Conservation Applied Research
& Development (CARD) Program

FINAL REPORT

LEDs: Energy Savings and Replicability in MN Livestock Facilities

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Abstract

This project report details the potential energy savings, cost-effectiveness and practical performance of Light Emitting Diode (LED) lamp technology in Minnesota's poultry industry. The goal of this project was to aid electric utility staff and Conservation Improvement Program administrators in working with poultry producers to capture electricity savings through LED energy efficient lighting. Some challenges remain regarding the practical implementation of LED lamps in poultry facilities, but the cost effectiveness and maintenance of bird productivity demonstrated in this project represent an attractive investment for electric utilities and poultry producers.

Executive Summary

With support from a Conservation Applied Research and Development (CARD) Grant from the Minnesota Department of Commerce, The Minnesota Project conducted a pilot project to measure the energy savings, performance and durability of Light Emitting Diode (LED) lamp technologies designed specifically for poultry facilities. Through this pilot project, The Minnesota Project and Plymouth, Minnesota-based LED lamp manufacturer Once Innovations, Inc. installed LED lamps in 23 poultry barns across Minnesota. In exchange for farmers' participation in the study, The Minnesota Project subsidized the cost of the lamps with grant funding and secured a manufacturer's discount from Once Innovations, Inc.

This project served to demonstrate the effectiveness of an early commercial energy efficient LED lamp technology as a potential measure in rural electric utility Conservation Improvement Program portfolios to help electric utilities attain their energy conservation goals. Primary objectives included:

- Demonstrating energy savings by recording and reporting pre- and post-retrofit energy consumption
- Investigating the cost-effectiveness of LED lights designed for poultry facilities
- Providing on-the-ground, observable examples of LED technology designed for harsh agricultural environments in Minnesota (durability)
- Examining whether LED technology would affect bird productivity
- Identifying program design considerations for utility conservation programs

Beginning in late spring 2011, the project team recruited poultry farmers who demonstrated an interest in LED lamp technology. After confirming relationships with the farmers, the project team recorded energy use of pre-installation lamp equipment in participating barns. After gathering baseline data including lighting schedules, number of lamps, and lamp wattage, the producers rewired barns, if necessary, and/or simply installed 12-watt LED lamps by switching out old lamps. Electrical rewiring and lamp retrofits coincided with cleaning periods between flocks when the barns were empty. During the later months of the project, The MN Project monitored the energy use quantitatively in kilowatt-hours saved by comparing pre- and post-install energy consumption. Practical performance of the LED lamps was determined qualitatively by speaking with producers on a regular basis to learn of lamp failures, any changes in bird performance, and barn operations under the new lamps.

Table 1 and Table 2 highlight the demonstrated energy savings and simple paybacks of LED lamp installation.

Table 1: Summary of Energy Savings for Participating Producers

Producer	No. of Barns	Barn Type	Lighting Changeout	Pre-Retrofit Annual Energy Use (kWh)	Post-Retrofit Annual Energy Use (kWh)	Annual Energy Savings (kWh)	Annual Energy Savings (%)
Lakewood Turkey	1	Turkey Finish	CFL to LED	6,805	4,417	2,388	35%
Gorans Bros. Turkey	1	Turkey Finish	CFL to LED	3,259	1,818	1,441	44%
Galaxy Farms	1	Turkey Brood	CFL to LED	4,508	2,352	2,156	48%
Sparboe Egg Farm	1	Egg-laying	CFL to LED	20,840	19,237	1,603	8%
Buysse Farm	1	Turkey Brood	CFL to LED/CFL	13,943	10,189	3,754	27%
Flying C Farms	2	Turkey Finish	HPS to LED	34,394	7,162	27,232	79%
WP Highway 40 West	1	Egg-laying	HPS to LED	63,060	14,875	48,185	76%
LSI/WP Highland	1	Egg-laying	HPS to LED	69,534	14,875	54,659	79%
LSI/WP Diamond	1	Turkey Brood	HPS/Incan to HPS/LED	59,851	30,746	29,105	49%
LSI/WP Westbrook	1	Turkey Brood	HPS/Incan to HPS/LED	45,694	30,401	15,293	33%
Zimmerman Farms	4	Turkey Finish	HPS/Incan to LED	53,455	12,257	41,198	77%
Evelo Farms	1	Turkey Brood	Incan to LED	15,680	1,882	13,798	88%
Langmo Farms	3	Turkey Finish	Incan to LED	43,549	6,968	36,581	84%
LSI/WP Old East Fransen	1	Turkey Brood	Incan to LED	15,329	1,983	13,346	87%
R & L Turkeys	1	Turkey Finish	Incan to LED	31,586	3,790	27,796	88%
LSI/WP New West Fransen	1	Turkey Brood	Halogen to LED[1]	10,986	1,983	9,003	82%
P & J Turkeys	1	Turkey Brood	Halogen to LED[1]	33,881	9,455	24,426	72%
Total Project	**23**			**526,353**	**156,716**	**314,708**	**63%**

1. Newly constructed barn; not a retrofit. Values were calculated by assuming lighting changed from halogen to LED.

Table 2: Summary of Total Project Costs, Annual Dollars Saved, and Payback Times

Producer	No. of Barns	Barn Type	Lighting Changeout	Money Saved Annually[1]	Total Project Costs *[Materials + Labor]*	Simple Payback (yrs)[2]	Total Incentives *[Subsidies + Rebates]*	Net Payback (yrs) *[with Total Incentives]*
Lakewood Turkey	1	Turkey Finish	CFL to LED	$258	$5,235	No Payback	$1,600	14.1
Gorans Bros. Turkey	1	Turkey Finish	CFL to LED	$155	$3,181	No Payback	$1,976	7.8
Galaxy Farms	1	Turkey Brood	CFL to LED	$233	$3,181	No Payback	$2,181	4.3
Sparboe Egg Farm	1	Egg-laying	CFL to LED	$173	$15,847	No Payback	$12,572	No Payback
Buysse Farm	1	Turkey Brood	CFL to LED/CFL	$405	$2,300	5.7	$1,075	3.0
Flying C Farms	2	Turkey Finish	HPS to LED	$2,938	$24,350	8.3	$13,200	3.8
WP Highway 40 West	1	Egg-laying	HPS to LED	$5,199	$9,240	1.8	$7,920	0.3
LSI/WP Highland	1	Egg-laying	HPS to LED	$5,898	$9,240	1.6	$7,920	0.2
LSI/WP Diamond	1	Turkey Brood	HPS/Incan to HPS/LED	$3,140	$4,690	1.5	$3,350	0.4
LSI/WP estbrook	1	Turkey Brood	HPS/Incan to HPS/LED	$1,650	$1,680	1.0	$1,440	0.1
Zimmerman Farms	4	Turkey Finish	HPS/Incan to LED	$4,445	$18,769	4.2	$13,969	1.1
Evelo Farms	1	Turkey Brood	Incan to LED	$1,489	$3,145	2.1	$2,045	0.7
Langmo Farms	3	Turkey Finish	Incan to LED	$3,947	$7,450	1.9	$5,525	0.5
LSI/WP Old East Fransen	1	Turkey Brood	Incan to LED	$1,440	$2,100	1.5	$1,800	0.2
R & L Turkeys	1	Turkey Finish	Incan to LED	$2,999	$2,940	1.0	$2,761	0.1
LSI/WP New West Fransen	1	Turkey Brood	Halogen to LED[3]	$971	$2,100	2.2	$1,800	0.3
P & J Turkeys	1	Turkey Brood	Halogen to LED[3]	$2,636	$5,250	2.0	$4,065	0.4
			Average:	**$2,234**	**$7,100**	**2.7**	**$5,012**	**2.3**
			Median:	**$1,650**	**$4,690**	**1.9**	**$2,761**	**0.5**

1. Assumes $0.1079/kWh electric rate.
2. When payback exceeded the life of the LED lighting using the producer's annual hours of lighting operation, then no payback was possible.
3. Newly constructed barn; not a retrofit. Values were calculated by assuming lighting changed from halogen to LED.

Over all, this project determined poultry-specific LED lamps offer significant energy savings opportunities for electric utilities and poultry producers, as well as attractive paybacks when replacing incandescent and/or high-pressure sodium lamps. Further, participating producers demonstrated LED lamp technology did not impair bird production. With a quick net average payback of 3.3 years and net median payback of 0.5 years, poultry producers have good reason to closely examine the cost-effectiveness of implementing LED lamp technology. Nonetheless, Conservation Improvement Program administrators and electric utility staff should take care in communicating, designing, and implementing LED lamp rebates in poultry barns. No barn is identical and one-to-one lamp exchanges are not likely to work in consideration of farmers' concerns about proper light levels and even lighting. Electric utility personnel would be served well by communicating regularly with poultry producers in order to understand flock rotations and the timing of barn upgrades as a means to implement energy efficient lighting in poultry facilities located in their service territories.

Introduction

This report details the potential energy savings, cost-effectiveness and practical performance of Light Emitting Diode (LED) lamp technology in Minnesota's poultry industry. The goal of this report is to aid electric utility staff and Conservation Improvement Program administrators in working with poultry producers to capture electric energy savings.

Background

Rural electric cooperatives are searching for opportunities to access energy efficiency improvements that will help them continue their work toward meeting their Conservation Improvement Program (CIP) goals.[1] Poultry production facilities, substantial customers for many rural electric cooperatives, present a moderate opportunity for electric energy efficiency improvements. Notably, Minnesota is the number one turkey producing state in the country. In 2012, the state raised approximately 46 million turkeys. [2] The state raised an additional 45.5 million[3] broiler chickens as well as produced 2.83 billion eggs[4] from approximately 10.4 million hens in 2012.

Lighting is a major energy use of the poultry industry and many producers keep their lamps on for the majority of the day to encourage feeding and growth. The Energy Independence and Security Act of 2007 will require the implementation of high performing lamp technologies across all industries as older lamp technologies phase out of existence. Consequently, Minnesota's poultry producers will require alternatives to incandescent lamps to maintain safe and productive growing conditions in their facilities. Though compact florescent lamps (CFLs) present a significant energy savings improvement over incandescent lamps, questions remain about CFLs' durability in harsh barn conditions. Further, some industry stakeholders have expressed hesitation towards installing CFL lamps in poultry production facilities because of difficulties with CFL lamp dimming or flickering, and the potential for the release of mercury into bird feeding areas due to broken lamps.

LED technology presents a viable alternative to incandescent lamps, but the upfront cost of converting to an LED lamp system can be relatively high. Producers have been reluctant to make such substantial

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[1] Minnesota Statutes 216B.241 pertain to the Conservation Improvement Program. MN Statutes establish for each individual utility and association an annual energy-savings goal equivalent to 1.5 percent of gross annual retail energy sales. The savings goals must be calculated based on the most recent three-year weather-normalized average.

[2] USDA, National Agricultural Statistics Service, Number of Turkeys Raised: 2012, (last visited Dec. 10, 2013).

[3] USDA, National Agricultural Statistics Service, Broiler Production by State: 2012, (last visited Dec. 10, 2013).

[4] USDA, National Agricultural Statistics Service, Annual Egg Production by States, (last visited Dec. 10, 2013).

investments to their production systems until the LED and agricultural industries can demonstrate that LED technology does not harm bird production, is dependable, cost-effective, and commercially replicable.

With support from a Conservation Applied Research and Development (CARD) Grant from the Minnesota Department of Commerce, The Minnesota Project conducted a pilot project to measure the energy savings, performance and durability of LED lamp technologies designed specifically for poultry facilities. Through this pilot project, The Minnesota Project and partner Once Innovations installed LED lamps in poultry production facilities across Minnesota. In exchange for farmers' participation in the study, The Minnesota Project subsidized the cost of the lamps with grant funding and secured a manufacturer's discount from project partner, Once Innovations, Inc.

The project team documented the energy use and performance of these newly-installed LED lamps in barns across the state to determine energy savings potential and to evaluate the dependability of LED technology for producers and electric utilities. The data gathered in this study will be used to help determine the potential for future inclusion in utility CIPs programs.

Minnesota Poultry Industry and Contract Production

Poultry production is a unique agricultural industry. While the poultry industry in Minnesota is rather large, it quickly segments into smaller groups of producers with individual production needs. It includes turkey, broiler chicken, and egg producers, each with different marketing, operational and logistical needs.[5] These industries have many similar production needs, but also require individualized lighting options.

Turkey Production in Minnesota

Minnesota is home to about 250 turkey farmers who operate about 600 different turkey farms.[6] The average turkey farmer in Minnesota raises three flocks per year, with an average flock size of about 15,000 birds. Minnesota is home to the world's largest turkey hatchery company, Willmar Poultry, and the second largest turkey processing company in the country, Jennie-O Turkey. As (Source: ESRI, a geographic information services company)

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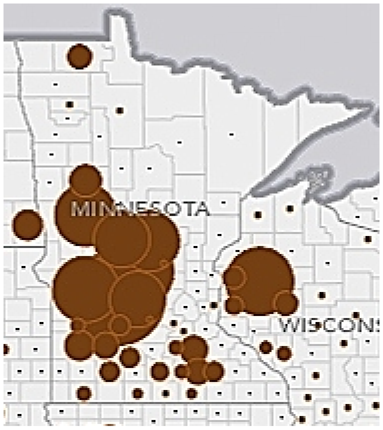
[5] The unique blend of shared needs and resources versus industry specific production requirements is exemplified through the industry's trade association setup in the Midwest. The Midwest Poultry Federation is a "poultry industry" trade association located in Minnesota that brings together each of these varying industries at its annual Midwest Poultry Federation Convention. This trade show typically fills St. Paul's Rivercentre and the range of activities taking place at this event can be confusing for an outsider. Two separate organizations, the Minnesota Turkey Growers Association and the (Chicken) Broiler and Egg Association of MN, each hold their own separate annual meetings. However, the Minnesota Turkey Growers Association shares office space and a website with the (Chicken) Broiler and Egg Association of Minnesota.

[6] Minnesota Turkey Growers Association, Minnesota Turkey Industry Facts Sheet, Aug. 2011.

Figure 1 indicates, a majority of turkey production in Minnesota takes place in the central counties of Minnesota, in particular Kandiyohi and Stearns counties.



(Source: ESRI, a geographic information services company)

Figure 1: Distribution and Density of Turkey Production

Turkey producers typically have at least two different types of barns on their farms: a "brooder" barn used for growing young poultry in a warmer, more secure environment, and a "grow-out," or "finishing," barn used for growing the poultry to their desired finish weights. This separation of young from old birds cuts down on disease transfer and pecking injures. Also, hens and toms are separated by barn to allow the farmer to meet their differing metabolisms, growth rates and feed requirements.

Most turkey producers purchase "poults" (recently hatched birds) from a hatchery, a facility where turkey poults are hatched from the eggs. At one or two days old, poults are transported to brooder barns within 24 hours of being removed from hatcheries. Brooder barns are climate-controlled and kept at a warm temperature initially (around 90 degrees) and gradually lowered as the poults' down is replaced with feathers. As Table 3 below illustrates, the turkeys brood for up to 6 weeks and are then moved to the grow-out barn to be "finished" for several months. The length of time in the "finishing" barn depends on the sex and type of turkey.

Table 3: Turkey Grow Out Periods

Type of Poultry	Time in Brood	Time in Grow-Out	Market Weight[7]
Brooders (light hens)	Up to 6 weeks	10-12 weeks	8-12 lbs.
Hens (female)	Up to 6 weeks	11-15 weeks	12 to 19 lbs.
Toms (male)	Up to 6 weeks	12-19 weeks (up to 25 weeks)	20-40 lbs.

[7] The weight of a finished tom, or any turkey, will vary depending on the producer's desires and/or his contract with the processor. Some turkeys are grown to be sold as whole birds (the Thanksgiving turkey) while others are grown to be processed for other uses, for example, deli meat or packaged dinners.

Depending on the type of turkeys raised, a farmer can grow between three to seven flocks a year. The time between flocks might be one to two weeks. In between each flock rotation, the barn is emptied, cleaned and disinfected to prevent the spread of disease from one flock to another. Any repairs or improvements to the facilities, including lighting retrofits, would be made between flocks in an empty barn to address logistical and biosecurity concerns.

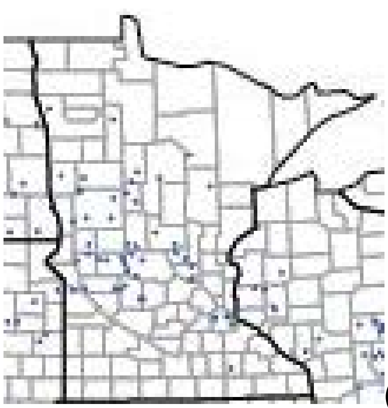
Lighting schedules for turkeys vary according to the sex, type of bird, season, and growing phase they are in. Table 4 below gives a generic picture of what a lighting schedule might look like for a turkey operation, with a more consistent lighting schedule used when birds are moved to the grow-out (or, finishing) barn.[8] Some farmers choose to employ differing lighting cycles such as an intermittent schedule or a "night light" in the last few weeks of grow-out.

Table 4: Typical Turkey Lighting Schedules

Stage of Poultry	Age	Minimum Light (Foot Candles)	Photo period (Light per Day)
Brooder (poults, both sexes)	0-3 days	9-10 fc	22-24 hours
	3-9 days	3-5 fc	16-22 hours
Grow out (Hens)	9 days and on	1-3 fc	16 hours
Grow out (Toms)	9 days and on	1-3 fc	16 hours

Chicken Broiler Production in Minnesota

As of 2012, Minnesota was ranked 20th in the country for broiler chicken production[9], and is home to Gold'n Plump Poultry and over 300 chicken farmers statewide. Much like the turkey industry, the majority of the broiler chicken production is located in the central counties of the state (**Error! Reference source not found.**).


(Source: National Agricultural Statistics Service 2007)

[8] Each producer involved in this project has adjusted the typical lighting schedule based on their farming experience and individual situation in order to optimize their operation.

[9] USDA, National Agricultural Statistics Service, Broilers: Inventory by State, US, 2012, (last visited Dec. 11, 2013).

Figure 2: Chicken Broiler Production Distribution

Chicken producers, unlike turkey producers, have only one type of poultry barn on their farms. Typically, chicken producers use brooding rings that keep chicks close to a heat source, food and water in the first week or two of their lives. After that time, the brooder rings are removed and the adolescent chickens are given free access to the barn space. Often, chicks are not separated by sex, though some farmers may choose to separate the chicks to address the differing feeding needs and growth rates between male and female birds. Chickens reach their full maturity and weight faster than turkeys and have a shorter grow-out period and faster flock turnaround (Table 5). Typically, chickens are grown to seven weeks old and then are processed. Some chicken products, for example Cornish hens, are processed as early as 4 weeks.

Table 5: Chicken Grow Out Periods

Type of Poultry	Time in Brood	Time in Grow-Out	End Market Weight
Broilers	10-14 days	2 to 7 weeks	~5 lbs.

After a flock leaves the farm for processing, the barn is cleaned thoroughly and disinfected to minimize disease transfer to any new flocks. It is not uncommon to receive the next flock of chicks within a week to two weeks after cleaning, though this time period varies depending on market prices, grow-out rates, processing contracts, and the producer. In all, chicken producers typically raise six to eight flocks yearly.

A typical lighting schedule for broiler chickens does not vary drastically from turkey production, although the specific schedule a farmer uses may differ depending on the breed and grow-out times. Generally, long periods of light are provided in the early days of a flock to facilitate chick growth and activity, and lighting hours are tapered off during the mid-point growing period. Finally, the photo period is increased again just before processing. Much like turkey production, some producers run intermittent lighting schedules or a lighting plan based on a period other than 24-hours, called ahemeral lighting. Table 6 below is an example of a generic broiler chicken lighting plan.

Table 6: Typical Chicken Lighting Schedules

<table>
<tr><th>Type Stage of Poultry</th><th>Age</th><th>Minimum Light (Foot Candles)</th><th>Photo Period (Light per Day)</th></tr>
<tr><td rowspan="3">Broilers</td><td>0 to 3 days</td><td>2-3 fc</td><td>22-24 hours</td></tr>
<tr><td>3 days to 7 weeks
(4 weeks for early finish)</td><td>0.5-1 fc</td><td>12-20 hours</td></tr>
<tr><td>Or, 4-7 weeks (8 to 3 days before processing)</td><td>0.5-1 fc</td><td>20-24 hours</td></tr>
</table>

Egg Production in Minnesota

Minnesota was ranked eighth in the country for egg production as of 2012.[10] Notable egg production companies in Minnesota include Sparboe Farms Company, Michael Foods, Rembrandt Foods, Land 'O' Lakes, Cargill, and Mendelson Egg Company.

Pullets, the young female chicks that become laying hens, are delivered to the farm within one or two days of hatching. Then, pullets are raised in cages or in a pullet house until they are 17-18 weeks of age when they have attained a healthy body weight to support egg production. At 17-18 weeks, birds are moved to the laying house where each hen is kept in a laying cage (unless "free-ranged").

When a flock of hens enters the laying house, only approximately 10-20% of the hens are actually laying eggs. This number quickly peaks to 90% or more at approximately 30 to 32 weeks of age. After the peak, egg production diminishes to about 50% at 60 to 70 weeks. At that time, the producer may choose to molt the flock[11] in order to rejuvenate egg laying rates. The laying rate ceases during molting. Approximately 10 weeks later, the flock returns to a 50% laying rate which ultimately increases to 80%. This new peak is short-lived, however, and the flock drops back to 50% production at 100 to 110 weeks (Table 7). At that point the flock could be molted a second time if the producer chooses. At any of the molting stages, the producer may choose to retire the flock to a spent hen facility for processing. While the laying house is vacant, it is cleaned and sanitized and the producer readies for a new batch of layers. The cleaning period between flocks is similar to that of broiler and turkey production though less frequent given the longer lifespan of egg-laying hens.

Table 7: Typical egg laying production cycle

Type of Poultry	Time in Pullet House	Time in Laying House
Pullets/Layers (Hens)	Up to 17-18 weeks old	18-80 weeks old; up to 100-130 weeks if molted

The lighting schedule for egg layers depends on the breed of the hen, particularly in the pullet stage. Much like poultry grown for meat consumption, the chicks are exposed to long periods of light in the beginning to encourage feeding and growth. For pullets, the long periods of light are incrementally decreased week by week until pullets are about 16 weeks old. Then, the photo period is again increased to cue sexual maturation in the chickens. At about 18 weeks old, when the birds are mature and moved to the laying house, the light is incrementally increased to a more consistent schedule of 15 to 16 hours of light per day. This schedule continues through the egg production cycle. In the case of molting, a producer can induce the flock to molt by decreasing the amount of light and restricting food for a set "fast period," thus mimicking winter. Then, the photo period length is increased again (as with spring)

[10] American Egg Board, Egg Industry Facts Sheet, (last visited December 12, 2013).

[11] Induce molting (shedding of feathers) by reducing feed and/or reducing light.

and the birds will start laying eggs once more. Table 8 below gives a general example of a lighting schedule for egg laying operations.

Table 8: Typical egg laying lighting schedule

Stage of Poultry	Age (Weeks)	Minimum Light (Foot Candles)	Photo period (Light per Day)
Pullets	0-2 weeks	1-3 fc	16-22 hours, decreasing by increments each week
	2-14 weeks	1-3 fc	8-16 hours, decreasing by increments each week
	15-17 weeks	1-3 fc	8-12.5 hours, lowest photo period
Layer Hens	18-24 weeks	0.5-2 fc	8-16 hours, increasing by increments each week
	24 weeks and onward	0.5-2 fc	15-16 hours
Molting Layer Hens	70-80 weeks and 100-110 weeks	0.5-2 fc	8-12.5 hours, decreasing to lowest photo period and back
	80-100 weeks and 110-130 weeks	0.5-2 fc	15-16 hours

Summary of Poultry Production

Table 9 below gives a range of estimates of the length of time producers keep their flocks in a particular barn as well as the number of flock rotations. Please note the timelines in this report are provided for mere guidance. Each farmer makes an individual judgment informed by experience and measurement about when a flock is ready to move into a new production stage, including a different barn.

Table 9: Summary of Poultry Production Schedules and Estimated Cycles*

Type of Poultry	Barn Type	Brooding		Grow out		Rotation		Cycles / year	
		Min	Max	Min	Max	Min	Max	Min	Max
Turkey	Brooder	6	8	--	--	1	2	5.2	7.4
Turkey	Hens (female)	--	--	11	15	1	2	4.3	3.1
Turkey	Toms (male)	--	--	12	25	1	2	1.9	4.0
Chicken	Broilers	0.7	2	2	7	1	2	5.8	17.3
Chicken	Eggs - pullet	17	18	--	--	1	2	2.6	2.9
Chicken	Eggs - layer w/o molt	--	--	18	80	1	2	0.4	0.64
Chicken	Eggs – layer with molt	--	--	18	130	1	2		

*All times in weeks.

Poultry Contract Production, Vertical Integration and Energy Efficiency

Over the decades, the poultry industry has made large strides in growing and processing efficiency. In earlier times, farmers raised poultry from eggs through the finishing cycle, which left barn facilities out of use as producers moved flocks individually from one stage of production to another. Over time, the hatcheries, production stages, and processing became separate businesses and operated in separate though sometimes overlapping markets. Nonetheless, inefficiencies were still plentiful. By the 1940s and 1950s, "integrators" began combining these businesses in order to reduce costs by coordinating the timing of production and processing capacity to maximize barn use and production. Now most farmers have a ratio of brooder and finishing barns that allows them to continually rotate flocks through their farm and onto a processing facility. Further, some farmers specialize in a particular growth phase of the poultry industry. Today, the majority of the poultry industry is grown under production contract between independent farmers and corporate processors in detailed coordination.[12]

In poultry contract growing, the farmer provides the barns, electricity, labor, and equipment, and the contracting processor provides the poults, feed and, depending on the contract terms, may also provide veterinary services, managerial assistance and heating fuel. Farmers may receive a payment bonus if their production costs are less than the average production costs of other farms under contract with the corporate processor. As this relates to CIPs, it is important to understand the degree of incentive a producer has for upgrading their lighting system or equipment. If a farmer bears the business costs of electricity directly under a poultry contract, obviously he has a greater incentive to save energy.

LED Agricultural Lighting as an Energy Efficiency Option

In Minnesota, most poultry facilities are located in the service territories of rural electric cooperatives or rural municipalities. These electric utilities are challenged with finding energy savings opportunities because of the relatively small number and size of consumers in their service territories. Achieving economies of scale in terms of energy savings is more difficult in comparison to larger municipal and investor-owned utilities with larger populations and manufacturing facilities in concentrated areas. Several Minnesota communities have had success with LED technology, for example, by employing LED street lamps to capture significant savings. Additionally, several studies on LED lighting in poultry and dairy barns and greenhouses – facilities regularly found in rural communities – have taken place around the country. Given these examples, advances in LED technologies, and Minnesota's large poultry industry, testing LED lighting in poultry facilities made sense as an energy efficiency option for Minnesota agriculture.

Previous research on LED lighting in poultry facilities examined broiler chicken farms in southern states under different environmental circumstances. The southern broiler chicken studies may not have had

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[12] National Chicken Council, Vertical Integration: What it is, and why it's good for the chicken industry…and you, (last visited Dec. 12, 2013). *See also* USDA, Economic Research Service, Evolution of Vertical Coordination in Poultry, Egg and Pork Industries

much relevance in a cold-climate state like Minnesota or in the context of turkey production. This pilot project served to demonstrate lamp durability, cost-effectiveness, and replicability for the poultry industry and electric utility businesses typical of rural central Minnesota. Providing on-the-ground, observable examples of LED lighting technology should encourage farmers and utilities to consider upgrading to LED technology as a way to facilitate production savings for farmers and achieve energy savings.

Other LED Lighting Projects in Agriculture

Several publicly funded studies on LED lighting in poultry facilities have already taken place. These studies are indicative of the poultry industry's interest, yet hesitancy to adopt new technologies.

University of Arkansas System's Division of Agriculture

In January 2010, the University of Arkansas System's Division of Agriculture's Poultry Science Department and the Arkansas Resource Conservation District Council were awarded a grant from the Arkansas Energy Office. This study sought to demonstrate whether existing incandescent lamps, cold cathodes and dimmable CFLs in broiler chicken facilities could be replaced by LED lighting technology. This study examined broiler chicken performance and LED lamp durability, and also measured energy savings for growers. The University of Arkansas tested three kinds of CFLs and three kinds of LED lamps on twenty participating broiler farms. At least two of the LED lamps tested proved to be energy efficient and optimal for broiler chicken performance. Additionally, the lamps were durable under typical barn conditions. Researchers concluded that LED technology at the time (November 2010) was better than existing energy efficient lighting technology (CFLs) and anticipated ready adoption of LED lighting technology. For further reading, the report, "Field Demonstration of Advanced Lighting Technologies for Poultry Houses Phase I Summary Update," is listed in the Additional Resources section.

University of Georgia, College of Agricultural & Environmental Sciences

In 2012, the University of Georgia began a privately funded, publicly researched lighting study to test four different LED lamps on one commercial broiler farm and one pullet farm. This study emphasized the quality of LED light, including the light intensity, lumen depreciation, and light distribution. It also compared LED lighting to CFL and incandescent lighting. This study found LED lamps saved 70 percent on power usage compared to incandescents and 30 percent power savings when compared to CFLs. No LED lamps were replaced during the first year of testing, whereas 90 percent of incandescent lamps required replacement during the same period. The project, "Evaluating LED Light Bulb Performance in Broiler Housing," is listed in the Additional Resources section.

University of Delaware, Animal and Food Science Department

The University of Delaware began an "applied poultry research" project to evaluate LED lighting technologies for poultry houses at the start of 2013. This one-year study is examining the mean time to lamp failure; light intensity drop-off; and energy efficiency of LED, CFL and cold cathode lamps. Results from this study are not yet available because it has not run to completion. More information on the study may be found by contacting Dr. Eric Benson through the University of Delaware's College of Agricultural Resources and Natural Resources' Bioresources Engineering Department (302) 831-2501.

Additional Studies

The LED lighting industry has funded many reports, case studies, and white papers independently. Next Gen Illumination, Inc. (NGI) [13] and SWITCH Lighting Company [14] have funded research on their own lights. The Journal of Poultry Science recently published a Brazilian study on broiler performance under LED lamps[15] and a Swiss study on egg-laying productivity under colored LED lamp.[16] Results from the Brazilian study indicated that chickens did not show a preference for white over yellow LEDs though feed conversion was slightly better under white LEDs and chickens under LEDs had better performance (feed efficiency, reduced mortality, and weight gain) than under CFL lamps. The Swiss study demonstrated minor effects of green LED light on explorative behavior in laying hens and that red LED light reduced aggression compared to white LED light. Additionally, red LED light accelerated sexual development in laying hens.

Project Description and Objectives

Project Description

This project began in late spring 2011. After recruiting and confirming relationships with poultry farmers that demonstrated an interest in LED technology, the project team recorded energy use of pre-installation lighting equipment in research site barns. After gathering sufficient baseline data, the producers rewired barns, if necessary, and/or simply replaced old lamps with appropriate LED lamps. Electrical rewiring and/or lamp replacements coincided with cleaning periods between flocks when the barns were empty. During the later months of the project, the project team quantified energy savings (kilowatt-hours) by calculating the anticipated pre- and post-install energy consumption. Practical performance of the LED lamps was determined qualitatively by speaking with producers on a regular basis to learn of lamp failures, changes in bird performance, and barn operations under the new lamps.

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[13] Next Gen Illumination, Inc., Independent Testing of LED Lights in Broiler Houses (White Paper), (last visited Dec. 17, 2013).

[14] SWITCH Lighting Company, Jakes Poultry Company in British Columbia, switches to Switch 75 LED bulbs for more light and lower energy bills, (last visited Dec. 17, 2013).

[15] Mendes A.S., S..J. Paixão, R. Restelatto, G.M. Morello, D.J. de Moura and J.C. Possenti, Performance and preference of broiler chickens exposed to different lighting sources, J. Appl. Poult. Res. 22(1):62-70 (2013), doi: 10.3382/japr.2012-00580

[16] Huber-Eicher B., A. Suter and P. Spring-Stahli, Effects of colored light emitting diode illumination on behavior and performance of laying hens, 2013, J. Appl. Poult. Sci. 92(4): 869-873. doi. 10.3382/ps. 2012-02679.

Project Objectives

This project served to demonstrate the effectiveness of early commercial LED lamps as a potential measure in the rural electric utility CIP portfolios to help them attain their energy conservation goals. Primary objectives included:

- Demonstrating energy savings by recording and reporting pre- and post-retrofit energy consumption
- Investigating the cost-effectiveness of LED lights designed for poultry facilities
- Providing on-the-ground, observable examples of LED technology designed for harsh agricultural environments in Minnesota (durability)
- Examining whether LED technology would affect bird productivity
- Identifying program design considerations for utility conservation programs

Light in Poultry Production

A properly lit barn enables poultry to live in an optimum growing environment free from crowding, [17] and allows farm workers to carry out their work efficiently. A well-designed lighting system also offers the potential for increases in production according to the bird's biological responses to changes in three main qualities: duration, intensity, and color. For example, decreasing the length of light in a day – as naturally happens in the autumn and winter – changes circadian rhythms and stimulates an adolescent bird to sexual maturity.

Significant academic research on poultry lighting notes the potential for production gains related to exposing poultry to different colors throughout the growing cycle.[18] This production potential relates to broader light spectrum perception in fowl through multiple receptors. Poultry have retinal photoreceptors in their eyes, pineal photoreceptors in their pineal glands on the top of their brain near the surface of their skin, and encephalic receptors in the hypothalamus of their brains. Poultry research indicates red and green hues increase growth rate at early ages, while blue hues increase growth rates at later ages and decrease incidences of cannibalism.

Light can be measured in terms of efficacy as well as power. A measure of efficacy is illuminance: the quality of light at a surface in lumens per unit of area. This measurement is taken in foot-candles or lumens per square foot (Lm/ft^2). Efficacy is a more accurate measure of light, but for purposes of familiarity, it is regularly stated as "watt equivalent" so as not to confuse consumers. For more

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[17] Birds generally 'flock' to areas of light. Where 'spotlighting' exists in barns due to uneven lighting conditions, birds will group in the most lighted areas, and often overcrowd one another.

[18] *See, for example:* Prayitno, Phillips, Stokes. "The effects of color and intensity of light on behavior and leg disorders in broiler chickens. Poult Sci. 1997 Dec; 76(12): 1674-81. *See Also:* Cao, Liu, Wang, Xie, Jia, Chen. "Green and Blue Monochromatic Lights Promote Growth and Development of Broilers Via Stimulating Testosterone Secretion and Myofiber Growth." J. Appl. Poult. Res. Summer 2008. Vol. 17, no. 2, 211-218

information on light measurement and comparing LEDs, CFLs and incandescent lamps, please visit the Clean Energy Resource Teams "Right Light Guide".

This project team installed LED lamps from project partner and LED lamp manufacturer Once Innovations of Plymouth, Minnesota. Once Innovations' LED lamps were specifically designed to shift the color spectrum emitted by the fixture as the light was dimmed, in addition to reduce the light intensity. While not an objective of this study from the outset, the color-dimming feature allowed for farmers to test for any gains in poultry production by reaching a broader light spectrum.

Table 10 outlines Once Innovation's poultry lighting products available to farmers at the time this project began and the applications for which they were designed.

Table 10: Once Innovations Lamp Types

Poultry Type	Once Innovations Lamps	Energy Use (watts)
Turkey and Broiler	AgriShift® PL Dim-to-Blue (Primary Light Source)	12
	AgriShift® FL (Feed Pan Light)	3
Egg Layers	AgriShift® PLE Dim-to-Red® (Primary Light Source)	12
	AgriShift® EL (Cage Lighting)	3

This pilot project was designed to outfit whole poultry barns for field-testing and tested the AgriShift® PL Dim-to-Blue® 12-watt fixtures and the AgriShift® PLE Dim-to-Red® 12-watt fixtures. Though offered to producers, the AgriShift® FL (Feed Pan Light) 3-watt fixtures and AgriShift® EL (Cage Lighting) 3-watt fixtures were not tested under this pilot because these applications occur in specific locations in poultry barns and would not have produced adequate data for a whole-barn lighting study.

Unlike most high pressure sodium and incandescent lamps, which produce light in only a small section of the color spectrum, Once Innovations' LED lamps produce light with a broader color spectrum. The LED lamps also produce some light that is observable by a bird, though not by a human. For example, Once Innovations' AgriShift PL produces a luminous flux of 840 lumens to the eye of poultry and 530 lumens to the eye of humans. That is, a Once Innovation lamp is producing sufficient amounts of light for poultry, some of which is not observable to the human eye. For this reason, a few farmers chose to keep some of the HPS or CFL fixtures on different switches after the lighting retrofit for employees to be able to see clearly.

Several farmers adjusted daily lighting schedules with the new AgriShift LED lamps. Many farmers took advantage of the dimming features, as will be described in the next sub-section, which slightly adjusted (increased or decreased) the amount of total lighting in a year, depending upon how dimming techniques were employed.

Methodology and Energy Savings Analysis

Information about pre- and post-retrofit flock cycle operations, lighting schedules, and lighting system energy consumption were used to estimate annual energy savings. Cost of project and subsidies were also used to estimate simple and net payback periods. A complete discussion of the methodology is included in Appendix A.

Results

Project Participants

The project team installed LED lamps in 22 barns across 12 producers (Table 11). No participating farmer in this pilot attributed a measurable production decrease due to use of the LED technology. Though beyond the scope of this project, many farmers observed positive changes in bird behavior: improved feed conversion (the ratio of feed consumed to bird weight gain) and calmer birds.

Table 11: Overview of Participating Producers

Site	Production	Barn Type	Utility	Utility Rebate
Flying C Farms	Turkey	Grow/Finish	Xcel Energy	No
Zimmerman Farms	Turkey	Grow/Finish	Steele-Waseca Cooperative Electric	Yes; covered rewiring costs
Lakewood Turkeys	Turkey	Grow/Finish	Meeker County Electric Cooperative	No
R&L Turkeys	Turkey	Grow/Finish	Alexandria Light & Power	Yes; rebate per fixture
Langmo Farms	Turkey	Grow/Finish	Kandiyohi Power Cooperative	Yes; rebate per fixture
Gorans Bros.	Turkey	Grow/Finish	Kandiyohi Power Cooperative	No
Evelo Farms	Turkey	Brood	Lake Region Electric Cooperative	No
D. Buysse Farm	Turkey	Brood	MN Valley Electric Co-op	No
P & J Turkeys	Turkey	Brood	Roseau Electric Cooperative	Yes; rebate per fixture
Life Science Innovations	Turkey	Brood	Kandiyohi Power Cooperative	Yes; rebate per fixture
Sparboe Eggs	Chicken	Egg-layer	Willmar Public Utilities	No
Life Science Innovations	Chicken	Egg-layer	Kandiyohi Power Cooperative	Yes; rebate per fixture

Results of LED Installations in Grower/Finisher Barns

Flying C Farms

Flying C Farms, the first producer to sign up for the pilot project, had two finishing barns participating in this pilot project. The pilot project installed 290 AgriShift 12-watt, blue-hued LED lamps in Flying C's two finishing barns. Evenly divided between the two barns, the LED lamps replaced 40 - 190-watt HPS fixtures (including 40-watt ballasts). Flying C Farms also installed a dimmer control in each of the barns to take advantage of the dimming capability of the Once Innovations lamps.

Midway thought the project, Flying C Farms installed a light curtain system (a translucent polyethylene plastic curtain with insulation features) to take advantage of natural light as part of a farm operational change. Though the light curtain installation significantly reduced the lighting hours for Flying C Farms, it also altered the before and after calculations for energy savings from the LED lamps. Flying C Farms now only turns its lights on approximately six hours per day when flocks are in the barns. For the purpose of this analysis, we ignore the effect of the light curtain system and assume that the post-retrofit lighting hours are the same as the pre-retrofit hours. Theoretical calculated energy savings results are shown in Table 12.

Table 12: Calculated Energy Savings Results for Flying C Farm

Pre-Retrofit System				Post-Retrofit System				Energy Savings
Type	**No.**	**Watts**	**kW**	**Type**	**No.**	**Watts**	**kW**	**kWh**
HPS	40	190	7,600	LED	290	12	3,480	
System (kW)			7,600	System (kW)			3,480	
Annual Hours			4,525.5	Annual Hours			4525.5*	
System (kWh)			**34,394**	**System (kWh)**			**15,749**	**18,645**

* Held constant despite reduction of lighting hours due to light curtain installation

Durability and program design observations:

- Six lamps out of 290 bulbs failed and were replaced under warranty.
- This producer saved a significant amount of money on labor costs during the rewiring of the barns with the assistance of a family member who is a licensed electrician.

Zimmerman Farms

Zimmerman Farms outfitted four finishing barns under this project with 204 AgriShift 12-watt, blue-hued LED lamps. The LED lamps replaced primarily incandescent lamps and some high pressure sodium fixtures. Zimmerman Farms utilized the lighting upgrade to replace deteriorating wiring and fixtures with the assistance of a $3500 Steele-Waseca Electric Cooperative rebate. Proprietor John Zimmerman and his staff rewired each of the barns with new conduit wiring and fixtures.

In the summer of 2012, Zimmerman Farms experienced a lightning strike that knocked out approximately 10 LED lamps. Once Innovations replaced these lamps under warranty and Zimmerman Farms introduced a surge protector as well. Calculated energy savings results are shown in Table 13.

Table 13: Calculated Energy Savings for Zimmerman Farms

Pre-Retrofit System				Post-Retrofit System				Energy Savings
Type	**No.**	**Watts**	**kW**	**Type**	**No.**	**Watts**	**kW**	**kwh**
HPS	24	190	4,560	LED	240	12	2,880	
Incandescent	80	100	8,000					
System (kW)			12,560	System (kW)			3,480	
Annual Hours			4,256	Annual Hours			4,256	
System (kWh)			**53,455**	**System (kWh)**			**12,257**	**41,198**

Durability and program design observations:

- Approximately 11 lamp failures out of 240 lamps since November 2011. 10 failures were solely due to a lightning strike in the summer of 2012. One additional lamp failed for unknown reasons. Lamps were replaced under warranty.
- No measurable change in poultry production.
- LED installation coincided with this farmer's need to upgrade aging electrical infrastructure for barn safety. Additionally, this farmer had been experimenting with LED technology prior to this project and was considered an "early adopter" in relation to other producers.
- Adding a surge protector for a small amount of money (i.e. $100) appears to be a worthwhile investment to protect thousands of dollars in lighting equipment for barn facilities that are exposed to the elements.

Lakewood Turkeys

Lakewood Turkeys placed LED lamps in one of its finishing barns under this project. Previously, Lakewood had already converted 58 CFL lamps to 52 LED lamps with 6 CFL lamps remaining in the subject barn. Lakewood was interested in increasing its light levels in this barn with more LED lamps, and, after hearing of the pilot project, decided to install 52 more LED lamps. In brief, the Lakewood Turkey finishing barn upgraded from 52 LED lamps and 6 CFL lamps to 104 LED lamps with 6 CFL lamps. Lakewood Turkeys introduced a small change in its lighting scheduling by using the "sunrise/sunset" feature of the LED lamps, resulting in a small reduction in annual run time. Calculated savings are shown in Table 14.

Table 14: Calculated Energy Savings from Lakewood Turkeys

Pre-Retrofit System				Post-Retrofit System				Energy Savings
Type	No.	Watts	kW	Type	No.	Watts	kW	kWh
LED	52	12	624	LED (new)	52	12	624	
CFL	58	23	1,334	LED (existing)	52	12	624	
				CFL (existing)	6	23	138	
System (kW)			1,958	System (kW)			1,386	
Annual Hours			3,475.5	Annual Hours			3,186.7	
System (kWh)			**6,805**	**System (kWh)**			**4,417**	**2,388**

Durability and program design observations:

- No reported lamp failures under this project though occasionally a lamp vibrated loose due to a passing freight train.
- Lakewood Turkey was disappointed with the light levels under its previous LED installation and chose to double the number of LEDs to achieve the desired light levels. This instance highlights the importance of measuring lumens to achieve the proper light levels and not relying on simple 1:1 bulb exchanges.

R & L Turkeys

R & L Turkeys, located near Alexandria, MN, made 1-to-1 lamp replacements of 100-watt incandescent bulbs with 12-watt Agrishift red-hued LED lamps from Once Innovations in one of its finishing barns. Table 15 summarizes calculated savings results.

Table 15: Calculated Energy Savings from R&L Turkeys

Pre-Retrofit System				Post-Retrofit System				Energy Savings
Type	No.	Watts	kW	Type	No.	Watts	kW	kWh
Incandescent	52	100	5,200	LED	52	12	624	
System (kW)			5,200	System (kW)			624	
Annual Hours			6,074.25	Annual Hours			6,074.25	
System (kWh)			**31,586**	**System (kWh)**			**3,790**	**27,796**

Durability and program design observations:

- 2 lamps out of 52 failed since June 2012 and were replaced promptly under warranty.
- R & L Turkey employees had difficulty adjusting to the light levels in the barn in order to conduct daily chores. According to staff, the LED lamps are directional and little light reflects around the facility, which made for low ambient light levels and some darker areas of the barn, causing birds to crowd together. The uneven lighting did not affect bird production. This producer suggested the LED lamps were better suited to a narrower barn, or might require an additional row of lights to address dark areas.

- When birds were ready to be moved to the processing facility, employees have had some trouble getting the birds to move out of the barns because of the difference between the red-hued LED fixtures and daylight.

Langmo Farms

Langmo Farms, headquartered in Litchfield, MN replaced all 175 of its 75-watt incandescent lamps with Once Innovations' 12-watt Agrishift, blue-hued LED lamps in a 1:1 exchange in three of its finishing barns. Table 16 displays calculated savings based on the 100% LED lamp replacement scenario.

Table 16: Calculated Savings Results for Langmo Farms

Pre-Retrofit System				Post-Retrofit System				Energy Savings
Type	**No.**	**Watts**	**kW**	**Type**	**No.**	**Watts**	**kW**	**kWh**
Incandescent	175	75	13,125	LED	175	12	2,100	
System (kW)			13,125	System (kW)			2,100	
Annual Hours			3,318	Annual Hours			3,318	
System (kWh)			**43,549**	**System (kWh)**			**6,968**	**36,581**

Durability and program design observations:

- Approximately 35 of 175 lamps failed since June 2012. All lights were replaced under warranty. Langmo Farms reported a suspected defect as the cause of the failures.
- Langmo Farms reported that bird production was adequate under the new LED lamps. Nonetheless, staff had concerns that areas of the barns were not sufficiently lit. Staff occasionally switched out LED fixtures for 75-watt incandescent lamps during darker months to avoid bird clustering.

Gorans Brothers, Inc.

Gorans Brothers, Inc., located near Blomkest, Minnesota in Kandiyohi County is testing the LED lamps in one of its finishing barns. Gorans Brothers has been impressed with the energy savings, though staff had some concerns about the light levels though management reported no measurable change in production. Savings calculations are shown in Table 17 below.

Table 17: Calculated Savings Results for Gorans Brothers, Inc.

Pre-Retrofit System				Post-Retrofit System				Energy Savings
Type	No.	Watts	kW	Type	No.	Watts	kW	kWh
CFL	39	23	897	LED	39	12	468	
System (kW)			897	System (kW)			468	
Annual Hours			3,633	Annual Hours			3,885	
System (kWh)			**3,259**	**System (kWh)**			**1,818**	**1,441**

Durability and program design observations:

- Gorans Brothers, Inc. reported no lamps had failed since they were installed in March 2012.
- Gorans Brothers installed a dimmer and dimed the LED lamps down to 10% overnight to rest its flocks; the LED lamps are never fully turned off. In addition, Gorans Brothers changed its lighting schedule post-install to add approximately an hour of daily "sunrise/sunset" via a dimmer control.

Results of LED Installations in Brooder Barns

Evelo Turkey Farms

Evelo Turkey Farms, based near Rothsay, Minnesota, tested the LED lamps in one of its brooder barns by replacing incandescent lamps. Evelo Turkey Farms appreciated the energy savings from switching out its 100-watt incandescent lamps (Table 18).

Table 18: Calculated Savings Results for Evelo Turkey Farms

Pre-Retrofit System				Post-Retrofit System				Energy Savings
Type	No.	Watts	kW	Type	No.	Watts	kW	kWh
Incandescent	40	100	4000	LED	40	12	480	
System (kW)			3920	System (kW)			480	
Annual Hours			3,920	Annual Hours			3,920	
System (kWh)			**15,680**	**System (kWh)**			**1,882**	**13,798**

Durability and program design observations:

- Evelo Farms did not report any lamp failures since the June 2012 retrofit.
- Evelo Turkey Farms did not report any operational changes.

Dennis Buysee Farm

Dennis Buysse was the project's first producer to install LED lamps in a brooder barn. Originally, Buysse's brooder barn contained 72 CFL lamps. In mid-2011, however, Buysse's brood barn burned down and was rebuilt. After learning of the pilot project from the manager of a nearby electric cooperative utility, Buysse decided to install half CFL and half LED lamps in the reconstructed brood barn. Calculated savings are displayed in Table 19.

Table 19: Calculated Savings for Dennis Buysee Farm

Pre-Retrofit System				Post-Retrofit System				Energy Savings
Type	**No.**	**Watts**	**kW**	**Type**	**No.**	**Watts**	**kW**	**kWh**
CFL	72	26	3,312	LED	36	12	432	
				CFL (existing)	36	26	936	
System (kW)			3,312	System (kW)			1,368	
Annual Hours			7,448	Annual Hours			7,448	
System (kWh)			**13,943**	**System (kWh)**			**10,189**	**3,754**

Durability and program design observations:

- Buysse Farms did not report any lamp failures since the April 2012 retrofit.
- Buysse Farms switched out half of its CFL lamps for LED lamps. Each type of lamp is on a different switch giving it the option to easily alter its lighting in the future.

P & J Turkeys

P & J Turkeys, in the far north near Roseau, MN, installed LED lamps in a newly constructed brooder barn. We calculated energy savings compared to a baseline lighting system of 43-watt halogen fixtures (Table 20). This methodology is consistent with how CIP administrators would report energy savings to the Minnesota Department of Commerce for lighting measures in new construction applications since the enactment of the 2007 Energy Independence and Security Act.

Table 20: Calculated Savings for P & J Turkeys

Pre-Retrofit System				Post-Retrofit System				Energy Savings
Type	**No.**	**Watts**	**kW**	**Type**	**No.**	**Watts**	**kW**	**kWh**
Halogen	120	43	5,160	LED	120	12	1,440	
System (kW)				System (kW)			1,440	
Annual Hours			6,566	Annual Hours			6,566	
System (kWh)			**33,881**	**System (kWh)**			**9,455**	**24,426**

Durability and program design observations:

- P & J Turkeys has not reported a lamp failure since its December 2012 retrofit.
- P & J Turkeys dims its lights to 10% output during the resting period; the lamps are never fully off.

Life Science Innovations (LSI) – East Fransen Brooder Barn

Life Science Innovations (LSI), a mainstay of the Minnesota turkey industry, replaced 60 - 60-watt lamps in one of its brooder barns with 12-watt LED lamps. LSI rewired a portion of this barn for the installation. Additionally, LSI altered its post-install schedule to leverage the sunrise/sunset and dimming features of the LED lamps and now runs its lights at 50% capacity when they are fully “on”. This practice resulted in even larger energy savings (Table 21).

Table 21: Calculated Savings for LSI East Fransen Brooder Barn

Pre-Retrofit System				Post-Retrofit System				Energy Savings
Type	**No.**	**Watts**	**kW**	**Type**	**No.**	**Watts**	**kW**	**kWh**
Incandescent	60	60	3,600	LED	60	12	720	
System (kW)			3,600	System (kW)			720	
Annual Hours			4,258	Annual Hours			2,753.5	
System (kWh)			**15,329**	**System (kWh)**			**1,983**	**13,346**

Durability and program design observations:

- LSI has not reported any lamp failures.
- LSI reported that the directional nature of the LED fixtures can make it difficult for staff to see and perform their tasks.
- LSI suggested a longitudinal study to determine whether the lights measurably increase poultry production.

Life Science Innovations (LSI) – West Fransen Brooder Barn

LSI constructed a new, twin barn next to the East Fransen brooder barn and opted to install LED lamps as a part of the construction. This barn operates under the same lighting schedule as the post-install East Fransen Barn. Similar to P & J Turkeys, a baseline of 43-watt halogen fixtures was assumed based on the effect ofthe 2007 Energy Independence and Security Act (Table 22).

Table 22: Calculated energy savings for LSI West Fransen Barn

Pre-Retrofit System				Post-Retrofit System				Energy Savings
Type	**No.**	**Watts**	**kW**	**Type**	**No.**	**Watts**	**kW**	**kWh**
Halogen	60	43	2,580	LED	60	12	720	
System (kW)			2,580	System (kW)			720	
Annual Hours			4,258	Annual Hours			2,753.5	
System (kWh)			**10,986**	**System (kWh)**			**1,983**	**9,003**

Durability and program design observations:

- LSI has not reported any failed lamps at the West Fransen Barn.

- LSI reported that the directional nature of the LED fixtures can make it difficult for staff to see and perform their tasks.

Life Science Innovations (LSI) – Brooder-Breeder Barns

LSI installed LED lamps in two brooder-breeder barns, the Diamond and Westbrook Barns. A brooder-breeder barn is a facility that lays turkey eggs to hatch into turkey poults for sale to independent turkey farmers in the region. The barns had similar pre-retrofit lighting systems consisting of HPS lamps and incandescent lamps. LSI replaced the incandescent lamps with LED lamps and kept the HPS fixtures in place in both barns. The pre- and post-install lighting schedules for these facilities did not change. Calculated savings for both facilities are shown in Table 23 and Table 24.

Table 23: Calculated energy savings for LSI Westbrook Barn

Pre-Retrofit System				Post-Retrofit System				Energy Savings
Type	**No.**	**Watts**	**kW**	**Type**	**No.**	**Watts**	**kW**	**kWh**
HPS	35	190	6,650	HPS (existing)	35	190	6,650	
Incandescent	24	60	1,440	LED	48	12	576	
Incandescent	24	100	2,400					
System (kW)			10,490	System (kW)			7,226	
Annual Hours			4,356	Annual Hours			4,207	
System (kWh)			**45,694**	**System (kWh)**			**30,401**	**15,293**

Table 24: Calculated Energy Savings for LSI Diamond Barn

Pre-Retrofit System				Post-Retrofit System				Energy Savings
Type	**No.**	**Watts**	**kW**	**Type**	**No.**	**Watts**	**kW**	**kWh**
HPS	30	190	5,700	HPS (existing)	30	190	5,700	
Incandescent	134	60		LED	134	12	1,608	
			8,040	System (kW)			7,308	
System (kW)			13,740					
Annual Hours			4,356	Annual Hours			4,207	
System (kWh)			**59,851**	**System (kWh)**			**30,746**	**29,105**

Durability and program design observations:

- LSI did not report any failed lamps in the brooder-breeder barns.
- LSI did not report any operational changes.

Results of LED Installations in Egg-laying Barns

Sparboe Egg Farms

Sparboe Egg Farms, located near Litchfield, MN, was the first chicken egg producing facility to test LED lamps under this project. Calculated savings are displayed in Table 25.

Table 25: Calculated energy savings for Sparboe Egg Farms

Pre-Retrofit System				Post-Retrofit System				Energy Savings
Type	No.	Watts	kW	Type	No.	Watts	kW	kWh
CFL	310	13	4,030	LED	310	12	3,720	
System (kW)			4,030	System (kW)				
Annual Hours			5,171	Annual Hours			5,171	
System (kWh)			**20,839**	**System (kWh)**			**19,236**	**1,603**

Durability and program design observations:

- Sparboe reported two lamp failures since the July 2012 retrofit.
- Sparboe noted that the LED lamps attract flies. This is a minor problem that did not impact bird production.
- Sparboe compensated for the directional nature of the LED lamps by tilting the fixture extensions to avoid spotlighting.
- Sparboe noted that the LED lamps were easy to clean and that the birds appeared to be much calmer under the blue-hued LED lamps, which helps staff care for the birds.

Life Science Innovations (LSI) – Highland Egg-laying Barn

LSI replaced two types of high-pressure sodium lamps in its Highland egg-laying facility. LSI replaced 40 250-watt HPS lamps and 13 150-watt HPS lamps with 264 12-watt LED lamps. The Highland barn reduced the post-install lighting hours by employing a 45-minute sunrise/sunset period bookending their daily lighting periods. Table 26 displays savings estimates.

Table 26: Calculated Savings for LSI Highland

Pre-Retrofit System				Post-Retrofit System				Energy Savings
Type	No.	Watts	kW	Type	No.	Watts	kW	kWh
HPS	40	290	11,600	LED	264	12	3,168	
HPS	13	190	2,470					
System (kW)			14,070	System (kW)			3,168	
Annual Hours			4,942	Annual Hours			4,695	
System (kWh)			**69,534**	**System (kWh)**			**14,875**	**54,659**

Durability and program design observations:

- LSI has not reported any lamp failures at the Highland barn.
- At this facility, the new LED fixtures were wired in hexagon shaped clusters for even light distribution to replace the lighting area of the high-pressure sodium fixtures. After the retrofit, staff had some difficulty adjusting to the directional nature of the light: The light from the LED fixtures did not reflect off of the barn's high ceiling, resulting in low ambient light levels that made it difficult for staff to see.
- The resulting lower energy consumption due to the lighting retrofit from HPS to LED lamps allowed LSI to avoid an expensive utility line upgrade and the need to purchase a costly back-up generator in the case of a power outage.

Life Science Innovations (LSI) – Highway 40 West Egg-laying Barn

LSI replaced 44 250-watt high-pressure sodium lamps by rewiring the barn to fit 264 evenly distributed 12-watt blue-hued LED lamps. Table 27 shows calculated savings. The Highway 40 West barn reduced the post-install lighting hours by employing a 45-minute sunrise/sunset period bookending their daily lighting periods.

Table 27: Calculated Savings for LSI Highway 40 West

Pre-Retrofit System				Post-Retrofit System				Energy Savings
Type	No.	Watts	kW	Type	No.	Watts	kW	kWh
HPS	44	290	12,760	LED	264	12	3,168	
System (kW)				System (kW)			3,168	
Annual Hours			4,942	Annual Hours			4,695	
System (kWh)			**63,060**	**System (kWh)**			**14,875**	**48,185**

Durability and program design observations:

- LSI did not report any lamp failures at this barn.
- LSI Staff appreciate that the Highway 40 West barn has a white false ceiling that partially reflects the light of the LED lamps. The lower ceiling improves the ambient light levels which helps staff complete their tasks in the barn.
- LSI staff observed the egg-laying hens were much calmer under the blue-hued LED lamps, making insemination easier.

Summary of Energy Savings Results

Table 28 shows the energy use before and after the lighting retrofits. The difference in the energy use before and after the lighting retrofits is the annual energy savings, shown in kWh and percentage.

Table 28: Summary of Energy Savings for Participating Producers

Producer	No. of Barns	Barn Type	Lighting Changeout	Pre-Retrofit Annual Energy Use (kWh)	Post-Retrofit Annual Energy Use (kWh)	Annual Energy Savings (kWh)	Annual Energy Savings (%)
Lakewood Turkey	1	Turkey Finish	CFL to LED	6,805	4,417	2,388	35%
Gorans Bros. Turkey	1	Turkey Finish	CFL to LED	3,259	1,818	1,441	44%
Galaxy Farms	1	Turkey Brood	CFL to LED	4,508	2,352	2,156	48%
Sparboe Egg Farm	1	Egg-laying	CFL to LED	20,840	19,237	1,603	8%
Buysse Farm	1	Turkey Brood	CFL to LED/CFL	13,943	10,189	3,754	27%
Flying C Farms	2	Turkey Finish	HPS to LED	34,394	7,162	27,232	79%
WP Highway 40 West	1	Egg-laying	HPS to LED	63,060	14,875	48,185	76%
LSI/WP Highland	1	Egg-laying	HPS to LED	69,534	14,875	54,659	79%
LSI/WP Diamond	1	Turkey Brood	HPS/Incan to HPS/LED	59,851	30,746	29,105	49%
LSI/WP Westbrook	1	Turkey Brood	HPS/Incan to HPS/LED	45,694	30,401	15,293	33%
Zimmerman Farms	4	Turkey Finish	HPS/Incan to LED	53,455	12,257	41,198	77%
Evelo Farms	1	Turkey Brood	Incan to LED	15,680	1,882	13,798	88%
Langmo Farms	3	Turkey Finish	Incan to LED	43,549	6,968	36,581	84%
LSI/WP Old East Fransen	1	Turkey Brood	Incan to LED	15,329	1,983	13,346	87%
R & L Turkeys	1	Turkey Finish	Incan to LED	31,586	3,790	27,796	88%
LSI/WP New West Fransen	1	Turkey Brood	Halogen to LED[1]	10,986	1,983	9,003	82%
P & J Turkeys	1	Turkey Brood	Halogen to LED[1]	33,881	9,455	24,426	72%
Total Project				**526,353**	**156,716**	**314,708**	**63%**

1. Newly constructed barn; not a retrofit. Values were calculated by assuming lighting changed from halogen to LED.

Costs, Savings and Payback

The costs, energy savings, and simple payback for participating farmers varied according to the type of lamps replaced, rewiring costs, and lighting schedules. Farmers that replaced efficient CFL lamps with LED lamps had longer payback timelines. In contrast, most farmers who switched out incandescent lamps for LED lamps with no need for rewiring in order to maintain comparable light levels had very quick paybacks. Generally, farmers who switched out either incandescent or high-pressure sodium lamps for LED lamps had extremely attractive paybacks. The results, including any rebate subsidies from local electric utilities are summarized in Table 29 below.

Table 29: Summary of Savings, Costs and Payback

Producer	No. of Barns	Barn Type	Lighting Changeout	Energy Saved Annually (kWh)	Money Saved Annually[1]	Materials Costs[2]	Labor/ Other Costs[3]	Total Project Costs *[Materials + Labor]*	Simple Payback (years)[4]	Subsidies[5]	Utility Rebates	Total Incentives *[Subsidies + Rebates]*	Net Payback (years) *[with Total Incentives]*
Lakewood Turkey	1	Turkey Finish	CFL to LED	2,388	$258	$2,835	$2,400	$5,235	No Payback	$1,600	-	$1,600	14.1
Gorans Bros. Turkey	1	Turkey Finish	CFL to LED	1,441	$155	$2,931	$250	$3,181	No Payback	$1,976	-	$1,976	7.8
Galaxy Farms	1	Turkey Brood	CFL to LED	2,156	$233	$3,181	-	$3,181	No Payback	$2,181	-	$2,181	4.3
Sparboe Egg Farm	1	Egg-laying	CFL to LED	1,603	$173	$15,847	-	$15,847	No Payback	$12,572	-	$12,572	No Payback
Buysse Farm	1	Turkey Brood	CFL to LED/CFL	3,754	$405	$2,050	$250	$2,300	5.7	$1,075	-	$1,075	3.0
Flying C Farms	2	Turkey Finish	HPS to LED	27,232	$2,938	$19,350	$5,000	$24,350	8.3	$13,200	-	$13,200	3.8
WP Highway 40 West	1	Egg-laying	HPS to LED	48,185	$5,199	$9,240	Unknown	$9,240	1.8	$6,600	$1,320	$7,920	0.3
LSI/WP Highland	1	Egg-laying	HPS to LED	54,659	$5,898	$9,240	-	$9,240	1.6	$6,600	$1,320	$7,920	0.2
LSI/WP Diamond	1	Turkey Brood	HPS/Incan to HPS/LED	29,105	$3,140	$4,690	-	$4,690	1.5	$3,350	-	$3,350	0.4
LSI/WP estbrook	1	Turkey Brood	HPS/Incan to HPS/LED	15,293	$1,650	$1,680	-	$1,680	1.0	$1,200	$240	$1,440	0.1
Zimmerman Farms	4	Turkey Finish	HPS/Incan to LED	41,198	$4,445	$15,269	$3,500	$18,769	4.2	$10,469	$3,500	$13,969	1.1
Evelo Farms	1	Turkey Brood	Incan to LED	13,798	$1,489	$3,145	-	$3,145	2.1	$2,045	-	$2,045	0.7
Langmo Farms	3	Turkey Finish	Incan to LED	36,581	$3,947	$7,450	-	$7,450	1.9	$3,775	$1,750	$5,525	0.5
LSI/WP Old East Fransen	1	Turkey Brood	Incan to LED	13,346	$1,440	$2,100	-	$2,100	1.5	$1,500	$300	$1,800	0.2
R & L Turkeys	1	Turkey Finish	Incan to LED	27,796	$2,999	$2,690	$250	$2,940	1.0	$1,395	$1,366	$2,761	0.1
LSI/WP New West Fransen	1	Turkey Brood	Halogen to LED[6]	9,003	$971	$2,100	-	$2,100	2.2	$1,500	$300	$1,800	0.3
P & J Turkeys	1	Turkey Brood	Halogen to LED[6]	24,426	$2,636	$5,250	-	$5,250	2.0	$3,225	$840	$4,065	0.4
			Average:	**20,704**	**$2,234**	**$6,415**	**728**	**$7,100**	**2.7**	**$4,368**	**643**	**$5,012**	**2.3**
			Median:	**15,293**	**$1,650**	**$3,181**	**-**	**$4,690**	**1.9**	**$2,181**	**240**	**$2,761**	**0.5**

1. Assumes $0.1079/kWh electric rate.
2. Includes fixture and dimmer controls costs.
3. Includes the cost of hiring an electrician to perform install and may include some materials provided by electrician. Does not include producer staff time to perform simple bulb changeouts.
4. When payback exceeded the life of the LED lighting using the producer's annual hours of lighting operation, then no payback was possible.
5. Includes ONCE Innovation's (manufacturer) discount on the LED lighting, CARD grant farmer match, and discount on dimmer controls.
6. Newly constructed barn; not a retrofit. Values were calculated by assuming lighting changed from halogen to LED.

Discussion of Results

In general, this project was successful in achieving significant energy savings for participating poultry producers. Poultry-specific LED lighting offers promise for helping electric utilities to achieve their CIP energy savings goals. Some challenges remain regarding the practical implementation of LED lamps in poultry facilities, but the cost-effectiveness and maintenance of bird productivity make this technology an attractive investment for electric utilities and poultry producers.

Demonstrating Energy Savings and Cost-Effectiveness of Poultry-Specific LED Lamps

Producers participating in this project were lighting their barns at 100% light intensity for at least 12 hours a day. Almost uniformly, participating producers reported a decrease in their electrical consumption following the LED poultry lamp retrofits. Obviously, producers who replaced higher-wattage incandescent and/or high-pressure sodium fixtures saw greater energy savings than those replacing efficient CFL fixtures. Producers who replaced CFL fixtures did not see reasonable paybacks though they highlighted other reasons for implementing LED lamps: ability to dim lamps and elimination of environmental concerns over CFL fixtures. Table 30 summarizes the average and median paybacks for different lamp replacements.

Table 30: Summary of Average and Median Payback

Pre-Retrofit Lighting System	Simple Payback (yrs)		Net Payback (yrs)	
	Average	Median	Average	Median
Incandescent	1.6	1.7	0.4	0.3
CFL	No Payback[1]	No Payback[1]	8.7	7.8
HPS	3.9	1.8	1.4	0.3
HPS/Incandescent	2.2	1.5	0.6	0.4

1. When payback exceeded the life of the LED lighting using the producer's annual hours of lighting operation, then no payback was possible.

In summary, the simple payback of replacing incandescent and/or high-pressure sodium fixtures has a very fast payback and appears to be a cost-effective conservation measure.

Observable LED Installations and Lamp Durability

This project demonstrated that poultry-specific LED lamps function well in poultry barns. These participating farmers will serve as examples for other producers considering LED lamp installations. Importantly, *no* farmer participating in this project reported a decrease in poultry production. Though not within the scope of this project, several producers reported anecdotally that LED lamp use had production benefits including calmer flocks and feed conversion efficiency (the measure of a bird's efficiency in converting feed mass into body weight). Many producers felt that a longitudinal study lasting several years would demonstrate whether LED lamps measurably increase production in addition to providing energy efficiency benefits. Regardless, the results of the LED installations in this project should spark interest and conversation amongst Minnesota's poultry industry about energy efficient lighting.

With a little exception, the LED lamps installed in this project generally withstood harsh barn conditions for the approximate one to two years they were under examination. Lamps that did fail during this project were replaced under a two-year warranty, which highlights the importance of the warranty length. The LED lights in this study were rated to last for 50,000 light hours or approximately ten years depending on the lighting schedule. Considering that this project ran for only 2.5 years, many producers installed the lights with a 'wait and see' approach regarding long-term durability and production effects; more time and measurement will make clear the LED lamps' impacts on production and operations.[19]

Program Design Considerations

Even, uniform lighting is appealing to producers.

A number of the producers involved in this study commented on the change in the quality of light resulting from the switch from larger HPS lamps to smaller LED lamps. Some producers were reluctant to rewire barns in order to accommodate the new technology, though they noted the benefit of having an even, more uniform light spread across their barns post-installation. In contrast, other producers struggled with the directional nature of the LED lamps, including the lack of ambient light and dark spots in the barn. Though the lamps did not impact bird production, some producers remarked they considered installing an additional row of lights to eliminate dark areas or areas where birds gathered unevenly. It was not clear from this project whether producers simply perceived low light levels because of the human spectrum of vision, or whether light levels were actually low. Regardless, no producer reported a decrease in poultry production.

Producers were concerned about their staff's ability to operate in the barn.

The primary function of a lighting system is to serve the poultry, not the farm workers. Yet, farm workers do need to be able to see in the barns to care for the flocks and some producers remarked their staff struggled to perform daily tasks because of low (to them) ambient light levels above the birds. This concern can be addressed either by designing the retrofit system to leave a handful of CFL lamps in operation on a separate switch that can be turned on when farm workers are working in the barns or by giving farm worker headlamps.

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[19] This 'wait and see' approach is likely well-informed. As in many industries, farmers are presented with many 'next big thing' opportunities from eager salespersons. They have become accustomed to taking a more measured approach to the introduction of new technologies (such as dimmable, color changing LEDs) that modify a fairly conventional part of their operation (lighting).

Timelines, communication and availability are key for purchase and installation decisions.

This project has demonstrated that all parties involved in the poultry lighting upgrade supply chain must be flexible and fast moving in relation to lamp purchase and installation decisions. Producers generally have about one to two weeks of barn downtime between the period when a flock is moved from a barn and new poults arrive to restart the growing cycle. Producers utilize this down period to perform routine maintenance, clean and sanitize, and make necessary upgrades in their barns. Most often, this "down" period is the best time for lighting upgrades to occur.

If a producer decides to make a lighting upgrade as a down period nears, the product must be readily available, or the producer may be forced to wait to complete the upgrade until the next production cycle ends, resulting in several weeks of continued lighting inefficiency. Product vendors, installers, and utilities attempting to design and implement incentive programs must work to provide sufficient information to the producer well ahead of the time for making a decision, and be ready to provide the product or service in a quick and efficient manner. Production cycles vary for each individual producer and utility account representatives are advised to stay in touch with farmers and communicate about best available times for lamp upgrades. Then, all parties can be prepared to move on a project within a limited implementation time frame.

In a perfect world, a producer would plan these upgrades in advance of the down period, so all of the logistics could be determined ahead of time. For some operations, advance planning is the method of operation. However, many farms and farmers do not always have time in their full schedules to plan upgrades weeks or months in advance. In addition, farms do not often have operations staff dedicated to facilities management. Farmers are required to monitor their facilities, manage daily farm operations, and address all other aspects of these highly intricate businesses. Projects such as lighting upgrades are often done when an opportune time and budget present themselves, and must be accomplished in that small window. Weather is also always a factor that can cause a quick shift in priorities for farm operations.

Farmers value a neutral voice and their industry associations.

Electric utilities that intend to implement an LED lighting rebate program should collaborate with poultry growers associations and the University of Minnesota Extension's Poultry Division. These entities have good relations with Minnesota's poultry farmers and offer a neutral voice about the advantages and disadvantages of many technologies, including LED lamps. Working with these groups would represent to poultry farmers that electric utilities are legitimately concerned about farmers' operations and productivity in addition to energy savings.

Conclusion

Poultry-specific LED lamps offer significant energy savings opportunities for electric utilities and poultry producers as well as attractive paybacks when replacing incandescent and/or high-pressure sodium lamps. However, electric utility staff should take care in communicating, designing, and implementing the introduction of LED lamps in poultry barns. No two barns are identical and one-to-one lamp exchanges are not likely to work where production concerns about uniform lighting is concerned. Wide-scale acceptance by a risk adverse industry such as poultry production will take time though highlighting the cost-effectiveness will attract farmers' attention. In addition, a longitudinal study on production impacts to poultry would have much more sway in the poultry community. At this point in time, questions remain about whether there are any durability and performance benefits from LED lamps in poultry facilities that extend beyond the length of the lamp warranty and about the anecdotal evidence of production increases. Revisiting the participating producers in a year or two would yield valuable information than is currently not available. Regardless, LED lighting in production agriculture should greatly assist electric utilities and poultry producers in electricity conservation.

Additional Resources

Brian Fairchild, "Evaluating LED Light Bulb Performance in Broiler Housing," University of Georgia, College of Agricultural & Environmental Sciences, 2012. Accessed February 19, 2014. http://www.caes.uga.edu/Applications/ImpactStatements/index.cfm?referenceInterface=IMPACT_STATEMENT&subInterface=detail_main&PK_ID=4412

Julia Layton, "How LED Light Bulbs Work", How Stuffworks, Inc. Accessed February 19, 2012. http://science.howstuffworks.com/environmental/green-tech/sustainable/led-light-bulb.htm

Dr. Susan Watkins, Susan Sullivan and Dr. H.L. Goodwin, "Field Demonstration of Advanced Lighting Technologies for Poultry Houses: Phase 1 Summary Update", Fiscal Year 2011 Annual Report, University of Arkansas System's Division of Agriculture. Accessed February 19, 2014. http://www.ozarksecc.com/pdfs/energy_grant_phase_1_report_final_with_aeo_comments_incoperated_rev_11_11_2010.pdf

Appendix A

Inputs

Generally, the project team calculated annual energy savings (kWh) by subtracting the total energy use of the new LED light fixtures and lighting schedule from the total energy use of the farmer's previous light fixtures and lighting schedule.

For each barn, the project team gathered the following inputs, some of which have different inputs for before and after the lighting retrofit (as noted with 'pre/post'):

- Barn type (brooder, finishing, egg-layer)
- Barn use schedule (occupied by flocks with lighting, cleaning, empty)
- Lighting schedules - including summer (long-day) and winter (short-day) lighting hours (pre/post)
- Number of light fixtures (pre/post)
- Lighting power consumption (pre/post)
- Dimming schedule (if any)

Inputs requiring further explanation are discussed in the sub-sections that follow.

Barn Use Schedule

Table A.1 below shows the assumed amount of time any given flock spends in the barn (lighting activity) and the amount of time spent cleaning barns between flocks (cleaning activity) for each type of barn. These inputs are based on data gathered from participating farms and a literature review of practices in the poultry industry. When farmers provided flock rotation schedules, their farm-specific inputs were used in lieu of the assumed inputs noted in Table A.1.

Table A.1: Flock Rotation Inputs

	Activity (weeks per flock)	
Barn Type	**Lighting**	**Cleaning**
Brooder	6	1
Finishing	15	1
Egg-Laying	98	4

Lighting Schedule

Each poultry producer has a unique lighting program, ranging from 12 hour blocks of continuous lighting to shorter on/off schedules (ahemeral lighting). In general, most producers operate their lamps between 12 and 18 hours per day with some seasonal changes between the summer and winter months to leverage natural light. The project team surveyed each participating farmer to confirm the type and number of lamps in their facility and the lighting schedule before and after LED lamp installation. Due to the range of management styles and barn facilities, no lighting program will fit every situation. Figures

A.1 and A.2 below display examples of sample winter (short daylight) and summer (long daylight) schedules.

Figure A.1: Sample Lighting Schedule – Brooder and Finishing Barn Weeks, Winter

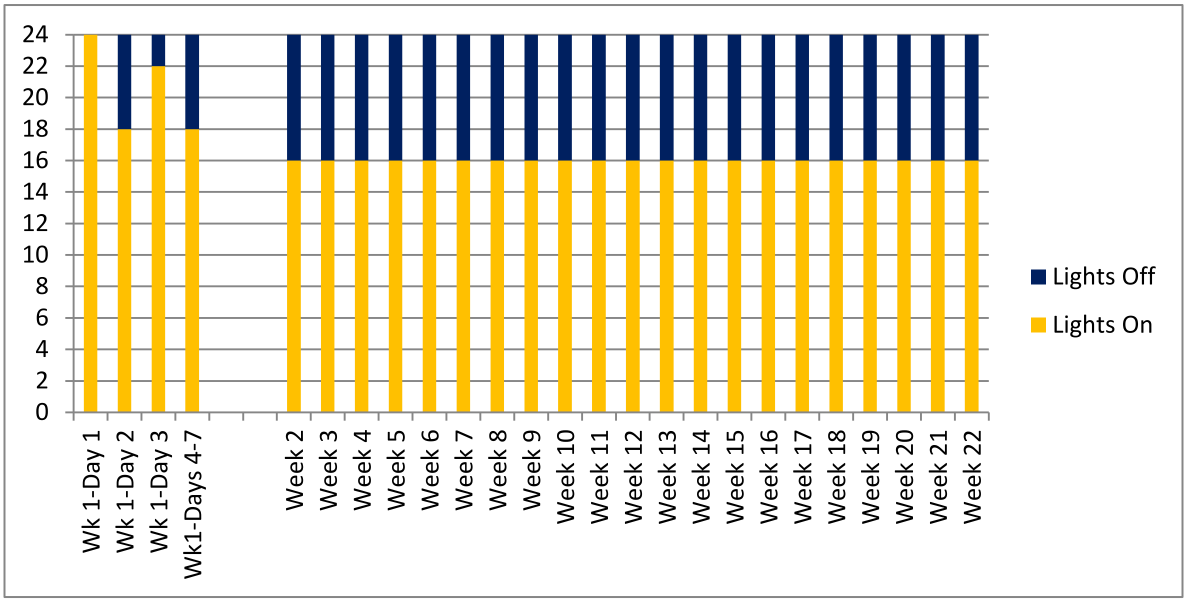
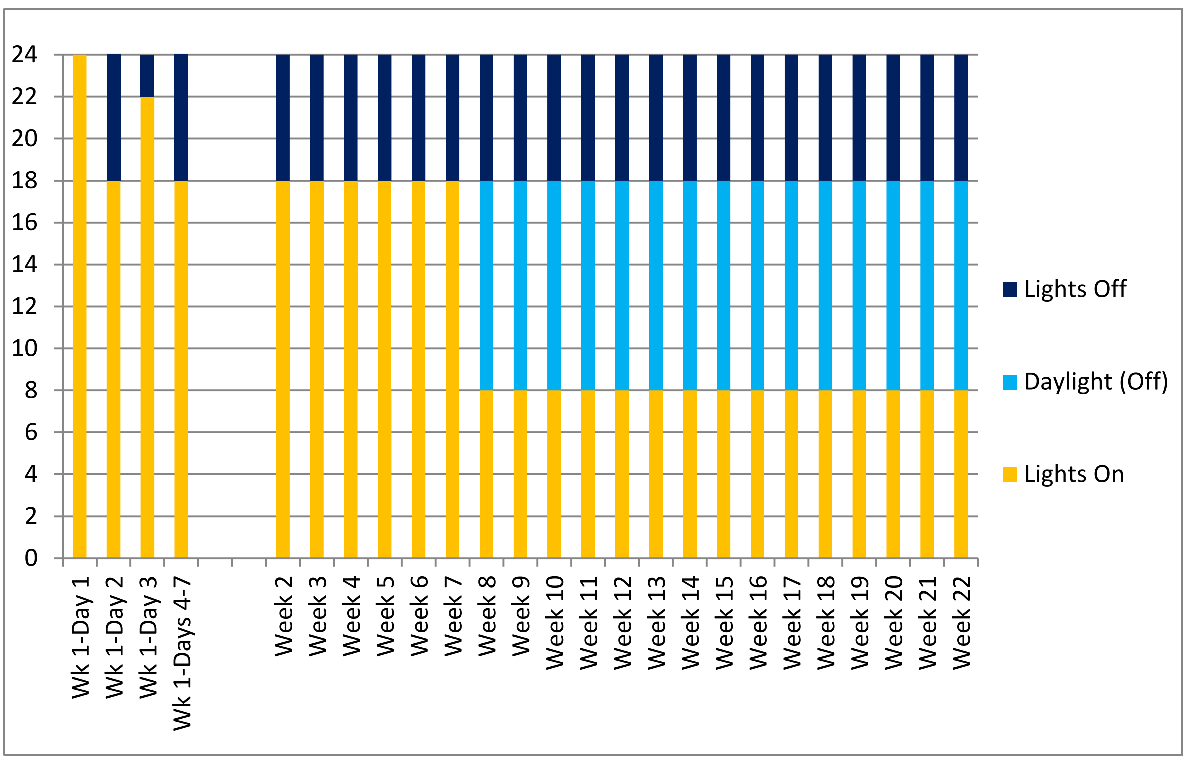


Figure A.2: Sample Lighting Schedule – Brooder and Finishing Barn Weeks, Summer



The assumed lighting schedule during cleaning weeks is 8 hours per day. If a farmer specified different cleaning day duration other than 8 hours, then the farm-specific input was used in the calculations.

The assumed period length for summer and winter periods is 6 months each. If a farmer specified a different period length other than 6 months, than the farm-specific input was used in the calculations.

Lighting Power Consumption

The lighting fixtures in place before the lighting retrofit varied. Most barns were equipped with uniform fixtures and wattage. However, some barns in this study were equipped with two existing lamp types. The existing lamp fixtures included the following:

- 150-watt high pressure sodium (HPS) bulbs with 40-watt ballast fixtures
- 250-watt HPS bulbs with 40-watt ballast fixtures
- Screw-in 60-watt incandescent bulbs
- Screw-in 75-watt incandescent bulbs
- Screw-in 100-watt incandescent bulbs
- Screw-in 13-watt compact fluorescent light (CFL) bulbs
- Screw-in 23-watt CFL bulbs
- Screw-in 26-watt CFL bulbs

The only fixtures with ballasts were the HPS fixtures. Each HPS fixture's ballast is assumed to consume 40 watts of power. In the calculations shown in this report, the power consumption of the ballast is combined with the power consumption of the HPS lamps as one amount of power consumption for the fixture as a whole.

This project team installed LED lamps from project partner and LED lamp manufacturer Once Innovations of Plymouth, Minnesota. Once Innovations' LED lamps were specifically designed to shift the color spectrum emitted by the fixture as the light was dimmed, in addition to reduce the light intensity. While not an objective of this study from the outset, the color-dimming feature allowed for farmers to test for any gains in poultry production by reaching a broader light spectrum.

Table A.2 outlines Once Innovation's poultry lighting products available to farmers at the time this project began and the applications for which they were designed.

Table A.2: Once Innovations Lamp Types

Poultry Type	Once Innovations Lamps	Energy Use (watts)
Turkey and Broiler	AgriShift® PL Dim-to-Blue (Primary Light Source)	12
	AgriShift® FL (Feed Pan Light)	3
Egg Layers	AgriShift® PLE Dim-to-Red® (Primary Light Source)	12
	AgriShift® EL (Cage Lighting)	3

This pilot project was designed to outfit whole poultry barns for field-testing and tested the AgriShift® PL Dim-to-Blue® 12-watt fixtures and the AgriShift® PLE Dim-to-Red® 12-watt fixtures. Though offered to producers, the AgriShift® FL (Feed Pan Light) 3-watt fixtures and AgriShift® EL (Cage Lighting) 3-watt fixtures were not tested under this pilot because these applications occur in specific locations in poultry barns and would not have produced adequate data for a whole-barn lighting study.

Unlike most high pressure sodium and incandescent lamps, which produce light in only a small section of the color spectrum, Once Innovations' LED lamps produce light spanning a wide color spectrum. The LED lamps also produce some light that is observable by the bird, though not by a human. For example, Once Innovations' AgriShift PL produces a luminous flux of 840 lumens to the eye of poultry and 530 lumens to the eye of humans. That is, a Once Innovation lamp is producing sufficient amounts of light for poultry, some of which is not observable to the human eye. For this reason, a few farmers chose to keep some of the HPS or CFL fixtures on different switches after the lighting retrofit for employees to be able to see clearly.

Several farmers adjusted daily lighting schedules with the new AgriShift LED lamps. Many farmers took advantage of the dimming features, as will be described in the next sub-section, which slightly adjusted (increased or decreased) the amount of total lighting in a year, depending upon how dimming techniques were employed.

Dimming Schedule

Since LED lamps perform much better at dimming (compared to CFL and HPS bulbs), approximately half of the farmers in this study decided to employ dimming techniques with their lamp retrofits. Some farmer participants applied one of two dimming techniques in this pilot:

1. Sunrise/sunset – To more closely mimic nature's sunrise and sunset, lights are brightened gradually from 0% to 100% in the morning for a period and dimmed gradually from 100% to 0% in the evening for a period. The period length varied among farmers from 20 to 40 minutes.
2. Overnight dim – In lieu of turning lights off (0%) overnight, lights are dimmed to a set point (e.g., 10% or 50%) for the overnight period. (Some farms provide lighting 24 hours per day, and therefore, do not employ this technique.)

Summary of Inputs

Table A.3 shows the list of input variables with units of measurement (if applicable), as determined individually for each barn.

Table A.3: List of Calculation Inputs

Variable	Units	Symbol
Lighting Activity	Weeks/Flock	LA
Cleaning Activity	Weeks/Flock	CA
Cleaning Lighting	Hours/Day	CL
Summer Period	Months	SP

Variable	Units	Symbol
Winter Period	Months	WP
Summer Lighting	Hours/Day	SL
Winter Lighting	Hours/Day	WL
Quantity of Lighting Fixtures	--	Q
Lighting Fixture Power Consumption	Watts	P

Calculations

Interim Calculations

A number of calculations were performed in preparation of calculating energy savings, including the following:

- Lighting and Cleaning Periods
- Total Power Draw
- Adjusting Summer and Winter Lighting for Dimming Techniques
- Summer and Winter Runtimes
- Annual Lighting Runtime

Using the lighting and cleaning activity schedules collected from the farmers, lighting and cleaning periods for the year were calculated. These periods represent the times of the year during which barns were lit. Two separate periods are needed because the daily lighting schedule when flocks are present is different than when the farmers are cleaning the barns and flocks are not present. Equations 1 and 2 show how the lighting and cleaning periods were calculated. It was assumed that the barns were empty the remaining weeks of the year, which ranged from 1 to 4 weeks. If a farmer specified the schedule by which the barns were empty, then the farm-specific inputs were used in the calculations. The number of lighting, cleaning and empty weeks were held constant for each barn for the before and after lighting retrofit energy calculations.

$$Lighting\ Period\ \left(\frac{weeks}{year}\right) = \left(\frac{52\ weeks/year}{LA+CA}\right) \times LA \qquad \text{Equation 1}$$

$$Cleaning\ Period\ \left(\frac{weeks}{year}\right) = \left(\frac{52\ weeks/year}{LA+CA}\right) \times CA \qquad \text{Equation 2}$$

Total power draw for each bard was calculated by summing the power draw of all lighting fixtures. Subscripts in Equation 3 indicate different fixture types.

$$Total\ Power\ Draw\ (watts) = (Q_1 \times P_1) + (Q_2 \times P_2) \qquad \text{Equation 3}$$

Summer and winter lighting (hours per day) were adjusted, based on the dimming techniques applied. As noted in the Dimming Schedules sub-section of this report, two techniques for dimming were employed. Equation 4 shows of how lighting was adjusted when the sunrise/sunset technique was employed.

$$Lighting_{\ dim}\left(\frac{hours}{day}\right) = (Lighting - Dim\ Period) + (Dim\ Period \times 50\%) \qquad \text{Equation 4}$$

Where, *Lighting* = hours each week light is scheduled to be on

Dim Period = sum hours of all sunrise and sunset periods within *Lighting*

The Dim Period is multiplied by 50%. We assume that 50% of power draw occurs at 50% light levels. Because sunrise/sunset sequence is brightening/lightening from 0% levels to 100% levels at a constant rate, the average power draw over the dimming period is 50% of full power. We apply the reduction is applied to lighting (time) instead of lighting power draw for ease of calculations.

Equation 5 shows how lighting was adjusted when the overnight dimming technique was employed.

$$Lighting_{\ dim}\left(\frac{hours}{day}\right) = Lighting + (Dim\ Period \times Dim\ Level) \qquad \text{Equation 5}$$

Where, *Lighting* = hours each week light is scheduled to be on

Dim Period = 24 hours minus *Lighting*

Dim Level, % = farm-specified light level (ranges from 10% to 50% in this study)

Since lighting schedules vary depending upon the season, lighting runtimes in hours were calculated for each season. Equations 6 and 7 show how summer and winter runtimes were calculated.

$$Summer\ Runtime, \frac{hours}{year} = \frac{SP}{12\ months/year} \times \frac{7\ days}{week} \times \big((LP \times SL) + (CP \times CL)\big) \qquad \text{Equation 6}$$

$$Winter\ Runtime, \frac{hours}{year} = \frac{WP}{12\ months/year} \times \frac{7\ days}{week} \times \big((LP \times WL) + (CP \times CL)\big) \qquad \text{Equation 7}$$

The annual lighting runtime is simply the sum of the summer and winter runtimes, as shown in Equation 8.

$$Annual\ Runtime, \frac{hours}{year} = Summer\ Runtime + Winter\ Runtime \qquad \text{Equation 8}$$

As noted in the sub-section on Lighting Power Consumption, farmers took advantage of the dimming features, which slightly adjusted (increased or decreased) the amount of total lighting in a year, depending upon how dimming techniques were employed. These slight differences in runtime between pre- and post-retrofit are reflected in the calculations.

Table A.4 summarizes the list of interim variables with units of measurement, as calculated using Equations 1 through 8.

Table A.4: List of Interim Variables

Variable	Units	Symbol
Lighting Period	Weeks/Year	LP
Cleaning Period	Weeks/Year	CP
Total Power Draw	Watts	TPD
Summer Runtime	Hours	SR
Winter Runtime	Hours	WR
Annual Runtime	Hours	AR

Energy Calculations

Annual energy use was calculated before-retrofit conditions and after-retrofit for each barn using Equation 9.

$$Annual\ Energy\ Use, \frac{kilowatt{-}hour\ (kWh)}{year} = \frac{(TPD \times AR)}{1000\ watts/kilowatt}$$ Equation 9

Energy savings for each barn in the study was calculated using Equation 10fit.

$$Energy\ Savings, \frac{kWh}{year} = Annual\ Energy\ Use_{Before} - Annual\ Energy\ Use_{After}$$ Equation 10

Simple Payback Calculations

Cost-effectiveness of these lighting retrofit projects was analyzed using a simple payback calculation. In order to do this, annual energy savings must be converted into terms of money using Equation 11.

$$Annual\ Energy\ Savings, \$/year = Energy\ Savings, \frac{kWh}{year} \times Unit\ Electricity\ Cost, \frac{\$}{kWh}$$ Equation 11

The electricity cost ($/kWh) was averaged between the year-to-date values for residential ($.12/kWh) and commercial ($.0958 kWh) rates according to the Energy Information Administration at $0.1079 per kWh. This figure was held constant in simple payback calculations to facilitate comparison.

Simple payback is calculated using Equation 12.

$$Simple\ Payback, Years = \frac{Total\ Project\ Cost, \$}{Annual\ Energy\ Savings, \$/year}$$ Equation 12

Simple payback can be calculated with or without incentives and rebates considered. This study analyzed both, which will be discussed in the Results section.

Appendix B

Alternate Cost Effectiveness Scenario

LED fixture costs reduced greatly over the duration of the project. At the beginning of the project, the cost per fixture was $65. At the end of the project, this cost reduced to only $35. This difference in product cost, which has been reflected in the materials cost in this report, will greatly affect the cost effectiveness of lighting retrofits in poultry barns.

Table 29 was reproduced as Table B.1 in order to create a scenario that may reflect how the cost effectiveness of a lighting retrofit to LEDs would look today and perhaps into the future. This alternate scenario was generated by holding the product cost constant at $35 per LED fixture and removing all subsidies (manufacturer's discount on bulbs and dimmer controls and CARD grant farmer match).

Table B.1: Summary of Savings, Costs and Payback with Product Cost at $35 per Fixture and No Subsidies

Producer	No. of Barns	Barn Type	Lighting Changeout	Energy Saved Annually (kWh)	Money Saved Annually[1]	Materials Costs[2]	Labor/ Other Costs[3]	Total Project Costs *[Materials + Labor]*	Simple Payback (years)[4]	Utility Rebates	Net Payback (years) *[with Total Incentives]*
Lakewood Turkey	1	Turkey Finish	CFL to LED	2,388	$258	$2,305	$2,400	$4,705	No Payback	-	No Payback
Gorans Bros. Turkey	1	Turkey Finish	CFL to LED	1,441	$155	$1,815	$250	$2,065	No Payback	-	No Payback
Galaxy Farms	1	Turkey Brood	CFL to LED	2,156	$233	$1,750	-	$1,750	7.5	-	7.5
Sparboe Egg Farm	1	Egg-laying	CFL to LED	1,603	$173	$11,200	-	$11,200	No Payback	-	No Payback
Buysse Farm	1	Turkey Brood	CFL to LED/CFL	3,754	$405	$1,850	$250	$2,100	5.2	-	5.2
Flying C Farms	2	Turkey Finish	HPS to LED	27,232	$2,938	$11,050	$5,000	$16,050	5.5	-	5.5
WP Highway 40 West	1	Egg-laying	HPS to LED	48,185	$5,199	$9,240	Unknown	$9,240	1.8	$1,320	1.5
LSI/WP Highland	1	Egg-laying	HPS to LED	54,659	$5,898	$9,240	-	$9,240	1.6	$1,320	1.3
LSI/WP Diamond	1	Turkey Brood	HPS/Incan to HPS/LED	29,105	$3,140	$4,690	-	$4,690	1.5	-	1.5
LSI/WP Westbrook	1	Turkey Brood	HPS/Incan to HPS/LED	15,293	$1,650	$1,680	-	$1,680	1.0	$240	0.9
Zimmerman Farms	4	Turkey Finish	HPS/Incan to LED	41,198	$4,445	$8,400	$3,500	$11,900	2.7	$3,500	1.9
Evelo Farms	1	Turkey Brood	Incan to LED	13,798	$1,489	$2,275	-	$2,275	1.5	-	1.5
Langmo Farms	3	Turkey Finish	Incan to LED	36,581	$3,947	$6,575	-	$6,575	1.7	$1,750	1.2
LSI/WP Old East Fransen	1	Turkey Brood	Incan to LED	13,346	$1,440	$2,100	-	$2,100	1.5	$300	1.2
R & L Turkeys	1	Turkey Finish	Incan to LED	27,796	$2,999	$2,410	$250	$2,660	0.9	$1,366	0.4
LSI/WP New West Fransen	1	Turkey Brood	Halogen to LED[5]	9,003	$971	$2,100	-	$2,100	2.2	$300	1.9
P & J Turkeys	1	Turkey Brood	Halogen to LED[5]	24,426	$2,636	$4,650	-	$4,650	1.8	$840	1.4
			Average:	20,704	$2,234	$4,902	$728	$5,587	2.6	$643	2.4
			Median:	15,293	$1,650	$2,410	-	$4,650	1.7	$240	1.5

1. Assumes $0.1079/kWh electric rate.
2. Includes fixture and dimmer controls costs.
3. Includes the cost of hiring an electrician to perform install and may include some materials provided by electrician. Does not include producer staff time to perform simple bulb changeouts.
4. When payback exceeded the life of the LED lighting using the producer's annual hours of lighting operation, then no payback was possible.
5. Newly constructed barn; not a retrofit. Values were calculated by assuming lighting changed from halogen to LED.