ASAE EP344.3 JAN2005
Lighting Systems for Agricultural Facilities

American Society of
Agricultural and Biological Engineers

STANDARD

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This Engineering Practice combines and therefore supersedes ASAE R286, Lighting for Dairy Farms, and ASAE R332, Poultry Industry Lighting, developed by the joint Illuminating Engineering Society—ASAE Farm Lighting Committee, EPP-46. R286 was adopted by ASAE June 1965; R332 was adopted by ASAE December 1969. This document was approved by the ASAE Electric Power and Processing Division Standards Committee and adopted by ASAE as ASAE Recommendation R344 February 1971; revised editorially and reclassified as an Engineering Practice December 1975; reconfirmed December 1980; revised March 1982; reconfirmed July 1986, December 1987; revised July 1988; reaffirmed December 1993, December 1998; December 1999; revised editorially March 2000; revised January 2005

1 Purpose and scope

1.1 This Engineering Practice is intended to guide those responsible for or concerned with, the design of lighting installations on or within agricultural facilities.

1.2 This Engineering Practice applies to the effective performance of workers as they accomplish specific tasks requiring various levels of illuminance and it applies to lighting installations used to change the physiological or biological properties of livestock, birds, fish and plants to alter their production capabilities.

1.3 The lighting recommendations are based on information obtained from search of current literature, from people and organizations active in this field, and from field measurements of lighting requirements for difficult seeing tasks. This document is in accordance with the latest knowledge and practice of the lighting field, and conforms to all official IESNA reports. However, future progress in agriculture and lighting will undoubtedly make revisions desirable.

1.4 Lighting systems must be installed safely. In all cases, the National Electrical Code and Building Codes, plus local codes, will take precedence. This document is primarily for effective, efficient production in agriculture.

2 Introduction

2.1 Lighting equipment

2.1.1 Lamps Light sources available for agriculture lighting applications include incandescent, fluorescent, low pressure sodium and high intensity discharge (HID). HID sources include mercury, metal halide and high-pressure sodium lamps. HID lamps are more efficient, have longer rated lives, and generate 2 to 5 times more light than the incandescent filament for the same amount of electrical energy. Refer to IESNA Lighting Handbook, Part II Lighting Engineering, Chapter 6 Light Sources.

2.1.1.1 Incandescent Lamps These lamps come in a variety of types and sizes. They are a high brightness source and should be used in appropriate luminaire to minimize glare. No auxiliary electrical equipment is required. These lamps can be dimmed.

2.1.1.2 Fluorescent Lamps These lamps provide a large light source. Even though surface brightness is relatively low, fluorescent lamps should always be housed in a suitable luminaire to minimize glare. In high humidity environments or areas subject to wash down, gasketted or weatherproof housings are required to prevent corrosion and premature failure of the light system. Fluorescent lamps are available in different sizes, types, and colors, which can provide good color rendering, cool or warm colors. Light output is highly dependant on operating temperature. At very high or extremely low ambient temperatures, light output drops. Cold start or low temperature starting ballasts along with an enclosure to maintain to temperature should be used in cold areas. Refer to IESNA Lighting Handbook, Part II Lighting Engineering, Chapter 6 Light Sources.

2.1.1.3 High Intensity Discharge Lamps HID lamps are used both outdoors and indoors. Ballasts are required for their operation. HID lamps differ in their color rendering ability, generally being lower than fluorescent or incandescent lamps. These lamps are not suited to applications where lights operate intermittently for a short duration due to their slow warm up time.

2.1.2 Luminaires

2.1.2.1 Light is emitted from most lamps in many directions.
A luminaire is designed to control the direction at which light is emitted so glare will be reduced and light directed more effectively on the objects to be seen. In most cases, luminaires should direct light downward to minimize losses. In some applications, it is desirable to have a portion of the light directed toward the ceiling. Some of the light striking a light-colored ceiling is reflected back to the visual tasks.

2.1.2.2 Luminaires control light distribution with reflectors (enamel, aluminum, glass, or plastic), refractors (glass or plastic diffusing lenses), or diffusers (glass or plastic diffusing shields). One or more of these devices might be used in the same luminaire. Reflectors and refractors direct light for more efficient utilization. Reflectors, refractors, and diffusing shields prevent glare. Refer to IESNA Lighting Handbook, Part II Lighting Engineering, Chapter 6 Light Sources.

2.1.2.3 A luminaire prevents water from striking hot lamps when used in damp locations, outdoor areas or areas which are washed. Weatherproof or gasketted housings are available for lamps used in humid environments, areas where water spray is a problem or when lamps are exposed to the weather.

2.1.3 Controls Electric lighting systems in agricultural applications can be controlled electronically. There are several reasons for equipping a lighting system with an electronic control.

- Visual and Production Performance: match light intensity to the application. Occupant visual performance may depend on the quantity and quality of the light; for example, visually inspecting livestock for health or produce for quality purposes is a demanding visual task. The application may be specific to the reproductive, growth or behavioural needs of the plant or livestock.
- Energy Management: matches light application to demand; thereby, reducing unnecessary energy, time of use and/or demand charges.

A wide variety of controls are used in agricultural operations depending on the application. These controls include switches, dimmers, photosensors, occupancy sensors, and timers. The information provided in this section comes from IESNA Lighting Handbook, Part V Special Topics, Chapter 27 Lighting Controls. For details on any of the areas discussed, please refer to the Handbook.

2.1.3.1 Switching Switching control allows lights to be switched on and off manually with simple wall-box switches, or remotely with relays, switchable circuit breakers, a control system, or occupancy sensors. The choice of switching control will depend on the application. Local manual switching controls give control over light levels according to their needs or the task are inexpensive.
Central switching controls are well suited to scheduled activities such as occupation of a space during prescribed hours of the day and week. Control systems are ideal for applications with multiple zones and changing lighting requirements over time. Greenhouse operations, for example, employ lighting control systems to match light requirements to the crop being grown in a particular zone.
Occupancy or motion sensors are used in applications where lights are required only during occupancy of a space. These sensors are ideally

Table 1 – Relative Life & Efficacy of Various Light Sources (IESNA Figure 6-3; Ontario Hydro, 1992)

System	Lamp Power (W)	Lamp Life (hrs)	Initial Lumens	Initial Efficacy (lm/W)	Mean Lumens	Mean Efficacy (lm/W)	Efficacy (Compared to mean regular incandescent)
Regular life Incandescent	100	1,000	1,650	17	1,535	16.5	---
Long life Incandescent	100	5,000	1,240	NA	1,200	12.4	0.75
26 W Electro-Magnetic Compact Fluorescent	26W + 6W ballast	10,000	1,800	70	1,655	51.7	3.2
32 W double tube T-8 with electronic ballast	64W + 6W ballast	20,000	5,600	88	4,760	68.0	4.7

suited to walkways, hallways, entrances to buildings, or to spaces where the user's hands are not free to activate a switch.

2.1.3.2 Dimming Dimming control allows the illuminance in an area to be adjusted smoothly and continuously to meet the lighting requirements of the occupants. Dimming systems are employed in the poultry industry for example to control daily light levels and light levels during the growout period of a crop of broiler chickens for instance.

Most incandescent lamp dimmers currently rely on solid-state switching components. These components can generate electromagnetic and audible noise as well as harmonic distortion, which requires filtering. The light output, life and color temperature of the lamp are affected by dimming. By reducing light output by 25%, lamp life triples. The lamp color appears warmer with reduced voltage.

Fluorescent lamps can be controlled with dimmers. Dimming is not as simple as reducing the input voltage, which eventually extinguishes the arc and reduces lamp life. Dimmers are available for lamps operated with standard magnetic ballasts, magnetic dimming ballasts, or electronic dimming ballasts. There are many factors affecting the reliability, stability and cost of dimming systems.

High Intensity Discharge lamps can be dimmed; however, the restrike delay, long warmup, and color shift limit their use in agricultural applications. Multi-level ballasts allow illuminance to be changed in steps. Continuous dimming to less than 20% full light output is available with certain equipment. Metal halide lamps shift color toward blue-green, and high-pressure sodium to yellow. The color shifts become noticeable below 60% of rated lamp power for metal halide and 40% for high-pressure sodium lamps.

2.1.3.3 Timing Devices Timers control lighting based on known or scheduled events, ideal for poultry, swine and dairy operations. They range from simple integral timers (spring-wound) to microprocessors. Microprocessors can be programmed for a sequence of events or multiple events and lighting effects for years in advance. An override is required in order to deviate from the preset schedule.

2.1.3.4 Sensing Devices Sensing devices include photosensors and occupancy or motion sensors. A photosensor transforms visible radiation (light) into an electrical signal, which controls a lighting system or lamp. The photosensor generally does not respond to UV and IR radiation. Design, placement, and calibration of interior photosensors are critical to ensure high quality lighting.

Occupancy or motion sensors provide local on-off control of luminaires automatically based on the presence or absence of occupants. Energy consumption is reduced and demand may be reduced as well.

2.1.4 Energy Efficient Lighting Energy efficiency varies with the type of light source. Table 1 shows the approximate efficiency of a number of light sources compared to a regular life incandescent source. Fluorescent, metal halide, and high-pressure sodium lighting systems have significantly higher first costs compared to incandescent. However, the energy cost savings combined with longer lamp life offsets the higher initial costs for energy efficient lighting systems. The energy efficient alternative will typically pay for itself in two years or less in applications where the lights are operated 8 hours per day or more (Chastain, 1992).

2.1.5 Starting Characteristics The two starting characteristics that influence lamp selection are starting temperature and warm-up period.

2.1.5.1 Starting temperature generally is only important when selecting a lighting system for unheated spaces in cold climates, such as naturally ventilated structures. Incandescent and high-pressure sodium lamps perform well at cold temperatures (-29°C or colder). The minimum starting temperatures for standard fluorescent lamps and ballasts is 10°C. Ballasts are available that allow fluorescent lamps to start at -29°C.

2.1.5.2 Incandescent and halogen lamps do not have a warm-up period. Standard fluorescent lamps have a slight starting delay, but it is not significant in most applications. Quick starting ballasts can be purchased if required. All of the high intensity discharge lamps have a significant warm-up period. The warm-up period can range from 1 to 15 minutes.

2.1.6 Emergency Lighting The need for emergency lighting must be evaluated during the design phase of the building. If the facility does not have an automatic start generator, emergency lighting units may be required, to illuminate the exit passageways in the building(s) in the event of a power outage. Be sure to consult federal, state, provincial and local codes that may apply. NFPA (National Fire Protection Association) 101 - The Life Safety Code can be used as a reference along with the State Fire Marshal's Office in the State where the facility will be built. Even if not required, the Engineer designing the building must always consider how to get people out of the building(s) in the event of an emergency.

Auxiliary Generators must be installed in accordance with NFPA (National Fire Protection Association) 70, the National Electrical Code, NFPA 110 Standard for Emergency and Standby Power Systems and any other federal, state, provincial and local codes that may apply. The local electrical utility also must approve any installation and the equipment used. The appropriate NFPA, federal, state, provincial and local codes must be followed with regard to the installation of fuel tanks. In some instances, fuel tanks may be located inside the building, if the appropriate codes are followed and authorities such as State Fire Marshal's Offices are consulted. Be sure to check and see if the insurance company insuring the facility has any guidelines that must be met.

2.1.7 Codes Many federal, state, provincial and local codes govern the use of lighting equipment. Some public health codes specify minimum illuminance levels required in processing plants, egg handling areas, milking and milk handling areas to maintain health standards. These required levels address the concern for proper sanitation and often are below those recommended for efficient performance of visual tasks.

Table 2 – General Characteristics of Light Sources

Lamp Type	Lamp Power (W)	CRI	Efficacy (lm/W)	Typical Lamp Life (hrs)
Incandescent	34 - 200	100	11 - 20	750 - 2,000
Halogen	50 - 150	100	18 - 25	2,000 - 3,000
Fluorescent	32 - 100	70 - 95	75 - 98	15,000 - 20,000
Compact Fluorescent	5 - 50	80 - 90	50 - 80	10,000
Metal Halide	70 – 1,000	60 - 80	60 - 94	7,500 - 20,000
High-pressure Sodium	35 – 1,000	20 - 80	63 - 125	15,000 - 24,000

Agriculture facilities include many types of environments, which may be wet, damp, corrosive, dirty, surrounded by combustible materials, or saturated with gasoline fumes. It is mandatory to follow the National Fire Protection Association Standard No. 70, National Electrical Code, and any local regulations that may be in effect when installing lighting equipment. Contact a local electrician, electric power supplier for assistance or refer to the Agricultural Wiring Handbook published by the National Food and Energy Council (US).

2.2 Lighting Quality

The initial quality of light in a work area must be considered in addition to the quantity. An installation's light quality is influenced by the color of the light source, light uniformity, glare, flicker, horizontal and vertical illuminance, luminaire noise, the environment and many more listed in IESNA Lighting Handbook, Part III Quality of the Visual Environment, Chapter 10 Quality of the Visual Environment. Maintenance of the lighting system keeps both the quality and quantity of light at acceptable levels over time.

2.2.1 Color

The color of the light source is an important light quality factor in agricultural facilities. Certain specialized visual tasks, notably color discrimination processes and some inspection activities, depend on appropriate light source color. Color also has certain psychological effects upon people. These factors should be considered when selecting light sources to obtain quality lighting. One measure of the color of a light source is the Color Rendering Index (CRI). The CRI and other typical characteristics are presented in Table 2. Incandescent and halogen lamps provide the greatest color rendition and have a CRI of 100. A CRI of 80 or more is recommended for office, milking, washing, product inspection, plant growth and animal treatment areas. High quality fluorescent or metal halide lamps can provide an energy efficient light source when a CRI of 80 or greater is needed.

2.2.2 Uniformity

2.2.2.1 The uniformity of illuminance is typically expressed as a uniformity ratio (maximum measured illuminance ÷ minimum measured illuminance). The formula for the coefficient of variation (CV=*standard deviation÷mean*) provides a more meaningful, unbiased measure of uniformity. Furthermore, the *CV* provides a normalized measure of the interval about the mean that contains a certain portion of the measurements. The *CV* can be expressed in units of percentage by multiplying by 100; therefore, CV = (standard deviation / mean) x 100.

2.2.2.2 One method of insuring uniformity in a lighting system is to lay out the luminaires with a "spacing-to-mounting-height ratio" less than the luminaire's published "Spacing Criterion" (SC) value. The spacing-to-mounting-height ratio is equal to the ratio of the fixture spacing, *s*, to the mounting height above the work plane, *Hp*. The value of *Hp* is the difference between the actual mounting height of the fixture above the floor and the work height. If an obvious work height is not apparent, then use a work height of 0.6 m, which is the approximate height of an animal's eyes for breeding purposes.

2.2.2.3 Light sources should be located to minimize shadows cast on the work area by workers and obstructions. Objects should receive illuminance from more than one direction to minimize the density of shadows and to provide uniform illuminance.

2.2.3 Glare

Glare is any brightness within the field of vision that causes discomfort, annoyance, reduction in vision, or eye fatigue. It usually is the result of uncontrolled light emitted directly by a luminaire, or reflected from a glossy surface that is in the normal line of sight in the work area. Proper selection and mounting of the luminaires (above the line of sight), and use of reflective matte finishes on interior surfaces will greatly reduce glare.

2.2.4 Environment

2.2.4.1 Room surfaces should have high reflectance, matte finishes to help prevent excessive brightness ratios. The ceilings, walls and floors can increase the utilization of light within a room by acting as a secondary large- area light source. Luminaires that direct some light upward toward a ceiling having a relatively high reflectance will help create a comfortable visual environment. Recommended reflectance values are presented in Table 4.

2.2.4.2 Maintenance is necessary to ensure that a high quality light environment is provided. Lamps, luminaires and room surfaces in production facilities tend to become quite dirty. Regular cleaning is required to maintain illuminance levels.

2.3 Lighting Quantity

2.3.1 General Comments Modern agriculture facilities need a high quality work environment to optimize plant, animal and worker efficiency, and comfort. Proper lighting is an environmental factor that is often overlooked, or given little attention during the planning, construction, and maintenance of a facility. However, it is just as important as ventilation, heating, or cooling.

The amount of the illumination needed in agriculture facilities varies depending on the type of production and the tasks performed in the work area. In response to the variability of lighting system requirements, this discussion is divided into several sections and subsections.

2.3.2 Livestock Lighting system requirements vary with the housing and livestock type. The housing system and task will determine whether natural and or supplemental lighting is required.

Table 3 – Summary of Lighting Uniformity Criteria for Livestock Facilities (Chastain et al., 1997)

Task Classification	Maximum *CV* (%)	Corresponding *s/Hp*
Visually intensive (i.e. milking)	25	0.87
Handling of livestock and equipment	45	1.57
General low-intensity lighting	55	1.92

Table 4 – Recommended Matte Reflectance Values

Surface	Reflectance (%)
Ceiling	80 to 90
Wall	40 to 60
Desk and bench top, equipment	25 to 45
Floor	20 minimum

2.3.2.1 Natural and Artificial Lighting Light sources can be natural or artificial depending on the task and quality of light required. Natural lighting is well suited to work areas where tasks can be adequately lit during the daytime, such as open feedlots, naturally ventilated facilities, or areas within buildings that can be illuminated by windows.

Natural light may be supplemented with artificial light for some tasks. In these cases, supplemental light might be required to maintain adequate light quality and photoperiod. Photoperiod refers to the duration of the light period. Many animals and plants require specific photoperiod (light) and scotoperiod (dark) phases for reproduction and growth. Natural daylight is significant in naturally ventilated, curtain-sided buildings. Winter light levels ranging from 200 lux (lx) on a cloudy day to as much as 53,000 lx on a clear day have been measured in curtain-sided dairy facilities (Chastain, et al., 1997). In these types of buildings, artificial lighting supplements the natural day length. A timer and photocell control the supplemental light system's operation.

In totally enclosed buildings, artificial lighting alone must provide the needed light quality and day length.

2.3.2.2 Buildings This section will discuss lighting systems in buildings housing various types of livestock.

2.3.2.2.1 Dairy and Beef Cattle Facilities High quality light at adequate levels and duration is required in facilities housing dairy and beef cattle. Based on a field study of lighting in dairy buildings, a *CV* of 25% or less represents a high degree of uniformity (Chastain, 1994). The coefficient of variation was found to correlate well with respect to the ratio of the average fixture spacing and mounting height above the work plane (*s/Hp*) (Chastain et al., 1997). The recommended uniformity criteria for livestock facilities are summarized in Table 2.

Research trials indicate that supplementing lactating cows with 16 to 18 hours of light per day increases milk production by 5 to 16% as compared to cows exposed to 13.5 hours or less of light per day (Peters, 1994; Dahl et al., 2000). The expected result of supplemental lighting for a commercial herd is a 5 lb increase in milk production coupled with a corresponding increase in feed intake. The response to supplemental lighting however is not immediate. The cows will require several weeks to adapt, and the increase in milk production precedes the increase in feed intake (Dahl et al., 2000).

In order to stimulate milk production, the lighting system must provide the following:

1) 150 lx of illuminance throughout the barn.
2) 16 to 18 hour continuous block of light. Providing illuminance for 24 hours a day does not produce a sustainable increase in milk yield, and operating the lighting system more than necessary wastes energy.

Table 5 – Recommended Illuminance Levels for Dairy Livestock Facilities (NFEC, 1993; MWPS, 1992; Leech and Person, 1993).

Work Area or Task	Illuminance (lx)
Parlour, pit and near udder	500
Parlour, stalls & return lanes	200
Parlour, holding area	100
Milk room, general	200
Milk room, washing	750-1,000
Stall barn, manger alley	100
Stall barn, milking alley	200
Drive-through feed alley	200

In contrast to extended light in lactating cows, recent evidence suggests that reduced photoperiod is of benefit to cows during the dry period (Miller et al., 2000). Cows that received 8 hours of light and 16 hours of darkness each day when dry produced 7 lbs more milk per day in the next lactation than contemporaries exposed to 16 hours of light per day. Furthermore, reduced photoperiod during the dry period improves immune function and health in cows as they transition into lactation relative to cows on longer photoperiods (Dahl et al., 2003).

Improved daily gains have also been observed for beef steers and dairy heifers (Peters, 1994). The lighting period needed is similar to that for lactating cows.

Recommended illuminance levels for dairy facilities are presented in Table 5.

In addition to providing adequate levels and duration of illuminance for production, a high level of uniformity is required in the parlour pit, office, and milk room washing area. These areas require high uniformity to perform demanding visual tasks.

2.3.2.2.2 Swine Facilities Lighting plays a significant role in reproductive and overall swine production performance. The cost of electricity for lighting is a small percentage of the cost of production for swine; however, it is possible to reduce energy costs, increase lighting levels and actually improve performance with well designed, energy efficient lighting systems. A good light system should provide proper light levels economically with low maintenance costs.

Incandescent lighting is very common in swine barns. A 100W 1,000 hour standard rated incandescent bulb should last 63 days in the breeding barn. Long life incandescent bulbs at 5,000 hours rated life still only last 312 days and the actual light output is reduced by about 25% over the regular 1,000 hour bulb.

Compact fluorescent (C.F.) lamp and ballast systems provide good energy efficiency and are easily retrofitted into incandescent fixtures. However, the shorter equipment life and higher cost to replace lamps and ballasts compared to T-8 fluorescent tube systems increases operating costs and reduces cash flow.

Barns with a ceiling height of less than 3.6 m should install T-8 fluorescent lamps with matching electronic ballast, mounted in a weatherproof fibreglass or plastic housing with gasketted diffuser. These units are more than four times as efficient and the lamps last at least 24 times as long as a regular life incandescent lamp. Refer to Table 2 for relative system efficiencies and lamp life.

Where barn ceiling height exceeds 3.6 m, the more efficient high intensity discharge (HID) fixtures should be considered. They are easier to install, maintain and require fewer fixtures to provide the same level of light. Types to be considered include:

- metal halide (white light, good color rendition, good to excellent life)
- high-pressure sodium (can be color corrected for good color rendition, excellent life, low cost)

Ceilings and walls should be white to maximize reflectance and reduce the number of lighting fixtures required.

Recommended Light Intensities and Photoperiods for Swine

Each level of production requires different light levels and photoperiods. See Table 6: Recommended Light Levels and Photoperiods for Swine Housing. The 1993 Recommended Code of Practice for the Care and Handling of Farm Animals - Pigs (Publication 1898/E, Agriculture and Agri-Food Canada) recommends at least 8 h of light per day, at a level adequate to observe pigs. Five footcandles are adequate and will be at least twice as much light as typically is found in many older swine barns. Design is critical to maximize light efficiency and minimize overlit or underlit areas.

Breeding/Gestation barns require lighting photoperiods from 14-16 hours per day, to bring on more quickly and extend breeding sow estrus. Nursery pigs, particularly those in SEW, should have 24 hours of light at low levels and higher levels for day time feeding, inspection, etc. Farrowing rooms also should have 24 hours of light per day, particularly where heat lamps are not used. Again, it can be low level during night time.

Table 6 – Recommended Light Levels and Photoperiods for Swine Housing (Allmond, 1986; Brandt et al., 1990; Claus et al., 1985; Evans et al., 1996; Feddes et al., 1988; Hoagland et al., 1981; Mutton, 1987; Ntunde et al., 1979; Perara et al., 1984; Petchey, 1987; Stevenson et al., 1983; Wheelhouse, 1982)

Type of Housing	Light Levels (lx)	Photoperiod (hrs/day)	Comments
Breeding/Gilts	>100	14-16	- necessary for estrus cycling
Gestation	>50	14-16	- to assist missed cycles, bring estrus on again
Farrowing	50-100	8	- if no heat lamps, light in room 24 h/d
Nursery	50	8	- light in room 24 h/d
Grower-Finisher	50	8	

2.3.2.2.3 Poultry Facilities Poultry farms and processing plants vary in function, size, layout and degree of mechanization; however, there are some areas common to most facilities. The following are brief discussions describing the operations in the major areas. Lighting requirements vary with the type of production and the task. The amount and duration of light required by the birds is significantly different from worker requirements. See Table 7 Lighting Guide for Poultry Production for light levels and photoperiod requirements directly associated with affecting production. Table 8 Lighting Guide for Poultry Industry Tasks provides information on tasks associated with but not directly affecting production.

Broiler Houses Broiler chicks are placed into large houses inside which they move about freely. The structures may utilize natural light with artificial supplement or rely totally on artificial light. A low level of general lighting is required so the birds can find food and water during non-daylight periods or for certain time periods each day in completely enclosed facilities. The light levels and photoperiod may be adjusted during the growing period to maximize growth and control losses. Light control is provided by a dimmer and timer system. Higher levels of supplemental lighting may be required occasionally in the confinement area for workers to perform tasks such as reading charts or controls, inspecting the birds and equipment, and cleaning. These lights may be on a separate circuit from the lighting circuit used to stimulate growth.

In many facilities, monitoring and control equipment as well as records are housed in a separate room. Localized, higher intensity lighting is needed in this area for record keeping, observation and adjustment of alarm and control systems and monitoring equipment.

Breeder Barns

Breeder birds are placed in separate facilities, which generally are totally enclosed blocking out all natural light. Artificial lighting on timing circuits controls the perceived day length. The hours of light per day stimulate reproduction and control the breeding process.

The lights for production are on their own circuit. A separate lighting circuit provides general lighting for feeding, inspection and cleaning. Localized, higher intensity lighting is needed for record keeping, observation and adjustment of alarm and control systems and monitoring equipment.

Laying Houses

Facilities housing laying hens may range in size from a few thousand to several hundred thousand birds. There are basically two types of laying houses, the floor type house and the cage type house. In floor type houses, the hens are free to move about the floor area. In cage type houses, hens are confined to cages with three to four hens per cage. A common size cage for housing four birds is 300 millimetres (12 inches) wide, 460 millimetres (18 inches) deep, and 400 millimetres (16 inches) high. Artificial lighting systems control the perceived day length in order to extend the egg laying period during the year.

Lights to stimulate production are on one circuit. General lighting for inspection and cleaning is on a separate circuit. Localized, higher

Table 7 – Lighting Guide For Poultry Production

Type of Poultry	Age (Weeks)	Minimum Light Level (lx)	Photoperiod (hrs/day)
Chickens			
Broilers	0 to 2.5	20-30	24
	2.5 to market	5-10	24
Breeders	0 to 3	30-50	14
	4 to 20	30-50	8
	20 to 64	30-50	15
Layers	0 to 6	10-30	16
	6 to 18	5-10	8
	18 to 80	5-10	15
Turkeys			
New Hens	0 to 8	30-50	8
Grow Out, Hens	8 to market	30-50	8
New Toms	0 to 8	30-50	16
Grow Out, Toms	8 to market	10-30	16
Breeder Hens	0 to 5	20	24
	5 to 8	20	8
	8 to 22	20	8
	22 to 30	20	8
	30 and up	20	13 to 15
Breeder Toms	0 to 5	20	24
	5 to 30	20	13 to 15
	30 and up	30	13 to 15

Table 8 – Lighting Guide For Poultry Industry Tasks

Area And Visual Tasks	Minimum on Task (lx)	Explanation
Brooding, Production and Laying Houses		
Feeding, Inspection and Cleaning	200	Provided by a lighting circuit separate from the circuit used to stimulate production and growth.
Charts and Records	300	Localized lighting is needed where charts and records are kept.
Thermometers, thermostats, and light controls	500	Localized lighting is needed to accurately determine readings or setting.
Hatcheries		
General area and loading platform	200	Needed for operators to move about readily. Needed for cleanliness of the general area.
Inside incubators	300	Portable or localized lighting is needed for inspection and cleaning inside incubators.
Dubbing station	1,500	Needed to prevent excessive cuts and injury to chicks. Supplementary lighting in addition to general lighting.
Sexing	10,000	Needed for sex sorting of baby chicks. Supplementary lighting should be used in a closed area to prevent excessive luminance ratios between the task area and the immediate surrounding area.
Egg Handling, Packing and Shipping		
General Cleanliness	500	General illuminance is needed to keep area clean and to detect any unsanitary conditions.
Egg quality inspection	500	Needed to examine and grade eggs. Note: Candling and other special grading equipment are used as separate devices for examining and grading eggs.
Loading platform, egg storage area, etc.	200	Needed for easy operator movement, and for operation of mechanical and loading equipment.
Egg Processing		
General lighting	700	Should meet food preparation area cleanliness requirements. Includes liquid processing, pasteurizing, and freezing of raw eggs.
Fowl Processing Plant		
General (excluding killing and unloading area)	700	General lighting for cleanliness, inspection, and sanitation. Should meet food preparation area requirements.
Government inspection station and grading stations	1,000	Needed to detect diseases and blemishes. Vertical illuminance is needed if birds are hanging.
Unloading and killing area	200	Needed to move about readily.
Feed Storage		
Grain, feed rations	100	Needed to read labels, scales, and detect impurities and spoilage in feed.
Processing	100	Needed for easy operator movement, read labels, scales, and equipment dials. Supplementary lighting is needed if machine repairs are necessary.
Charts and records	300	If detailed records or charts are kept in the feed room, localized lighting in this area is needed.

intensity lighting also is needed for record keeping, observation and adjustment of alarm and control systems and monitoring equipment.

Egg Handling, Packing and Shipping

The egg handling area may be located in a separate or adjoined building. When the eggs arrive at the egg processing area, they are either stored in a refrigerated area or loaded directly onto a washer. After the eggs have been washed, they are sorted and graded. Rough shells, cracked shells, and dirty or stained eggs are removed at the grading table. Candling equipment is used inside an enclosed booth to sort eggs that have internal defects such as blood spots or meat spots. If mechanization is used, the eggs are sorted according to size by a machine and placed in an egg carton for shipment. The cartons are held in refrigerated storage until they are ready for shipment to retail outlets. General lighting is needed to keep the area clean and detect any unsanitary conditions. Higher intensity, task specific lighting is necessary to examine and grade eggs. In the loading platform and egg storage areas, general lighting is needed for operation of mechanical and loading equipment.

Raw Egg Processing

Eggs, which are to be marketed as liquid, frozen, or powdered products, are processed in this area. The area must meet the sanitary requirements of a public food preparation area as set up by the health department. Cracked eggs, eggs with shell defects and stains, plus grade A eggs, are utilized in the processing of liquid eggs. The eggs are broken out of their shells and pumped into a holding tank. The liquid eggs for interstate shipment are pasteurized and packaged. Some states also require all broken-out eggs to be pasteurized for intrastate shipment. In addition, liquid eggs may be frozen at the processing area and shipped as a frozen product. General lighting must supply adequate light levels and uniformity to ensure that cleanliness requirements for a food preparation area are met.

Hatchery

Fertile eggs are brought to the hatchery, loaded onto trays and placed in incubators. The incubators maintain a temperature required for embryo development. After twenty-one days, the chick is hatched. When hatched, baby chicks are sorted according to sex. The male chicks are disposed of and the females are marketed as layers. Most of the female chicks have their combs dubbed, a process whereby the top of the comb is clipped off. As a result, the mature bird has a smooth comb, which helps prevent the comb from catching in the wires of the laying cages. Broiler chicks are handled in much the same manner except they are not sex-sorted or dubbed.

General lighting is needed for cleaning and easy movement of operators. Supplementary lighting is required for inspecting and cleaning inside incubators, and at dubbing stations to prevent cuts and injuries to chicks. Task specific lighting is necessary for sex sorting and should be provided in a closed area to prevent excessive luminance ratios between task area and the immediate surrounding area.

Poultry Processing Plant

The birds are brought to the plant in crates of about 20 per crate. Crates are unloaded and the birds hung by the feet on a continuously revolving overhead carriage. They pass by an area where they receive a slight electrical shock, which stuns them just before killing. They move through a bleeding area and then into the scalding tanks. Feathers are then removed by machine and the birds move on to the processing area. All birds are government inspected for wholesomeness after eviscerating, are thoroughly washed, inspected again, and sorted according to grade. Generally, the processed birds are then packed in ice and shipped to retail outlets.

General lighting is needed for cleanliness, inspection and sanitation. Supplementary lighting is required to detect diseases and blemishes (vertical illuminance if the birds are hanging).

2.3.2.2.4 Other

Horses

Brood Mare

Day length is the primary environmental factor that regulates the seasonal reproductive cycle of the mare (King, 1993; Evans et al., 1990). Since all foals are given a birthday of January 1, it is a relatively common practice to manipulate the estrous cycle in the mare to produce a foal as close to January 1 as possible. Due to an 11 month gestation period, this requires that the mare be bred out of season in winter. Provision of 14 to 16 hours of light followed by darkness has been shown to stimulate estrous. The minimum amount of light needed is 22 to 32 lux (Vogelsang, 1993; Evans et al., 1990). Since 108 lux are needed in a box stall (Table 9), this light requirement can be satisfied by controlling the stall fixture with a timer.

Table 10 – Recommended Illuminance Levels for Common Indoor Work Areas in Livestock Facilities (NFEC, 1993; MWPS, 1992; Leech and Person, 1993)

Work Area or Task	Illuminance (lx)
General, all types of livestock	
Housing area & feed bunk	100
Animal handling	200
Veterinary treatment	1,000
Office, General	500
Office, Task lighting	750−1,000
Feed room, mixing	200
Ladders & stairs	200
Toilet	200−300
Farm shop, active storage	100
General machinery repair	300
Rough bench work	500
Detailed bench work	1,000
General storage	50
Loading platform	200
Read charts, thermometers, etc.	200−300
Haymow & silo	30
Equipment & utility rooms	100−200
Sheep	
Lambing	100
Growing & finishing	100

Table 9 – Recommended Illuminance Levels for Horse Facilities (NFEC, 1993; MWPS, 1992; Leech and Person, 1993)

Work Area or Task	Illuminance (lx)
Box stalls	100
Tack room	300-400
Breeding	150-200

Stallion

Day length also influences sperm production in the stallion. Sperm production in the winter is typically half of that produced in the summer breeding season (King, 1993). Controlling the photoperiod for the stallion in the same way as for the mare will improve off-season breeding performance (Hudson, 1996). Table 9 Recommended Illuminance Levels for Horse Facilities lists light intensities for different work areas in a horse barn.

2.3.2.2.5 General Work Areas

Illuminance levels recommended for general livestock facility work areas within buildings are presented in Table 10. The IESNA lists recommended lighting levels for general workplace lighting in offices and industrial facilities. An attempt has been made to provide a fairly comprehensive list of tasks that might be performed in livestock facilities. In the event that a task is not listed in Table 10, please refer to IESNA Lighting Handbook, Part IV Lighting Application, Chapter 11 Office Lighting, and Chapter 19 Industrial Lighting for further information.

2.3.2.3 Open Lot Facilities

Important considerations in lighting beef and dairy cattle feedlots include comfort for the workers and cattle, production efficiency of the cattle, and feedlot security.

2.3.2.3.1 Lighting Systems and Principles

Principles of selection for cattle feedlot lighting systems consist of:

A) using the lowest lamp wattage to yield acceptable lighting levels in various areas
B) selecting an efficient type of lamp/luminaire
C) providing automatic control of lighting/lamp operation
D) providing adequate lighting system maintenance.

2.3.2.3.2 Feed Pen Lighting

Feedlot and dairy cattle feed pen lighting is provided for several production reasons. Feed pen lighting allows the animals to ″see″ where the food and water sources are as well as feel more comfortable during dark periods since cattle are inherently nervous in the dark. During high temperature periods, cattle are more likely to eat during the coolest part of the day so providing light over the food source helps maintain production. The lighting also allows workers to move about during the night and not scare or spook the animals, allowing various work activities to be performed at every hour of the day.

Lighting sources should be located over or very near feed bunks, which generally are located adjacent to the alleyways along which feed trucks move to deposit feed into the feed bunks. Common lamp types used in cattle feed pens include mercury vapour and high-pressure sodium. The mounting pole height influences the lamp size, which in turn affects energy efficiency of the lamp. Lamp efficiency increases with lamp wattage and taller poles allow larger, more efficient lamps to be used. The use of taller poles, larger wattage lamps and good directional control will reduce the number of poles and luminaires required. Taller poles may cost more, but the extra expense may be offset by a reduction in the number required and energy savings from the increased lamp efficiency. Most feed yard lighting systems are operated with single-phase 120-volt service; however, higher voltage 240 and 277-volt systems can also be found. Individual photoelectric control on each light generally is used to

Table 11 – Recommended Lighting Levels in Areas of Feedyards

Feed Yard Area or Task	Illuminance (lx)
Feed Processing	
Scales	50
Commodity Receiving Areas	100
Hay and Grain Storage	50
Concentrate Storage	100
Feed Processing	200
Special Pens and Chutes	
General	100
Sick Animal Treatment	500
Feed Pens	
Feed Bunk Area	10–30
Waterer Area	2.5
Centre and Rear of Pens	2.5
Security Lighting	2

turn individual lights on and off when light levels change. Individual photocell control allows for better continuity of service when photocells fail.

2.3.2.3.3 Loading Pens & Chutes A higher level of illuminance for worker convenience is required in loading areas and chutes where cattle may be moved, visually evaluated, and/or treated for illness. It is important to provide light from several directions in these areas so that the potential for shadows is reduced.

2.3.2.3.4 Feed Mill/Office Many larger feedlots operate the feed milling facilities at night to take advantage of lower time-of-day electricity rates. Lighting recommendations for general offices and commercial grain elevators or similar work areas and tasks will generally apply with these types of facilities.

2.3.2.3.5 Recommended Lighting Levels The Illuminating Engineering Society and ASAE have developed standards for various industries and tasks, including various components of cattle feedlots. A summary of recommended lighting levels in cattle feedlots is presented in Table 11. Good color rendition is necessary in feedlot offices, cattle sorting, feed processing, and veterinary service areas, but is not as essential in feed pens.

2.3.2.3.6 Lighting System Maintenance Lighting system maintenance at cattle feedlots should be performed once every three months. All automatic control equipment should be checked to ensure it is functioning properly and not leaving the lights on during daylight periods. Faulty lamps should be replaced, and dirty lamps/fixtures should be cleaned.

2.3.3 GREENHOUSE LIGHTING SYSTEM DESIGN The use of electrical light sources to supplement natural lighting in greenhouse production systems has become a common practice. The application of lighting systems in greenhouses is a complex technology that is dependent on the types of plants grown, the local incidence of natural sunlight, the availability of electric energy, and the availability of control systems to maximize lighting for enhanced plant performance. While the term "light" strictly applies only to visible electromagnetic radiation (approximately 380 to 770 nm), it will be used in this discussion also to refer to electromagnetic radiation that is useful for growth and development of plants (between 400 and 700 nm). See the photobiology section of the Illuminating Engineering Society handbook for a discussion of specific plant responses to electromagnetic radiation.

Supplemental lighting in greenhouses generally is designed to either enhance photosynthesis in the crop (assimilation lighting), or to control flowering and fruiting (photoperiod lighting).

Supplemental lighting provides a number of advantages to the grower:

- reduced dependency on sunlight
- increased productivity
- higher plant quality
- shorter growing times
- opportunity for controlled seedling production
- control over timing of flowering of plants/shrubs
- control over timing of plant production (to best meet market needs)

2.3.3.1 Design Objectives Greenhouse lighting systems generally are designed to meet three main objectives:

- instantaneous light intensity or daily light integral
- uniformity
- photoperiod.

The light intensity available for plant growth, in the 400-700 nm range, generally is reported in the units of micromoles of photons ("particles" of light) per square meter per second. One mole equals Avogadro's number of photons and one micromol equals a millionth of a mole. This radiation range frequently is referred to as Photosynthetic Photon Flux Density (PPFD). It closely approximates the photosynthetic response curve, and sensors are readily available to measure in this unit (McCree, 1972). Conversion factors between PAR (μmol m^{-2} s^{-1}) and visible light (lux) depend on the light source, and are shown in Table 12. Additional useful conversion factors are presented in Table 13.

Optimum PAR or daily integrated PAR levels are not always readily available for many crops. The designer must ascertain from the client or from research data what design values to select, and also adjust for incoming solar radiation at the site (Spaargaren, 2001). A general guideline for research greenhouses is that the natural sunlight plus supplemental lighting supply a minimum daily light integral of 26 moles per m^2 per day (Dietzer et al., 1994). Generally, supplemental PAR intensities for commercial greenhouses are in the range of 50 - 200 μmol m^{-2} s^{-1} . However, if the lighting system is used only for photoperiod control, then much lower PAR intensities in the range of 1-3 μmol m^{-2} s^{-1} are usually suitable (Mpelkas, 1991; Weir, 1975). These values are measured on a horizontal plane at the surface of the crop canopy.

Ideally, the PAR intensity at the top of the crop canopy would be perfectly uniform. However, luminaire spacing and intensity distributions, combined with economic considerations, require the acceptance of a degree of variation in the PAR intensity (Albright and Both, 1994; Both et

Table 12 – Converting Light Units for Several Different Light Sources (Spaargaren, 2001; Thimijan and Heins, 1983).

Light Source	PAR 400-700 nm (μ mol m^{-2} s^{-1})	Visible 380-770 nm (lx)	Visible 380-770 nm (fc)	Solar Radiation 280-2,800 nm (W m^{-2})
Sunlight	100	5,600	520	48.3
High-pressure Sodium (HPS)	100	8,500	790	44.4
Metal Halide (MH)	100	7,100	660	48.3
Incandescent (INC)	100	5,000	465	48.3
Fluorescent, Cool White (FCW)	100	7,400	688	44.4
Low Pressure Sodium (LPS)	100	10,600	985	45.2

Note: For example, for sunlight: 100 μ mol m^{-2} s^{-1} (PAR) = 520 (fc) (visible radiation) = 5,600 lux (visible radiation) = 48.3 W m^{-2} (solar radiation). The last conversion assumes that 45% of the solar radiation occurs in the PAR waveband.

Table 13 – Additional Useful Light Conversion Factors.

Solar radiation (280-2,800 nm):
1 Langley (Ly) = 1 cal cm^{-2}
1 cal cm^{-2} = 4.184 J cm^{-2}
PAR (400-700 nm):
1 Einstein m^{-2} = 1 mol m^{-2}
1 μ Einstein m^{-2} s^{-1} = 1 μ mol m^{-2} s^{-1}
Visible radiation (380-770 nm):
1 fc = 10.76 lux
Conversion from solar radiation to PAR:
1 MJ m^{-2} = 2.08 mol m^{-2} (Ting and Giacomelli, 1987)
100 Ly d^{-1} = 8.70 mol m^{-2} d^{-1}

al., 2002; Ciolkosz et al., 2001). In research greenhouses, a maximum variability of +/- 15% from average is considered acceptable (Both, 1994), while commercial greenhouses tend to vary somewhat more.

Photoperiod requirements of a lighting system can be best thought of in terms of the length of the dark period plants are exposed to during a 24 hour period. Thus, if a plant requires a minimum photoperiod of 17 hours, the corresponding dark period is 7 hours. If the night length at the site is naturally 12 hours long, then photoperiod control can be obtained by turning the lighting system on for 30 minutes in the middle of the night, thus effectively reducing the maximum dark period to just under 6 hours. Some species have a maximum allowable dark period in order to grow and develop properly, while some require a dark period that is longer than a certain minimum amount. It is important to take the length of the dark period into consideration if assimilative lighting is to be used during nighttime hours. Also, it is important to evaluate the site for sources of stray light from neighboring structures. Stray light, if bright enough, may have an unwanted photoperiodic effect on the crop.

2.3.3.2 System Selection Lamps for greenhouse lighting generally are selected for their electrical efficiency because of the high electrical demand from the systems. Compact size also is a positive attribute because smaller lamps and luminaires tend to create smaller shadows. Currently, the high-pressure sodium lamp is preferred. Low pressure sodium lamps generally are not used because their large reflector size tends to block a high amount of incoming sunlight.

Spectral quality of the light source is usually not an issue because the high proportion of sunlight received by the plants tends to overcome any spectral deficiencies in the light sources (Ehret et al., 1989). Some plant species however, show slightly different growth responses under different light sources. In these installations, a less efficient light source may result in better economic value for the crop (Clarke and Devine, 1984).

Photoperiodic lighting systems historically have used incandescent lamps because of their relatively low installation cost; and even though they are electrically inefficient, they are needed only for a few minutes each night. A recent energy and cost efficient alternative to incandescent lamps are the compact fluorescent lamps (deGraaf-van der Zande and Blacquiere, 1992).

Greenhouse luminaires are specially designed for operation in the greenhouse environment. Other luminaire types should not be considered unless they can perform well in the hot, humid, corrosive environment. Factors to consider in luminaire selection include optical efficiency, electrical efficiency (Both et al., 1997), reflector size, mounting height, ease of installation and maintenance, and ballast location. Occasionally, it can be desirable to locate the ballasts remotely in order to reduce the shading effect of the luminaire.

Switching and controls usually are a component of a greenhouse environmental control system, which is supplied separately from the lighting system. Communication with the controls provider is imperative to ensure that the client receives the type of system control needed, and that either the electrical or controls contractor provides all system components. Manual override controls should be included as part of the control system. Dimming controls are rarely an economic alternative for greenhouse lighting systems. The control of supplemental lighting can be integrated with the control of the shading system (Albright et al., 2000), particularly when control of the daily integrated PAR level is desired.

2.3.3.3 Layout and Design Luminaire layout generally is done on a rectangular grid above the plant canopy (Mpelkas, 1984). Alternatively, luminaries can be mounted in a staggered grid in an attempt to improve light uniformity (Ciolkosz et al., 2001). When possible, locate the luminaires on structural members of the greenhouse to reduce the need for additional support. Luminaires should be located below thermal screens so that the screens may be drawn at night even when the lamps are operating. The effect of any screens or curtains in the greenhouse needs to be taken into account during the design process, provided that they will be drawn while the lamps are operating. Decreasing PAR intensities at the edges of the greenhouse can be countered by increasing the number of luminaires along the greenhouse perimeter (Both, 1994).

2.3.3.4 Maintenance System maintenance generally consists of regular luminaire cleaning, and relamping as needed. The client should be informed of the importance of these tasks. Depending on the specifics of the design, group relamping may be an economical alternative.

2.3.3.5 Headhouse Lighting The headhouse is a structure used for plant handling procedures such as planting, grading, and shipping plant material. It usually is located directly adjacent to the greenhouse. Lighting requirements for the headhouse correspond to the activities taking place in the various areas. Generally, these activities include potting, sorting, packing, shipping, and (cold) storage. The design for these areas should be conducted based on the client's needs and the appropriate design criteria for those tasks, as set forth in Table 10.

2.3.4 Fruit and Vegetable Processing and Storage Fruit and vegetable sorting operations can benefit from lighting changes that match the characteristics and color output of the light with the color of the produce being sorted. Most defects on produce are in the brown or gray tones. Light provided for inspection must have both the right intensity and spectral quality to reveal these defects. Proper lighting design also reduces worker fatigue and eyestrain, resulting in better sorting efficiency. Many operations currently use cool white or warm white lights, which researchers say can mask defects. Many of these lights are being phased out by government mandate because they are not energy efficient.

High CRI SP-30 lights are recommended for most fruit and vegetable inspection areas. SP-30s are 2 times more expensive than cool white, but the relative light output of the SP-30 lamp was among the highest tested. Tungsten halogen quartz lighting also produced good color recognition and enhanced the ability to see brown defects, but is more expensive.

The average illuminance level needed at the produce level for effective visual sorting is between 2,500 and 5,000 lux. The lower levels are adequate for light-colored produce and the higher level is needed for dark-colored produce.

The color of the sorting surface is also important. Using black or gray (but not glossy) belts is beneficial.

Select dark colors for equipment parts and employee clothing. It is important to screen task lights so they do not glare in the workers' eyes. Minimize the influence of natural, stray, and general area lighting in the sorting area.

2.3.5 Indoor Aquaculture Indoor aquaculture is a relatively new industry. The lighting needs for fish production are limited. Lighting however can play a crucial role in the productivity of a facility and as such must be considered in the overall design.

2.3.5.1 Effects of Lighting on Fish Production Lighting effects on fish populations can be classified in three categories: growth rate effects, maturation effects, and vigour.

2.3.5.1.1 Growth Rate Effects Photoperiod and light intensity in many species influence growth rate. Often, only a very low light level difference is needed (<1 lux) to induce photoperiod responses in fish, which include increased activity and time spent feeding. Fish can be extremely sensitive to environmental shock - including sudden changes in light level. The resulting stress can negatively affect feeding and growth of the fish. Thus, dimming circuits or banked lamps on a slow ramp-up and down may be needed to prevent stress and insure proper growth.

2.3.5.1.2 Maturation Effects Manipulating the photoperiod can control speed of maturation of some fish species. One method is to vary the photoperiod above the fish tanks from day to day so as to simulate the natural fluctuations in day length from season to season. In selected species, the annual maturation cycle of the fish can be compressed to 9 or even 6 months by compressing the day length cycle to that period.

2.3.5.1.3 Vigour Fish vigour, or survival rate, also is dependant on lighting. Generally, increased photoperiods will result in greater vigour of the fish crop.

2.3.5.2 Specific Species Recommendations The following recommendations need to be used with some caution. Current research is insufficient for many species; as a result, the recommendations regarding lighting are based on limited data. Combining these recommendations with the knowledge and desires of the grower will assist in the design of a system that optimizes production.

Atlantic Salmon - Long photoperiods during the freshwater period result in an increased growth rate relative to shorter photoperiods (Sigholt et al, 1989) and continuous light results in a higher growth rates than the use of a simulated daylight cycle (Krakenes et al., 1991). Long photoperiods interrupted by 2 months of short photoperiods results in faster maturation and higher survival rates, compared to constant long photoperiods (Duston et al., 1995).

Coho Salmon - Absence of a dark period (24 hr light/day) results in reduced growth rate, silvering index, and seawater adaptability (Thorarensen et al., 1989).

Pink Salmon – Mature faster by accelerating the seasonal photoperiod (Beacham et al., 1993).

Greenback Flounder - Absence of lighting results in death of the species. An 18-24 hour photoperiod is recommended for optimum production (Hart et al., 1996).

Silver Carp - A light level of 100 lux at the water surface is recommended for raising larvae of this species (Radenko et al., 1992).

Rainbow Trout - A long photoperiod (16 hr) results in increased growth and feed conversion (Mason et al., 1991).

Striped Bass - Reproductive cycles can be compressed to 6 or 9 months by compressing the photoperiod cycle, but reproductive success diminishes as a result (Blythe et al., 1994).

2.3.5.3 Lighting Other Areas in the Facility Lighting systems for walkway, processing, packaging, and shipping areas should be designed according to recommendations in the General Work Areas section. Often, lighting requirements for operation of the facility will not be compatible with the needs of the fish. Thus, care must be taken to ensure that lighting for human needs does not negatively affect the fish population.

3 Glossary of terms

3.1 Diffuser: A device used to redirect the illumination by the process of diffuse transmission.

3.2 Candela: The SI unit of luminous intensity. One candela is one lumen per steradian. Formerly known as Candle. For more information on this term, see the IESNA Lighting Handbook Reference Volume.

3.3 Footcandle (fc): The unit of illuminance when the foot is the unit of length. It is the illuminance on a surface one square foot in area on which is uniformly distributed a flux of one lumen. It equals one lumen per square foot.

3.4 General lighting: Lighting designed to provide a uniform level of illuminance throughout the area involved.

3.5 Glare: The effect of brightness or brightness differences within the visual field sufficiently high to cause annoyance, discomfort, or loss in visual performance.

3.6 Illuminance: The density of the luminous flux incident on a surface; it is the quotient of the luminous flux by the area of the surface when the latter is uniformly illuminated.

3.7 Local Lighting: Illuminance provided over a relatively small area or confined space without any surrounding general lighting.

3.8 Louver: A series of baffles used to shield a source from direct view at certain angles or to absorb unwanted light.

3.9 Lumen (lm): The unit of the time rate of flow of light (luminous energy) equal to the energy emitted through a unit solid angle (one steradian) from a uniform point source of one candela.

3.10 Luminaire: A complete lighting unit consisting of a lamp or lamps together with the parts designed to distribute the light, to position and protect the lamps, and to connect the lamps to the power supply.

3.11 Lux (lx): The unit of illuminance when the meter is the unit of length. It is the illuminance on a surface one square meter in area on which is uniformly distributed a flux of one lumen. It equals one lumen per square meter.

3.12 Reflector: A device used to redirect the light from a source primarily by the process of reflection.

3.13 Refractor: A device used to redirect the illuminance primarily by the process of refraction. (The bending of a ray of light as it passes obliquely from one medium to another in which its velocity is different.)

3.14 Shielding Angle (of a luminaire): The angle between a horizontal line through the light center and the line of sight at which the base source first becomes visible.

3.15 Supplemental Lighting: Lighting used to provide a specific amount or quality of illuminance which cannot be readily obtained by the general lighting system, and which supplements the general lighting system.

3.16 Visual Task: Conventionally designates those details and objects that must be seen for the performance of a given activity, and includes the immediate background of the details or objects.

3.17 Work Plane: The plane at which work is done, and on which, illuminance is specified and measured. Unless otherwise indicated, this is assumed to be a horizontal plane 0.75 m (2.5 ft) above the floor.

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