"To see, or not to see, that is the question."
Lighting Low Profile Cross Ventilated Dairy Houses

J. P. Harner and J. F. Smith, Kansas State University
K. Janni, University of Minnesota

TAKE HOME MESSAGES

- Low profile cross ventilated freestall buildings allow implementation of long day lighting for lactating cows and short day lighting for dry cows.
- Lighting design in low profile cross ventilated buildings should provide 25 or more footcandles of light.
- Fluorescent or metal halide lights are used in lighting LPCV buildings
- The mounting height of fixtures is lower in LPCV buildings than natural ventilated freestall buildings.

INTRODUCTION

Light is a vital component in the daily operations 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.

LIGHT REQUIREMENTS AND AVAILABILITY

The recommendation for lactating dairy cows is 16 to 18 hours of continuous light (16L to 18L) each day, followed by 6 to 8 hours 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 hour 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 hours of light and 16 hours of dark (8L). Cows exposed to 8 L versus 16 L during the dry period produce 7 lbs/day more milk in the following lactation (Miller et al., 2000). Meeting the lighting requirement of both dry and lactating cows in a LPCV facility can be challenging.

Figure 1 illustrates the daylight hours for Kansas City, KS in the course of a year. Daylight hours are defined as the hours between sunrise and sunset on the 15th of each month. As the figure shows, the maximum daylight hours are 14.9 in June, and the least amount of daylight is 9.6 hours in December. On the average, only 12.2 hours occur daily between sunrise and sunset during the year, which means an additional 25% of daylight hours are necessary when implementing long-day lighting. Even naturally-ventilated freestalls fall short of the recommended 16 to 18 hours of light because of the changing seasons.

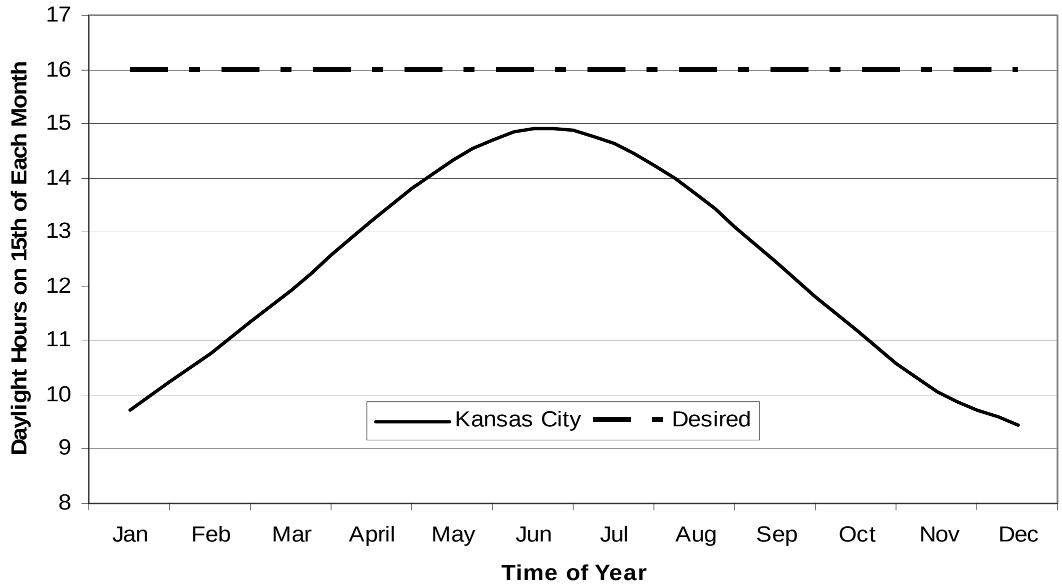

Figure 1: Daylight Hours on the 15th of Each Month in Kansas City, Kansas

ILLUMINATION LEVELS

Light intensity is expressed in footcandles (fc), or lumens per square foot. Lumens are the amount of light output from a light source, such as a lamp or bulb. Table 1 lists recommended illumination levels for different areas in a dairy facility, along with examples of outdoor light levels and recommendations for other locations. 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 fixture. The initial lumens per fixture may be used if 30 fc is the design parameter.

LIGHTING SYSTEM PERFORMANCE

Important performance characteristics for lighting systems in dairy facilities are: light intensity or illumination level, photoperiod or duration, color characteristics, and uniformity. The lighting equipment installed should be selected to meet the performance recommendations described.

Table 1: Recommended Illumination Levels for Outdoor Areas and Other Locations (ASABE 2006)

Work Area or Task	**Illumination Level (foot-candles)**
Various Locations on a Dairy	
Freestall feeding area	20
Housing and resting area	20
Parlor holding pen	10
Parlor pit and near udder	50
Parlor stalls and return lanes	20
Milk room - general lighting	20
Milk room – washing area	75-100
Milking parlor – loading platform	20
Utility or equipment room	20
Storage room	10
Office	50
Treatment & maternity area - General lighting	20
Treatment and maternity area - Surgery	100
Outdoor Lighting & Other Examples	
Full Daylight	1,000
Overcast Day	100
Twilight	1
Full Moon	0.1
Supermarket, mechanical workshop	70
Show Rooms, Offices, Study Libraries	50
Warehouses, Homes, Theaters	15

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, 2006). The American Society of Agricultural and Biological Engineers Standard EP344.3 (ASABE, 2006) 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. Table 2 shows the recommendations for uniformity in Standard EP344.3 (ASABE, 2006).

Table 2: Summary of Lighting Uniformity Criteria for Livestock Facilities (Chastain et al. 1997, ASABE 2006)

Task Classification	**Maximum CV (%)**	**Corresponding Spacing to Mounting Height Ratio**
Visually intensive (i.e. milking)	25	0.87
Handling of livestock and equipment	45	1.57
General low-intensity lighting	55	1.92

The initial design in low profile cross ventilated buildings should strive for an illumination uniformity ratio at 1.5 :1 to 2:1 throughout all the buildings to avoid shadows and dark spots, or a CV of 25 to 45 percent.

Fluorescent lights contain ballasts that initiate and maintain the bulbs' light. Electronic ballasts are recommended over other ballasts because they are more energy efficient, generate less heat, have a longer life expectancy, and operate and start at colder temperatures (0° F). High light output (HLO) fluorescent fixtures are available with electronic ballasts, and they generally emit 33% more light with only an 8% increase in energy usage. Magnetic and electromagnetic ballasts are not recommended because they generate waste heat, hum or click, and cause the light to flicker at cold temperatures. These ballasts also have difficulty starting at temperatures of 50°F or less.

New dairy facilities often use fluorescent and metal halide fixtures to provide lighting. Compact fluorescent lights also can be used to replace incandescent lights when the existing fixture meets the National Electric Code safety requirements for livestock buildings, but tube fluorescent lights provide the best life-cycle cost option for new construction (Chastain and Hiatt, 1998). Studies also show that T-8 lamps are more energy efficient than T-12 lamps. Table 3 lists the size, efficiency, and lamp life of common light sources used in dairy facilities.

Table 3: Characteristics of Common Lamps (ASABE, 2006)

Lamp Type	**Lamp Size (watts)**	**Efficiency (lumens/watt)**	**Typical Lamp Life (hours)**
Incandescent	60-200	15-20	750-1,000
Halogen	50-150	18-25	2,000-3,000
Fluorescent	32-100	75-98	15-20,000
Compact Fluorescent	5-50	50-80	10,000
Metal Halide	75-400	80-92	15,000-20,000
High Pressure Sodium	100- 400	90-110	15,000- 24,000

Extra light fixtures and protected compact fluorescent lights should be installed at waterers and left on for 24 hours per day in order to encourage drinking during both light and dark periods. Some factors considered in lighting system designs include building surface reflectivity, light loss due to dust and dirt accumulation, and decreased light output with increased usage. Dahl et al (1998) recommend decreasing the lumens per blub by one-third to compensate light decay in the design phase. Prompt light replacement and periodic cleaning minimizes light loss over time. Additional lighting design information for dairy facilities is available from lighting anufacturers. Software is available for designing uniform lighting through the housing area based on desired illumination.

COLOR CHARACTERISTICS OF BULBS

Sunlight is made of various wavelengths of light which produce different colors, or rainbows. The color characteristic temperature (CCT) and color rendition index (CRI) 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 1,500 to 6,500 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 4 outlines CCT and CRI values for some common lights.

Table 4: Color Characteristic Temperature and Color Rendition Index Values for Common Lights (Janni 2000)

Lamp Type	Color Characteristic Temperature (deg K)	Color Rendition Index
Incandescent	2,500-3,000	100
Halogen	3,000-3,500	100
Fluorescent	3,500-5,000	70-95
High Intensity Discharge		
Mercury Vapor	n/a	20-60
Metal Halide	3,700-5,000	60-80
High Pressure Sodium	2,000- 2,700	n/a

The color characteristic temperature of fluorescent lights depends on the type of bulb installed. The last two digits in the bulb number indicate the CCT of a fluorescent bulb. For example, a fluorescent bulb with the number F32 T8 SP41 means that it is a 32-watt fluorescent T-8 (1-inch diameter) bulb with a CCT of 4,100 K.

Metal halide, high-pressure sodium, and mercury vapor lights comprise a group of long-lasting, high-intensity discharge lights that are used to light large areas because they emit large amounts of lumens, as shown in Table 4 above. Metal halide lights give off a fairly white light with a CCT value up to 5,000 K and CRI values up to 80%. As a result, their use in dairy facilities is growing. High-pressure sodium lights emit a gold or yellowish light with a CCT value up 2,700 K and CRI values up to 60% and are typically not used in the housing area. Table 5 compares the color appearance and resulting object colors of various lamps.

Table 5: Color Appearance and Resulting Object Colors for Common Lamps (Hoke. 1998)

Type of Lamp	**Color Appearance**	**Object Colors Enhanced**	**Object Colors Dulled**
Incandescent Halogen	Yellowish White	Warm Colors	Cool Colors
Fluorescent			
Warm White	Yellowish White	Orange, blue, yellow	Red, blue
Cool White	White	Orange, blue, yellow	Red
Cool White Deluxe	White	All nearly equal	None appreciable
High Intensity Discharge			
Clear Mercury	Blue/green	Yellow, green, purple	Red, orange
Metal Halide	White	Orange, yellow, blue	Deep Red
High Pressure Sodium	Yellow/orange	Yellow	All except yellow

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) (Janni, 2000). The mounting height is the distance from the bottom of the fixture 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. Standard 32-watt T-8 fluorescent lights are generally used when they can be placed seven to eight feet above the work surface. The work surface in dairy housing is usually 1-3 feet above the floor or at a height equal to the cow's eye level while resting in the free stalls. High-light-output (HLO) 32-watt T-8 fluorescent lights are used if the lights must be placed higher, up to 14 feet above the lighted area. Table 6 provides typical mounting heights and horizontal separation distances needed to produce a standard illumination level of 20 fc.

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 and freestall areas. In milking parlors and stall barns, mount fluorescent lights below structural members and other equipment to minimize shadows.

Table 6: Mounting Heights and Separation Distances for Common Lights (Janni, 2000)

Lamp Type	**Mounting Height (feet)**	**Separation Distance (feet)**
Standard Fluorescent (32 W, T-8)	7-8	10-16
HLO Fluorescent (32 W, T-8)	9-12	12-20
Metal Halide – 175 W	11-14	14-24
Metal Halide - 250 W*	20- 35	24-28
Metal Halide – 400 W*	24-30	25- 40

* Typical for 96-112 ft wide freestall barns with 12 ft sidewalls and 4:12 roof slope

Figure 2 illustrates the spacing to mounting height ratio for three different 250 W metal halide light fixtures. As the ratio increases, more lumens are distributed outward from the fixture. Lumen distribution is determined by the diffuser, or lens covering, rather than the bulb wattage

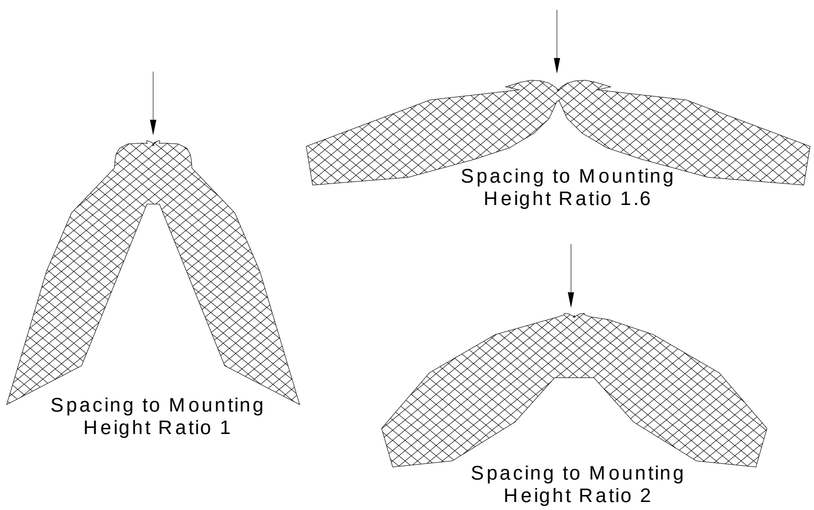

Figure 2: Impact of Diffuse on Light Pattern and Spacing to Mounting Height Ratio

The mounting height is different than the ceiling height and depends on the slope of the roof, as illustrated in Figure 3. 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, fluorescent or low bay metal halide fixtures are used in LPCV buildings, rather than hay bay metal halide fixtures.

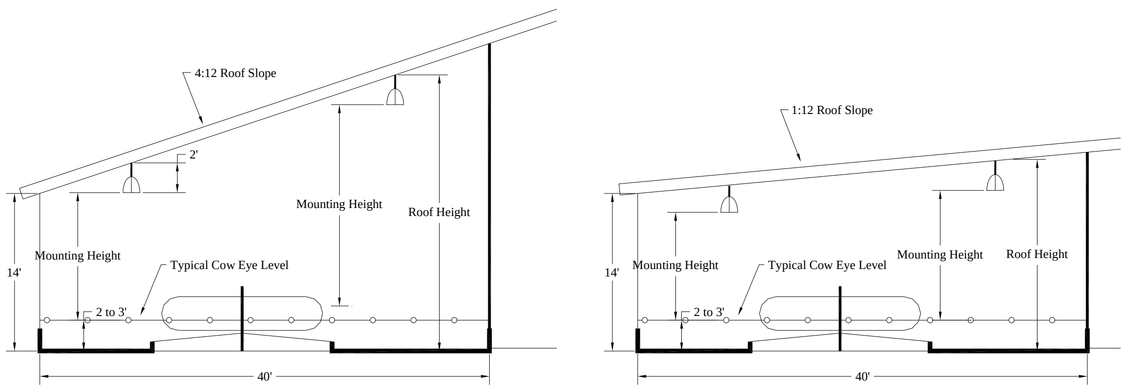

Figure 3: Impact of Roof Slope on Mounting Height in Dairy Housing

FIXTURES

Most metal halide lights used in dairy housing are either high or low bay fixtures, as shown in Figure 4. High bay fixtures require a higher mounting height and direct the light downward beneath the lamp. The diffuser, or lens, on low bay lights spreads the light pattern over a larger area. In low profile cross ventilated dairy facilities, low bay lights should be considered. The type of diffuser on the fixture determines the spacing to mounting ratio.

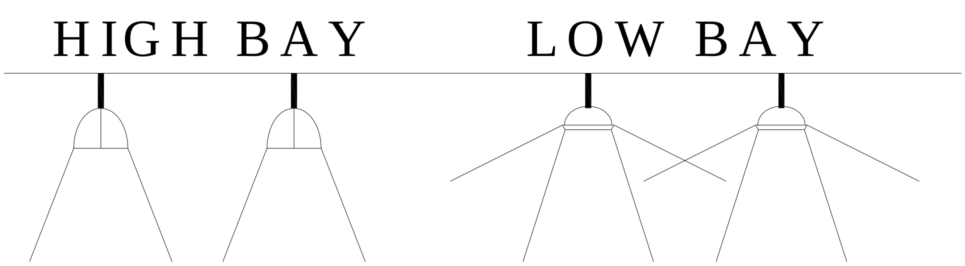

Figure 4: Comparison of High and Low Bay Lights

LUMENS AND LAMP LIFE

Manufacturers provide the angle off-center of the points at which the intensity of the light drops to 10 and 50% of the maximum value. The maximum spacing to mounting height ratio is based on the luminance midpoint between two fixtures and is equal to the luminance directly beneath a fixture. Manufacturers also provide information on initial and average lumens per bulb.

Typical lamp life information of high-intensity discharge lamps is shown in Table 7. These values are based on 10 hours of operation per day, and the initial lumens are based on the lumen output after 100 hours of use. If the lamp life is 24,000 hours or greater, then 67% of the lamps are still operational at 24,000 hours. If the rated lamp life is less than 24,000 hours, then 50% of the lamps are operating at the rate life. Operating a lamp only 5 hours per start rather than 10 reduces the lamp life to 75% of the rating. The light output decreases over time, and the average lumens is measured at 40% of the lamp life.

Table 7: Comparison of Initial and Average Lumens for Different Lamps

Type of Lamp	Initial Lumens	Average Lumens
150 W – Metal Halide	12,000	8,500
250 W – Metal Halide	22,000	17,000
400 W – Metal Halide	42,000	32,000
250 W – High Pressure Sodium	28,000	27,000
400 W – High Pressure Sodium	50,000	45,000

LPCV Light Measurements

Figure 5 shows a graph of light measurements inside an LPCV building using fluorescent lights. Light measurements, taken at points designated represent the average of the 10 readings along the pen length. Light data recorded measured the illumination in footcandles. The illumination for the building was 27 +/- 13.5 fc. Average values per location ranged from 9.9 to 44.8 fc. The average light levels exceed the normal recommendation of 15 to 20 fc for the housing area. With exception of the stalls next to the pads and fans, light levels are within or exceed the recommended light levels. Light measurements were taken when the facility was only 6 months old, so the light level may decline as the bulb efficiency decreases and dust accumulates. The uniformity of luminance was 12.7 using the data set of measured light levels and the coefficient of variation was 50 percent.

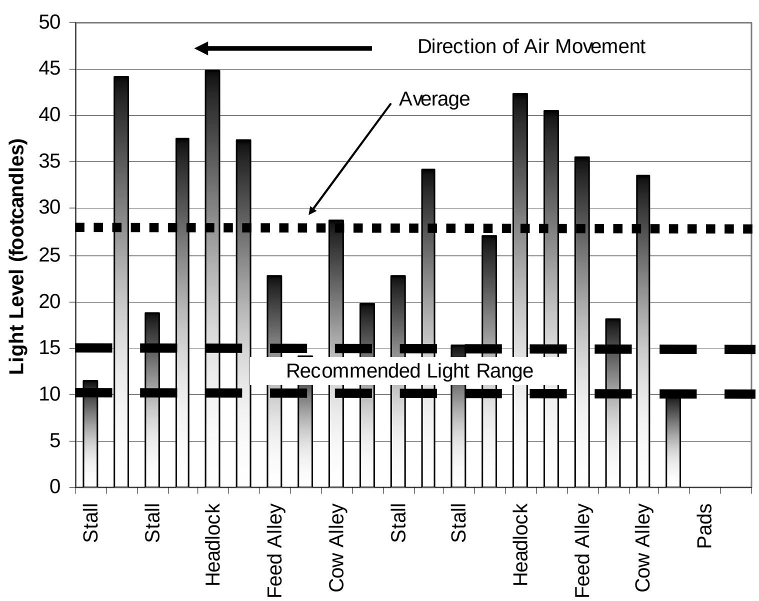

Figure 5: Fluorescent Light Levels Inside a Low Profile Cross Ventilated Freestall Facility

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 fixtures should be used instead of UL-listed fixtures 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

In summary, proper lighting of LPCV facilities is essential. A lighting schedule needs to be determined from the start of operation so that each of the dairy housing areas is lit with a minimum of 25 fc. Ideally, all lactating cows need to be on a lighting schedule which provides them with 16L per day. The only time lactating cows do not experience a dark period is when they are in the milking parlor. Providing short-day lighting for dry cows can be difficult if the dry cows are housed in the same facility as the lactating cows. LPCV facilities provide a unique opportunity to control lighting, but a properly planned lighting system is essential.

REFERENCES

Anon. 2008. Illuminance – Recommended Light Levels. The Engineering Toolbox. URL:http://www.engineeringtoolbox.com/light-level-rooms-d_708.html

ASAE. 1997. EP344.2. Lighting for Dairy Farms and the Poultry Industry. ASAE Standards. 44th Edition. American Society of Agricultural Engineers. St. Joseph. MI

ASAE. 2006. EP344.3. Lighting for Agricultural Facilities. ASAE Standards. 53rd Edition. American Society of Agricultural Engineers. St. Joseph. MI

Chastain, J. and R. Nicolai. 1996. Dairy lighting system for free stall barns and milking centers. University of Minnesota AEU-12.

Chastain, J. and R. Hiatt. 1998. Supplemental Lighting for Improved Milk Production. National Food and Energy Council, Columbia, MO.

Janni. K. 2000. Lighting Dairy Facilities. URL: http://www.bae.umn.edu/extens/ennotes/ensum99/lighting.html. University of Minnesota.

Miller, A. R., R. A. Erdman, L. W. Douglass, and G. E. Dahl. 2000. "Effects of Photoperiodic Manipulation During the Dry Period of Dairy Cows. *J. Dairy Sci*. 83:962-967.