1. Please describe your original lighting system:

	<u># of responses</u>
Incandescent lamps (a.k.a. 'traditional' light bulbs)	6
Compact fluorescent	4
Four foot fluorescent lamps	3
Other	0
<u>No previous lights</u>	0
Total responses	13

2. Using the scale below, please rate the lighting quality for your "original" lighting system by circling the appropriate answers:

	Very Poor	Poor	Ok	Good	Excellent	Total
Brightness	0	2	5	5	1	13
Color	1	2	3	5	2	13
Appearance	1	2	5	2	3	13
Dimming	5	0	2	0	2	9
Glare	1	5	4	3	0	13
Noise	1	1	4	2	4	12

Comment: Not all customers used dimming.

3. Were you able to install the LED lights yourself or did you have to hire a contractor?

	<u># of responses</u>
Yes, I was able to install the LED lights myself	10
<u>No, I had to hire a contractor</u>	3
Total responses	13

Comments: (1) Most customers who replaced 4 ft. linear fluorescent fixtures or hard-wired compact fluorescent lights hired electrical contractors to complete the work. (2) Customers who replaced screw-in compact fluorescent or incandescent lamps were able to complete the installation themselves.

4. If you installed the LED lights, how easy were they to install?

	<u># of responses</u>
The LED lights were very easy to install	5
The LED lights were somewhat easy to install	5
The LED lights were somewhat difficult to install	0
The LED lights were very difficult to install	0
Total responses	10

Comments: (1) Some customers experienced slight difficulties attaching the grounding wire. (2) One customer experienced problems with the LR6 springs. (3) One customer had to extend the wires of the original fixture in order to install the LR6 because the existing wires were too short to allow the LR6 to clear the ceiling line.

5. Besides the SMUD grant, what motivated you to replace your original lights with the LED lights? (Please check all that apply)

	<u># of responses</u>
Desire to be "green" or energy efficient	7
Reduce my electric bill	11
Did not like my old lights	7
Old lights couldn't be dimmed	2
Reduce heat	6
Wanted to modernize my home	3
Other	0

Comments: Most common reasons were (1) Reduce electric bill (2) Desire to be green (3) Did not like old lights / lights too hot.

6. According to the manufacturer, the LR6 LED lights should last at least 10 years. Taking this into account, while comparing price with quality and energy savings, if you were to buy the fixtures on your own, what would be the most you would be willing to pay?

	<u># of responses</u>
Less than \$10 per light	0
\$10 to \$20 per light	1
\$20 to \$30 per light	4
\$30 to \$40 per light	2
\$40 to \$50 per light	1
\$50 to \$60 per light	2
\$60 to \$70 per light	1
\$70 to \$80 per light	1
\$80 to \$100 per light	1
Total responses	13

Comments: (1) Most customers said they were only willing to spend \$20 to \$40 per light. (2) Customers said they might be willing to pay a higher price if they were convinced the LR6 would last 10 years or more and the dimming was improved.

7. Using the scale below, please rate the lighting quality for your NEW LED lights by circling the appropriate answers:

	Very Poor	Poor	Ok	Good	Excellent	Totals
Brightness	0	0	0	1	12	13
Color	0	1	1	0	11	13
Appearance	0	0	1	1	11	13
Dimming	1	1	2	3	0	7
Glare	2	0	1	1	9	13
Noise	1	0	0	1	11	13

Comments: (1) Not all customers used dimmers. (2) Customers who used incompatible dimmers were very dissatisfied with the dimming of the LR6. (3) Some customers felt that Cree should have been more specific about the dimming capabilities of the LR6 (i.e. the LR6 is not fully dimmable).

8. Part of our research project is to determine the best method(s) for making these lights available to consumers like you.

a. Where did you purchase your LED lights?

b. Did you get advice on installation? Guarantees? Please describe your experience:

Comment: Eleven customers purchased their lights from a local lighting specialty shop. Two customers bought their lights online. Customers said they liked the expertise and advice from the staff at the specialty lighting store.

9. If given a choice, where would you most likely want to buy the LED lights in the future? Please indicate your preferences by circling the appropriate answers:

	Do not prefer	Ok	Prefer
Home improvement (e.g. Home Depot)	1	3	7
Internet	5	3	3
Lighting specialty store	2	5	5
Big Box retail (e.g. Wal-Mart)	2	4	6

Comments: (1) Not all customers answered this question for each category. (2) Some customers replied "whoever has the best price." (3) Strongest preferences were given to home improvement and big box retail stores.

10. Would you recommend this light to your friends (without SMUD funding)?

	<u># of responses</u>
Yes, I would recommend these LED lights to a friend	11
No, I would not recommend these LED lights to a friend	2
Total responses	13

Comments: (1) The two homeowners who would not recommend the LR6 cited high cost and lack of full dimming capability. (2) Even customers who said they would recommend the LR6 expressed concern that the price was too high.