

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

LTL NUMBER: 15484 DATE: 04-23-2009
 PREPARED FOR: COOPER LIGHTING
 CATALOG NUMBER: 0790312E002
 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 LED120A0004V33F
 POWER FACTOR: 0.982
 ELECTRICAL VALUES: 120.0VAC, 0.7945A, 93.64W
 NOTE: THIS TEST WAS PERFORMED USING THE CALIBRATED PHOTOMETRIC METHOD OF ABSOLUTE PHOTOMETRY.*



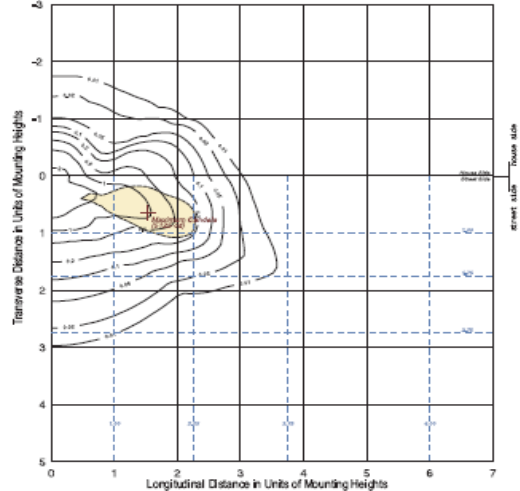
IES CLASSIFICATION: TYPE II
 INDIVIDUAL CLASSIFICATION: SHORT
 CUPOL CLASSIFICATION: CUPOL**

FLUX DISTRIBUTION

IREXON SIDE	DOWNWARD	UPWARD	TOTALS
96.61	0.00	0.00	96.61
366.30	0.00	366.30	
TOTALS	479.11	0.00	479.11

*DATA WAS ACQUIRED USING THE CALIBRATED PHOTOMETRIC METHOD OF ABSOLUTE PHOTOMETRY AS SET FORTH IN IESNA PUBLICATION 90-1678 (PHOTOMETRIC COMPARISON USED 1000 AS A STANDARD). A STRUCTURAL MEASUREMENT FACTOR WAS USED TO CORRECT THE STRUCTURAL DEVIATION OF THE REFLECTOR AND THE INITIAL FLUX DISTRIBUTION OF THE TEST SUBJECT.
TESTING WAS PERFORMED IN ACCORDANCE WITH IES LM-79-08.
 TEST ANGLE IN INCIDENTS AND REPORT FORMATTING WAS BASED ON IES LM-79-08.

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



LONGITUDINAL DISTANCE IN UNITS OF MOUNTING HEIGHT
 TRANSVERSE DISTANCE IN UNITS OF MOUNTING HEIGHT
 PREDICTION OF HALF-MAX CANDELA CONTOUR
 PAGE 3-LTL NUMBER 15494

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	5	7	10	10	10	9	0	0	11	12	12
85	22	24	32	33	33	31	23	34	28	40	26
82.5	42	46	57	52	54	51	54	72	70	61	44
80	61	70	78	68	69	66	99	140	127	82	59
77.5	88	91	94	89	79	89	147	209	237	139	80
75	115	113	115	115	100	114	214	274	405	438	249
72.5	161	160	154	147	132	143	300	633	584	379	238
70	252	253	245	235	228	227	476	1459	1417	1054	571
67.5	377	376	374	372	364	427	895	2652	2797	2332	1026
65	498	493	492	488	500	718	1319	3783	3928	3379	1421
62.5	521	518	517	537	579	1004	1601	4269	4447	3304	1603
60	599	595	596	634	739	1280	1813	4928	5004	3601	1832
57.5	621	620	632	693	817	1372	1962	5014	5128	3735	1971
55	675	679	713	799	969	1502	1949	5049	4917	3625	2141
52.5	620	629	696	836	1047	1219	1647	4763	4763	3774	2202
50	548	555	619	707	866	1016	1267	4366	4437	3577	2113
47.5	424	427	456	500	566	636	700	3637	3637	2912	1726
45	292	292	300	300	300	300	300	2500	2500	2000	1250
42.5	192	192	192	192	192	192	192	1500	1500	1200	750
40	120	120	120	120	120	120	120	1000	1000	800	500
37.5	72	72	72	72	72	72	72	600	600	500	300
35	48	48	48	48	48	48	48	400	400	350	200
32.5	36	36	36	36	36	36	36	300	300	280	150
30	24	24	24	24	24	24	24	200	200	200	100
27.5	18	18	18	18	18	18	18	150	150	150	75
25	12	12	12	12	12	12	12	100	100	100	50
22.5	8	8	8	8	8	8	8	75	75	75	37.5
20	6	6	6	6	6	6	6	60	60	60	30
17.5	4	4	4	4	4	4	4	45	45	45	22.5
15	3	3	3	3	3	3	3	30	30	30	15
12.5	2	2	2	2	2	2	2	20	20	20	10
10	1	1	1	1	1	1	1	15	15	15	7.5
7.5	1	1	1	1	1	1	1	10	10	10	5
5	0	0	0	0	0	0	0	5	5	5	2.5
2.5	0	0	0	0	0	0	0	2.5	2.5	2.5	1.25
0	0	0	0	0	0	0	0	0	0	0	0

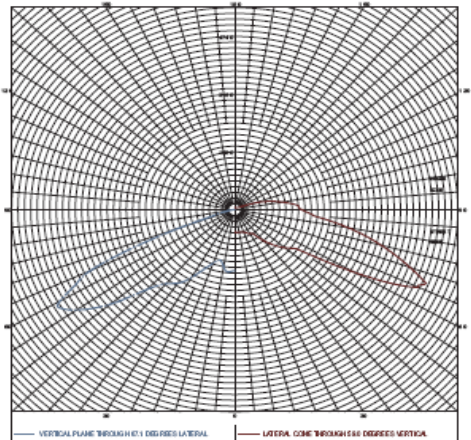
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CANDELA DISTRIBUTION

	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	1	1
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	88	82	68	50	41	38	41	42	36	35
72.5	110	104	93	70	52	44	41	44	43	39	38
70	132	129	115	74	55	49	44	46	46	41	40
67.5	152	151	136	89	63	53	47	49	47	43	42
65	167	163	150	105	73	59	51	50	50	44	44
62.5	184	180	167	123	86	64	55	55	52	47	47
60	192	183	170	135	95	69	60	57	56	51	50
57.5	199	192	179	143	96	71	63	59	58	53	52
55	206	197	184	152	97	73	67	62	63	57	56
52.5	187	182	169	143	91	75	72	66	75	62	59
50	178	179	176	146	91	79	77	71	81	68	66
47.5	169	170	175	150	93	84	84	77	84	75	73
45	142	147	154	158	95	87	89	80	89	84	82
42.5	105	109	114	134	98	90	95	93	97	93	90
40	79	83	87	109	100	92	104	105	105	106	103
37.5	58	61	64	82	92	86	97	97	97	97	97
35	42	44	46	61	71	67	77	77	77	77	77
32.5	30	31	32	44	51	48	57	57	57	57	57
30	21	21	21	29	34	32	38	38	38	38	38
27.5	15	15	15	20	24	22	27	27	27	27	27
25	10	10	10	14	17	16	19	19	19	19	19
22.5	7	7	7	10	12	11	13	13	13	13	13
20	5	5	5	7	9	8	10	10	10	10	10
17.5	3	3	3	4	5	4	5	5	5	5	5
15	2	2	2	3	4	3	4	4	4	4	4
12.5	1	1	1	2	3	2	3	3	3	3	3
10	1	1	1	1	2	1	2	2	2	2	2
7.5	0	0	0	1	1	1	1	1	1	1	1
5	0	0	0	0	1	1	1	1	1	1	1
2.5	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0

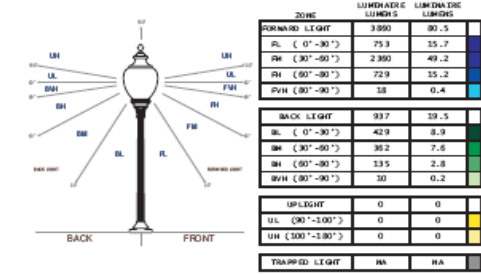
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MAXIMUM PLANE AND CONE PLOTS OF CANDELA

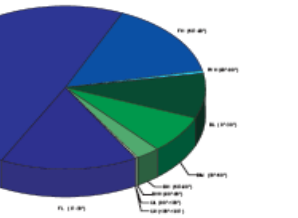


VERTICAL PLANE THROUGH 0 DEGREE LUMINAIRE
 LUMINAIRE CONE THROUGH 0 DEGREE VERTICAL
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FLUX DISTRIBUTION TABLE BASED ON THE IESNA LUMINAIRE CLASSIFICATION SYSTEM



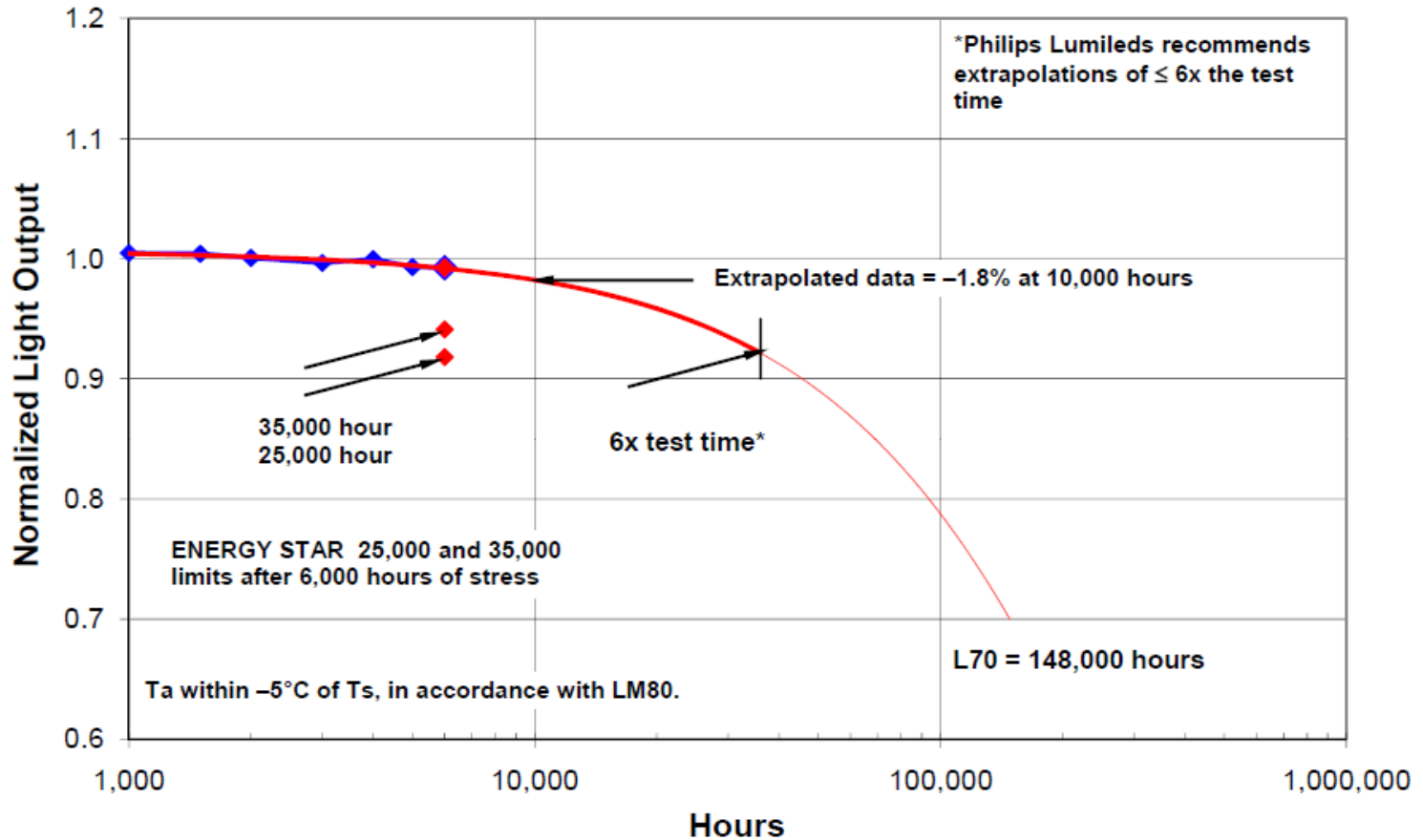
ZONE	BEAM SPREAD	FOOTCANDLES
FORWARD LIGHT	90.5	90.5
FL (0°-30°)	75.9	55.7
SM (30°-60°)	23.90	49.2
SH (60°-90°)	72.9	35.2
PWH (90°-90°)	18	0.4
BACK LIGHT	93.7	39.5
BL (0°-30°)	42.9	8.9
SM (30°-60°)	36.2	7.6
SH (60°-90°)	33.5	2.8
BWH (90°-90°)	30	0.2
UP LIGHT	0	0
UL (00°-100°)	0	0
UH (100°-180°)	0	0
THRUPOD LIGHT	NA	NA



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Lumen Maintenance Projection for White LXM3-PWx1 LUXEON Rebel under these conditions 55°C, 0.35A ($T_{junction} \cong 68^\circ\text{C}$) 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

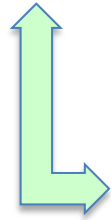
LED Sources

- ✧ 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. Their lumen output degrades over time. This can be maintained through drive current control.

LIGHT LOSS FACTORS (SOLID STATE LIGHTING)

$$LLF = LLD \times LDD \times ATF \times HE \times VE \times BF \times CD$$



LLD: Lamp Lumen Depreciation

LDD: Luminaire Dirt Depreciation

ATF: Ambient Temperature Effects

HE: Heat Extraction

VE: Voltage Effects

BF: Driver and Lamp Factors

CD: Component Depreciation

Maintenance Factors

Equipment Factors

LIGHT LOSS EQUIPMENT FACTORS

$$LLF = LLD \times LDD \times ATF \times HE \times VE \times BF \times CD$$

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

$$LLF = LLD \times LDD \times ATF \times HE \times VE \times BF \times CD$$

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.](#)

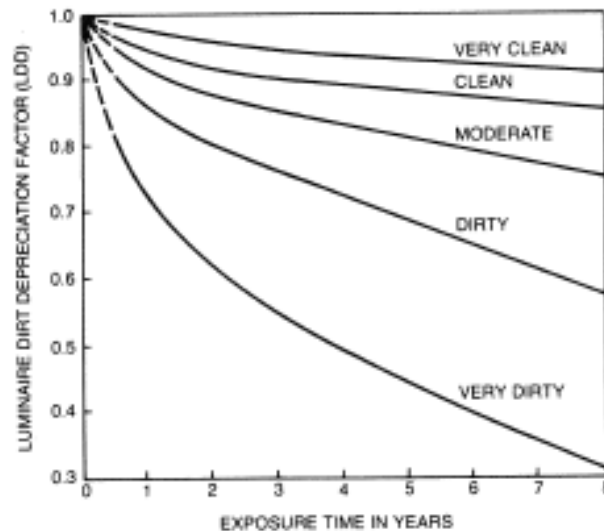
LIGHT LOSS MAINTENANCE FACTORS

$$LLF = LLD \times LDD \times ATF \times HE \times VE \times BF \times CD$$

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

$$\text{LLF} = \text{LLD} \times \text{LDD} \times \text{ATF} \times \text{HE} \times \text{VE} \times \text{BF} \times \text{CD}$$

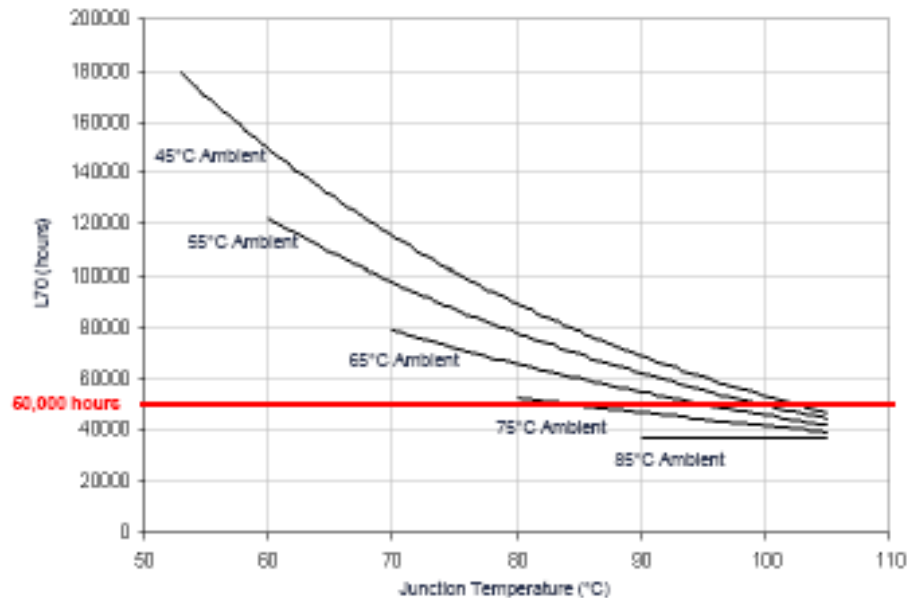
Lamp Lumen Depreciation – lumen output depreciates over time resulting in a gradual reduction in light levels.

LLD

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

L70 vs Junction Temperature vs Ambient Temperature

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



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 L₇₀ MEAN IN TIME

LED LMF MULTIPLIER EXAMPLE: 525mA @ 5°C

$$0.86 \times 1.05 = 0.90$$

obtained from
chart below

See step 2
from previous page
for more information

LEDs gain 0.25% lumen
output for each degree C
below 25%

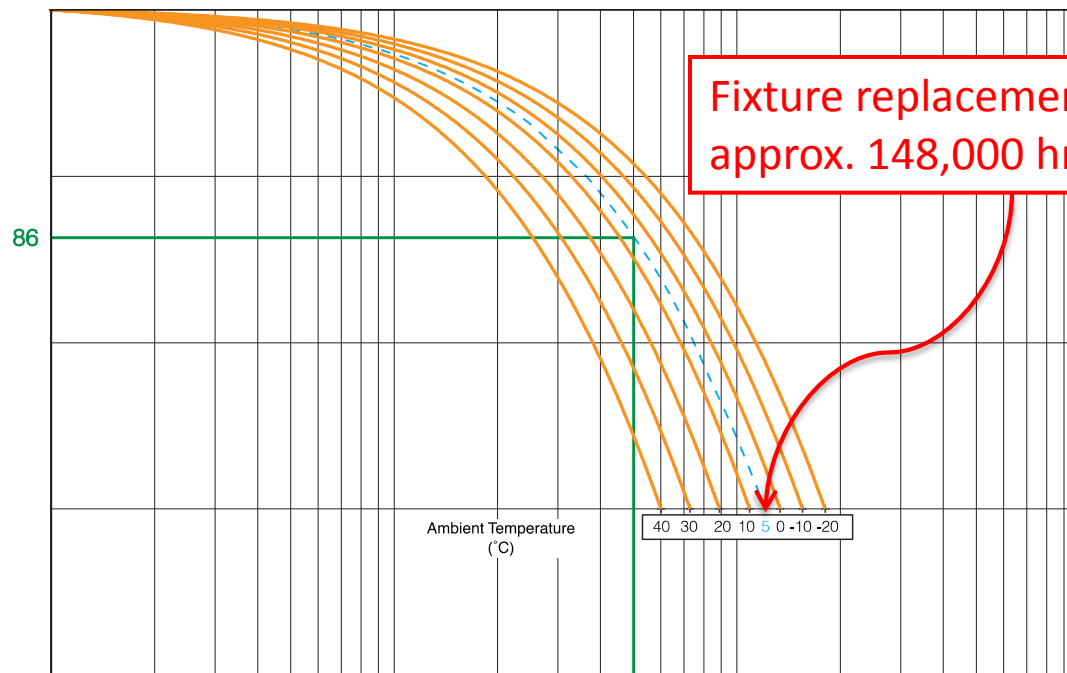
New multiplier
for this example

$$25 - 5 = 20$$

$$20 \times .25 = 5\%$$

$$0.05 + 1.000 = 1.05$$

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



36-6800 • www.BetaLED.com

WHAT DOES L₇₀ MEAN IN DESIGN

✧ Increase in system hardware for new installations



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?

Table 8-5 Payback Calculator

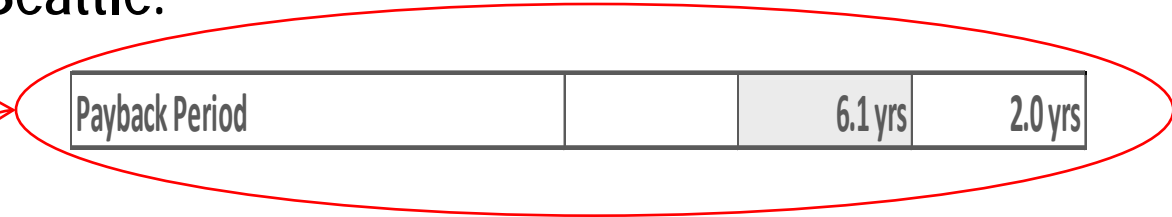
Description	Base System	Luminaire A2	Luminaire A2
Number of Luminaires	1	1	1
Number of Lamps per Luminaire	1	1	1
Cost per Luminaire	\$ 133.00	\$ 428.00	\$ 250.00
Installation Cost	\$ 63.91	\$ 63.91	\$ 63.91
Initial Cost	\$ 196.91	\$ 491.91	\$ 313.91
Annual Operations Cost per Fixture			
Watts per Fixture (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
kWh 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 Annualized 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 fixture
 ****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

LED LUMINAIRE COST/BENEFIT

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.



WHAT DOES L_{AL} MEAN FOR LLD

LED LMF MULTIPLIER EXAMPLE: 525mA @ 5°C

$$0.86 \times 1.05 = 0.90$$

obtained from chart below

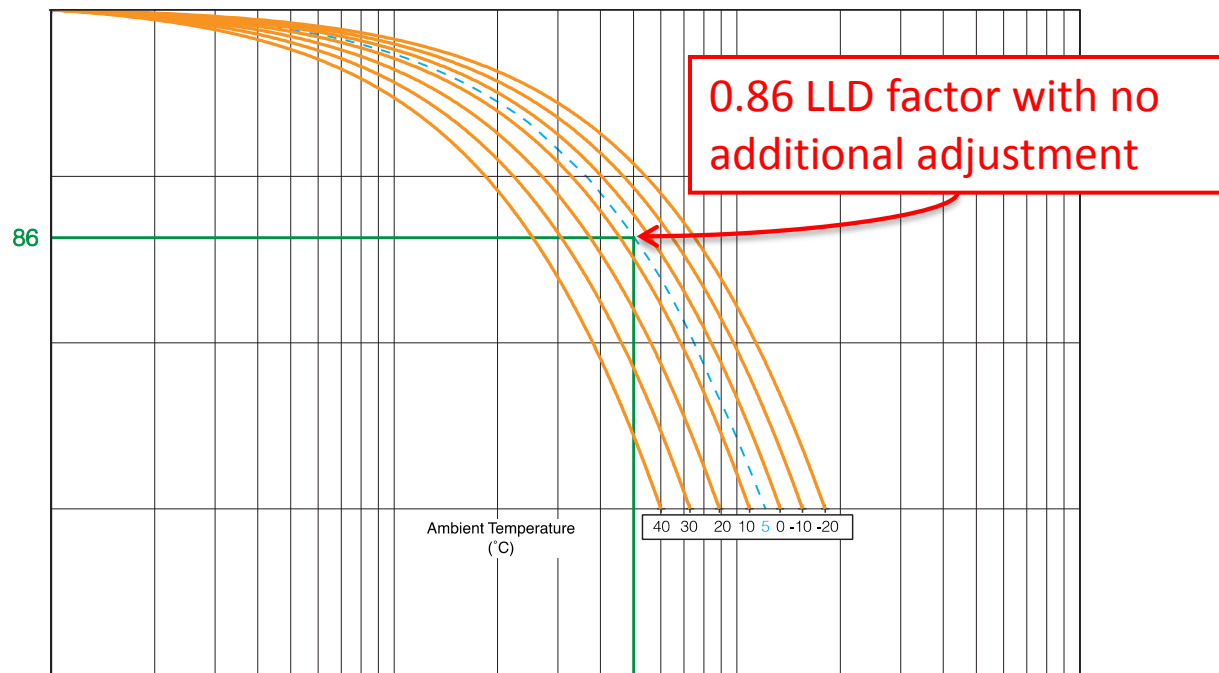
See step 2 from previous page for more information

LEDs gain 0.25% lumen output for each degree C below 25%

25 - 5 = 20
20 x .25 = 5%
0.05 + 1.000 = 1.05

New multiplier for this example

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



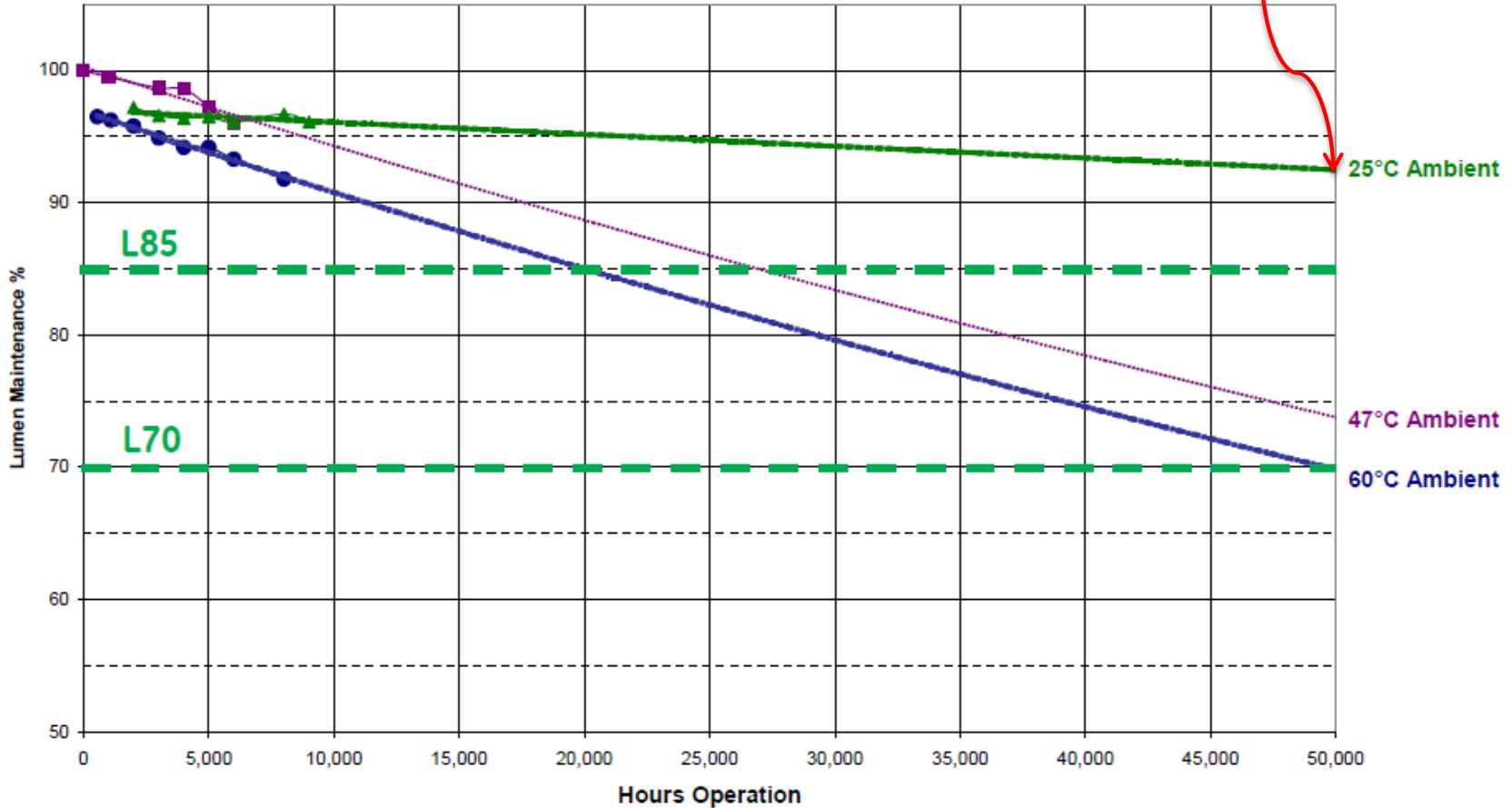
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WHAT DOES L_{AL} MEAN FOR LLD

Evolve™ LED

5) System Level Lumen Maintenance Exponential Projections

0.93 LLD factor with no additional adjustment



GE Internal Test Data

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

6 /
GE Title or job number /
1/12/2010

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 L₇₀ 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.** L₇₀ 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.