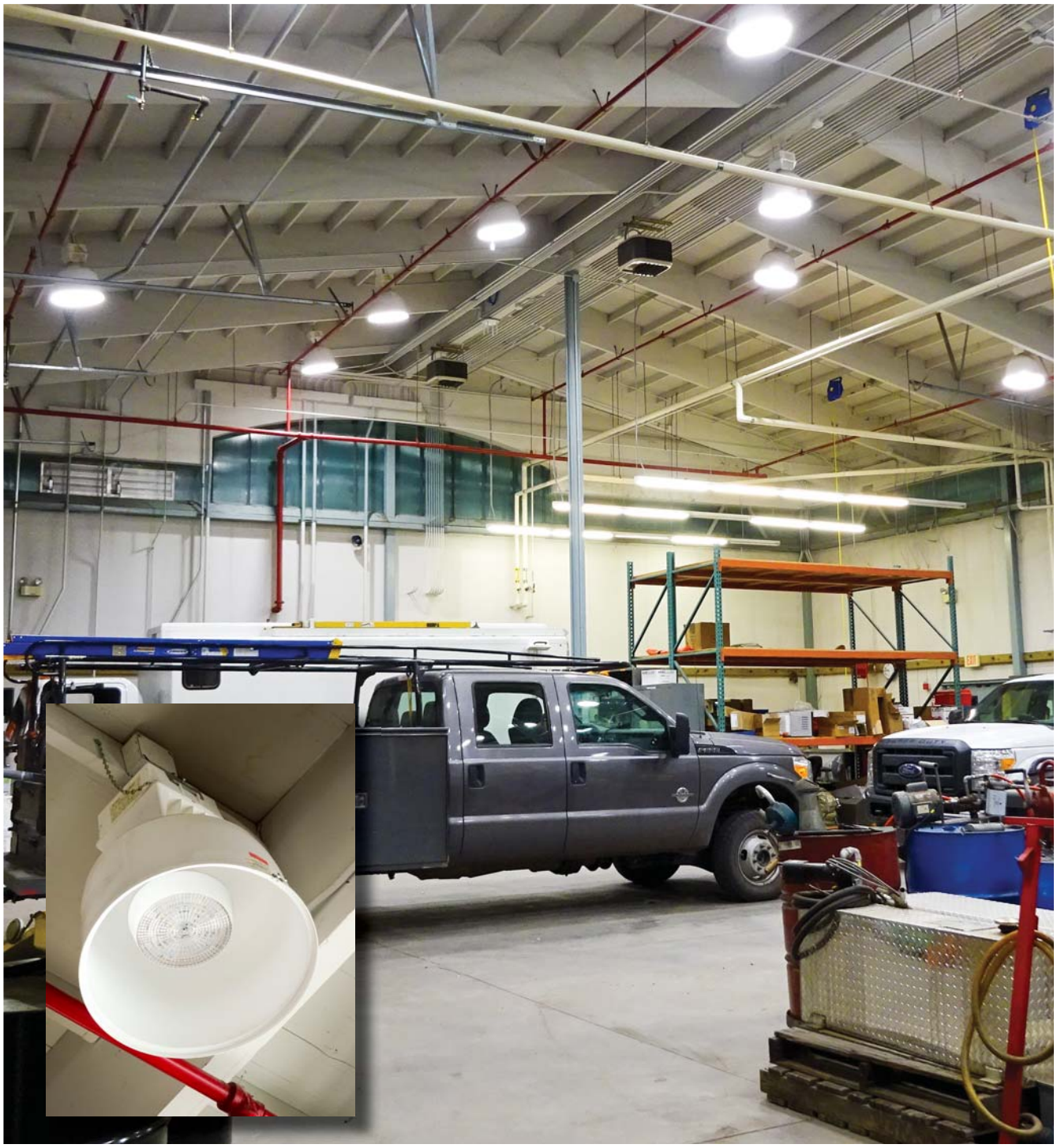
FIELD TEST

DELTA

Demonstration and Evaluation of Lighting Technologies and Applications

MOGUL SCREW-BASE LED REPLACEMENT LAMPS FOR HIGH BAY ENVIRONMENTS



For spaces such as warehouses and shops, conventional lighting often consists of high bay luminaires operating high-intensity discharge (HID) sources. These high-wattage lamps are typically designed to fit into larger, "mogul" sockets. Mogul screw-base light-emitting diode (LED) replacement lamps are available that allow existing luminaires to be reused. These lamps have the potential to save substantial energy, as well as reduce maintenance and improve color characteristics. However, LED lamps may change the luminaire's light distribution, thus occupants may notice a difference in the distribution of light in their environment.

Background

Retrofit Procedure

To install a mogul screw-base LED replacement lamp, electricians remove the HID lamp and typically remove or disable the HID ballast.[1] Because LEDs are electronic devices, they can be damaged by power surges, so some manufacturers recommend adding a surge protector to the circuit.[2] The Lighting Research Center (LRC) recommends installing a fast-acting fuse to protect against "non-passive failure" (e.g., explosion) in case a conventional HID lamp is later installed without reconnecting the ballast.[3]

Lenses

Conventional HID high bay luminaires are often fully enclosed. They employ a lens to protect against possible non-passive lamp failures, and/or to spread the light more uniformly across the high bay space. LED replacement lamps, however, are not subject to non-passive lamp failures thus do not require lens protection, and may already have integral optics to distribute the light widely. Furthermore, LED lamps are expected to operate more effectively from improved heat management due to ventilation in open luminaires. Thus these LED lamps may perform even better when lenses are removed.

BPA Maintenance Facility before and after installation of LED replacement lamps

Application Profile

The BPA Maintenance Facility is a 5,000 square foot (465 m^2) warehouse and shop for electrical utility workers serving southern Oregon. The space is used for storing vehicles, electrical equipment and supplies. During normal operations, electrical personnel briefly visit the shop on weekdays, at the beginning and end of their shifts. The facility is also occasionally used on nights and weekends for repair or assembly tasks and for weather-related electrical emergencies.

Daylight is readily available from clerestory windows on all four sides of the facility. The electric lighting was installed when the facility was built in the early 1990s. The majority of the lighting consists of 21 high bay luminaires, with opaque sides and prismatic diffuser lenses on the bottom. The lighting is mounted on the sloped ceiling, ranging in height from 20 to 23.5 ft (6.1 to 7.2 m). In 2015, the LRC evaluated the lighting in the shop before and after installation of the LED replacement lamps. The table on the following page shows key features of the electric lighting.

---

1 At least one manufacturer uses the HID ballast to operate their LED lamp.

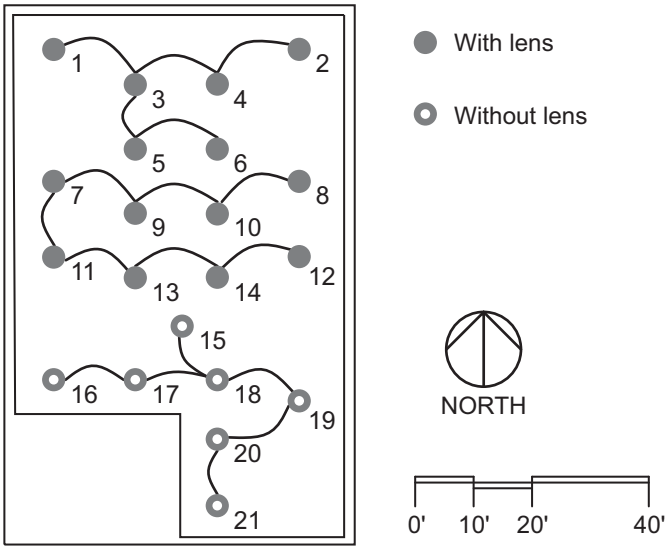
2 Some manufacturers require a surge protector at each luminaire for warranty purposes.

3 For results of laboratory testing of several HPS lamps with bypassed ballasts, see the LRC's 2015 report: https://www.bpa.gov/EE/Technology/EE-emerging-technologies/Projects-Reports-Archives/Documents/Mogul_Base_HID_Persistence_Tests_2015.pdf

The existing 400 W (nominal) metal halide lamps were not new; out of 21, two were distinctly dim and green in color, four were not operating, and all the diffuser lenses were dirty. When the new LED replacement lamps were installed, the luminaires were also cleaned. For one circuit, lenses were not replaced; for the two other circuits, lenses were cleaned and re-installed, enabling comparisons with and without lenses.

Field Test Objectives

- Assess ease of retrofit
- Compare worker acceptance before and after LED retrofit
  - After retrofit, compare worker acceptance with and without lenses
- Compare energy performance before and after retrofit



The diagram above shows the plan view layout of the luminaires.

	Before	After
Type	High bay luminaires with metal halide lamps [a]	Mogul screw-base LED replacement lamps [b]
Rated Watts per Luminaire	457 W	148 W
Power Density [c]	1.8 W/ft² (0.17 m²)	0.7 W/ft² (0.07 m²)
Lamp Model	Philips MH400/U/ED28	Light Efficient Design LED-8032M42
Rated Lamp Light Output (initial)	36,000 lumens (mean: 24,000 lumens)	15,020 lumens
Rated Lamp Life	20,000 hours	up to 50,000 hours [d]
Rated Correlated Color Temperature	4000 K	4191 K
Rated Color Rendering Index	63	84
Example		

[a] Field measurements were not available; these represent generic industry standard expectations. Non-operational lamps are assumed to draw 20 W.

[b] Reported here are manufacturer claims. Other manufacturer claims include: THD (20.1%) and power factor (0.962) at 277 V. Manufacturer states "retro-fitted fixture retains UL approval under UL Classified 1598C." Warranty of five years.

[c] The area lighted by the HID luminaires was 4439 ft² (412.4 m²); overall warehouse size was 5052 ft² (469.3 m²).

[d] For more information about life of LED systems, consult IES-LM-84-14, *IES Approved Method for Measuring Luminous Flux and Color Maintenance of LED Lamps, Light Engines, and Luminaires*, as well as IES TM-28-14, *Projecting Long-Term Luminous Flux Maintenance of LED Lamps and Luminaires*.

Illuminance Comparison

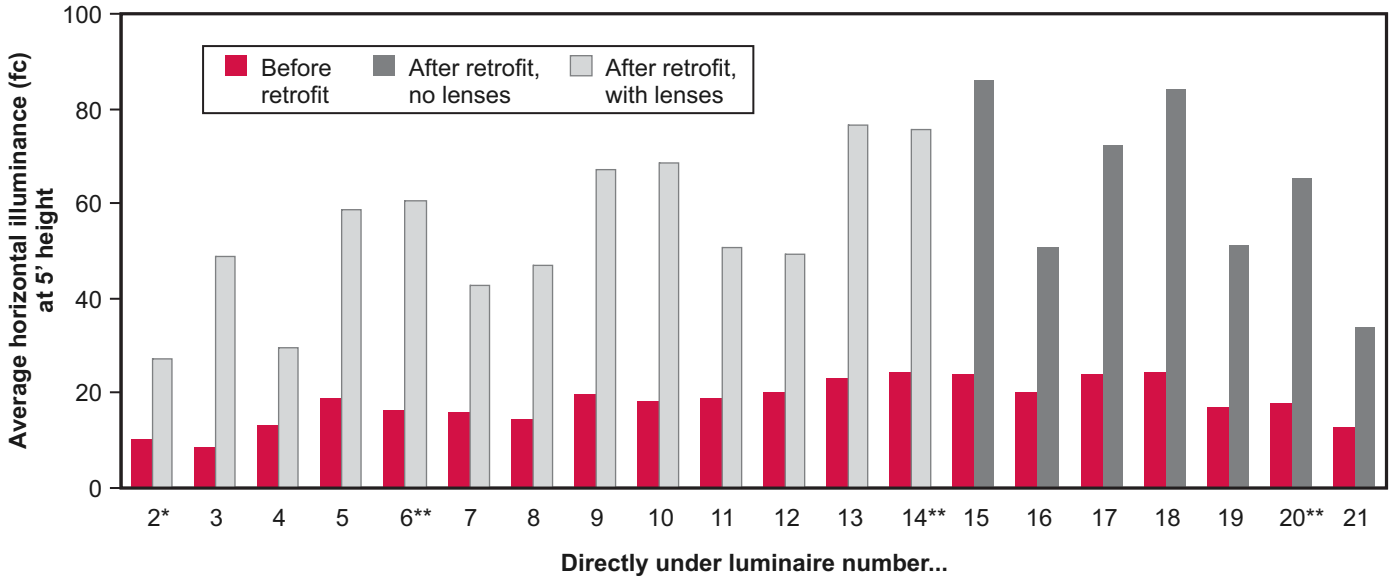
The LRC measured illuminance in the facility before and after retrofit. Due to obstructions from equipment and vehicles, measurements were collected at 5 ft. (1.5 m) above the ground, under each of the luminaires.[4] Daylight contribution was removed arithmetically.[5] The graph below shows the average of three rounds of measurements at various times of day.

The newly cleaned, retrofitted luminaires increased light levels substantially (approximately 3x). Before the retrofit, illuminances from electric light ranged 9-25 footcandles (fc). (Light levels would have been substantially higher if new MH lamps had been installed and luminaires cleaned.) After the retrofit, illuminances at the same locations ranged 27-76 fc with lenses, and 34-86 fc without lenses. Light was distributed widely in the space before and after the retrofit; even under burned-out lamps before the retrofit, light levels were similar to adjacent measurement positions. Prismatic lenses (before and after retrofit) and overlapping light distribution softened shadows.

This facility had few storage racks; the LED lamps used in this demo produced a light distribution that was suitable for the environment. When considering retrofits, specifiers should confirm that the light distribution matches the needs of the space, especially with extensive vertical shelving.

[4] Measurements under luminaire #1 were omitted due to obstruction from welding hood installed underneath.

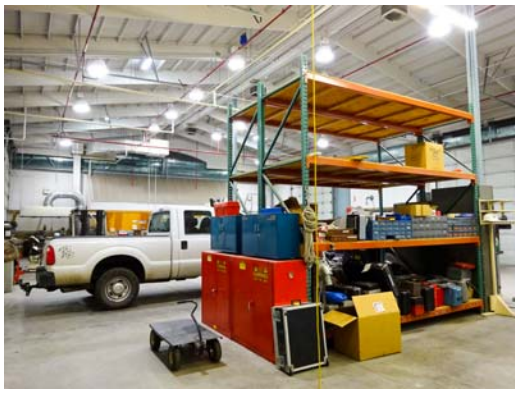
[5] Measurements were collected with both daylight and electric light, then repeated at each location with daylight-only. Contribution of daylight was removed by subtracting these measurements.

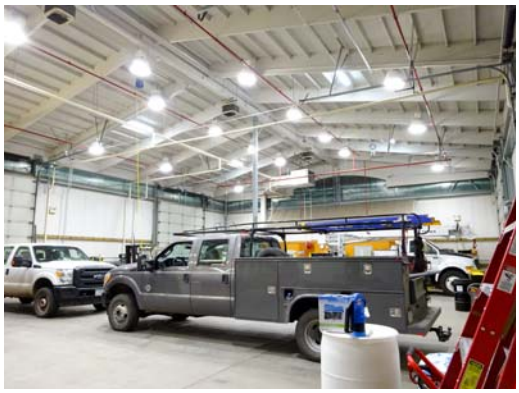


* Due to obstruction by heavy equipment, this point was located at 3′-8″ height

** Burned-out lamp directly above, for "before" measurement only

Horizontal illuminance before vs. after retrofit (electric only; average of three measurements).





The facility was mostly open with few storage racks.

Worker Response

The LRC administered an anonymous questionnaire to workers both before (n=5) and after (n=4) the retrofit. Despite the small number of available responses, the results were rated positively. None of the lighting features were rated worse after the retrofit; all were rated equal or better.

Higher light levels were noticeable to the occupants. Despite three times higher light levels, the workers did not indicate that there was too much light in the shop after retrofit. Conversely, before the retrofit (with degraded electric light output), more workers felt there was not enough light, compared to after the retrofit.

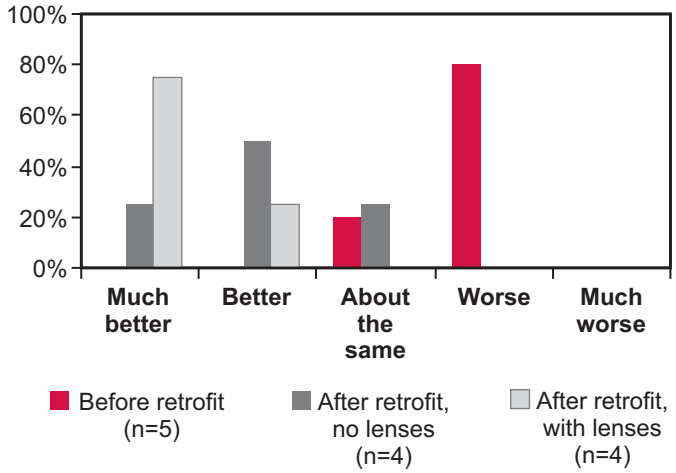
After the retrofit, worker responses differentiated between areas with and without lenses. For questions about shadows, color, flicker, and comfort, more workers preferred the luminaires with lenses than without lenses.

Finally, overall ratings improved with the retrofit; none of the workers rated the lighting positively before the retrofit, but after the retrofit, most of the workers (75%-100%) rated the lighting as "better" or "much better" than other shops.

Before: Too dark
"It's kind of a dungeon over there," (gesturing to corner).

After: Lenses
"Diffuser (lenses) are better; there is a glare without them."

"Compared to other workshops similar to this one, the lighting in this shop is..."

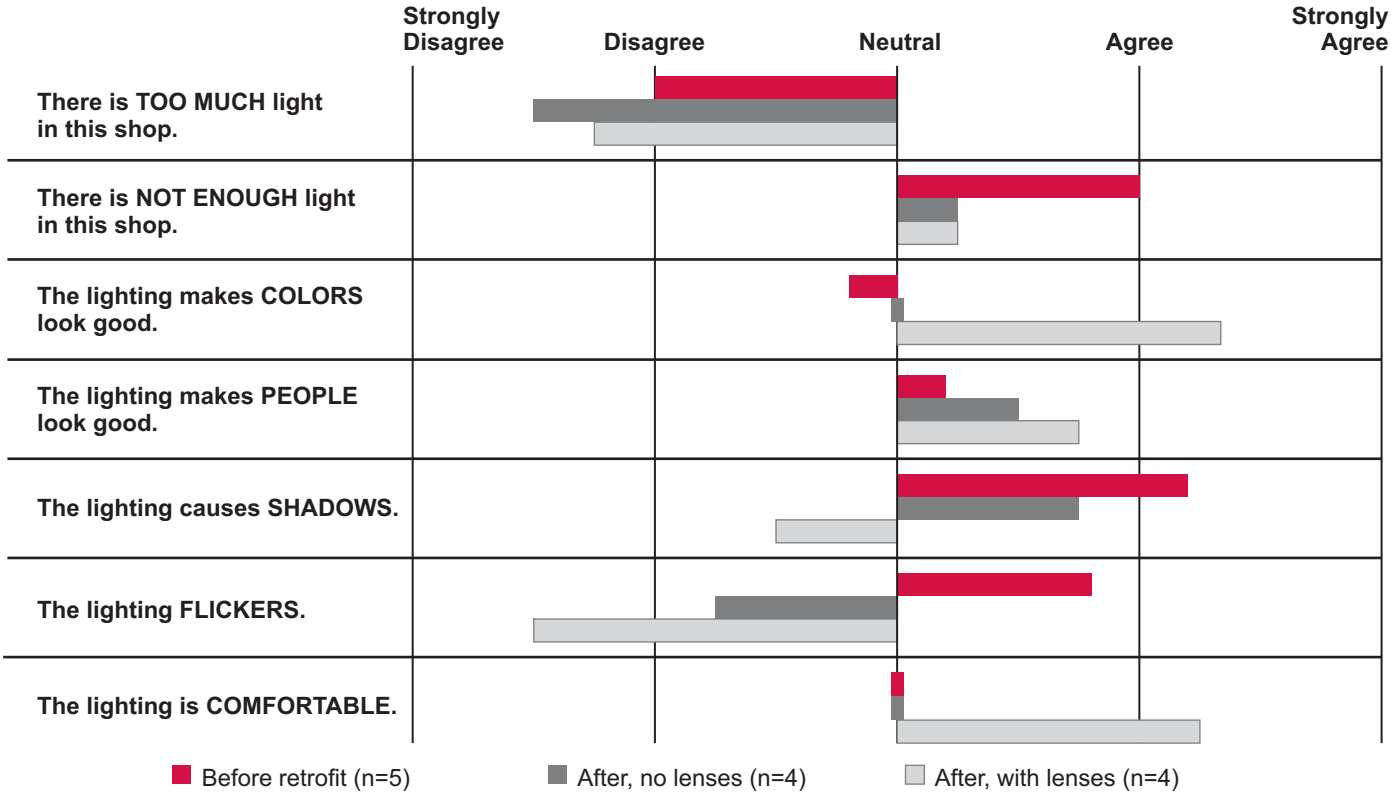


After: Colors
"I love these lights. Yesterday I was doing some wiring. I'm color blind. I could really see. The differences (in colored wire) stood out more. Almost like natural daylight!"

After: Shadows
"We used to be able to see our shadows when we were working in here at night."

After: Overall
"It's WAY better now… it used to be SO much worse!"

"Put these lights in the Redmond shop!"



Questionnaire responses, average.

Installation and Maintenance

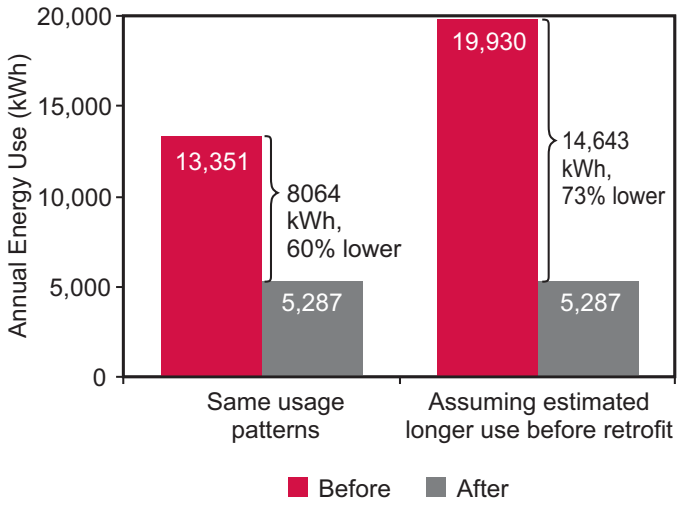
The electrician had positive comments about installing these LED lamps. He reported that the retrofits were "very easy" to install, requiring just 15 minutes each, with a bucket truck;[6] if the luminaires had been mounted within ladder height, he expects the installation would have taken him even less time. Removing ballasts was typical for his previous lighting retrofits. Installing a surge protector at each luminaire was unusual for him. In his other retrofit work, surge protectors were usually installed at the panel. Fuse installations were common in his experience, especially with retrofits of pole-mounted outdoor lighting.

The specified surge protectors were not a stock item at the local electrical distributor, requiring some lead time before retrofit could take place. The wiring installation instructions for this LED retrofit product were sufficient for the electrician's needs. He did not need to contact the manufacturer with technical support questions. The electrician commented that this retrofit required less time than removing the old luminaire and installing a new one. Mounting the luminaires takes the most time in his opinion. He expects that retrofits of wall-mounted luminaires would also be quick retrofits. Based on this experience, the electrician agreed that he would "definitely" do this kind of LED retrofit again.

Power Density, Hours of Operation, and Energy

The LED retrofits in this demonstration had considerably lower rated power density (0.7 W/ft²) than the conventional metal halide lighting (1.8 W/ft²).

Before the retrofit, the lights were left on overnight frequently, apparently for several days at a time. After the retrofit, lights were on overnight three times less frequently. Two explanations are possible. Unlike conventional metal halide lamps, these LED lamps turn on instantly without restrike delay; previous restrike delay may have impacted the occupants' manual switching behavior. Alternatively, the plentiful daylight may have made electric lighting less noticeable, especially with degraded electric light output before retrofit.



Annual energy (kWh) comparisons.

The LRC used the monitoring data to estimate annual energy use. This LED retrofit is estimated to save over 8000 kWh annually due to reduced power demand alone, a 60% savings.[7] Because the previous metal halide luminaires were left on overnight three times more frequently,[8] this retrofit is estimated to save almost 15,000 kWh annually when assuming longer baseline operating hours.[9]

Another advantage of the instant restrike characteristics of these LED lamps is the opportunity to use controls to save even more energy. Because clerestory windows supply plentiful daylight in the space, it may not be obvious that lights are left on when departing; automatic lighting controls such as vacancy sensors or a time clock could increase energy savings, without concern about restrike time.

At other sites with less plentiful daylight or more intensive operations, baseline annual hours of use would likely be even longer, thus energy savings could be higher.

[6] Retrofit consisted of removing the ballast, installing the surge protector and fuse, screwing in the retrofit product, and cleaning the diffuser lenses.

[7] If all HID lamps had been operating before the retrofit, energy savings would have been 67%.

[8] Assuming 12 hours of use per overnight; actual pre-retrofit lighting use may have been higher due to continuous/24-hour use.

[9] Circuits 1 and 2 had estimated overnight use of an additional 765 hours per year each; circuit 3 had estimated 973 additional hours of use per year.

Pollution Avoided

The LED retrofits reduce emissions according to the U.S. Environmental Protection Agency calculator for pollution avoided due to energy saved.[10]

Annual pollution avoided due to energy savings

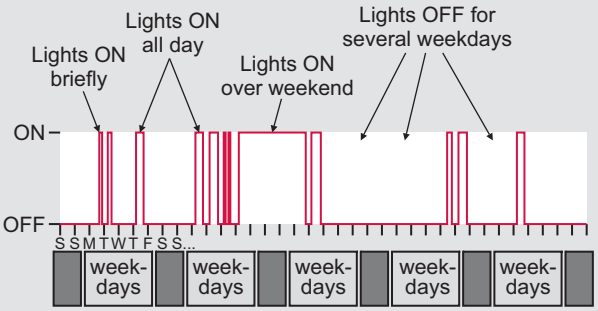
	Pollution Avoided					
	SO_2		NO_x		CO_2	
	lbs	kg	lbs	kg	lbs	kg
Assuming same hours of use before and after retrofit	6.5	2.9	6.5	2.9	5,678	2,576
Assuming longer hours of use before retrofit	11.7	5.3	11.7	5.3	10,310	4,677

Hours-of-Use Monitoring Methodology

Before the retrofit (April-May 2015), monitoring of lighting activity patterns was attempted, but due to limitations on access to luminaires up at the ceiling, logging devices had to be located a few feet away from the luminaires. As a result of the distance from the light source, daylight contribution obscured the contribution from the electric lighting during daytime. Though inconclusive for daytime energy calculations, these data were useful to show when lights were left on overnight.

After the retrofit (October-November 2015), monitoring devices were mounted on the luminaires to record use of lighting. Data for two out of three circuits were usable; data from the third device was corrupted and not usable. The two functioning devices showed near-identical usage patterns. Thus for energy calculations, all three circuits were assumed to be operating in unison.

The monitoring data were used to estimate annual hours of use, and to calculate annual energy use. As shown below, the lights are operated intermittently. Some days the lights were operated briefly; some days lights were left on all day; but most frequently lights were left off all day. In one instance, lights were left on over the weekend. Annual operating hours after the retrofit were estimated to be at least 1700 hours based on this observed pattern of behavior.



Luminaire activity during "after" monitoring period

Economics

This LED retrofit is estimated to save over $900 annually assuming the same hours of use before and after retrofit.[11] This would translate to a payback period of 9.5 years, including cost of LED lamps, surge protectors, fuses, labor and equipment rental.

If one assumes the conventional metal halide luminaires were left on overnight more frequently, this retrofit is estimated to save $1300 annually. This would reduce the payback period to 6.4 years.

Several factors contributing to long payback periods:

- Low annual hours of use due to plentiful daylight and low occupancy rates
- Low electricity rates
- High cost of LED products

This case study evaluated the retrofit performance shortly after the LED lamps were installed. At time of publication, no statements can be made regarding the long-term performance of this product.

[10] Accessed online February 2016 at http://www.epa.gov/cleanenergy/energy-and-you/how-clean.html

NO_x = "In the atmosphere, nitrogen oxides can contribute to formation of photochemical ozone (smog), can impair visibility, and have health consequences; they are thus considered pollutants."

SO_2= "High concentrations of sulfur dioxide affect breathing and may aggravate existing respiratory and cardiovascular disease. Sulfur dioxide is also a primary contributor to acid rain. In addition, sulfur compounds in the air contribute to visibility impairment in large parts of the country."

CO_2 = "It is the principal anthropogenic greenhouse gas that affects the earth's radiative balance. It is the reference gas against which other greenhouse gases are measured."

[11] Assuming energy supply and delivery charges of 6.7¢/kWh and demand charges of $6.26/monthly kW.

Lessons Learned

- The mogul screw-base LED replacement lamps demonstrated at this site direct the light downward (thus delivering the light to a horizontal workplane more effectively than the previous metal halide lamps). LED lamps such as these have the potential to illuminate high bay environments at equal or higher light levels, with lower power demand.
  - Power demand of the LED retrofit was 60% lower than the conventional metal halide luminaires, without reducing light levels or creating hotspots underneath.
  - The retrofit increased light levels noticeably, compared to the existing degraded metal halide lamps with dirty lenses. Because lights were also turned off more frequently after the retrofit, higher energy savings (73%) were estimated.
- Payback periods were long, but might be shorter at other sites with longer hours of use, higher electricity rates, or lower-cost LEDs.
- Instant restrike characteristics of LEDs provide opportunities for other energy-saving technologies, such as vacancy/occupancy sensors or time clocks.
- The electrician had positive feedback about the installation experience.
- While few workers were available to answer the questionnaire, overall their feedback about the retrofit was enthusiastically positive.
  - Workers preferred luminaires with the lenses reinstalled, compared to those left open.

Field Test DELTA
Issue 7
Mogul Screw-base LED Replacement Lamps for High Bay Environments
May 2016

Field Test DELTA evaluates new energy-efficient lighting products to independently verify field performance claims and to suggest improvements. A primary goal of the Field Test DELTA program is to facilitate rapid market acceptance of innovative energy-efficient technologies.

Program Director and Author: Jennifer Brons

Additional Assistance: Trina Beaudoin, Matt Caraway, Kassandra Gonzales, Howard Ohlhous, Bonnie Westlake

Technical Review: Russ Leslie, Leora Radetsky

Editor: Rebekah Mullaney

Graphic Design: Dennis Guyon

Photography: Jennifer Brons

SPONSOR
Bonneville Power Administration (BPA)

CREDITS

BPA: Mary Matteson Bryan, Karen Janowitz, Levin Nock, Craig Sanders, Mira Vowles, Jennifer Williams, and the workers at the BPA site (who shared their opinions about the lighting)

Electrical Contractor: Larry Hand, Quality Electric

Technical Assistance: Ernesto Mendoza and Chacko Oommen, Philips Lighting Electronics North America

Equipment Manufacturers: Light Efficient Design (LED retrofit kits), Thomas Research Products (surge protectors)

Lighting Research Center

Rensselaer Polytechnic Institute
21 Union Street
Troy, NY 12180-3590
(518) 687-7100

www.lrc.rpi.edu

ISSN 1075-3966

Rensselaer