Pacific Northwest NATIONAL LABORATORY

PNNL-SA-160065

Changes in lighting needed to achieve 30% or 40% less than ANSI/ASHRAE/IES Standard 90.1-2019 Lighting Power Density Values

February 2021

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U.S. DEPARTMENT OF ENERGY

Prepared for the U.S. Department of Energy
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The energy savings analysis is complete for ANSI/ASHRAE/IES Std. 90.1-2016[1] (Std. 90.1). The energy savings analysis for Std. 90.1-2019 is underway and expected to be published in 2021. The analysis in this memo addresses the potential changes in inputs to the lighting to achieve 30% or 40% below Std. 90.1-2019 lighting power density (LPD) values. Note that LPD values are not the same as lighting energy. The use of lighting controls can reduce energy usage independent of LPD values.

Interior LPD values are developed for Std. 90.1 via a spreadsheet model. This spreadsheet model has been verified via photometric software modeling.[2] Fundamentally, the model determines the desired horizontal illuminance for a space and divides this value by the product of light loss factors (LLF), light source efficacy, and the coefficient of utilization (CU) as shown in this equation: $LPD = \frac{Illuminance}{LightSource\ Efficacy\ x\ LLF\ x\ CU}$.[3] For a lighting design to have an LPD 30% (or 40%) lower than Std. 90.1-2019, there are three possible methods.[4]

1. The design provides 70% (60% in the case of 40%) of the illuminance assumed in the Std. 90.1-2019 model.
2. The light source efficacy, LLF, CU, or the product of the three is 143% greater (167% in the case of the 40%) than the assumption in the Std. 90.1-2019 model.
3. A combination of 1 and 2 where less illuminance and greater efficacy, LLF, and CU are used.

Although those are the possible options, some aspects of the options are more technically or realistically achievable than other options. The following bullets address these aspects:

- **Illuminance** – the Std. 90.1-2019 model bases the illuminance on Illuminating Engineering Society (IES) recommendations. It is possible for skilled designers and engineers to provide a targeted design only providing the necessary illuminance in key areas; it may be very hard to achieve a 30% reduction in illuminance. Further as designs consider health and wellness aspects of lighting, they are often increasing the lighting in the space beyond the IES photometric recommendations to achieve non-visual effects of lighting. For example, the IES photopic illuminance for an office is roughly 30 horizontal footcandles (fc), but the UL Design Guide for Circadian Lighting recommends designing to 50 horizontal fc for circadian entrainment. Therefore, it is hard to achieve this level of design without sacrificing lighting or lighting quality. The potential need for increased

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[1] Energy Savings Analysis: ANSI/ASHRAE/IES Standard 90.1-2016. October 2017

[2] Report in draft

[3] *An Empirical Data Based Method for Development of Lighting Energy Standards*. Journal of the Illuminating Engineering Society. Volume 28, 1999

[4] See calculations section for supporting math

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light levels for these purposes makes it even less likely to achieve these targeted levels of energy reduction.

- **Light Loss Factors (LLF)** – are a design aspect to account for the entropy of the lighting system and the space. Spaces get dirty, light fixtures get dirty; dirt reduces the amount of light in the space. All light sources degrade in output and it needs to be accounted for in the design. IES guidance is to account for LLF in the design. This does mean that initially the space may have more light, but as the space is used and time passes, the design still provides the appropriate amount of light. Research papers have shown ultra-efficient designs (often significantly below Std. 90.1-2019), even meeting circadian stimulus, but those research papers did not factor in LLF into their designs.[5,6] It is critical that the design account for light loss factors. The Std. 90.1-2019 model assumes an aggregate LLF of 0.69 (0.96 for room surface dirt depreciation, 0.85 for LED lumen depreciation, and 0.85 – 0.90 for luminaire dirt depreciation). The values assumed to develop the Std. 90.1-2019 model are based on research and expert experience. It is incredibly difficult to improve upon LLFs as they are a function of the space and account for physical changes that occur in the space over time. Spaces can be cleaned to account for dirt accumulation, but historically there has been low success with cleaning the dirt from interior lighting in spaces. Lighting can be increased over time to account for lamp lumen depreciation (known as lumen maintenance), but this has energy implications. It is also an increased lighting controls cost and often is not implemented.
- **Coefficient of Utilization (CU)** – is basically the effectiveness of the light fixture to deliver lumens to the work plane. CU is a function of the fixture optical design, room geometry, and the surface reflectance in the space. The Std. 90.1-2019 model uses room geometries for each space based on a large database of those types of spaces. Similarly, the Std. 90.1-2019 model assigns room reflectance surface values to each space based on common practice / experience. Some designs may have different reflectance values, which yields only a small change. In terms of LED fixtures and CU, fixture optical design has approached near maximum CU.[7] Therefore, it is unlikely that CU would be improved by the designer or engineer trying to comply with a reduced LPD target.
- **Light Source Efficacy –** Table 1 presents the light source efficacy from the Std. 90.1-2019 model. The table is differentiated by light fixture type. Efficacy varies by fixture type. Table 1 also provides two columns depicting the efficacy of the fixture types at 143% and 167% more than the Std. 90.1-2019 model to achieve the 30% and 40% reduction respectively. Finally, Table 1 also provides the most recent DOE solid-state lighting energy savings forecast estimates LED luminaire efficacy in 2025 and 2035.[8]

[5] *The Effectiveness of Light-Emitting Diode Lighting for Providing Circadian Stimulus in Office Spaces while minimizing energy use.* Lighting Research and Technology. 2019; 0: 1-22
[6] Personal communication from J Snyder, Lighting Research Center to Michael Myer, PNNL, that the designs in the LR&T paper assume light loss factors of 1.0.
[7] Paper in draft
[8] Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (https://www.energy.gov/sites/prod/files/2020/02/f72/2019_ssl-energy-savings-forecast.pdf)

Table 1. Light Source Efficacy

Fixture Type	Portion of Std. 90.1-2019 model*	Average Efficacy (lm/W) in Std. 90.1-2019 model**	143% Improvement in Efficacy (lm/W)	167% Improvement in Efficacy (lm/W)	2025 DOE Projected Efficacy (lm/W)	2035 DOE Projected Efficacy (lm/W)
Cove	7%	88	126	147	N.S.	N.S.
Downlight	29%	76	109	127	83/95	76 / 133
High Bay	7%	133	190	222	152	181
Linear Suspended	4%	107	153	179	126	152
Indirect Pendant	4%	86	123	142	126	152
Low Bay	7%	124	177	207	152	181
Parking Garage	1%	110	157	184	129	151
Task Lighting	9%	62	89	149	N.S.	N.S.
Troffer	27%	99	142	165	126	152
Wall Grazer	4%	75	107	125	N.S.	N.S.
Wall Washer	2%	67	96	112	N.S.	N.S.

*** Does not sum to 100% because of rounding.**
**** Each fixture type has multiple sub-types. Each sub-type is comprised of an aggregate of multiple real products. This an average of the sub-types and not average weighted by use within the model.**
N.S. means not specified in that table

Comparing the needed efficacy improvements in Table 1with the projected improvements indicates that these levels are not likely to be reached or cost effective. Also, some high efficacy products may be years away, even beyond 2035, as shown in the table.

In conclusion, sites opting for designs that are 30% or 40% lower than Std. 90.1 LPD values can opt for a design that provides less illuminance than in the Std. 90.1-2019 model, which is aligned with American National Standard (ANSI) recommended light levels produced by the IES. Alternatively, or even in addition, more efficient equipment would be required and still may not meet the LPD value while designing to acceptable light loss factors.

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Calculations:

$$LPD = \frac{Illuminance}{Light\ Source\ Efficacy\ x\ LLF\ x\ CU} = \frac{E}{LSE_1\ x\ TF}$$

LSE_1 = Light Source Efficacy
TF = LLF x CU

Option 1

$$LPD_{90.1-2019} = \frac{E_1}{LSE_1\ x\ TF_1} \quad | \quad 70\%\ x\ LPD_{90.1-2019} = \frac{E_2}{LSE_1\ x\ TF_1}$$

$$\frac{E_1}{LPD_{90.1-2019}} = LSE_1 x\ TF_1 \quad | \quad \frac{E_2}{70\%\ x\ LPD_{90.1-2019}} = LSE_1 x\ TF_1$$

$$\frac{E_1}{LPD_{90.1-2019}} = \frac{E_2}{70\%\ x\ LPD_{90.1-2019}}$$

$$E_1\ x\ 70\%\ x\ LPD_{90.1-2019} = E_2\ x\ LPD_{90.1-2019}$$

$$E_1\ x\ 70\% = E_2$$

Option 2 (process same for LSE, LLF, or CU)

$$LPD_{90.1-2019} = \frac{E}{LSE_1\ x\ TF} \quad | \quad 70\%\ x\ LPD_{90.1-2019}\ \frac{E}{LSE_2\ x\ TF}$$

$$E = LPD_{90.1-2019}\ x\ LSE_1 x\ TF \ | \quad E = 70\%\ x\ LPD_{90.1-2019}\ x\ LSE_2 x\ TF$$

$$LPD_{90.1-2019}\ x\ LSE_1 x\ TF = 70\%\ x\ LPD_{90.1-2019}\ x\ LSE_2 x\ TF$$

$$LPD_{90.1-2019}\ x\ LSE_1 = 70\%\ x\ LPD_{90.1-2019}\ x\ LSE_2$$

$$LSE_1 = 70\%\ x\ LSE_2$$

$$LSE_2 = \frac{LSE_1}{70\%} \rightarrow LSE_2 = 143\%\ LSE_1$$

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