Application of Light Emitting Diodes in Dairy Facilities

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INTRODUCTION

Light is a vital component in the daily operation of a dairy facility, even though lactating and dry dairy cattle require different amounts of light exposure. Increased cow performance, greater well-being, and safer working conditions make lighting an important environmental characteristic. Because cows are able to move more easily through uniformly lit entrances and exits, increased quality lighting improves cow movement and efficiency. Herdsmen, veterinarians, and other animal care workers often report that easier and more accurate cow observation and care take place in well-lit facilities. The most common light source utilized in dairies has been florescent and metal halide. Many are exploring the option of light emitting diodes or **LED** lights due to the energy savings per lumen output.

Understanding the lighting terminology is important. A brief definition of the following terms helps in understanding differences between light luminaires:

- Lumens are the overall light output or quantity of a lamp
- Color rendition index (**CRI**) is a measure of the quality of light or the lamp's ability to render the true color of an object as compared to natural light. Measured from 0 to 100 with 100 being ideal natural light. The normal range is from 60 (average) to 90 (best)
- Energy efficiency or luminaire efficacy is the efficiency of a lamp/ballast system and measured in lumens per kilowatt of electricity.
- Lamps refer to a bulb.
- Luminaire or fixture is the complete light system including lamps, electronics, and housing.
- Color characteristic temperature (**CCT**) or Kelvin temperature is used to describe the color of light and is measured in Kelvin temperature from 2000 to 10,000 K. Lamps with a Kelvin temperature below 5,000 tend to have a yellow tint; 5,000 to 6,000 range are considered white; and higher than 6,000 tend to have a blue tint.
- Light intensity or illumination level is the amount of light arriving at a surface: 1 lumen per square foot equals 1 foot-candles (**fc**); or 1 lumen per square meter equals 1 **lux**.
- Luminaire maintenance is the percentage of initial lumens that a source maintains at a given number of operating hours.
- Lumen depreciation is the decline or decrease in lumen output over time.

Sunlight is made of various wavelengths of light which produce different colors or rainbows. The CCT and color rendition index (**CR**I) are used to describe color characteristics of artificial lights. The CCT describes the color of the light using a Kelvin temperature scale that ranges from

Table 1. Characteristics of common lamps (ASABE, 2006).

Lamp Type	Lamp Size (watts)	Efficiency (lumens/watt)	Typical Lamp Life (hr)	Color Rendition Index
Incandescent	60 - 200	15 - 20	750 - 1,000	99 +
Halogen	50 -150	18 - 25	2,000 - 3,000	80 - 100
Fluorescent	32 - 100	75 - 98	15,000 - 20,000	50 - 90
Metal halide	75- 400	80 - 92	15,000 - 20,000	70 - 85
High pressure sodium	100 - 400	90 - 110	15,000 - 24,000	0 - 24
Light emitting diodes	10 - 250	75 - 110	30,000 - 100,000	60 - 80

1,500 to 10,000 degrees K. Artificial lights with CCT values close to 6,500 K produce a white light that closely resembles natural sunshine. The CRI indicates a light's ability to render the true color of an object. CRI values range from 0 to 100. Lights with high CRI values produce light that renders true color, while lights with lower CRI values produce some color distortion of an object. Table 1 lists the size, efficiency, and lamp life of common light sources used in dairy facilities.

LIGHT EMITTING DIODES

Light emitting diode (**LED**) lamps are known for a long life of 30,000 to 100,000 hr. If lamps are on for 20 hr/d, the bulbs should not have to be replaced for 8 yr assuming a lamp life of 60,000 hr. However, as with metal halide lamps, the LED light output declines over time. It is generally assumed that light levels equal to 50 to 70 % of the original level are acceptable. Manufactures may quote the life of a LED lamp as L70 or L50 which means at the hours quoted the light level is 70 or 50 % of the original value.

The environmental temperature influences the life of a LED lamp. The LED chip light is designed to operate in an environment of 25 °C (77 °F). The lamp life is reduced if the LED cannot dissipate the heat generated; therefore maintenance is required for cleaning LED luminaires. Most LED luminaires can operate in an environment ranging from -20 °C (-4 °F) to 40 °C (104 °F). Some luminaires have a lower temperature rating of -30 to -40 °C (-22 to -40 °F) so dairies need to work with suppliers to make sure the ballast operating temperatures match local environmental conditions. LED luminaires used in agricultural applications should be watertight and constructed of corrosion resistant materials. Janni (2012) notes "lamps with polycarbonate lenses and an ingress protection rating of IP-65 rating will be dust proof and able to withstand water jets."

The Lighting Facts website (http://www.lightingfacts.com) has a product list of LED luminaires with the LED Lighting Facts® label. Table 2 compares the performance of high bay and low bay luminaires; however, not all of the luminaires may be suitable for an agricultural building environment. Luminaire efficiency ranged from 78 to 117 **lm/W** (lumens/watt) and averaged 92 lm/W.

Table 2. Summary of luminaire properties listed on Lighting Facts website.

	High Bay	Low Bay
No. of luminaire listed on lighting Facts website	88	29
Luminaire wattage	162 : 100 – 250*	123 : 70 - 250
Lamp lumens	14,836 : 25,324 – 8,391	7,465 : 19,128 – 3.042
Lumens / latt	92 : 78 - 117	93 : 73 – 117
Color retention index	75 : 68 – 88	76 : 68 -88
Color characteristic temperature (K)	4,855 : 6,500 – 3,079	4,748 : 6,500 – 2,979

* average value : maximum value – minimum value

The color rendition index values ranged from 68 to 88 and averaged 75.

Good quality LED luminaires are very energy efficient, have long useful lives, operate well in cold temperatures, and are essentially instant-on devices. They are also easily integrated with electronic controls like timers, dimmers, and occupancy sensors. The main disadvantage of LED luminaires is the initial costs of the devices. They commonly cost 2 to 3 times more than comparable fluorescent or metal halide lamps. However, with long useful lives (60,000 hr or more) that reduce replacement lamp cost and labor costs for maintenance and the higher efficiency, good quality LED luminaires can be more economical over the life of the LED.

COMPARISONS BETWEEN LED AND METAL HALIDE LIGHTS

Cost comparison of LED and metal halide (**MH**) based on 100,000 hr of operation was based on data obtained from one supplier of LED and metal halide low bay luminaires. Actual cost will vary between suppliers, installation, local green energy tax incentives, and maintenance cost. The assumptions used in the analysis were:

- Low profile cross ventilated building
- 3,600 cows in the facility
- Building dimensions are 400 ft by 1,000 ft
- Average ceiling height is 17 ft
- Work surface area is assumed at 2.5 ft above the floor
- Light intensity or illumination is 25 fc
- Electrical energy is $0.l0/kW/hr (power factor or electrical demand not considered)
- Assume installation cost is 50 % of luminaire cost
- Based on 100,000 hr of life
- All MH lamps are replaced once useful life is reached
- Assumes MH ballast replaced at 50,000 hr
- Assume cleaning cost of LED luminaires equals 10 % of initial lamp luminaire cost
- Assumes replacement cost of metal halide bulbs equals 50 % of lamp cost and lamps cleaned when lamps replaced
- Does not consider green energy tax incentives or impact of interest

Table 3 provides a cost comparison between LED vs MH for a 400 ft by 1,000 ft

Table 3. Cost comparison between LED and MH for example installation.

	LED	Metal Halide
Lamp wattage (W)	78	250
Luminaire wattage (W)	96	288
Lumens / luminaire	7,600	23,800
Energy efficiency	79	80
Color Retention Index	68	90
Total luminaires	1,210	600
Lamp luminaire cost	$389 / luminaire	$215 / luminaire
Lamp life	100,000	15,000
Luminaire cost	$7.06 / hr	$1.93 / hr
Maintenance cost	$0.47 / hr	$1.88 /hr
Electrical cost	$11.61 /hr	$17.28 / hr
Total cost	$19.15 /hr	$21.09 /hr
Cost/cow/day assuming 16 hr of lights on	8.5¢/d/cow	9.3¢/d/cow

building and 100,000 hr of light on time. In this example, the difference in LED vs MH luminaire cost is $7.06/hr vs $1.93/hr. The maintenance cost which includes cleaning cost for the LED luminaires and replacement of six lamps, one ballast and cleaning of the MH luminaires is $0.47/hr vs $1.88/hr based on 100,000 hr of operation. The electrical cost comparison of LED vs MH is $11.61/hr to $17.28 /hr. Overall cost includes luminaire, maintenance, and electrical cost for LED to MH is $19.15/hr vs $21.09. In reviewing the cost in this example, the electrical energy savings and low maintenance cost of LED’s offset the initial cost savings of the MH based on 100,000 hr of operation.

ILLUMINATION LEVELS AND LIGHT REQUIREMENTS

The recommendation for lactating dairy cows is 16 to 18 hr of continuous light (16L to 18L) each day, followed by 6 to 8 hr of darkness (6D to 8D). Studies reveal that 24 consecutive hours of light do not greatly increase milk yield response, as compared to the milk yield of lactating cows exposed to only the recommended daily amount of light (Dahl et al., 1998). However, providing a 6 to 8 hr period of continuous darkness is often difficult in operations that milk three times a day. In those cases, light amount and quality are crucial. Dry cows have a short-day lighting requirement of 8 hr of light and 16 hr of dark (8L). Cows exposed to 8 L versus 16 L during the dry period produce 7 lb/d more milk in the following lactation (Miller et al., 2000).

Recommended light intensity for an office and milk pit is 50 fc, while treatment areas and milk room wash area require 100 fc. The recommended light intensity in the housing area, feed center, and other areas on a dairy is 20 fc. Detailed illumination levels for dairies may be found in the American Society of Agricultural and Biological Engineers Standard EP344.3 (ASABE, 2005). Illumination uniformity in dairy facilities is especially critical for visually difficult tasks or intense work areas, but general requirements are not well-established. Lighting uniformity is typically defined as the ratio of the maximum illumination level (fc) to the minimum fc value (ASABE, 2005). The American Society of Agricultural and Biological Engineers Standard EP344.3 (ASABE, 2005) recommends using the coefficient of variation (**CV**) to define uniformity. Chastian (1994) found a high degree of uniformity of the CV was 25 % or less. The CV is an unbiased measure of uniformity.

The current recommendation is to provide 15 to 20 fc during daylight hours and 1 to 5 fc during the dark period to allow for animal movement to the parlor. Though darkness is not officially defined, levels around 2 to 3 fc are considered sufficient. For low profile cross ventilated (**LPCV**) buildings, the daylight hour lighting should be increased to 25 to 30 fc. If 25 fc is used as the design parameter, then the current recommendation is to use the average lumens per luminaire. The initial lumens per luminaire may be used if 30 fc is the design parameter. Extra light luminaires should be installed at waterers and left on for 24 hr/d in order to encourage drinking during both light and dark periods.

Factors not usually considered in lighting system designs include building surface reflectivity, light loss due to dust and dirt accumulation, and decreased light output with increased usage. Prompt light replacement and periodic cleaning minimizes light loss over time. Additional lighting design information for dairy facilities is available from lighting manufacturers. Software is available for designing uniform lighting through the housing area based on desired illumination.

MOUNTING HEIGHT AND SEPARATION DISTANCES

The relationship between the illumination level and lumen output from a single light or bank of lights depends on many factors, but distance between the light and the illuminated area is an important consideration.

Illumination levels decrease rapidly when the distance from the light source increases. Both the mounting height and the separation distance between evenly distributed lights effect the average illumination level (i.e., fc). The mounting height is the distance from the bottom of the luminaire to the work surface. Excessively high mounting heights waste light by dispersing it over too large of an area, and excessive separation distances decrease illumination uniformity.

Because cow flow is often slowed by cows stopping to investigate shadows and dark areas around corners and doorways, lights should be mounted in order to minimize shadows. In freestall barns with trusses, mount lights at or below the bottom chord so that the trusses do not block light from reaching the feed bunk or freestall areas and increasing shadows or nonuniformity in lighting. In milking parlors and stall barns, mount lights below structural members and other equipment to minimize shadows. To minimize variability

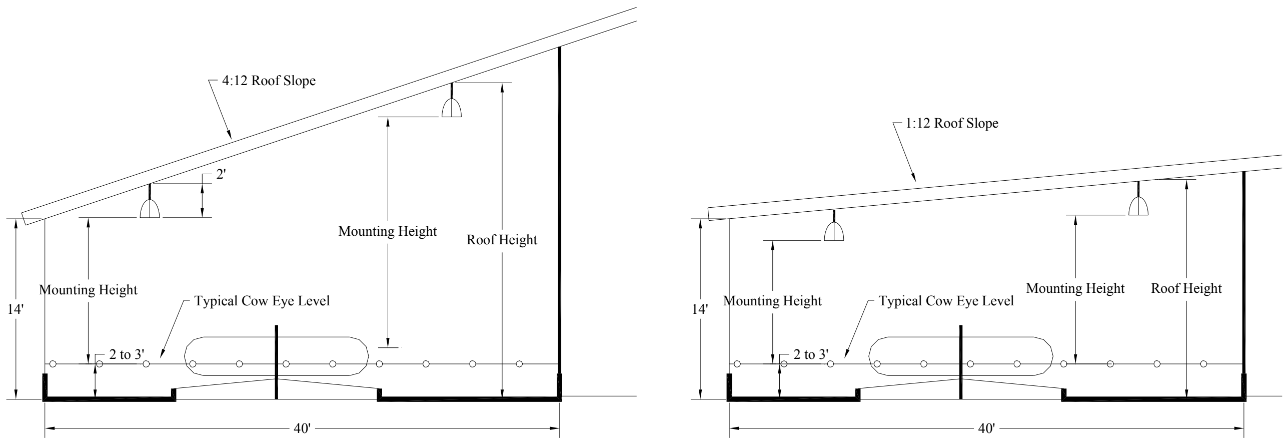

Figure 1. Impact of roof slope on mounting height in dairy housing

in light intensity through a pen or housing area, dairies may want to increase the number of LED luminaire, but at smaller wattage.

The mounting height is different than the ceiling height and depends on the slope of the roof, as illustrated in Figure 1. The mounting height is higher in a building with a 4/12 roof slope as compared to a building with a 1/12 roof slope. Therefore, LED, fluorescent, or low bay metal halide luminaires are used in LPCV buildings, rather than high bay luminaires. High bay LED luminaires are more common than low bay LED luminaires. It will be important to work with manufacturing company to make sure appropriate lights are selected.

SAFETY AND ELECTRICAL CODES

Lights installed in dairy barns must meet National Electric Code (**NEC**) requirements (NFPA 70, 1996) for use in agricultural buildings and all applicable state electrical codes. UL-approved luminaires should be used instead of UL-listed luminaires and, since dairy barns are damp and dusty, lights should be watertight and constructed of corrosion-resistant materials (Article 547).Wiring in dairy facilities should also meet NEC requirements for agricultural buildings (Article 547). To minimize the potential for fire and stray voltage, a knowledgeable and qualified electrician should do all wiring.

CONCLUSION

LED luminaire are an option for dairies. The energy cost savings and low maintenance cost offset the higher initial cost of the luminaire when compared to metal halide luminaires. Dairies should work with suppliers to make sure the luminaire meets local codes. Consideration should also be given to the operating environmental temperatures. LED may be purchased with a color rendering index similar to metal halide. Dairies with low ceiling or mounting heights will need to work with suppliers in selecting appropriate luminaires to assure uniformity of the illumination levels inside buildings.

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