Lighting System Efficiency Calculations

Energy Performance Analysis - ENERGY STAR & ASHRAE 90.1 Standards

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1. Luminous Efficacy Calculations

Luminous Efficacy

Efficacy (lm/W) = Luminous Flux (lumens) / Electrical Power (watts)

System Efficacy = Fixture Efficacy × Ballast/Driver Factor × Thermal Factor

LED Troffer Performance Analysis:

Fixture Type	Power (W)	Luminous Output (lm)	Efficacy (lm/W)	ENERGY STAR Min.
2x4 LED Troffer	32	4,200	131.3	110
2x2 LED Troffer	18	2,400	133.3	115
Linear LED Strip	24	3,600	150.0	120
LED High Bay	150	22,500	150.0	130

System-Level Calculation Example:

- LED Chip Efficacy: 180 lm/W
- Driver Efficiency: 92%
- Optical Efficiency: 85%
- Thermal Derating: 95%
- System Efficacy = 180 × 0.92 × 0.85 × 0.95 = 133.9 lm/W

All fixtures exceed ENERGY STAR requirements
Average System Efficacy: 141.2 lm/W
Status: COMPLIANT ✓

2. Lighting Power Density (LPD)

Lighting Power Density

$$\text{LPD (W/ft}^2\text{)} = \text{Total Connected Lighting Load (W)} / \text{Floor Area (ft}^2\text{)}$$

$$\text{LPD (W/m}^2\text{)} = \text{Total Connected Lighting Load (W)} / \text{Floor Area (m}^2\text{)}$$

Office Building LPD Analysis:

Space Type	Area (ft²)	Connected Load (W)	Actual LPD (W/ft²)	ASHRAE 90.1 Limit
Open Office	12,000	9,600	0.80	0.90
Private Office	2,400	2,160	0.90	1.00
Conference Room	800	960	1.20	1.30
Corridor	1,200	600	0.50	0.60
Lobby	600	780	1.30	1.40

Building-Wide LPD Calculation:

- Total Connected Load: 9,600 + 2,160 + 960 + 600 + 780 = 14,100 W
- Total Floor Area: 12,000 + 2,400 + 800 + 1,200 + 600 = 17,000 ft²
- Building LPD = 14,100 ÷ 17,000 = 0.83 W/ft²
- ASHRAE 90.1 Building Method Allowance: 0.90 W/ft²

Actual Building LPD: 0.83 W/ft²
ASHRAE 90.1 Allowance: 0.90 W/ft²
Energy Savings: 8.3% below code
Status: COMPLIANT ✓

3. Illuminance & Uniformity

Illuminance Calculations

Average Illuminance = (Σ Point Measurements) / Number of Points

Uniformity Ratio = E_{min} / E_{avg}

Utilization Factor = Luminous Flux on Work Plane / Total Lamp Flux

Office Lighting Grid Analysis (30 ft × 40 ft):

Average Illuminance

520

lux (48 fc)

Minimum

380

lux (35 fc)

Maximum

650

lux (60 fc)

Uniformity

0.73

ratio

IES Recommendations vs. Measured:

- IES Recommended (Office Tasks): 500 lux (46 fc)
- Measured Average: 520 lux (48 fc) ✓
- IES Uniformity Minimum: 0.70
- Measured Uniformity: 0.73 ✓

Utilization Factor Calculation:

- Total Fixture Output: 24 fixtures × 4,200 lm = 100,800 lm
- Work Plane Flux: 520 lux × 111.5 m² = 58,000 lm
- Utilization Factor = 58,000 ÷ 100,800 = 0.575 = 57.5%

4. Daylight Integration & Controls

Daylight Factor & Dimming

$$\text{Daylight Factor} = (E_{indoor} / E_{outdoor}) \times 100\%$$

$$\text{Dimming Level} = (\text{Target Illuminance} - \text{Daylight Contribution}) / \text{Design Illuminance}$$

Perimeter Zone Daylight Analysis:

Time	Outdoor Illuminance	Indoor Daylight	Daylight Factor	Electric Light Level
9:00 AM	25,000 lux	750 lux	3.0%	0% (OFF)
12:00 PM	80,000 lux	2,400 lux	3.0%	0% (OFF)
3:00 PM	40,000 lux	1,200 lux	3.0%	0% (OFF)
6:00 PM	5,000 lux	150 lux	3.0%	75%
8:00 PM	0 lux	0 lux	0%	100%

Annual Energy Savings Calculation:

- Perimeter Zone Area: 4,800 ft² (40% of total)
- Installed LPD: 0.80 W/ft²
- Average Dimming Factor: 35% (daylight + occupancy)
- Annual Operating Hours: 3,000 hours
- Energy Savings = 4,800 × 0.80 × 0.35 × 3,000 = 4,032 kWh/year

Daylight Factor: 3.0% (Good for office work)
Annual Energy Savings: 4,032 kWh
Cost Savings: $483/year @ $0.12/kWh
Control System ROI: 3.2 years

5. LED Lifetime & Maintenance

L70 Lifetime & Lumen Maintenance

L70 Lifetime = Hours when lumen output drops to 70% of initial

Lumen Maintenance Factor = Current Output / Initial Output

LED Performance Degradation Analysis:

Operating Hours	Lumen Maintenance	Power Consumption	Efficacy (lm/W)	Status
0 (Initial)	100%	32.0 W	131.3	New
10,000	98%	32.0 W	128.7	Excellent
25,000	92%	32.0 W	120.8	Good
50,000	85%	32.0 W	111.6	Acceptable
70,000	70%	32.0 W	91.9	L70 Reached

Maintenance Schedule Calculation:

- Annual Operating Hours: 3,000 hours
- L70 Lifetime: 70,000 hours
- Expected Service Life: 70,000 ÷ 3,000 = 23.3 years
- Recommended Group Replacement: 20 years

Total Cost of Ownership (10-year analysis):

- Initial Cost: $85/fixture × 24 fixtures = $2,040
- Energy Cost: 14.1 kW × 3,000 hrs × $0.12/kWh × 10 years = $5,076
- Maintenance Cost: $0 (no lamp replacements needed)
- Total 10-year Cost: $7,116

L70 Lifetime: 70,000 hours (23.3 years)
10-Year Energy Cost: $5,076
Maintenance Savings vs. Fluorescent: $1,800
Total System ROI: 2.8 years

Important: L70 calculations based on IES TM-21 methodology and manufacturer LM-80 test data. Actual performance may vary based on operating temperature, drive current, and environmental conditions.