ENERGY STAR® LED LAMP THIRD PARTY TESTING AND VERIFICATION

Testing Result Summary from 2013 - 2015

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Table of Contents

Executive Summary 3
Summary Results 4
Methodology 14
Detailed Results by Requirement 16
- Luminous Efficacy 16
- Light Output (exemption: PAR, MR, and MRX lamps) 16
- Light Output - Center Beam Intensity (PAR, MR, and MRX lamps) 17
- Elevated Temperature Light Output Ratio (Directional lamps) 17
- Luminous Intensity Distribution (Omnidirectional and Decorative lamps) 17
- Correlated Color Temperature 17
- Color Rendering Index - R_a 18
- Color Maintenance 19
- Color Angular Uniformity (Directional lamps) 19
- 3,000-Hour Lumen Maintenance 20
- 6,000-Hour Lumen Maintenance 21
- Rated Life 22
- Rapid Cycle 22
- Power Factor 22
- Frequency 22
- Start Time 22
- Transient Protection 23
- Dimensional Requirements 23

Conclusion 24

List of Figures and Tables

Figures 1a-d: Summary Results by Requirement 4
Figure 2: Number of Tests Failed: Aggregate 10
Figure 3: Test Results by Model Type: Aggregate 11
Figure 4: Requirements Failed by Lamp Type 12
Figure 5: Light Output Percent Deviation from Specification 16
Figure 6: 3,000-Hour Lumen Maintenance Results 20
Figure 7: 6,000-Hour Lumen Maintenance Results 21

Table 1: Percent Passing and Failing Each Requirement by Lamp Type 7
Table 2: Marginal Failure Criteria Table 8
Table 3: Failures for All Models Tested 11
Table 4: Models Failed by Year 13
Table 5: Tests Required for ENERGY STAR Verification Testing 14
Table 6: Light Output Summary Results 16
Table 7: Center Beam Intensity Detailed Failure Information 17
Table 8: Correlated Color Temperature Detailed Failure Information 18
Table 9: Color Rendering Index (R_a) Detailed Failure Information 18
Table 10: Color Maintenance Detailed Failure Information 19
Table 11: Color Angular Uniformity Detailed Failure Information 19
Table 12: 3,000-Hour Lumen Maintenance Summary Results 20
Table 13: 6,000-Hour Lumen Maintenance Summary Results 21
Table 14: Start Time Detailed Failure Information 22
Table 15: Transient Protection Detailed Failure Information 23
Table 16: Dimensional Requirements Detailed Failure Information 23

Executive Summary

As of October 17, 2016, the ENERGY STAR LED Lamp Third Party Verification Program completed testing and verification of 201 base models of ENERGY STAR certified LED lamps.[1]

Overall, 23% (47) of all base models were reported as verification testing failures, not meeting one or more requirements for ENERGY STAR certification. These base models represent 114 privately labeled models.

Failures were observed on 11 out of 17 total requirements across the three lamp types: omnidirectional, directional, and decorative. Each model was subjected to the same nine core tests, plus two out of five additional tests chosen at random.[2] In addition to these core and randomly selected tests, omnidirectional and decorative lamps were also tested for luminous intensity distribution, and directional lamps for color angular uniformity and light output ratio. Out of all tests, no models failed efficacy, elevated temperature light output ratio, luminous intensity distribution, rapid cycle, power factor, or frequency. The lumen maintenance requirements were the most frequently failed, with 11% of models failing the 6,000-hour lumen maintenance requirement and 7% of models failing the 3,000-hour lumen maintenance requirement.

Results were fairly consistent across the three lamp types in terms of both the failure rates as well as the type of performance requirements that failed. The failure rates for the three lamp types are:

- **Omnidirectional Lamps:** 17% fully failed at least one requirement, and an additional 3% marginally failed at least one requirement
- **Directional Lamps:** 18% with one or more full failure (6% marginal)
- **Decorative Lamps:** 21% with one or more full failure (7% marginal)

Of the 36 lamps that fully failed one or more requirements, 20 models failed just one requirement, while 16 failed two or more. The percentage of lamps tested that failed two or more requirements are as follows: 7% of directional lamps, 8% of omnidirectional lamps, and 14% of decorative lamps. 2% of lamps failed four requirements, and they were all directional. Directional lamps were subject to 13 requirements, while omnidirectional and decorative lamps were subject to 12 requirements.

Use discretion when generalizing from the results described in this report to the entire market of ENERGY STAR certified LEDs. The test data summarized in this report is informative, but not necessarily reflective of the most prominent models in the market, or those with the largest shipments (that data is not immediately available to EPA). The products tested for verification testing, and included here, reflect both nominations and random selections. In addition, products included here may no longer be on the ENERGY STAR Qualified Products List, as the Qualified Products List is a contemporaneous listing that continues to shift after product selection occurs and verification testing has begun. This report includes the best current verification testing data available on the performance of ENERGY STAR certified LED lamps sold at retail.

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[1] Excludes two models for the following reasons: lab error during product selection, and lab testing error.

[2] The nine core tests include efficacy, correlated color temperature, color rendering index, color maintenance, light output, rapid cycle, rated life, 3,000-hour lumen maintenance, and 6,000-hour lumen maintenance. CBs selected two of the following five tests at random: power factor, frequency, start time, transient protection, and lamp dimensions.

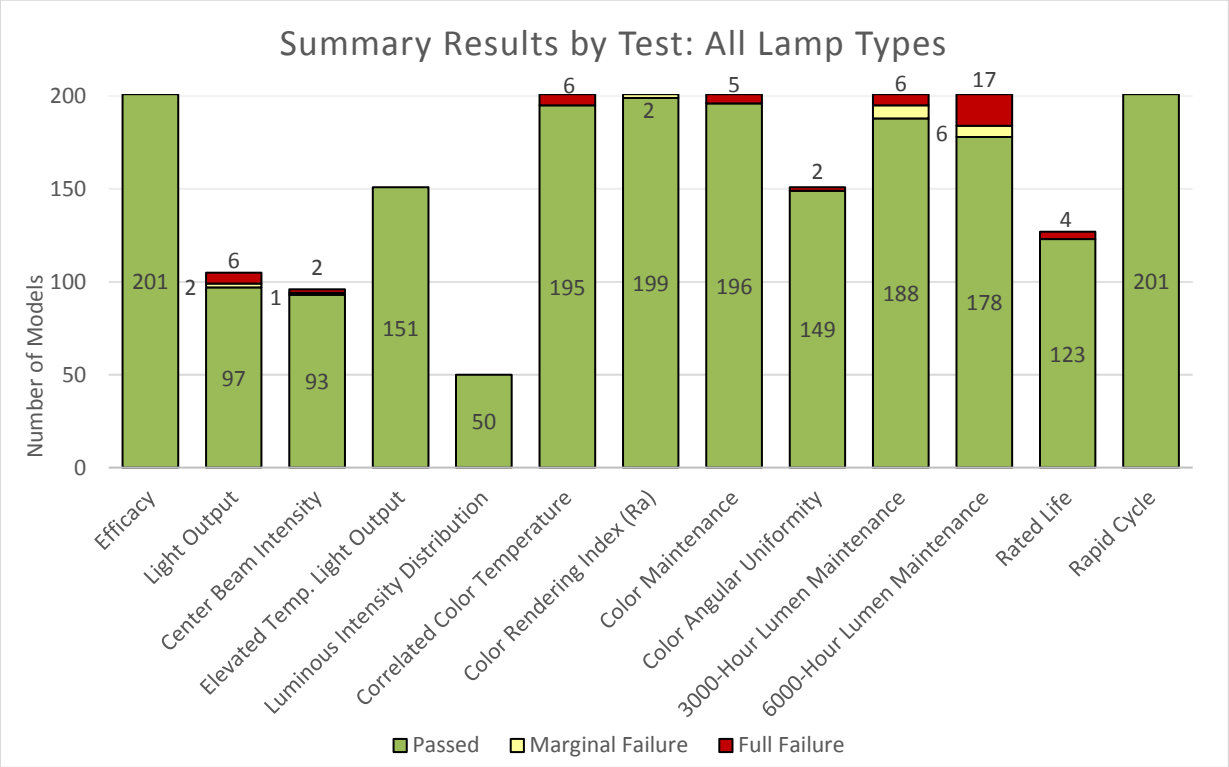
Summary Results

EPA Directive #2015-01, Revised December 14, 2015, ENERGY STAR Lamps Verification Testing– Test Requirements, Sample Sizes and Reporting Failures (178KB) states that for purposes of verification testing, certification bodies (CBs) must test certified lamps against a limited set of core performance requirements, as applicable to the specific model. This is a summary of verification testing results of ENERGY STAR certified LED lamp models selected between November 2013 and December 2015, and that completed full verification testing by October 17, 2016. During that time, verification testing was conducted on 201 ENERGY STAR certified products, including 36 omnidirectional lamps, 151 directional lamps, and 14 decorative lamps.[3]

Out of all tests, no failures were observed for the following requirements: efficacy, elevated temperature light output ratio, luminous intensity distribution, rapid cycle, power factor, and frequency requirements.

Two out of five requirements that apply to LED lamps are chosen at random and are not included in Figures 1a-d. Of these five requirements, four failures were observed. There was one model that failed each the start time and transient protection requirements, and two models that failed the dimensional requirements.

Figure 1a: Summary Results by Requirement - All Lamp Types[4, 5]



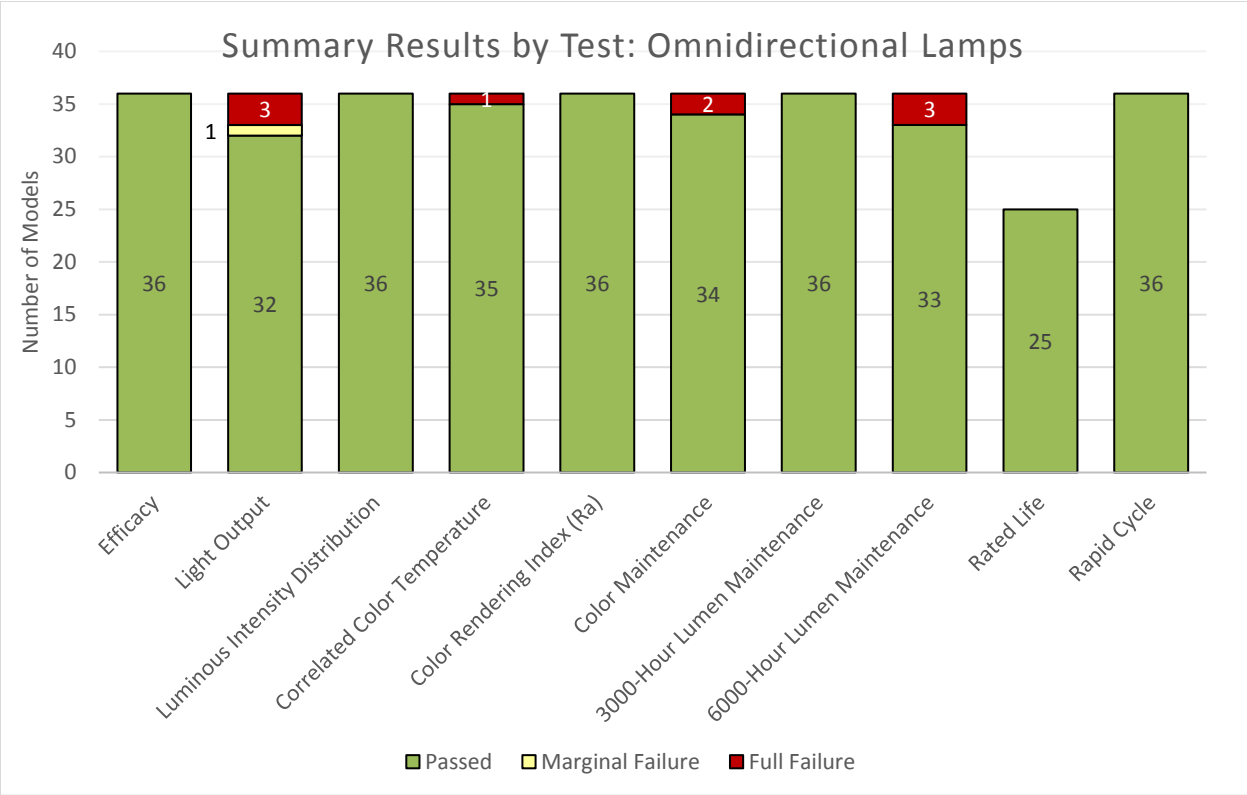
[3] Excludes two models for the following reasons: lab error during product selection, and lab testing error.

[4] EPA has defined marginal failures in the Lamps Verification Testing: Marginal Failure Table.

[5] Luminous intensity distribution test applies to omnidirectional and decorative lamps only. Elevated temperature light output ratio (elevated temperature) applies only to directional lamps; omnidirectional, decorative, and lamps labeled "not for use in enclosed or recessed fixtures" or equivalent statement are exempt. Center beam intensity

The most frequently failed requirement across all lamp types was the 6,000-hour lumen maintenance requirement, which has a similar full failure rate across the three lamp types. The full failure rate was 8% for omnidirectional lamps (0% marginal), 9% for directional lamps (4% marginal), and 7% for decorative lamps. The full failure rate across all three lamp types was 8% (3% marginal). See Figures 1b.-d. and Table 1: Percent Passing and Failing Each Requirement by Lamp Type.

Figure 1b: Summary Results by Requirement - Omnidirectional lamps (n=36)



applies to some directional (PAR and MR) lamps only, and light output applies to omnidirectional, decorative, and some directional (R, BR, ER) lamps only.

Figure 1c: Summary Results by Requirement – Directional lamps (n=151)

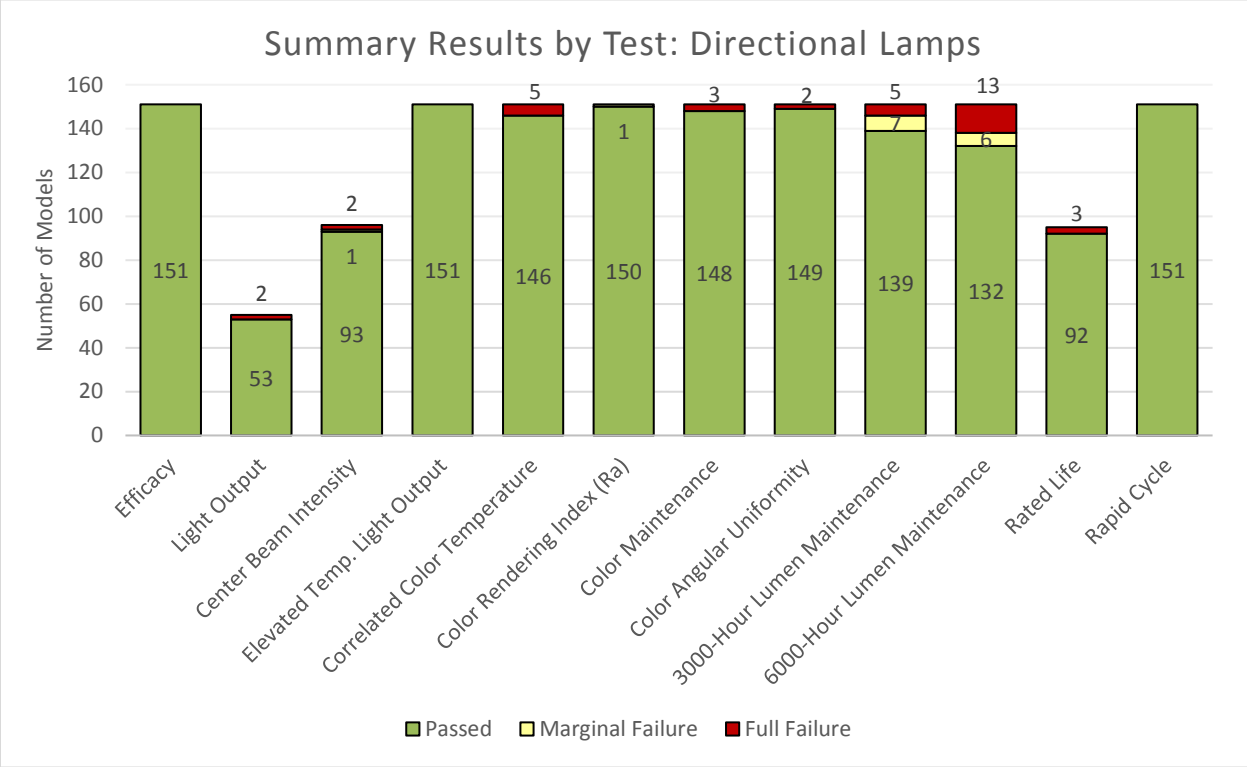


Figure 1d: Summary Results by Requirement – Decorative lamps (n=14)

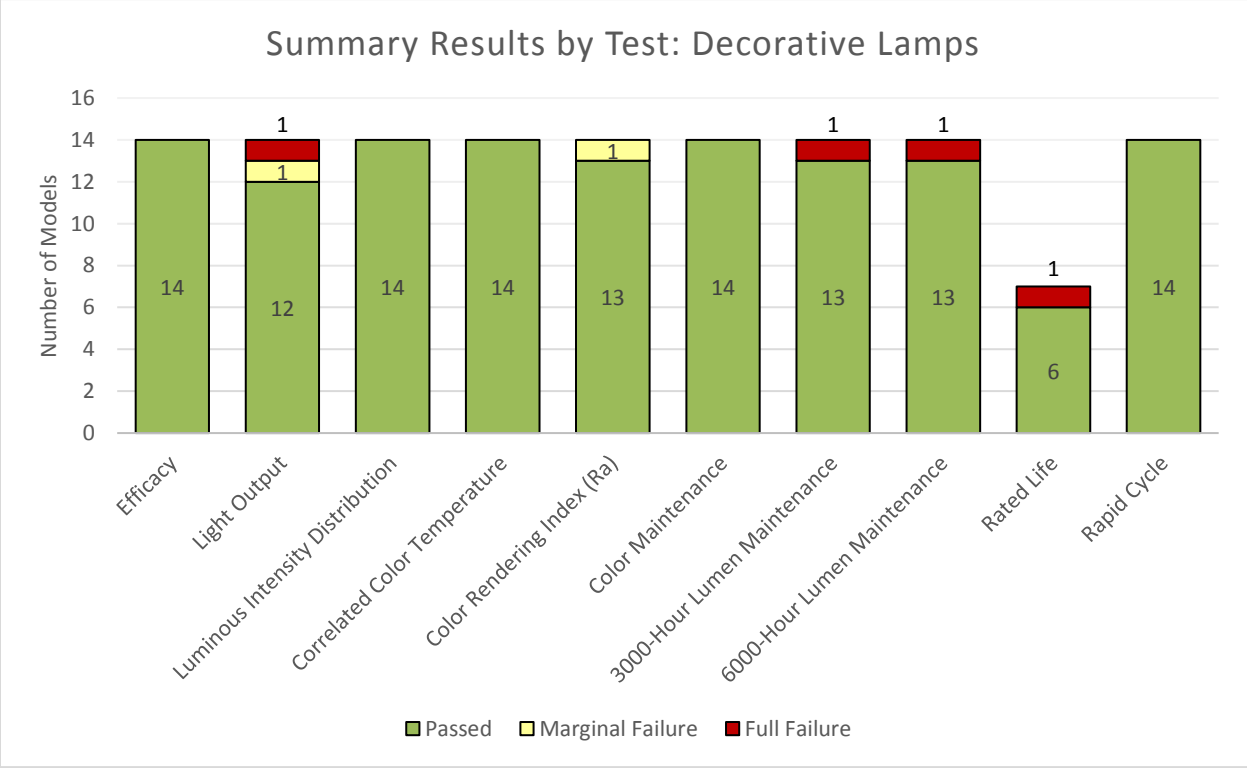


Table 1: Percent Passing and Failing Each Requirement by Lamp Type[6]

Requirement	Lamp Type	Passed	% Full Failure (Marginal)
Efficacy	**All Types**	**100.0%**	**0.0%**
Light Output	Omnidirectional	88.9%	8.3% (2.8%)
	Directional	96.4%	3.6%
	Decorative	85.7%	7.1% (7.1%)
	All Types	**92.4%**	**5.7% (1.9%)**
Center Beam Intensity	Directional	96.9%	2.1% (1.0%)
Elevated Temp. Light Output	Directional	100.0%	0.0%
Luminous Intensity Distribution (Omnidirectional and Decorative)	**All Types**	**100.0%**	**0.0%**
Correlated Color Temperature	Omnidirectional	97.2%	2.8%
	Directional	96.7%	3.3%
	Decorative	100.0%	0.0%
	All Types	**97.0%**	**3.0%**
Color Rendering Index (R_a)	Omnidirectional	100.0%	0.0%
	Directional	99.3%	0.0% (0.7%)
	Decorative	92.9%	0.0% (7.1%)
	All Types	**99.0%**	**0.0% (1.0%)**
Color Maintenance	Omnidirectional	94.4%	5.6%
	Directional	98.0%	2.0%
	Decorative	100.0%	0.0%
	All Types	**97.5%**	**2.5%**
Color Angular Uniformity	Directional	98.7%	1.3%
3,000-hour Lumen Maintenance	Omnidirectional	100.0%	0.0%
	Directional	92.1%	3.3% (4.6%)
	Decorative	92.9%	7.1%
	All Types	**93.5%**	**3.0% (3.5%)**
6,000-hour Lumen Maintenance	Omnidirectional	91.7%	8.3%
	Directional	87.4%	8.6% (4.0%)
	Decorative	92.9%	7.1%
	All Types	**88.6%**	**8.5% (3.0%)**
Rated Life	Omnidirectional	100.0%	0.0%
	Directional	98.0%	2.0%
	Decorative	92.9%	7.1%
	All Types	**98.0%**	**2.0%**
Rapid Cycle	**All Types**	**100.0%**	**0.0%**

[6] Excludes: Tests where CB randomly selects two out of five tests.

Table 1 excludes the five randomly selected requirements. If the failures from the randomly selected requirements are included, there are 70 total instances of failure across all 201 models and 17 total requirements. Of these 70 instances of failure, there were 51 full failures and 19 marginal failures.

Table 2: Marginal Failure Criteria Table[7]

After publication of the first consolidated technology-neutral ENERGY STAR Lamps specification, EPA issued revised criteria for "marginal failure" conditions under which a manufacturer could request a retest. The result is the following table published in January 2015.

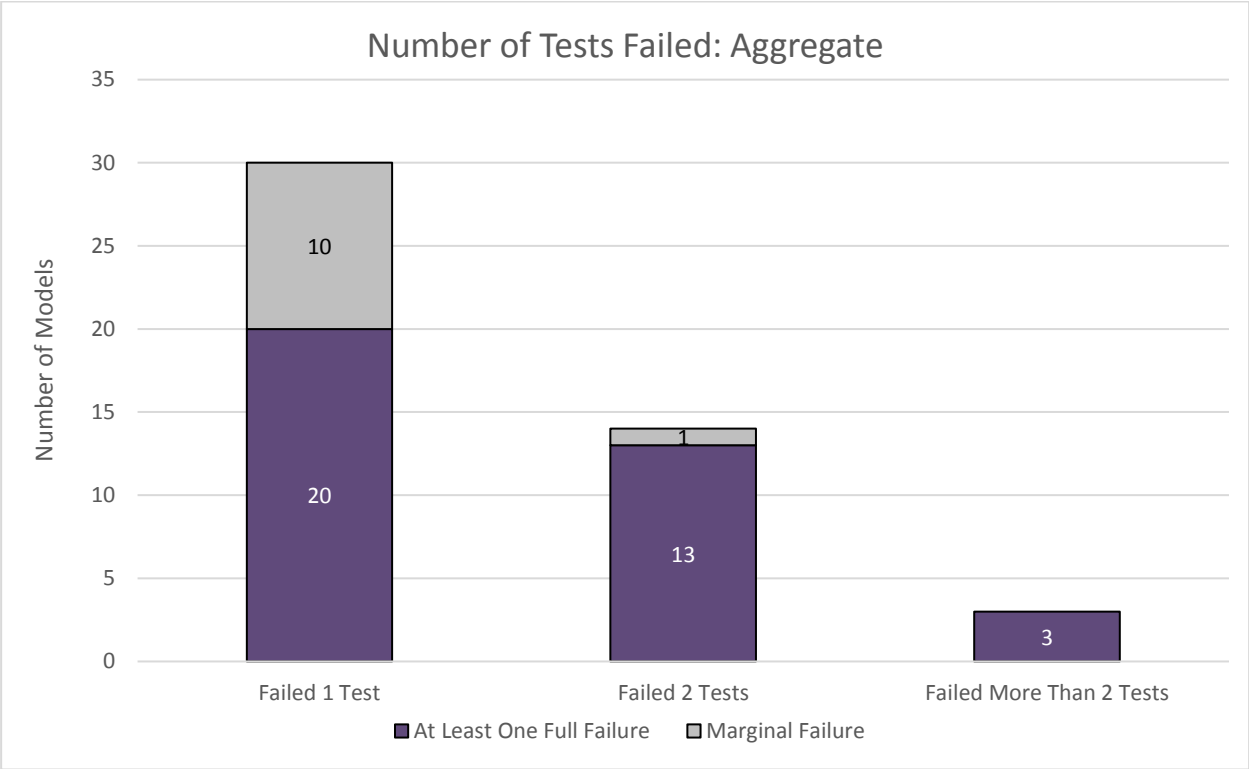
Requirement	Passing Criteria	Marginal Failure	Full Failure
Efficacy	Varies depending upon rated wattage	Measured average value and 8 or more units fail after 3% tolerance is applied	Measured average value and/or at least 3 lamps individually fail to meet efficacy > 6%
Light Output (Omnidirectional, Decorative, and Directional - R, BR, ER)	Varies depending upon wattage equivalency claim	Measured average value and 8 or more units fail after 3% tolerance is applied	Measured average value and/or at least 3 lamps individually fail to meet efficacy > 6%
Center Beam Intensity (Directional - PAR, MR, MRX)	Varies, minimum value calculated by the benchmark tool	≤ 6% below value	More than 6% below value
Elevated Temperature Light Output Ratio (Directional only)	Varies depending upon beam angle and wattage equivalency claim	85% ≤ Light Output < 90%	< 85%
Luminous Intensity Distribution (Omnidirectional and Decorative only)	Varies by lamp type	≤ 85% of the luminous intensity measured values vary by no more than 25% from the average of all measured values	> 5% of total flux in the 135° to 180° zone and/or > 85% of the luminous intensity measured values vary by > 25% from the average of all measured values
Correlated Color Temperature	9 out of 10 samples in the quadrangle	2 samples fall outside the 7 steps	3 samples fall outside the 7 steps
Color Rendering Index (R_a)	Color Rendering Index (R_a) ≥ 80. The average of units tested shall meet the requirements and no more than 3 units shall have R_a < 77. No unit shall have R_a < 75.	Average up to 3 points below requirement, or 4 units fall below 77 but average is at least 80	Average is ≤ 76, or 5 units fall below 77, or any unit has CRI < 75

[7] Source: Lamps Verification Testing: Marginal Failure Table. https://www.energystar.gov/ia/partners/downloads/mou/Lamps_V1.1_Marginal_Fail_Table.pdf?2a1e-835c

Requirement	Passing Criteria	Marginal Failure	Full Failure
Color Maintenance	Lamp change in chromaticity from 0-hour measurement, at any measurement point during the first 6,000 hours of lamp operation, shall be within a total distance of 0.007 on the CIE[8] 1976 u'v' diagram. Nine or more units shall meet the requirement.	0.007 – 0.0075 average, and/or 2 samples fail to meet requirement	> 0.0075
Color Angular Uniformity (Directional only)	Variation of chromaticity across the beam angle of the lamp shall be within a total distance of 0.006 from the weighted average point on the u'v' diagram	0.006 – 0.007	> 0.007
3,000-hour Lumen Maintenance	≥ 25,000 hour rated life: ≥ 95.8% ≥ 15,000 hour rated life: ≥ 93.1%	> 3% to ≤ 6%	> 6%
6,000-hour Lumen Maintenance	≥ 25,000 hour rated life: ≥ 91.8% ≥ 15,000 hour rated life: ≥ 86.7%	> 3% to ≤ 6%	> 6%
Rated life	Decorative: ≥ 15,000 hours All other lamps: ≥ 25,000 hours All units operational at 3,000 hours, ≥ 90% units operational at 6,000 hours	No marginal criteria	Model does not meet passing criteria
Rapid Cycle	At least 5 out of 6 units shall survive the minimum number of cycles	2 units fail to survive	3 units fail to survive
Power Factor[9]	The average of 10 lamp models shall have a power factor greater than or equal to 0.665	≤ 5% below	> 5% below
Start Time	> 1000ms	> 1000 and ≤ 1500 milliseconds	> 1500 milliseconds
Transient Protection[10]	All 5 units fully operational	1 unit fails	2 units fail
Dimensional Requirements	Lamp shall comply with American National Standards Institute minimum and maximum overall length (MOL) and diameter values, where they exist	Omnidirectional Lamp: ±5% tolerance for MOL	Omnidirectional lamp: > ±5% for MOL; all other lamps: does not meet requirements

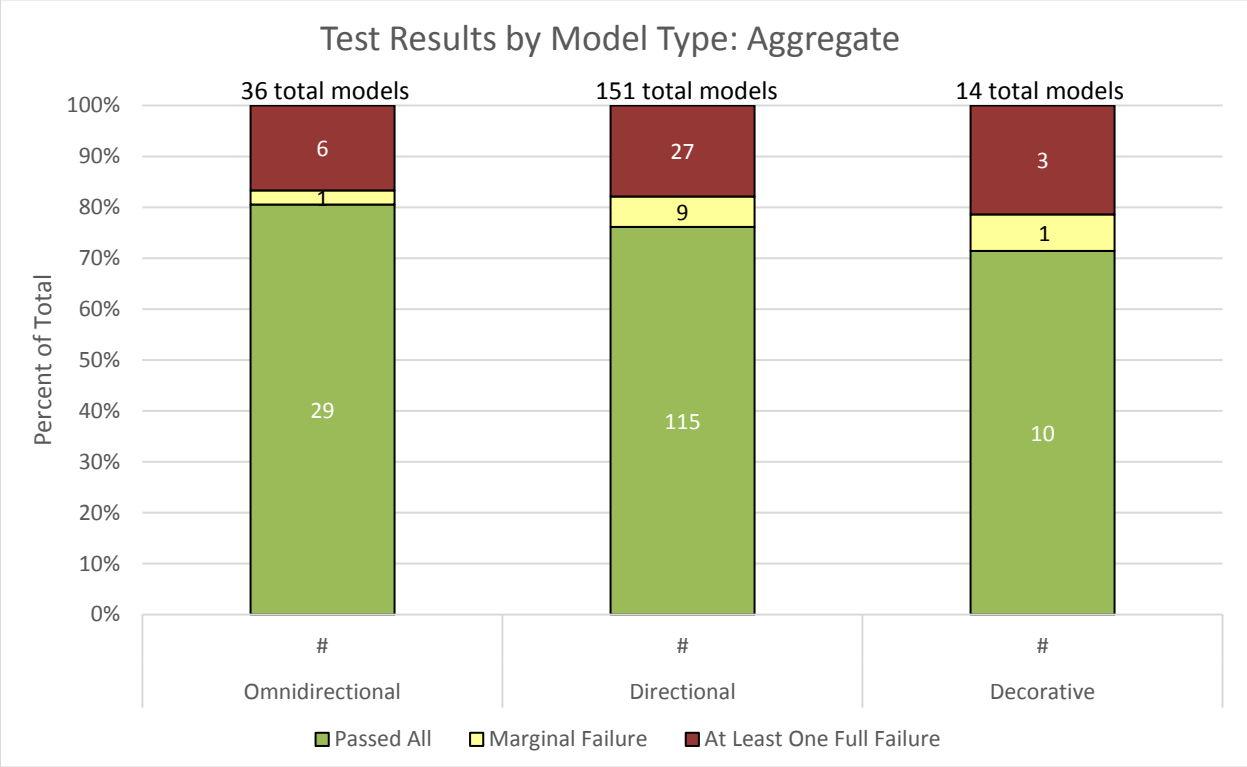
[8] Commission Internationale de l'Eclairage
[9] Exemption: Lamps ≤ 5 watts
[10] Exemption: Low voltage lamps

Figure 2: Number of Tests Failed: Aggregate



Of the 201 models tested, 36 models were reported as having fully failed the lamps specification requirement, out of which 20 models fully failed one requirement, 13 models fully failed two requirements, and three models fully failed four requirements. A total of 11 models marginally failed one or more requirement, including 10 models that marginally failed one requirement, and one model that marginally failed two requirements. See Figure 2.

Figure 3: Test Results by Model Type: Aggregate



Overall failure rates are fairly consistent across lamp types. Similar proportions of each lamp type failed across requirements, with proportions of lamps fully failing of 17% for omnidirectional lamps (3% marginal), 18% for directional lamps (6% marginal failure), and 21% for decorative lamps (7% marginal). Marginal failure rates were also comparable across model types. Decorative lamps failed at a slightly greater proportion, but this product category also has the smallest sample size. See Figure 3 and Table 3.

Table 3: Failures for All Models Tested

	All Lamp Types		Omnidirectional		Directional		Decorative	
	#	%	#	%	#	%	#	%
Passed All	153	76%	29	81%	115	76%	10	71%
Marginal Failure	12	6%	0	0%	11	7%	1	7%
At Least One Full Failure	36	18%	6	17%	27	18%	3	21%
Failed 1 Requirement	20	10%	3	8%	16	11%	1	7%
Failed 2 Requirements	13	6%	3	8%	8	5%	2	14%
Failed 4 Requirements	3	1%	0	0%	3	2%	0	0%
Total Models Tested	201	100%	36	18%	151	75%	14	7%

The number of requirements failed per lamp type varied slightly across lamp types. All three lamps that failed more than two requirements were directional lamps, although more directional lamps were tested than omnidirectional and decorative lamps. Directional lamps were also subjected to 13 requirements, while omnidirectional and decorative lamps were subject to 12 requirements.

Figure 4: Requirements Failed by Lamp Type[11]

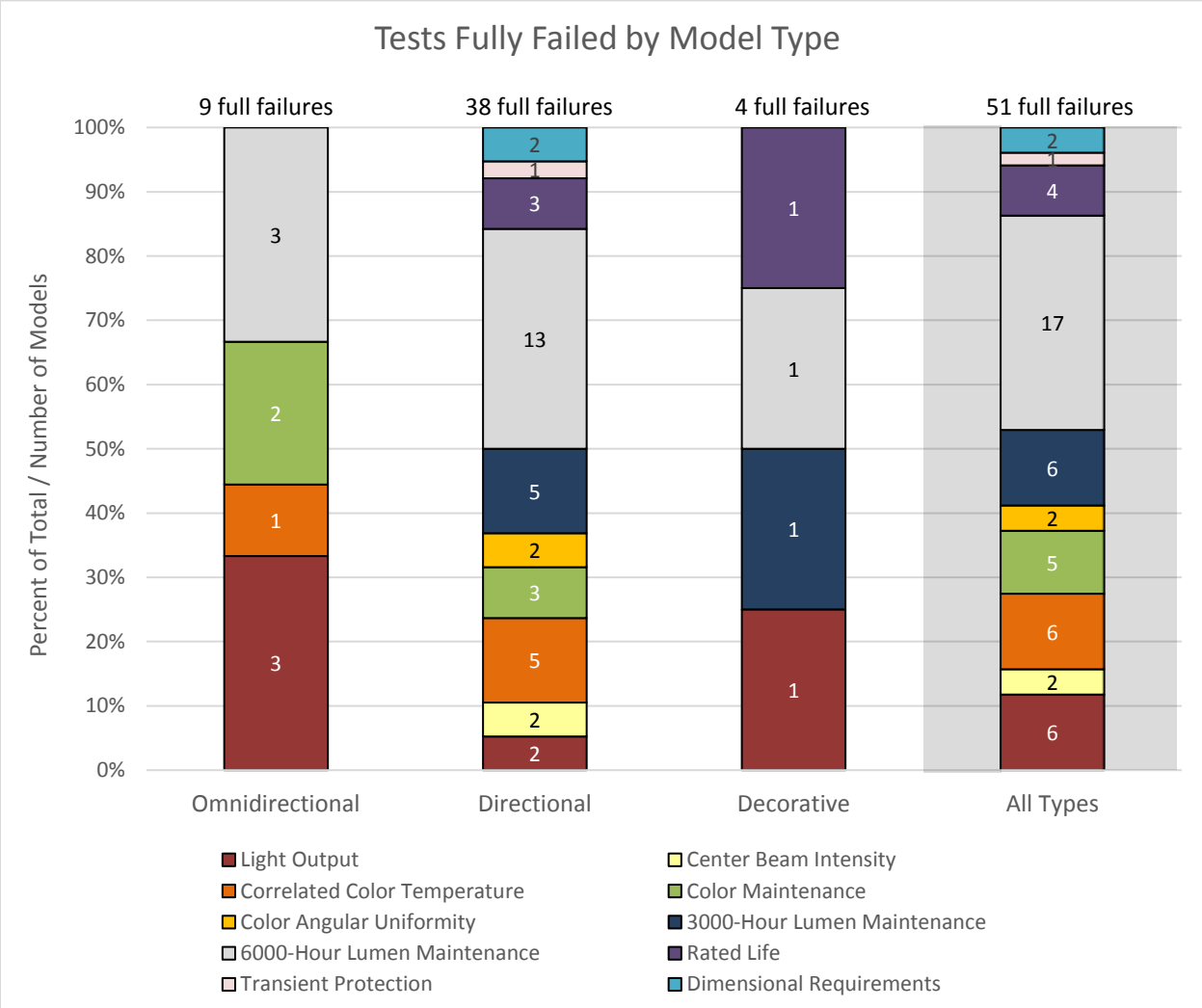


Figure 4 shows how full failures are distributed across the 10 requirements where there were full failures. There were 51 instances of full failures overall. The 6,000-hour lumen maintenance requirement was the most common requirement failed, and it represents 33% of all full failures. By comparison, 12% of all full failures were 3,000-hour lumen maintenance failures.

[11] No verification testing failures for the following tests: efficacy, elevated temperature, luminous intensity distribution, rapid cycle

Table 4: Models Failed by Year

	Models with At Least One Full Failure		Models with Only Marginal Failures		Total # of models tested
	#	%	#	%	
2013	0	0%	1	25%	4
2014	9	13%	2	3%	68
2015	27	21%	8	6%	129
Overall	**36**	**18%**	**11**	**5%**	**201**

Between 2013 and 2015, ENERGY STAR certified LED lamps had an overall full failure rate of 18% and a marginal failure rate of 5%. Looking across the years, the full failure rate increases from 13% in 2014 to 21% in 2015. The marginal rate also increases slightly from 3% in 2014 to 6% in 2015. Although the overall failure rates include 2013, the small number of samples (n=4) tested in 2013 make it difficult to draw conclusions from that year's data.

Methodology

Models were tested in accordance with the version of the ENERGY STAR Lamps specification that they were certified to. The majority of LED lamps tested in this period were certified and verified to Version 1.1 of the ENERGY STAR Lamps specification published on August 28, 2014 and effective September 30, 2014.[12] ENERGY STAR verification testing requirements call for 10% of unique ENERGY STAR certified LED lamp models to undergo verification testing during a calendar year. Up to half of the total verification testing selections are selected by EPA, utilities, brand owner organizations, states, efficiency program sponsors, and other government entities. The remainder is selected using a random generator.

Product selection is conducted in December of the year prior to the verification testing year. For example, 2013 selections were determined in December 2012, 2014 selections in December 2013, and so on. This report presents results for the 201 models from the 2013-2015 selections, all of which have completed full verification testing by October 17, 2016.[13]

At the conclusion of each test, the laboratory sends the completed lab report to an EPA-recognized CB. The CB reviews the test report and determines whether the test results meet the relevant ENERGY STAR specification. If the CB determines that the model fails to meet any of the requirements according to the ENERGY STAR Lamps specification and the verification testing directive, the CB refers the failure to EPA.

Table 5: Tests Required for ENERGY STAR Verification Testing[14]

Omnidirectional and Decorative	Directional	Test type	Passing Criteria
Efficacy	Efficacy	Photometric	Varies depending upon rated wattage
Light Output	Light Output (R, BR, ER) Center Beam Intensity (PAR, MR, MRX)	Photometric	Varies depending upon wattage equivalency claim
N/A	Elevated Temperature Light Output Ratio	Photometric	Varies depending upon beam angle and wattage equivalency claim
Luminous Intensity Distribution	N/A	Photometric	Varies by lamp type
Correlated Color Temperature	Correlated Color Temperature	Photometric	9 out of 10 samples must fall within the a seven-step quadrangle
Color Rendering Index (R_a)	Color Rendering Index (R_a)	Photometric	Color Rendering Index (R_a) ≥ 80. The average of units tested shall meet the requirements and no more than 3 units shall have R_a < 77. No unit shall have R_a < 75.

[12] The current ENERGY STAR Lamps Program Requirements can be downloaded from the ENERRGY STAR website. Lamps tested before August 28, 2014 were tested against the Integral LED lamps v1.4 specification.

[13] Exception: models that were disqualified prior to completion of 6,000 hour testing, if partner requested to cease verification testing.

[14] For the power factor, frequency, start time, transient protection, and dimensional requirements: Per Directive No. 2015-01, the CB randomly selects two of the five tests for verification testing.

Omnidirectional and Decorative	Directional	Test type	Passing Criteria
Color Maintenance	Color Maintenance	Photometric	Lamp change in chromaticity from 0-hour measurement, at any measurement point during the first 6,000 hours of lamp operation, shall be within a total distance of 0.007 on the CIE 1976 u'v' diagram. Nine or more units shall meet the requirement.
N/A	Color Angular Uniformity	Photometric	Variation of chromaticity across the beam angle of the lamp shall be within a total distance of 0.006 from the weighted average point on the u'v' diagram.
3,000-hour Lumen Maintenance	3,000-hour Lumen Maintenance	Lifetime Performance	≥ 25,000 hour rated life: ≥ 95.8% ≥ 15,000 hour rated life: ≥ 93.1%
6,000-hour Lumen Maintenance	6,000-hour Lumen Maintenance	Lifetime Performance	≥ 25,000 hour rated life: ≥ 91.8% ≥ 15,000 hour rated life: ≥ 86.7%
Rated Life	Rated Life	Lifetime Performance	Decorative: ≥ 15,000 hours All other lamps: ≥ 25,000 hours All units operational at 3,000 hours ≥ 90% units operational at 6,000 hours
Rapid Cycle	Rapid Cycle	Lifetime Performance	At least 5 out of 6 units shall survive the minimum number of cycles.
Power Factor	Power Factor	Electronic	≥ 0.7
Frequency	Frequency	Electronic	≥ 120Hz
Start Time	Start Time	Electronic	< 1 second
Transient Protection	Transient Protection	Electronic	Lamp shall survive 7 strikes of a 100kHz ring wave, 2.5 kV level. All units shall be fully operational at the completion of testing.
Dimensional Requirements	Dimensional Requirements	N/A	Omnidirectional Lamp: ±5% tolerance for MOL

Detailed Results by Requirement

This section presents detailed failure results for the ENERGY STAR LED lamps verification testing initiated between November 2013 and December 2015. For each of the 17 requirements, results are presented by lamp type.

Luminous Efficacy

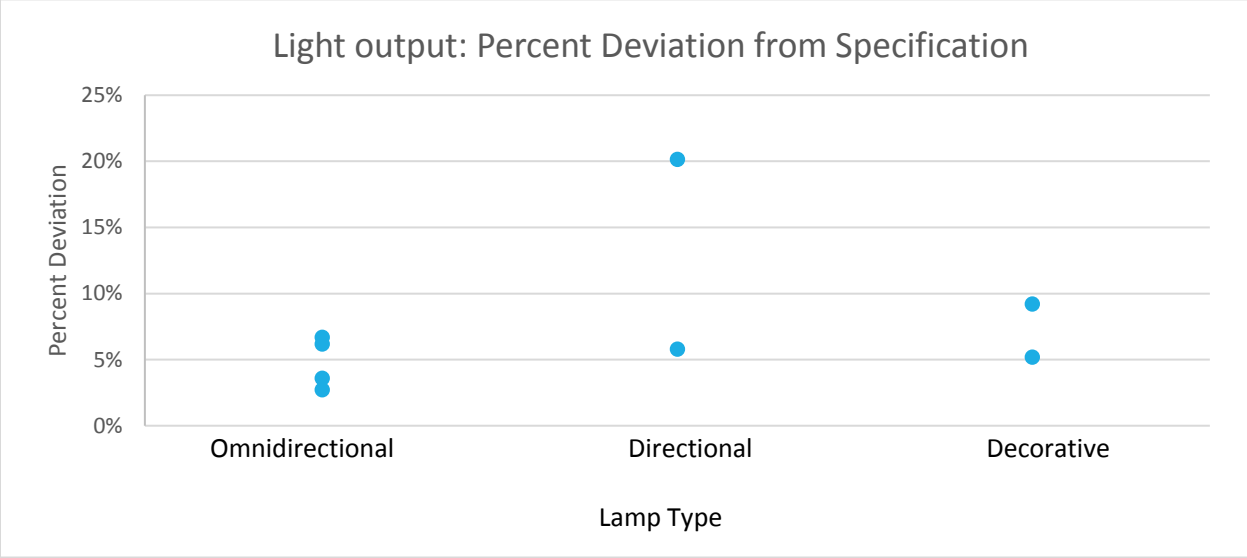
Efficacy is light output divided by power; it is measured in lumens per watt. Models must have a measured efficacy of at least the ENERGY STAR efficacy requirement for that model type (with a tolerance of 3%) to pass the requirement.

All models passed the luminous efficacy requirement.

Light Output (exemption: PAR, MR, and MRX lamps)

Reported initial light output (measured in lumens) for each lamp model must fall within the range of the referenced incandescent lamp (i.e., for wattage equivalency claim made on the lamp, its base or packaging, product literature or point-of-purchase materials, either printed or electronic). In addition, eight or more units (out of 10) shall individually meet the requirement.

Figure 5: Light Output Percent Deviation from Specification



There were eight reported light output failures, including six full failures and three marginal failures.

Table 6: Light Output Summary Results

Requirement	Lamp type	Passed		Full Failures (Marginal Failures)	
		#	%	#	%
Light Output	Omnidirectional	32	88.9%	3 (1)	8.3% (2.8%)
	Directional	53	96.4%	2	3.6%
	Decorative	12	85.7%	1 (1)	7.0% (7.0%)
	All Types	**97**	**92.4%**	**6 (2)**	**5.7% (1.9%)**

Light Output - Center Beam Intensity (PAR, MR, and MRX lamps)

The center beam Intensity requirement specifies the light emitting power of a point source in a particular direction. The center beam intensity must exceed the minimum value calculated by the ENERGY STAR Lamp Center Beam Intensity Benchmark Tool (i.e., for the wattage equivalency claim made on the lamp, its base or packaging, product literature or point-of-purchase materials, either printed or electronic).

Three models were reported as having failed the center beam intensity requirement. As this requirement is limited to directional (PAR, MR, and MRX) lamps only, all center beam intensity failures were directional lamps.

Table 7: Center Beam Intensity Detailed Failure Information

Model Type	Spec Requirement	Test Result	% Deviation from Spec	Marginal or Full Failure
Directional	9502 candela	9089 candela	4.4%	Marginal Failure
Directional	906 candela	658 candela	31.7%	Full Failure
Directional	2231 candela	2061 candela	7.9%	Full Failure

Elevated Temperature Light Output Ratio (Directional lamps)

Elevated temperature is the ratio of the light output of the lamp when tested in the same elevated temperature condition required for lumen maintenance, to its initial light output. The tested lamp shall maintain ≥ 90% of initial light output measured at ambient temperature when tested in the same elevated temperature condition required for lumen maintenance.

Only directional lamps are required to meet the elevated temperature light output ratio requirement, and all models passed.

Luminous Intensity Distribution (Omnidirectional and Decorative lamps)

The luminous intensity distribution requirement specifies the light emitting power of a point source in a particular direction. Luminous intensity distribution shall emulate that of the referenced incandescent lamp.

Only omnidirectional and decorative lamps are required to meet the luminous intensity distribution requirement, and all models passed.

Correlated Color Temperature

Correlated color temperature (CCT) is a measure of the color appearance of a lamp model measured in Kelvin. CCT is scored based on the 7-step MacAdam ellipse or the American National Standards Institute (ANSI) quadrangle for the manufacturer's specified color temperature.

All models were tested to this requirement, out of which there were six models reported as failures.

Table 8: Correlated Color Temperature Detailed Failure Information

Model Type	Spec requirement	Test Result	Full or Marginal Failure
Directional	≥ 9 out of 10 samples in range	0 of 10 samples in range	Full Failure
	2700K Claim	3019K	
Directional	≥ 9 out of 10 samples in range	7 out of 10 samples in range	Full Failure
	5000K Claim	5259K	
Directional	≥ 9 out of 10 samples in range	8 out of 10 samples in range	Full Failure
	2700K Claim	2831K	
Directional	≥ 9 out of 10 samples in range	0 out of 10 samples in range	Full Failure
	5000K Claim	4621K	
Directional	≥ 9 out of 10 samples in range	0 out of 10 samples in range	Full Failure
	3000K Claim	3270K	
Omnidirectional	≥ 9 out of 10 samples in range	0 out of 10 samples in range	Full Failure
	2700K Claim	2890K	

Color Rendering Index - R_a

Color rendering index (CRI) is a measure of a light source's ability to accurately render the color of illuminated objects; this is the effect of a light source on the color appearance of the objects it illuminates. It measures the degree of color shift objects undergo when illuminated by a light source as compared with the color of those same objects when illuminated by a reference source of comparable color temperature. CRI is defined according to Commission Internationale de l'Eclairage (CIE)'s Publication No. 13.3 1995.

Models tested to Lamps Version 1.1 were only subjected to CRI (R_a) criteria. Two models were reported as having marginally failed this requirement.

Table 9: Color Rendering Index (R_a) Detailed Failure Information

Model Type	Spec Requirement	Test Result	% Deviation from Spec	Marginal or Full Failure
Directional	≥ 80.0	78.4	2.0%	Marginal Failure
Decorative	≥ 80.0	79.6	0.5%	Marginal Failure

Color Maintenance

Color maintenance is a measure of the variation in chromaticity from 0-hour measurement, at any measurement point during the first 6,000 hours of lamp operation. Lamp change in chromaticity from 0-hour measurement, at any measurement point during the first 6,000 hours of lamp operation must fall within a certain distance on the CIE 1976 u'v' diagram.

Four models failed to meet the color maintenance requirement.

Table 10: Color Maintenance Detailed Failure Information

Model Type	Spec Requirement	Test Result	% Deviation from Spec	Marginal or Full Failure
Directional	≤ 0.007	4 samples > 0.007	N/A	Full Failure
Directional	≤ 0.007	0.06	158.2%	Full Failure
Directional	≤ 0.007	0.03	128.2%	Full Failure
Omnidirectional	≤ 0.007	10 samples > 0.007	N/A	Full Failure
Omnidirectional	≤ 0.007	10 samples > 0.007	N/A	Full Failure

Color Angular Uniformity (Directional lamps)

Color angular uniformity is a measure of the variation of chromaticity across the beam angle of the lamp. Color angular uniformity shall be within a total distance of 0.006 from the weighted average point on the CIE 1976 (u'v') diagram.

Only directional lamps are subject to the color angular uniformity requirement. Of all directional lamps, two lamps failed to meet this requirement.

Table 11: Color Angular Uniformity Detailed Failure Information

Model Type	Spec Requirement	Test Result	% Deviation from Spec	Marginal or Full Failure
Directional	≤ 0.006	0.0113	61.3%	Full Failure
Directional	≤ 0.006	0.0158	89.9%	Full Failure

3,000-Hour Lumen Maintenance

The 3,000-hour lumen maintenance test is an initial measurement of how well a product maintains its light output level over time. The lumen output is measured after 3,000 hours of time and is expressed as a percentage of the measured initial lumen output. Lumen maintenance is the converse of lumen depreciation.

Models with a rated life claim of 25,000 hours must maintain at least 95.8% of initial light output at 3,000 hours. Models with a rated life claim of 15,000 hours must retain at least 93.1% of initial light output.

Thirteen models failed this requirement, including six full failures and seven marginal failures. The full failures ranged from a 14% to 39% deviation from the specification requirement.

Figure 6: 3,000-Hour Lumen Maintenance Results

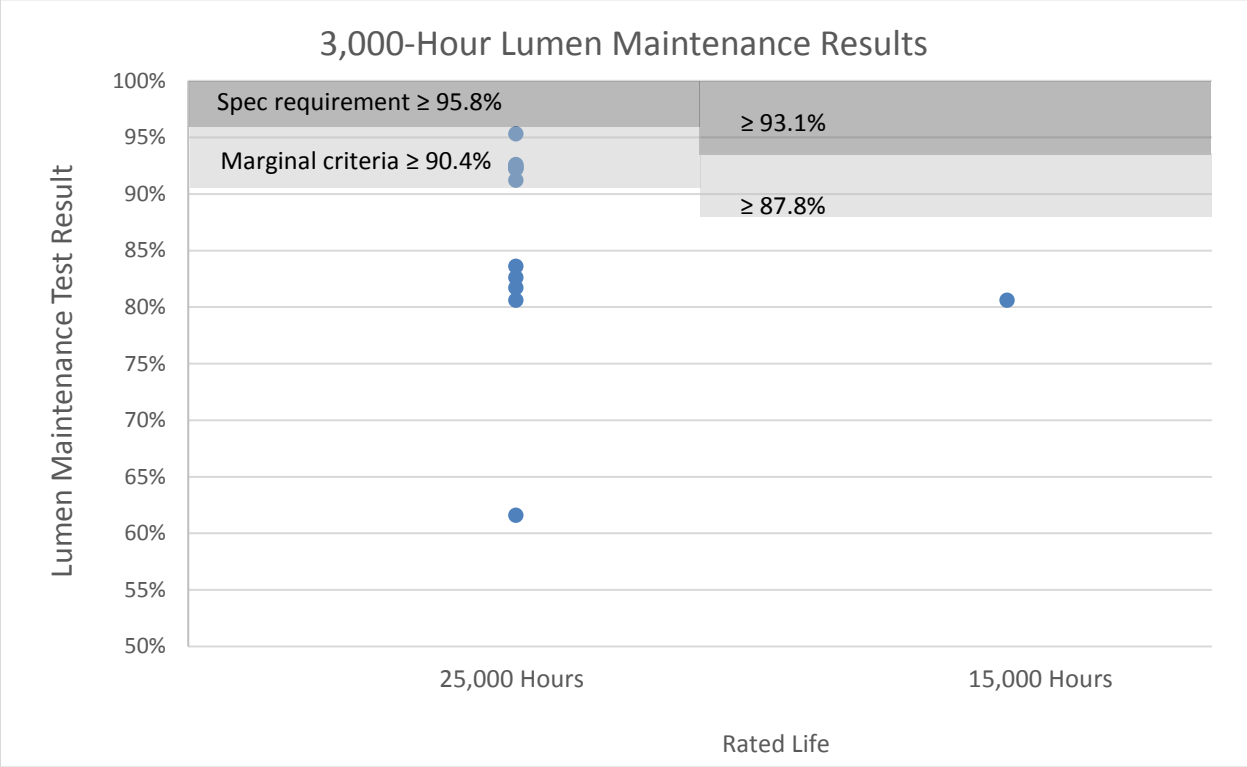


Table 12: 3,000-Hour Lumen Maintenance Summary Results

Requirement	Lamp type	Spec requirement	Passed		Full Failures (Marginal Failures)	
			#	%	#	%
3,000-hour Lumen Maintenance	Omnidirectional	≥ 95.8%	36	100.0%	0	0.0%
	Directional	≥ 95.8%	139	92.1%	5 (7)	3.3% (4.6%)
	Decorative	≥ 93.1%	13	92.9%	1	7.1%
	All Types		**188**	**93.5%**	**6 (7)**	**3% (3.5%)**

6,000-Hour Lumen Maintenance

6,000-hour lumen maintenance measures the lumen output after 6,000 hours of testing and is expressed as a percentage of the measured initial lumen output. The reported values are the average lumen maintenance of ≥ 9 surviving units for lamps certified to Lamps Version 1.1, and the average lumen maintenance of all 10 units for lamps certified to Integral LED lamps Version 1.4.

A total of 23 models failed the 6,000-hour lumen maintenance requirement (12% of total tested). This includes 17 full failures and six marginal failures. The worst performing model was a 43% deviation from the specification requirement. Six models that failed at the 3,000-hour mark also failed at the 6,000-hour mark. One model discontinued verification testing after failing at 3,000 hours.

Figure 7: 6,000-Hour Lumen Maintenance Results

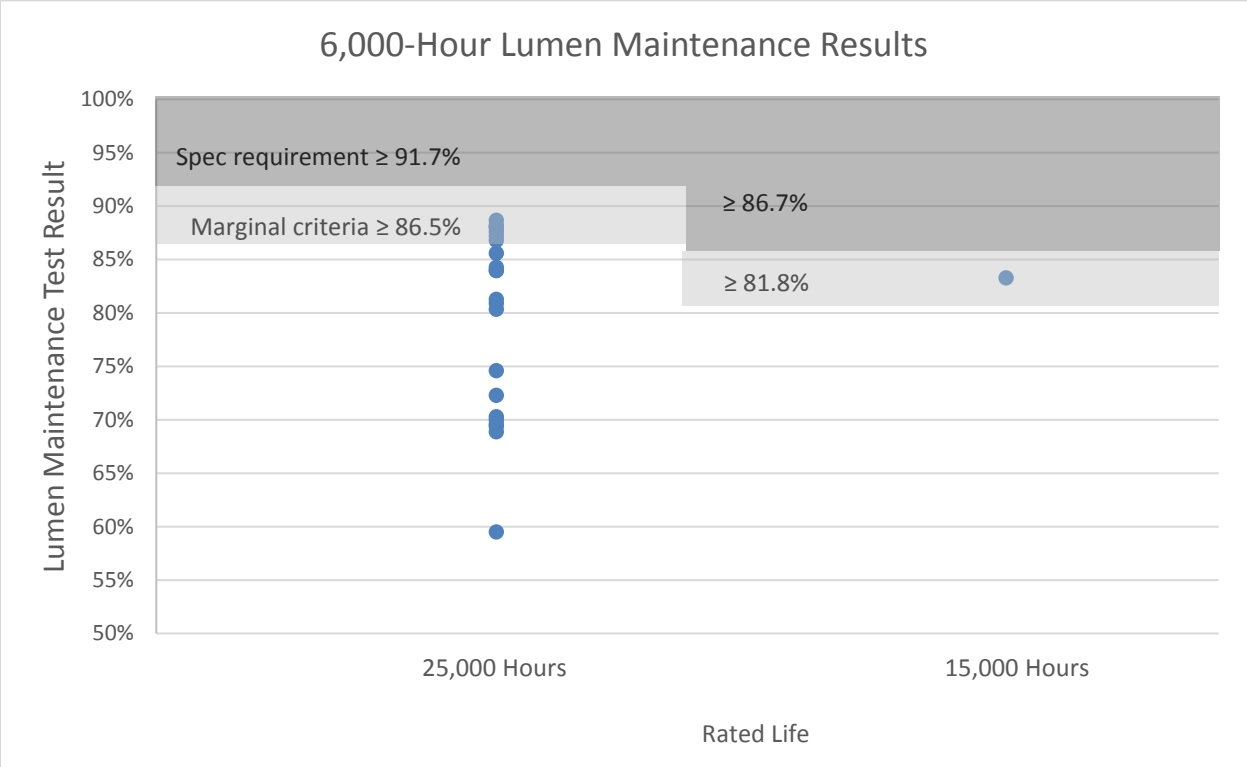


Table 13: 6,000-Hour Lumen Maintenance Summary Results

Requirement	Lamp type	Spec requirement	Passed		Full Failures (Marginal Failures)	
			#	%	#	%
6,000-hour Lumen Maintenance	Omnidirectional	≥ 91.8%	33	91.7%	3	8.3%
	Directional	≥ 91.8%	132	87.4%	13 (6)	8.6% (4.0%)
	Decorative	≥ 86.7%	13	92.9%	1	7.1%
	All Types		**178**	**88.6%**	**17 (6)**	**8.5% (3.0%)**

Rated Life

The rated life criteria sets the requirement of the minimum elapsed operating time over which the defined population of LED lamps should maintain a target percent of initial light output. Additionally, at 3,000 hours, any catastrophic failure - where a lamp is no longer operational - is considered a rated life failure. At 6,000 hours, two catastrophic failures would be considered a rated life failure.[15]

Four models failed the rated life requirement. All four models failed because exactly one lamp became non-operational at 3,000 hours. Of these four models, three are directional lamps and one is a decorative lamp.

Rapid Cycle

The rapid cycle stress test cycles the lamp through intervals of being on and then off for two or five minute cycles. This requirement tests the lamps' ability to survive being frequently turned on and off.

No models failed the rapid cycle requirement.

Power Factor

Power factor is the measure of the active power of the LED lamp divided by the apparent power. In other words, it is the input power in watts divided by the product of root mean square (RMS) input voltage and RMS input current of a ballast or driver.

During verification testing, CBs may select this requirement out of a list of five at random. There were no reported power factor failures.

Frequency

Frequency measures the number of complete oscillations per second of the lamp light output waveform.

During verification testing, CBs may select this requirement out of a list of five at random. There were no reported frequency failures.

Start Time

The start time criteria measures the time (in milliseconds) after switching an LED lamp on for it to start and remain lit. In order words, it is the time between the application of electrical power for the lamp to remain continuously illuminated.

During verification testing, CBs may select this requirement out of a list of five at random. One model was reported to have marginally failed the start time requirement.

Table 14: Start Time Detailed Failure Information

Model Type	Spec Requirement	Test Result	Marginal or Full Failure
Directional	< 1 sec	1.5 sec	Marginal Failure

[15] Rated life was not a requirement of Integral LED Lamps Version 1.4, so 74 LED lamps were not evaluated for this requirement.

Transient Protection

Transient protection is a measure of the lamp's ability to protect against surges in voltage. Lamps are subjected to seven strikes of a 100 kHz ring wave, at 2.5kV.

During verification testing, CBs may select this requirement out of a list of five at random. One model was reported to have fully failed the transient protection requirement. For this failure, only one out of five samples survived the voltage surge.

Table 15: Transient Protection Detailed Failure Information

Model Type	Spec Requirement	Test Result	Marginal or Full Failure
Directional	All 5 samples survive	1 surviving sample	Full Failure

Dimensional Requirements

Dimensional requirements address whether a lamps' minimum overall length (min OAL), maximum overall length (MOL), and diameter fall within a standard range. Two models failed to meet the dimensional requirements.

Table 16: Dimensional Requirements Detailed Failure Information

Model Type	Spec Requirement	Test Result	% Deviation	Marginal or Full Failure
Directional	Min OAL is 69.9mm	63.7mm	9.3%	Full Failure
Directional	MOL is 95.3mm	121.7mm	24.3%	Full Failure

Conclusion

The performance of the 201 models that were selected for verification testing between November 2013 and December 2015 indicates fairly consistent performance across ENERGY STAR certified LED lamps. Overall failures rates are similar across lamp types, and there are no outliers in terms of lamp types that failed certain requirements significantly more than other lamp types.

Most requirements had low failure rates, with only two requirements with overall failure rates greater than 5%: 3,000-hour lumen maintenance, and 6,000-hour lumen maintenance. The 6,000-hour lumen maintenance requirement was the most frequently failed requirement; 12% of all models tested failed to meet this requirement, including some models that failed with a significant deviation from the specification. Fewer models (7%) failed to meet the 3,000-hour lumen maintenance requirement, and several models also had a significant deviation from the requirement. Lumen maintenance is a feature that consumers are likely to notice, especially if lumen maintenance drops significantly.

The verification testing program provides a mechanism for EPA to monitor the continued performance of ENERGY STAR certified models available in the marketplace. One should exercise caution when generalizing from the test results described in this report for three key reasons:

First, the ENERGY STAR certified product list is highly dynamic. The test results used in this report were based on products selected in 2013-2015. Many of those models are no longer available, and new models are continually introduced.

Second, certain subsamples of tested models are quite small. For example, only 14 decorative lamps were selected for verification testing during the period referenced in this report, and so provide a limited examination of this product type.

Third, the tested models do not necessarily reflect their prominence in the market. Some of the models that have been tested are sold in large volumes while others have much smaller sales volumes. The test results have not been weighted to reflect these differences.