SUMMARY OF DAIRY LIGHTING RESEARCH AND PRACTICE

Kevin A. Janni, Ph.D., P.E
Professor, Extension Engineer and Head
Department of Biosystems and Agricultural Engineering
University of Minnesota

Introduction

Light is an important environmental characteristic in dairy facilities. Proper lighting and light management have physiological effects on dairy cattle, which if properly managed can enhance cow performance and heifer growth. Proper lighting also helps improve animal movement and observation. It also creates a safer and more pleasant work environment for caregivers so that they can do their jobs more easily and better. Lighting systems must be designed, installed and managed to enhance the animal performance, meet design and safety standards, and be economical.

The purposes of this article are to

- Describe basic lighting characteristics.
- Review lighting research.
- Outline recommended light management for enhanced dairy animals performance.
- Describe lighting system elements for providing proper lighting for both animals and caregivers.

Basic Lighting Characteristics

Key lighting-system performance characteristics for dairy facilities include:

- Light intensity or illumination level,
- Photoperiod or duration,
- Color characteristics, and
- Uniformity.

Light Intensity
Light intensity is measured using a light meter and expressed in foot-candles (fc), which has units of lumens per square foot. Lumens are the amount of light put out by a light source. In the metric system illumination level is expressed in terms of lux, where 1 fc equals 10.76 lux. The relation between lumen output from a single light or bank of lights and the illumination level below depends on many factors, but distance between the light and the illuminated area is one of the most important. Other factors include lamp cleanliness, age, and configuration. Wall reflectance and color also affects light levels.

Photoperiod
Photoperiod describes the amount of time, in hours, that light is present or provided in a 24-hour period. Sixteen to 18 hours of continuous light (16L to 18L) followed by six to eight hours of darkness (6D to 8D) is generally defined as an extended day or long day photoperiod. Short light days or short day photoperiod have less than 12 hours of continuous light per day. Natural

THIS ARTICLE IS SPONSORED BY THE
MINNESOTA DAIRY HEALTH CONFERENCE.

UNIVERSITY OF MINNESOTA

College of Veterinary Medicine

VETERINARY CONTINUING EDUCATION

ST. PAUL, MINNESOTA
UNITED STATES OF MINNESOTA

photoperiods based on sunrise and sunset times for Minnesota range from 7.75 hours in December to 15.5 hours in June.

Color Characteristics
Sunlight is made up of light at different wavelengths that produce different colors (i.e., 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 K. Lights with CCT values closer to 6,500 K produce a whiter light that more closely approximates 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 higher CRI values produce light that renders a truer color. Lights with lower CRI values produce some color distortion. Table 1 lists CCT and CRI values for common light sources.

Table 1. Color characteristic temperature and color rendition index values for common lights.

Lamp Type	Color Characteristic Temperature (K)	Color Rendition Index
Incandescent	2,500 to 3,000	100
Halogen	3,000 to 3,500	100
Fluorescent	3,500 to 5,000	70 to 95
High Intensity Discharge		
Mercury Vapor		20 to 60
Metal Halide	3,700 to 5,000	60 to 80
High Pressure Sodium	2,000 to 2,700	40 to 60

Uniformity
ASAE [1] defines light uniformity as the ratio of the maximum illumination level (fc) to the minimum fc value within a space. Greater uniformity is needed for more visually difficult tasks. Satisfactory uniformity ratios range from 1.5:1 for visually difficult tasks to 5:1 for less difficult tasks [1].

Physiological and Production Effects

Secretion of the hormone melatonin is suppressed in cows when exposed to light [5,21]. Increased light exposure time reduces the amount of time that high melatonin concentrations are found in the blood. This melatonin concentration pattern influences secretions of other hormones particularly prolactin (PRL) and insulin-like growth factor-I (IGF-I). Researchers believe that changes in IGF-I are important to the increase in milk yield observed in cows exposed to extended day lighting [3].

Numerous research studies have documented that dairy cows given 16 hours of continuous light each day (16L) had increased milk production from 5 to 16% (8% being typical), increased feed intake about 6%, and maintained reproductive performance compared to cows that received 13.5 hours or less of light [3,12,15,17,19]. This response to 16 hours of extended day lighting is not immediate. A response can take 2 to 4 weeks or longer to develop [3,23] assuming that nutrition and other management conditions are acceptable. In other research, extended day lighting combined with bST had an additive effect on milk production [12].

Research on lighting for dry cows and heifers before calving has produced conflicting results. In one study extended day lighting introduced 4 to 6 weeks before parturition increased milk production during the first two months of the lactation [8]. In other studies, dry cows on short day lighting, 8 to 12 hours continuous light, had increased milk production during lactation than dry cows on extended day lighting [13,18].

Other researchers observed that heifers exposed to long days (16L) had increased growth rates and achieved puberty earlier than herd mates exposed to short days [9,16,22]. A recent study indicates that heifers conditioned to 37 fc (400 lx) for 16 hours had inhibited melatonin secretions for an initial few hours when exposed to 8 hours at 37 fc followed by 8 additional hours at different intensities ranging from 5 to 37 fc [11].

Light Management

Light Intensity

To obtain cow and heifer production responses, Dahl [6] recommends providing 15 fc of light intensity 3 feet above the stall floor even though responses were observed at intensities as low as 10 to 12 fc [23]. The extra 5 fc is recommended to account for dirty lamps and burned out bulbs [6]. In addition, lumen output from a lamp decreases with age. The recommended light intensity to produce the physiological response from extended day lighting is necessary throughout a barn including the freestalls and manger [6].

Darkness is not defined. Dahl [6] suggests that cows cannot detect light at less than 5 fc. One study suggests that cattle can detect differences in light intensities as low as 0.5 fc (5 lux) [20]. Cattle may perceive darkness relative to the difference in intensity between light and dark periods or intensities. This may explain why a partial decrease in light intensity allowed melatonin secretions to increase with time even at levels at 10 fc and above [11]. More research is needed on the effects of changing light intensities.

Table 2 lists recommended illumination levels for different areas in a dairy facility. These recommended lighting levels are based on illumination needed by people to complete the corresponding work or task listed. Illumination levels increase as the difficulty of seeing needed to complete each task increases. These illumination levels are not based on animal responses or needs. The 20 fc minimum level for the feeding area is for caregivers to detect foreign objects in feed [1].

Table 2. Recommended illumination levels (ASAE, 2001).

Work Area or Task	Illumination level (fc)	Work Area or Task	Illumination level (fc)
Freestall feeding area	20	Milking Parlor	
Housing & resting area	10	General lighting	20
Holding area	10	Operator pit	50
Treatment and maternity areas		Milk room	
General lighting	20	General lighting	20
Surgery	100	Washing area	100
Utility or equipment room	20	Bulk tank interior	100
Storage room	10	Loading platform	20
Office	50		

Photoperiod

Dahl [5] recommended the following photoperiods for dairy animals at different stages.

- Heifers
  Use long days for more rapid gain and greater mammary parenchymal growth
- Dry cows and heifers in the last 2 months of gestation
  Use short days to enhance cow and heifer response to enhanced lighting during the subsequent lactation
- Lactating cows
  Use long days to improve milk yields both with and without bST use.

Twenty-four hours of continuous light each day is not recommended. It does not provide additional milk yield response compared to 16L:8D [4]. Based on limited studies, it appears that cows exposed to 24 hours of continuous light lose the hormonal shifts associated with higher milk production [6]. It is a challenge to provide a 6 to 8 hour period of continuous darkness in operations that milk three times a day (3X).

The photoperiod can be controlled with a timer and a photocell in series or a timer alone [2]. The timer and photocell in series is the most energy efficient. The timer turns the lights on and off at set times, while the photocell overrides the timer (turns the lights off) when there is sufficient natural sunlight. Chastain and Hiatt [2] recommend that the photocell be located under the eave on the northwest corner of the freestall barn. The photocell needs to be shielded from both interior and exterior lighting to work properly. Two-phase timers allow for a manual override. A timer alone can be used to turn the lights on and off to provide 16 to 18 hours of light. In this case the lights are on even if there is plenty of sunshine.

In work areas, light switches can be used to manually turn lights on and off as needed. Motion detectors can be used to automatically turn lights off when no one is working in an area (i.e., office, and equipment room) to save energy.

It is important to measure light intensity with a light meter to ensure that recommended light levels are provided. Light meters can be purchased from either electrical or photography suppliers.

Color

Standard incandescent, halogen, fluorescent, metal halide and high-pressure sodium lamps are commonly used in dairy facilities. They all have acceptable color characteristics to produce the production responses desired from cows and heifers given extended day lighting.

High-pressure sodium lights put out a gold or yellowish light. Some people do not respond well to the yellowish light [6]. Professionals in the field also report that red is not clearly distinguishable from brown under high-pressure sodium lights. This means that bloody discharges may not be recognizable under high-pressure sodium lights, which may lead to a missed diagnosis.

Uniformity

Required illumination uniformity in dairy facilities has not been established. Professionals in the field suggest that cow movement and performance is improved if light illumination levels along the feed bunk or manger area and cow walkways are closer to the 1.5:1 ratio. For example, if 20 fc were the maximum level measured along the feed manger, the lowest measured light intensity needed to maintain the 1.5:1 ratio would be 13 fc (20/13 = 1.54/1). Installing more lights and decreasing the separation distance between lights generally increases illumination uniformity. Mounting high output lamps to low increases non-uniformity. Some non-uniformity is acceptable because installing an excessive number of lights is too expensive.

Common Light Source Characteristics

Table 3 lists general characteristics of common light sources used in dairy facilities. Dairy facilities are typically using fluorescent and either metal halide or high-pressure sodium lights to provide most of the general-purpose lighting. Halogen lamps are used for spot lighting.

Table 3. General characteristics of common light sources.

Lamp Type	Lamp Sizes (watt)	Efficiency (lumens/watt)	Typical Lamp Life (hours)
Incandescent	60 to 200	15 to 20	750 to 1000
Halogen	50 to 150	18 to 25	2,000 to 3,000
Fluorescent (ballast)			
T-12 (electromagnetic)	34	66	20,000
T-8 (electronic)	32	98	20,000
T-8 HLO (electronic)	32	92	24,000
High Intensity Discharge			
Mercury Vapor	50 to 250	40 to 50	16,000 to 24,000
Metal Halide	75 to 400	80 to 92	15,000 to 20,000
High Pressure Sodium	100 to 400	90 to 110	15,000 to 24,000

Fluorescent Lights

Standard 32-watt T-8 fluorescent lights are usually used when they can be placed 7 to 8 feet above the lighted area. High-light-output (HLO) 32-watt T-8 fluorescent lights are used if the lights must be placed higher, up to 12 feet above the lighted area. Compact fluorescent lights 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 [2].

Fluorescent bulbs come in different diameters. T-8 bulbs are 1 inch in diameter while T-12 bulbs are 1.5 inches in diameter. T-8 lamps are recommended over the older T-12 lamps because T-8 lamps are more energy efficient.

The color characteristic temperature of fluorescent lights depends on the bulb installed in the light. 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.

Fluorescent lights have ballasts that start and keep the bulbs lit. Electronic ballasts are recommended because they are more energy efficient, generate less heat, have a longer life expectancy, and operate and start at colder temperatures (0 F) than other ballasts. Fluorescent bulbs also last longer when electronic ballasts are used. Magnetic and electromagnetic ballasts are not recommended. They generate more waste heat, can hum or click, and cause light flickering at cold temperatures. Magnetic ballasts have operating and starting problems at temperatures of 50 F and below. They can also produce harmonic distortions, which can affect electronic equipment (i.e., computers). Electromagnetic ballasts have operating and starting problems at temperatures of 40 F and below.

High light output (HLO) fluorescent fixtures are available with electronic ballasts. HLO lights generally put out 33% more light with only an 8% increase in energy usage. They are more expensive, approximately 20%, and are generally used only when either extra lumens are required or the fluorescent lamps need to be mounted between 9 and 12 ft above the lighted area.

High Intensity Discharge Lights
Metal halide and high pressure sodium lights are part of a group of long lasting high intensity discharge lights that put out large amounts of lumens. They are used to light large areas and both are used commonly in dairy facilities.

Mercury vapor lights are another type of high intensity discharge light. They have been used commonly as yard lights and give off a bluish light. They are not recommended for use in dairy facilities because the mercury in burned-out lights can be an environmental hazard and the CRI values are lower than other better options.

Mounting Height and Separation Distances
Distance is the enemy of light [7]. Illumination levels decrease rapidly with increasing distance from the light source. Both the mounting height and separation distance between evenly distributed lamps affect the average illumination level (i.e., fc). Excessively high mounting heights waste light by dispersing it over too large of an area. Excessive separation distances decrease illumination uniformity. Table 4 lists some typical mounting heights for select lights that produce an average illumination level of 20 fc. The values for the 250 W and 400 W metal halide lamps work well in typical four-row and six-row barns (96 to 112 ft wide) with 12 ft

sidewalls and 4:12 roof slopes. A rule-of-thumb is to have separation distances between 1.2 and 1.7 times the mounting height.

Table 4. Typical mounting heights and horizontal separation distances for select lights to produce an illumination level of 20 fc.

Lamp Type	Mounting heights (ft)	Separation distances (ft)
Standard fluorescent (32 W, T-8)	7 to 8	10 to 16
HLO fluorescent (32 W, T-8)	9 to 12	12 to 20
Metal halide		
175 W	11 to 14	24 to 28
250 W*	14 to 24	24 to 30
400 W*	20 to 35	25 to 40

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

Locate and mount lights to minimize shadows. Cows often stop to investigate shadows and dark areas around corners and exits and entrances before proceeding, which slows cow flow. In freestall barns with trusses, mount lights at or below the bottom chord so that the truss members do not block the 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.

Metal halide and high-pressure sodium lamps can be either mounted directly (i.e., hard-wired) to a structural member or suspended on a sturdy chain using a hook, cord, and plug (HCP). HCP mounting is customary in freestall barns and allows height adjustment to improve light distribution and uniformity. An eyebolt is preferable to a simple hook when attaching the chain to the building to prevent the chain from unhooking and the lamp falling. A safety clip on the lamp is also recommended.

Nightlights

Dahl [6] does not recommend leaving on a "night light" to ensure that cows find feed and water during darkness. He reports that low intensity red lighting (7.5W bulbs at 20 to 30 ft intervals mounted 10 ft above the floor) have been used successfully for cow observation and movement during dark periods. Some producers install extra light fixtures, protected compact fluorescent lights left on continuously (24 hours/day), at waterers to encourage drinking during both light and dark periods.

Enhanced Lighting Economics

Enhanced lighting for the milking herd is profitable [2,3,6]. The increased milk production generates a payback of less than one year considering initial, installation, operating, replacement costs of the lights, and the increased feed intake [2]. Light management produces an attractive return on investment even in times of low milk prices [6]. A spreadsheet for estimating the number of lamps required to illuminate freestall or tie-stall barns and to calculate a net-profit is available on the World Wide Web at http://il-traill.outreach.uiuc.edu/photoperiod/.

In addition, many producers report that increased and better quality lighting improves cow movement, observation, and care. Cows move more easily through uniformly well-lit entrances and exits. Herdspeople, veterinarians, and other animal caregivers often report easier and better cow observation and care. This means that sick cows can be more quickly spotted and treated. Workers also report that a well-lit area is a more pleasant work environment. Increased cow performance and well being coupled with better working conditions make lighting an important environmental characteristic in a dairy facility.

Safety and Electrical Codes

Lights installed in dairy barns should meet National Electric Code (NEC) requirements for use in agricultural buildings [14]. Be sure to follow all applicable state electrical codes too. Use UL approved fixtures not UL listed fixtures. Dairy barns are damp and dusty so lights installed 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.

Consider installing a standby lamp with battery backup in freestall barns to provide emergency light for employees during a power failure. This lamp would be wired to turn on in the event of a power failure to provide.

Conclusion

Extended day lighting can improve dairy cow performance and heifer growth. Proper lighting improves cow movement and observation. It also improves working conditions and safety. Many factors affect lighting-system performance. This article discussed some of the key factors for planning a lighting system for dairy facilities. An experienced lighting professional can help design a safe, economical, and effective lighting system.

Acknowledgements

The author acknowledges the assistance that Jerry Martens and Al Eissens provided for this manuscript.

References

1. ASAE. 2001. Lighting for dairy farms and the poultry industry. EP344.2. ASAE Standards. ASAE, St. Joseph, MI 49085-9659. Pp. 660-664.

2. Chastain, J. P. and R. S. Hiatt. 1998. Supplemental lighting for dairy milk production. National Food and Energy Council, Columbia, MO 65203. Pp. 20.

3. Dahl, G. E., T. H. Elsasser, A. V. Capuco, R. A. Erdman, and R. R. Peters. 1997 Effects of long day photoperiod on milk yield and circulating insulin-like growth factor-l. J. Dairy Sci. 80:2784-2789.

4. Dahl, G. E., J. P. Chastain, and R. R. Peters. 1998. Manipulation of photoperiod to increase milk production in cattle: biological, economical and practical considerations. IN: Proc. Fourth Int. Dairy Housing Conf., ASAE, St. Joseph, MI 49085-9659. Pp. 259-265.

5. Dahl, G. E., B. A. Buchanan and H. A. Tucker. 2000. Photoperiodic effects on dairy cattle: A review. J. Dairy Sci. 83:885-893.

6. Dahl, G. E. 2002. Photoperiod Management of Dairy Cattle. IN: Feeding and Management Practices to Maximize Profitability, MWPS-4SD12. MidWest Plan Service, Ames, IA 50011. Pp. 27-32.

7. Eissens, A. 1998. Personal communications.

8. Gustafson, G. M. 1994. Effects of changes in light hormonal secretion and milk production of dairy cows in early lactation. Acta Agrc. Scand. An. Sci. 44:160-168.

9. Hansen, P. J. 1985. Seasonal modulation of puberty and postpartum anestrus in cattle: a review. Livest. Prod. Sci. 12:309-327.

10. Kaufman, J. E. and J. F. Christensen. 1984. IES Lighting Handbook. Illuminating Engineering Society of North America, New York.

11. Lawson, T. J. and A. D. Kennedy. 2001. Inhibition of nighttime melatonin secretion in cattle: threshold light intensity for dairy cattle. Can. J. Anim. Sci 81(1):153-156.

12. Miller A. R. E., E. P. Stanisiewski, R. A. Erdman, L. W. Douglass, and G. E. Dahl. 1999. Effects of long daily photoperiod and bovine somatotropin (Trobest®) on milk yield in cows. J. Dairy Sci. 82:1716-1722.

13. Miller A. R. E., 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.

14. NFPA 70. 1999. National Electric Code. National Fire Protection Assoc. Batterymarch Park, Quincy, MA 02269.

15. Peters, R. R., L. T. Chapin, K. B. Leining, and H.A. Tucker. 1978. Supplemental lighting stimulates growth and lactation in cattle. Science 199:911-912.

16. Peters, R. R., L. T. Chapin, R. S. Emery and H. A. Tucker. 1980. Growth and hormonal response of heifers to various photoperiods. J. Anim. Sci. 51:1148-1153.

17. Peters, R. R., L. T. Chapin, R. S. Emery, and H.A. Tucker. 1981. Milk yield, feed intake, prolactin, growth hormone, and glucocorticoid response of cows to supplemental light. J. Dairy Sci. 64:1671-1678.

18. Petitlerc, D., C. Vinet, G. Roy, and P. Lacasse. 1998. Prepartum photoperiod and melatonin feeding on milk production and prolactin concentrations of dairy heifers and cows. J. Dairy Sci. 81(Suppl. 1):251 (Abstr.).

19. Philips, C. J. C. and S. A. Schofield. 1989. The effect of supplementary light on production and behavior of dairy cows. Anim. Prod. 48:293-303.

20. Philips, C. J. C. and L. Weiguo. 1991. Brightness discrimination abilities of calves relative to those of humans. Appl. Anim. Behav. Sci. 31:25-33.

21. Reiter, R. J. 1991. Pineal melatonin: cell biology of its synthesis and its physiological interactions. Endocrine Rev. 12:151-180.

22. Tucker, H. A., D. Petitclerc and S. A. Zinn. 1984. The influence of photoperiod on body weight gain, body composition, nutrient uptake and hormone secretion. J. Anim. Sci. 59:1610-1620.

23. Tucker, H. A. 1992. Manipulation of photoperiod to improve lactation, growth, and reproduction. IN: Large Dairy Herd Management, H. H. Van Horn and C. J. Wilcox, ed. Amer. Dairy Sci. Assoc., Champaign, IL. Pp. 146-152.