ENERGY SAVINGS FROM LED REFRIGERATION DISPLAY CASE LIGHTING

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Abstract

This paper presents the results from several field monitoring studies to determine the energy savings that result from using LEDs for refrigeration display case lighting.

Introduction and Overview

Improvements in the performance of lighting used in refrigerator display cases can have significant impacts on energy use. For the studies reported in this paper, field monitoring of refrigeration display cases in actual supermarkets was used to collect data in order to assess the performance of LED lighting in such applications.

The results of these studies are presented in this paper. These are based on two studies conducted in supermarkets in two different areas.

Description of Technology

Conventionally, fluorescent lamps (originally T12s, more recently T8s) have been used to illuminate refrigerated display cases in supermarkets. However, there are several disadvantages of using fluorescent lighting for illuminating these cases. Fluorescent lamps do not perform well in cold temperatures; their output dropping noticebly as temperature drops. Using motion sensors with fluorescent refrigeration display case lighting is usually infeasible because there are start problems with fluorescent lighting under cold conditions; frequent starting under cold conditions also reduces the life of a fluorescent lamp. Finally, the waste heat that fluorescent lighting produces is dissipated inside the case, adding to the refrigeration load.

Light-emitting diodes (LEDs) are semiconductor devices that convert electricity to light. LED lighting is also called “solid state lighting” because the light is emitted from a solid block of semiconductor material. When tested under laboratory conditions, LED devices have performed well, being considerably more efficient than incandescent lights. However, LEDs may perform less effectively in actual use because of technical and design issues. Moreover, LED lighting is generally more expensive than traditional fluorescent lighting, limiting the market for LED lighting in general use.

LED lighting has recently been developed as an alternative means for illuminating refrigerated display cases. Using LEDs for illuminating refrigerated display cases has several advantages. LEDs perform well in cold temperatures. The heat generated by an LED system can easily be transferred outside the case entirely, resulting in reduced refrigeration energy needs. Because LEDs are directional in nature, there is less wasted light, which means even greater energy savings. As a solid state technology, LEDs are easy to dim as well. Also, there are no start problems or reduced lamp life when using LEDs under cold conditions.

Because they can be dimmed more efficiently than fluorescents, LEDs can also be used more easily with motion sensors. Rapid and frequent on/off cycles do not affect the life of the LED, enabling the use of movement-triggered controls. These controls can reduce the annual operating hours for an LED lighting system.

Determining Savings from LED Lighting

The major sources of savings from using LED lighting for refrigerated display cases are (1) reduced connected load because of lower wattage of LEDs required for a given level of lighting; (2) reduced hours of use when LED lighting is installed with motion sensors; and (3) reduced refrigeration load.

Savings from using LED lighting for refrigerated display cases can be calculated with the following equation:

$$kWh_{savings} = \left(\#\, fixt_{base} \times Watts / fixt_{base} \times hours_{base} - \#\, fixt_{as-built} \times Watts / fixt_{as-built} \times hours_{as-built}\right) \times HCIF / 1000$$

where:

$kWh_{savings}$ = annual energy savings

$hours_{base}$ = baseline annual operation hours of the fixtures

$hours_{as\text{-}built}$ = post-retrofit annual operation hours of the fixtures, including impact of lighting controls

$HCIF$ = heating/cooling interaction factor

Besides savings from reduced wattage and reduced hours of use, additional energy savings accrue from LED lighting because of the reduction in heat generated from the case lighting, which reduces display case compressor energy use. These compressor-related energy savings are calculated by applying HCIF, which is a factor measuring lighting-cooling interaction. HCIF is calculated as follows:

$$HCIF = \frac{COP + 1}{COP}$$

$$COP = \eta(1.7603 - 0.377T + 0.004T^2)$$

where:

η = COP for compressor rack at rated conditions (1.5 for a low temperature rack and 2.8 for a medium temperature rack)

T = outside dry bulb air temperature in ^{o}C

The equation to calculate COP for grocery store condenser racks is taken from NREL, 2008. The calculated value for COP depends on outdoor air, which varies throughout the year. An average temperature is used to calculate an annual average COP.

Results from Demonstration Project

A project was conducted in a particpating supermarket in northern California to demonstrate the performance of LED lighting for refrigerated display cases under real world conditions. The project had three phases.

- In the first phase, existing fluorescent fixtures in cases on one aisle of the store were replaced with new LED fixtures. Energy consumption was evaluated and customers were surveyed for their reactions to the lighting change.
- In the second phase, motion sensors were installed and tested on three freezer cases. Energy consumption and usage patterns were evaluated using customer energy management system data.
- In phase 3, the results from the first two phases were evaluated to determine whether remaining cases should be retrofitted with LED fixtures and sensors. This phase also included monitoring impacts upon product sales and the refrigeration system.

The supermarket at which the demonstration project was conducted had a total of 21 five-door refrigerated display cases and 5 two-door cases (for a total of 115 doors). The original lighting system for each five-door case consisted of T8 fluorescent lamps and electronic ballasts designed for low temperature applications. The connected lighting load for each five-door case was 352 Watts. Operating hours for the case lighting were from 5 a.m. to 11 p.m. on weekdays and from 6 a.m. to 11 p.m. on weekends (for a total of 6,205 hours of operation per year). The case lights were turned off between 11 p.m. and 5 a.m. through the use of an energy management system.

For the demonstration project, the fluorescent lighting for a five-door case in a middle aisle of the strore was replaced with LED lighting. The connected lighting load for the case with the LED lighting was reduced to 189 watts. The LED system also included dimming power supplies that were controlled by motion sensors. When no customers were near the case, the LEDs were dimmed down from maximum output. When a shopper approached the case, the LEDs were smoothly ramped up to full output.

To collect the data needed to determine savings from the LED lighting, lighting loggers and power monitoring equipment were installed both on the cases with LED lighting and on cases in an adjacent aisle where the original fluorescent lighting was still in place. Monitoring equipment was used that allowed direct measurement of the lighting energy usage. The cases with LED lighting were first monitored for a period of several weeks with the occupancy sensors disengaged. After this period, the occupancy sensors were engaged and additional monitoring was conducted for several more weeks.

Intercept interviews were also conducted to collect information on customers' reactions to the LED lighting. Two separate surveys were conducted as part of this study. In the first survey, shoppers were asked to compare the LED lighting to the fluorescent lighting when the motion sensors were not engaged. A second survey was conducted several weeks later after the motion sensors for the LED lighting were engaged. Interviews for each survey were conducted during morning, afternoon, and evening hours.

The estimated energy savings for the LED lighting, both without motion sensors and with motion sensors are reported in Table 1. Without motion sensors, the LED lighting reduced annual kWh usage by 46.3 percent. With the motion sensors engaged, the LED lighting reduced annual kWh usage by 69.2 percent. In order to calculate annual savings estimates, data from the monitoring periods were linearly extrapolated.

Table 1. Energy Use and Savings: LED Lighting versus Fluorescent Lighting for Five-Door Freezer Case (Without Heating/Cooling Interaction Factor)

Lighting Energy Parameter	***Fluorescent Lighting***	***LED Only (Without Sensors)***	***LED with Motion Sensors***
Watts per five-door freezer case	352	189	189
Hours of lighting use per year	6,205	6,205	3,564
Estimated annual kWh per five-door freezer case	2,182	1,171	672
Estimated annual kWh savings per five-door case for LED lighting	n/a	1,011	1,510
Annual LED kWh savings as percent of baseline fluorescent lighting kWh usage		46.3%	69.2%

As noted above, in addition to direct lighting savings, installation of LED lighting can also provide refrigeration savings. A study by the Rensselaer Polytechnic Institute Lighting Research Center [1] indicates that every kWh saved by switching to LED lighting results in an additional 0.45 kWh in refrigeration savings. The calculation of additional refrigeration savings is more precise in the present study because it accounts for COP of the specific equipment.

These refrigeration savings occur because reducing wattage within a refrigerated space means less load on the refrigeration system. In addition, LEDs do not produce infrared light but fluorescent lighting does. Infrared light from fluorescent lamps is converted to heat when it strikes products within a case. LEDs do produce heat, but most of this heat can be conducted outside of the freezer case (e.g., through contact with the door frame). The load on the low-temperature refrigeration system is thereby reduced.

Another aspect of this demonstration project was to gauge customer reaction to the LED lighting. Key findings from the surveys conducted for this purpose are as follows.

- 66 percent of surveyed customers did not notice that the fluorescent lights had been replaced with LEDs.
- Customer reaction to the new LED fixtures was mixed. This was attributable to the prototype fixtures used for this project producing shadows on the center of the product shelves.
- 80 percent of surveyed customers did not notice the dimming system. Of the 20 percent who did notice, most said it would not affect their shopping experience. This finding suggests that ramping is superior to low-high switching, in that switching between high and low output may be distracting to shoppers.

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[1] *Energy-Efficient Lighting Alternative for Commercial Refrigeration*, Rensselaer Polytechnic Institute Lighting Research Center, available at http://www.lrc.rpi.edu/programs/solidstate/pdf/FreezerLighting-FinalReport.pdf

Results from M&V Study

A second study of LED lighting for refrigerated display cases was undertaken as part of an overall evaluation of a commercial retrofit rebate program for a utility in a southwestern state. Under that program, a supermarket chain had received incentive payments to install LED lighting for refrigerated display cases at a number of its stores.

As part of the effort to verify the savings from these installations, field measurements were taken at three of the stores and used to determine the energy savings that resulted when fluorescent lighting in refrigerated display cases was replaced with LED lighting in the supermarkets. This effort also included determining the savings from installing motion sensors as well as LEDs for some cases.

Various types of information were collected to use in measuring and verifying the savings from the LED lighting. Manufacturer's information on the LED strips was obtained before going on-site. Once on-site, field staff collected nameplate information and took one-time power measurements of a known quantity of LED lighting in both freezers and refrigerated cases. The temperature set points of all freezer and refrigerator cases were recorded. Lighting loggers were installed on the cases with LED lighting at the three stores to take continuous field measurements on hours of use. (Type of loggers used?) Temperature\RH loggers were installed inside a freezer and a refrigerator to record both temperature and RH.

The LED lighting retrofits for the stores involved replacing T12 fluorescent lighting in refrigerated and freezer cases with LED lighting. Motion sensors were also installed for most of the freezer cases. Table 2 shows the reduction in connected load that resulted for the three stores studied. Repacing fluorescent lighting with LED lighting resulted in a 68.5 percent reduction of connected lighting load.

Table 2. Changes in Connected Loads from Retrofitting Freezer and Refrigerated Cases with LED Lighting

LED Retrofit	***Original Connected Lighting Load (kW)***	***Retrofit Connected Lighting Load (kW)***	***Percent Reduction in Connected Load***
LEDs with motion sensors replacing T12s in freezer cases	22.040	7.476	66.1%
LEDs replacing T12s in freezer cases	7.366	2.079	71.8%
LEDs replacing T12s in refrigerated cases	3.944	0.945	76.0%
Totals	33,350	10,500	68.5%

The monitoring of hours of use showed that installation of motion sensors reduced lighting hours of operation from 4,922 hours per year to 4,158 hours, a reduction of 15.5 percent.

Table 3 shows the annual kWh savings for the three monitored stores that resulted from replacing fluorescent lighting with LED lighting. No heating/cooling interaction factor was applied in calculating the savings reported in Table 3. Retroffiting to LED lighting resulted in savings in lighting energy of 72.0 percent.

Table 3. Annual kWh Savings for Lighting That Resulted from Retrofitting Freezer and Refrigerated Cases with LED Lighting (Without Heating/Cooling Interaction Factor)

LED Retrofit	***Annual kWh Usage Fluorescent Lighting (kWh)***	***Annual kWh Usage LED Lighting (kWh)***	***Savings from Using LED Lighting***	***Percent Savings***
LEDs with motion sensors replacing T12s in freezer cases	108,481	31,085	77,396	71.3%
LEDs replacing T12s in freezer cases	36,255	10,233	26,023	71.8%
LEDs replacing T12s in refrigerated cases	19,412	4,651	14,761	76.0%
Totals	164,149	45,969	118,179	72.0%

Additional energy savings accrue from the reduction in heat generated from case lighting, reducing display case compressor energy use. These compressor-related energy savings were measured by applying heating/cooling interactive factors that were calculated for both medium and low temperature cases from cooling efficiency name plate data. Table 4 shows the annual kWh savings for the three monitored stores after a heating/cooling interaction factor was applied to the calculated lighting savings. When the HCIF was applied, savings from retrofitting to LED lighting resulted in savings of about 106 percent.for freezer cases and about 96 percent for refrigerator cases. How can savings be more than the 164,149 kWh pre usage (explain). Almost all of the savings with HCIF applied are larger than the entire pre/baseline annual fluorescent lighting usage.

Table 4. Annual kWh Savings (Lighting and Cooling) That Resulted from Retrofitting Freezer and Refrigerated Cases with LED Lighting (With Heating/Cooling Interaction Factor Applied)

LED Retrofit	***Savings from Using LED Lighting***	***HCIF***	***Savings with HCIF Applied***	***Percent Savings***
LEDs with motion sensors replacing T12s in freezer cases	77,396	1.485	114,966	106.0%
LEDs replacing T12s in freezer cases	26,023	1.485	38,655	106.6%
LEDs replacing T12s in refrigerated cases	14,761	1.260	18,605	95.8%
Totals	118,179		172,226	104.9%

Conclusions

This paper presented the potential savings performance of LED lighting in refrigerated display cases in supermarkets based on measurements taken from actual LED lighting installations in supermarkets. The results reported here show that use of LED lighting in refrigerated display cases significantly reduce the amount of energy in the display cases. These results contribute to better quantifying the large savings potential from using LED lighting for refrigerated display cases under actual field conditions.

References

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