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# *Expanded LED benefits through an automated long day lighting system at a 3x milking dairy farm*

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ABSTRACT. *The goal of this study was to design and test an energy efficient lighting system that will meet long day lighting (LDL) criteria under Michigan conditions. This project, conducted on a 1,000-cow commercial dairy farm in Webberville, MI, used dimmable 150-Watt high-bay and 60-Watt canopy LED luminaires paired with a dynamic control system. This control system utilized a feature called daylight harvesting (DLH) to save energy by dimming the LED luminaires when there was natural light available inside the barns. The data demonstrated that the implemented system with DLH consumed 62% less energy than a theoretical metal halide HID system, and 44% less energy than a featureless version of the implemented LED layout without DLH capability. The significant discrepancy between the theoretical calculations and the actual energy usage of this LDL system confirmed the need to collect empirical data to accurately characterize the energy saving benefits of implementing daylight harvesting with LED luminaires.*

***Keywords.*** *Barns, dairy farms, data acquisition and control, daylight harvesting, energy conservation, engineering, lighting, long day lighting, Michigan.*

## Introduction

Controlling length of day for dairy cows has been shown to increase milk production by as much as 5% to 9%. In the past milk producers were using the artificial growth hormone rBST to boost milk production, but a public outcry resulted in retailers refusing to accept milk from farms that used rBST to increase milk production. This resulted in a significant reduction in milk output from dairy farms and a significant decline in revenue, since rBST increases milk production by 10-15%. Dairy farmers have been looking for an alternative way of gaining back that lost milk production that would be acceptable to consumers. One method is to add more cows to the herd, but that brings about a large capital investment, increased labor, and an increase in feed as well as manure to apply on fields. In addition, larger herd sizes also create adverse environmental impacts. Since dairy products are a large contributor to Michigan's agricultural sector and economy, production losses cause significant implications for both the state and farmers. Therefore, aside from buying more milking cows, Michigan farms are seeking unconventional means of increasing their production without incurring negative environmental and economic consequences (Thomas et al., 2017).

Long day lighting (LDL) is one proven method of increasing production that has seen increased popularity among Michigan farmers. Literature has demonstrated that LDL can increase milk production in dairy cows by 5% to 9% (Collier, Dahl, & VanBaale, 2006; Dahl, Buchanan, & Tucker, 2010). While LDL is a proven method that has been around since the 1980s, Michigan farmers' attempts at implementing LDL systems have fallen short of these results. It was discovered by agricultural engineers and Extension staff at Michigan State University that the criteria for achieving long day lighting was not being met. An automatic, reliable system is crucial to managing a successful LDL system. If an increasing number of farmers adopt such a system, there could be numerous economic and environmental benefits for the whole state.

LDL technology is based on creating a lighting regime that manipulates light intensity and duration. Historically, LDL systems have utilized 16-18 hours of light each day, at 15-20 foot-candles (fc), followed by 6-8 hours of darkness, at 1-4 fc. From an animal science perspective, this lighting regime has a regulating effect on the melatonin levels in cows. This causes increased production of hormones that stimulate lactation, and therefore increases overall production (Dahl et al., 2010). Case studies have shown that LDL can also have positive behavioral changes on the cows. Farmers who have implemented LDL have observed that their animals seem to be more relaxed. Since barns with LDL have more consistent light distributions, animal crowding is reduced, creating a cleaner and healthier environment for the herd (Thomas et al., 2017).

From an energy perspective, using LED luminaires in place of traditional metal halide luminaires to implement an LDL system can result in significant energy savings due to the increased efficiency of LED lighting. Metal halide (HID) luminaires also cannot be dimmed when additional light is naturally provided, a process called daylight harvesting (DLH). Energy consumption is an important economic consideration for large dairy farms (450+ cows) since they are such large consumers of energy in Michigan. As farm size increases, electricity becomes a greater portion of total energy consumption. This is illustrated in Table 1, which demonstrates that while total energy consumption per cow and per hundredweight (cwt) of milk decreases with farm size, electricity consumed per cow and per cwt at first decreases with increasing farm size, and then increases to levels similar to the smallest farm size category. This is because large farms tend to milk three times per day and have better ventilation, making them much more productive, but increasing their electricity consumption (VanZweden, Go, & Surbrook, 2018).

**Table 1. Energy consumption metrics for Michigan dairy operations (VanZweden, Go, & Surbrook, 2018)**

| Herd size | Energy used per cwt milk produced (kWh) | Energy used per milk cow (kWh) | Electricity used per milk cow (kWh) | Electricity used per cwt milk produced (kWh) | Electricity as % of total energy usage |
|---|---|---|---|---|---|
| 20-99 | 22.29 | 4300 | 866 | 4.49 | 20% |
| 100-249 | 12.27 | 2854 | 732 | 3.15 | 26% |
| 250-449 | 9.71 | 2428 | 534 | 2.14 | 22% |
| 450+ | 8.07 | 2213 | 875 | 3.19 | 40% |
| **Weighted Averages:** | **9.97** | **2532** | **771** | **3.04** | **30%** |

In 2017, an LDL system using LED luminaires was proven successful at a 100 milking cow Michigan dairy farm that practices twice a day milking. This project is described in "A Dairy Long Day Lighting Success Story: MI Dairy Increases Production and Cuts Costs," which can be found in the ASABE technical library. The project examined in this 2017 report utilized dimmable LED luminaires, light sensors, and a GRAFIK Eye QS controller to create an LDL system (Thomas et al., 2017).

In comparison to the 2017 LDL system, the project discussed in this report, performed by a research team from Michigan State University, sought to implement an LDL system at a large dairy farm that performs milking three times a day. This was a challenging feat since the 24/7 milking operation limits the dark period exposure needed by the cows.

# Goal/Objectives

The goal of this study was to illustrate the expanded energy efficiency benefits from using LED luminaires to implement long day lighting on a large dairy farm compared to using traditional HID luminaires. Merely calculating the energy consumption of HID and LED luminaires based on their rated power draw and comparing those numbers would not accurately portray the energy consumption of LED luminaires that are dynamically controlled to dim when natural lighting is available in the barn (daylight harvesting). Therefore, it was necessary to collect empirical energy consumption data on a dynamically controlled LED LDL system to better understand the expanded benefits of using LED luminaires to implement long day lighting.

In order to meet the project goal, the following objectives were required:

- Collect initial energy consumption data
- Calculate theoretical energy usage of a pro forma LDL system with HID luminaires
- Replace existing T-8 fluorescent luminaires in barns with dynamically controlled LED luminaires
- Program the control system with daylight harvesting feature to meet minimum light levels
- Collect and analyze post-implementation energy data

# Methods

The project site, located in Webberville, Michigan, was a grade A dairy and crop farm on 2,000 acres that operated 24/7 and milked three times per day. The milking herd consisted of Holstein cows that were housed in two separate barns, referred to as the east barn and west barn throughout this report. At any given time, approximately 1,000 cows were in lactation, and in addition approximately 75 were dry, 600 were heifers, and 60 were calves. The farm produced an average of 85 pounds of milk per day per cow.

Funding for the project was a grant from DTE Energy, a Michigan utility company, through their E-Challenge program for Colleges and Universities. DTE had some requirements for the equipment that could be used to implement the project. Most notably, the team was required to use components that were made in Michigan whenever possible. The project also stipulated that the lighting and control system used be listed by DesignLights Consortium (DLC).

After evaluating a number of lighting and control systems, the team found that it was necessary to purchase the lighting and control systems from different suppliers in order to meet the conditions of the project. The team evaluated the suppliers that offered DLC listed lighting and control system combinations, but none of those systems were manufactured in Michigan. Therefore, the team had to find lighting and control systems that were from separate suppliers. There were no control systems that met the project's need that were manufactured in Michigan.

All luminaires were purchased from Everlast Lighting in Jackson, Michigan. Everlast assembles all their luminaires and fabricates all custom parts in Michigan. The lighting control system was purchased from Synapse in Huntsville, Alabama. All lighting and control systems were listed by Design Lights Consortium (DLC).

Two types of LED luminaires were purchased from Everlast: 150-Watt high-bays and 60-Watt canopies. The team worked with Everlast engineers to overcome the challenge of incorporating a Synapse DIM10-250 0-10V lighting control module inside each dimmable luminaire. The high-bay luminaires required a custom-made weatherproof enclosure, shown in Figure 1, to be added above the dimmable driver. This enclosure housed the DIM10-250 and served as an anchor for the mounting hook. Non-dimmable canopy luminaires were used for safety lights in the center aisles and required no modification since all center aisle lights in each barn are controlled by a single DIM10-250 controller located near the electric panels.

While the west barn and southern half of the east barn utilized high-clearance scissor trusses, the northern half of the east barn had low clearance webbed coffer trusses. Figure 2 illustrates this difference. These coffer trusses had a maximum luminaire mounting height of 12 feet for the outer light rows, as opposed to almost 16 feet for the scissor trusses. This condition precluded the use of high-bay luminaires in the northern half of the east barn, since their focused beam at only 12 feet from the ground could create dark areas between luminaires. After consulting with Everlast, it was decided that dimmable canopy luminaires would be used for the two outer rows of this unique area. However, since Everlast normally does not offer dimmable canopy luminaires, modifications needed to be made to their existing non-dimmable canopy luminaire. Everlast replaced the non-dimmable drivers with dimmable drivers and made a custom bracket to hold the DIM10-250. Figure 1 shows an almost complete canopy luminaire with the DIM10-250 control module incorporated into the canopy shell. Unlike the high-bay luminaires, the canopies are mostly hollow and can house all the additional equipment within the existing shell.


**Figure 1. Left: dimmable high bay luminaire with weatherproof box, bird spikes, and antenna; Right: inside of a dimmable canopy luminaire with the DIM10-250 (top) and dimmable driver (bottom)**

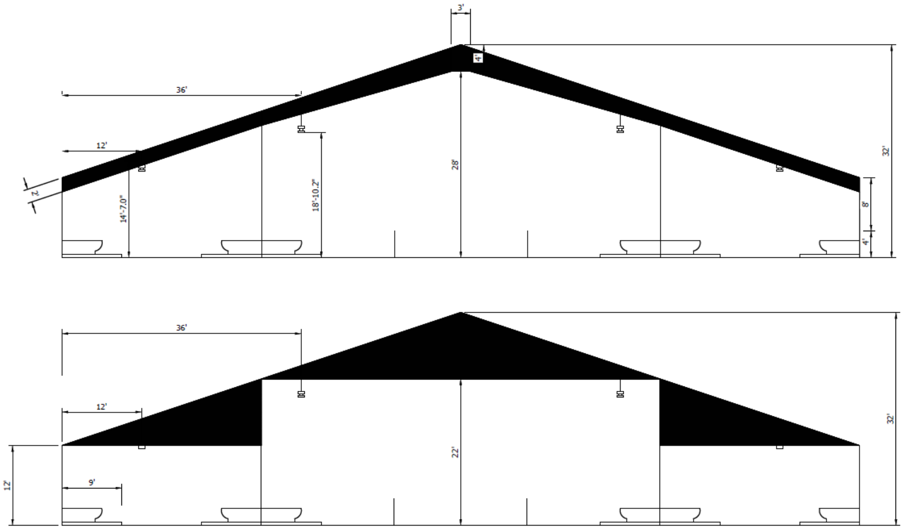


**Figure 2. Solid scissor trusses (top) vs. webbed coffer trusses (bottom) with light placement**

In southern Michigan, a 16-hour day length only occurs in June. Even during lighted day in Michigan, the required illumination levels necessary to gain the results of long day lighting can only be achieved by adding artificial light within the barns. However, the lighting layouts are designed to provide the required light levels when there is no natural light. When natural light is available within the barns, the luminaires do not need to be operating at their maximum output to maintain the required illumination levels. The process of dynamically dimming the luminaires in the barns to save energy when natural light is available is called daylight harvesting (DLH).

There are two control methods for DLH—closed loop and open loop. Closed loop DLH would utilize sensors placed throughout the barn. These sensors would measure the actual illumination levels in the building and maintain a constant level by dimming or brightening the luminaires. That way, on a sunny day the luminaires would be dimmed in areas where the sun was already providing natural light. It would also allow for very granular control of the luminaires for maximum energy savings and light level consistency. Finally, as light output of the luminaires naturally decreases with age, a closed loop system would automatically increase the luminaire output.

Synapse utilizes an open loop control method for DLH. An open loop DLH system monitors the light levels just outside of the building and then adjusts the light levels inside the building based on the amount of sunlight measured outside. This system uses fewer photocells than a closed loop system, but since they could be exposed to direct sunlight and rain, weatherproof photocells were required. The main disadvantage of an open loop system is that it requires much more calibration and monitoring than a closed loop system since one failed sensor can affect an entire row of luminaires in the barn. This system also does not automatically compensate for the decreased light output of aging luminaires since it is not monitoring the illumination levels inside the barn.

Synapse supplied photocells that were capable of exposure to moisture and direct sunlight. In addition, each sensor needed to be connected to an AIM-121 sensor controller or a DIM10-250 light controller. The placement of these sensors around the perimeters and peaks of the barns would have made connecting them to DIM10-250 controllers that were already inside the luminaires very difficult, so additional AIM-121 sensor controllers were also ordered from Synapse. Each AIM-121 is capable of handling up to two separate daylight sensors.

Installation of the lighting system took place between May and September of 2018, and installation costs were paid by the farm owner. All installation was done by either an electrician or members of the team. Since the electrical infrastructure was outdated in both barns, the electrician started by installing new circuit breaker panels specifically for the new lighting system. For the west barn, a new feeder line was run underground from the main electrical service. The east barn had separate panels for the ventilation systems and lighting. Since the existing lighting panel was not satisfactory, a new lighting panel was tapped off the feeder to the ventilation panel, which was also in a more accessible location.

Before the new luminaires could be mounted, the team had to complete their assembly. Everlast Lighting shipped the luminaires almost completely assembled with the Synapse DIM-250 controller already installed. However, the controller antenna and MAC address label had to be installed on the outside of each dimmable luminaire. To make the MAC addresses easier to see, large labels were printed and affixed to the side of each luminaire, shown in Figure 1. The only luminaires that did not need any additional assembly were the non-dimmable canopies that are used during the 'dark' period of the day for employee safety. Bird spikes were also added to the top of the high-bay luminaires since they had ample space for bird nesting.

The DLH system also had to be assembled from the parts sent from Synapse. A total of ten photocells were needed to reliably control the luminaires in the barns: four in the west barn, one in the west barn parlor connector, and five photocells in the east barn. Five AIM-121 controllers and one DIM10-250 were used to control these ten photocells. Each AIM-121 was installed inside a waterproof box. One photocell was mounted directly to the side of five of the boxes with AIM-121 controllers inside. An example is shown in Figure 3. The single DIM10-250 controlled one photocell and the non-dimmable safety luminaires in the center aisle of the west barn. Four of the AIM-121 units controlled two separate photocells. The additional photocells were connected to the shared AIM-121 with digital control cable and were mounted in their own small junction boxes.

**Figure 3. Weatherproof box housing the AIM-121 sensor controller, with side-mounted sensor**

While the team was performing the final assembly on each luminaire, the electrician was installing the supply wiring. The team used Visual 2017 and AutoCAD to design the final lighting layouts for the barns. Each barn had four rows of dimmable luminaires and one center row of non-dimmable safety luminaires, as shown in the Appendix A-1 through A-3. There were eleven separate circuits for the luminaires: ten for each of the ten rows of luminaires and one for the west barn parlor connector. In addition, there was a separate circuit in each barn that powered the data acquisition system (DAQ) and lighting controls.

All the Synapse light and sensor controllers wirelessly communicate with a gateway controller. This device communicates with the farm's router through an ethernet cable. This ethernet cable also connects to the DAQ systems which monitors total energy usage and measures actual light levels inside the barns. The team installed all communication systems in the two barns.

Once the gateway and luminaires were installed, Synapse sent a representative to the farm to commission the control system. The technician wirelessly connected to the gateway and gave each luminaire a name and location. Different 'zones' were created such as 'West Barn Column 1' or 'East Barn Center.' The main reason the Synapse technician was present for the commissioning was to properly calibrate the daylight harvesting system. All luminaires except for the non-dimmable safety canopies in the center row of each barn are controlled by the DLH system. Fortunately, it was sunny when the technician was working, so it was possible to program the DLH system for maximum dimming on a sunny day while still providing at least 15 fc of illumination in the cow resting/feeding barns.

To program the SimplySnap system, the programmer must be connected to the farm's router. At this time, programming can only be done at the farm or while using TeamViewer, which requires someone at the farm to activate the program on the host computer. To bring up the SimplySnap program, the IP address of the gateway must be typed into a web browser on the farm's computer. Once logged into the SimplySnap system, different 'Scenes' can be created. Each scene attributes a selected behavior to different zones. The three behaviors that can be selected are 'On', 'Off', or 'Dim'. Dim levels can be set between 0% and 100%. Since the SimplySnap system does not have a ramp-up or ramp-down feature, 15 separate scenes were created to control all dimmable zones at sequentially higher light intensities. To simulate a sunrise or sunset, these 15 scenes can be called in the morning in one-minute intervals from dim to bright, or at night from bright to dim.

The light protocol for the long day lighting system is based on the sunrise (6:00 a.m. EDST) and sunset (9:20 p.m. EDST) of the longest day of the year in southern Michigan. At 5:59 a.m., only the center safety luminaires are on in the main barns, as well as three of the six high-bay luminaires dimmed to 6% in the milking parlor connector. At 6 a.m., all of the dimmable luminaires on the farm turn on at 6%, and sequentially get brighter at one-minute intervals until they reach full brightness at 6:14 a.m.

Once the sun actually rises, the DLH system takes over control of all dimmable luminaires and dims them to save energy. On a sunny day, it is common for all of the high-bay luminaires to be dimmed to only 10%, which saves energy while still maintaining appropriate light levels for the cows. At 9:15 p.m., the center safety luminaires turn on in both barns, giving employees a five-minute warning that the night light protocol is about to start. At 9:20 p.m., all dimmable luminaires start to sequentially dim at 1-minute intervals. All dimmable luminaires in the main barns turn off at 9:35 p.m. In the parlor connector, only three of the six high-bay luminaires turn off, while the other three remain on throughout the dark period at 6% brightness. This is necessary since there are no safety luminaires in the connector, so workers can drive cows through the connector throughout the night.

Figure 4 shows the layout of the data acquisition system. The west barn houses the actual DAQ server, which logs data from three separate units. The DAQ server is the Acqsuite EMB by Obvius LLC and can be remotely accessed through the manufacturer's website. The first unit connected to the DAQ server is the power meter, which monitors power in real-time and logs energy usage over time. The meter used was the Accuvium KL energy meter from AccuEnergy. AccuSplit Series current transformers are placed around each light circuit feeder wire and feed current and voltage data into the energy meter.

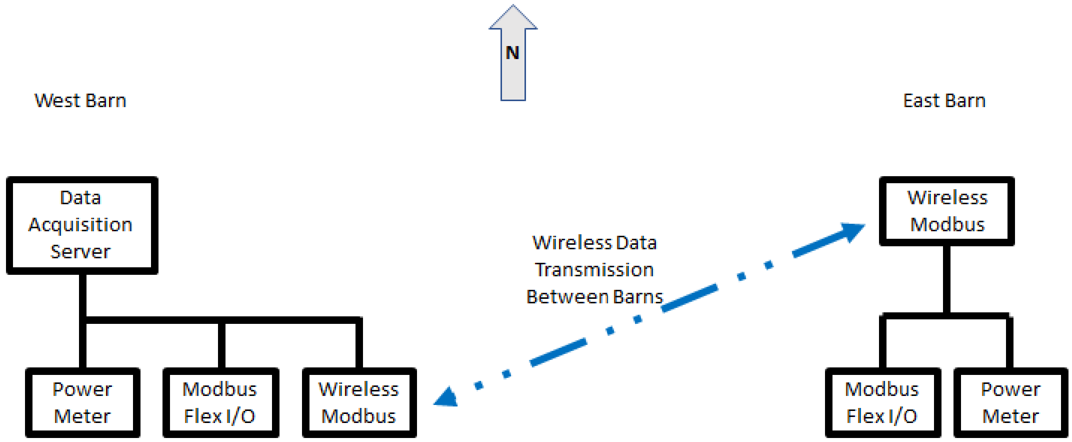


**Figure 4. DAQ Layout**

The second unit connected to the DAQ server is the Modbus Flex I/O Module made by Obvius LLC. This unit inputs light level data from multiple photocells inside both barns. These photocells had to be mounted 7-8 feet off of the ground to prevent damage from curious cows. They do not read the actual light levels that the cows are seeing. Instead, they are only used to monitor changes in light levels and are remotely monitored. This is useful for fine tuning the light control system to optimize light distribution and energy consumption.

The third unit connected to the DAQ server is the ModHopper Wireless Modbus by Obvious LLC. The Modbus wirelessly communicates with another Modbus in the east barn, inputting two additional sets of data to the DAQ server—east barn light levels and east barn energy data.

The installation process had a few challenges. Since the facility is a dairy farm that operates around the clock, accommodations had to be made to ensure the flow of operations was not interrupted. For example, little work was done during the hottest weeks of the summer since the ventilation systems could not be shut down. This should not be a problem in the future since the new lighting system is powered through a separate electrical panel. In addition, the team discovered early in the installation process that the luminaires were not at the specified distances. This was quickly rectified, and the rest of the luminaires were installed properly.

## Results/Discussion

There are currently 193 days of energy consumption data available spanning September 20, 2018 through March 31, 2019. Figure 5 illustrates the power draw of the west barn over a 2-day period, along with the theoretical power draws of a featureless LED layout and metal halide HID layout. Table 2 shows the actual energy consumption for the west and east barns. It also shows the energy consumption of the original T-8 fluorescent luminaires as well as two theoretical values—an identical LED layout using non-dimmable luminaires and an equivalent layout that utilizes HID luminaires. Table 3 shows the percent savings of the implemented system compared to a featureless LED layout or a theoretical HID layout.

The first column in Table 2 shows the energy consumption of the T-8 fluorescent luminaires that were originally inside the west and east barns and were energized 24/7. The west barn had 48 working T-8 lamps and 28 non-working lamps. The east barn had 42 working T-8 lamps and 14 non-working lamps. After sunset, the best light levels measured in either barn were less than 4 fc.

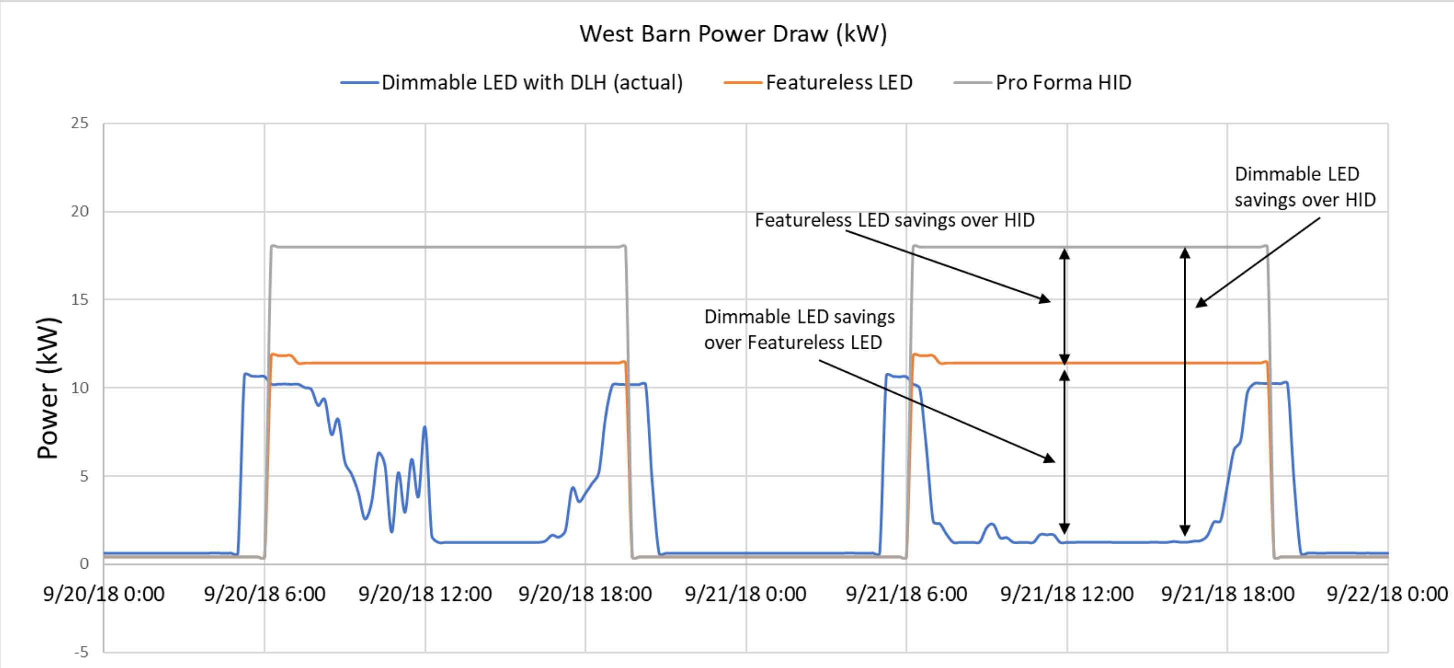


**Figure 5. West barn power draw**

**Table 2. Energy consumption of the west and east barns**

| Barn | Original T-8 (kWh) | Theoretical HID (kWh) | Featureless LED (kWh) | Dimmable LED with DLH (kWh) |
|---|---|---|---|---|
| West | 6114 | 53847 | 34893 | 19695 |
| East | 4864 | 35898 | 27242 | 14822 |
| **Total:** | **10978** | **89745** | **62135** | **34517** |

**Table 3. Percent energy savings of implemented system compared to the pro forma layout and the featureless LED layout**

| Barn | % Diff HID | % Diff Featureless |
|---|---|---|
| West | 63% | 44% |
| East | 59% | 46% |
| **Total:** | **62%** | **44%** |

The purpose of this study was to evaluate the advantages of implementing long day lighting using dynamically controlled LED luminaires instead of the HID or fluorescent luminaires that have been typically used in the literature to implement LDL. In conjunction with the team, Everlast Lighting developed a theoretical lighting layout using HID luminaires that would provide lighting levels equivalent to the actual LED layout. This design utilized 72 250-Watt HID luminaires in the west barn and 48 in the east barn. The second column in Table 2 shows the theoretical energy consumption of the LDL HID layouts for the west and east barns. Column one in Table 3 shows that the actual energy consumption of the implemented system was 62% less than the theoretical HID system. This is because LED luminaires are inherently more efficient than their HID counterparts, and a DLH control system was implemented with the LED luminaires to further increase the energy savings.

The presented energy data shows the difficulty in predicting energy usage of a long day lighting system that uses a dynamic control system, validating the need for this study. This is illustrated in the difference between columns three and four in Table 2 and columns two and three in Table 3, where the actual energy consumption for both barns is about 44% less than the calculated LED energy consumption. Column three in Table 2 was calculated under the assumption that the 150-Watt LED high-bay and 60-Watt canopy luminaires were energized at maximum output throughout the 15.5 hour 'day' period. However, dynamic control capabilities allowed the use of daylight harvesting, which significantly reduced the luminaire output and energy usage during the day when the sun was providing various levels of illumination inside the barns. This measured data is quantified in column four of Table 2. On a typical sunny day, most of the luminaires are only operating at 10% of their maximum output due to the DLH system control.

The control of the luminaires by the DLH system is illustrated by the power graph in Figure 5. As can be seen in this figure, non-dimmable LED or HID luminaires would be drawing their rated power through the 'day' period. Daylight harvesting allows the LED luminaires to be dimmed and therefore draw much less power when the sun is bright. As shown on the morning of September 20, clouds had covered the sun for a few hours and the DLH system reacted accordingly, raising the light levels and therefore the power draw.

Although additional data over a longer period of time will be needed to better understand energy savings associated with DLH, the approximately $30,000 extra in equipment for this feature could have a payback of less than 5 years. Table 4 shows the projected yearly energy and cost savings of the implemented system compared to the theoretical HID layout and a featureless LED layout.

**Table 4. Projected annual energy and cost savings of the implemented system**

| Implemented system compared to: | Projected annual energy savings (kWh) | Projected annual cost savings at $0.12/kWh |
|---|---|---|
| HID | 104,446 | $ 12,534 |
| Featureless LED | 52,231 | $ 6,268 |

# Conclusion

The presented and discussed data supports the purpose of this study—that empirical data is necessary to accurately characterize the energy consumption of a long day lighting system that utilizes a dynamically controlled LED lighting system. However, given the difficulties and delays that have been encountered throughout the implementation process of this project, more energy data would be helpful to more accurately represent the energy savings daylight harvesting offers. An additional eight to twelve months of energy data would give a more accurate indication of DLH energy savings. The current data does include winter, which is important since there are many cloudy or overcast days that will cause the luminaires to operate at higher output. Although outside of the purpose of this study, milk data must be collected over the next year and analyzed to quantify a statistically significant increase in milk production. The increase in milk production can then be expressed in terms of additional milking cows and used as a management tool by the farmer. In conclusion, this study shows that the additional control capabilities of an LED lighting system makes LED luminaires an excellent option for LDL.

If this study were to be conducted again, there are a few aspects that the team would change. The main adjustment would be eliminating the requirement that both the lighting and control system must be DLC listed. The project funding partners had this requirement, but it limited the potential lighting and control systems that could be used. While searching for control systems that met the needs of the study, the team encountered other control systems that offered more granular control of the luminaires and required little to no modification. In future replications of this study, the team would evaluate control systems solely based on their features to determine which system would be best suited for this unique application.

Before this technology is ready for widespread use, more energy and milk production data must be gathered to better understand the energy consumption of this system and quantify the increase in milk production for a large farm that milks three times per day. Once the data has been gathered and analyzed, the team and farm owner will work with the Michigan State University Extension staff to disseminate the final data and conclusions from this study for large dairy farms that operate a three a day milking schedule.

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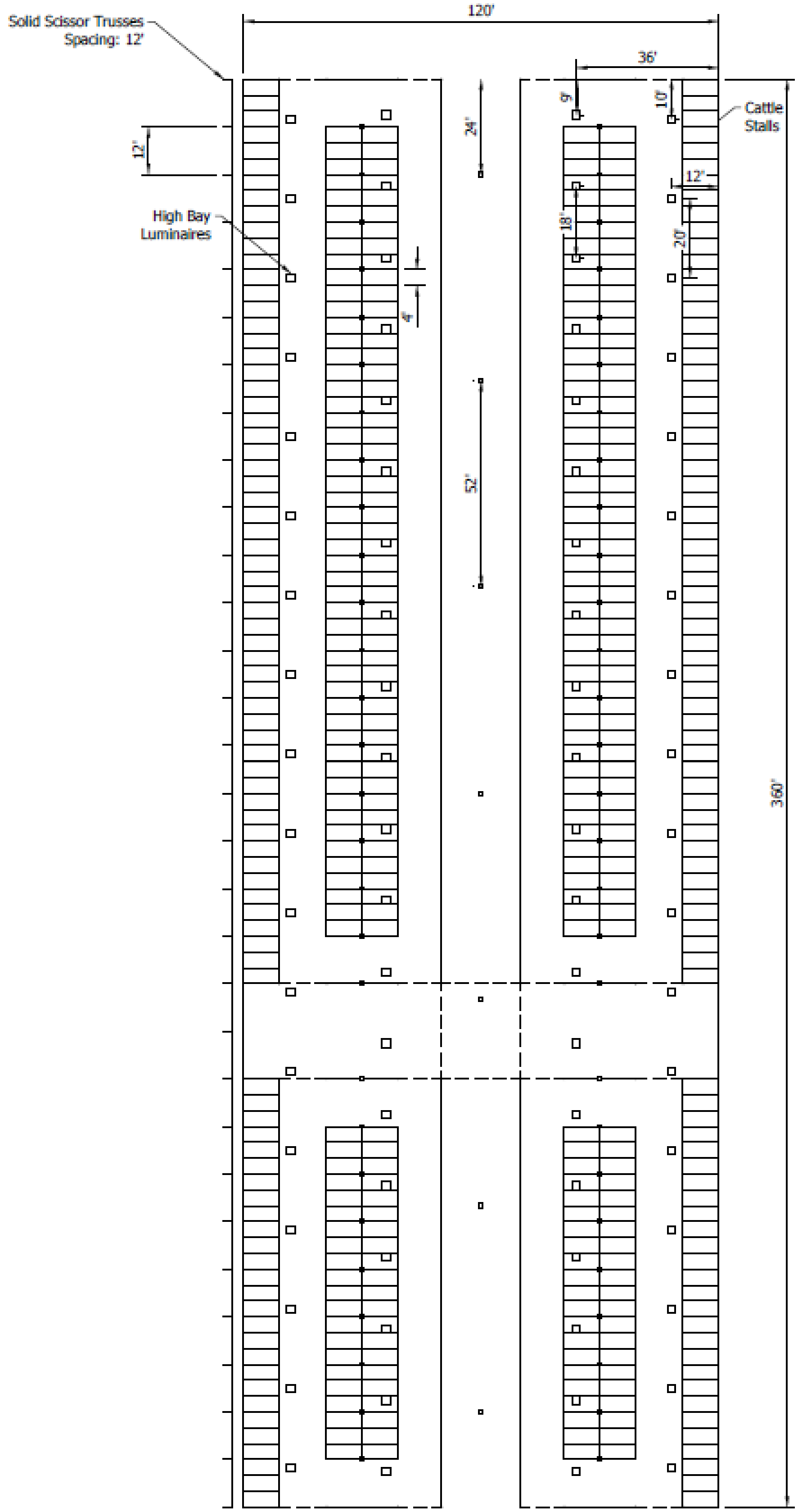
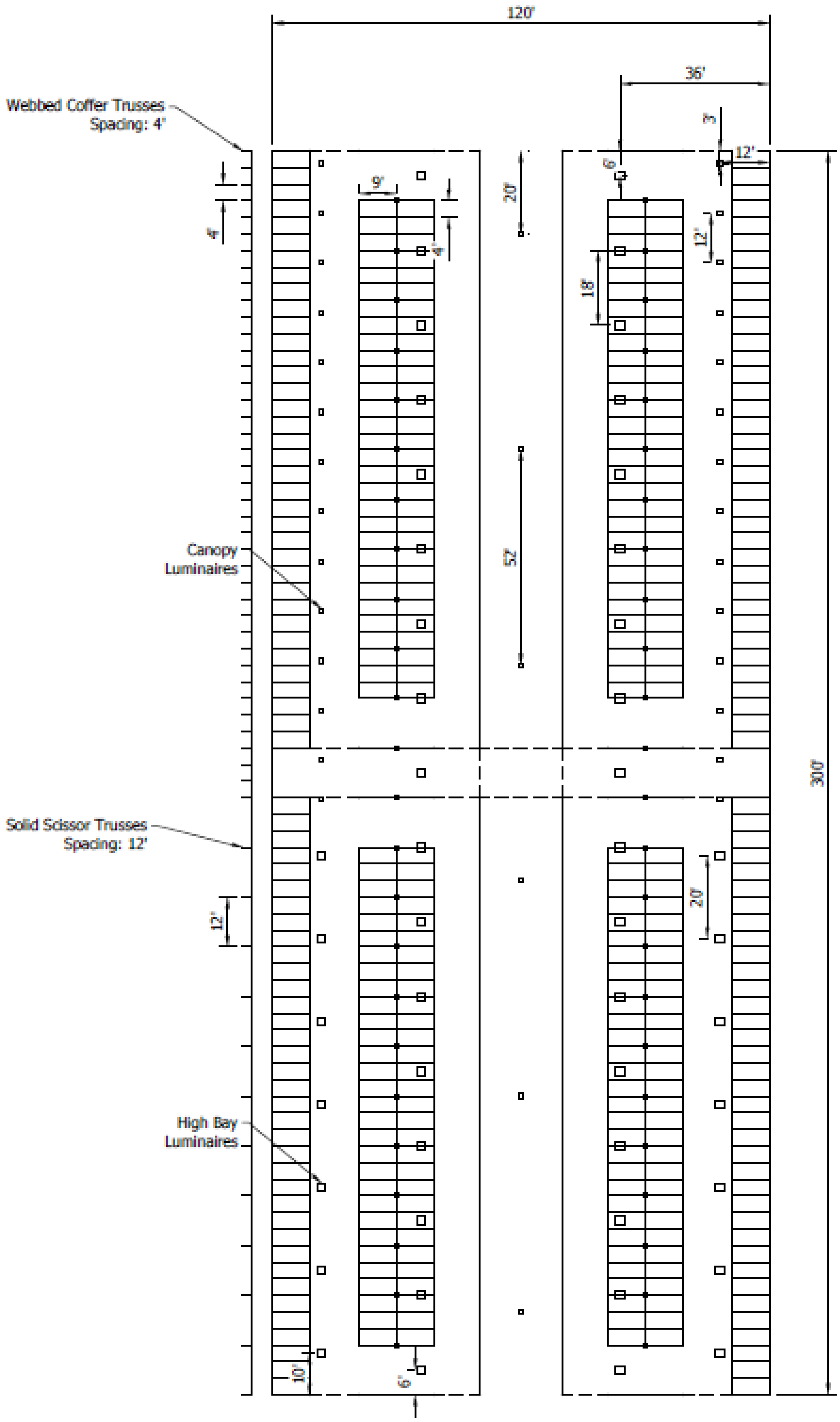
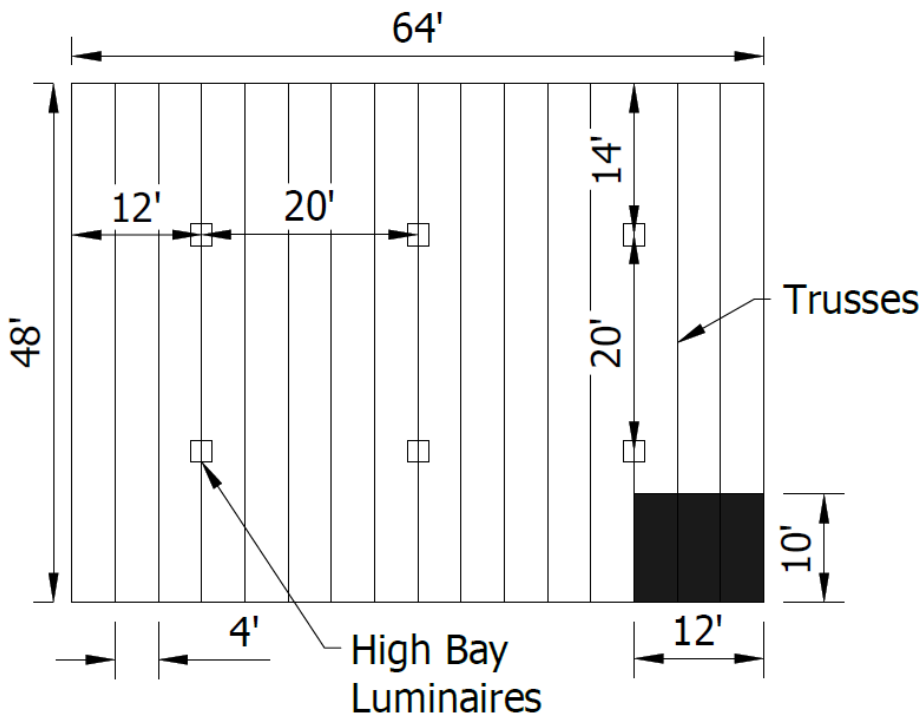
# Appendix A



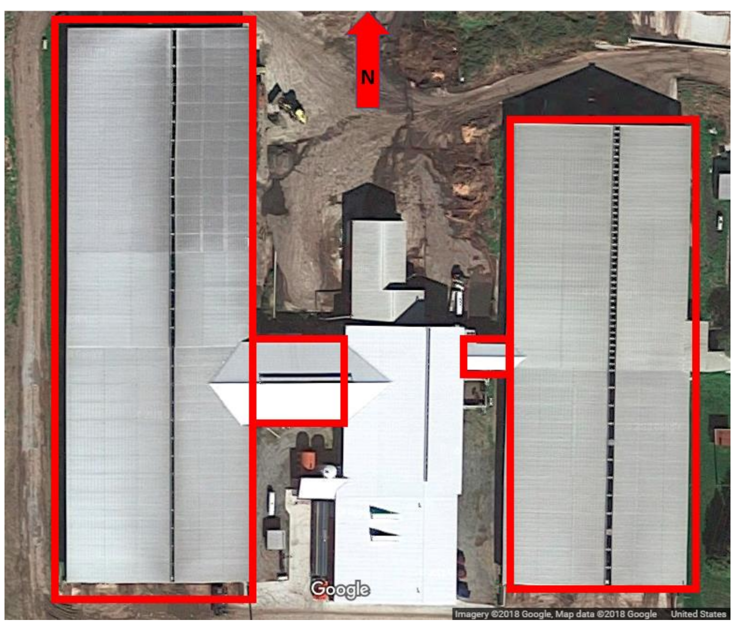

**Appendix A-1. Top view of the west barn with LDL layout**




**Appendix A-2. Top view of the east barn with LDL layout**




**Appendix A-3. West barn parlor connector LDL layout**




**Appendix A-4. Top view of barns. LDL areas highlighted in red**