

Luminaire Dirt Depreciation (LDD): Field Data from Several Exterior Lighting Projects

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Abstract

Luminaire dirt depreciation (LDD) data were evaluated for seven luminaires from three different project sites in Philadelphia PA, Minneapolis MN, and Yuma AZ. In each case, the luminaires were removed from the installation, carefully packaged and transported to a photometric testing laboratory, and then tested in the “as-is” or dirty condition, cleaned, and re-tested. In terms of light output, the results showed that the Illuminating Engineering Society (IES) RP-36-15 method for estimating LDD was applicable to the LED luminaires evaluated. General claims of lower levels of dirt depreciation (or higher LDD values) for LED luminaires than for luminaires using conventional light sources were not supported by the test data for the LED luminaires in these three projects. While the overall measured lumen depreciation due to accumulated dirt closely matched IES estimates for LDD, the data indicated that the accumulated dirt on the luminaires dramatically altered the luminous intensity distribution of the luminaires, with reductions in intensity of more than 25% at peak angles. These effects on luminous intensity distribution are not accounted for in IES LDD estimates.

Key words: LED sources and systems; luminaires; maintenance; optics and luminaire design; roadway lighting

1. Introduction

1.1 Background

The use of LED luminaires has increased rapidly in exterior lighting applications. However, manufacturers, specifiers, and users of these products seem uncertain about the relevance of Illuminating Engineering Society (IES) luminaire dirt depreciation (LDD) estimates for LED luminaires, with some advocating the use of LDD estimates for LED systems that are much higher (i.e., estimating less depreciation due to dirt) than IES procedures would indicate. Furthermore, IES LDD estimates adjust the total light output from luminaires without regard for any changes in the luminous intensity distribution that may result from accumulated dirt.

Are the IES procedures for estimating LDD factors [IESNA 2015, 2014] relevant for LED systems? Does dirt depreciation also affect the distribution of light from luminaires, and if so, to what extent and in what ways? To investigate these questions, the authors evaluated data from seven luminaires at three different sites documented as part of the U.S. Department of Energy (DOE) GATEWAY program. In each case, the luminaires were removed from the installation, carefully packaged and transported to a photometric testing laboratory, and then tested in the “as-is” or dirty condition, cleaned, and re-tested. All testing was conducted at photometric laboratories accredited by the National Voluntary Laboratory Accreditation Program, and the luminaires were tested according to IES LM-79 procedures. The seven luminaires had the following characteristics:

- One luminaire had been operating for 7 months (about 2,300 operating hours) at the Philadelphia International Airport.
- Two luminaires had been operating for 14 months (about 4,600 hours) at the I-35W Bridge in Minneapolis, MN, and two additional luminaires had been operating for 56 months (about 18,500 hours) at the same site.
- Two luminaires had been operating for 20 months (about 6,600 hours) at the Customs and Border Protection site along the U.S.-Mexico border near Yuma, AZ.

This paper presents the testing results from these seven luminaires, from different geographic locations and with different operating hours, providing important insights into questions related to dirt depreciation of LED luminaires.

1.2 Prior literature

LDD values were first published by IESNA in the Fourth Edition of the Lighting Handbook [Kaufman 1966]. The Tenth Edition [DiLaura et al. 2011] describes two different methods of determining LDD for interior luminaires: one for luminaires used in non-industrial spaces and one for luminaires used in industrial spaces.¹ Both methods combine three main factors in determining the expected depreciation in light output due to dirt accumulation: (1) how long the luminaires have been operating, (2) the degree of dirt present in the operating environment, and (3) the type of luminaire, in terms of its structural and photometric distribution characteristics. Both methods provide LDD curves that are defined by the equation

$$LDD = e^{-At^B}, \quad (1)$$

¹ For a detailed history of IES LDD procedures, see Levin et al. 2002; Davis and Partridge 2004; and IESNA 2016.

where t is the time in months since installation or cleaning, and A and B are coefficients defined for different combinations of luminaire type and environment.

Although the IES Tenth Edition *Lighting Handbook* does not present information on LDD for roadway or other exterior lighting applications, the relevant IES Recommended Practice documents, RP-36-15 and RP-8-14 [IESNA 2015, 2014], cover LDD for roadway lighting. RP-36-15 presents the most current IES methods for estimating LDD values, and uses the same method as documented in RP-8-14. Unlike the process for interior luminaires, where a formula is presented for calculating the LDD value, the process for roadway luminaires entails visually estimating the LDD value from curves that plot the estimated LDD as a function of the length of time since installation or cleaning, in months. For roadway luminaires, a group of curves is shown, with a separate curve for each of five environmental conditions: very clean, clean, moderate, dirty, and very dirty. These environmental conditions are defined in terms of the proximity to smoke- or dust-generating activities, the traffic level, and the ambient particulate level.

Several studies with fluorescent light sources have reported field-measured LDD data that question the accuracy of the IES estimated values. Levin et al. [2002] reported on a 3-year study in which LDD values were measured every 6 months. The researchers developed a custom device [Brackett and Levin 1996] that enabled relative measurements of the total light output of the luminaires, and evaluated over 1000 recessed fluorescent luminaires from 197 office, school, and retail sites. Six luminaires at each site were evaluated. At each 6-month measurement period, the light output of one luminaire was measured, then the luminaire was cleaned, and the light output was re-measured. The process was repeated for a different luminaire at each 6-month interval. The results showed less dirt depreciation than predicted by the IES methods: the IES estimating methods predicted depreciation of 25% (an LDD of 0.75) for louvered luminaires and 20% (LDD of 0.80) for lensed luminaires after 36 months, whereas the Levin study found depreciation of 11% (LDD of 0.89) for both luminaire types after 36 months.

The Levin study evaluated recessed direct luminaires in clean or very clean environments. Davis and Partridge [2004] extended this by evaluating a library area with indirect luminaires, which have the most dirt depreciation (lowest LDD values) in the IES method, and by evaluating an installation that fit within the IES “moderate” condition, since the moveable stacks were assumed to generate higher ambient dirt and dust levels. The effect of dirt accumulation on the luminaires’ light output was assessed by measuring vertical illuminances on a grid of 18 points on the stacks with the luminaires in their existing “dirty” condition, then cleaning the luminaires and repeating the measurements. The luminaires had not been cleaned for more than 36 months, which is the longest period for which the IES graphs provide an estimate. The IES method predicted depreciation in light output of over 40%; however, Davis and Partridge [2004] found only 29% depreciation due to dirt.

For streetlighting, van Dusen [1971] proposed a process for estimating LDD based on four luminaire categories, five ambient environment categories defined by the level of suspended particulates, and the cleaning time interval. He included recommended LDD values, although the paper provided no basis for the proposed values and presented no field data to support the recommended values.

Light loss factors for sports lighting were documented for 37 sports fields by Houser and others [2010]. While the study documented total light losses that were greater than 20%, which the authors stated as a common assumption in design practice, LDD as a component of total light loss was not individually studied, and several of the variables that affect LDD were not reported. A subsequent paper by Houser and others [2011] reported on the measured uniformity of illuminance at these sports fields, and noted that dirt accumulation on the luminaires could affect the illuminance distribution, since the dirt serves to diffuse the luminous intensity distribution.

More recently, IES RES-1-16 [IESNA 2016] reported extensive measurements of the effects of dirt accumulation and cleaning practices on streetlighting luminaires. The RES-1-16 document evaluates different cleaning methods and materials, and reports on differences between various luminaire optical materials and approaches. Results are not directly compared to IES estimated values, but the range of depreciation due to dirt reported was between 1% and 3.8% per year.

2. Methods

2.1 I-35W Bridge

In November 2009, two luminaires that were installed in August 2008 as part of a new LED lighting system on the I-35W Bridge in Minneapolis, MN, were removed by the Minnesota Department of Transportation (MnDOT), packed, and shipped to Luminaire Testing Laboratory (LTL) in Allentown, PA (now an Underwriters Laboratories facility), for photometric testing. These luminaires had luminous area of 11" by 21", power draw of 238 W, and used 200 LEDs with discrete clear plastic optics on each LED and no cover. Based on the photometric test data, the distribution was classified as Type VS Very Short and they had a backlight-uplight-glare (BUG) rating of B4-U0-G2 [IESNA 2011]. Both units were tested in their "as-is" or dirty condition, then cleaned by the laboratory and tested again. These two luminaires had operated for about 14 months at the time they were tested.

In May of 2013, two additional luminaires from this site that were also installed in August 2008 were removed by MnDOT, packed, and shipped to LTL for photometric testing. Based on the photometric test data, one of these luminaires had power draw of 278 W, used 240 LEDs with discrete plastic optics on each LED and no cover, and had a distribution Type III Short and BUG rating of B3-U1-G4. The other had power draw of 233 W, used 200 LEDs with discrete clear plastic optics on each LED and no cover, and had a distribution Type VS Short and BUG rating of B3-U1-G2. Both units were tested in their "as-is" or dirty condition, then cleaned by the laboratory and tested again. These two luminaires had operated for about 56 months at the time they were tested.

As reported by Kinzey and Davis [2014], these four luminaires were removed and tested as an extension of an earlier evaluation project at the site. Luminous intensity distribution was measured for each luminaire using the absolute photometry method, in accordance with IES LM-79 procedures.

2.2 U.S. Border, Yuma, AZ

In March 2014, six luminaires were installed at three pole locations (two luminaires on each pole) as part of a trial installation of an LED lighting system at the U.S. Customs and Border Protection Yuma Sector site along the U.S.-Mexico border. As part of an initial evaluation of the performance of the trial LED installation, DOE researchers measured illuminances at the site, then repeated these measurements about every 6 months over a three year period [Wilkerson et al. 2016]. These measurements revealed that both the illuminance levels and the illuminance distribution were changing to a greater extent than expected. To evaluate potential causes for these changes, two luminaires were removed from the site in November 2015 and shipped to the photometric testing laboratory at Eaton Lighting. Based on the photometric test data, these luminaires had power draw of 378 W, used 112 LEDs with clear discrete optics on each LED and no cover, and had a Type III Short distribution with BUG rating of B4-U1-G4. Both units were tested in their "as-is" or dirty condition, then cleaned by the laboratory and tested again. These two luminaires had operated for about 20 months at the time they were tested. All tests were conducted in accordance with IES LM-79 procedures. A photograph of one of the LED arrays used in these luminaires is provided in Figure 1, showing the accumulated dirt that was present before the "as-is" testing.



Figure 1. LED array with accumulated dirt from the project site in Yuma, AZ.

2.3 Philadelphia Airport

In October 2014, three luminaires were installed at one pole location as part of a trial installation of an LED lighting system at Philadelphia International Airport (PHL). After an initial evaluation of the installation, one of the three luminaires was removed in May 2015 and replaced with a different luminaire as part of a more extensive second trial (see Davis and Wilkerson [2015] for details). The luminaire that was removed had power draw of 804 W and used 240 LEDs with clear discrete optics on each LED and no cover. Based on the photometric test data, its distribution was classified as Type III Short and it had a BUG rating of B5-U1-G5. The luminaire was carefully packed and delivered to LTL, a short drive from PHL. LTL tested the luminaire in its “as-is” or dirty condition, then cleaned the luminaire and tested it again in the clean condition. The luminaire had operated for about 7 months at the time of testing. All tests were conducted in accordance with IES LM-79 procedures.

3. Results

Table 1 summarizes the testing results for the seven luminaires from the three exterior project sites described above. For each luminaire, the table lists the total light output, peak luminous intensity, and nadir luminous intensity for both the clean and the dirty conditions. The angle of peak intensity ranged from 55° to 65° for these luminaires. For the desired comparisons, the angle at which the peak intensity

occurred for the clean condition of a luminaire was also used for reporting the peak intensity for the dirty condition of that luminaire, although in some cases the accumulated dirt slightly changed the angle where peak intensity occurred.

Table 1. Summary of photometric testing results.

MONTHS	LUMINAIRE & CONDITION	LIGHT OUTPUT (lm)	NADIR INTENSITY (cd)	PEAK INTENSITY (cd)
7	PHL Clean	61,789	4725	39,180
	PHL Dirty	60,673	4699	37,284
	% of Clean	98.2%	99.4%	95.2%
14	I-35W a Clean	15,227	1573	5016
	I-35W a Dirty	14,520	1658	4780
	% of Clean	95.4%	105.4%	95.3%
14	I-35W b Clean	15,245	1565	4901
	I-35W b Dirty	14,670	1690	4711
	% of Clean	96.2%	108.0%	96.1%
20	Yuma a Clean	29,881	3436	17,697
	Yuma a Dirty	27,782	3990	12,922
	% of Clean	93.0%	116.1%	73.0%
20	Yuma b Clean	27,472	3218	16,195
	Yuma b Dirty	24,956	3883	11,775
	% of Clean	90.8%	120.7%	72.7%
56	I-35W d Clean	15,653	2239	7533
	I-35W d Dirty	13,975	2423	6251
	% of Clean	89.3%	108.2%	83.0%
56	I-35W c Clean	13,194	1306	4209
	I-35W c Dirty	11,341	1635	3648
	% of Clean	86.0%	125.2%	86.7%

4. Discussion

4.1 Comparison to IES values for overall LDD

Table 2 shows the measured overall LDD value for the tested luminaires, and the estimated LDD value for each of the five IES RP-36-15 environmental conditions, at the related time period. Since the ambient particulate level at the three project locations does not exceed 150 micrograms per cubic meter, the very clean condition is indicated for all three sites. However, the description of the very clean condition in the referenced IES documents indicates light traffic, generally limited to residential or rural areas, which does not accurately describe these project locations. Instead, the clean condition's description of moderate to heavy traffic is appropriate.

Table 2 shows that the IES RP-36-15 method provides a suitable estimate for the measured LDD value when using the IES clean condition. Figure 2 illustrates this finding, with the seven measured LDD values plotting very close to the line derived from the IES estimated values for the clean environmental condition. Based on these data, the IES RP-36-15 method for estimating LDD seems applicable to the LED luminaires evaluated. General claims of lower levels of dirt depreciation (or higher LDD values) for

LED luminaires than for luminaires using conventional light sources are not supported by the test data for the LED luminaires in these three projects.

Table 2. Comparison of tested and IES RP-36-15 estimated LDD values for exterior applications.

MONTHS	PROJECT	TESTED LDD VALUE	IES ESTIMATED LDD VALUE				
			VERY CLEAN	CLEAN	MODERATE	DIRTY	VERY DIRTY
7	PHL	0.982	0.98	0.96	0.94	0.89	0.78
14	I-35W	0.958	0.98	0.95	0.91	0.85	0.70
20	YUMA	0.919	0.97	0.92	0.89	0.82	0.65
56	I-35W	0.868	0.93	0.88	0.82	0.70	0.48

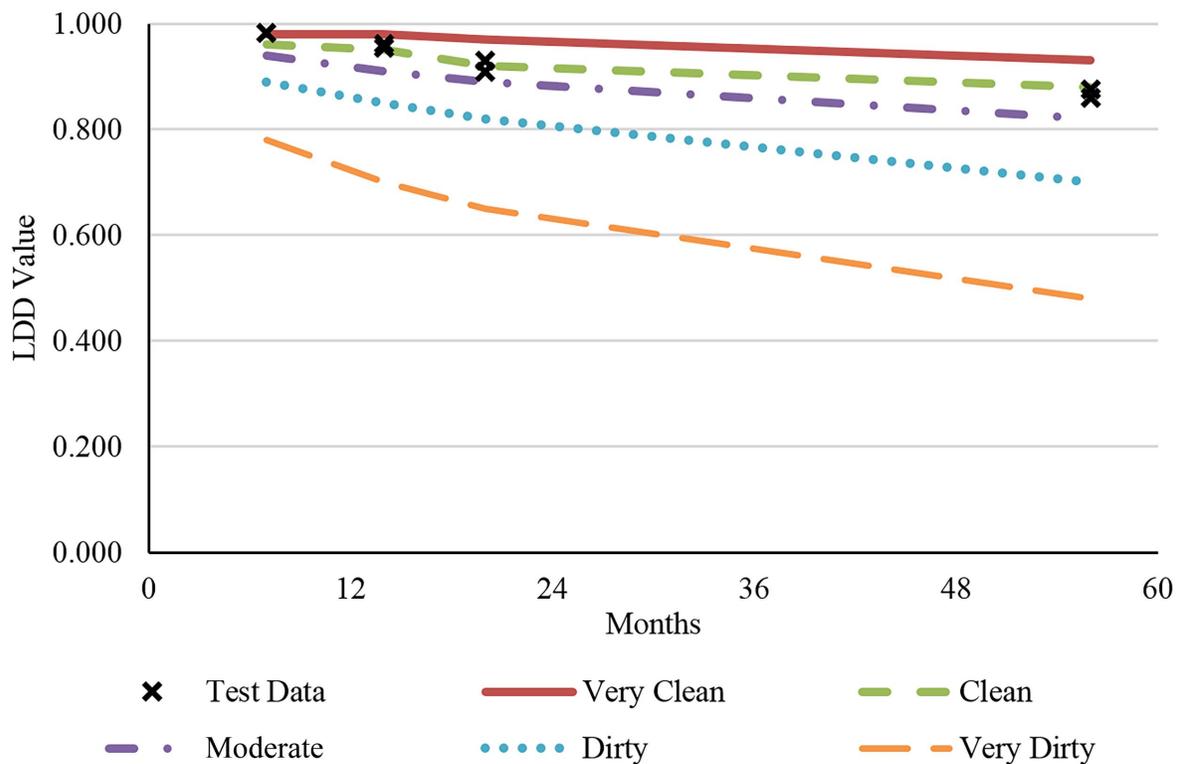


Figure 2. Measured dirt depreciation values compared with IES estimated values from RP-36-15, for five different environmental conditions.

In addition to the comparisons to the RP-36-15 LDD method, the measured LDD values from the three exterior project sites were also compared to the calculated values from the LDD formula provided in the IES Tenth Edition Handbook, which focuses on interior lighting applications. Those results are shown in Table 3. In this case, the measured LDD values were greater than the IES estimated values for the shorter time periods (7, 14, and 20 months), indicating that there was less depreciation in light output due to dirt than the IES formula predicts. At 56 months, the IES clean condition and measured values were the same.

Table 3. Comparison of tested and IES Handbook estimated LDD values for interior applications.

MONTHS	PROJECT	TESTED VALUE	IES CALCULATED VALUE					
			OPEN/UNVENT			OTHER		
			CLEAN	MODERATE	DIRTY	CLEAN	MODERATE	DIRTY
7	PHL	0.982	0.945	0.891	0.817	0.945	0.932	0.846
14	I-35W	0.958	0.926	0.841	0.705	0.926	0.892	0.785
20	YUMA	0.919	0.914	0.807	0.630	0.914	0.864	0.746
56	I-35W	0.868	0.868	0.676	0.355	0.868	0.740	0.602

One point worth noting when applying the IES LDD estimates to LED luminaires is that, unlike luminaires using fluorescent and HID sources, luminaires using LEDs often employ heat sinks to dissipate heat away from the LEDs. Since LED light output is directly affected by the LED junction temperature, dirt accumulation on the heat sinks that affects the heat transfer away from the LEDs could contribute to a reduction in light output over time. Consequently, the total light output reduction from dirt accumulation may be a combination of the effect on the optical materials and the effect on the heat sink materials. These effects were not separately evaluated in this project. While dirt accumulation on the heat sink may contribute to an overall reduction in light output, it would not be expected to contribute to an effect on luminous intensity distribution as discussed below; these effects result from dirt on the optical materials. Heat sink effects are likely to vary based on the design and materials used for the heat sink, and seem to be an important consideration for future revisions to IES LDD estimation procedures that address LED luminaires.

4.2 Effects on luminous intensity distribution

IES RP-36-15 [IESNA 2015] states, “LDD is not used to predict any changes to light distribution that may occur.” While the overall measured lumen depreciation due to accumulated dirt closely matched IES estimates for LDD, the data shown in Table 1 also indicate that the accumulated dirt on the luminaires dramatically altered the luminous intensity distribution of the luminaires. (In fact, the changes in illuminance distribution at the Yuma project stimulated the deeper investigations into dirt depreciation reported here.) For one of the luminaires tested after 20 months, for example, the overall measured LDD factor was 0.91, a 9% decrease in light output. But while the accumulated dirt decreased the luminaire’s overall output, it increased the luminous intensity at nadir by 20% relative to the clean condition. And the decrease in intensity at higher angles due to dirt was much greater than the overall decrease – at the angle of peak intensity, the luminous intensity decreased by 27%, compared to the overall 9% decrease in light output.

Given that the luminaire types included in this evaluation produce a “batwing” intensity distribution with the peak intensity at high angles (ranging from 55° to 65° for these seven luminaires), the noted effects of dirt accumulation on the intensity distributions are not surprising. Accumulated dirt serves as a diffusing optical element, scattering the light directed towards peak angles and redirecting it towards lower photometric angles. This effect is illustrated in Figure 3, which compares the polar plots of luminous intensity distribution for the clean and dirty conditions of the luminaires that had operated for 20 months before cleaning. The reduction in intensity at high angles near the peak intensity is clearly shown, along with the corresponding increase in intensity at angles near nadir.

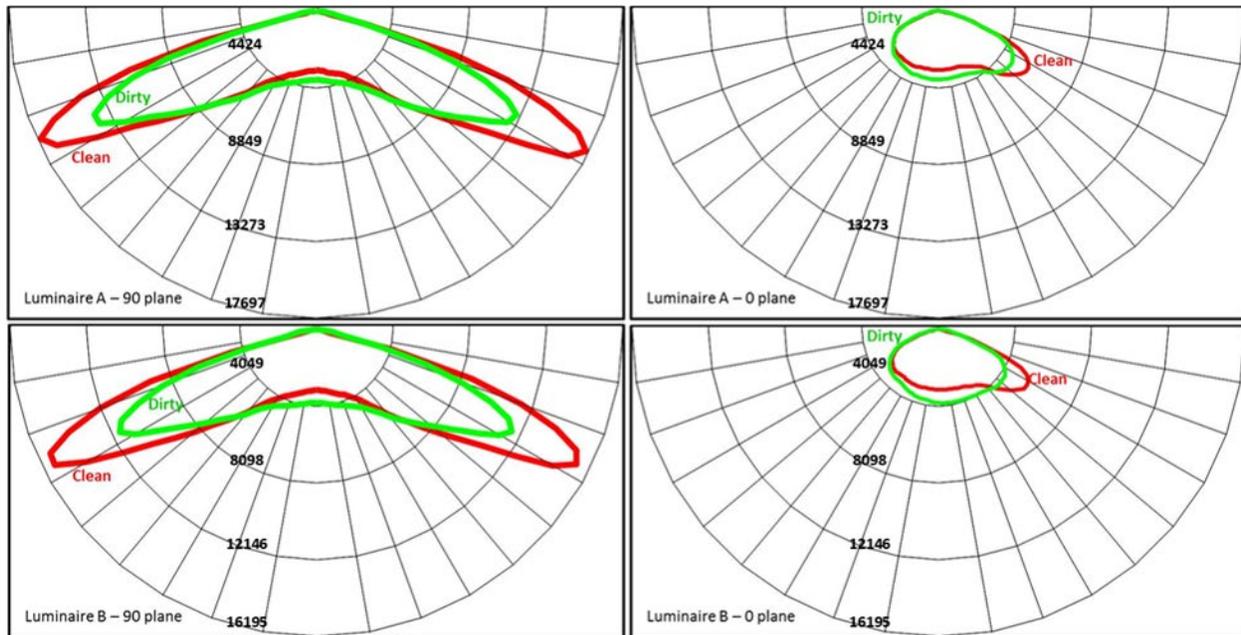


Figure 3. Polar plots of luminous intensity values for the clean and dirty luminaire conditions for the two tested luminaires from the Yuma project site.

The differential effects of dirt based on angle shown in Table 1 may also indicate the importance of the luminaire's optical design in determining the effects of dirt. For example, the reduction in peak intensity after 20 months was over 25% for both of the luminaires tested from the Yuma project, while the effect on peak intensity after 56 months was less than 20% for the two luminaires tested at that time from the I-35W Bridge location. Although dirt had a greater effect on overall light output after 56 months relative to 20 months, the effect on peak light output was less for the luminaires at 56 months. The differences in optical design between the luminaires from these two projects may partly explain these differences in the effect of dirt accumulation on intensity distribution. Possible differences in LDD based on luminaire characteristics are discussed in IES RES-1-16 [IESNA 2016].

The changes in luminous intensity distribution due to dirt did not substantially affect the luminaire categorizations or BUG ratings. The two luminaires tested after 20 months changed from a Type III when clean to a Type II when dirty; the categories for the other five luminaires did not change. The glare values in the BUG ratings were reduced by one unit when dirty for the two luminaires tested after 56 months; otherwise the BUG ratings did not change for the tested luminaires.

5. Conclusion

Accurate estimates of light loss factors such as LDD, along with a plan for regular maintenance of the luminaires, have important implications for lighting system performance over time, and for energy use, since they directly affect the number of luminaires needed to achieve photometric targets such as illuminance. Failing to accurately account for LDD may result in maintained illuminances that fall below recommended levels, if the LDD value used was greater than merited, or it may result in wasted energy because of overlighting, if the LDD value used was less than merited.

Changes in intensity distribution due to dirt are not addressed in IES LDD methods, in part because the effects may be expected to vary greatly depending on the optical design of the luminaire. However, the data presented here indicate that the effects of dirt on intensity distribution can be quite significant, with reductions in intensity of more than 25% at peak angles. For engineers and designers who depend

on accurate intensity distribution data for detailed lighting calculations, these effects suggest that further research and revised IES LDD guidelines may be needed, since those calculated results may not be relevant once dirt has accumulated. Since the data presented here represent just seven luminaires from three projects, future studies can broaden both the luminaire types and the environmental conditions, to investigate whether the findings reported here can be generalized to other conditions, and to better inform future improvements to LDD estimation methods.

However, the good news is that LDD is recoverable. The testing reported here demonstrated that once a dirty luminaire was cleaned, its performance was restored, at least for the seven luminaires tested and for the cleaning methods used. Further explorations of the effects of dirt accumulation on both total light output and luminous intensity distribution are needed for different luminaire types, as well as the effects of different cleaning methods, before IES LDD guidance can be revised. In addition, luminaire characteristics that are unique to LED luminaires, such as the strategies employed for thermal management and for managing or altering the possible accumulation of dirt, need to be considered in revised LDD guidelines. In the meantime, designing for a planned schedule of cleaning according to manufacturers' recommended cleaning methods may help mitigate the effects of dirt on both overall luminaire output and luminaire intensity distribution. While LED luminaires offer many important benefits relative to HID and other conventional sources, they are not immune to the effects of dirt depreciation, and the LDD light loss factor remains an important consideration for LED systems.

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7. Disclosure statement

The authors report no conflicts of interest.

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