Municipal Solid-State STREET LIGHTING CONSORTIUM

Sponsored by the U.S. Department of Energy

SOLID-STATE STREET LIGHTING CALCULATING LIGHT LOSS FACTORS

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OUTLINE

- Why Use Light Loss Factors
- Standards
- Lamp Life
- Light Loss Factors
  - Equipment Factors
  - Maintenance Factors
    - Luminaire Dirt Depreciation (LDD)
    - Lamp Lumen Depreciation (LLD)
- L_{70}
- L_{AL}

WHY WE USE LIGHT LOSS FACTORS (LLF)

- Luminaires age over time resulting in reduced lumen output
- Recognized standards identify minimum light level requirements to be maintained on roadways and areas for life of lighting system.
  - IESNA RP-8-00
  - AASHTO
- LLF allows the forecasting of system performance over a given lifetime to meet the minimum lighting standards
- Can help minimize liability – system has been planned and designed for future operation, not just for the day it is installed.

Street and Area Lighting Goal

Security, Safety, Commercial Interests, Community Pride

STANDARDS

- IESNA LM-79-08: IESNA Approved Method for the Electrical and Photometric Measurements of Solid-State Lighting
- IESNA LM-80-08: IESNA Approved Method for Measuring Lumen Maintenance of LED Lighting Sources
- IESNA TM-21-11: Projecting Long Term Lumen Maintenance of LED Light Sources

IESNA LM-79-08

LUMINAIRE TESTING LABORATORY, INC.

LTL NUMBER: 15484 DATE: 04-21-2009
PREPARED FOR: COOPER LIGHTING
CATALOG NUMBER: OVN03LEDEU2
LUMINAIRE: CAST ALUMINUM HOUSING, CAST WHITE ENAMEL ALUMINUM REFLECTOR, NO ENCLOSURE.
LAMP: 63 WHITE LEDS WITH CLEAR PLASTIC OPTICS BELOW EACH.
LED POWER SUPPLY: ONE ADVANCE LED120A0024V33F
POWER FACTOR: 0.982
ELECTRICAL VALUES: 120.0VAC, 0.7945A, 93.6W
NOTE: THIS TEST WAS PERFORMED USING THE CALIBRATED PHOTODETECTOR METHOD OF ABSOLUTE PHOTOMETRY."

IES CLASSIFICATION: TYPE II
LONGITUDINAL CLASSIFICATION: SHORT
CUTOFF CLASSIFICATION: CUTOFF**

FLUX DISTRIBUTION

LUMENS	IES UPWARD	UPWARD	TOTALS
HOUSE SIDE	936.61	0.00	936.61
STREET SIDE	3860.20	0.00	3860.20
TOTALS	4797.11	0.00	4797.11

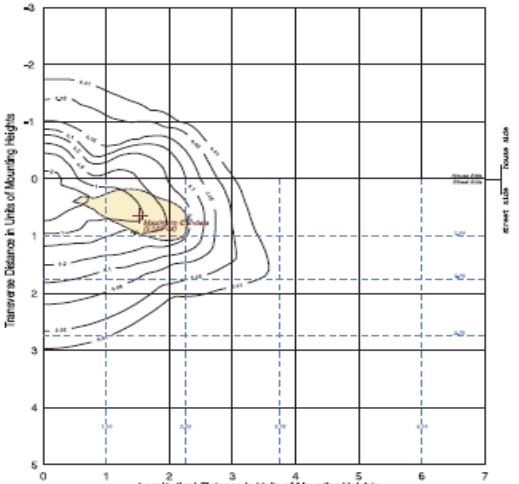
Approved By:

"DATA WAS ACQUIRED USING THE CALIBRATED PHOTODETECTOR METHOD OF ABSOLUTE PHOTOMETRY. A UIT MODEL 4100 PHOTODETECTOR AND UIT MODEL 4576 OPTOMETER COMBINATION WERE USED AS A STANDARD. A SPECTRAL MISMATCH CORRECTION FACTOR WAS EMPLOYED BASED ON THE SPECTRAL RESPONSIVITY OF THE PHOTODETECTOR AND THE SPECTRAL POWER DISTRIBUTION OF THE UUT (DUT).

TESTING WAS PERFORMED IN ACCORDANCE WITH IES LM-79-08.
TEST ANGULAR INCREMENTS AND REPORT FORMATTING WAS BASED ON IES LM-31-95.

LUMINAIRE TESTING LABORATORY, INC.

ISOFOOTCANDLE LINES OF HORIZONTAL ILLUMINATION
VALUES BASED ON 25.00 FOOT MOUNTING HEIGHT



PROJECTION OF HALF-MAX CANDELA CONTOUR

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LUMINAIRE TESTING LABORATORY, INC.

CANDELA DISTRIBUTION

	0	5	15	25	35	45	55	65	67.1	75	85
180	0	0	0	0	0	0	0	0	0	0	0
175	0	0	0	0	0	0	0	0	0	0	0
165	0	0	0	0	0	0	0	0	0	0	0
155	0	0	0	0	0	0	0	0	0	0	0
145	0	0	0	0	0	0	0	0	0	0	0
135	0	0	0	0	0	0	0	0	0	0	0
125	0	0	0	0	0	0	0	0	0	0	0
115	0	0	0	0	0	0	0	0	0	0	0
105	0	0	0	0	0	0	0	0	0	0	0
95	0	0	0	0	0	0	0	0	0	0	0
90	0	0	0	0	0	0	0	0	0	0	0
87.5	6	7	10	10	10	9	9	11	11	12	12
85	22	24	32	33	33	31	33	34	33	30	26
82.5	42	46	57	52	54	51	54	72	70	61	44
80	61	70	78	68	69	66	99	140	127	92	59
77.5	88	91	94	89	79	89	147	269	237	139	80
75	111	113	111	111	100	114	214	465	438	249	118
72.5	161	160	154	147	132	143	320	633	584	379	226
70	252	253	245	235	228	227	476	1459	1417	1054	511
67.5	377	376	374	372	384	427	855	2852	2757	2332	1026
65	455	453	452	465	500	718	1319	3763	3938	3079	1421
62.5	521	518	517	537	579	1004	1601	4269	4447	3304	1603
60	589	588	596	634	739	1280	1813	4698	5004	3601	1832
59	621	620	632	693	817	1372	1862	5014	5125	3755	1971
57.5	675	679	713	799	969	1552	1948	4967	5049	3865	2141
55	820	829	866	986	1294	1647	2119	4747	4783	3774	2202
52.5	948	965	979	1077	1618	1713	2320	4396	4437	3577	2113
50	1127	1128	1124	1378	1866	1781	2471	3984	4026	3300	1949
47.5	1243	1247	1350	1701	1956	1770	2537	3486	3528	2912	1728
45	1422	1448	1657	1937	1909	1788	2535	3071	3098	2446	1424
40	2126	2112	2121	2093	1879	1900	2596	2688	2641	1874	1051
35	2467	2457	2371	2202	2124	2336	2681	2561	2483	1675	977
30	2378	2375	2263	2238	2374	2532	2657	2296	2148	1479	976
25	2114	2113	2169	2197	2295	2307	2262	1909	1798	1389	1077
20	1830	1547	1661	1810	1932	1996	1872	1621	1556	1327	1272
15	1546	1544	1583	1634	1670	1698	1603	1457	1434	1406	1439
10	1566	1559	1566	1575	1570	1557	1543	1568	1587	1627	1625
5	1589	1562	1590	1611	1640	1687	1715	1705	1705	1690	1674
0	1669	1669	1669	1669	1669	1669	1669	1669	1669	1669	1669

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LUMINAIRE TESTING LABORATORY, INC.

CANDELA DISTRIBUTION

	90	95	105	115	125	135	145	155	165	175	180
180	0	0	0	0	0	0	0	0	0	0	0
175	0	0	0	0	0	0	0	0	0	0	0
165	0	0	0	0	0	0	0	0	0	0	0
155	0	0	0	0	0	0	0	0	0	0	0
145	0	0	0	0	0	0	0	0	0	0	0
135	0	0	0	0	0	0	0	0	0	0	0
125	0	0	0	0	0	0	0	0	0	0	0
115	0	0	0	0	0	0	0	0	0	0	0
105	0	0	0	0	0	0	0	0	0	0	0
95	0	0	0	0	0	0	0	0	0	0	0
90	0	0	0	0	0	0	0	0	0	0	0
87.5	11	11	9	7	6	4	2	1	1	0	0
85	27	29	31	26	18	15	14	13	13	10	9
82.5	40	42	49	43	31	26	24	23	24	18	18
80	53	56	61	50	39	33	30	29	32	25	25
77.5	69	70	72	60	47	39	34	36	38	31	30
75	90	86	82	68	50	41	38	41	42	36	35
72.5	170	134	93	70	52	44	41	44	43	39	38
70	322	219	115	74	55	49	44	46	46	41	40
67.5	712	571	293	95	63	53	47	47	47	43	42
65	1107	993	596	155	73	59	51	50	50	44	44
62.5	1354	1280	807	203	86	64	55	55	52	47	47
60	1562	1453	898	208	95	69	60	57	56	51	50
59	1660	1524	873	208	96	71	63	59	58	53	52
57.5	1706	1621	907	196	94	73	67	62	63	57	55
55	1817	1622	868	173	91	75	72	66	75	62	59
52.5	1758	1519	776	148	91	79	77	71	81	68	66
50	1609	1380	615	129	93	84	84	77	84	75	73
47.5	1402	1137	454	126	95	87	89	84	89	84	81
45	1125	889	384	134	98	90	95	93	97	93	90
40	799	630	314	169	136	142	164	165	165	156	153
35	762	660	443	323	266	315	352	370	370	361	367
30	892	831	695	602	552	587	621	621	604	585	592
25	1057	1038	973	927	856	862	869	853	822	820	831
20	1277	1275	1236	1183	1067	971	923	898	880	885	907
15	1462	1422	1379	1327	1262	1113	963	885	852	850	866
10	1600	1579	1526	1467	1429	1378	1298	1218	1145	1111	1122
5	1652	1641	1602	1570	1552	1539	1503	1468	1462	1478	1490
0	1669	1669	1669	1669	1669	1669	1669	1669	1669	1669	1669

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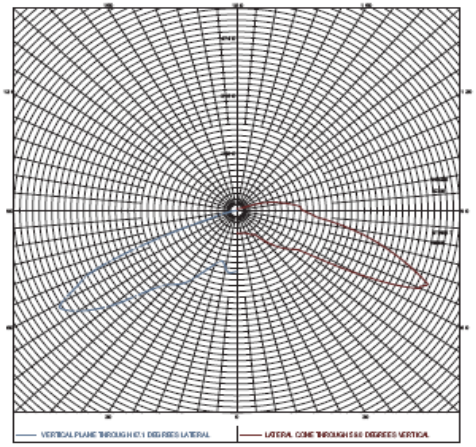
LUMINAIRE TESTING LABORATORY, INC.

MAXIMUM PLANE AND CONE PLOTS OF CANDELA



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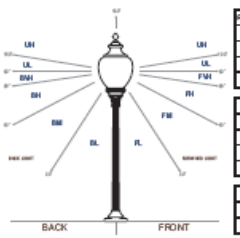
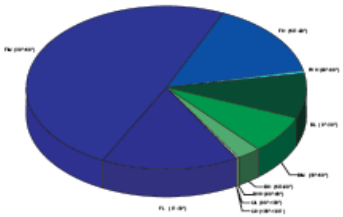
LUMINAIRE TESTING LABORATORY, INC.

FLUX DISTRIBUTION TABLE BASED ON THE IESNA LUMINAIRE CLASSIFICATION SYSTEM

FLUX



ZONE	LUMINAIRE LUMENS	% OF LUMINAIRE LUMENS
FORWARD LIGHT	3890	80.5
FL (0°-30°)	753	15.7
FM (30°-60°)	2360	49.2
FH (60°-80°)	729	15.2
FVH (80°-90°)	18	0.4
BACK LIGHT	937	19.5
BL (0°-30°)	429	8.9
BM (30°-60°)	362	7.6
BH (60°-80°)	135	2.8
BVH (80°-90°)	10	0.2
UPLIGHT	0	0
UL (90°-100°)	0	0
UH (100°-180°)	0	0
TRAPPED LIGHT	NA	NA



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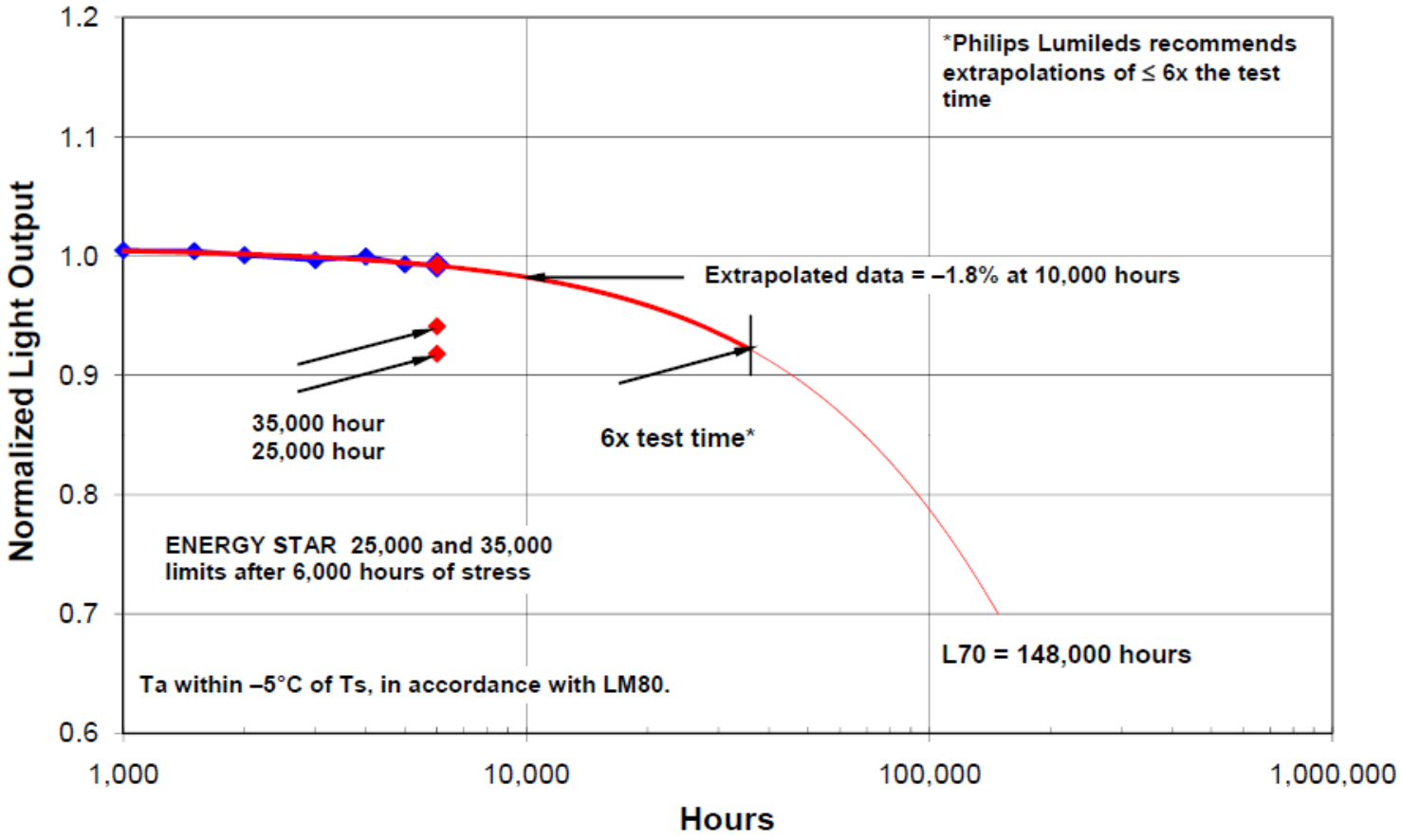
IESNA LM-80-08

PHILIPS LUMILEDS

Lumen Maintenance Projection for White LXM3-PWx1 LUXEON Rebel under these conditions

55°C, 0.35A (Tjunction ≅ 68°C) Normalized to 1 at 24 hours



RATED LAMP LIFE

HID Sources

- Time in hours at which 50% of a large sample group of initially installed lamps fail

Note:
Incandescent and fluorescent lamps are rated the same

LED Sources

- L_p = time in hours to which the lumen output has degraded to a percent "p" of initial lumens
- L_{70} commonly used
- Use LM-80 report to help determine L_p

Note:

LED lamps do not typically catastrophically fail. There lumen output degrades over time. This can be maintained through drive current control.

LIGHT LOSS FACTORS (SOLID STATE LIGHTING)

LLF = LLD x LDD x ATF x HE x VE x BF x CD

LLD: Lamp Lumen Depreciation
LDD: Luminaire Dirt Depreciation

Maintenance Factors

ATF: Ambient Temperature Effects
HE: Heat Extraction
VE: Voltage Effects
BF: Driver and Lamp Factors
CD: Component Depreciation

Equipment Factors

LIGHT LOSS EQUIPMENT FACTORS

LLF = LLD x LDD x ATF x HE x VE x BF x CD

Ambient Temperature Effects – utilizes historic ambient temperature data for area and luminaire performance data from the manufacturer

- Based on "on/off" control, max/min operation temperatures, incident sunshine on luminaire and daytime heat effects. Work with manufacturer.

Heat Extraction – luminaire has a thermal capacitance based on mass, specific heat of materials, and rate of dissipation.

- If system changes over time, it's thermal performance should be evaluated. Work with manufacturer.

LIGHT LOSS EQUIPMENT FACTORS

LLF = LLD x LDD x ATF x HE x VE x BF x CD

Voltage Effects – Most systems operate between 120 and 277 VAC. Efficiencies can vary with changes in input voltages.

- Evaluate system for sensitive to these variations, voltage dips, or power line transients. Work with manufacturer.

Driver and Lamp Factors – Some drivers provide AC and some DC current to LED. Drivers can be dimmable (continuous or step). Efficiency of the driver is reduced when LED load decreases.

- Evaluate if power supply output varies with operating temperature, current type and driver loading effects. Work with manufacturer.

Component Depreciation – Components can be affected by heat and environmental aging. Optical systems are effected by UV and reflective surfaces by humidity and oxidation.

- Evaluate potential for aging and UV effects. Work with manufacturer.

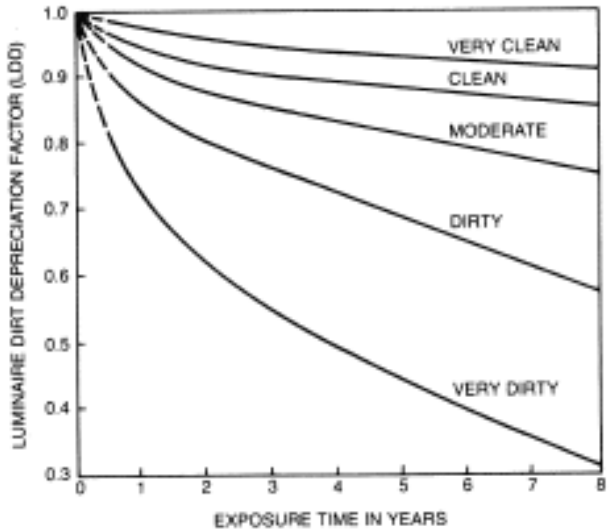
LIGHT LOSS MAINTENANCE FACTORS

LLF = LLD x **LDD** x ATF x HE x VE x BF x CD

Luminaire Dirt Depreciation – Dirt accumulates on the inside and outside of refractors, reflectors, and lamps, resulting in reduction of lumen output.

SOURCES FOR LDD DATA

- Historical site data
- Perform field measurements
- RP-8-05, Fig. 5 – LDD curves based on ambient environmental conditions and exposure time (cleaning frequency)



SELECT THE APPROPRIATE CURVE IN ACCORDANCE WITH THE TYPE OF AMBIENT AS DESCRIBED BY THE FOLLOWING EXAMPLES:

VERY CLEAN—No nearby smoke or dust generating activities and a low ambient contaminant level. Light traffic. Generally limited to residential or rural areas. The ambient particulate level is no more than 150 micrograms per cubic meter.

CLEAN—No nearby smoke or dust generating activities. Moderate to heavy traffic. The ambient particulate level is no more than 300 micrograms per cubic meter.

MODERATE—Moderate smoke or dust generating activities nearby. The ambient particulate level is no more than 600 micrograms per cubic meter.

DIRTY—Smoke or dust plumes generated by nearby activities may occasionally envelope the luminaires.

VERY DIRTY—As above but the luminaires are commonly enveloped by smoke or dust plumes.

LIGHT LOSS MAINTENANCE FACTORS

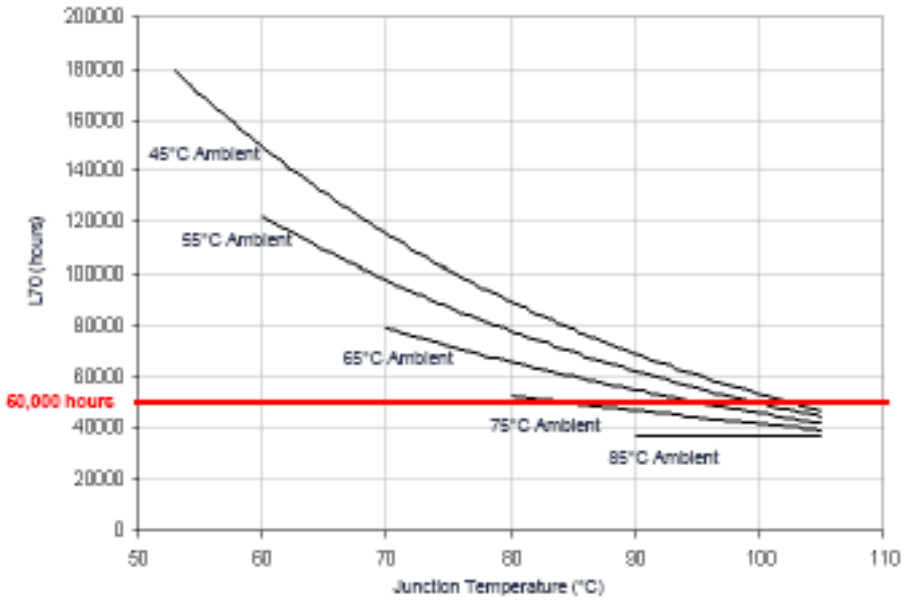
LLF = LLD x LDD x ATF x HE x VE x BF x CD

Lamp Lumen Depreciation – lumen output depreciates over time resulting in a gradual reduction in light levels.

LLD

Lumen Maintenance is a function of T_j and T_a within the LED package.

- LED's do not radiate heat
- Conduction and Convection are needed to keep LED's cool.



CREE LED Light

SOURCES FOR LLD MEASUREMENTS

- Manufacturer test data – these test should be done by independent laboratories.
- References include IESNA LM-79-08, LM-80-08, and LM-21-11.
- Reliable field test results.

METHODS FOR CALCULATING LLD

- L_{70} – life of system is based on luminaire retaining 70% of original lumen output
- Application Life (L_{AL}) – life of system is based on a chosen number of operating hours equal to or greater than the pay back period of the luminaire.

WHY L_{70}?

LM-80-08 lists a couple of examples, one indicates L_{70} (hours) = time to 70% lumen maintenance.

- OR -

The *Design Guide for Roadway Lighting Maintenance DG-4-03* indicates the "best time schedule" for relamping of HID luminaires is when the cost of **installation, energy use,** and **relamping** is minimal. This occurs at approximately 70% of rated lamp life.

- MOST LIKELY BECAUSE OF THE FOLLOWING -

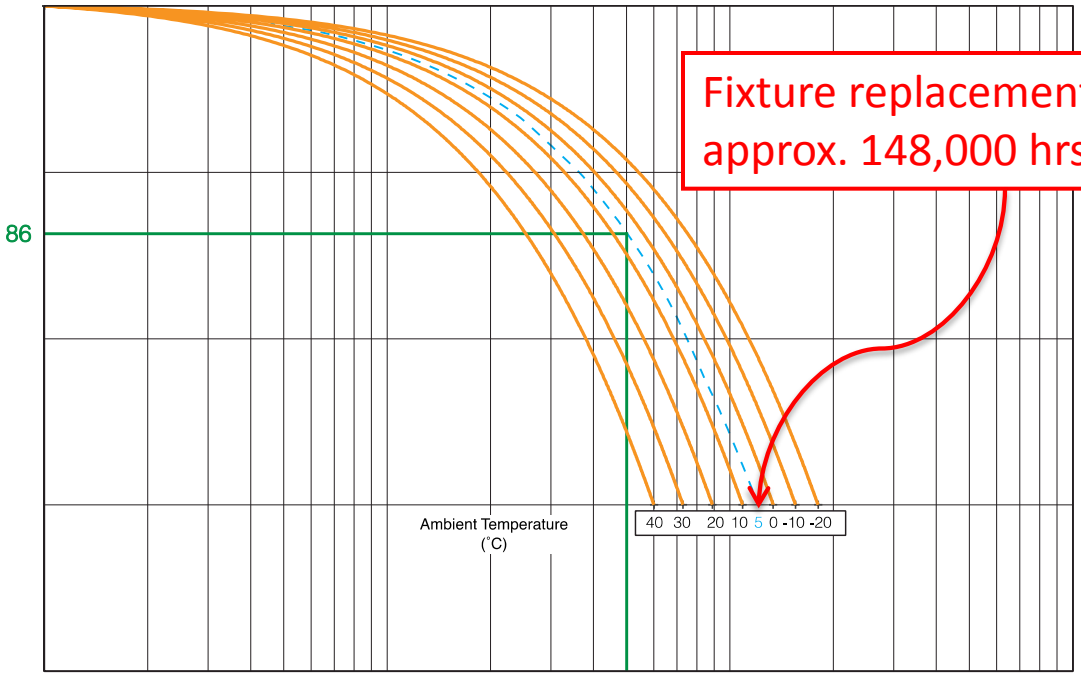
For a common application such as general lighting in an office environment, research has shown that the majority of occupants in a space will accept light level reductions of up to 30% with little notice, particularly if the reduction is gradual.[1] Therefore a level of 70% of initial light level could be considered an appropriate threshold of useful life for general lighting. Based on this research, the Alliance for Solid State Illumination Systems and Technologies (ASSIST), a group led by the Lighting Research Center (LRC), recommends defining useful life as the point at which light output has declined to 70% of initial lumens

WHAT DOES L_{70} MEAN IN TIME

LED LMF MULTIPLIER EXAMPLE: 525mA @ 5˚C

0.86	x	1.05	=	0.90
obtained from chart below		LEDs gain 0.25% lumen output for each degree C below 25%		New multiplier for this example
See step 2 from previous page for more information		25 - 5 = 20 20 x .25 = 5% 0.05 + 1.000 = 1.05		

BetaLED® LEDway® 525mA Lumen Maintenance Predictions vs. Ambient Temperature



Fixture replacement at approx. 148,000 hrs (34 years)

beta LED® By RUUD LIGHTING

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WHAT DOES L_{70} MEAN IN DESIGN

- Increase in system hardware for new installations

FROM  TO 

Increases maintenance needs & higher capital costs

- Prohibitive use of LED's on upgrade to existing installations due to light levels not able to be met
- Higher initial lumen output diminishing to designed level at 34 years

- Wasted energy costs until end of life when design minimum light levels are met.
- Large change in lumen output.

LLD BASED ON APPLICATION LIFE (L_{AL})

- Life of system is based on a chosen number of operating hours equal to or greater than the pay back period of the luminaire. Payback determined by a cost/benefit analysis
- Lets make some basic assumptions to illustrate:
  - 12 year luminaire life (50,000 hours)
  - Retain L_{70} as an absolute minimum light level
  - Maintenance will occur once during lifetime of fixture
  - Failure rate of 10%

Hold it, what about our payback period, can we achieve it?

LED LUMINAIRE COST/BENEFIT

Table 8-5 Payback Calculator

Decription	Base System	Luminaire A2	Luminaire A2
Number of Luminaires	1	1	1
Number of Lamps per Luminaire	1	1	1
Cost per Luminaire	$ 133.00	$ 428.00	$ 250.00
Installation Cost	$ 63.91	$ 63.91	$ 63.91
Initial Cost	**$ 196.91**	**$ 491.91**	**$ 313.91**
Annual Operations Cost per Fixture			
Watts per Fixture (luminaire and ballast/driver)	142	109	109
kW per Fixture	0.142	0.109	0.109
Annual Hours of Operation (12 hrs per day)	4,380 hrs	4,380 hrs	4,380 hrs
kW Hours per Year	622.0 kWh	477.4 kWh	477.4 kWh
Electric Rate ($/kWH)	$ 0.0530	$ 0.0530	$ 0.0530
Annual Energy Cost	**$ 32.96**	**$ 25.30**	**$ 25.30**
Annual Maintenance Cost			
Fixture Life (yrs)	15 yrs	15 yrs	15 yrs
Lamp Life (hrs)*	30,000 hrs	50,000 hrs	50,000 hrs
Lamp Life (yrs)	6.8 yrs	11.4 yrs	11.4 yrs
Theoretical Relamps/Cleanings Over Life of Fixture	2.2	1.3	1.3
Scheduled Relamps/Cleaning Over Life of Fixture	3.0	1.0	1.0
*Cost per Relamp/Cleaning (maintenance + parts)***	$ 102.43	$ 35.00	$ 35.00
Annualized Relamp/Cleaning Cost	$ 20.49	$ 2.33	$ 2.33
Other Annulized Costs (Catastrophic Failure/Damage)***	$ 29.25	$ 11.70	$ 11.70
Annual Maintenance Cost	**$ 49.74**	**$ 14.03**	**$ 14.03**
Conservation Rebate			
kWh Saved Compared to Base System****	NA	144.54 kWh	144.54 kWh
Adjustments (Conservation Rebate $0.23/kWh)	**NA**	**$ 31.80**	**$ 31.80**
Payback (Compared to Base HPS System)			
Adjusted Initial Cost per Fixture	$ 196.91	$ 460.12	$ 282.12
Rebate Adjusted			
Annual Operations Cost	$ 32.96	$ 25.30	$ 25.30
Annual Operations Savings	NA	$ 7.66	$ 7.66
Annual Maintenance Cost	$ 49.74	$ 14.03	$ 14.03
Annual Maintenance Savings	NA	$ 35.70	$ 35.70
Total Annual O&M Savings	NA	$ 43.36	$ 43.36
Payback Period		**6.1 yrs**	**2.0 yrs**

* Current Manufacturer Claims for life of LED is 50,000 hrs to 100,000 hrs.
Low end of projected life used for comparison purposes.
** LED fixtures to be cleaned only, no relamp required.
***Assumes a 25% failure rate for HPS luminaires and theoretical 10% failure for LED fixtur
****Savings shown as a positive number.

Energy Demand and Savings

Watts per Fixture	142	109	109
Base kWh	621.96	477.42	477.42
Savings in kWh (Compared to Base System)	NA	144.54	144.54

Currently pay back is achievable within 2 to 6 years of installation when compared to existing HID installations of 100W HPS luminaires in residential areas at least in Seattle.

Payback Period		6.1 yrs	2.0 yrs

WHAT DOES L_{AL} MEAN FOR LLD

LED LMF MULTIPLIER EXAMPLE: 525mA @ 5˚C

0.86	x	1.05	=	0.90
obtained from chart below		LEDs gain 0.25% lumen output for each degree C below 25%		New multiplier for this example
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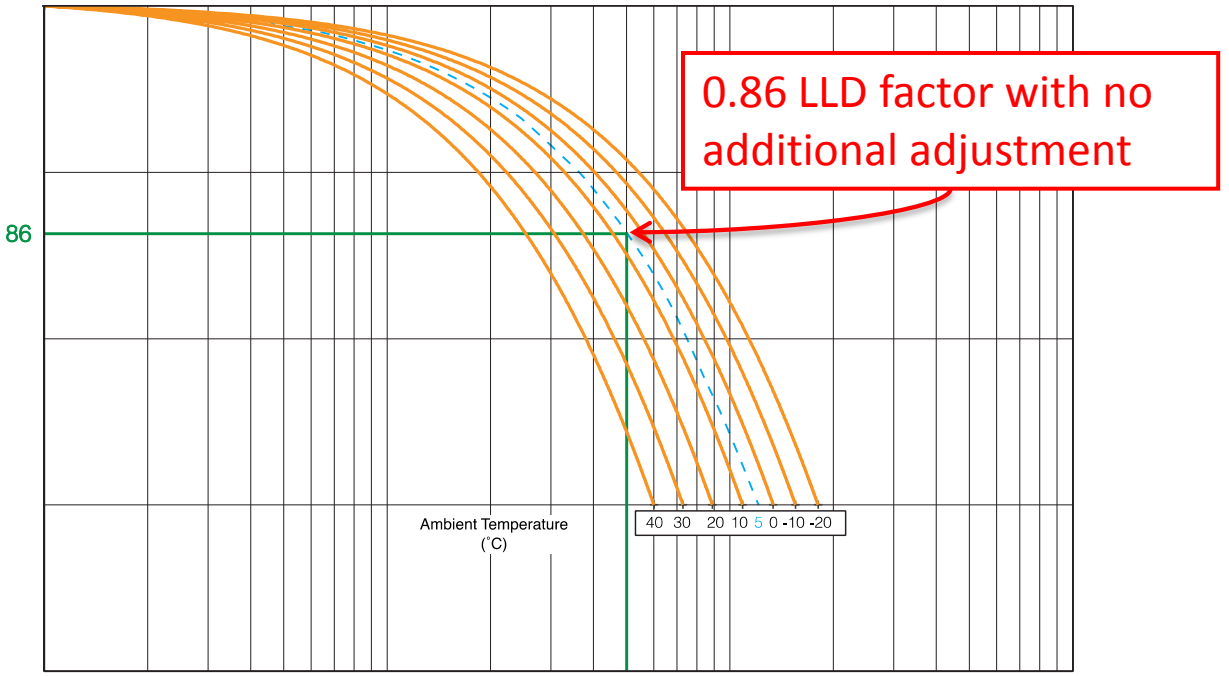
BetaLED® LEDway® 525mA Lumen Maintenance Predictions vs. Ambient Temperature



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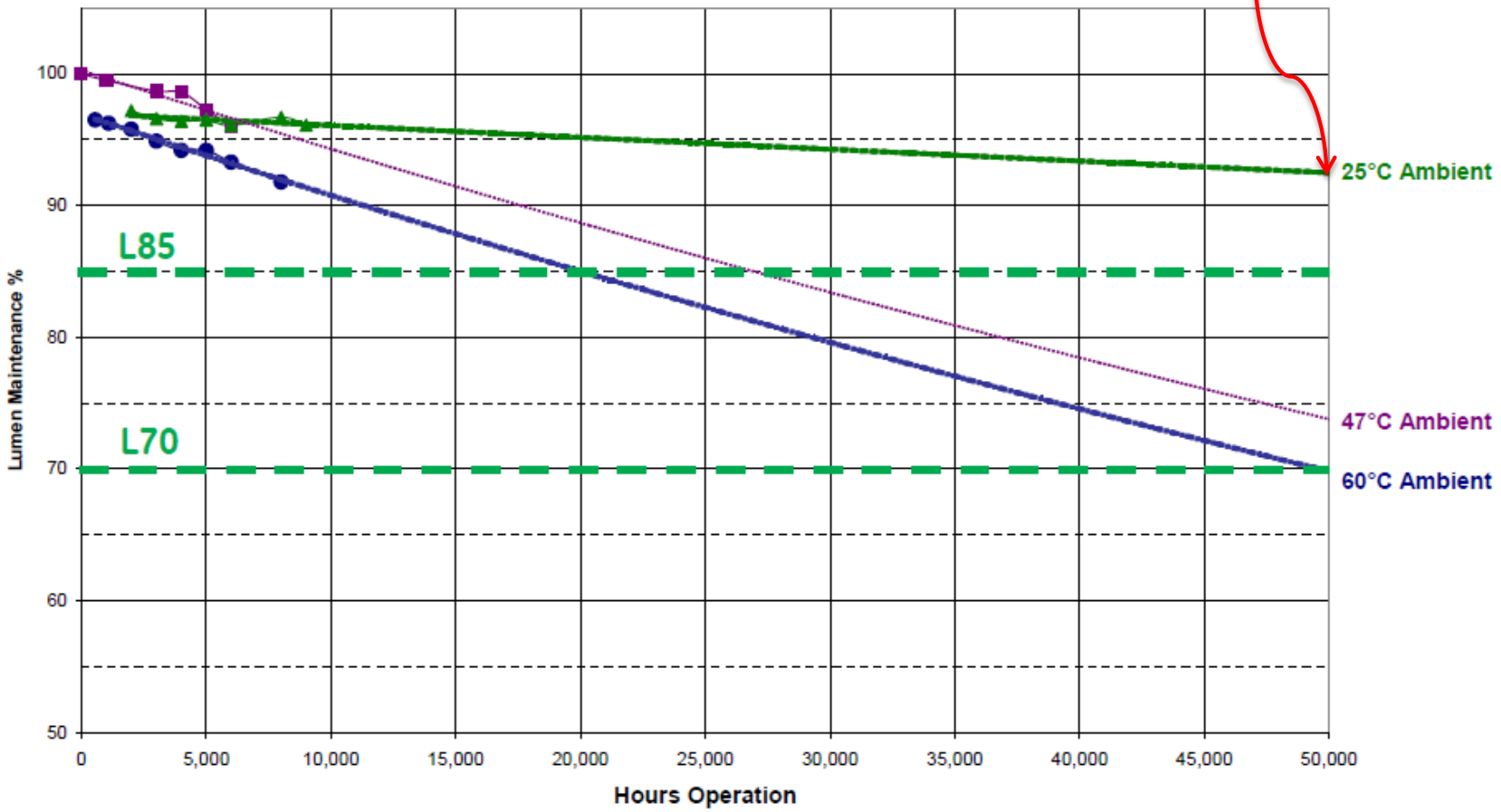
WHAT DOES L_{AL} MEAN FOR LLD

Evolve™ LED

5) System Level Lumen Maintenance Exponential Projections

0.93 LLD factor with no additional adjustment



imagination at work

GE Internal Test Data

The information in this document is subject to change without notice.

WHAT DOES L_{AL} MEAN IN DESIGN COMPARED TO L_{70}

- Less hardware for new installations

Less hardware = less maintenance needs and less capital cost

- LED fixtures can be used for more upgrades of existing systems because light levels are more easily met
- Initial lumen output less than with L_{70}

Less wasted energy costs due to lower initial lumens

- Less variation in lumen levels over life of system compared to L_{70}

L_{AL} BENEFITS

- Better definition of system life by time. System is not defined by minimum lumen maintenance that varies between manufacturers and LED packages.
- Greater operating temperature range. System is designed to a shorter time frame than L_{70} allowing the use in a wider range of temperatures.
- Unique system design possible governed by Agency/Utility needs.
- More replacement options at selected end of life. L_{70} is still on the horizon, do I still have good light levels and can I replace system today or a year from now.
- Reduced lumen depreciation across the life of the fixture. Better lighting with less variability in lumen levels to end of life.
- Reduce wasted energy due to lower initial lumen levels needed since system is designed for near future and not distant future (i.e. 12 years not 34 years).
- Ability to deploy more LED systems due to less lumen depreciation across fixture life.