Pearls of Wisdom: Assuring Efficient Lighting Product Quality and Program Integrity

Description of the Development and Results of the PEARL Program

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Abstract

This paper presents an overview of the Program for the Evaluation and Assessment of Residential Lighting (PEARL) program's development and accomplishments to date. Quality assurance is a crucial element in the success of efforts to promote energy efficient technologies and transform markets. The PEARL program addresses quality assurance in energy efficient lighting. In six test cycles, over 120 models of bare, covered, and reflector CFLs were tested for compliance with ENERGY STAR specifications. Results confirmed that not all products comply, leading in some cases to delisting or retesting of products by the ENERGY STAR program. Testing has helped sponsors protect their investment in lighting programs and it has been proposed has a model quality assurance process that can be incorporated into the national program.

Introduction

A quality product is an important selling factor that can determine whether a new technology is embraced by the market or languishes in relative obscurity. Moreover, assurance of product integrity helps protect program and brand integrity. Compact fluorescent lamps (CFLs) are a technology for which product quality has been identified as one barrier to increased market acceptance. CFLs have been an important technology promoted by energy efficient programs since the 1990's. Some participants in residential lighting programs complained about premature failure and inadequate light output from CFLs. When the ENERGY STAR program developed a specification for residential lighting products, it relied on manufacturers' self-reported information to determine which products qualified. Most US energy efficiency programs use ENERGY STAR qualification as an entrance requirement. Once a product has been ENERGY STAR qualified, it becomes eligible to receive financial incentives and other marketing support. Due to these incentives and marketing support, ENERGY STAR qualified CFLs dominate the domestic CFL market[1]. Lighting program administrators who spend hundreds of millions of dollars each year on the promotion of ENERGY STAR CFLS view independent testing of ENERGY STAR CFLs as a strategy to help their lighting programs succeed as well as to protect the integrity of the ENERGY STAR brand.

[1] ENERGY STAR operates primarily in the US, but other countries are starting to implement parts of it as well.

The purpose of this paper is to describe the Program for the Evaluation and Assessment of Residential Lighting (PEARL), an independent quality assurance process, as well as to present aggregate results of the PEARL testing and to discuss its impact on the national ENERGY STAR program.

Background

For many years, energy efficiency program administrators faced challenges with residential lighting programs due to customer dissatisfaction with some CFL products. Program evaluation results documented that poor product performance and quality were among the barriers that limited the success of residential lighting programs. Furthermore, following the advent of the ENERGY STAR specifications for CFL lamps and fixtures, administrators continued to hear anecdotal reports of premature failure and insufficient light output, of specific ENERGY STAR qualified products. However, given the lack of better data, program administrators continued to use manufacturer product performance claims to calculate energy savings and program benefits. While some program administrators had contracted for independent testing of products in their residential lighting programs prior to the development of ENERGY STAR specifications for CFLs, there was no comprehensive, continuous, or systematic independent testing prior to 2000.

In response to concerns about product quality, a group of stakeholders, including the Natural Resources Defense Council (NRDC) and utilities and other lighting program administrators, established PEARL, an independent third-party testing process. The intent of the testing was to replicate the tests that manufacturers are required to perform before submitting products for qualification under ENERGY STAR, in order to verify that some critical components of selected ENERGY STAR qualified CFL bulbs and fixtures purchased at retail comply with key ENERGY STAR performance criteria. It also serves as a check on the accuracy of product performance data submitted by manufacturers. Any seller of CFLs that meets the ENERGY STAR's efficiency and quality requirements can qualify under the ENERGY STAR program, and put the ENERGY STAR logo on their product packaging. To show compliance with the ENERGY STAR requirements, CFL manufacturers must submit test data from an accredited laboratory to the US DOE.

The initiators of PEARL established a Board to oversee funding and management of independent testing. They contracted with a test facility, the Lighting Research Center (LRC) at Rensselaer Polytechnic Institute in Troy, New York. While PEARL has received funds from EPA and DOE, the majority of the funding has come from local and regional program administrators. Utilities and energy efficiency organizations in the U.S. and Canada cosponsor PEARL[2] and the NRDC administers the program.

PEARL's Test Process

Each round of product testing is referred to as a cycle. A cycle begins with development of a schedule and funding. The costs of testing are significant. While they vary from cycle to cycle, depending on the sample sizes, number of models, and tests included, a rough average cost is $900 per bulb. The relatively high cost of testing is in part due to the fact that light is difficult to measure, the

[2] Cosponsors currently include Bonneville Power Administration, Midwest Energy Efficiency Alliance, New York State Research and Development Authority, Northwest Energy Efficiency Alliance (NEEA), Northeast Energy Efficiency Partnerships (NEEP), Efficiency Maine, Efficiency Vermont, Long Island Power Authority, National Grid, Connecticut Light and Power, Western Massachusetts Electric Company, NSTAR Electric and Gas Company, United Illuminating Company, Unitil, Cape Light Compact, Pacific Gas and Electric Company, Sacramento Municipal Utility District, Southern California Edison, the Wisconsin Energy Conservation Corporation, and Natural Resources Canada, with technical assistance from DOE and EPA.

equipment is expensive, and there are a limited number of facilities available. It is important to note that PEARL's costs include coverage of some of LRC's expenses associated with accreditation, as well as additional services to the PEARL Board such as special test development, data analysis, reporting, and participation in Board meetings. By comparison, independent testing labs without the special services can test bulbs for one fourth of the cost. Each the test cycle includes the following steps:

Product Nomination. PEARL Board members suggest products for testing. Typically, the Board chooses ENERGY STAR CFLs to test based on customer complaints or other concerns, sales volumes, and prior PEARL results.

Product Acquisition. Samples are purchased by sponsors from lighting retailers and shipped to the testing facility[3]. In an attempt to purchase CFL samples across multiple production runs, samples are purchased from three different regions of the US. Sample sizes varied from cycle to cycle. After cycle two, sample sizes were doubled, from three to six, and in the sixth cycle, samples of ten lamps of each model have been tested.

Testing. The Lighting Research Center (LRC), an accredited independent laboratory, conducts tests using the CFLs provided by PEARL. The tests are intended to replicate the testing that manufacturers are required to perform before submitting products for qualification under ENERGY STAR. Both manufacturers' qualification testing of products qualified for ENERGY STAR and PEARL quality assurance (QA) testing were done at National Voluntary Laboratory Accreditation Program (NVLAP) accredited laboratories using state-of-the-art equipment. LRC provides quantitative results and "pass" or "fail" information relative to the ENERGY STAR specification on a range of parameters. Currently, the focus of the PEARL Board's interest is on four parameters: efficacy, lumen maintenance, durability, and product lifetime. These are considered of highest importance to the PEARL Board members, and they are a subset of the more than twenty parameters required for the screw base CFL ENERGY STAR specification. More information about these tests is provided below. In addition to these tests, LRC also tests characteristics such as start time, color quality, correlated color temperature, and power factor, as well as verifying other manufacturer-supplied information such as model number, start temperature, warranty, ENERGY STAR label, and operating frequency.

Reporting of Test Results. Interim and final test results are kept confidential, reported to the PEARL Board and US Department of Energy (DOE) and US Environmental Protection Agency (EPA) ENERGY STAR program administrators. Board members receive measurement and verification information as well as summaries focusing on the four key parameters. Manufacturers receive interim and final results for their products only. Interim results include tests that can be completed within a relatively short time frame, while the final test results include the product lifetime and forty percent of rated life tests.

Test Results

Since its inception, PEARL has funded six cycles of testing. Because data from the PEARL tests are proprietary, the authors relied on compilations of data provided by authors, Board members and contractors. Results of the PEARL tests are generally presented in aggregate and summary form, to

[3] The practice of drawing sample from retail sources differs from manufacturers' pre-qualification testing that is often performed before a CFL enters commercial production on samples provided by the manufacturer.

preserve confidentiality. While little detail on the earlier cycles is readily available, changes in the lighting product market coupled with the small sample sizes and small number of models tested make test results from cycles one through three somewhat outdated and less relevant.

To date, as shown in Table 1, PEARL has tested 124 CFL models made by 21 manufacturers. This represents less than seven percent of the ENERGY STAR-qualified CFL models currently listed on the website. As shown in Tables 2 and 3, most of the products that have been tested are bare bulbs. Bare bulbs include any size or configuration of tubes that is not enclosed. As the name suggests, covered products have tubes enclosed in some kind of transparent or translucent covering, while reflector CFLs incorporate a reflector that directs the light. The products tested include products across the range of wattages of products available, as well as specialty models such as dimmable, three-way, outdoor, and flood lights.[4] The rated wattage of the products tested ranges from 5 to 42 watts.

Table 1. PEARL Testing: Models by Cycle

Cycle	**1**	**2**	**3**	**4**	**5**	**6**	**Total**
Number of Models Tested	13	18	20	20	18	35	124
Number of Manufacturers represented	7	12	12	11	10	14	21

Table 2. Distribution of Types of Products Tested

Cycles	**2-3**	**4-6**	**2-6**
Bare	71%	69%	70%
Covered	13%	7%	9%
Reflector	16%	24%	21%
Total	38	73	111

Table 3. Distribution of Products by Wattage

Cycles 4-6	**5 – 15 Watts**	**16 – 22 Watts**	**23+ Watts**	
Bare	28%	22%	25%	75%
Covered	3%	3%	na	6%
Reflector	8%	11%	2%	21%
	39%	36%	27%	

Compliance with ENERGY STAR

Across all cycles of testing, PEARL results confirmed that not all ENERGY STAR CFLs are in full compliance with the specifications[5]. Table 4 shows that one third of the products tested in cycles 4 through 6 failed at least one of the four core PEARL tests required for compliance with ENERGY STAR. As shown in Figure 1, as a group, the bare lamps perform significantly better than the covered or reflector lamps that have been tested, especially with respect to efficacy and lumen maintenance. Figure 2 illustrates that ENERGY STAR compliance rates tend to be higher in the later cycles, particularly five and six. While the samples are not representative or comparable, PEARL Board

[4] Results for dimmable and three-way CFLs have been excluded from detailed test results reported here due to the small number of models tested.

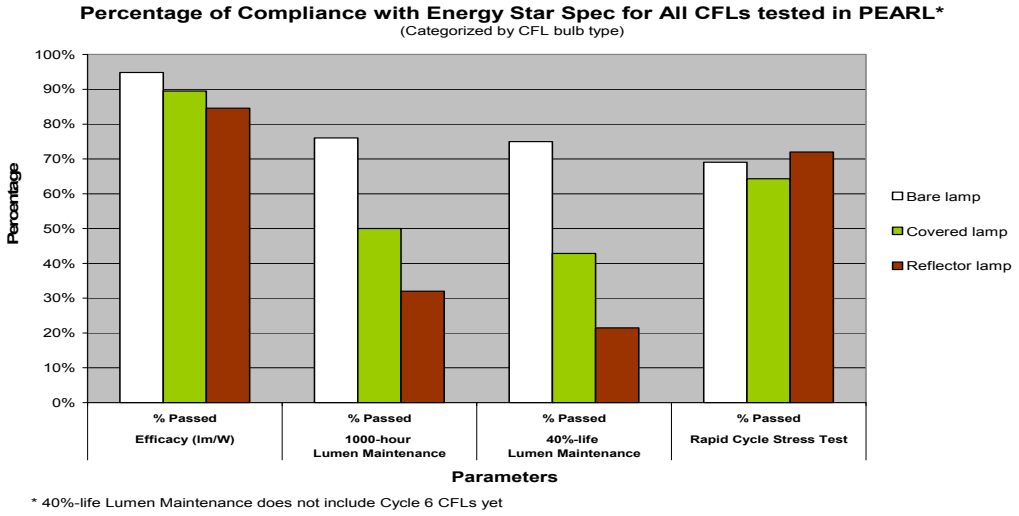
[5] Manufacturers are required to submit "pre-qualification" test data from accredited laboratories to qualify their products under ENERGY STAR.

members have suggested that this may indicate an increase in overall product quality since PEARL began.

Table 4. Aggregate Test Results, Cycles 4 - 6

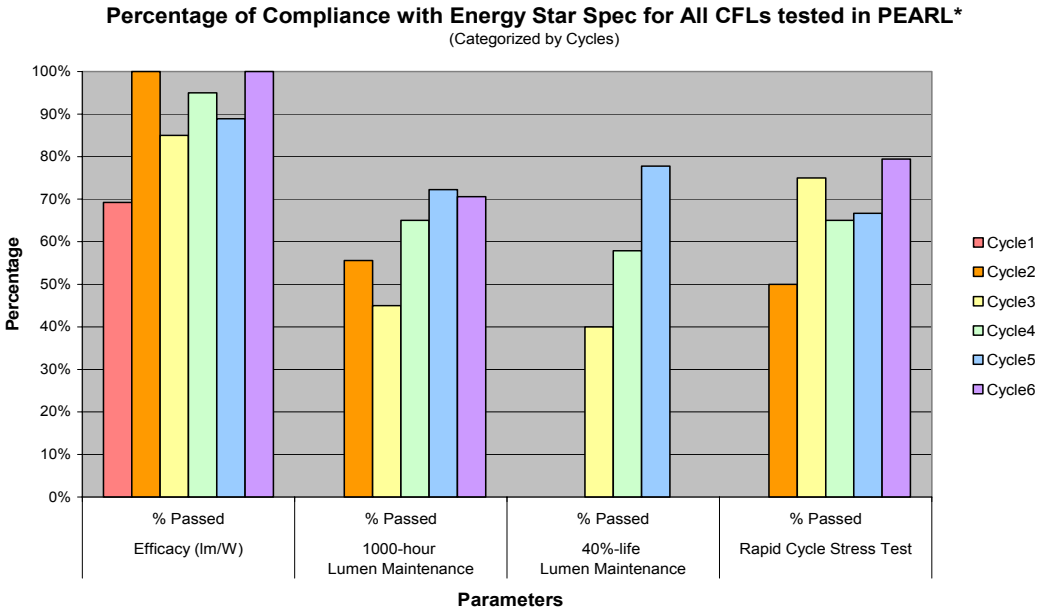
Pass 4 Tests	39 (63%)
Fail 1 or More of 4 Tests	22 (35%)
Results TBD	1 (2%)

Figure 1. PEARL Test Results and Compliance with ENERGY STAR



* 40%-life Lumen Maintenance does not include Cycle 6 CFLs yet

Figure 2. PEARL Test Results by Cycle



* 40%-life Lumen Maintenance does not include Cycle 6 CFLs yet

Efficacy. Light output is measured as lumens per watt after an initial burn-in period of 100 hours of operation. To qualify for ENERGY STAR, CFLs must meet or exceed a minimum listed lumens per watt. The exact specification varies with type of lamp and rated wattage. As expected, efficacy increases with rated power, and efficacy of covered products and reflectors is lower than that of bare bulbs. The majority of the products that were tested comply with the ENERGY STAR specifications for efficacy. However, some models within every product fail to comply, and as shown in Table 5, there is at least a 20 lumen per watt range in efficacy for each product type.

Table 5. Aggregated results of PEARL Efficacy Test

Rated Wattage	Lumens per Watt at 100 hours of operation	Bare	Covered	Reflector
<15 Watts	Min	51	34*	37
	Max	69	59	52
	Average	52	49	43
	n	*41*	*53*	*25*
15 Watts	Min	54*	33*	28*
	Max	74	66	54
	Average	64	54	44
	n	*94*	*28*	*65*
16 – 22 Watts	Min	54	33	28
	Max	74	66	54
	Average	67	57	46
	n	*106*	*3*	*55*
>= 23 Watts	Min	55	na	39*
	Max	79	na	60
	Average	68	na	49
	n	*141*	*0*	*20*

* Test result does not meet ENERGY STAR specification

Lumen Maintenance. Lumens are measured after the 100 hour burn-in period, after 1000 hours of rated life and again at 40% of rated life[6]. Lumen depreciation, decline in light output, is a characteristic of most fluorescent light sources. To qualify as ENERGY STAR at 1000 hours an average of five lamps must be a minimum of 90% of the initial 100-hour lumen output. Also, at 40% of rated life, an average of five lamps must be at 80% of the initial lumen output. As shown in Table 6, as a group, the reflector CFLs that were tested did not comply with ENERGY STAR specifications. Furthermore, covered and reflector products experience a greater decline in light output over time than bare CFLS, and rates of compliance with ENERGY STAR lumen maintenance specifications for these products decreased as the products usage increased from 1000 hours to 40% of rated life.

[6] Most products tested were rated for 6,000 hours of life. 40% of rated life is thus 2400 hours.

Table 6. Aggregated Results of PEARL Lumen Maintenance Tests

Average Lumen Maintenance	Bare	Covered	Reflector
At 1000 hours	94%	90%	86%
n	*340*	*75*	*157*
At 40% of rated life	85%	81%	76%
n	*312*	*66*	*143*

Durability. The ENERGY STAR specification requires that CFLs pass a stress test in which at least five CFLs must meet or exceed the minimum number of cycles defined as being turned on for five minutes, off or five minutes for every two hours of rated life[7]. This test was developed to serve as an indicator of CFLs' performance under difficult conditions. As shown in Table 7, product performance is somewhat consistent across product types for this test. Similarly, as shown in Figure 1, roughly 65 to 75 percent of the products tested through PEARL complied with the ENERGY STAR rapid cycle test requirement.

Table 7. Number of Products That Failed PEARL Rapid Cycle Stress Tests (all cycles)

Rated Wattage	Bare	Covered	Reflector
<=15 Watts	36	6	13
n	*156*	*66*	*78*
16 – 22 Watts	12	2	8
n	*90*	*6*	*60*
>= 23 Watts	24		0
n	*138*	*0*	*12*
All	72 (19%)	8 (11%)	21 (14%)
n	*384*	*72*	*150*

Product Lifetime. PEARL and ENERGY STAR define an interim life test as survival through 40% of rated life. Ten units of each model are tested, five base up and five base down.[8] During PEARL testing, as shown in Table 8, bare CFLs had a higher failure rate than covered or reflector CFLs.

Table 8. Failures Prior to 40% of Rated Life During Lumen Maintenance Testing

CFL Type	Bare	Covered	Reflector
Failures	24 (9%)	3 (7%)	6 (5%)
n	*255*	*45*	*115*

[7] For example, a CFL rated for 6,000 hours of life would need to survive 3,000 switches.

[8] An average rated life test is also conducted, although results are not included here. As in the 40% of rated life test, it uses ten units of each model, five base up and five base down. This test measures the number of units that survive for at least as long as the hours of rated life as declared by the manufacturer on the packaging (usually 6,000 hours). Average rated life is a metric established by the lighting industry. It is determined by operating a large sample of CFLs under test conditions with a constant ambient temperature and a regular switching schedule until fifty percent of the sample fails.

Impacts of PEARL on the ENERGY STAR CFL Program

Even though testing has not included a large portion of the ENERGY STAR products yet, PEARL has had a positive impact on maintaining integrity of the ENERGY STAR brand and lighting product quality assurance. PEARL has evolved over time in various ways, ranging from the types of tests, the sample sizes, and uses of the test results, and the relationship of PEARL to the DOE ENERGY STAR Program. In the first three cycles of testing, the tests conducted through PEARL were not fully aligned with the types of information and product test results ENERGY STAR was requesting from manufacturers. For example, in cycle two, PEARL initiated rapid cycle test that was not a requirement of ENERGY STAR. Also, as mentioned above, in the first three cycles PEARL tests used smaller sample sizes than were required by ENERGY STAR[9]. Since the fourth cycle, however, PEARL and ENERGY STAR have become increasingly interactive. For example, in cycle five, PEARL added a lifetime test, as a result of changes to the ENERGY STAR specification. PEARL has provided an important, impartial source of documentation that the ENERGY STAR lighting program has been able to use to address quality assurance concerns. Two examples of this include product delisting and product requalification. Building on these activities, PEARL, DOE and other stakeholders are seeking to institutionalize quality assurance as part of the ENERGY STAR CFL Program.

Delisting of ENERGY STAR Products. Based on PEARL test results from cycle four, DOE delisted several ENERGY STAR CFLs. Some products were delisted following the interim test results, while others were delisted based on the final tests. Subsequently, DOE delisted products based on interim and final test results from PEARL cycle five. For cycle six, DOE distributed delisting letters to manufacturers in May 2005 based on the final cycle six test data. Anecdotal evidence suggests that delisting is helping manufacturers improve their operations as well as protecting customers. For example one concerned manufacturer who upon receiving news that their product has been delisted, remarked " this has blown everybody away, its such a big deal." This company is now going through an intense effort to find out what went wrong and how to prevent it from reoccuring.

Requalification of Reflector Bulbs. PEARL results were among a variety of sources of information that documented poor performance of many covered CFLs, in particular reflector lamps. At the ENERGY STAR Partner meeting in March 2004, DOE requested industry support for voluntary requalification of ENERGY STAR CFL reflector bulbs. However relatively few products were nominated by manufacturers for retesting. In response, DOE required that all ENERGY STAR reflector bulbs be requalified under the existing ENERGY STAR specification at manufacturers' expense. This testing began in the fall of 2004 and is expected to be completed in mid-2005.

Elevated Temperature Testing for Reflector CFLs. Currently, ENERGY STAR testing and the PEARL testing employed for Cycles 1 through 6 have been on open test racks conducted at room temperature. However, many reflector lamps are used in recessed cans, some of which are both airtight and situated in insulated ceilings. These applications expose reflector CFLs to significantly higher operating temperatures, which can erode their performance and decrease their lifetime. This phenomena has been well documented by on-going product research and procurement efforts by Pacific Northwest National Laboratories.[10] As part of their efforts, PNNL developed an elevated temperature test

[9] ENERGY STAR requires a sample size of ten for core tests. Additional products (samples of six) are required for the rapid cycle test.
[10] See http://www.pnl.gov/rlamps/

procedure for reflector CFLs to simulate in-situ conditions in an airtight, insulated recessed can. In 2004, PEARL decided to test several reflector lamp CFL models using this elevated temperature test procedure. This testing is ongoing and results are expected in the third quarter of 2005. At a recent ENERGY STAR Lighting Partner Meeting (April 2005), DOE expressed their intent to require elevated temperature testing for reflector CFLs in the next versions of the ENERGY STAR CFL specification.[11]

DOE Proposal to institutionalize third party testing of ENERGY STAR CFLs. Since 2002, PEARL Board has been in discussions with industry and DOE and EPA to develop a more robust ENERGY STAR quality assurance process. This process would include a third-party testing component that would replace PEARL. Stakeholders participating in this effort include representatives from EPA, DOE (including their contractor D&R), NRDC, NEEA, NEEP, independently owned utilities in California, the National Electric Manufacturers Association (NEMA), several major manufacturers and some testing labs. In the spring of 2004, an idea was proposed that third party testing become part of the ENERGY STAR CFL program though not part of the specification requirements. Under this proposal, manufacturers would underwrite a significant amount of the cost of independent product testing. It is likely that up to twenty percent of all ENERGY STAR models could be tested, a much larger and more representative sample than is feasible to test under the current PEARL process. By April 2005, DOE completed a draft of this idea for public review and solicited comments. Funding, product nominations, handling the confidentiality of the test results, and other aspects of the administration of this process are among the unresolved issues that are still under discussion. Current plans are for DOE to roll out the third party testing process during 2005.

Discussion

Beyond the raw test results presented above, it is important to consider more generally what PEARL tests can and cannot tell us. PEARL has helped highlight important differences between three important sources of product information: manufacturer-reported information; independent lab tests; and real-life conditions. PEARL has demonstrated that manufacturers' ENERGY STAR qualification information is not necessarily consistent with its independent tests. Whatever the cause of the discrepancies may be, PEARL results have illustrated the benefits of quality assurance as a component of a product branding program. Currently, PEARL and the proposed DOE-institutionalized version of PEARL are designed to police quality, protecting customers but also protecting manufacturers by keeping the identity of manufacturers confidential. However, PEARL could potentially evolve into a more public source of information, in which manufacturers see value in having their products' performance publicized. Consumer Reports is an example of publicly available results of product performance tests.

Another distinction in product information related to testing is between laboratory conditions and real-life conditions. At best, PEARL tests and ENERGY STAR specifications try to simulate real life conditions through the stress test, and requiring cycles of on and off switching in conjunction with bulb run time as part of measuring product lifetime. However, none of these replicate typical household conditions or patterns of use. Quality assurance and independent testing are necessary but may not be sufficient to effectively demonstrate product performance.

It is also important to keep in mind that products tested by PEARL are not fully representative of the overall CFL market. The products were selected for testing as a result of a nomination process, and they typically include some products likely to represent a large market share, as well as some that were

[11] Comments made by Richard Karney, ENERGY STAR Program Manager, US DOE, at the National ENERGY STAR Partner Meeting, April 6, 2005. Las Vegas, NV.

selected because of concerns about quality and performance. However, if third party testing could be expanded to include a larger number of products, as is being discussed by DOE and manufacturers and other stakeholders, then it would be possible to characterize product quality and potentially document changes market-wide changes in product performance over time, based on independent test results.

PEARL test results have been useful as indicators of technical issues and product characteristics that merit further attention by program administrators and within the industry. Some of the comparisons of the performance of bare CFLs versus covered and reflector products are a good example. In the PEARL tests bare bulbs fare better than the other products with respect to lumen maintenance. One likely explanation is that higher operating temperatures in the reflectors and covered products contribute to lumen depreciation. Examination of PEARL test results could help point to and justify research on product design changes for certain product types. In the PEARL tests, bare bulbs fared slightly worse than covered and reflector CFLs with respect to interim life and durability. From a commercial perspective this is somewhat insignificant for reflectors and covered CFLs; if they can't sustain adequate lumens they are unlikely to remain in use for the full duration of their life. However, the results also point to a potential concern about bare bulbs, as failure rates of ten percent are relatively high for a commercialized product.

Finally the evolution of the PEARL program itself confirms that the value of quality assurance is recognized by many stakeholders in domestic residential lighting programs. An effort that was initiated by program sponsors has been embraced by DOE program administrators, lighting manufacturers, however, the devil is in the details.

Relevance of PEARL and Quality Assurance for Evaluators and Program Managers

Since 2000, sponsors of PEARL have funded over $40 million in incentives to support the sale of CFLs. At the regional level, sponsors of the testing can withhold promotional funding for products based on test results. Testing has helped sponsors protect their investment in lighting programs. ENERGY STAR has no independent product testing capacity, therefore independent quality assurance testing is also helping to maintain the integrity of the national ENERGY STAR CFL program, initially through test results and currently by serving as a model of quality assurance process that can be incorporated into the national program.

The few years of experience with PEARL have already shown the importance of flexibility in quality assurance programs. The products and the types of tests of interest have evolved over time.

Lessons from the experience of establishing quality assurance testing for CFLs have relevance for other ENERGY STAR products. For example, concerns about performance and quality have impeded the market adoption of other high efficiency products, such as electronic ballasts, heat pump water heaters and condensing gas furnaces. In some cases, these concerns have been addressed but in others, the concerns are still a major impediment.

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