M.L. 2014 Project Abstract
For the Period Ending June 30, 2017

PROJECT TITLE: Transitioning Minnesota Farms to Local Energy
PROJECT MANAGER: Michael Reese
AFFILIATION: University of Minnesota West Central Research and Outreach Center
MAILING ADDRESS: 46352 State Hwy 329
CITY/STATE/ZIP: Morris, MN 56267
PHONE: (320) 589-1711
E-MAIL: reesem@morris.umn.edu
WEBSITE: https://wcroc.cfans.umn.edu/research-programs/renewable-energy
FUNDING SOURCE: Environment and Natural Resources Trust Fund
LEGAL CITATION: M.L. 2014, Chp. 226, Sec. 2, Subd. 08d

APPROPRIATION AMOUNT: $ 500,000
AMOUNT SPENT: $ 429,012
AMOUNT REMAINING: $ 70,988

Overall Project Outcomes and Results

Agriculture production requires large amounts of fossil energy. The use of fossil energy for agriculture impacts the environment, air, water, and economy. The goal of this project was to provide swine producers with research-based information enabling the transition to clean, locally-produced energy. The project was organized into four tasks.

The first task was to design clean energy systems for modern swine facilities.

- Energy consumption was audited at six commercial swine production facilities and the West Central Research and Outreach Center (WCROC).
- Facilities included breed-to-wean, nursery, and finishing buildings.
- Energy consumption data enabled rankings of energy loads for each phase of production.
- Results, for example, indicated that heat lamps for piglets used on average 49% of the electrical energy consumed in a farrowing facility. Producers would benefit by upgrading to energy efficient heating for piglets.
- An engineering firm analyzed several energy efficiency measures (EEM) appropriate for swine production to reduce energy consumption.
- Return on Investments (ROI) were calculated for each EEM.

Task two involved field testing of a clean energy system.

- A 27 kW solar PV system was installed and tested on the WCROC swine finishing facility.
- The system provided all energy consumed within the facility generating 30,000 kWhr per year.
- Solar PV system ROIs were modeled for commercial swine facilities. Installation costs are declining but incentives are still needed to achieve simple paybacks under 10 to 15 years.

Life Cycle Assessment (LCA) was employed in Task 3.

- LCA was used to analyze the amount of fossil energy consumed and carbon dioxide emitted during swine production. Energy improvements were also modeled.
- Results indicated the Global Warming Potential (GWP) emissions in the broader swine lifecycle were highest for feed production, which accounted for almost 60% percent of fossil energy and 50% of greenhouse gas emissions.
- Producers have management control on roughly 25% of the fossil energy consumed.
- On-farm renewable energy systems can significantly lower fossil energy use on farms.

Task 4 involved dissemination of results and education which is described below.

Project Results Use and Dissemination

The Midwest Farm Energy Conference was hosted at the WCROC in June 2017. Approximately 90 farmers and other guests participated in the event. Swine energy workshops were conducted in other regions of the State. Energy information was provided to producers, who in total, market over 3 million pigs per year and represent over 90% of the State's annual production. In addition, energy curriculum was developed for agriculture and science educators teaching secondary and post-secondary technical students. The curriculum is being made available on-line. Additional materials including conference video and slide presentations can be accessed at https://wcroc.cfans.umn.edu/research-programs/renewable-energy.

Environment and Natural Resources Trust Fund (ENRTF) M.L. 2014 Work Plan Final Report

Date of Report: August 11, 2017

Final Report

Date of Work Plan Approval: June 4, 2014

Project Completion Date: June 30, 2017

Does this submission include an amendment request? No

PROJECT TITLE: Transitioning Minnesota Farms to Local Energy

Project Manager: Michael Reese

Organization: University of Minnesota West Central Research and Outreach Center

Mailing Address: 46352 State Hwy 329

City/State/Zip Code: Morris, MN 56267

Telephone Number: (320) 589-1711

Email Address: reesem@morris.umn.edu

Web Address: wcroc.cfans.umn.edu/

Location:

The research and conference will be conducted in Stevens County. Two workshops will be held in southern Minnesota. The impact will be statewide.

Total ENRTF Project Budget:	**ENRTF Appropriation:**	**$500,000**
	Amount Spent:	**$429,012**
	Balance:	**$ 70,988**

Legal Citation: M.L. 2014, Chp. 226, Sec. 2, Subd. 08d

Appropriation Language:
$500,000 the second year is from the trust fund to the Board of Regents of the University of Minnesota for the West Central Research and Outreach Center in Morris to develop clean energy strategies for Minnesota farms in order to reduce fossil fuel energy use and increase local energy production. Any installation of infrastructure or improvements must be at the University of Minnesota West Central Research and Outreach Center. This appropriation is available until June 30, 2017, by which time the project must be completed and final products delivered.

I. PROJECT TITLE: Transitioning Minnesota Farms to Local Energy

II. PROJECT STATEMENT:

The University of Minnesota West Central Research and Outreach Center (WCROC) has a strategic goal to reduce fossil energy consumption within production agriculture. This project will leverage current efforts by further developing clean energy strategies for Minnesota swine farms. The 2008 MN Climate Change Advisory Group Final Report indicates agriculture contributes 14% of the total greenhouse gas emissions in the state; second only to electrical generation. Production agriculture's dependence on fossil energy carries significant economic and ecological risks. Current research at WCROC is focused on lowering the carbon footprint of grains and feeds through renewable synthetic fertilizer production and reduced field tillage. However, research is needed to optimize clean energy strategies for livestock facilities. According to the National Agricultural Statistic Service, Minnesota has 468,000 dairy cows and 7.8 million pigs (2012). The energy consumed within livestock facilities is the equivalent consumption of several large cities. Minnesota farmers historically have adopted technology to efficiently use resources and optimize production. However, implementation of clean energy technologies on farms has been extremely slow. In lieu of proven systems, farmers continue to opt for conventional fossil-based energy. Adoption of clean energy systems in crop and livestock production will position the State's agricultural sector to be globally competitive particularly as consumers are increasingly demanding low carbon footprint products. The overall project goals are to significantly decrease use of fossil energy, reduce carbon emissions within production agriculture, and to increase adoption of locally-produced renewable energy technologies. The project team proposes to evaluate applicability and implementation of clean energy technologies in swine production. The team will leverage current research by designing and testing integrated clean energy systems, conduct life cycle assessment, and provide producers with tested clean energy designs for swine facilities. Agricultural producers and secondary students will learn about clean energy strategies through research, demonstration, and hands-on learning experiences. Results from this project are anticipated to have a significant impact on transitioning commercial swine production facilities to locally produced, clean energy.

III. PROJECT STATUS UPDATES:

Project Status as of January 1, 2015:

The project is proceeding according to plan, but it has taken a little longer than planned to get all the electric usage data loggers installed in swine barns. All data loggers are now in operation. In addition to total barn electric, LP gas, diesel, and water usage, 76 individual electric loads are being monitored on 6 commercial barns. This data will be used to perform Life Cycle Analyses (LCA) of the various stages of pork production and inform an energy modeling study of swine barns with the goal of developing more efficient and economical energy systems.

By the next report, a solar PV array will be installed on the roof of one of the swine barns on the WCROC campus. Moreover, energy monitoring data collected on WCROC barns and commercial barns will begin to provide an unprecedented view of energy use in pork production.

Project Status as of July 1, 2015:

Energy monitoring in swine barns is continuing. Additional sensors and data loggers have been installed to resolve site specific uncertainties in the electricity usage. Data from these data loggers was presented at the 2015 Midwest Farm Energy Conference held at the WCROC from June 17th to the 19th.

A contract has been initiated to model barns with energy efficiency measures (EEM) to determine what steps could be taken to reduce energy use in swine barns. This should be complete by the next reporting period.

A 27 kW solar PV system was installed on the roof of the finishing barn on the WCROC farm site. The system was interconnected to the utility grid on June 10th, 2015.

Project Status as of January 1, 2016:
Commercial swine building energy monitoring is proceeding on schedule, although several additional sensors and data loggers were added into the buildings to resolve measurement discrepancies.

A contract for swine building energy modeling was executed with the AKF Group, an engineering and design firm with an office located in Minneapolis. Baseline energy models have been completed for three swine buildings on the WCROC campus. Models incorporating energy efficiency measures (EEM) in each building are underway and should be complete by the next reporting period.

Problems with the internet connection to the solar array inverters on the WCROC finishing barn were resolved to allow for more streamlined data collection.

The baseline life cycle assessment model is near completion with the next steps of adding actual energy and production data.

An initial course curriculum outline for secondary and technical students has been completed. The format will allow for the addition of results from this project.

Project Status as of July 1, 2016:
Commercial swine building energy monitoring continues to go well. There have, however, been power issues with several data loggers requiring replacement of the faulty loggers. Originally, 19 data loggers with 76 electric current sensors were installed in 6 commercial swine facilities to monitor electricity usage. It was hoped that the installed sensors would capture 70 to 80% of the total electricity usage in each facility, but there were several more circuits in some of the facilities than expected leaving an undesirably large amount of electricity usage unaccounted for. To remedy this situation, 11 data loggers and 44 current sensors have been added bringing the total to 30 data loggers with 120 sensors across all 6 facilities. There are an additional 3 data loggers with 48 current sensors installed in the three WCROC swine barns.

The AKF Group has completed analysis and modeling of energy efficiency measures (EEM) for all three barns (breed-to-wean, nursery, and finishing). An intern was hired for the summer of 2016 to complete Return on Investment (ROI) calculations for these EEMs, and has made progress on completing this task.

We have continued to monitor solar production from the WCROC finishing barn solar PV panels and an update on production has been included. A second intern was hired for the summer of 2016 to analyze and summarize the data from the WCROC finishing barn's solar array and analyze solar production compared to the electric load profile of the barn.

Amendment Request (August 19, 2016):
Additional funds, over what was originally budgeted, were used to purchase data loggers and AC current sensors for the swine energy monitoring project as part of the LCCMR grant to transition MN farms to local energy. There are three primary reasons that led to the unexpected expenses.

First, the commercial hog farms had complicated electrical systems often with several buildings being powered from a single electrical panel. Moreover, some of the facilities constructed new buildings during our monitoring period which were fed from the same panels and meters we are monitoring. These complications required several additional loggers and sensors to adequately monitor the electrical loads directly related to swine production and to subtract out the new building loads that are not a part of the production activities we are monitoring.

Second, several of the installed HOBO brand data loggers proved to be unreliable by running the batteries down prematurely. Some of these units just need more frequent battery replacement (the advertised battery life is longer than our monitoring period), but some needed to be replaced.

Finally, it was discovered that the primary meter for the nursery barn at the WCROC has been mislabeled on our electric bill for many years. In fact, there is no meter monitoring the nursery barn. A new logger and current sensor set was required to remedy this situation.

The costs associated with installation of the solar PV system for the swine facility came under budget by $24,105. These funds were originally requested if additional supports were necessary on the swine facility roof for mounting the solar system. The added supports were not necessary. Therefore, we request $12,000 be re-budgeted from this budget line to the "Equipment / Tools / Supplies" category with $6,000 each for the "Energy Meters" budget line and the "Data Loggers" budget line. A portion of this request is retroactive to the purchase date of additional meters, sensors, loggers, and similar components. The remaining balance will be used to cover the unforeseen need of battery and component replacement.

As a second request, we wish to re-budget the remaining $12,105 from the "Solar PV System" to the "Personnel" category and the "Junior Scientist" budget line. The collaborating swine producers have agreed to allow a second year of data collection at no-cost / no further stipend. The re-budget will allow us to retain the junior scientist to collect data from the commercial swine facilities on a continued basis.

Amendment Approved by LCCMR 08/30/2016

Project Status as of January 1, 2017:
Energy monitoring in commercial swine barns continues. No additional data loggers or sensors have been added to the commercial facilities. As a minimum, 70% of the total electricity usage in each facility is being measured. There were power issues with several loggers, again, requiring replacement of the faulty loggers. One additional sensor has been added to the WCROC farrowing barn to capture usage from a previously unmeasured circuit.

The AKF Group has completed the final report, "WCROC Swine Barn Energy Modeling Narrative". The report contains final analysis and modeling of energy efficiency measures (EEMs) for all three WCROC swine barns. The intern hired for the summer of 2016 has completed Return on Investment (ROI) calculations for each EEM included in AKF's final report.

Solar production from the WCROC finishing barn solar PV panels continues to be monitored and an update on production has been included. The intern hired for the summer of 2016 has analyzed and summarized data from the WCROC finishing barn's solar array and compared it to the electric load profile of the barn.

Course curriculum for secondary and technical students continues to be developed. A planning committee has been established and dates have been set for the 2017 Midwest Farm Energy Conference which will be June 13th and 14th, 2017. The conference will showcase project results and energy systems to farmers and other agricultural and energy professionals.

Amendment Request (January 30, 2017)
An amendment is requested to the "Other" category within the budget. This requests only impacts Activity 4 and is re-budgeting funds from supporting conference transportation (buses) to other conference budget needs (printing and postage). We propose to reduce the budget for "Buses for the Ag Energy Conference" to $2,000, add a line "Postage for conference brochures and cards" with a budget of $1,800, and add $1,000 to "Publications and printing". The conference planning committee has decided that three buses will not be necessary. For past conferences, we have needed three buses to transport participants to renewable energy sites away from the West Central Research and Outreach Center. The planning committee has decided this past

year that we will only be touring sites at the WCROC which means that one bus will be sufficient to move people back and forth. In addition, we will not be providing transportation with a bus from the Twin Cities as the committee did not feel this has been utilized enough in the past. Therefore, we are requesting postage and additional printing to cover costs of promoting the conference. Our contact listed has been greatly expanded over the past two and a half years since this project began so additional printing and postage is required beyond what was initially projected.

Amendment Approved by LCCMR 02/06/2017

Overall Project Outcomes and Results:
Agriculture production is a large industry within Minnesota and currently requires large amounts of imported fossil energy. The use of fossil energy for agriculture impacts the environment, air, water, and economy. The goal of this project was to provide swine producers with research-based information enabling the transition to clean, locally-produced energy. The project was organized into four tasks. The first task was to design clean energy systems for modern swine facilities. Research began by auditing energy consumption at six commercial swine production facilities as well as the University of Minnesota West Central Research and Outreach Center (WCROC). Commercial swine facilities included breed to wean, nursery, and finishing facilities. Baseline energy consumption data enabled researchers to prioritize high to low energy loads for each phase of production. Then an engineering firm analyzed several energy efficiency measures (EEM) appropriate for swine production. Return on Investments (ROI) were calculated for each EEM.

The second task, was to field test clean energy systems and develop effective control strategies. A 27 kW solar PV system was installed and tested on the WCROC swine finishing facility. On an annual basis, the system provided all energy consumed within the facility generating roughly 30,000 kWhr per year. Solar PV system ROIs were then modeled for commercial swine facilities including incentives available to swine producers.

Life Cycle Assessment was employed in Track 3 to identify areas where swine farm operations could be changed to improve the sustainability of the pork supply chain. LCA methodology was used to analyze the amount of fossil energy used by and carbon dioxide emitted during the swine production cycle. The specific goal of the work was to develop a model for understanding how energy use and greenhouse gas emissions could be reduced using conservation techniques or renewable electricity. Results indicated the Global Warming Potential (GWP) emissions in the broader swine lifecycle were highest for feed production, which accounted for almost 60% percent of fossil energy and 50% of greenhouse gas emissions. The fossil energy portion of the production system that can be directly controlled by the hog growers is producer is roughly 25% of the energy of producing pork. Renewable energy replacements for fossil based electricity, such as solar PV, can significantly lower fossil energy use for swine production.

Track 4 involved dissemination of results and education. The Midwest Farm Energy Conference was hosted at the WCROC in June 2017. Approximately 90 farmers and other guests participated in the event. Swine energy workshops were conducted in other regions of the State. Energy information was provided to producers, who in total, market over 3 million pigs per year and represent over 90% of the State's annual production. In addition, energy curriculum was developed for agriculture and science educators teaching secondary and post-secondary technical students. The curriculum is being made available on-line. Additional materials including conference video and slide presentations can be accessed at https://wcroc.cfans.umn.edu/research-programs/renewable-energy.

IV. PROJECT ACTIVITIES AND OUTCOMES:

ACTIVITY 1: Design clean energy systems for modern swine facilities
Description: The team will utilize the model swine facilities at the WCROC to determine baseline energy use. An engineering firm with experience in modeling and incorporating clean energy systems will use the

information to recommend clean energy systems and rank them based on energy savings and / or return on investment. The engineering firm will complete designs incorporating thermal and electrical energy systems into swine facilities.

Most pork production systems consist of three distinct phases: breeding-to-wean, nursery, and finishing. The breeding-to-wean phase includes adult sows that are mated, housed during pregnancy, give birth to piglets, and raise piglets to weaning age of about 21 days. When piglets are weaned, they are moved to the nursery phase. The nursery phase entails raising a piglet from 3 weeks of age (about 12 lb body weight) to 9 weeks of age (about 50 lb body weight). At the end of the nursery phase, pigs are moved to the finishing phase which houses the pig until about 25 weeks of age (265 lb body weight) when they are marketed. In some production systems, the nursery and finishing phases are combined. During each phase of production (breed-to-wean, nursery, finishing), pigs have very different requirements for the ideal environmental temperature which demands very different inputs of fossil fuels. Previous researchers (Lammers et al. 2010, 2012) have reported the energy use for pork production systems in the Upper Midwest region of the U.S. However, these researchers relied solely on data from the scientific literature to estimate energy use in a variety of pork production systems. They never actually measured the energy consumption of operating, commercial pork production systems.

The study proposed herein will provide actual energy consumption data for commercial pork production systems. The data will be invaluable to our group and other researchers that seek to improve the energy efficiency of pork production systems. We propose to monitor the energy consumption of operating, commercial pork production systems for one calendar year. One year of monitoring is essential to understand influences of seasons and weather patterns on energy use in commercial systems. We will identify commercial pork producers that operate swine facilities that are characteristic of production systems in Minnesota. We will select 2 breed-to-wean, 2 nursery, and 2 finishing farms for monitoring. At each farm, we will record monthly the consumption of electricity and heating fuel. Electric metering / sensing devices will be installed at each farm to record the total amount of electricity used by the farm. Most farms use liquid propane to heat their buildings so we will record the gallons of liquid propane used each month. In some cases, natural gas may be used to heat barns. In those cases, we will use their existing gas meter to record monthly consumption. In addition, we will record monthly inventory of pigs in the building and monthly output of pigs from the farm. The pig outputs on the breed-to-wean farms will be weaned piglets and cull sows. The pig outputs in the nursery phase are the number of pigs moved to finishing and the pig outputs from the finishing phase are the number of pigs marketed for harvest. In addition, we will collect monthly weather conditions from the NOAA weather observation site closest to each pig production farm that we are monitoring.

Based on the analysis of the data, the AKF Group (or an equivalent firm) will model clean energy alternatives for conventional Minnesota swine facilities and will assist in projecting Return-on-Investment for the clean energy systems. As a full service consulting engineering company, the Minneapolis office of the AKF Group has considerable experience in energy design and modeling. AFK has specific experience modeling the variable energy production of on-site renewable energy systems and then matching the generation technologies to the loads. The engineering firm will utilize the baseline energy consumption data measured at the WCROC and on-farm swine facilities to model energy-optimized retrofits. The project team will direct an undergraduate student intern to project the Return-on-Investment (ROI) for a suite of energy-optimized retrofits. The student will also evaluate the impact of Minnesota's new solar incentives on the ROI for producers.

Within the model, potentially all energy loads may be converted to electricity and these loads will be made as small as possible with efficiency upgrades. Eventually, on-site renewable electric generation could supply some or the entire electric load allowing the buildings to approach net-zero (producing as much energy as is used). For example, the swine nursery at the WCROC is representative of current industry practices and uses about 12,000 kWh of electricity and 7,500 therms of natural gas per year. The largest energy load in a nursery is space heating due to the small size of the pigs. In fact, some heating is often required even in the summertime. Heating loads can be efficiently converted to electricity by using a heat pump which has a Coefficient of

Performance (COP) of about 2.5 in a Minnesota climate. The natural gas used in the nursery (7,500 therms) delivers about 132,000 kWh of actual heating energy assuming a 60% efficient furnace. This study will investigate potential heat sources for the heat pump including the ground and air, as well as other unconventional sources like manure lagoons. A heat pump will require about 53,000 kWh of electrical energy to replace the current gas furnaces. One of the goals of the study will be to see if enough energy savings can be obtained to make a building's energy usage less than what can be produced on the roof of that building with a solar PV system. Additional generation could be provided by a small-scale wind turbine or ground mounted solar PV array.

A finishing barn does not have a significant heating load, but does require cooling (even in winter). Cooling is usually accomplished with large amounts of ventilation. Another possibility that will be investigated is using an air source heat pump to provide cooling using chilled beams. Chilled beams are an efficient way to cool a space, but require careful management of humidity to prevent condensation on the beams. Condensation is probably not an issue in a pig barn and may even provide more cooling by dripping water on the pigs. An advantage of chilled beams is they can be installed into existing barns without altering the existing ventilation system and do not place delicate cooling coils in the harsh environment of a pig barn. Cooling may even enhance pig performance on hot days and cooling loads naturally coincide with high solar resource days. One of the questions that will be answered with this study is whether or not the energy needed to provide cooling can be offset by reduced ventilation demands.

Finally, the engineering firm will provide professionally engineered design for installing a 20 kW solar PV system at the West Central Research and Outreach Center swine facilities. Efforts will be made to standardize the design of the solar installation as it potentially may then be utilized for similar on-farm swine facilities. The use of solar photovoltaic (PV) systems is a logical choice to performance test for the production of electrical energy for swine facilities. Standard swine buildings are generally configured in an east to west layout providing an almost ideal southern exposed roof. In addition, new solar PV programs were put in statute during the 2013 Minnesota Legislative Session. Combined with the availability of federal USDA REAP grants and declining costs for solar PV, swine producers may be able to cost effectively generate electricity to meet their load requirements. Solar PV also has peak production capacity during hot summer days which also matches high-energy load times for swine facilities (ventilation and water pumping).

Summary Budget Information for Activity 1: **ENRTF Budget: $ 186,444**
Amount Spent: $ 159,539
Balance: $ 26,905

Activity Completion Date: August 31, 2015

Outcome	**Completion Date**	**Budget**
1. *Install energy meters at the swine facilities and record energy consumption data for one year*	7/30/2015	$109,939
2. *Model clean energy alternatives for Minnesota swine facilities and project return-on-investment*	7/30/2015	$39,058
3. *Complete designs of clean energy systems for field testing at the WCROC swine facilities*	8/31/2015	$37,447

Activity Status as of January 1, 2015:

To begin the research, protocols were established to monitor the WCROC and on-farm swine facilities. A junior scientist was hired on November 3rd to help with installation and monitoring of data logging equipment in swine barns. Since then, all 6 commercial monitoring sites have been selected (2 sow/farrowing units, 2 nurseries, and 2 finishing units) and energy sensors have been installed and are in operation. Additionally, 3 barns on the WCROC campus have been instrumented and data is being recorded. The goal is to collect data for a full year to capture any seasonal variations in energy usage. Monitoring will, therefore, need to be extended through December of 2015.

Arrangements have been made with barn owners to collect purchase records for other energy sources used in the barns like propane and diesel. Water consumption will also be monitored where meters are present or estimated from well electricity sensors where meters are not present. Barn owner pig inventory records will also be provided so energy use can be calculated on a per pig or per pound of pork basis. This information will be the basis of Life Cycle Analyses to be conducted under Activity 3.

The data gathered will also provide the baseline case to be used in the modeling study conducted by AKF. The contract for AKF is in final negotiations so the study should be completed on time.

Activity Status as of July 1, 2015:
Energy monitoring on six commercial farms continues, but there have been unique circumstances on four of the six barns that have required additional sensors. For example, one of the commercial sow units completed construction on a gilt development unit (GDU) on the same site early in our monitoring period. The GDU draws electricity from the monitored sow unit so additional sensors were required to measure the GDU usage so it could be subtracted from the total sow unit usage. Another interesting discovery is that most commercial swine barns have a back-up electric generator with an electric oil heater running year round. These heaters use a surprising amount of electricity requiring additional monitoring or accounting. It is also common for farmers to use portable electric heaters to supplement heat in offices and other areas where water lines might freeze. These are the kind of discoveries that were expected, but they have required modifications to the monitoring plan which will extend the time it takes to get a full year of data. Examples of initial results are presented in Attachment Figures 3 and 4.

The contract to model swine barns including energy efficiency measures (EEM's) has been initiated with AKF Group in Minneapolis. The final report including recommendations for the best facility modifications and clean energy options should be complete by September of this year.

Activity Status as of January 1, 2016:
Commercial swine barn energy monitoring: Both breed to wean facilities added a Gilt Development Unit (GDU) to develop their own breeding sows. However both GDUs use the same utility electric meter as their respective existing facilities - the same meters being used to monitor the total electrical usage at the breed to wean barns for this project. Additional data loggers and sensors were installed to measure the electrical energy passing through the main feeds to both GDUs so it could be subtracted from the meter readings. Additional sensors were also added to several barns to better measure some of the miscellaneous loads like storage room heaters and lights, office equipment, water heaters for worker showers, and heat and air conditioning in office areas because the total size of the unmeasured, miscellaneous load was larger than expected. The additional sensors have resulted in much higher ratios of monitored loads to total metered loads. Ratios of monitored loads range from about 75% in the sow units to over 90% at the finish units. The sow units are very large, complex facilities requiring a lot of workers and continuous effort breeding and caring for the needs of sows as well as the needs of piglets which are being born daily. By comparison, finishing units are much simpler with pigs being housed in group pens for several months needing relatively little human care thanks to automatic feed augers and waterers. Therefore it is expected that there will be more unmeasured miscellaneous loads at the sow facilities than at the finish facilities with the nurseries falling somewhere in the middle. Monitoring will continue through the next reporting period. Data analysis will also continue with the final report containing a summary of all the data from all the barns.

Energy modeling of swine barns: AKF has completed the initial energy model for each type of swine facility – breed to wean, nursery, and finish. The models account for the building geometry, construction materials, energy infrastructure, and management practices. Also, a preliminary decision matrix has been created listing possible energy efficiency measures (EEM) for each barn type with pros, cons, and relative cost opinions. The next stage of modeling will incorporate the selected EEM's to predict potential energy savings and obtain engineering cost estimates so an economic analysis can be completed as well.

Activity Status as of July 1, 2016:

Commercial swine building energy monitoring: Miscellaneous and unknown loads from the commercial barns have been pinpointed, so there is a good grasp on each of the commercial building as a whole in regards to where electricity is being used. As it would be cost prohibitive to purchase more data loggers and sensors to capture 100% of the use in each building, it has been determined where miscellaneous energy is being used by moving sensors around to capture the use of different, miscellaneous loads in these large facilities. At the sow units, electrical energy captured has increased to closer to 80% of the total electrical energy being used. At the nurseries, 70-80% of the energy is being captured; and at the finishing units, 80-90% of energy is being captured by data loggers and sensors. The electrical and thermal data collected from the barns has been analyzed on a per pig basis to obtain preliminary estimates of the amount of electrical energy used and the electrical cost to produce one pig. Electrical, thermal, water, and pig inventory data will continue to be collected on a monthly basis, and the final report is continually being updated with analyzed data. We have been granted permission from the producers to continue to monitor energy use in their facilities until the spring of 2017, allowing us to obtain more consumption data from a second fall and winter.

Energy modeling of swine barns: The AKF Group has completed their final draft on energy efficient measures (EEMs) and it is currently being reviewed by University staff. AKF's final report will be included in the next update. Cost analysis of these retrofits, annual energy savings, and pros and cons for each EEM are included in the draft report. An intern was hired for the summer of 2016 and is performing a Return on Investment (ROI) analysis for each EEM outlined in the model. The intern is also working to evaluate the impact of Minnesota's solar incentives on the ROI.

Activity Status as of January 1, 2017:

Commercial swine building energy monitoring: Electrical energy use captured by installed data loggers remains at 80% in the large commercial sow units, 70-80% in the nurseries, and 80-90% in the finishing barns. The electrical and thermal data collected from the barns has been analyzed on a per pig basis to obtain preliminary estimates of the amount of electrical and thermal energy used and the electrical and thermal cost to produce one pig. The chart below provides preliminary data for the electrical and thermal costs to produce one pig in 2015. Electrical, thermal, water, and pig inventory data will continue to be collected on a monthly basis, and will be included in the final report.

Preliminary 2015 Electric and Thermal Cost to Produce One Pig					
Barn	kWh	Cost in electricity	Gallons of propane	Cost in propane	Total energy cost
BW2	11.4	$1.14	0.34	$0.41	$1.55
BW6	12.2	$1.22	0.31	$0.37	$1.59
N3	2.3	$0.23	0.43	$0.52	$0.75
N7	2.1	$0.21	0.41	$0.49	$0.70
F4	15.4	$1.54	0.25	$0.30	$1.84
F5	3.1	$0.31	0.34	$0.41	$0.72

BW= Breed-to-wean, N=Nursery, and F=Finishing

Energy modeling of swine barns: The AKF Group has completed the final report which has been reviewed by University staff. The report, entitled, "WCROC Swine Barn Energy Modeling Narrative", includes cost analysis of the retrofits, annual energy savings, and pros and cons for each EEM in all three WCROC swine barns. AKF's final report is attached to this report. The intern hired for the summer of 2016 completed Return on Investment (ROI) calculations for each EEM included in AKF's final report. As a requirement of the internship, a research paper was completed and a public presentation was given in August, 2016.

Final Report Summary:

Install energy meters at the swine facilities and record energy consumption data for one year

Understanding energy consumption in conventional swine production facilities is the first critical step towards improving energy systems. Energy monitoring of commercial swine production facilities was performed from November 2014 to April 2017 which was essential in understanding the influences of seasons and patterns on energy usage. To collect baseline energy data, two commercial facilities from west central Minnesota that are representative of typical Upper Midwest swine production systems were selected from each phase of production (Table 1.): two breed-to-wean barns (BWA & BWB), two nursery barns (NBA & NBB), and two finishing barns (FBA & FBB). At each of these facilities, researchers recorded and analyzed monthly consumption of electricity and heating fuel. In addition, monthly pig inventories and monthly pig production of each facility were recorded. All barns were located in west central Minnesota.

Facility Information

Breed-to-Wean Barn A (BWA) was a 2,600 sow facility. The farrowing and north gestation rooms in this barn were power-ventilated, while the south sow gestation rooms were curtain-sided with stirring fans for air movement. The floors were fully slatted with shallow manure pits and scrapers for manure management. The north gestation room consisted of 763 stalls and 8 pens. The south east gestation room consisted of 756 stalls, and the south west gestation room consisted of 612 stalls. The north farrowing barn consisted of four rooms with 52 stalls in each room, which were identical in size, structure, and electrical loads. The south farrowing barn was different than the aforementioned barn and was made up of 9 rooms with 24 stalls in each room. The 9 rooms in the south barn were identical in size, structure, and electrical loads. There were several miscellaneous rooms within the unit used for pressure washers, mechanical rooms, wash rooms, and storage rooms. The unit had a central office area with showers, bathrooms, laundry area, and a kitchen. Lastly, an additional gilt developer unit (GDU) was commissioned during January of 2015 and was dedicated to providing replacement gilts to the main sow unit.

Breed-to-Wean Barn B (BWB) was a 3,300 sow facility. The farrowing rooms in this facility were power-ventilated, and the gestation room was tunnel-ventilated in the summer and power-ventilated in the winter. The floors were fully slatted over deep manure pits for manure management. There were 10 farrowing rooms which were identical in size, structure, and electrical loads. Each room consisted of 48 farrowing stalls. There was one additional farrowing room that was half the size of the other rooms and consisted of 24 stalls. The unit had several miscellaneous rooms that served as a pressure washer room, storage rooms, work room, and refrigerator and wash rooms. The unit had a central office area with showers, bathrooms, laundry area, and a kitchen. During late June of 2015, a new GDU was added to provide replacement gilts for the main gestation unit.

Nursery Barn A (NBA) was a 3,000 head, power-ventilated facility. There were 3 nursery rooms that housed 1,000 pigs each and had fully-slatted floors and were identical in size, structure, and electrical loads. The unit also consisted of a load out and storage area, office and laundry area, and shower room.

Nursery Barn B (NBB) was a 10,200 head, power-ventilated facility. There were 8 nursery rooms that housed 1,000 pigs each and had fully-slatted floors and were identical in size, structure, and electrical loads. There were two additional 1,100 head nursery rooms which also had fully-slatted floors and were identical to each other in size, structure, and electrical loads. The unit had several miscellaneous rooms including a pressure washer room, mechanical room, and storage room. There was also a central office area which had showers, a bathroom, laundry area, and kitchen.

Finishing Barn A (FBA) was a 2,400 head, tunnel-ventilated facility. There were 2 finishing rooms that housed 1,200 pigs each and had fully-slatted floors and were identical in size, structure, and electrical loads. The unit also consisted of a load out and storage area, office and laundry area, and shower room.

Finishing Barn B (FBB) was a 1,060 head, curtain-sided facility. There were 2 finishing rooms that housed 530 pigs each and had fully-slatted floors and were identical in size and structure and consisted of the same electrical loads. The unit also had a central storage room and pressure washer room and a load out hallway.

Table 1. Commercial swine barn details

Barn	Barn Capacity	Barn Type
Breed-to-Wean Barn A (BWA)	2,600 sows	Power-ventilated farrowing and north gestation rooms, curtain-sided south gestation rooms
Breed-to-Wean Barn B (BWB)	3,300 sows	Power-ventilated farrowing rooms and tunnel/power-ventilated gestation room
Nursery Barn A (NBA)	3,000 feeder pigs	Power-ventilated
Nursery Barn B (NBB)	10,000 feeder pigs	Power-ventilated
Finishing Barn A (FBA)	2,400 finishing pigs	Tunnel-ventilated
Finishing Barn B (FBB)	1,060 finishing pigs	Curtain-sided

Figure 1. An example of a power-ventilated

Figure 2. An example of a curtain-sided pig barn.

Biosecurity

Preventing the introduction of potentially devastating disease agents has always been a challenge for pork producers. Typically, strict biosecurity programs are put into effect on pig farms to maintain the health and welfare of the swine and to protect the farmer's financial interests. Renewable energy scientists from the University of Minnesota West Central Research and Outreach Center (WCROC) followed the biosecurity protocols for all commercial facilities and complied with any adjustments throughout the monitoring period. Most breed-to-wean, nursery, and finishing facilities are operated on a continuous basis, therefore they always contain pigs of different ages and weights. To combat the spreading of diseases and sicknesses through a production system, producers follow an All-In/All-Out (AIAO) production method which involves grouping pigs of similar age and weight together. Pigs are farrowed in specific rooms. Weaned pigs from each specific room are kept together and moved to a nursery room and eventually to a finishing room without commingling pigs from other rooms. Marketing is done one room at a time, and rooms are pressure washed and disinfected between groups of pigs to minimize the transmission of disease and sickness (Clark et al., 1995).

Data collection

In each swine facility, data were collected from two general categories of energy used in pork production: electrical energy and thermal energy provided by heating fuel (propane or natural gas).

Electrical Energy
In this study, we measured energy of loads directly related to the pigs. However, to determine if an adequate amount of these loads were being monitored, researchers compared the monthly data recorded by sensors located in the barn (in kilowatt hours) to the electricity provider's billed kilowatt hours used per month. In some facilities where the collected data were not representative of the entire barn, we measured loads that were not directly related to pigs, such as outbuildings not related to the production units, but powered from the same utility meter. Researchers monitored these circuits separately to subtract the usage of these outbuilding loads from the swine barn data.

For BWA and BWB, gilt development units (GDUs) were added in 2015 after monitoring of the barns began. A GDU supports breed-to-wean units but is not directly involved in weaned pig production. So, electrical and thermal energy used in these units was subtracted from the total use of the breed-to-wean barns.
Stand-alone HOBO (HOBO UX120-006M, Onset Computer Corporation, Bourne, MA) data loggers were installed to monitor key individual electric loads. These loads were chosen based on categories known to consume the most energy (e.g. ventilation fans, heat lamps, feed lines) and other loads that are representative of swine production systems (see Table 2). Electrical energy monitoring required access to the barn's circuit breaker boxes to install the data loggers and apply current sensors to specific loads. No wiring was added or altered, and the current sensors simply snapped around existing electrical wiring (Figure 4). CR Magnetic CR9580-10, 20, and 50 ampere (amp) sensors (CR Magnetics, St. Louis, MO) were connected to input adapter cables (CABLE-ADAP10, Onset Computer Corporation, Bourne, MA) using wire nuts and were then plugged into one of the 4 available channels in the data logger. Magnelab DCT 25, 50, 100, 250, and 500 amp sensors (Magnelab Inc., Longmont, CO) were also used. The Magnelab sensors connected directly to input adapter cables which were then plugged into the data logger. The adapter cables were strung through cable gland joints which were installed on the side of the electrical box and the data loggers attached to the side of the boxes using magnets (Figure 5). The self-powered, split core current sensors generate a 0-5 volts direct current (DC) signal proportional to the input alternating current (AC) current. The output signal is average sensing (as instantaneous power varies from one moment to the next) and calibrated to Root Mean Square (RMS) (CR Magnetics).
Each data logger was programmed to collect a current reading every 30 seconds and an average recording from each 30 second recording was stored on the logger every 10 minutes. Data was collected using a laptop equipped with "HOBOware" software (HOBOware Pro Version 3, Onset Computer Corporation, Bourne, MA) and a USB cable connecting the data logger to the laptop. The data were collected monthly and exported from the HOBOware Program into Microsoft Excel (2013). Each 10 minute average value of electric current was converted into power using the power equation described below and multiplied by 1/6 of an hour to determine energy usage in kilowatt hours. The resulting 10 minute average energy usage values were then summed for each load each day to obtain a total energy usage per day.

The measured current is used to calculate the power (kilowatts) and energy (kilowatt hours) consumed by the measured load using the following equation (U.S. Department of Energy, 2001):

$$P = V * I * \ phase * PF$$

Where: *P*= Power in watts
V= Voltage, line to ground, in volts
I= Current, on one phase, in Amperes (Amps)
Phase= Number of phases in the circuit, unitless
PF= Power Factor, unitless

An instantaneous power measurement requires instantaneous measurement of the current and voltage on all phases of the supply lines to every load measured. This would require 6 sensors on a three phase load and would make the number of sensors and data loggers needed for a typical barn cost prohibitive. Several reasonable assumptions were made to simplify the measurement set-up without significantly sacrificing measurement accuracy.

In calculating power, it is important that the voltage is measured between one phase line and neutral. The voltage was measured once when the sensors were installed and was considered to remain constant. This is a reasonable assumption since supply voltage changes very little in a properly wired electrical system. Multi-phase loads were assumed to be balanced meaning the same amount of current flows in each phase line. All multi-phase loads measured in the swine barns were AC motors which, theoretically, produce balanced loads. Assuming balanced loads means only one current sensor is required for each load and that the measured current is multiplied by the number of phase lines to calculate the total current.

The final element in the power equation is the power factor (PF) which varies between zero and one. A purely resistive load like a heating element or incandescent light bulb has a power factor equal to one. An AC motor has a power factor that varies with the load on the motor; higher loading produces a higher power factor. The power factor accounts for the fact that some of the supplied power to a motor is not consumed by the motor, but instead creates the magnetic field that allows the motor to operate. Adding the power factor to the power equation allows the calculation of the power actually consumed by the motor. Operating motors at a low power factor is undesirable, so motors are typically sized so they are at least 70% loaded under normal conditions. A study by the U.S. Department of Energy (U.S. Department of Energy, 1997) shows that a typical motor loaded between 70% and 100% of its rated load will operate with a power factor generally between 80% and 90%. For this study the power factor of all motor loads was set at 85%. These assumptions allow a reasonable estimate of power consumption with a manageable amount of sensor and data logging equipment. . The power factor of loads which had mixed resistive and inductive loads combined into one sensor, for example when measuring a whole electric sub feed panel, were estimated based on the ratio of resistive to inductive loads within the sensor.

Additionally, as measuring the current on all of the loads in each barn was not feasible, other assumptions were made to compare the utility meter data to data collected by researchers. In each barn in this study, the loads from only one whole room in the facility were measured. There were 2 to 11 identically sized rooms within a facility, each containing identical loads. The data recorded from the loads in the measured room were multiplied by the appropriate number of identical loads in the other rooms in the barn. Pig flow through each barn is a continuous process with each period or turn occurring multiple times per year in each room. Therefore, the energy used by each load in a monitored room is representative of all other similar rooms in the facility on an annual basis even though the actual size and weight of pigs is not the same in each room at any given time. Thirty four total data loggers were installed and 133 total loads were monitored across all 6 commercial swine barns.

Equipment uses

Feed system- actuators are a component of a feedline which control the switching on of motors within the feed system to move feed down the line. Feedline motors and feed auger motors are used to move pig feed from feed bins, down the feedline, and into pig feeders. The horsepower (HP) of these motors typically range from 1/4 HP to 2 HP.

Lighting- lighting is used in all areas of a barn. The way lights are used varies across each individual facility due to management practices. Lights might be left on all day in some barns or only used for a short amount of time in other barns. The type of lighting can vary across barns as well. For example, in BWA, compact fluorescent lights (CFLs) were used, whereas light-emitting diodes (LEDs) were used in BWB.

Ventilation- one of the most important components of all pig barns, mechanical ventilation can include different types of fans which can serve different purposes. Ventilation systems are used to control the moisture and heat produced by the animals in the barn. In addition, ventilation systems remove air contaminants produced from manure, feed, and the pigs themselves (Jacobson, 2004). Basket/stirring fans are typically hung inside a room and are used for supplemental cooling and air distribution. Pit fans are mounted on manure pit access ports of deep-pitted barns to remove gases generated by manure. Pit fans are typically used for minimum ventilation. Wall/exhaust fans are used to exchange the desired amount of air in a pig housing unit (Jacobson, 2004). The

primary function of a cool cell is to cool the pigs, and air needs to be drawn through the cool cell by ventilation fans. Therefore, cool cells are part of a ventilation system. Cooling cells work by evaporating water into incoming air which decreases the incoming air temperature.
Manure system- there are different ways in which producers manage their manure. Monitoring in this study included under-slat manure scrapers, which push the manure into a storage system. Water pumps are used to flush shallow manure pits into a manure storage system. Lift pumps are used to lift slurry from the facility into a manure storage system.
Heat (for pigs)- heaters for pig rooms consist of propane, or in some instances, natural gas- fired heaters. The electric load being measured is the heater fan.
Pressure washer- pressure washers are used to clean rooms after a group of pigs has left the room. This minimizes the spread of disease and sickness through the production system.
Curtains- although this is a form of ventilation, curtain ventilation is different than mechanical ventilation, as buoyancy and wind forces are used to naturally ventilate the barn. Curtains can be adjusted to let more outside air through the barn while using minimal electricity.
Heat lamps- as piglets require higher temperatures, especially during the first several days after birth, heat lamps are typically used in breed-to-wean barns to provide supplemental heating. Heat lamps can range from 100 watt bulbs to 250 watt bulbs, depending on management style of the barn.
Controllers- controllers in pig barns rely on sensors in the pig rooms to provide optimal environmental conditions for pigs. Controllers regulate ventilation, heating, and humidity within a room.
Office (human use)- office use includes electrical loads such as space heaters, washing and drying machines for clothes, refrigerators, computers, stoves, lighting, bathroom and shower rooms, water heaters, etc.
Gilt developer- gilt developer units (GDUs) are facilities dedicated to raising replacement females for the sow herd. In the case of both breed-to-wean barns in this study, GDUs were located on the same site. However, the GDUs were managed separately from the breed-to-wean units and could therefore be monitored separately from the sow unit.
Miscellaneous loads- miscellaneous loads included hallway heaters and lights, workrooms, storage rooms, etc.

Thermal energy

For the purpose of this study, data from both electrical and heating fuel consumption was obtained. Heating fuel consumption was obtained from the producer’s records and receipts from gas utility companies. Each of the six commercial buildings used propane to heat their buildings and pressure wash. However, BWA and NBA switched from propane to natural gas during the summer of 2016 and FBB used diesel for pressure washing. At each swine facility, propane tank fill reports and natural gas consumption reports were obtained from the producers and analyzed to observe monthly and yearly use. Due to fluctuations of oil prices throughout the year and variations in costs to each barn, the yearly average price of propane across the six commercial barns was $1.21 per gallon in 2015 and $1.20 per gallon in 2016. These costs were used to calculate the cost of propane per pig produced.

Pig inventories

Monthly pig inventories were reported by each producer, because these numbers can drastically affect energy used in the barn and help in identifying daily routines in the barn. Pig production records were also collected to calculate amount of energy (both electric and thermal) used to produce one pig from each phase of production.

Swine Energy Audit Results and Discussion

The overarching goal of this commercial swine energy monitoring project was to understand how much energy is used to produce weaned piglets, feeder pigs, and market weight hogs, and to determine where, specifically, that energy is used within each production stage. This energy use data can then point to areas where both cost and energy consumption might be reduced.

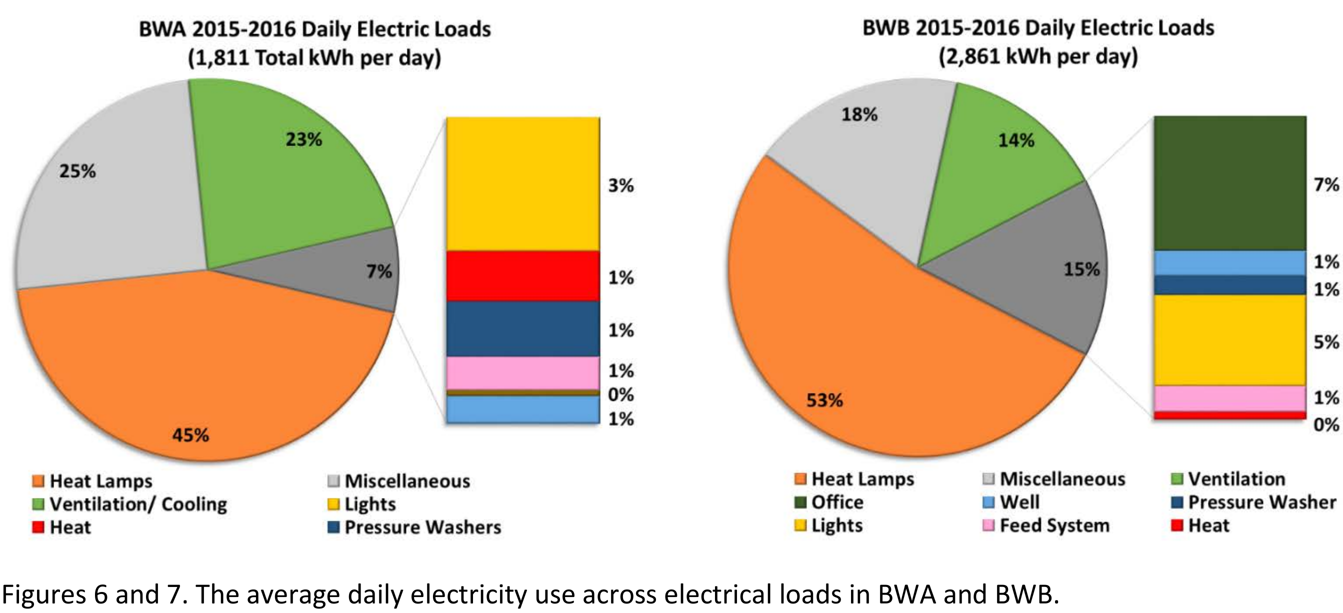
Breed-to-Wean Barn A and Breed-to-Wean Barn B (BWA and BWB)

Electric and thermal energy was calculated using $ .10/kWh for both years (average price per kWh across the Midwest) and $1.21/gal in 2015 and $1.20/gal in 2016 (using the average price per gallon across all units in this study). The kWh used per pig and the associated costs per pig remain fairly constant over the course of both 2015 and 2016 (Table 3). This can be expected, as electricity is used to maintain production and facility management throughout the building and to power fixed and constant loads. Both facilities used comparable amounts of electrical energy to produce one weaned piglet, regardless of barn size and structure.

The daily average electricity distribution across loads in BWA and BWB is shown in Figures 6 and 7. The largest electric load across both units were heat lamps followed by miscellaneous loads. Heat lamps accounted for about 50% of the total electricity used in each facility. Miscellaneous loads are the difference between the facility utility electric meter and the total of all loads monitored during this study. As these breed-to-wean units were extensive in size and complexity, it was simply not feasible to have sensors installed on every single load within the unit. Loads in the miscellaneous category are comprised of loads not directly related to pig care such as hallway heaters and lights, workroom heaters and lights, storage rooms, etc.

Table 3. Electric and thermal consumption and total costs per weaned pig produced.

Year	Barn	Total pigs weaned	Total electricity used by facility (kWh)	kWh/ pig	$ electricity/ pig	Total propane used by facility (gal.)	Gal. propane/ pig	$ propane/ pig	Total energy cost/pig
2015	BWA	57,965	658,558	11.36	$1.14	19,668	0.34	$0.41	$1.55
	BWB	85,874	1,045,541	12.18	$1.22	27,016	0.31	$0.38	$1.60
2016	BWA	58,872	663,751	11.27	$1.13	4,168	0.07	$0.09	$1.29
	BWB	89,469	1,043,038	11.66	$1.17	27,008	0.30	$0.36	$1.53



Figures 6 and 7. The average daily electricity use across electrical loads in BWA and BWB.

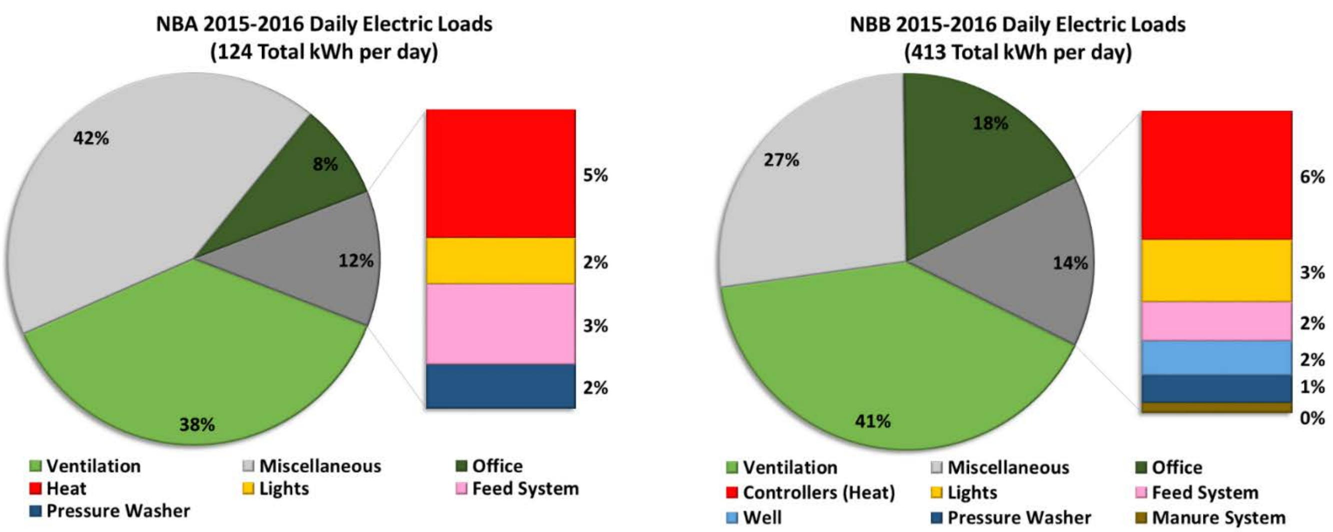
Nursery Barn A and Nursery Barn B (NBA and NBB) Electric and Thermal Energy Summary

The kWh used per pig and the associated costs per pig remain fairly constant over the course of both 2015 and 2016 (Table 4). This can be expected, as electricity is used to maintain production and facility management throughout the building and to power fixed and constant loads. Both facilities used comparable amounts of electrical energy to produce one weaned piglet regardless of barn structure and, most notably, regardless of the fact that NBB was 4 times as large as NBA.

Table 4. Electric and thermal consumption and total costs per feeder pig produced.

Year	Barn	Total feeders produced	Total electricity used by facility (kWh)	kWh /pig	$ electricity/ pig	Total propane used by facility (gal.)	Gal. propane / pig	$ propane / pig	Total energy cost/pig
2015	NBA	19,596	44,354	2.26	$0.23	8,434	0.43	$0.52	$0.75
	NBB	71,522	157,313	2.20	$0.22	31,175	0.44	$0.53	$0.75
2016	NBA	18,609	46,428	2.49	$0.25	4,192	0.23	$0.27	$0.76
	NBB	71,778	143,882	2.00	$0.20	26,975	0.38	$0.45	$0.65

The daily average electricity distribution across loads in NBA and NBB is shown in Figures 8 and 9. The largest electric load across both units was ventilation, which used about 40% of the electricity used by the whole unit. Miscellaneous loads used the second-most amount of electrical energy. Specifically, in NBA, there was an additional shed onsite which contained several smaller electrical loads and a back-up generator equipped with an engine block heater. Monitoring an engine block heater at another site revealed that a block heater can use a significant amount of electricity- up to 36 kWh per day.



Figures 8 and 9. The average daily electricity use across electrical loads in NBA and NBB.

Finishing Barn A and Finishing Barn B (FBA and FBB) Electric and Thermal Energy Summary

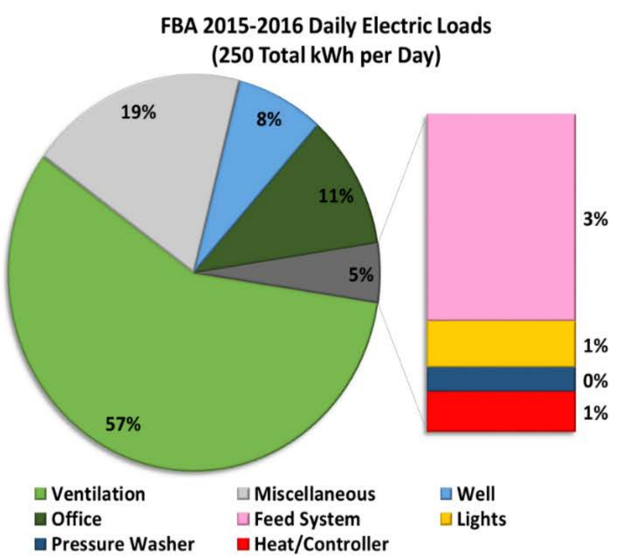
In comparing FBA and FBB (Table 5), a relatively large difference is seen in the electrical use of each barn. As FBA was a tunnel-ventilated barn and FBB was a curtain-sided barn, FBA was expected to use (proportionally) more electrical energy than FBB due to the increased ventilation requirements. There was also a slight rise in the amount of electricity used at FBB from 2015 to 2016. This can be attributed to the fact that during 2016, the pigs entered the barn at a lower weight which required heater fans to be used more to provide adequate heating for the smaller pigs. Another reason FBB saw a rise in electricity use was because from May 2015 to March 2016, one pit fan motor was not working. When the fan was fixed in March 2016, a rise in ventilation occurred. Comparing propane use of FBA and FBB in Table 5, FBB used slightly more propane per market pig than in FBA. This result was expected due to the fact that FBB was a curtain-sided barn, meaning there is typically less insulation on the curtains than there would be on a solid-walled barn such as FBA. Another result to note is that propane use in FBB was higher during 2016 than 2015. Again, propane use increased due to the fact that the pigs in this barn were placed in FBB when they were at a lower weight compared to 2015. The smaller pigs therefore required more heating to maintain pig performance and comfort.

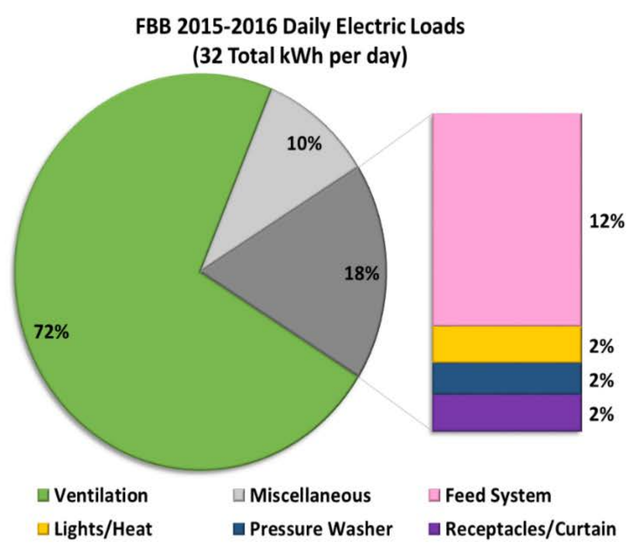
Table 5. Electric and thermal consumption and total costs per finished pig produced.

Year	Barn	Total Market Hogs produced	Total electricity used by facility (kWh)	kWh/pig	$ electricity / pig	Total propane used by facility (gal.)	Gal. propane / pig	$ propane / pig	Total energy cost/pig
2015	FBA	5,837	90,048	15.43	$1.54	1,440	0.25	$0.30	$1.84
	FBB	2,970	9,282	3.13	$0.31	996	0.34	$0.41	$0.72
2016	FBA	6,819	92,231	13.53	$1.35	2,990	0.44	$0.53	$1.88
	FBB	2,655	13,928	5.25	$0.52	1,695	0.64	$0.77	$1.29

*FBB used diesel to provide fuel to a pressure washer. As the diesel tank is located on the farm site and is used for other machinery, an estimate of 75 gallons of diesel per year was used by the pressure washer as estimated by the producer.

The daily average electricity distribution across loads in FBA and FBB is shown in Figures 10 and 11. The largest electric load across both units was ventilation, which used over 50% of the electricity used by the entire barn. In the case of FBA, there was an additional shed onsite which was powered from the same utility meter. The shed had several smaller electrical loads as well as a generator engine block heater. Through monitoring of an engine block heater on another site, researchers concluded that the block heater may have used a significant amount of electricity- up to 36 kWh per day if running all hours of the day (during winter, for example). We are confident that in both units, electrical energy used directly for the care of the pigs was adequately captured.





Figures 10 and 11. The average daily electricity use across electrical loads in FBA and FBB.

The objective of this study to provide actual baseline electric and thermal energy consumption within pork production systems in the Upper Midwest was accomplished. Previous studies have reported energy use within these systems, however, this is the first study of its kind to parcel out individual electric use past the utility meter. This unique aspect allows insight into where electrical energy is specifically being used within each phase of pork production and where there is potential to reduce usage.

The findings from this study are comparable to other industry reported measures. Anecdotal evidence from a breed-to-wean production system of 70,000 sows, indicates average electrical use per weaned pig was 9.7 kWh across the whole system. Units within this system ranged from 5 kWh to 12 kWh per weaned pig, the 5 kWh per weaned pig unit having put various efficiency measures into place. Comparing these industry findings to this study where results ranged from 11.27 to 12.18 kWh per weaned pig produced, the findings from this study are comparable with those of the previously mentioned measures. As electric energy was further parceled out among various loads within the breed-to-wean units, the findings of this study point to areas within barns where there is a potential to reduce usage such as in heat lamps, which were found to be the top users of electrical energy by far across breed-to-wean units.

Nursery findings from this study are also comparable to other industry measures. Brumm (2015) reported industry measures of about 1.8 kWh and 0.31 gallons of propane per feeder pig produced. These measures are comparable to our findings, which ranged from 2.0 kWh to 2.49 kWh per feeder pig produced and from 0.38 to 0.44 gallons of propane per feeder pig produced.

Finishing industry measures from Brumm, (2015) also report 11.2 kWh per finished pig produced in a tunnel-ventilated unit. Our findings, which ranged from 13.53 kWh to 15.43 kWh per finished pig produced in FBA, are comparable with the aforementioned measure. The differences may arise from several factors such as overventilation (especially during the winter), additional space heating, or geographical location.
All barns are unique based on barn size and structure, ventilation systems, manure systems, climate and geographical location and management style. Therefore, it was expected that there may be some differences within this study from unit to unit. However, differences are minimal, and we are fully confident that our results capture an accurate depiction of Midwest pork production units and point to areas with production phases where there is potential to reduce both electric and thermal energy consumption.

The complete swine energy audit report is included in the supporting documents.

Swine Energy Audit References

Barber, E.M., H.L. Classen, and P.A. Thacker. 1989. Energy use in the production and housing of poultry and swine- an overview. Can. J. Anim. Sci. 69: 7-21.

Brumm, M. 2015. Production Contracts [PowerPoint slides]. Retrieved from personal source.

Clark, K., C. Hurt, K. Foster, J. Hale. 1995. Positioning your pork operation for the 21st century- Chapter Nine: All-In/All-Out Production. Purdue University Cooperative Extension Service, West Lafayette, IN. Accessed May 24, 2017. http://www.ansc.purdue.edu/swine/porkpage/21stcentury/chapter09.pdf.

FAO, 2006a. Livestock a major threat to the environment. Food and Agriculture Organization of the United Nations, Rome, Italy. Accessed July 19, 2016. http://dicaveggie.com/wp-content/uploads/2014/10/Livestock-a-major-threat-to-environment.pdf.

FAO, 2006b. World Agriculture: Towards 2030/2050, Interim Report. Food and Agriculture Organization of the United Nations, Rome, Italy.

FAOstat, 2014. United Nations Food and Agriculture Organization Statistical Databases and Datasets. Accessed July 19, 2016. http://faostat3.fao.org/browse/Q/QA/E

Jacobson, L.D. (2004). Mechanical Ventilation for Pig Housing. Retrieved from http://www.thepigsite.com/articles/186/mechanical-ventilation-for-pig-housing/

Lammers, P.J., M.D. Kenealy, J.B. Kliebenstein, J.D. Harmon, M.J. Helmers, and M.S. Honeyman. 2012. Energy use in pig production: An examination of current Iowa systems. J. Anim. Sci. 90: 1056-1068.

McMichael, A.J., J.W. Powles, C.D. Butler, and R. Uauy. 2007. Food, livestock production, energy, climate change, and health. The Lancet. 370: 1253-1263.

USDA. 2016. Quarterly Hogs and Pigs. USDA National Agricultural Statistics Service, Washington, DC. Accessed July 19, 2016. http://usda.mannlib.cornell.edu/usda/current/HogsPigs/HogsPigs-06-24-2016.pdf.

U.S. Department of Energy. 1997. Determining Electric Motor Load and Efficiency. 1st ed. Accessed June 27, 2016.http://infohouse.p2ric.org/ref/40/39569.pdf.

U.S. Department of Energy. 2001. Improving Fan Performance- A Sourcebook for Industry. Accessed June 27, 2016. https://energy.gov/sites/prod/files/2014/05/f16/fan_sourcebook.pdf.

Model clean energy alternatives for Minnesota swine facilities and project return-on-investment

The following swine energy modeling results are summarized from information developed by the AKF Group, the engineering firm that was commissioned for this task. The WCROC swine program consists of barns for each of the three major swine production stages. These barns are representative of typical commercial operations for gestation/farrowing, nursery, and finishing. The barns are located at the WCROC facility in Morris, MN.

AKF Group has prepared energy models to determine the energy cost impacts of the proposed design and renovations. The existing buildings were calibrated using owner provided energy use data as well as data collected from typical commercial barns serving the same functions. The calibrations are intended to represent the actual facilities at the WCROC with commercial production operating schedules. The calibrated models were then used to analyze the results of potential energy conservation measures (ECMs). The ECM's were determined prior to developing the energy models using a decision matrix for each barn type.

The energy models used to estimate and compare annual energy consumption have been created with the software program eQUEST, version 3-64, using the DOE-2.2 simulation engine developed by the US Department of Energy. The program calculates building energy use on an hourly basis for 8,760 hours per year (full year) and utilizes typical meteorological year (TMY) weather data.

Table 6. Summary of Energy Conservation Measures Modeled for the WCROC Swine Facilities (AKF Group)

ECM	Barn	Electrical Savings (kWh/yr)	Natural Gas Savings (therms/yr)	Propane Savings (gallons/yr)	Energy Savings (MBtu)	Energy Cost Savings ($)	Energy Cost Savings Propane ($/yr)	Installed Cost Opinion* ($)	Natural Gas Payback (yrs)	Propane Payback (yrs)
LED Lighting										
	Nursery	6,173	(88)	(97)	12.3	530	430	6,000	11.3	14.0
Daylight Harvesting										
	Nursery	4,999	(70)	(77)	10	430	351	1,500	3.5	4.3
Solar Chimney										
	Nursery	2,100	-	-	7.2	202	202	6,000	29.7	29.7
Curtain Sided Barn										
	Finishing	10,607	(224)	(246)	13.8	856	603			
Earth Tube Pre-conditioning										
	Farrowing	(1,736)	1,349	1,482	129.0	823	2,353	10,000	12.2	4.3
	Nursery	(4,388)	1,899	2,087	174.9	944	3,125	20,000	21.2	6.4
	Finishing	(1,873)	493	542	42.9	181	741	10,000	55.2	13.5
Variable Speed Fans										
	Nursery	1,979	-	-	6.8	191		1,000	5.2	
	Finishing	347	-	-	1.2	33		1,000	29.9	
Heat Lamp Controllers										
	Farrowing	7,431	(194)	(213)	6.0	573	353	3,000	5.2	8.5
Night Temperature Setback										
	Nursery	-	928	1,020	92.8	690	1,734	500	0.7	0.3
	Finishing	-	471	518	47.1	340	880	500	1.5	0.6
Water to Water Heat Pump										
	Farrowing	7,500	-	-	25.6	722		50,000	69.2	
Air Conditioning (Traditional)										
	Nursery	2,593	(17)	(19)	7.2	237	218	80,000	337.6	367.1
	Finishing	3,265	33		14.5	338	314	80,000	236.7	254.4
Air Conditioning (Geothermal)										
	Farrowing	(30,671)	4,607	5,063	356.0	427	5,653	175,000	409.8	31.0
	Nursery	(34,711)	4,634	5,092	345.0	59	5,314	200,000	3,389.8	37.6
	Finishing	(4,780)	1,229	1,351	106.6	441	1,836	150,000	340.1	81.7

Energy Modeling Conclusions

Outdoor air ventilation is required 24 hours per day in all swine barn types to control moisture and odor from the manure pits below the pens. This heating load caused by the ventilation is the largest energy user in the barns. ECMs that reduce the heating load of the required ventilation, such as earth tube pre-conditioning, can be very effective in reducing the energy use and cost of swine barns.

The decision to implement any of the above ECMs will largely depend on the goals of the owner. Options like LED lighting and night temperature setback are relatively simple to install and could provide value regardless of the goals. Other ECMs, like geothermal, have large energy and cost savings but will have high initial capital costs and the simple payback on investment may be too high to be effective on a cost saving basis. However, if the goal were to eliminate natural gas/propane usage and to have a Net Zero facility that could run on renewables, then geothermal may be worth the investment.

Combining ECMs will reduce the impact of some of the individual measures but can result in a final product that has a great savings and shorter simple payback. This would require further energy modeling to determine the value of the different combinations of options. The driving factor in the cost of the geothermal option is the heating load it is sized to handle. As this load is reduced through ECMs like earth tube pre-conditioning and night temperature setback the size and cost of the geothermal wellfield will decrease and make it a more attractive solution. As technology develops, costs tend to decrease so the economic viability may improve with time.

The complete AKF Swine Energy Modeling report is included in the supporting documents.

ACTIVITY 2: Field test clean energy systems and develop effective control strategies

Description: A 20 kW solar photovoltaic system will be installed at the WCROC swine facilities. Control systems will be installed and field tested. The control of farm-scale clean energy systems is deficient and a barrier to adoption of clean energy systems. The control system will integrate building control regimens with the often variable solar PV generation. The solar PV system will be performance tested for two years for production and reliability. Once installed, production data from the 20 kW solar PV system will be measured and analyzed over a two year time frame to determine gross and net energy production including diurnal and seasonal variation. The project team will direct an undergraduate student intern to assist in collecting data and evaluating the results. The student intern will develop a written report and provide a public presentation summarizing the results from the field test of the solar PV system.

Summary Budget Information for Activity 2:	**ENRTF Budget:**	**$ 203,089**
	Amount Spent:	**$ 170,879**
	Balance:	**$ 32,210**

Activity Completion Date: June 30, 2017

Outcome	**Completion Date**	**Budget**
1. *Install a 20 kW solar PV system at the WCROC swine facilities*	7/15/2015	$104,048
2. *Install automated control systems to integrate clean energy systems*	7/15/2015	$33,650
3. *Conduct field tests with control systems*	6/1/2017	$30,207
4. *Performance test of the solar PV system for up to two years*	6/30/2017	$35,183

Activity Status as of January 1, 2015:

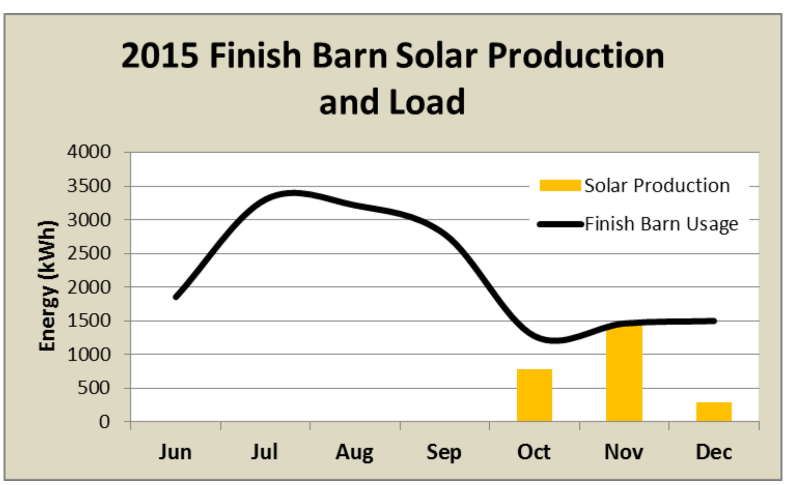
One of the swine barns on the WCROC campus will host a solar PV array. Two of three bids have been received for this system and both are within the allotted budget so this task should be completed on time.

Activity Status as of July 1, 2015:

A 27 kW PV system was installed by Zenergy LLC from Sebeka, MN, and was interconnected to the utility grid on June 10th. The system consists of 96 Heline 60M, 280 Watt modules (See Pictures 3 and 4) meeting the Made in Minnesota (MiM) program requirements. The system came within budget and should produce about 36,000 kWh of electricity per year. Additional larger expenses have been incurred as a result of the solar installation but are not shown in the Summary Budget Information as the expenses did not reconcile prior to this report.

Activity Status as of January 1, 2016:

There were a few problems with the internet connection to the array inverters which prevented data collection until mid-September. The data is available and is stored in the utility meter that was installed during interconnection and will be retrieved from the utility. The chart below shows the system production so far

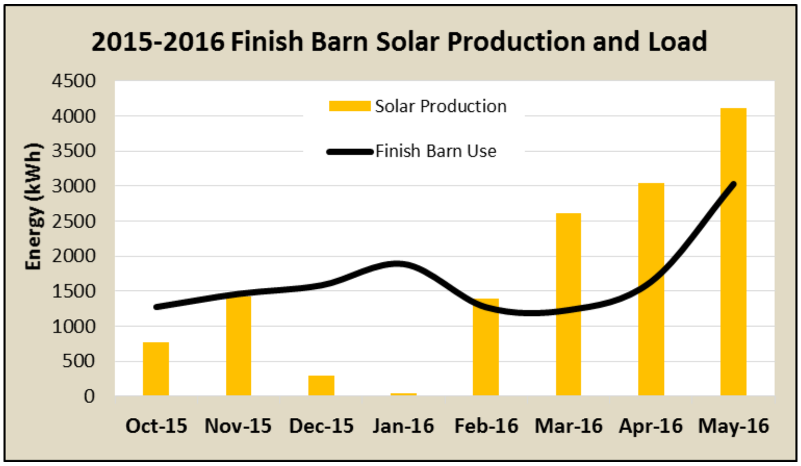


(minus the missing data) compared to the electricity actually used in the finish barn during the same time frame. The finish barn electrical usage is from a utility meter dedicated to the finish barn.

December typically produces the lowest solar energy output of the year and this December has been particularly cloudy. The panels have been covered in snow for a good part of the month as well. Pictures are being taken to document how quickly snow clears from the panels. So far it has taken about 5 days for the panels to clear after a snow fall and there have been several snowfalls this December. This will continue to be monitored and compared to other solar energy systems.

Activity Status as of July 1, 2016:

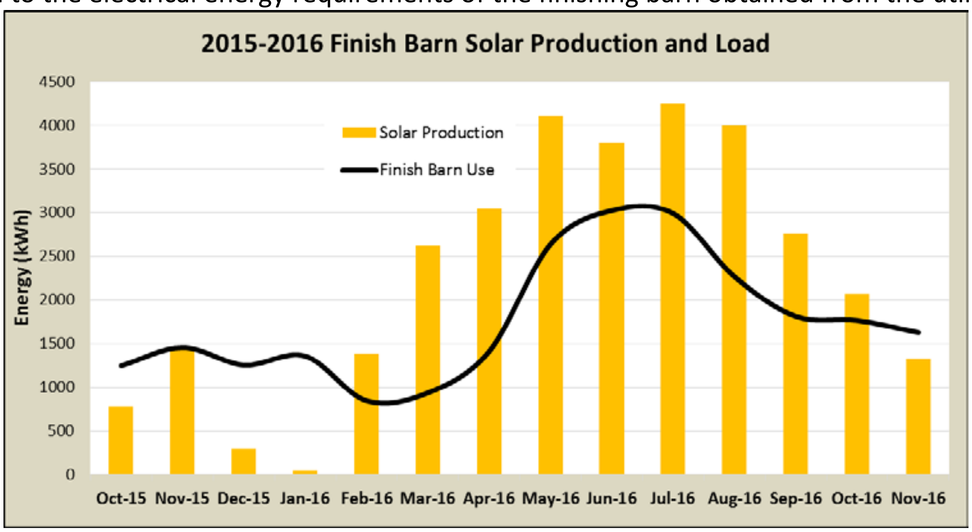
A summer intern was hired to collect data and evaluate production results from the 27 kW solar photovoltaic array installed on the roof of the WCROC finishing barn. The chart below shows the production from the array compared to the load in the finishing barn taken from the utility meter.



As it was predicted early on in the project, the solar array will produce the most energy during the summer months, when solar radiation is highest. The predicted increased production can be observed beginning earlier this spring and is well matched to the increasing load due to expanded use of ventilation fans to cool the pigs.

Activity Status as of January 1, 2017:

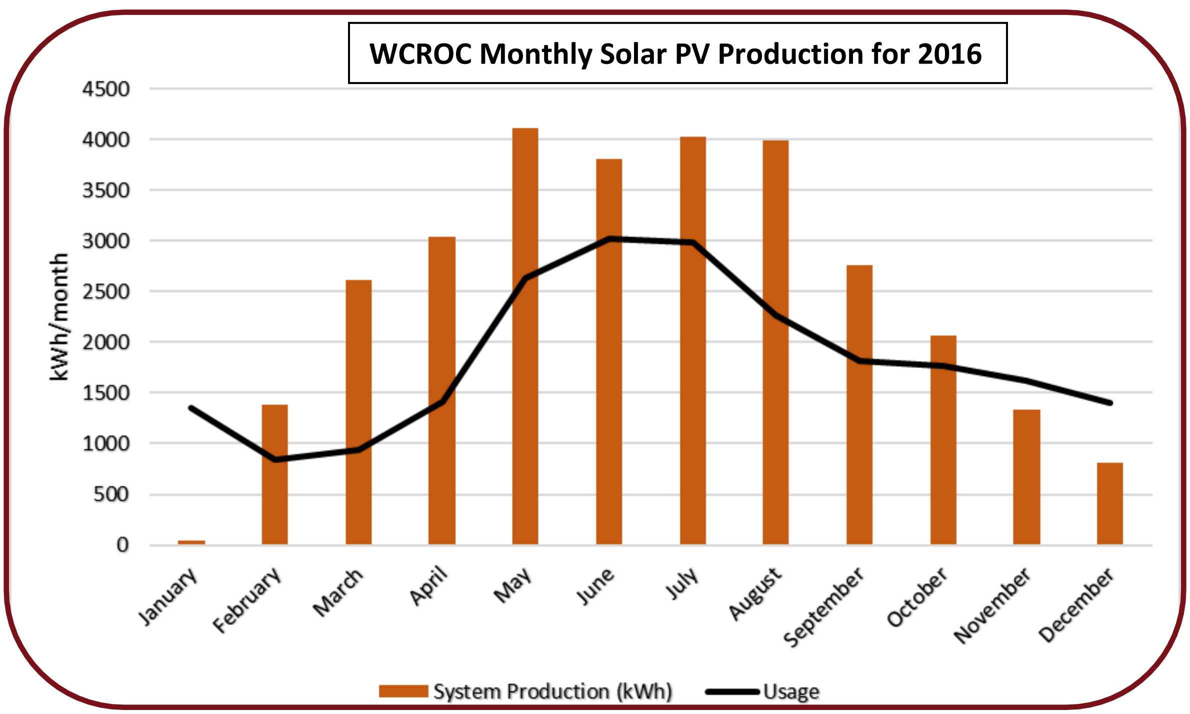
The intern hired during the summer of 2016 analyzed production results from the 27 kW PV array installed on the roof of the WCROC finishing barn. As a requirement of the internship, a research paper was completed and a public presentation was given in August, 2016. The chart below displays the updated production from the PV array compared to the electrical energy requirements of the finishing barn obtained from the utility meter.



As can be seen in the chart, the production from the solar array remains consistent with predicted production. During the summer, the finishing barn required more energy due to an increased use in ventilation fans. During this time when solar energy was more available, production of the solar array exceeded the requirements of the entire barn. As the days become shorter, solar production is predicted to decrease as can be seen above. The array will be monitored for snow cover this winter to document how quickly snow clears from the panels.

Final Report Summary:

The focus of Activity 2 was to begin the process towards improving swine energy systems and the first step was to install and test a solar PV system on the WCROC swine finishing facility. A 26.9 kW DC array was installed in June 2015. The system utilized 96 Heliene model 60M 280 modules. Heliene qualifies as "Made-in-Minnesota" and this designation could be utilized by some Minnesota swine producers for additional incentives from Xcel Energy. Each module provides 280 watts and has an efficiency of 17.4%. Three SolarEdge SD9k inverters were also installed. SolarEdge power optimizers were also on each module. One full year of data is presented in the graph below. An important question is addressed with this graph. Is there adequate roof space on swine facilities to produce all the power required within the facility? The graph shows that more power is produced on an annual basis than what is consumed in this particular case. On a monthly basis, energy generation is higher than load in most months except during winter. Insolation is lower in winter months but snow build up also occurred at various times during the winter. Mounting solar PV systems on the ground will allow for easier access to remove snow. If space is limited and roof top installation is required, some losses may need to be included in financial modeling for days that snow covers panels.



A basic economic evaluation was performed on the WCROC solar PV system. Annual production from the system was approximately 30,000 kWh per year over the course of two years. Annual value of electricity sold equaled $3,000 (at $0.10 /kWh). The capital cost of the system was $86,000 or $3.18 / watt. Without state and federal incentives, this resulted in a 28.7 year simple pay back. If the 30% federal investment tax credit was added, a 20 year simple payback would be achieved. Adding the Made-in-Minnesota incentive for 10 years at $0.15 / kWh would result in an 11.5 year simple pay back.

Finally, a case study and financial model were developed using various system sizes and incentives. The table below indicates the system size and whether a specific incentive was included in the model. This table can be used by livestock producers to get a general idea if a solar PV system may work for them. However, each location and farm has unique variables so it is necessary to evaluate on an individual basis.

Case Study of Solar PV with Various Sizes and Incentives

Size (Name-plate KW)	Capital Costs ($)	1st Year Production (KWh)	1st Year Revenue ($)	ITC	MACRS Depre-ciation	Grants	Xcel Solar Rewards	MiM	Simple Payback (Years)
20 kW	$60,000	28,000	$2,800	●	●				18
20 kW	$42,000	28,000	$2,800	●	●	●			9
20 kW	$60,000	28,000	$5,040	●	●		●		10
20 kW	$60,000	28,000	$5,880	●	●			●	**8**
20 kW	$60,000	28,000	$5,040	●	●	●	●		**4**
20 kW	$60,000	28,000	$5,880	●	●	●		●	**3.5**
40 kW	$120,000	55,073	$5,507	●	●				18
40 kW	$84,000	55,073	$5,507	●	●	●			**9**
40 kW	$120,000	55,073	$11,565	●	●			●	**8**
40 kW	$84,000	55,073	$11,565	●	●	●		●	**4**
65 kW	$195,000	85,028	$8,503	●	●				18
65 kW	$136,500	85,028	$8,503	●	●	●			**9**

Another task within this activity was to install upgraded control systems and test various control strategies. The solar PV system was operated continuously after installation to obtain production data. Upgraded controls were installed in the swine facilities. These controls allow for automated control of HVAC systems. Initial testing was conducted to refine operation parameters. Control strategies will be further evaluated in the second phase of this study which is currently in progress. The second phase brings in additional optimized energy measures which may allow for dynamic strategies.

ACTIVITY 3: Perform a life cycle assessment

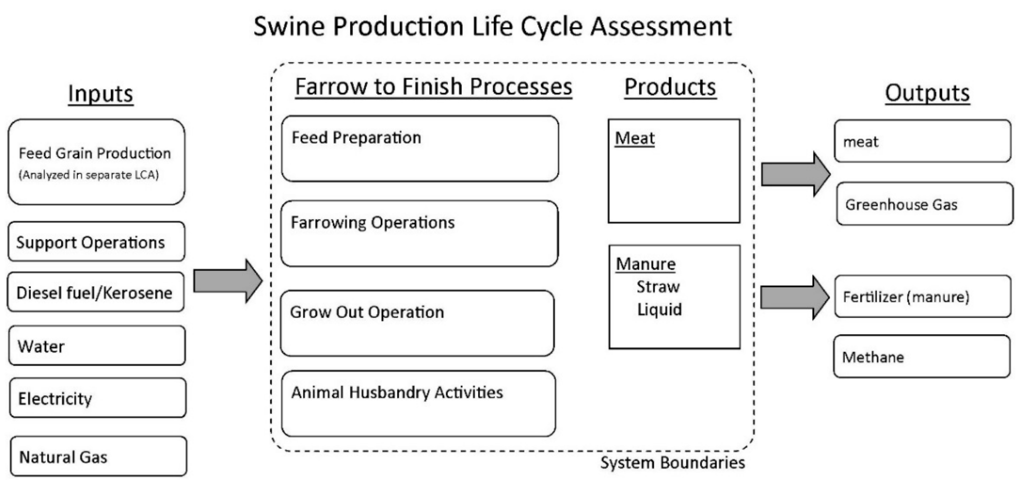
Description: A life cycle analysis will be performed on the WCROC swine nursery comparing conventional with the clean energy systems. This study will use life cycle assessment (LCA) to quantify the potential for energy conservation in swine production. Life cycle assessment is an accounting method used to track inputs and outputs in complex production and manufacturing systems. This work will build upon ongoing studies of the baseline energy consumption in swine, dairy, and cropping systems being researched at WCROC. In that work, the standard amount of energy used for producing pork, milk, and grain is also being analyzed using LCA methodology. This project will further refine the baseline fossil energy used in producing pork, and then assess the energy and greenhouse gas emission impacts of introducing energy-saving technologies into the swine production system. Technologies being investigated include adding solar PV panels to the facilities, bringing in more efficient ventilation systems, and possibly adding heat pumps. Each of these technologies will be selected based on the costs of retrofitting existing hog facilities, ease of use by producers, and potential to save energy.

For this project, the LCA methodology involves first identifying all inputs and outputs associated with producing hogs. This work will be done using WCROC's swine production research facilities as an energy test bed. An analysis will be conducted to identify high energy inputs such as heating and cooling facilities, feeding animals, construction/operation of the farm buildings and equipment, and all activities related to manure management. Seemingly smaller inputs into the system (like water, medications, and office facilities for staff) will also be documented. Each of these inputs is analyzed in terms of how much fossil energy was needed to incorporate the specific input into the swine production system. The next step is to examine the outputs from the system; in this case the main outputs will be live pigs leaving the facility and manures which will be used as fertilizer.

Using specifically designed LCA software, these inputs and outputs will be linked together in a complex model that ties the amount of inputs (i.e. BTUs of fossil energy) to the units of output (lbs of live pig). The final analysis will examine how many BTUs of fossil energy are needed to produce 1 pound of live pig leaving the facility. This energy input data will be used for a calculation of how much greenhouse gas is emitted in the production of 1 pound of live pig.

The LCA will be performed with appropriate ISO standards and the National Pork Board Lifecycle Assessment Study as guides for data collection and analysis. The LCA will focus on activities directly related to swine husbandry using per pound pork as a functional unit (see Figure 1).

Figure 1. Swine production life cycle assessment schematic



This LCA sets the production boundary at the farm gate and does not consider transportation/manufacture/or marketing of pork products. LCA data for inputs not inside the pork production system, such as grain production, will use both standard literature reference values and data from our separate LCA of WCROC's agronomic activities. One challenge in this system is estimating the impact of swine production system size (scale) on energy savings from particular technologies. Energy and GHG impacts from implementing conservation measures at large farms will likely be different than at smaller farms. Using our fairly modest production system, we will be able to look at the savings at smaller operations. However, scaling factors may need to be developed that can estimate how larger or smaller operations will benefit from these technologies.

Summary Budget Information for Activity 3:	**ENRTF Budget:**	**$ 61,655**
	Amount Spent:	**$ 55,854**
	Balance:	**$ 5,801**

Activity Completion Date: April 1, 2017

Outcome	Completion Date	Budget

1. *Complete a life cycle assessment of the WCROC conventional swine facilities using field data and literature values*	4/1/2017	$61,655

Activity Status as of January 1, 2015:
The LCA team is beginning to build the LCA model of the swine system. Early work includes incorporating information about the livestock housing, feeding, heating, cooling, and water into the model. In addition, the operation of tractors, trucks, and other infrastructure used in the swine operation is being documented. Data will be continually added to strengthen the modelling as the project progresses. Renewable energy inputs will be modeled once those systems are installed and energy data is available.

Activity Status as of July 1, 2015:
LCA work of the swine system is currently focusing on feed inputs (corn, soybeans, and other feed ingredients) and the energy needed and carbon emitted in producing feed. The model will include the ability to select between the regional specific data from feed cropping systems at the WCROC and national LCA estimates for the US. As energy and other data becomes available from other activities of this project, it will be incorporated into the model.

Activity Status as of January 1, 2016:
Work on LCA modeling for the project is progressing. The basic model of the swine production system is nearing functional use. In order to complete it, specific energy data will be added. The first years' worth of energy data has been collected and is being converted to the functional units needed for inclusion in the LCA. WCROC Cropping data for organic and non-organic data production systems will be added shortly. Additionally, it will need updating with manure and water data to be reasonably accurate. This work will continue over the next year.

Activity Status as of July 1, 2016:
Cropping data needed for swine feed production has been added to swine LCA modeling. Additional work on the swine feed system will look at mineral, nutrient, and growth supplements. Analysis has begun to evaluate changes needed to accommodate on-site energy production for WCROC systems. Initial examinations of energy consumption and production data from both on-farm and WCROC found that data patterns should be further analyzed before its use in the final models. As the energy auditing team provides additional information and explanations, the data will be further examined in the model.

Activity Status as of January 1, 2017:
During the last reporting period, the swine production life cycle assessment (LCA) model was revised with new cropping data and new model pathways for feed ingredients. The cropping data added included the revised 2013 to 2015 data for corn and soybeans. 2016 crop data is still being analyzed and should be added in before the final report. In addition, more information was added about secondary feed ingredients such as calcium, whey, and important amino acids. The feed production pathways were expanded to allow data from crops produced at the West Central Research and Outreach Center, as well as other national crop production datasets found in lifecycle assessment databases. Data from the energy audits of the WCROC farm and off-site commercial farms is being examined to see how it can be best integrated into the model. Currently, the LCA model has a simplistic system that adds the total energy used during production into the lifecycle assessment. As the energy data is compiled and analyzed, more complex model pathways are being planned that will separate out each area of energy use and the technologies used to reduce energy use. This will allow for testing different assumptions about the energy efficiency of swine production buildings constructed with different technologies and equipment. Currently, we are planning to examine the following technology scenarios using our data; WCROC conventional current technologies, WCROC alternative housing systems, commercial farm average technologies, commercial farm best technologies, WCROC best technologies, and commercial theoretical technologies.

Final Report Summary:

During the last reporting period, Life cycle assessment work for activity 3 was completed. Results from the model were analyzed and a summary LCA report was written (attached as APPENDIX). The following is an abridged version of the main report methods and findings:

During the last reporting period, Life cycle assessment work for activity 3 was completed. Results from the model were analyzed and a summary LCA report was written (submitted in supporting documents). The following is an abridged version of the main report methods and findings:

Background

The study employed lifecycle assessment (LCA) methodology to track resource inputs and outputs of the system and to analyze the amount of fossil energy used by and carbon dioxide (GWP) emitted during the swine production cycle. LCA methodology is essentially an organized method of tracking inputs and outputs into the swine production system and assigning impacts to them. The LCA work done for this project was done using ISO 14000 standard methodology as a general guide. SimaPro (7.2) software was used for modeling swine systems and calculating result data.

In addition to energy data, cropping system data was used from the WCROC research farm which is a supplier of feed ingredients to the swine system at WCROC. It also relied on data found in databases and literature when data was not available from WCROC or on-farm studies. Background databases used in conjunction with the SimaPro work included Ecoinvent (2.0), US LCI, and Agri-footprint. For global warming calculations, GWP 100a (IPCC 2013) was used to calculate impacts. Fossil energy impacts were calculated using the CED 1.08 method with the addition of United States based fossil energy sources.

To evaluate a variety of swine systems, different sets of data were used to look at the specific systems used at WCROC and hypothetical systems designed based on data from commercial farms. It was intended that using the different data would allow us to assess high performing and lower performing systems from the sustainability standpoint. The data was used to both look at impacts on individual growth stages and as for a complete cradle to gate modeled swine production systems,

Results

The initial LCA model develop as part of this project has been continually updated with new data on growth stages, inputs, and outputs as the data has become available. The current model includes data on all major inputs and outputs including; feed systems, building systems, and manure systems. By its nature, LCA models are designed to allow continual improvements and refinements. With the model that we have developed, we plan to examine individual heating, cooling, and ventilation system changes in newly funded grant projects. In addition, there are a number of improvements that we hope to make in the model as new data becomes available. Therefore, this model will continue to be used for swine production energy and GWP research into the future.

In terms of fossil energy sources used for the entire swine production system (base on WCROC data), natural gas and crude oil and lignite coal were the most used primary energy sources (Figure 2). In addition to being used in the grain production system (for grain drying), natural gas was used for electricity generation, building heat, and hot water. Much of the crude oil was used for vehicles and tractors for growing and transporting feed. Lignite coal was used in production of electricity, with the Minnesota based grid supplying more than 50% coal-based electricity. Commercial swine operations were slightly different in terms of natural gas use as rural farms are often not connected to a natural gas utility. These farms typically use propane as a heating source and for grain drying.

Energy

The total fossil energy for the modeled production systems is shown in Figure 4A, which is expressed in terms of the energy used for producing one market hog when combining all of the swine growth stages (Figure 3). The large impact that feed production has on the overall system is visible in the systems shown. Unfortunately, swine producers can't directly reduce the majority cropping energy impacts. A more detailed assessment of the energy needed specifically for housing or building systems (Figure 4B) shows that there are large differences in the amount of fossil energy needed between the different production systems. This figure also shows how the use of renewable electricity can decrease the amount of fossil energy needed. Depending how much fossil based electricity was used in the swine production building system, solar PV electricity reduced the fossil energy demand by between 42% (alternative) and 68% (commercial best).

Global Warming Potential

The analysis showed a similar situation in management of swine GWP as with swine fossil energy use, very little of the GWP emissions are able to be directly controlled by swine producers. The major areas of GWP impacts are feed production and manure management (Figure 5A). Though there are some methods of reducing manure emissions with feed additives, these are not economically feasible and are not all that effective. As with fossil energy, carbon emissions in feed ingredient production are also difficult for swine producers to influence. This leaves the building system part of swine production as the major area for pork producers to manage for GWP reduction. Unfortunately, it accounts for only about 10% of the total GWP impacts. However, our work with renewable energy does show that greenhouse gases can be significantly reduced in the building systems area (Figure 5B).

Implications

The findings of this work indicate that there are some areas that could be more heavily target by producers wishing to reduce their environmental impacts. On-farm activities of swine operations are within their control and can be impacted by farm management decisions. Unfortunately, because grain and feed ingredient production is such a large part of the impacts, it is difficult for swine producers to directly reduce the majority system sustainability impacts.

Future Work and Areas for Refining LCA

The swine life cycle model was designed as a tool to investigate a wide variety of issues related to the sustainability of pork production. It is able to be customized and expanded to meet many needs for swine sustainability research and is an important asset for Minnesota researchers. It was anticipated that the model would be used for new research efforts, and new funding has been secured to examine other swine production issues. As with all LCA models, the data collected on swine production is the key to making an accurate model. Going forward, we will continue to collect new data, both on the farm and off, to improve model results.

Conclusions

- A model was developed that can track energy use and greenhouse gas emissions though the swine production system at a moderate resolution, with the ability to be refined as more data becomes available. This model is designed and already committed for further research that examines questions regarding swine life cycle energy and carbon footprints with potential new technologies and organic production.
- Energy use and GWP emissions in the broader swine lifecycle were highest for feed production, which accounted for almost 60% percent of fossil energy and 50% of greenhouse gas emissions.

- The fossil energy portion of the production system that can be directly controlled by the hog growers is producer is roughly 25% of the energy of producing pork. On-farm renewable solar electricity can significantly lower the fossil energy use on the farm. However, replacements for natural gas/propane, diesel, and gasoline will be needed to further reduce fossil energy use.
- The fossil energy and GWP impacts for feed crop production and feed ingredients are an important area that must be addressed to continue reductions in environmental impacts of swine production systems.

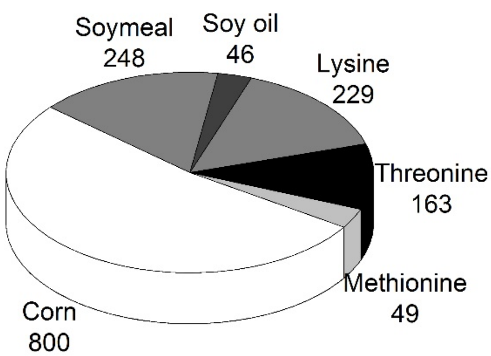


Figure 1. Fossil Energy for Major Feed Ingredients. Each of the feed ingredients is listed with the amount of fossil energy (in MJ) required to produce of the ingredients required to grow a single 120 kg market weight hog.

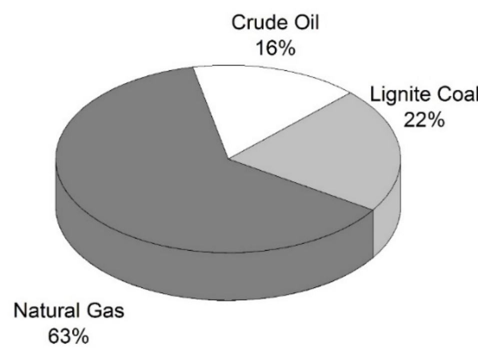


Figure 2. Key Sources of Fossil Energy for The Swine Production System. The primary energy sources for the production of pork and the relative percentage of each used.

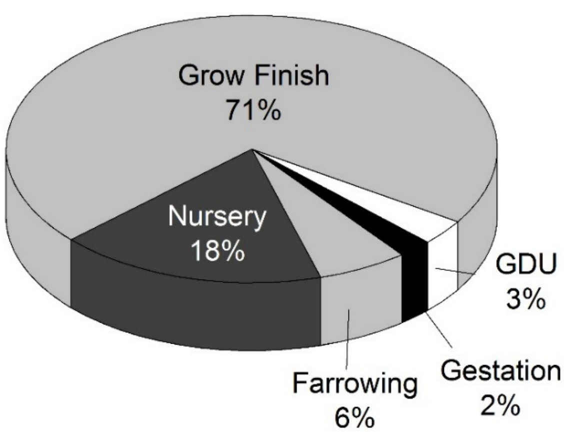
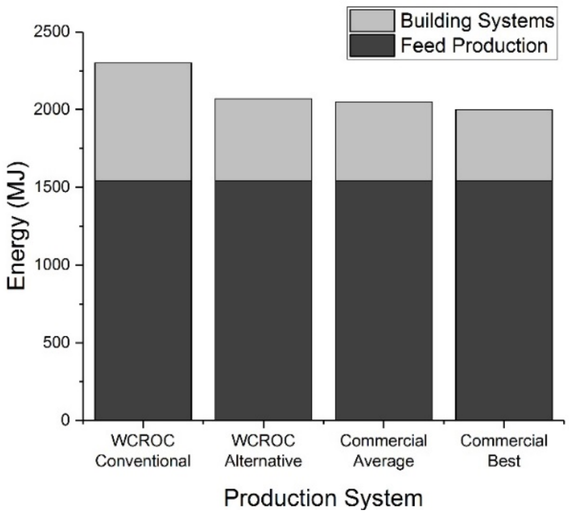
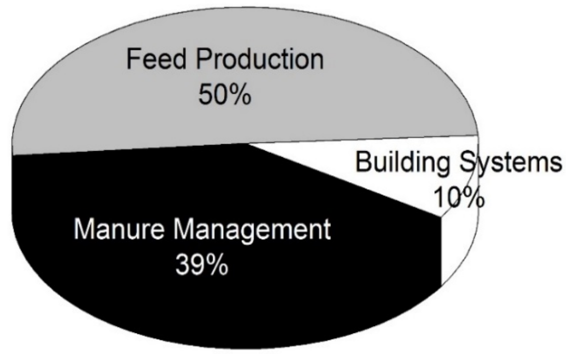


Figure 3. Relative Fossil Energy Contribution of Each Growth Stage. The relative contribution of the building system energy is shown for each stage is shown for the WCROC swine production system.

A) Total Swine System Fossil Energy



A) GWP Emissions from Swine System Components



B) Building Energy With Renewable Production

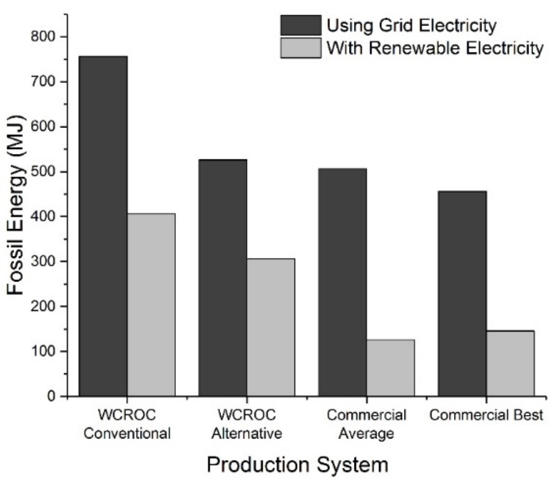


Figure 4. Fossil Energy For Swine Production Systems. These figures show the fossil energy needed for A) the entire swine production system and B) building system. Data is based on the energy needed for one market weight hog (120kg)

B) GWP Emissions With Renewable Energy

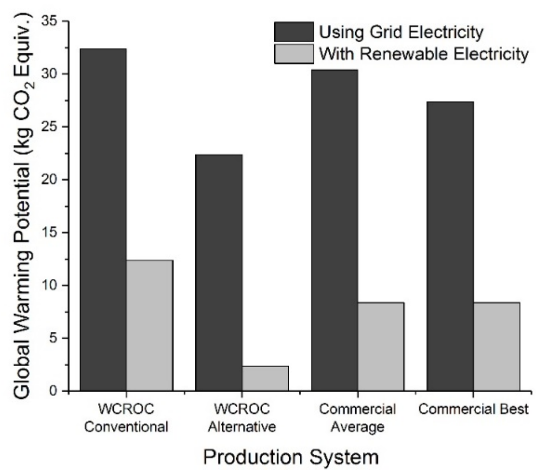


Figure 5. Global Warming Potential for the Swine Production System. The Global Warming Potential (kg of CO_2 Equivalents) for the system is shown A) as a comparison of the major GWP emitters and B) by the potential reduction using renewable energy.

Activity 4: Educate farmers and students about clean energy strategies for Minnesota farms

Description: Perhaps the most effective approach to change the way energy is used in crop and livestock systems is to educate agricultural students about clean energy technologies. Based on the research results and literature review, curriculum will be developed for secondary and technical students. Agricultural producers and other key stakeholders will be provided with educational opportunities including an agricultural energy conference and tour, two regional agricultural energy workshops across the State, and the completion of a bulletin entitled “Energy Strategies for Minnesota Swine Facilities”.

The information developed as a result of this project will be transferred to producers through several outreach efforts. The primary method will be through a statewide conference and tour at the West Central Research and Outreach Center. The conference will provide producers actionable information they can use to improve energy utilization in swine facilities. Producers appreciate experiencing first-hand new systems and technology, so a bus tour will be held in conjunction with the workshop. Producers will tour the renewable energy systems at the WCROC (and other systems within close proximity) including solar thermal, solar PV, large and small scale wind, geothermal heat pumps, and energy efficient systems and controls. Two regional workshops will be presented in regions with high concentrations of swine producers (south central and southwest Minnesota). The workshops will present practical information that swine producers can use in their swine facilities including results from this project. Though not a deliverable of this project, the results are likely to be published in peer-reviewed swine production journals as well as industry magazines. The information generated as a result of this project will also be included on the WCROC Renewable Energy Program website.

Summary Budget Information for Activity 4:	**ENRTF Budget:**	**$ 48,812**
	Amount Spent:	**$ 42,739**
	Balance:	**$ 6,073**

Activity Completion Date: June 30, 2017

Outcome	**Completion Date**	**Budget**
1. *Develop agricultural energy curriculum for secondary and technical students*	8/1/2016	$11,455
2. *Host an agricultural energy conference and tour to showcase clean energy systems*	6/30/2017	$11,313
3. *Conduct two regional agricultural energy workshops in southern Minnesota*	4/15/2017	$7,371
4. Complete a “Energy Strategies for Minnesota Swine Facilities” bulletin	6/15/2017	$14,320
5. Submit semi-annual reports and a comprehensive final report	6/30/2017	$4,353

Activity Status as of January 1, 2015:
This activity will start once data from the previous activities are available.

Activity Status as of July 1, 2015:
This activity will start once data from the previous activities are available.

Activity Status as of January 1, 2016:
A preliminary outline has been prepared showing the proposed topics of instruction for the secondary/technical school curriculum and is shown below. The outline provides a framework to organize project results as they become available and will continue to be updated and modified as the project progresses.

Activity Status as of July 1, 2016:
Curriculum development is underway. Curriculum is being formatted in a way that will provide several short “modules” for secondary and technical instructors to use. Examples of topics to include range from human-induced climate change to renewable energy in agriculture. Hands-on laboratory/field experience is another valuable aspect that will be included in these modules. Several resources have been identified to help with the planning process including individuals and graduation standards.

Activity Status as of January 1, 2017:
Course curriculum for secondary and technical students is being developed in the form of PowerPoint presentations. The “Agricultural Energy Curriculum” will follow requirements for Minnesota Academic Standards in science and mathematics, targeting three standards in each of the presentations. The presentations will cover main topics such as introduction of energy in agricultural systems, energy conservation and efficiency in

agriculture, energy conservation and efficiency in livestock systems, and renewable energy in agriculture. Results from this study will be included in the curriculum.

Final Report Summary:
Task 4 activities involved the dissemination of results to various audiences but were primarily focused to swine producers and professionals. The Midwest Farm Energy Conference was hosted at the WCROC on June 13 and 14th, 2017. Approximately 90 attendees participated in tours and presentations over the two day conference. The second day of the conference focused exclusively on swine energy systems and detailed the results of this study as well as provided tours to see the swine energy systems. Conference planning was aided by swine producer and energy professional volunteers including representatives from Christensen Farms (largest swine producer in Minnesota), Dr. Mike Brumm (Brumm Swine Consultancy), Clean Energy Resource Teams (CERTS) representatives, Runestone Electric, Kandiyohi Power, Great River Energy, and other University experts. Videos of the conference presentations as well as the Power Point presentations can be viewed at https://wcroc.cfans.umn.edu/events-education/2017-midwest-farm-energy-conference. Swine producers at the conference represented about 2.2 million pigs marketed per year.

In addition to the conference, the project team provided outreach in the form of shorter workshops geared towards swine producers. The first workshop was presented by Johnston and Reese during the Minnesota Pork Congress on January 18, 2017 at the Minneapolis Convention Center. A second workshop was presented at two locations (Jackson and Sleepy Eye, MN) on May 31, 2017. The producers attending the workshop represented about 1.9 million pigs marketed per year.

Several presentation of results have been made at local, regional, and national swine producer and professional meetings and conferences. Professor Lee Johnston gave a presentation titled "*Reducing fossil fuel use in swine - one piece at a time" at the* National Pork Board Swine Educators Conference in St. Louis, MO on September 27, 2016. This presentation in particular was impactful as over one hundred swine educators from across the nation attended.

Agriculture energy systems curriculum was developed for use by educators who teach agriculture and science secondary and post-secondary technical students. The curriculum incorporates research results from this study. Teachers from across the state have been contacted regarding the curriculum and its availability. The curriculum is included in the supporting documents. Finally, several informational bulletins have been developed and are updated as new results and information becomes available.

V. DISSEMINATION:

Description: The dissemination of the information generated in this project is described in Activity 4. The project team will develop curriculum for secondary and technical students. A statewide agricultural energy conference and tour will be held at the WCROC in Morris to showcase clean energy systems. Two regional workshops will be held in key swine production areas within the state. A bulletin will be developed titled "Energy Strategies for Minnesota Swine Facilities". The bulletin will be made available both in paper and electronic formats. The information generated as a result of the project will be placed on the WCROC Renewable Energy Program website at wcroc.cfans.umn.edu/RenewableEnergy and other groups such as the Clean Energy Resource Teams (CERTS) and swine producer organizations will be encouraged to link to the site.

Status as of January 1, 2015:
A Midwest Farm Energy Conference is being planned for June 17-19, 2015. Although not funded as part of this project, the conference will showcase research and results from this sponsored project.

Status as of July 1, 2015:

The Midwest Farm Energy Conference was held at the WCROC from June 17th through June 19th. Preliminary data from the swine barn energy monitoring protocol was presented and the solar PV system was included on a tour of AG energy systems.

Status as of January 1, 2016:
Current efforts on information dissemination are focusing on development of secondary and technical student curriculum. The project has been presented to several producer groups and organizations. At this time, more data and analysis is required to report results to producers.

Status as of July 1, 2016:
Planning is underway for the next Midwest Farm Energy Conference to be held during the summer of 2017. A planning committee is being formed to begin more rigorous planning, focusing on the topic of energy in pork production systems. The committee is made up of a cross section of University and utility experts. "Save the Date" cards are being formatted to handout at various events.

Status as of January 1, 2017:
The Midwest Farm Energy Conference committee continues to meet and plan for the 2017 conference. The committee includes representatives from two rural electric co-ops, a large swine producer, a private swine consultant, Clean Energy Resource Teams (CERTS), U of MN Department of Bioproducts and Bioengineering, and U of MN WCROC staff. The conference is being planned for June 13th and June 14th, 2017. "Save the Date" cards and brochures have been created to hand out at various events. Brochures are being distributed at major regional swine industry conferences. A pdf of the brochure is attached. A draft program agenda has been created and keynote and conference speakers have been confirmed. The speakers include University faculty and staff, utility and production specialists, and financial experts. There will be a heavy focus on energy use in swine production systems with tours and presentations included. A conference communication plan has been developed and includes submitting press releases to several local and regional newspapers and industry publications.

Several presentation of initial results have been made at local, regional, and national swine producer and professional meetings and conferences. Professor Lee Johnston gave a presentation titled "*Reducing fossil fuel use in swine - one piece at a time" at the* National Pork Board Swine Educators Conference in St. Louis, MO on September 27, 2016. A workshop will be presented by Johnston and Reese during the Minnesota Pork Congress on January 18, 2017 at the Minneapolis Convention Center. A second workshop is being planned for southern Minnesota in early spring 2017.

Curriculum continues to be developed for secondary and technical students, incorporating results from this study. In order to better disseminate the curriculum, science and agriculture teachers will be targeted for Midwest Farm Energy Conference invitations and will include a discounted participation fee.

Final Report Summary:
Task 4 activities involved the dissemination of results to various audiences but were primarily focused to swine producers and professionals. The Midwest Farm Energy Conference was hosted at the WCROC on June 13 and 14th, 2017. Approximately 90 attendees participated in tours and presentations over the two day conference. The second day of the conference focused exclusively on swine energy systems and detailed the results of this study as well as provided tours to see the swine energy systems. Conference planning was aided by swine producer and energy professional volunteers including representatives from Christensen Farms (largest swine producer in Minnesota), Dr. Mike Brumm (Brumm Swine Consultancy), Clean Energy Resource Teams (CERTS) representatives, Runestone Electric, Kandiyohi Power, Great River Energy, and other University experts. Videos of the conference presentations as well as the Power Point presentations can be viewed at https://wcroc.cfans.umn.edu/events-education/2017-midwest-farm-energy-conference. Swine producers at the conference represented about 2.2 million pigs marketed per year.

In addition to the conference, the project team provided outreach in the form of shorter workshops geared towards swine producers. The first workshop was presented by Johnston and Reese during the Minnesota Pork Congress on January 18, 2017 at the Minneapolis Convention Center. A second workshop was presented at two locations (Jackson and Sleepy Eye, MN) on May 31, 2017. The producers attending the workshop represented about 1.9 million pigs marketed per year.

Several presentation of results have been made at local, regional, and national swine producer and professional meetings and conferences. Professor Lee Johnston gave a presentation titled "*Reducing fossil fuel use in swine - one piece at a time" at the* National Pork Board Swine Educators Conference in St. Louis, MO on September 27, 2016. This presentation in particular was impactful as over one hundred swine educators from across the nation attended.

Agriculture energy systems curriculum was developed for use by educators who teach agriculture and science secondary and post-secondary technical students. The curriculum incorporates research results from this study. Teachers from across the state have been contacted regarding the curriculum and its availability. The curriculum is included in the supporting documents. Finally, several informational bulletins have been developed and are updated as new results and information becomes available.

VI. PROJECT BUDGET SUMMARY:

A. ENRTF Budget Overview:

Budget Category	$ Amount Spent	Explanation
Personnel:	$ 220,001	1 project coordinator at 20%, 40%, 20% FTE in years 1,2, and 3 respectively; 1 life cycle analysis researcher at 5% FTE for 3 years; 1 junior scientist at 100% FTE for 2.5 years; and 1 undergraduate student intern for two years during summer term
Professional/Technical/Service Contracts:	$ 102,521	1 contract with AKF Engineering or equivalent firm for modeling, pre-design, design, and commissioning; Up to 6 contracts with swine producers for stipends to participate in baseline energy auditing study, 1 contract with a general contractor for the installation of the solar PV system; and 1 contract with a mechanical contractor for installation of control systems and meters
Equipment/Tools/Supplies:	$ 11,111	Energy meters and data loggers for the swine facilities.
Capital Expenditures over $5,000:	$ 86,006	27 kW solar PV system at the WCROC swine facilities; control systems for the WCROC swine building(s)
Printing:	$ 2,545	Publication and printing of curriculum, Ag Energy Conference materials, regional workshop materials, and extension bulletins
Travel Expenses in MN:	$ 4,173	Mileage, lodging, meals
Other:	$ 2,655	One bus and postage for the Ag Energy Conference; software for life cycle analysis
TOTAL ENRTF BUDGET:	**$429,012**	

Explanation of Use of Classified Staff: Not Applicable

Explanation of Capital Expenditures Greater Than $5,000: One solar photovoltaic system is being purchased and installed at the University of Minnesota West Central Research and Outreach Center. The system will be performance tested with results added to the models for optimizing commercial swine facilities. In addition, a control system will be purchased for the WCROC swine nursery which will enable data acquisition and assist with field testing and modeling integration of energy systems. Following the project, the WCROC will continue to use the equipment on similar projects for its expected serviceable life. If the equipment is sold prior to the end of its serviceable life, the proceeds will be paid back to the Environment and Natural Resources Trust Fund.

Number of Full-time Equivalents (FTE) Directly Funded with this ENRTF Appropriation: ~4.0 (~1.33 FTEs for three years)

Number of Full-time Equivalents (FTE) Estimated to Be Funded through Contracts with this ENRTF Appropriation: Not applicable. The contracts are for professional engineering services and equipment installation.

B. Other Funds:

Source of Funds	$ Amount Proposed	$ Amount Spent	Use of Other Funds
Non-state			
University of Minnesota – Unrecovered Indirect Costs (ICR) used as in-kind match.	$155,296	$133,247	Indirect costs – Reduced amount reflects amount of direct expenditures.
State			
	$	$	
TOTAL OTHER FUNDS:	**$155,296**	**$133,247**	

VII. PROJECT STRATEGY:

A. Project Partners: Michael Reese, U of MN WCROC Renewable Energy Director, will serve as the principle investigator and project manager. He will be responsible for all reports and deliverables. Dr. Lee Johnston (U of MN Swine Scientist) will be a co-principle investigator managing the activities within the WCROC swine facilities and assisting in interfacing with the collaborating swine producers. Dr. Larry Jacobson (U of MN Agricultural Engineer) and Dr. Brad Heins (U of MN Dairy Scientist) will be co-investigators and provide guidance on clean energy designs and testing in livestock facilities. They will also participate in the outreach activities. Dr. Joel Tallaksen (WCROC Renewable Energy Scientist) will serve as a co-investigator and be responsible for the life cycle analysis and oversee the basic economic evaluation. Eric Buchanan (WCROC Renewable Energy Scientist and Engineer) will be the project coordinator assisting in the design, installation, testing, and control strategies of the clean energy technologies. He will also assist with the outreach and dissemination of results. AKF Engineering (Minneapolis) or equivalent will provide consulting services for clean energy modeling, designing, commissioning, and control strategies.

B. Project Impact and Long-term Strategy: There are approximately 7.8 million pigs in Minnesota. Past research at the WCROC has shown significant energy and cost savings with off-the-shelf technologies. Proven energy optimized systems have the potential to significantly lower the energy consumed in swine facilities and begin the transition to locally-produced, clean energy. The WCROC has a 10-year strategic plan to reduce fossil energy consumption and the carbon footprint within production agriculture. This proposal will leverage and build upon current projects. Funding has been received through the U of MN Initiative for Renewable Energy and the Environment ($350k) to measure energy consumption within a model dairy and test clean thermal energy systems. The funded project will also evaluate greenhouse gas emissions within portions of crop and dairy production. Long-term funding will be sought to research alternatives to fossil energy within all agricultural crop and livestock enterprises.

C. Spending History:

Funding Source	M.L. 2008 or FY09	M.L. 2009 or FY10	M.L. 2010 or FY11	M.L. 2011 or FY12-13	M.L. 2013 or FY14
U of MN IREE (Crops and Dairy)				$350,000	
U of MN RARF (Dairy and Swine) – The swine portion of this project is related to diurnal control of temperature or lowering the temperature during evening hours to conserve energy.				$167,061	
Xcel RDF Pending PUC Approval (Dairy facilities only – If approved, the project will add small wind and solar system to the WCROC dairy parlor)					$982,408

VIII. ACQUISITION/RESTORATION LIST: Not applicable

IX. VISUAL ELEMENT or MAP(S): Please see the end of this document for the visual elements

X. ACQUISITION/RESTORATION REQUIREMENTS WORKSHEET: Not applicable

XI. RESEARCH ADDENDUM: As detailed in the activity sections

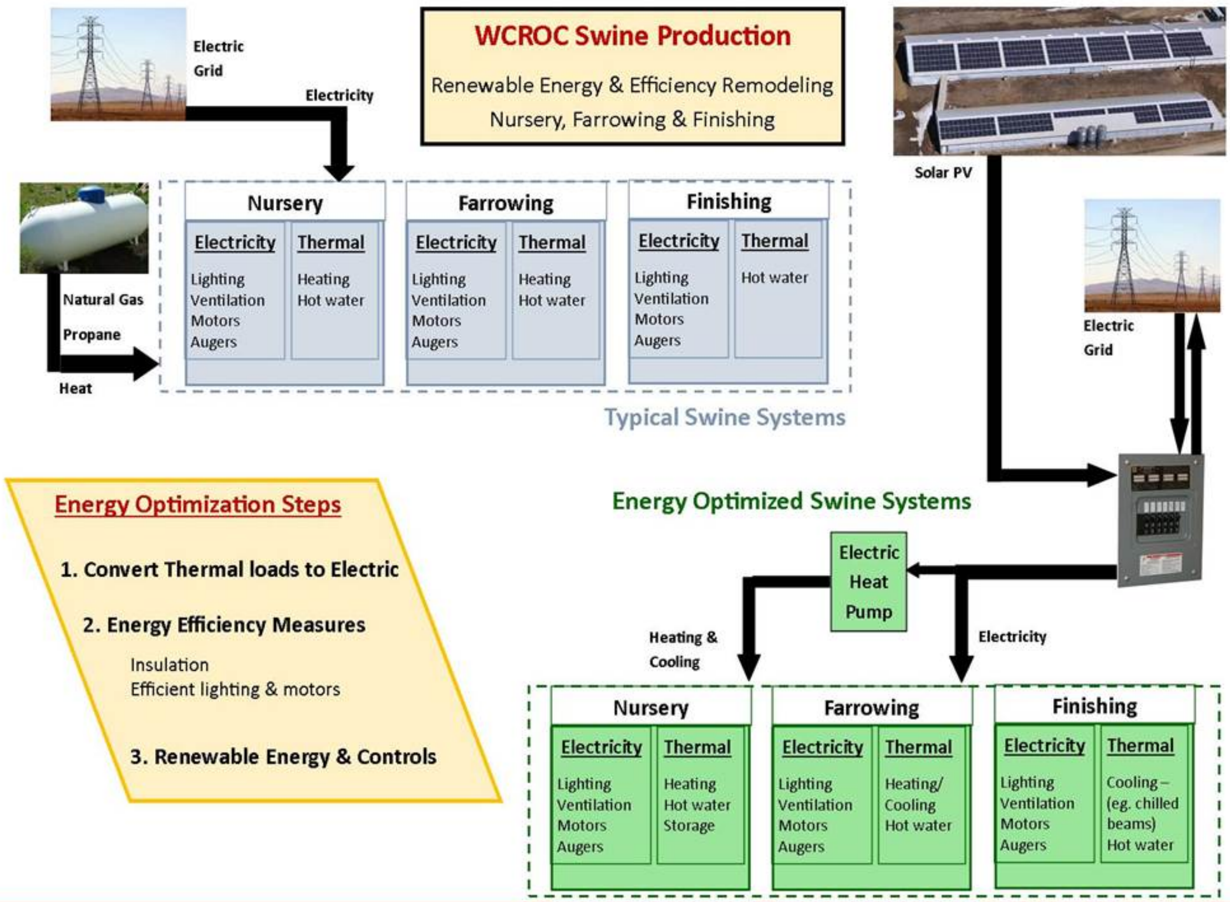
XII. REPORTING REQUIREMENTS:
Periodic work plan status update reports will be submitted no later than January 1, 2015; July 1, 2015; January 1, 2016; July 1, 2016; and January 1, 2017. A final report and associated products will be submitted between June 30 and August 15, 2017.

<u>Literature Cited</u>

Lammers, P. J., M. S. Honeyman, J. D. Harmon, and M. J. Helmers. 2010. Energy and carbon inventory of Iowa swine production facilities. Agric. Systems 103:551-561.

Lammers, P. J., M. D. Kenealy, J. B. Kliebenstein, J. D. Harmon, M. J. Helmers, and M. S. Honeyman. 2012. Energy use in pig production: An examination of current Iowa systems. J. Anim. Sci. 90:1056-1068.

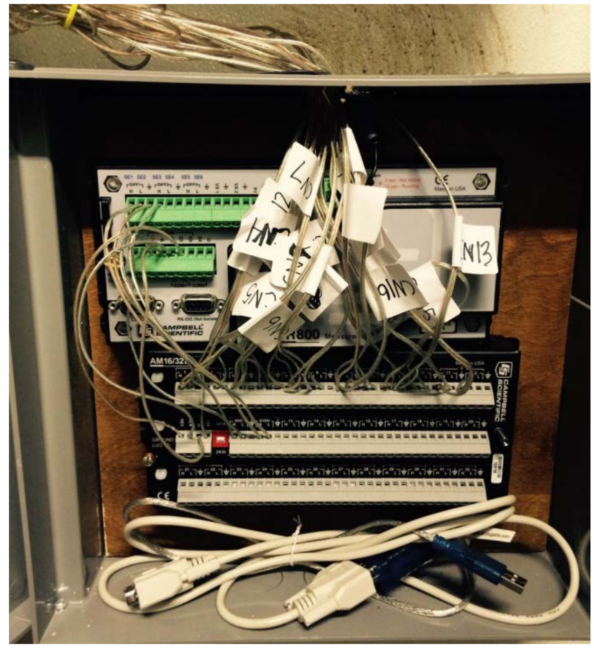
Visual Element: Basic Schematic of Conventional and Optimized Energy Systems for Swine Facilities



UNIVERSITY OF MINNESOTA
Driven to Discover

Attachments: January 1, 2015

Picture 1. Data loggers being installed in circuit breaker box at a commercial finishing barn



Picture 2. Data logger in WCROC farrowing barn

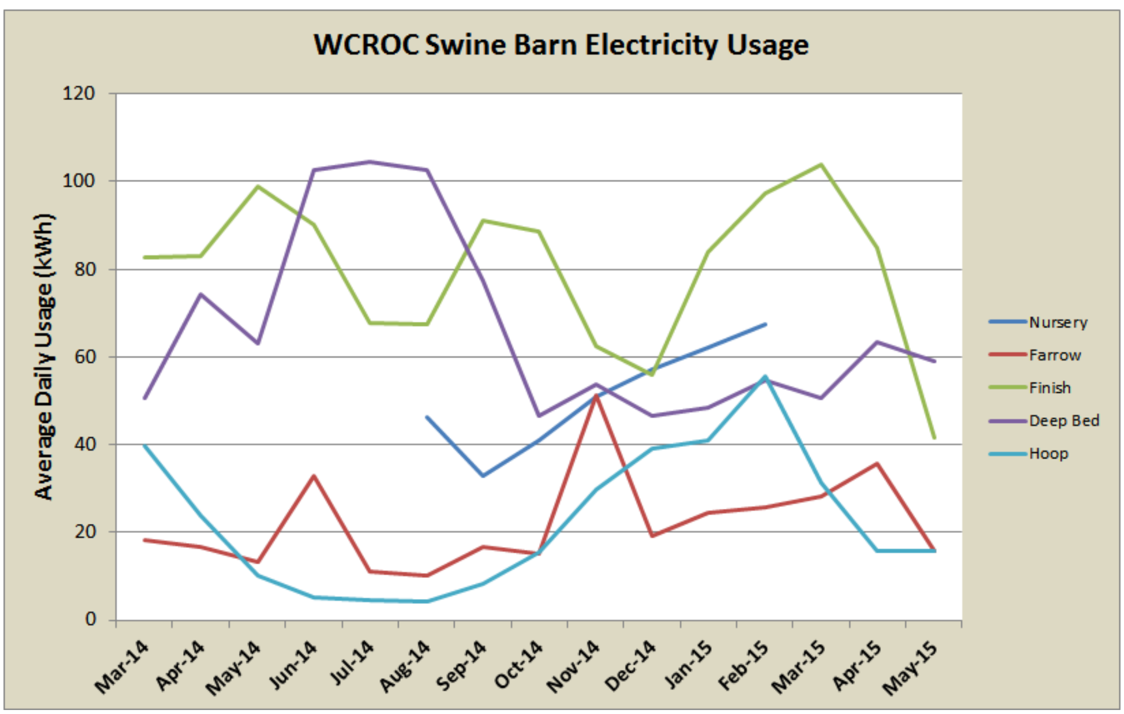


Figure 6. WCROC swine facility electrical energy consumption compiled from utility meter

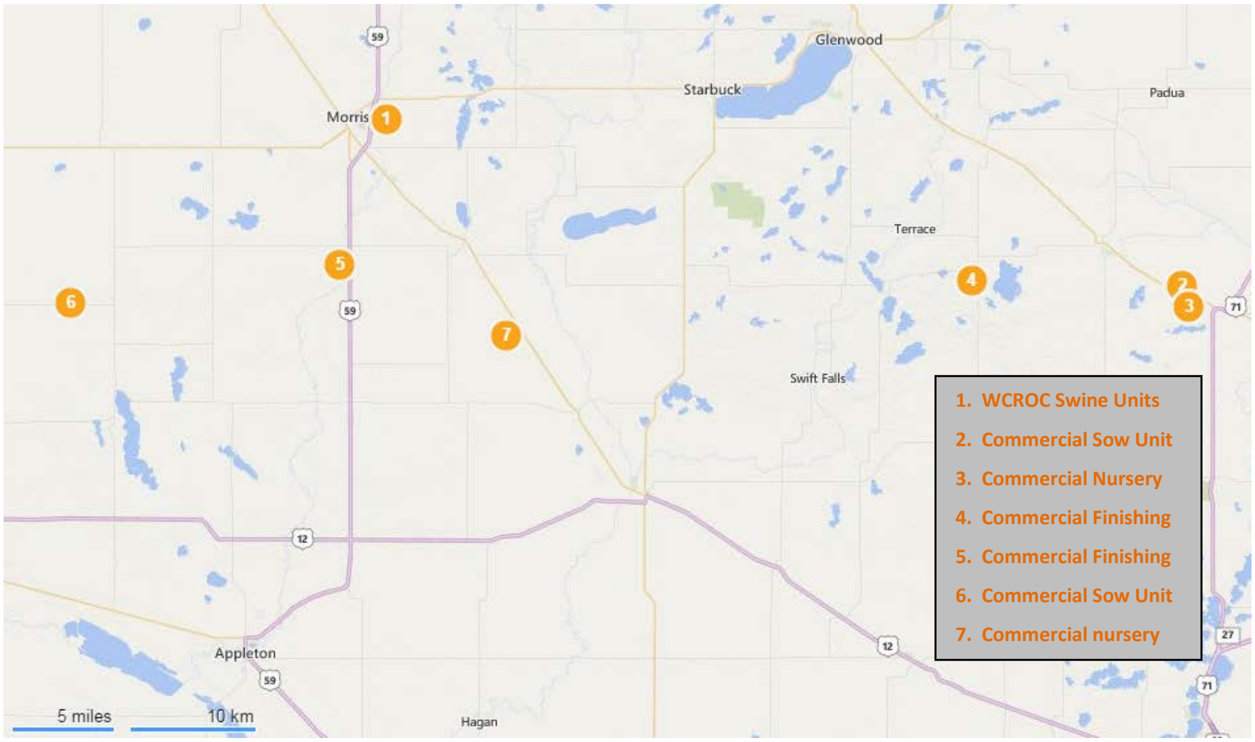


Figure 7. Map indicating location of swine facility monitoring

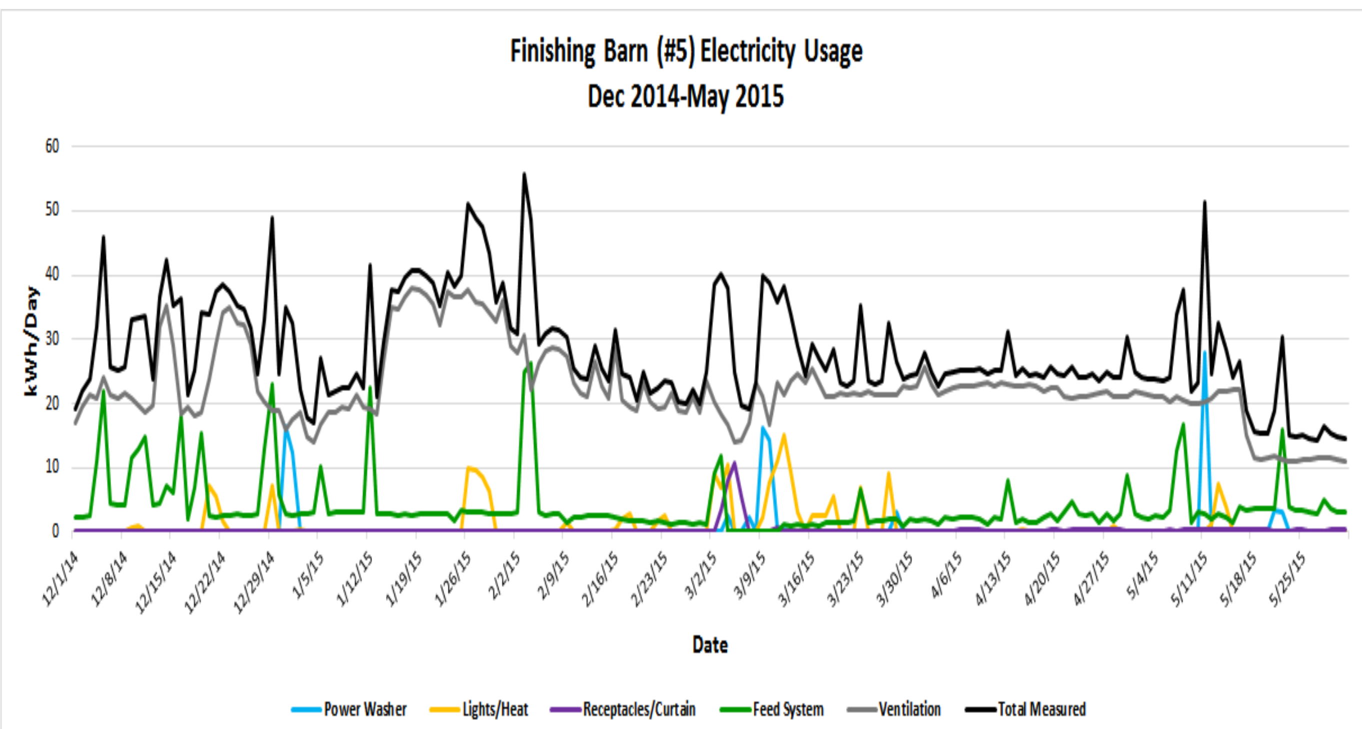


Figure 8 Example of weekly energy usage data from a cooperator swine facility

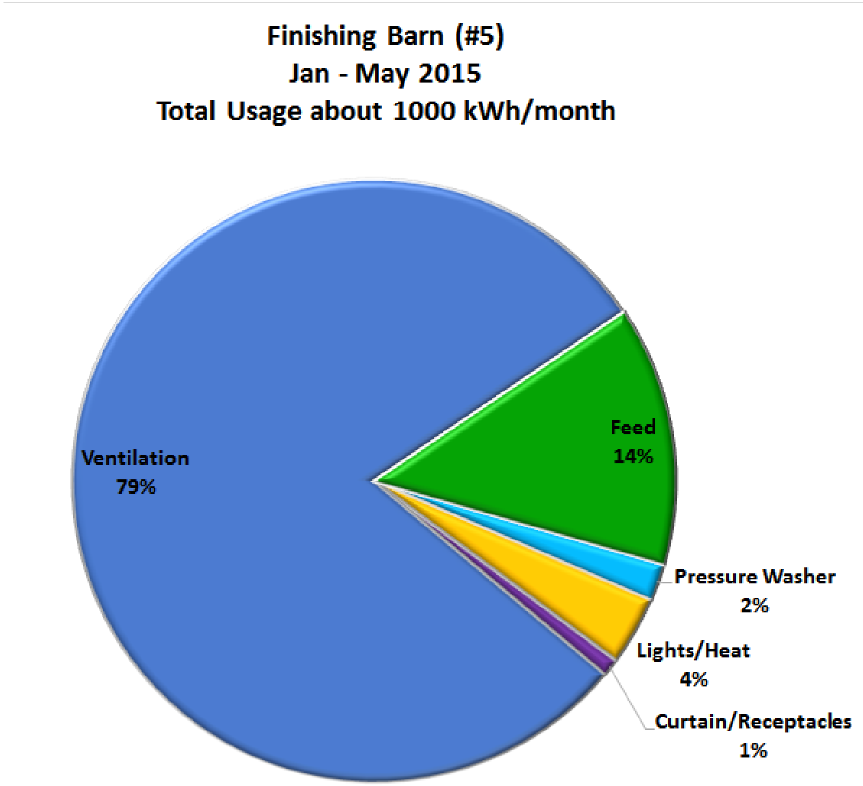


Figure 9. Example breakdown of energy used for processes within a cooperator swine facility

Picture 3. 27 kW Solar PV System on WCROC Swine Facility – West Side

Picture 4. 27 kW Solar PV System on WCROC Swine Facility – East Side

Attachments: January 1, 2017

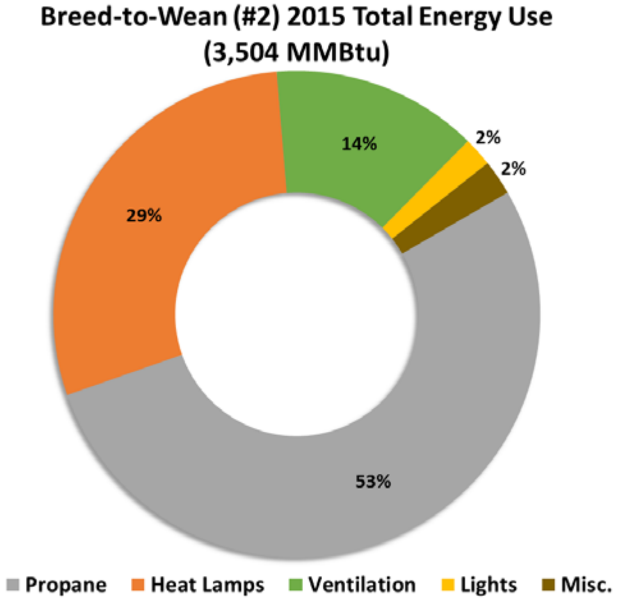


Figure 5. Total energy use in 2015 of propane and electrical categories in commercial Breed-to-Wean Barn #2.

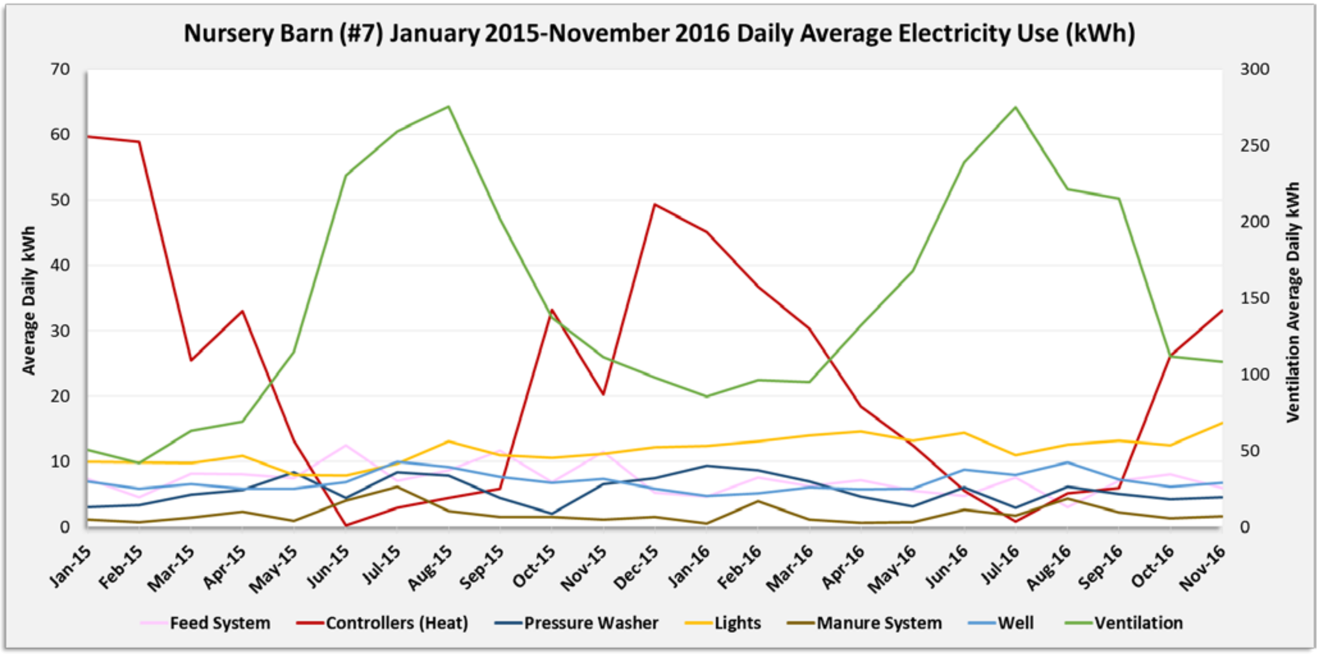


Figure 6. Average daily electricity use of electrical loads in Nursery Barn #7.

Picture 5. Photo of West Finishing Barn solar panels taken on 12/22/16, 6 days after a large snowstorm.

Picture 6. Photo of East Finishing Barn solar panels taken on 12/22/16, 6 days after a large snowstorm.

2017 Midwest Farm Energy Conference Brochure (Page 1 and 2 of a trifold):

2017 Midwest Farm Energy Conference

Tuesday, June 13th

U of MN West Central Research and Outreach Center, Morris

Registration 12:00 PM

Afternoon Sessions 1:00 PM
Emphasis on renewable energy initiatives for Midwest dairies

- Energy Consumption in MN Dairies
- Creating a Net-Zero Energy Dairy
- Life Cycle Assessment
- Utilizing Wastewater for Sustainable Production
- Tour of WCROC Dairy

Networking & Social Hour 5:30 PM

Dinner and Keynote Speakers 6:30 PM
(Meal provided)

Keynote Speakers:

Dean Brian Buhr, College of Food, Agriculture, and Natural Resource Sciences, U of MN

President Barry Dunn, South Dakota State University

Mark Greenwood, Sr. Vice President, Relationship Management at AgStar Financial Services

Wednesday, June 14th

Breakfast and Welcome 7:30 AM

Morning Sessions 8:00 AM
Emphasis on renewable energy initiatives for swine production

- Why Producers Should Care About Swine Energy Systems
- Energy Conservation in Livestock Production
- Reducing Fossil Fuel Use in Swine Production
- Energy Consumption Across Six MN Commercial Facilities
- Financing, Economics, and Case Studies

Lunch 12:00 PM

Tour of Swine Energy Systems

Conference Wrap-Up 2:30 PM

Funding for swine and dairy renewable energy projects at the U of MN WCROC provided by:

Minnesota Environment & Natural Resources Trust Fund (through LCCMR)

U of MN Agricultural Rapid Response Fund

Xcel Renewable Development Fund

Initiative for Renewable Energy & the Environment (IREE)

Conference Pricing

Full Conference Rate $80.00

Includes all conference sessions, tours, handouts, and keynote dinner. Student pricing available.

Register before April 1, 2017 for the early bird full conference rate of $60
Hurry! The first 20 registrants will be entered for a door prize!

Singe Day Rate $50.00

Select which day you plan to attend. Includes sessions, tours, handouts, and meals for selected day.

Keynote Dinner only (June 13) $15.00

Join us for social hour, networking, dinner, and keynote speakers at 5:30 pm on June 13th.

Registration Information

Register Online

http://z.umn.edu/mfec2017

Access the above link for conference details including hotel accommodations, agenda, and presenters.

Questions? Contact Esther at 320-589-1711

The University of Minnesota is an equal opportunity educator and employer. To request disability accommodations, please contact Esther Jordan at the WCROC at (320) 589-1711 or ejordan@umn.edu

A report by AKF Engineers titled "Swine Barn Energy Modeling Narrative" has been attached in a second file. The report is a deliverable of Activity 1.

August 11, 2017 Report Pictures and Documents will be sent and uploaded as supporting documentation.

Environment and Natural Resources Trust Fund
M.L. 2014 Final Attachment A Project Budget

Project Title: *Transitioning Minnesota Farms to Local Energy*
Legal Citation: **M.L. 2014, Chp. 226, Sec. 2, Subd. 08d**
Project Manager: *Michael Reese*
Organization: *University of Minnesota West Central Research and Outreach Center*
M.L. 2014 ENRTF Appropriation: $ *500,000*
Project Length and Completion Date: *3 Years, June 30, 2017*
Date of Final Report: August 11, 2017

ENVIRONMENT AND NATURAL RESOURCES TRUST FUND BUDGET	Revised Activity 1 Budget 08/16/2016	Amount Spent	Activity 1 Balance	Revised Activity 2 Budget 08/16/2016	Amount Spent	Activity 2 Balance	Activity 3 Budget	Amount Spent	Activity 3 Balance	Revised Activity 4 Budget 01/30/17	Amount Spent	Activity 4 Balance	Revised TOTAL BUDGET 01/30/2017	REVISED TOTAL BALANCE
BUDGET ITEM							***Perform a life cycle assessment***							
Personnel (Wages and Benefits)	$76,755	$64,652	$12,103	$64,651	$64,651	$0	$55,855	$55,854	$1	$34,847	$34,844	$3	$232,108	$12,107
Project Coordinator - Eric Buchanan (FTEs =20% Year 1, 40% Year 2, 20% Year 3) 36.8 % fringe rate														
Life Cycle Analysis Researcher - Dr. Joel Tallaksen (5% FTE) 36.8 % fringe rate														
Junior Scientist - Technician for data collection, system testing (100% FTE - 2.75 Yrs) 36.8 % fringe rate														
Undergrad Student Intern - Clean Energy Technology for MN Swine Facilities (2 Yrs) 7.44% Fringe Rate														
Professional/Technical/Service Contracts														
AKF Engineering (or equivalent firm) - Modeling, Pre-design, Design, Commissioning, and Control Optimization Engineering Professional Services	$62,000	$57,153	$4,848										$62,000	$4,848
Farmer Contracts - Funds for monitoring of on-farm systems	$24,000	$24,000	$0										$24,000	$0
General Contractor -Zenergy LLC - Installation of the solar PV system		$0	$0	$28,154	$17,599	$10,555							$28,154	$10,555
Mechanical Contractor(s) -Runestone Electric and Asmus Electric-Installation of energy meters / control systems	$2,550	$1,884	$666	$7,650	$1,884	$5,766							$10,200	$6,431
Equipment/Tools/Supplies														
Energy Meters and Components for Swine Building(s) to measure energy consumption	$10,800	$5,450	$5,350										$10,800	$5,350
Data Loggers and Components for Swine Building(s) for data collection and acquisition	$9,600	$5,661	$3,939										$9,600	$3,939
Capital Expenditures Over $5,000														
20 kW solar photovotaic (electric) system				$75,895	$73,667	$2,228							$75,895	$2,228
Control system for WCROC Swine Facilities				$26,000	$12,339	$13,661							$26,000	$13,661
Printing Curriculum, Ag Energy Conference materials, regional workshop materials, and extension bulletin printing.										$6,400	$2,545	$3,855	$6,400	$3,855
Travel expenses in Minnesota Eight trips by Dr. Jacobson from Saint Paul to Morris, MN (330 miles @ $.56 / mi); Travel by project team to two regional workshops across the State (2 trips, 400 miles each, $.56 / mi); Lodging and meals for WCROC project team at two regional workshops (4 people / 2 nights @ $80 / room and $40 ea for meals); Travel, lodging and meals for Larry Jacobson at two regional workshops (400 miles and 2 trips @ .56, 2 nights @ $80 / room and $40 ea for meals); Travel, lodging, and meals for six ag energy conference speakers (6 @ 330 mi and $80 / room and $40 ea for meals)	$739	$739	$0	$739	$739	$0				$3,765	$2,695	$1,070	$5,243	$1,070
Other														
Buses for the ag energy conference										$2,000	$1,425	$575	$2,000	$575
Postage for conference brochures and save-the date cards (5000 units *$.22 bulk rate for brochures and *$.14 bulk rate for postcards) (01/30/17)										$1,800	$1,230	$570	$1,800	$570
Life cycle analysis software to perform the study							$5,800	$0	$5,800			$0	$5,800	$5,800
COLUMN TOTAL	**$186,444**	**$159,539**	**$26,905**	**$203,089**	**$170,879**	**$32,210**	**$61,655**	**$55,854**	**$5,801**	**$48,812**	**$42,739**	**$6,073**	**$500,000**	**$70,988**

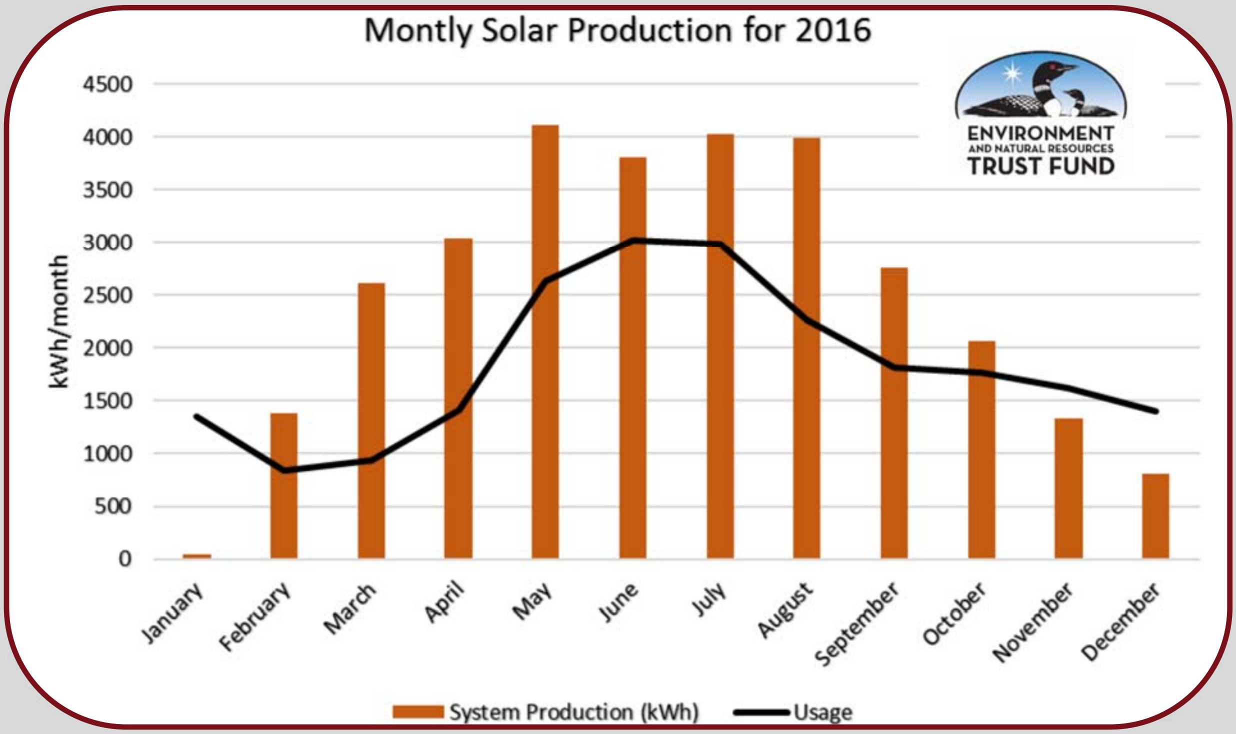
WCROC Swine Finishing Barn Solar PV System

Finishing Barn System Data

- **26.9 kW DC array installed in June 2015**
- **96 Heliene model 60M 280 modules**
  - **280 Watts each, efficiency = 17.4%**
- **3 SE9K inverters by SolarEdge Technologies, Inc.**
  - **SolarEdge power optimizer on each module**
- **3 phase fixed array mounted at 20⁰ facing south**
- ***Funded by Minnesota Environment and Natural Re-***

Economics

- Annal production from system ⇨ in 2016 was ⇨ about 30,000 kWh worth $3,000 at 10¢/kWh
- Total system cost was $86,000($3.18/W) ⇨ 28.7 year simple pay back without incentives
- With 30% federal credit $60,200 ⇨ 20 year pay back
- Adding the Made in Minnesota incentive for 10 years @ 15¢/kWh ⇨ 11.5 year pay back



PVWatts is a free online estimating tool provided by the NREL, http://gisatnrel.nrel.gov/PVWatts_Viewer/index.html

UNIVERSITY OF MINNESOTA
Driven to Discover℠

West Central Research & Outreach Center
46352 State Hwy 329 Morris, MN 56267
Phone: (320) 589-1711
Website: wcroc.cfans.umn.edu

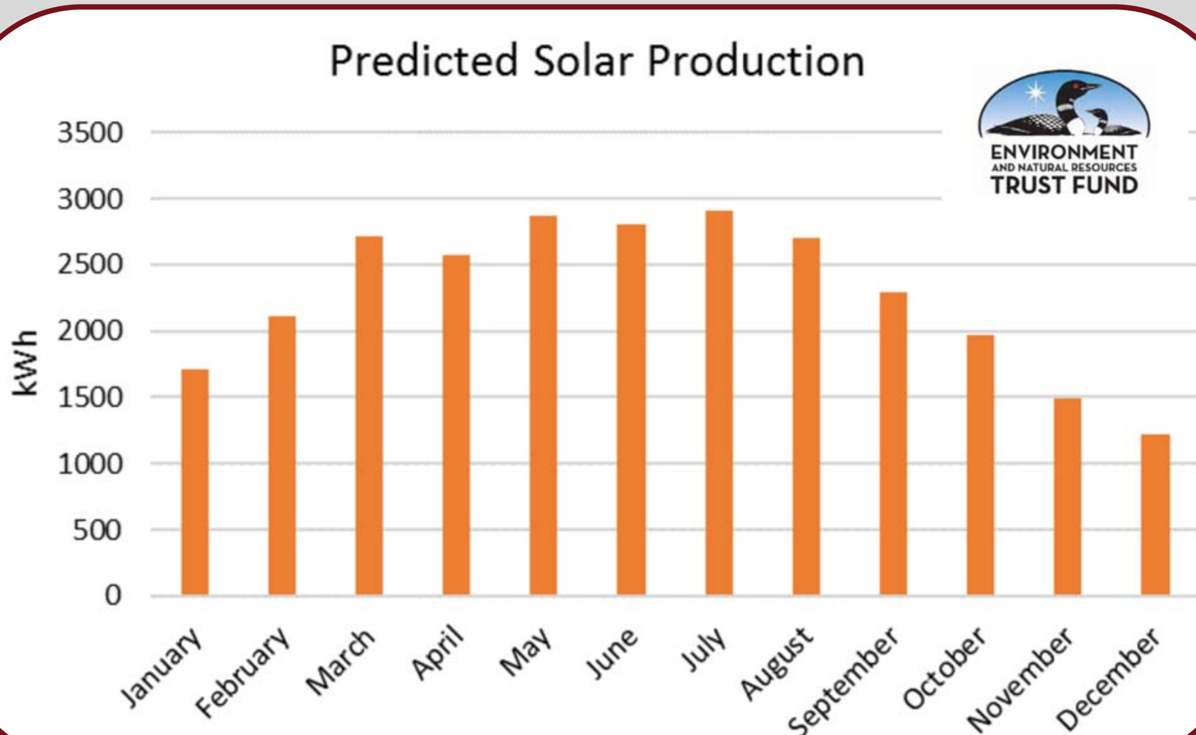
WCROC Swine Farrowing Barn Solar PV System

Farrowing Barn System Data

- **19.8 kW DC array installed in June 2017**
- **62 Heliene model 72M 320 modules**
- **2 SE9K inverters by SolarEdge Technologies, Inc.**
  - **SolarEdge power optimizer on each module**
- **3 phase ground mounted array mounted at 30º**
- ***Funded by Minnesota Environment and Natural Re-***

Economics

- Annual production from system is predicted to be about 27,393 kWh worth $2739 at 10¢/kWh
- Total system cost was $59,000($2.98/W) 21.5 ⇨ year simple pay back without incentives
- With 30% federal credit $41,300 ⇨ 15 year pay back
- Adding the Made in Minnesota incentive for 10 years @ 10¢/kWh ⇨ 10.6 year pay back



PVWatts is a free online estimating tool provided by the NREL, http://gisatnrel.nrel.gov/PVWatts_Viewer/index.html

University of Minnesota
Driven to Discover℠

West Central Research & Outreach Center
46352 State Hwy 329 Morris, MN 56267
Phone: (320) 589-1711
Website: wcroc.cfans.umn.edu

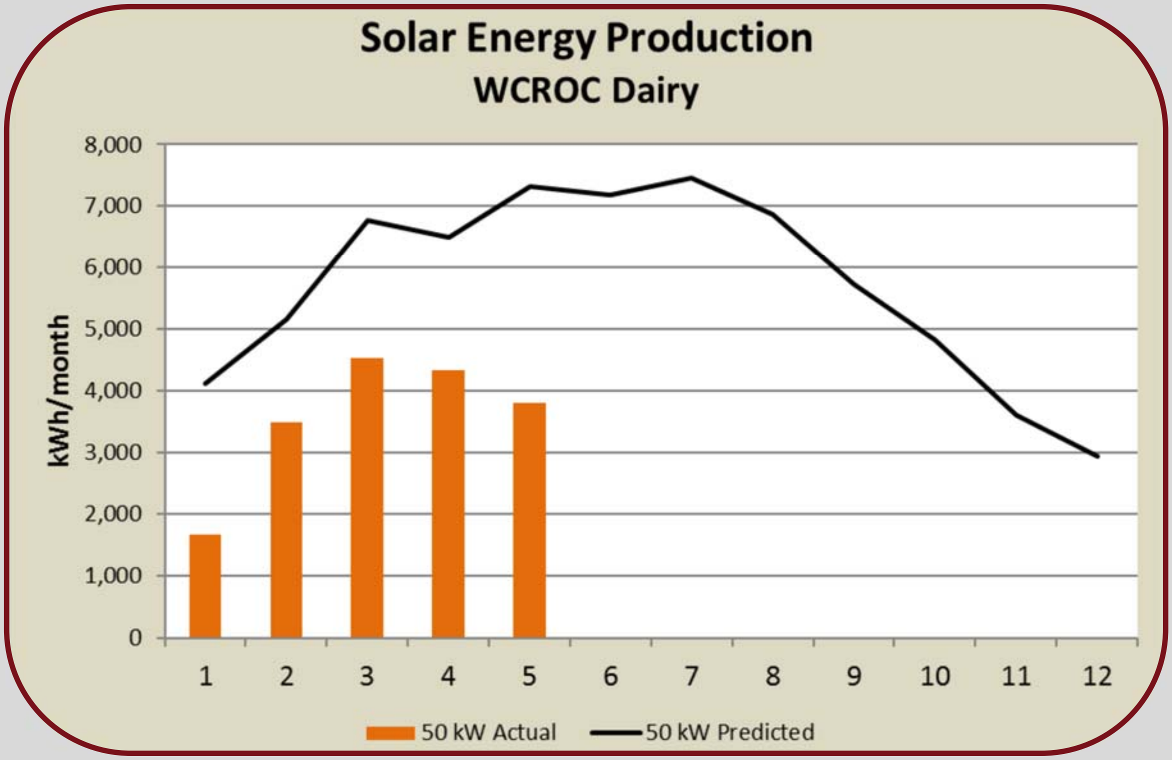
WCROC Dairy Barn Solar Energy

System Data

- **50 kW DC array installed on October 4, 2016**
  - **TenKSolar Reflect XTG array**
  - **120 model 410W modules in a XT26 system**
  - **4 tenKsolar 10.8 kW RAIS inverter bus**
    - **each with 18 LEED 600 W micro inverters**

Expected Performance/Economics

- Annual production from PV system projected to be 70,000 kWh worth $7,000 at 10₵/kWh
- Total solar system cost $138,000 ($2.77/W) ⇨ 19.7 year simple pay back without incentives
- Adding the Made in Minnesota incentive for 10 years @ 13¢/kWh ⇨ 8.6 year pay back



PVWatts is a free online estimating tool provided by the NREL, http://gisatnrel.nrel.gov/PVWatts_Viewer/index.html

University of Minnesota
Driven to Discover℠

West Central Research & Outreach Center
46352 State Hwy 329 Morris, MN 56267
Phone: (320) 589-1711
Website: wcroc.cfans.umn.edu

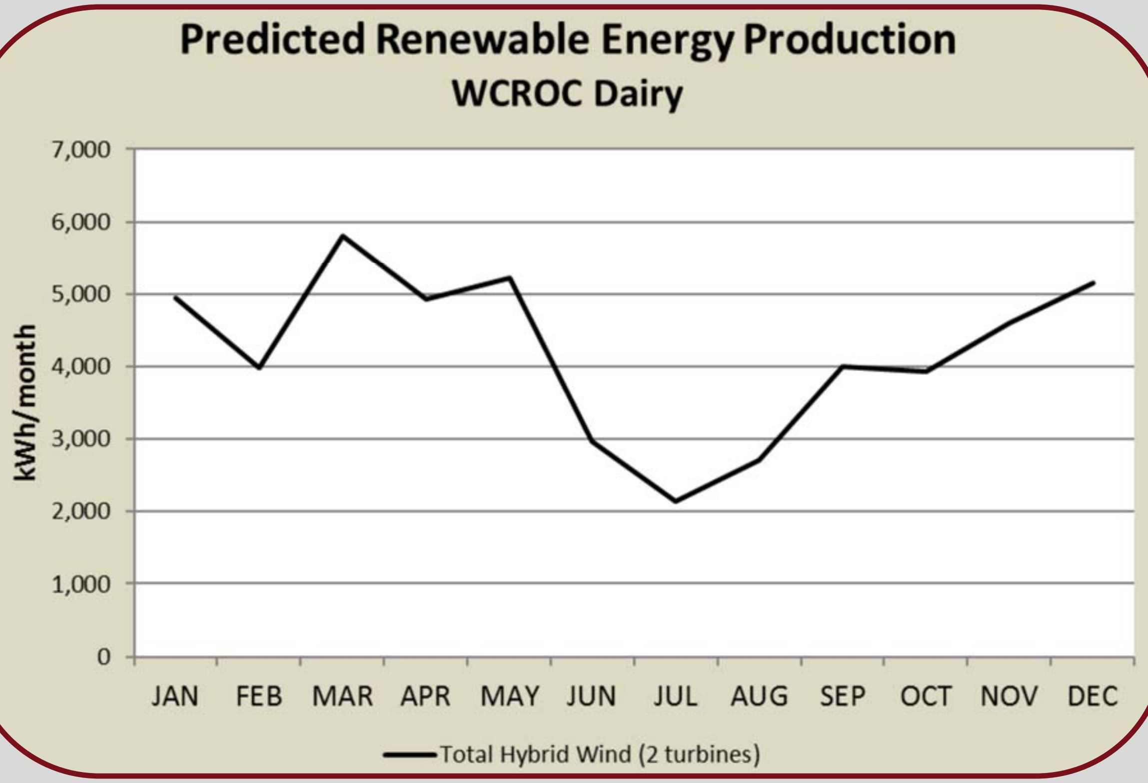
WCROC Dairy Barn Wind Energy

System Data

-Two 10 kW wind turbines installed on June 6, 2017
- Turbine model VT10 from Ventera
  - 3 blade, downwind turbine, 270 peak RPM
  - Cut-in speed: 6 mph, survival wind speed: 130 mph
  - Bergey 10.4 kW inverter
- ARE 70 foot fold-down tower
  - 4 kW pole mount solar PV system on one turbine
  - Base diameter: 15 ft

Expected Performance/Economics

- Annual predicted generation for each turbine is 22,400 kWh worth $2240 at 10¢/kWh
- Total wind system cost was $78,400 per tower ⇨ 35 year simple pay back without incentives
- With 30% federal credit $54,880 ⇨ 24.5 year pay back



University of Minnesota
Driven to Discover℠

West Central Research & Outreach Center
46352 State Hwy 329 Morris, MN 56267
Phone: (320) 589-1711
Website: wcroc.cfans.umn.edu

Electric and Thermal Energy Strategies for Minnesota Swine Farms:

Finance and Economics

Presented by:
Michael Reese, Renewable Energy Director
West Central Research and Outreach Center

Presented at:
2017 MN Pork Congress, Minneapolis
January 18, 2017

University of Minnesota
Driven to Discover

Why renewable energy and energy efficiency for farms?

1. **The technology has improved** (less expensive, more reliable, produce more, easier / safer to interconnect and maintain).

2. **The systems can be practical and may provide a reasonable financial return.**

3. **State and Federal incentives are available to farmers.**

4. **Ag commodity processors and retailers may place a premium (or mandate) low carbon footprint products.**

5. **Renewable energy fits the farming philosophy** (Land-based, creates independence, may improve efficiency, production of a commodity).

University of Minnesota West Central Research and Outreach Center

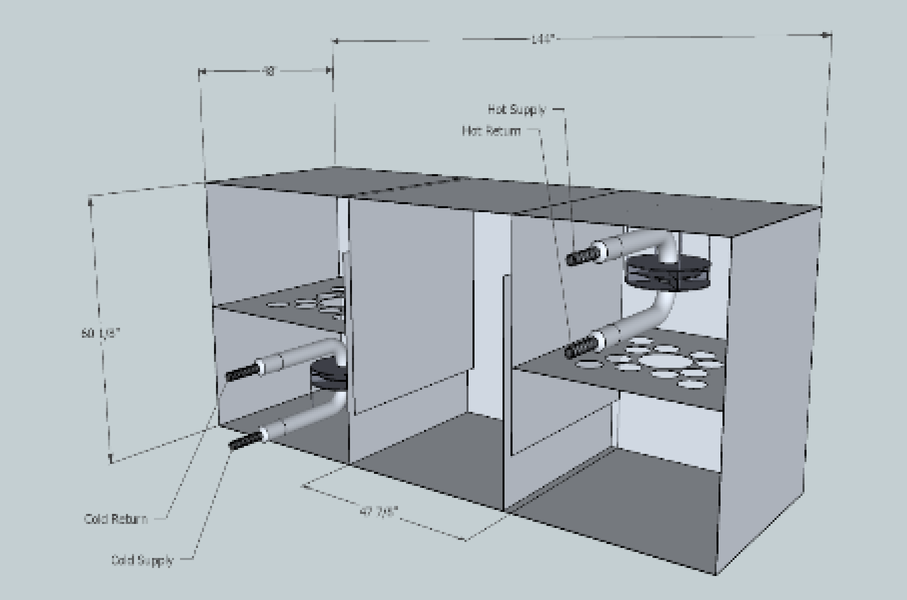
WCROC 27 kW Solar PV System on Swine Finishing Facility

WCROC 50 kW Solar PV System (TenKSolar Ground Mount)

WCROC Solar Thermal Systems

Evacuated Tube Collector

Absorption Chiller


144"
Hot Supply
Hot Return
Cold Return
Cold Supply
47 7/8"


Flat Plate Collector

WCROC 10 kW Ventera Wind Turbines

Installation in Winter 2017

SPECIFICATIONS:

Wind Turbine—Model VT10—240
10kW at 29mph-13m/s
Cut—In Wind Speed: 6mph-2.7m/s,
Survival Wind Speed: 130 mph-58 m/s
Total Weight of turbine and blades:
580lbs – 263kg
3 blade, downwind,
Diameter: 22 feet-6.7m
Swept Area: 380 SF/35.25 SM
RPM: 270 peak,
Blade: Glass fiber engineered plastic,
injection molded
Generator Rating: 15kva 240vac
at 250rpm, 3 phase

In general, the best current opportunities for swine producers:

1. Energy Efficiency Improvements

2. Solar Photovoltaic (Solar Electric)

-Other opportunities possible
on case-by-case basis.

Potential for Energy Efficiency Improvements at WCROC Swine Facilities

			Electricity + Propane	
Energy Conservation Measure	**Barn Applied to**	**Investment Costs**	**Payback Period (years)**	**Annual Return on Investment**
Night Temperature Setback	N	$ 500.00	**0.2**	**458.8%**
Variable Speed Fans	N	$ 1,000.00	**3.4**	**25.7%**
Earth Tube	Fa	$ 10,000.00	**3.9**	**21.8%**
Heat Lamp Controllers	Fa	$ 3,000.00	**6.1**	**17.1%**
LED Lighting	N	$ 12,000.00	**17.0**	**1.9%**
Geothermal Heat Exchange	Fa	$ 175,000.00	**27.7**	**-0.4%**
Traditional Air Conditioning	Fi	$ 80,000.00	**-**	**-4.01%**
Solar Chimney	N	$ 6,000.00	**-**	**-7.1%**

AKF Group LLC, 2016 (Study commissioned by WCROC)

Why Solar PV?

1. Capital costs have decreased significantly in last decade
2. Low Operation, maintenance, and repair – Increased longevity and durability
3. Technology has improved
4. Generation best matches load or highest generation during peak loads
5. Grants and incentives available to farmers and other businesses
6. Large southern facing roofs on swine barns MAY BE a benefit

***Solar PV will NOT be a good fit for all swine farms!**

Grants and Incentives: (Partial List)

1. **Property Assessed Clean Energy (PACE)**
   -5 to 10 year loan paid back through real estate tax
2. **USDA Rural Energy for America Program**
   -Grant for up to 25% of capital cost - Loan program available
   -Competitive application process – low success rates
3. **MN AGRI Livestock Facility Loan Program**
   -Grant for up to 5% of an energy system tied to livestock facilities - $50k max ($25k /year)
   -About 60% of qualified applicants are funded

Grants and Incentives: (Partial List)

4. **Utility Incentives:**

   <u>Made-in-Minnesota Solar Program</u> – Provides payments between $0.10-$0.13 / kWh for 10 years for commercial systems below 40 kW nameplate in an IOU service territory

   <u>Xcel Solar Rewards</u> – Payments for $0.08 . kWh for 10 years for residential or business systems less than 20 kW.

   <u>Net Metering –</u> For systems less than 40 kW in nameplate capacity.

   -Check with your utility for other potential incentives such as **<u>CIP payments</u>**.

5. **Federal Investment Tax Credit (ITC)**

   -30% ITC through December 31, 2019 – then rate decreases

   -Capital costs x .3

6. **Modified Accelerated Cost Recovery (MACRS) Depreciation**

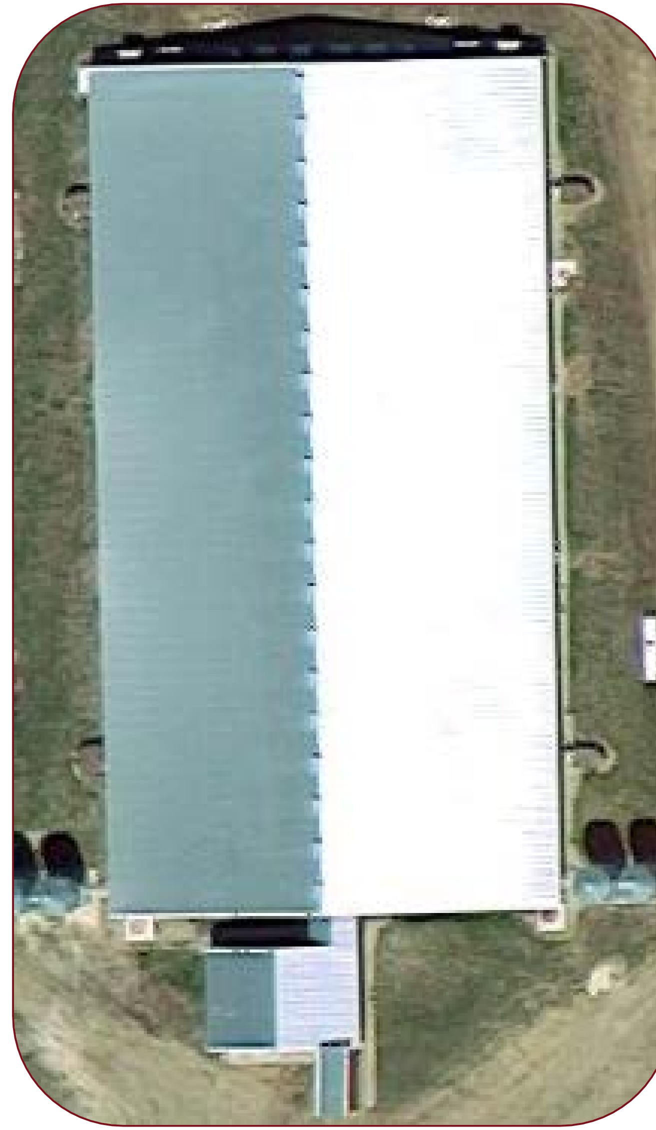
   -MACRS Depreciation for Years 0-5

   -85% of solar PV capital costs (due to ITC benefit)

   -Depends on federal tax rate for individual (Eg. 28% or 38%)

Case Study: 2400 Head Swine Finishing Unit

Owner is participating in energy audit study and requested solar PV analysis

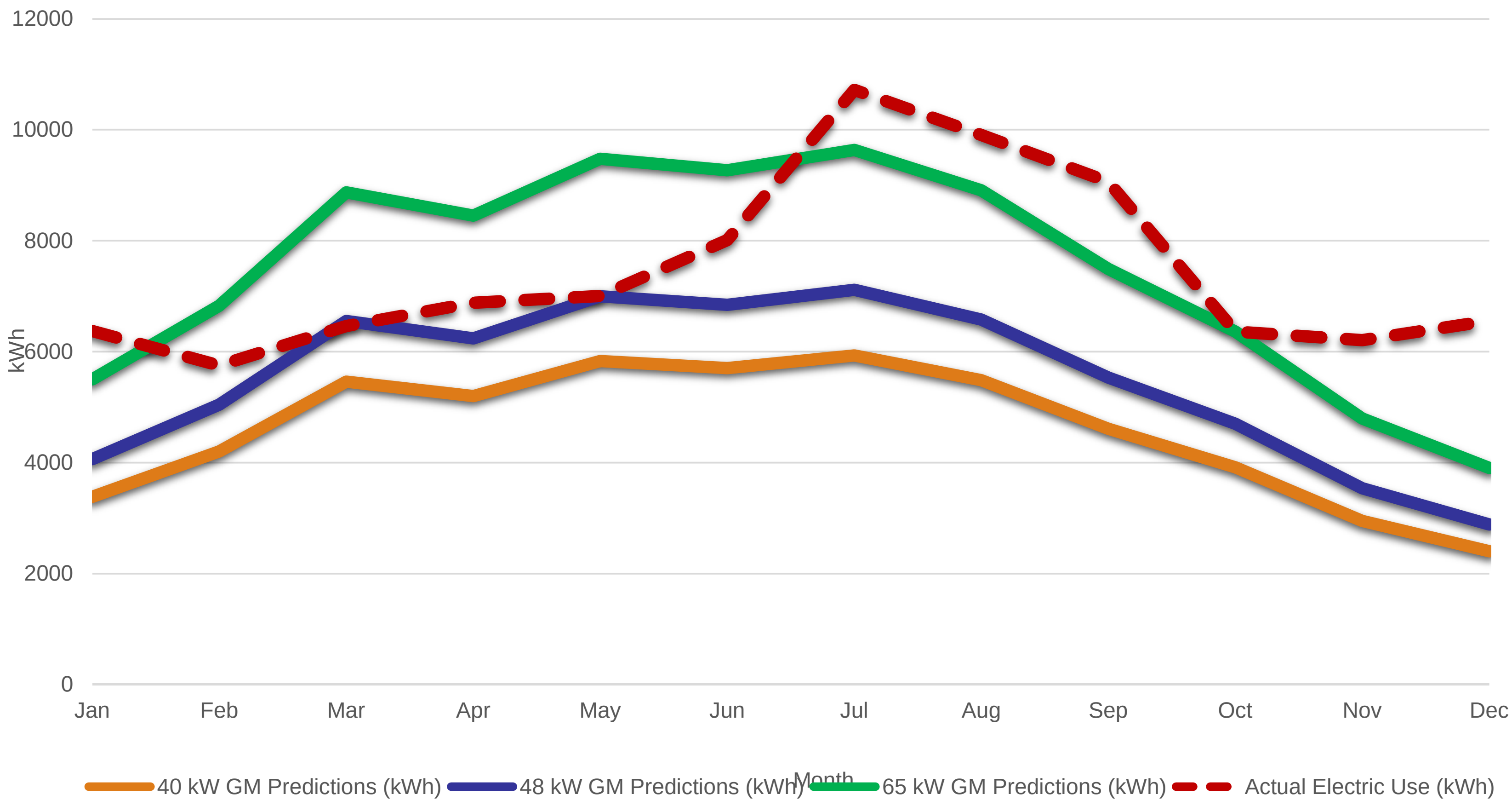


Specifications:

- 2400 head divided into two 1200 head rooms
- 100 feet x 200 feet (20,000 square feet)
- Building is oriented north and south
- Tunnel ventilated
- 5,800 hogs per year
- 89,287 kWh total electrical energy use per year
- 7,441 kWh average electrical energy use per month
- 10,720 kWh per month maximum (July)
- 5,749 kWh per month minimum (Feb)

Case Study: 2400 Head Swine Finishing Unit

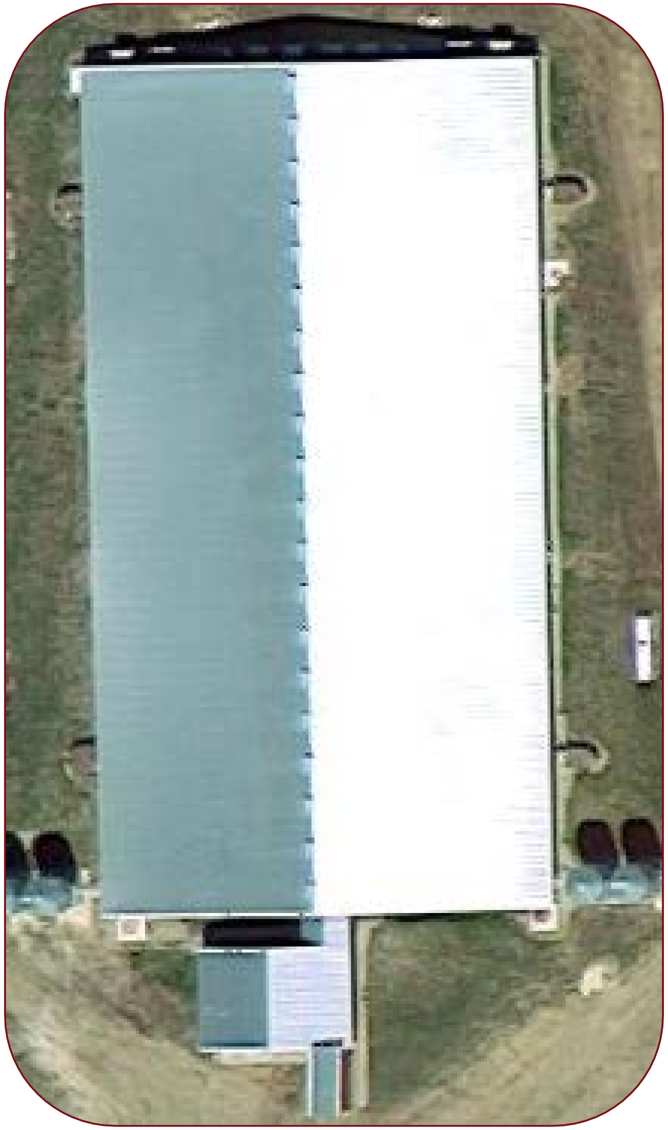
System Sizing - Load vs Projected Generation



Case Study: Financial Pro Forma for Solar PV

Assumptions:

- Capital cost equals $3 /watt of nameplate
- Production estimated by multiplying nameplate capacity (in watts) by 1.4
- $0.10 / kWh in Year 1 (3% escalator)
- 25-year life expectancy of solar system
- 25-year warranty on panels and brackets
- 20-year extended warranty on inverter(s)
- 1-year warranty on install
- 28% federal tax bracket
- 4% Interest – debt or owner equity
- 10-year debt
- <u>Assumed could make full use of tax benefits</u>
- Module degradation rate of 0.5% per year
- 3% inflation rate per year on electric rate and operating expenses



Case Study: Financial Pro Forma for Solar PV

Three sizes evaluated:

20 kW nameplate with:

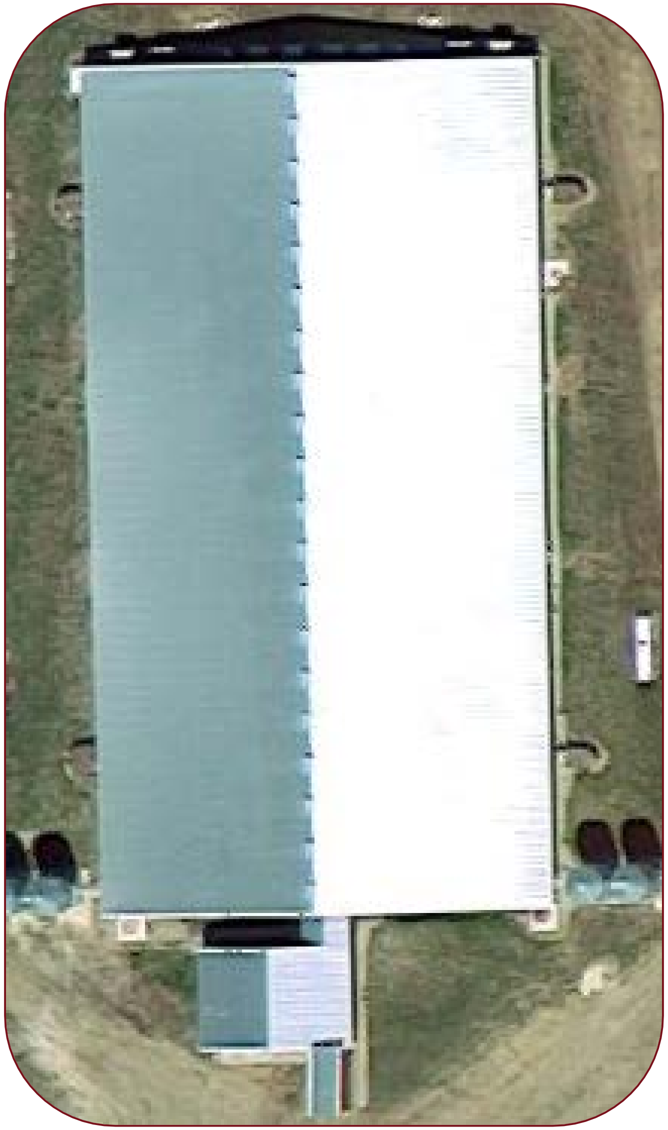
1. Tax Benefits Only
2. USDA REAP and MN AGRI Livestock Grant
3. Xcel Solar Rewards ($0.08/kWh for 10 years)
4. Xcel Made-in-Minnesota
5. All Benefits (5a – Solar Rewards, 5b – MiM)

40 kW nameplate with:

1. Tax Benefits Only
2. USDA REAP and MN AGRI Livestock Grant
3. Made-in-Minnesota Solar Incentive ($0.11/kWh for 10 years)
4. All Above Benefits

65 kW nameplate with:

1. Tax Benefits Only
2. USDA REAP and MN AGRI Livestock Grant



Case Study: Financial Pro Forma for Solar PV

YEAR	0	1	2	3	4	5	6
REVENUES							
Net kWh/yr		55073	54798	54524	54251	53980	53710
PPA Rate ($/kWh)		0.1000	0.1030	0.1061	0.1093	0.1126	0.1159
Utility Incentive (Xcel MiM)		0.1100	0.1100	0.1100	0.1100	0.1100	0.1100
Total Savings from Electric Bill		$11,565	$11,672	$11,782	$11,896	$12,013	$12,135
EXPENSES							
Operation & Mgt.		$250	$256	$263	$269	$276	$283
Financial Management		$250	$256	$263	$269	$276	$283
Service, Warranty, & Repair		$800	$800	$800	$800	$800	$800
Electrical Usage		$0	$0	$0	$0	$0	$0
Professional Services		$250	$258	$265	$273	$281	$290
Real Estate Tax Increase		$0	$0	$0	$0	$0	$0
Land Lease		$0	$0	$0	$0	$0	$0
Insurance		$360	$371	$382	$393	$405	$417
Demand and Other Utilty Charges		$116	$117	$118	$119	$120	$121
Total Expenses		$2,026	$2,058	$2,090	$2,124	$2,159	$2,194
Operating Cash		$9,540	$9,614	$9,692	$9,772	$9,855	$9,940
Debt Principle		$84,000	$77,004	$69,727	$62,160	$54,290	$46,105
Debt Service		$10,356	$10,356	$10,356	$10,356	$10,356	$10,356
Cash Flow (Op. Cash minus Debt Serv.)		-$817	-$742	-$665	-$585	-$502	-$416
GROSS INCOME							
Revenue		$11,565	$11,672	$11,782	$11,896	$12,013	$12,135
Minus Operating Expenses		$2,026	$2,058	$2,090	$2,124	$2,159	$2,194
Minus Interest (4 %)		$3,360	$3,080	$2,789	$2,486	$2,172	$1,844
Plus Depreciation @ 28% Tax Rate		$6,720	$10,752	$6,451	$3,871	$3,871	$1,935
Plus Investment Tax Credit		$36,000					
Net Taxable Income (Loss)		$48,900	$17,286	$13,354	$11,156	$11,554	$10,031
Cummalative Cash Flow with Tax Benefits	($84,000)	($35,100)	($17,814)	($4,460)	$6,696	$18,250	$28,281
ASSUMPTIONS		40 KW					
Project Cost		$120,000					
Debt		$84,000					
Equity							
REAP Grant		$30,000					
MN AGRI Livestock Grant		$6,000					
ACRS Depreciation-5 years @ 28 % Tax Bracket							

Case Study: Financial Pro Forma for Solar PV

Size (Name-plate KW)	Capital Costs ($)	1st Year Production (KWh)	1st Year Revenue ($)	ITC	MACRS Depre-ciation	Grants	Xcel Solar Rewards	MiM	Simple Payback (Years)
20 kW	$60,000	28,000	$2,800	●	●				18
20 kW	$42,000	28,000	$2,800	●	●	●			9
20 kW	$60,000	28,000	$5,040	●	●		●		10
20 kW	$60,000	28,000	$5,880	●	●			●	**8**
20 kW	$60,000	28,000	$5,040	●	●	●	●		**4**
20 kW	$60,000	28,000	$5,880	●	●	●		●	**3.5**
40 kW	$120,000	55,073	$5,507	●	●				18
40 kW	$84,000	55,073	$5,507	●	●	●			**9**
40 kW	$120,000	55,073	$11,565	●	●			●	**8**
40 kW	$84,000	55,073	$11,565	●	●	●		●	**4**
65 kW	$195,000	85,028	$8,503	●	●				18
65 kW	$136,500	85,028	$8,503	●	●	●			**9**

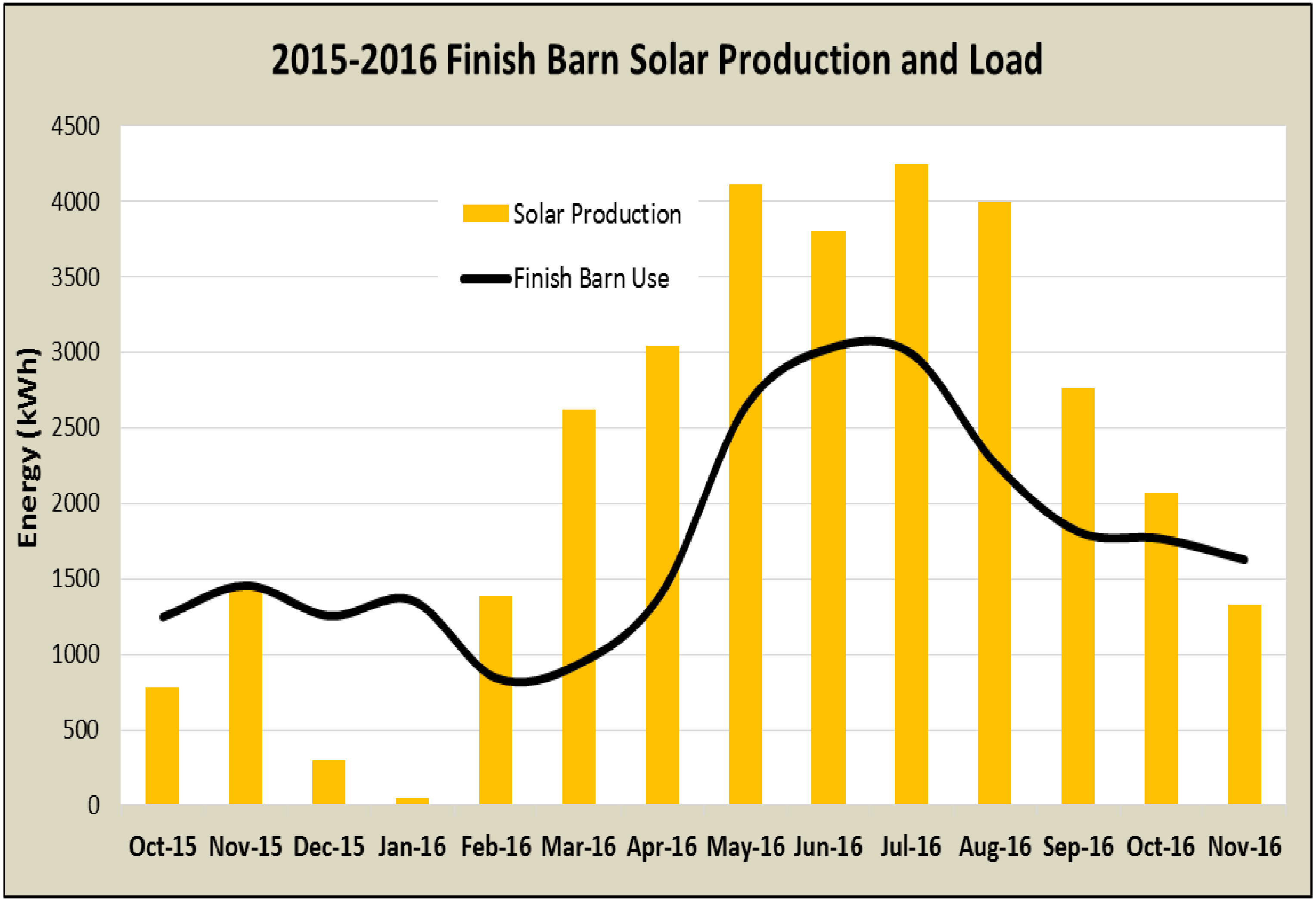
Case Study: Financial Pro Forma for Solar PV

Size (Name-plate KW)	Capital Costs ($)	1st Year Production (KWh)	1st Year Revenue ($)	ITC	MACRS Depre-ciation	Grants	Xcel Solar Rewards	MiM	Simple Payback (Years)
20 kW	$60,000	28,000	$2,800	●	●				18
20 kW	$42,000	28,000	$2,800	●	●	●			9
20 kW	$60,000	28,000	$5,040	●	●		●		10
20 kW	$60,000	28,000	$5,880	●	●			●	**8**
20 kW	$60,000	28,000	$5,040	●	●	●	●		**4**
20 kW	$60,000	28,000	$5,880	●	●	●		●	**3.5**
40 kW	$120,000	55,073	$5,507	●	●				18
40 kW	$84,000	55,073	$5,507	●	●	●			**9**
40 kW	$120,000	55,073	$11,565	●	●			●	**8**
40 kW	$84,000	55,073	$11,565	●	●	●		●	**4**
65 kW	$195,000	85,028	$8,503	●	●				18
65 kW	$136,500	85,028	$8,503	●	●	●			**9**

Other Considerations:

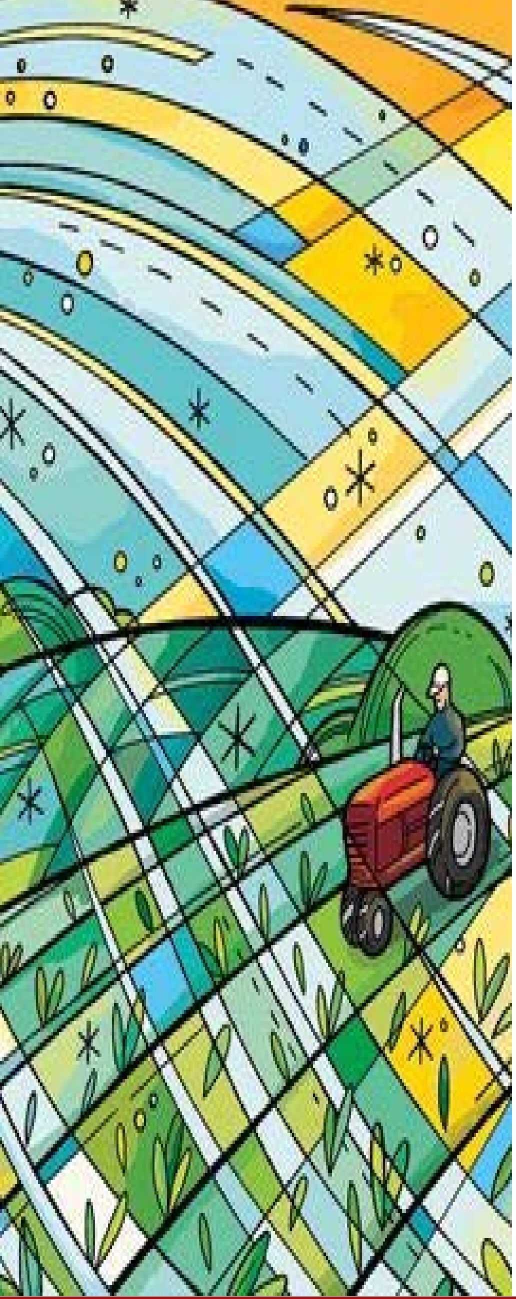
1. Capital Costs (Is it turn key? Permits, etc.)
2. Warranties
3. Work with a reputable contractor
4. Utility service territory – Demand Charges
5. Can you fully utilize tax benefits?
6. Lower GHGs / Public Perception
7. Roof versus Ground Mount
   - -Space available / suitability for solar panels
   - -Snow – Cover panels, shift load / roof collapse
   - -Age of roof /building
   - -Obstacle for vehicles, snow blowing, etc
   - -Cleaning
   - -Multi-benefit - Shade / shelter

WCROC 27 kW Solar PV System on Swine Finishing Facility

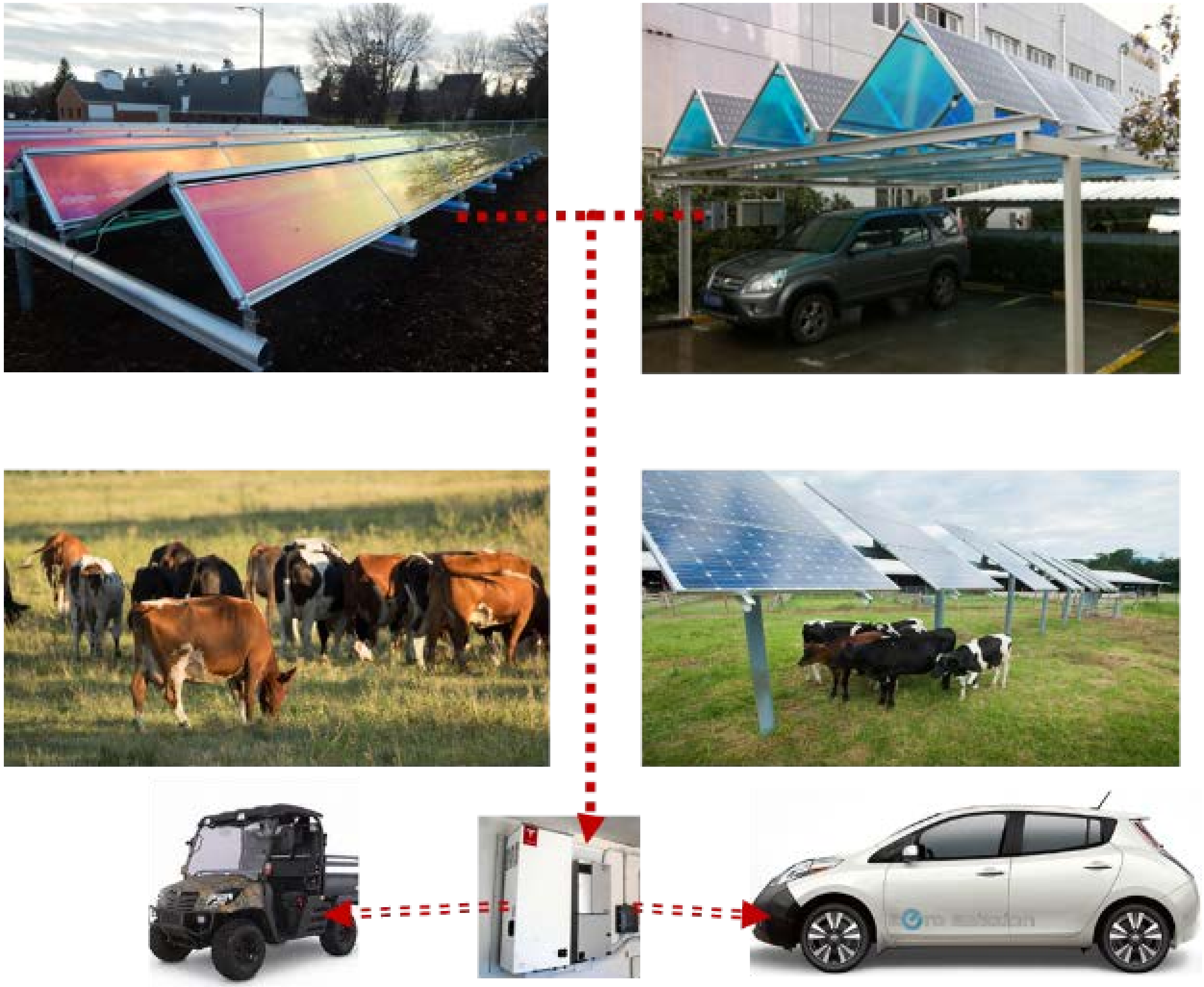


WCROC 27 kW Solar PV System on Swine Finishing Facility

December 22, 2016



Multi-benefits



Take Home Message:

- ✓ Energy efficiency upgrades can have a short-term return-on-investment
- ✓ A solar PV system may be financially viable for your swine farm
- ✓ State, federal, and utility grants and incentives are available
- ✓ Reputable contractors are available to remove complexities
- ✓ U of MN energy research is helping to lower costs and serve as an unbiased source of information

2017 Midwest Farm Energy Conference,

June 13 -14, 2017

West Central Research & Outreach Center - Morris

- Excellent speakers including:

  Mr. Mark Greenwood, AgStar Financial

  Dr. Brian Buhr, Dean – U of MN College of Food, Agricultural, and Natural Resource Sciences

  Dr. Barry Dunn, President, South Dakota State Univ.

  Dr. Jay Harmon, Iowa State

- Tours of innovative, farm-scale renewable energy systems

- For more information or to register, go to: http://wcroc.cfans.umn.edu/mfec-registration

Renewable Energy

Staff:

1. **Rob Gardner**, Assistant Professor
2. **Joel Tallaksen**, Scientist
3. **Eric Buchanan**, Scientist
4. **Cory Marquart**, Assistant Scientist
5. **Kirsten Sharpe**, Junior Scientist
6. **Michael Reese**, Renewable Energy Program Director

Contact Information:

Michael Reese
Director- Renewable Energy
West Central Research & Outreach Center
University of Minnesota
Phone: (320) 589-1711
Web: http://renewables.morris.umn.edu
reesem@morris.umn.edu

Acknowledgements:

MN Environmental and Natural Resources
Trust Fund through LCCMR
U of MN MnDRIVE
U of MN IREE
U of MN Rapid Agriculture Response Fund
State of Minnesota
Xcel RDF
And the Renewable Energy Team!

Reducing Fossil Fuel Use in Swine - One Piece at a Time

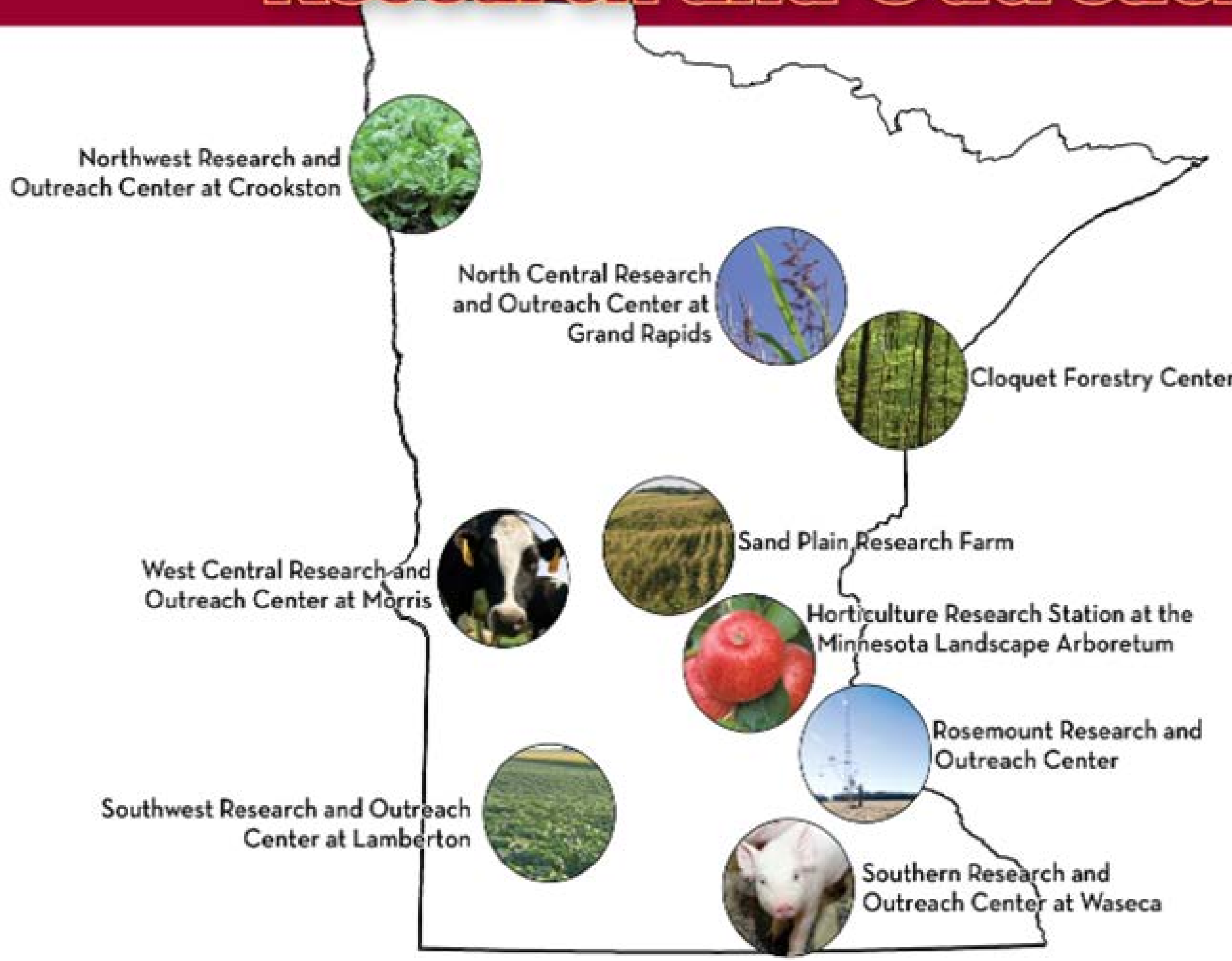
Lee J. Johnston, Professor

University of Minnesota

West Central Research and Outreach Ctr.

NPB Swine Educators Conference
St. Louis, MO
September 27, 2016

Research and Outreach



University of Minnesota

Greening of Ag Project

* Consumer supply chains are asking for reduced environmental impacts
* Modern production agriculture uses significant fossil fuel resources
  * Fertilizer, crop protection products, diesel, electricity, heating fuels
* Is there a way to reduce the use of these fuels without compromising or maybe improving production?

University of Minnesota

University of Minnesota

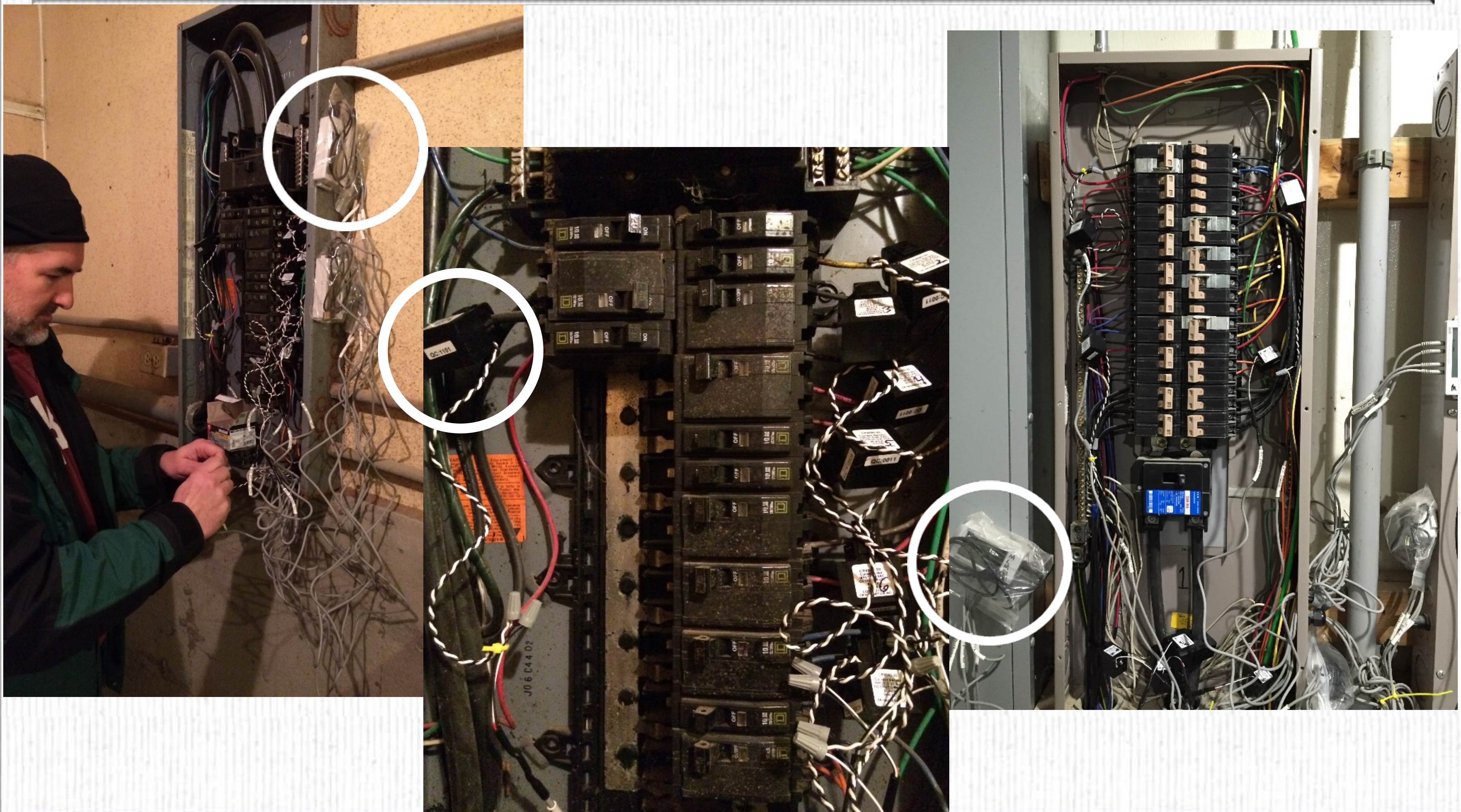
Greening of Ag Project

- Currently, three pronged
  - Dairy production
  - Crops production
  - Swine production
- Upcoming aspects
  - Algae production
  - Horticulture?

Swine Barn Energy Monitoring

- Monitoring monthly electrical use of representative loads within each barn
- Recording electrical use in each barn
- Monitoring use of heating fuels in each barn
- Recording pig production from each barn

Sensors and Dataloggers



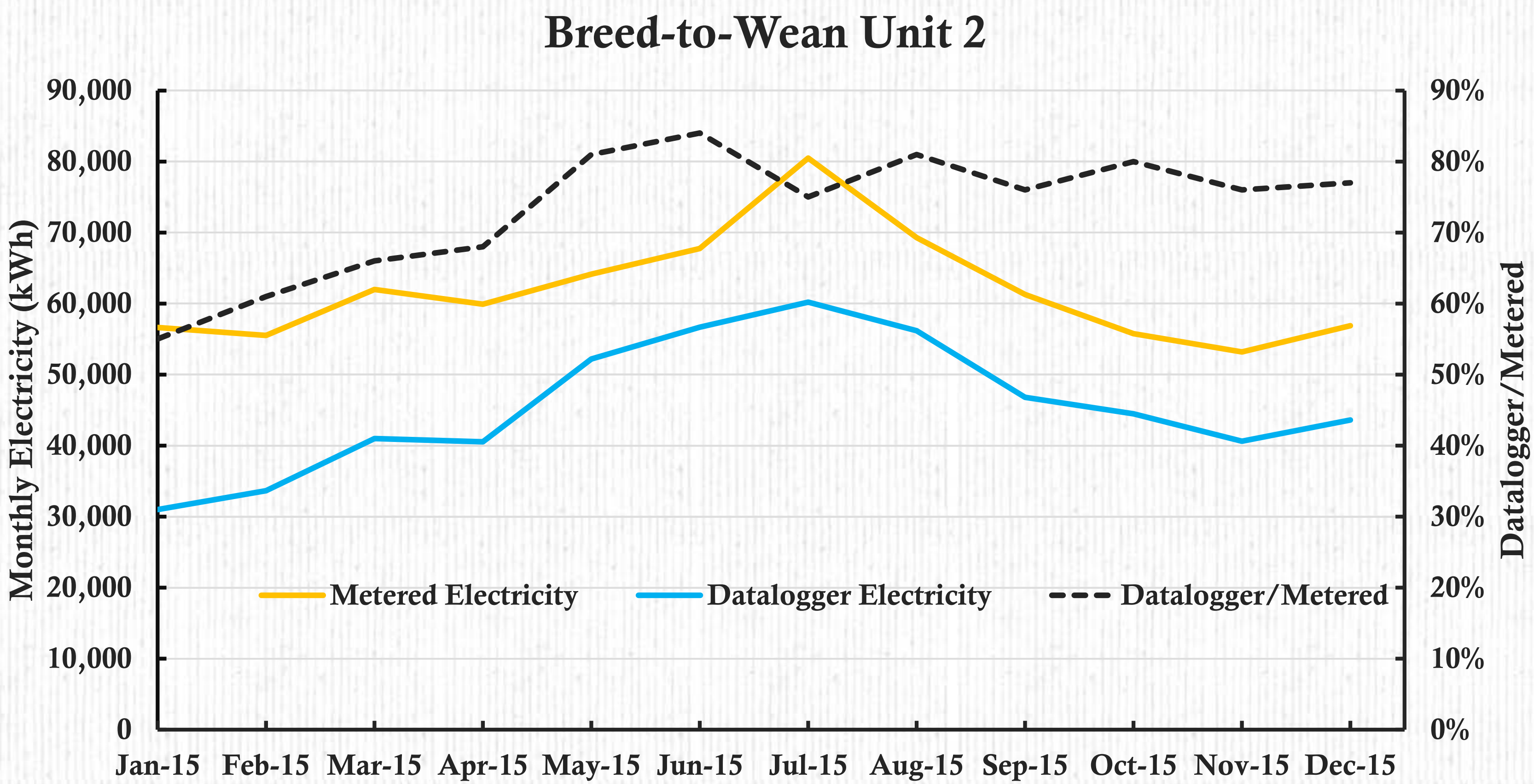
Swine Barn Energy Monitoring

Breed to Wean Barns

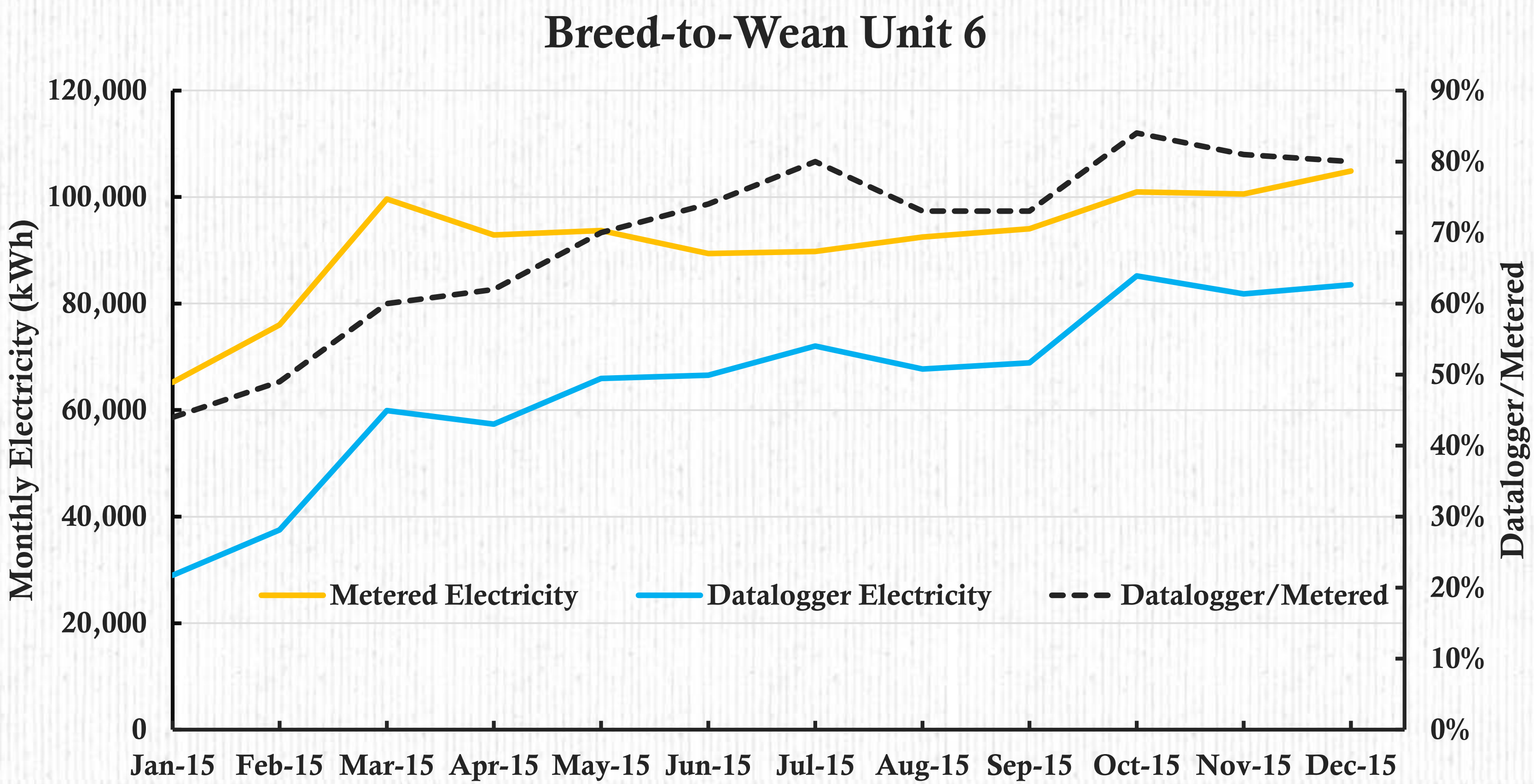
- Breed to wean barn #2
  - Gestation barn unit is curtain sided
  - Farrowing rooms are power ventilated
- Electrical usage
  - Uses 54,880 kWh/month on ave.
  - About 2500 sows
  - 57,965 weaned pigs per year
  - **11.4 kWh per weaned pig**

- Breed to wean barn #6
  - Gestation barn is cross-ventilated
  - Farrowing rooms are power ventilated
- Electrical usage
  - Uses 87,100 kWh/month on ave.
  - 3,300 sows
  - 85,874 weaned pigs per year
  - **12.2 kWh per weaned pig**

Proportion of Electrical Loads Recorded

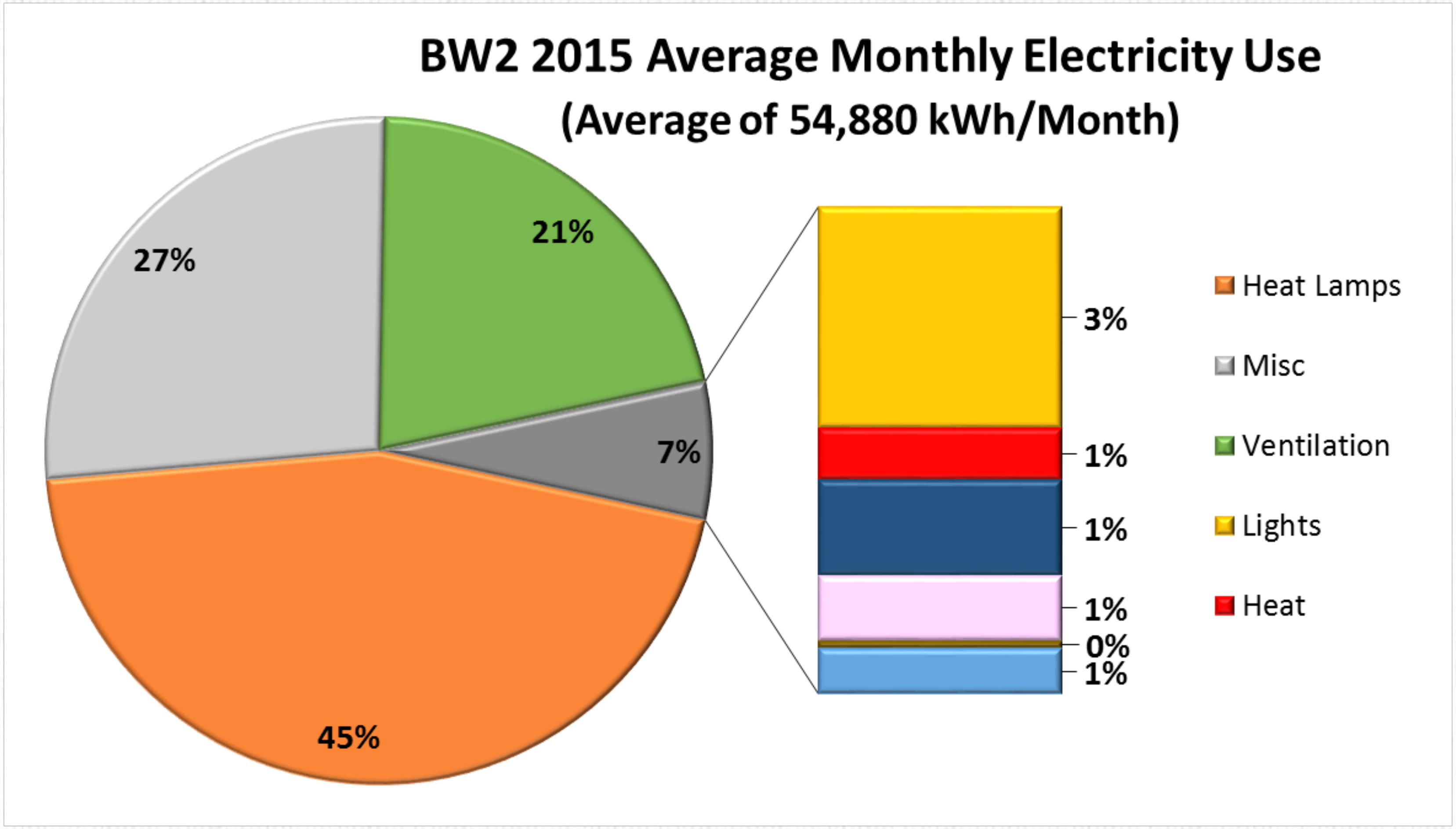


Proportion of Electrical Loads Recorded

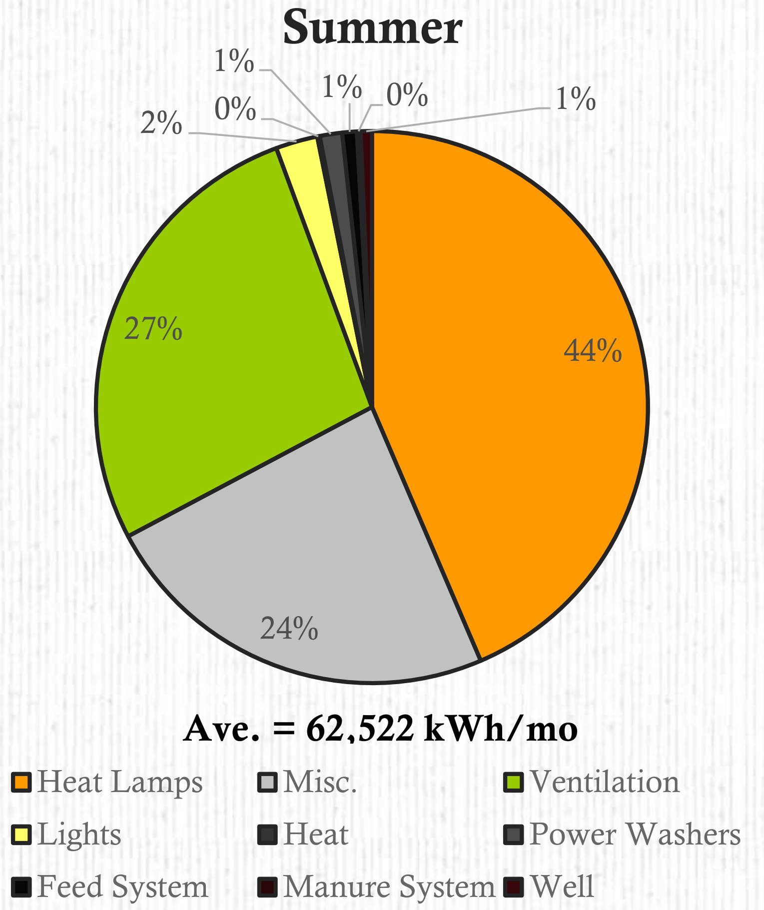


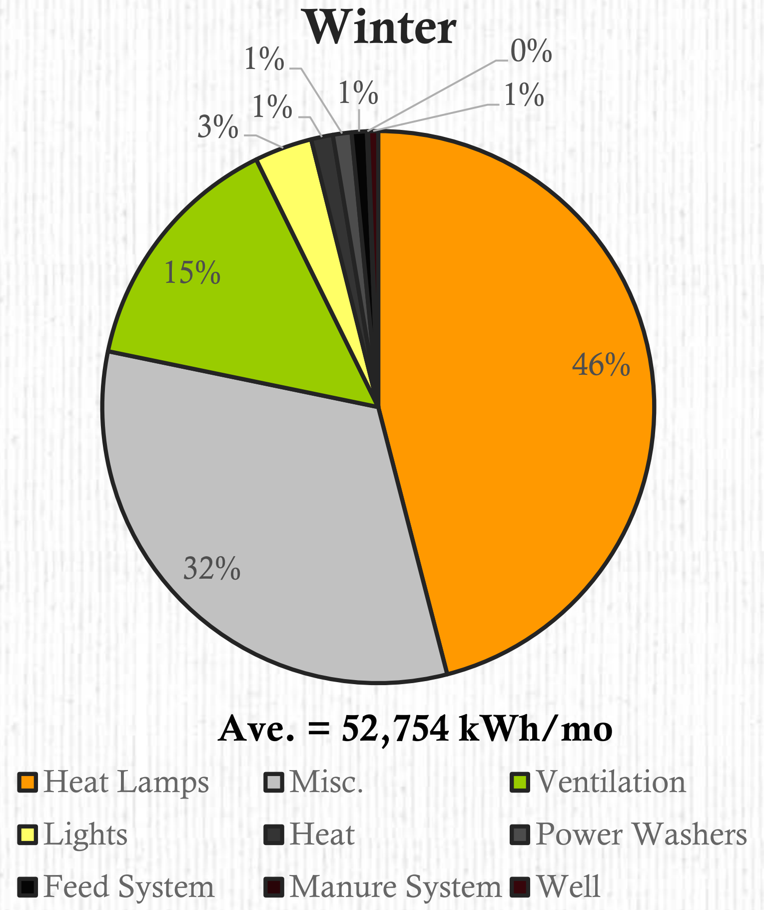
University of Minnesota

Monthly Electricity Use – Breed to Wean Unit

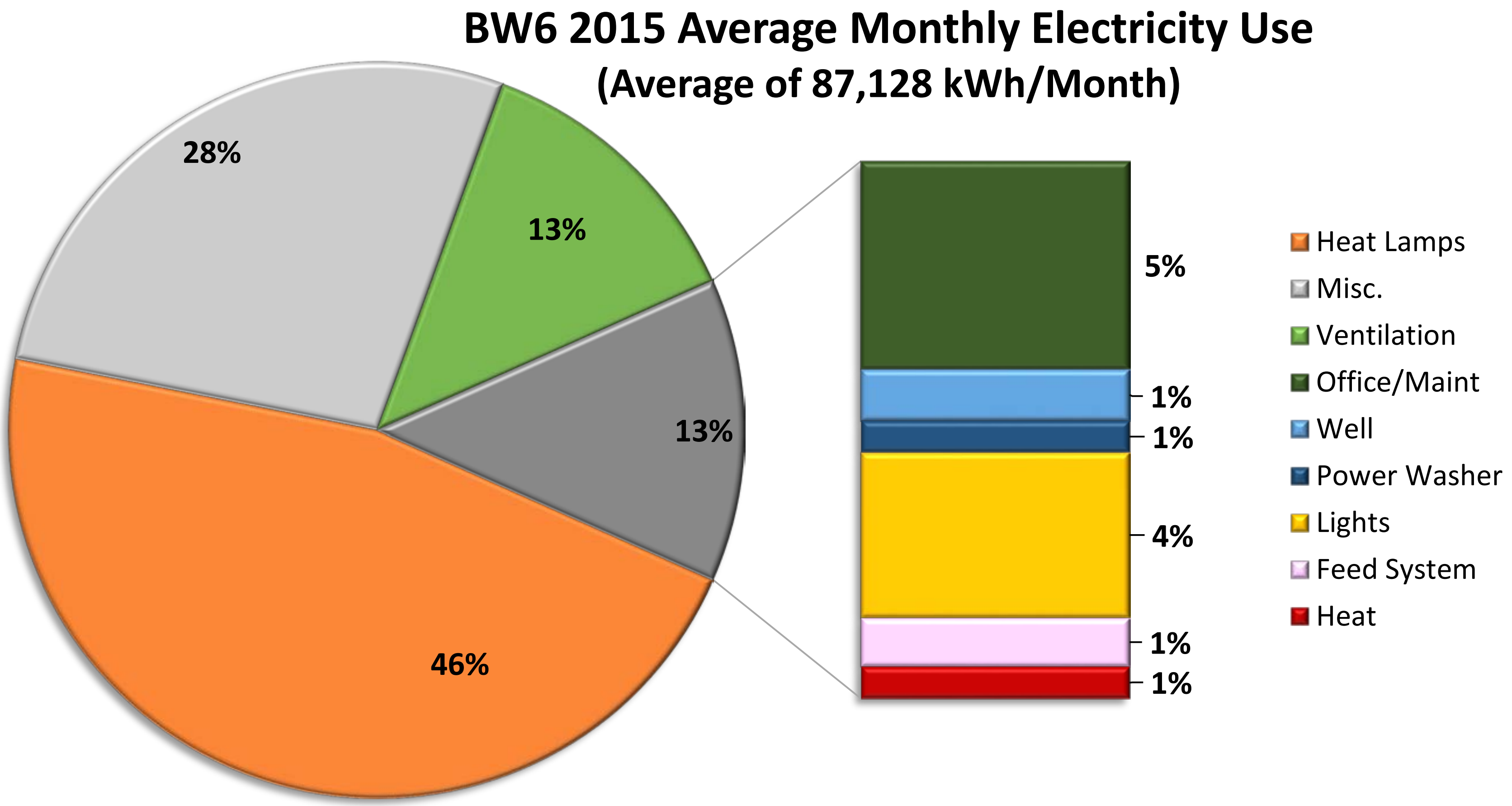


Seasonal Electric Loads: Breed to Wean Unit 2

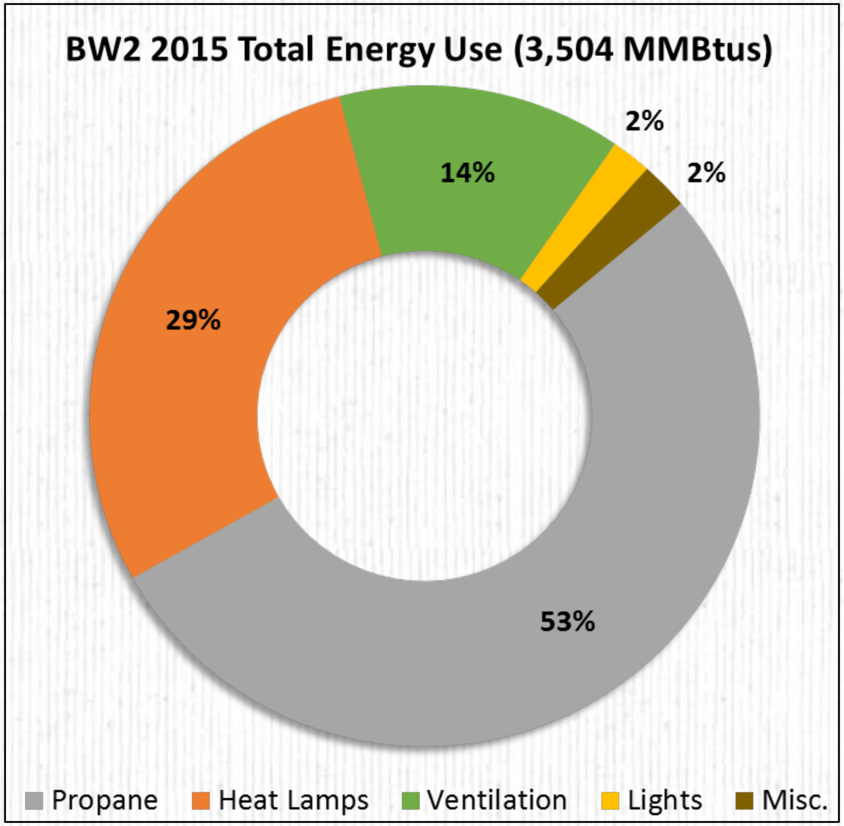


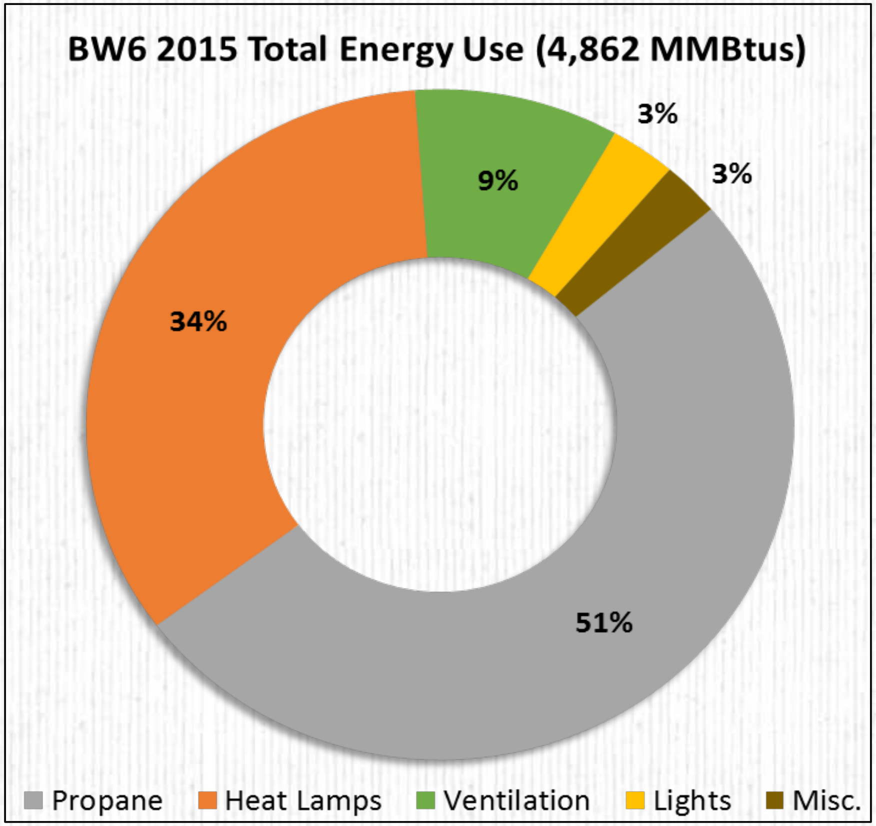


Monthly Electricity Use – Breed to Wean Unit



Total Fossil Energy Use (Heat + Elec): Breed to Wean Units





University of Minnesota

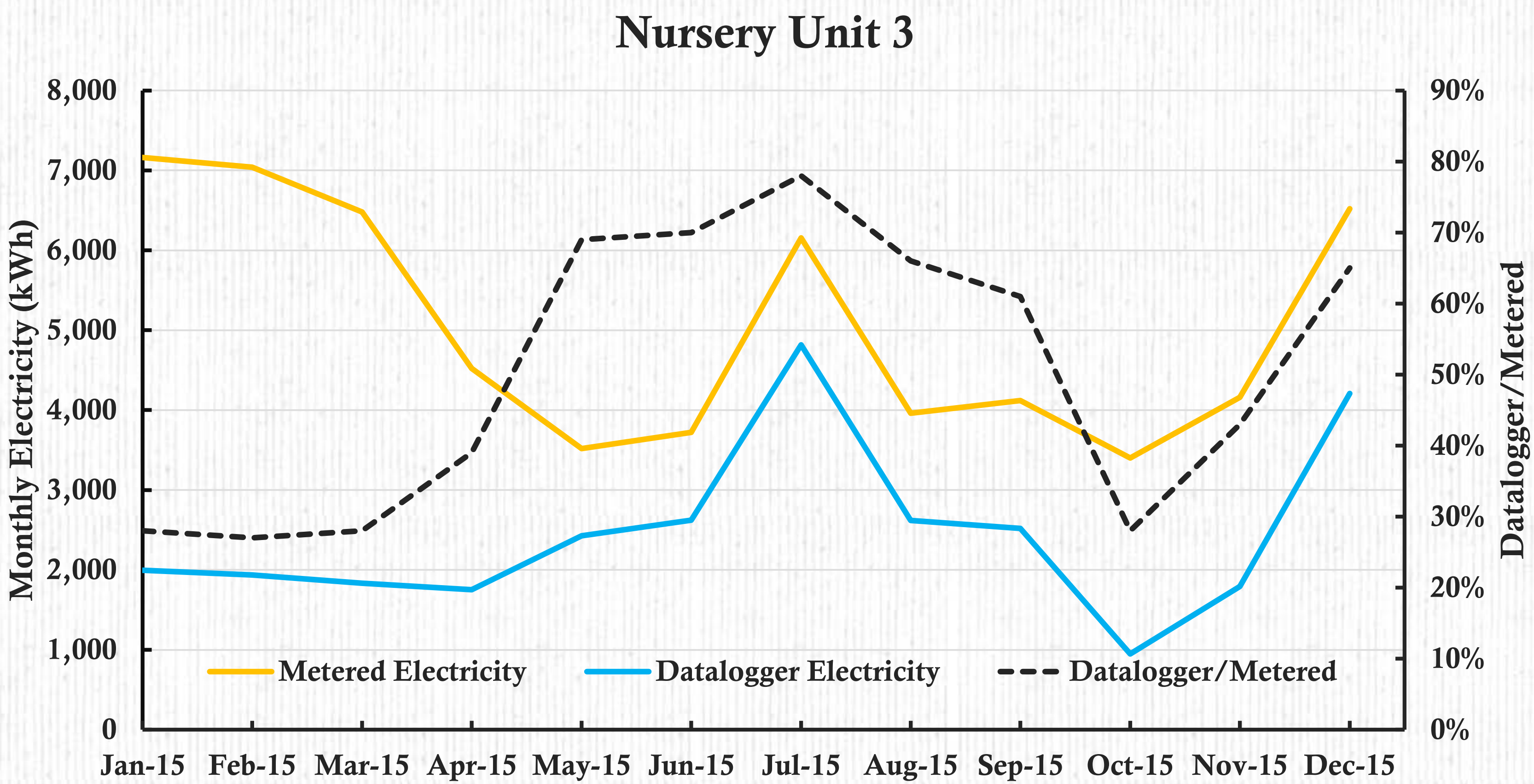
Swine Barn Energy Monitoring

Nurseries

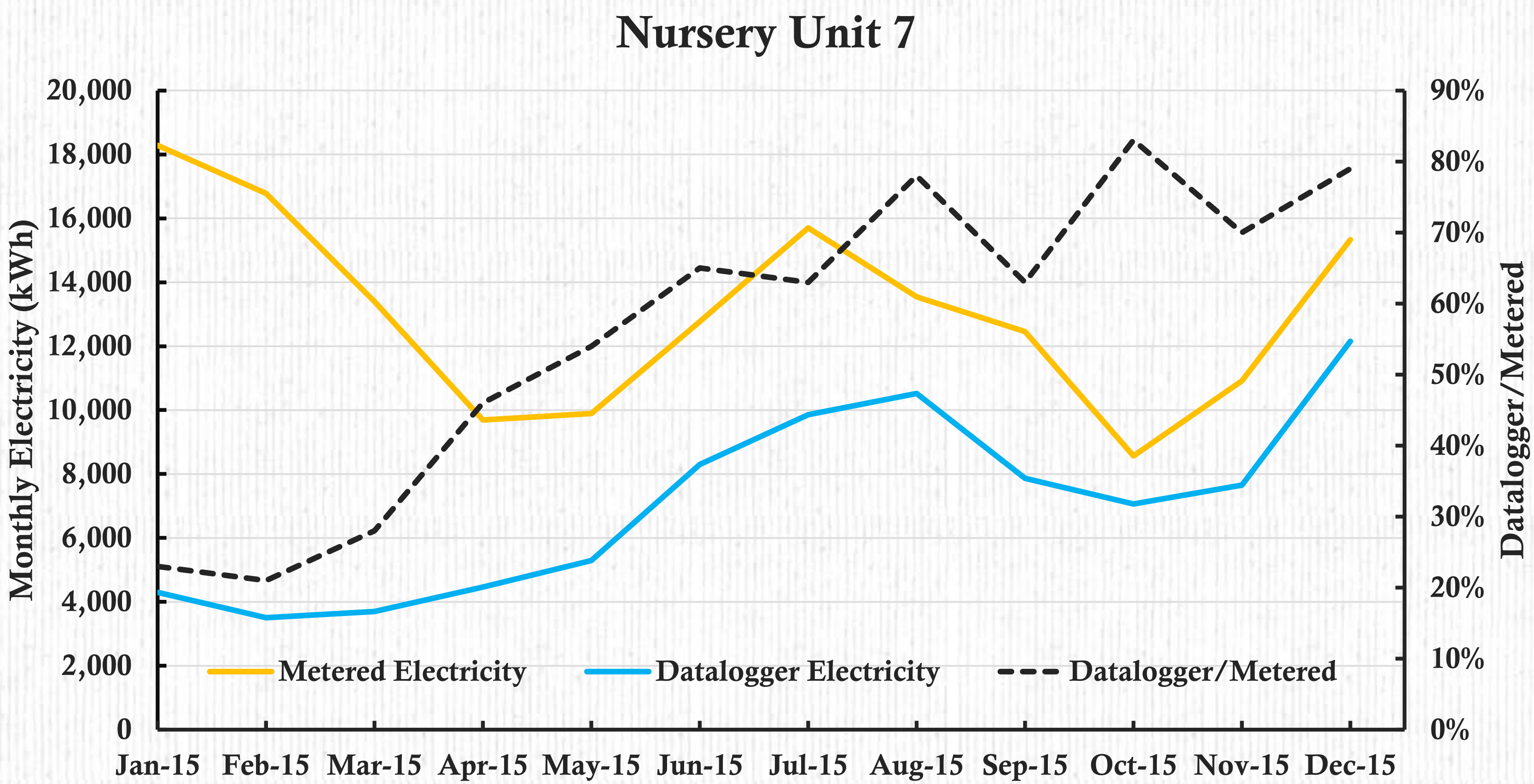
- Nursery barn #3
  - Nursery rooms power ventilated
- Electrical usage
  - Uses 3,700 kWh/month on ave.
  - 19,596 pigs per year
  - **2.3 kWh per pig produced**

- Nursery barn #7
  - Nursery rooms power ventilated
- Electrical usage
  - Uses 13,100 kWh/month on ave.
  - 76,700 pigs per year
  - **2.05 kWh per pig produced**

Proportion of Electrical Loads Recorded

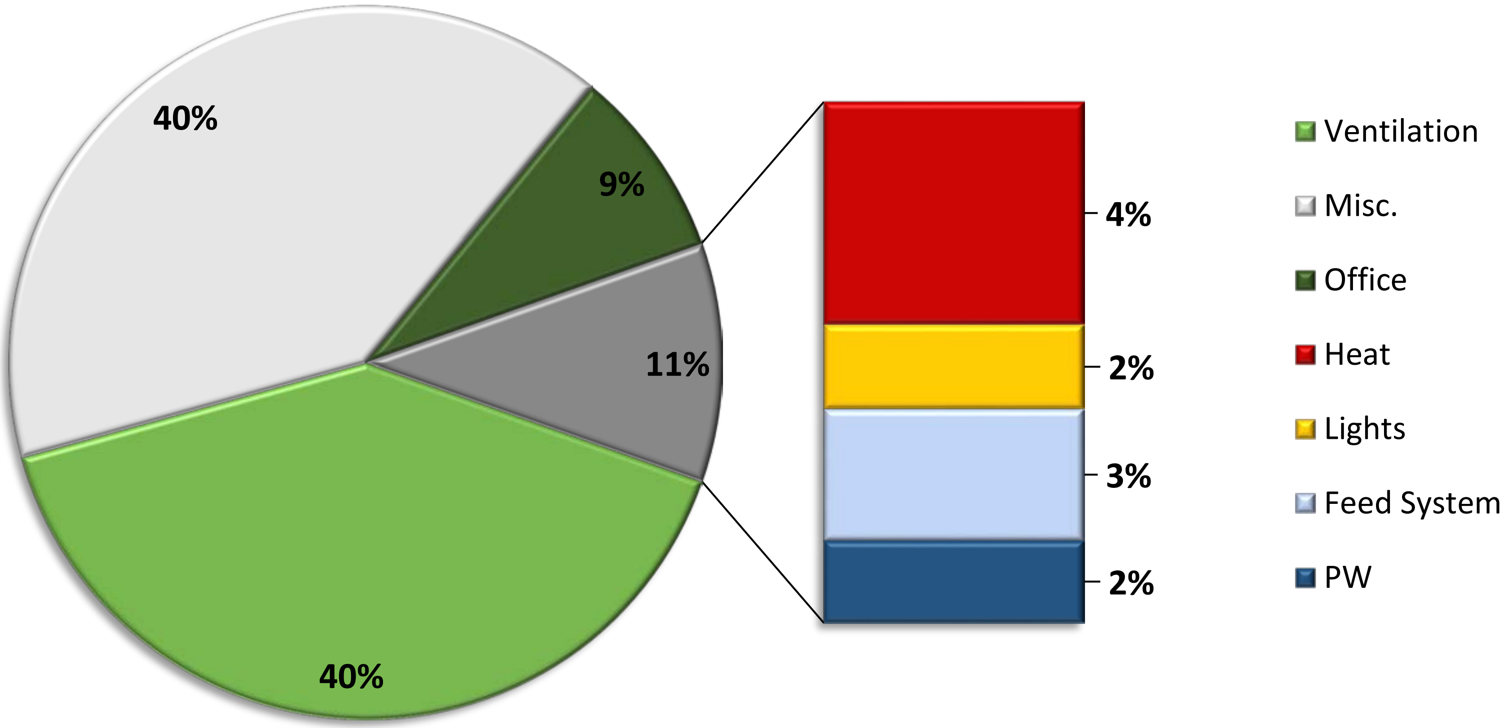


Proportion of Electrical Loads Recorded

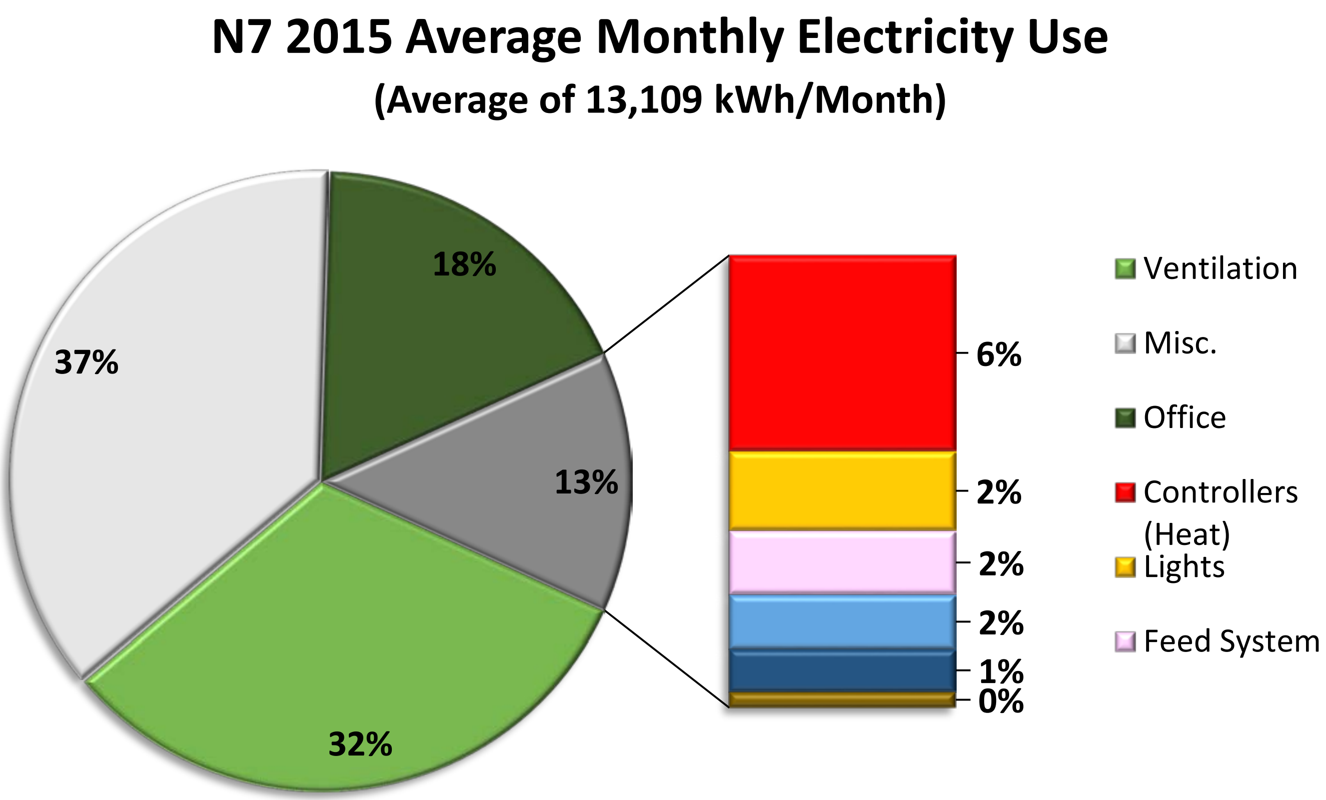


Monthly Electricity Use - Nursery

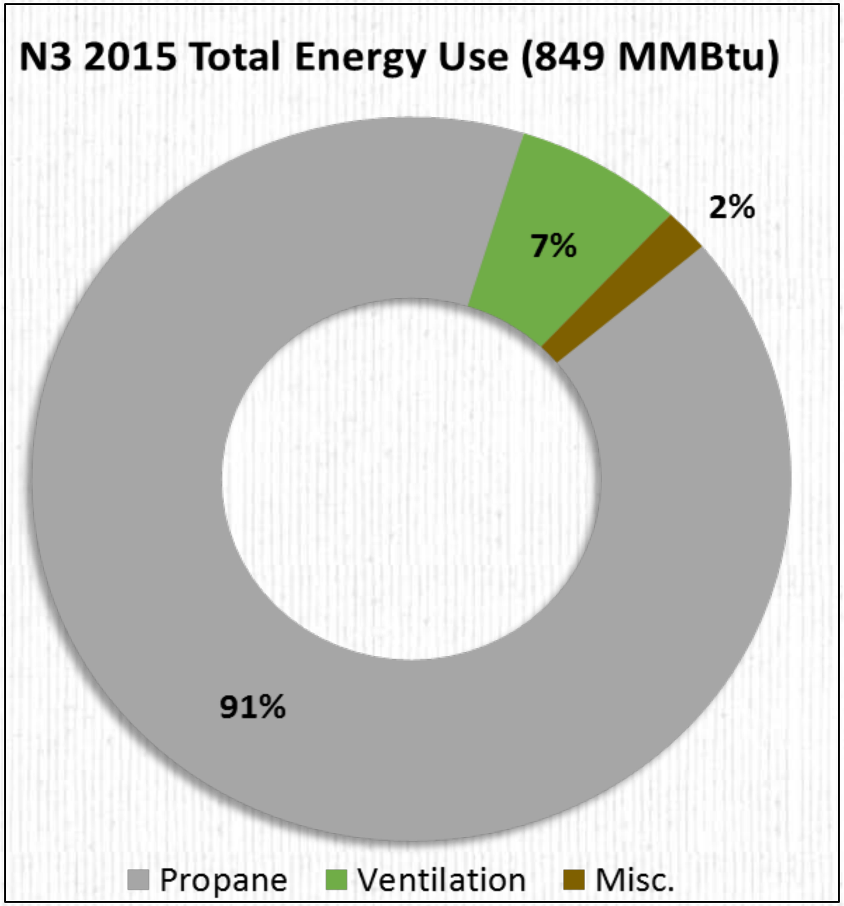
N3 2015 Average Monthly Electricity Use
(Average of 3,696 kWh/Month)

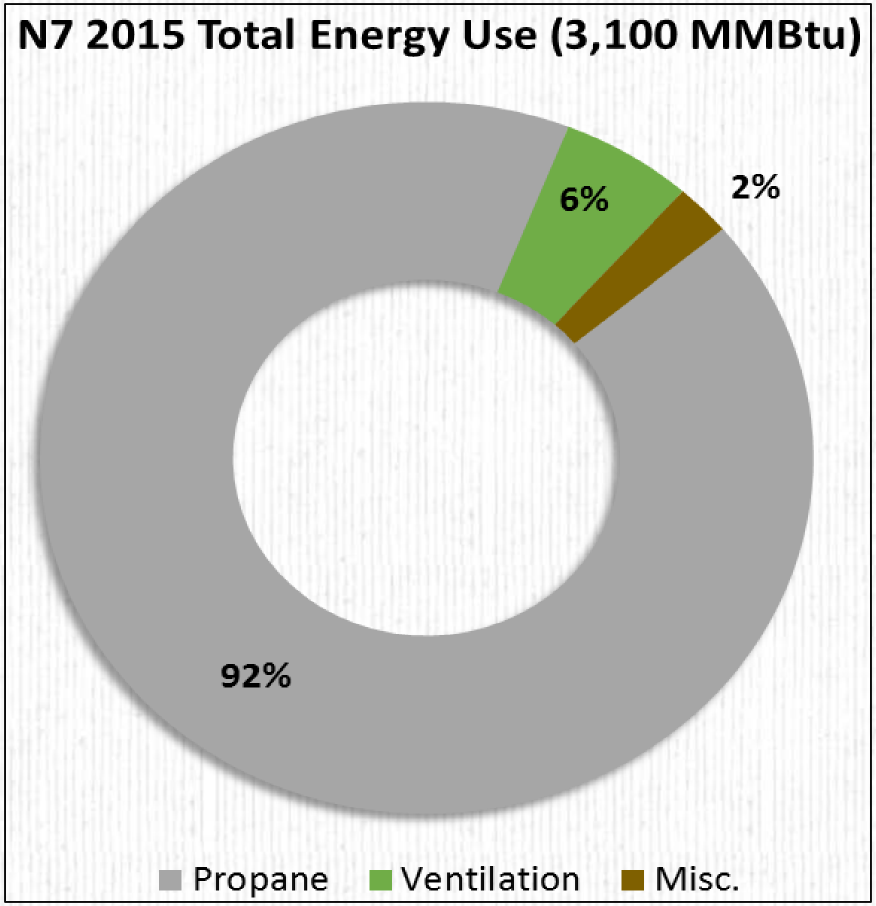


Monthly Electricity Use - Nursery



Total Fossil Energy Use (Heat + Elec): Nurseries





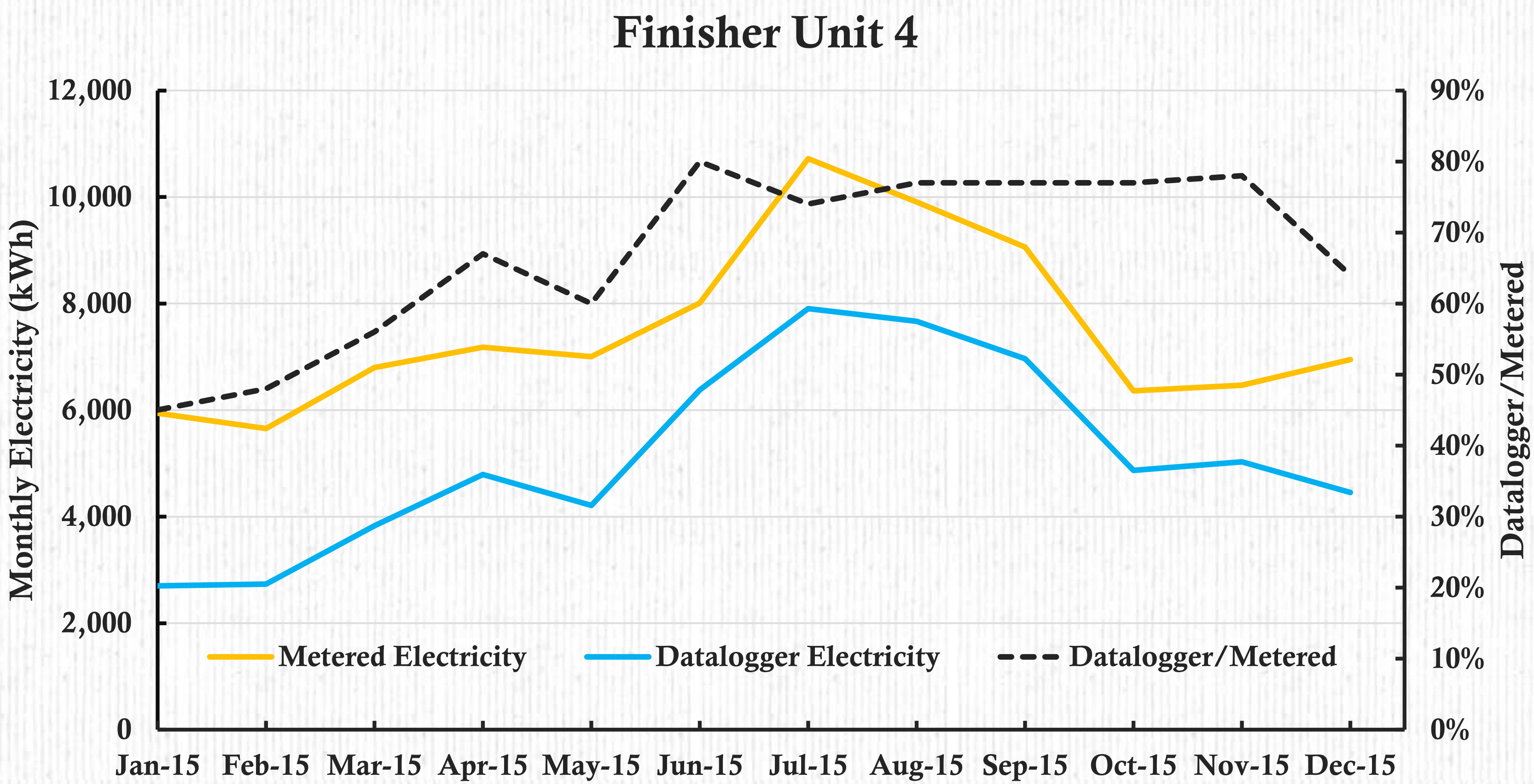
Swine Barn Energy Monitoring

Finishing Barns

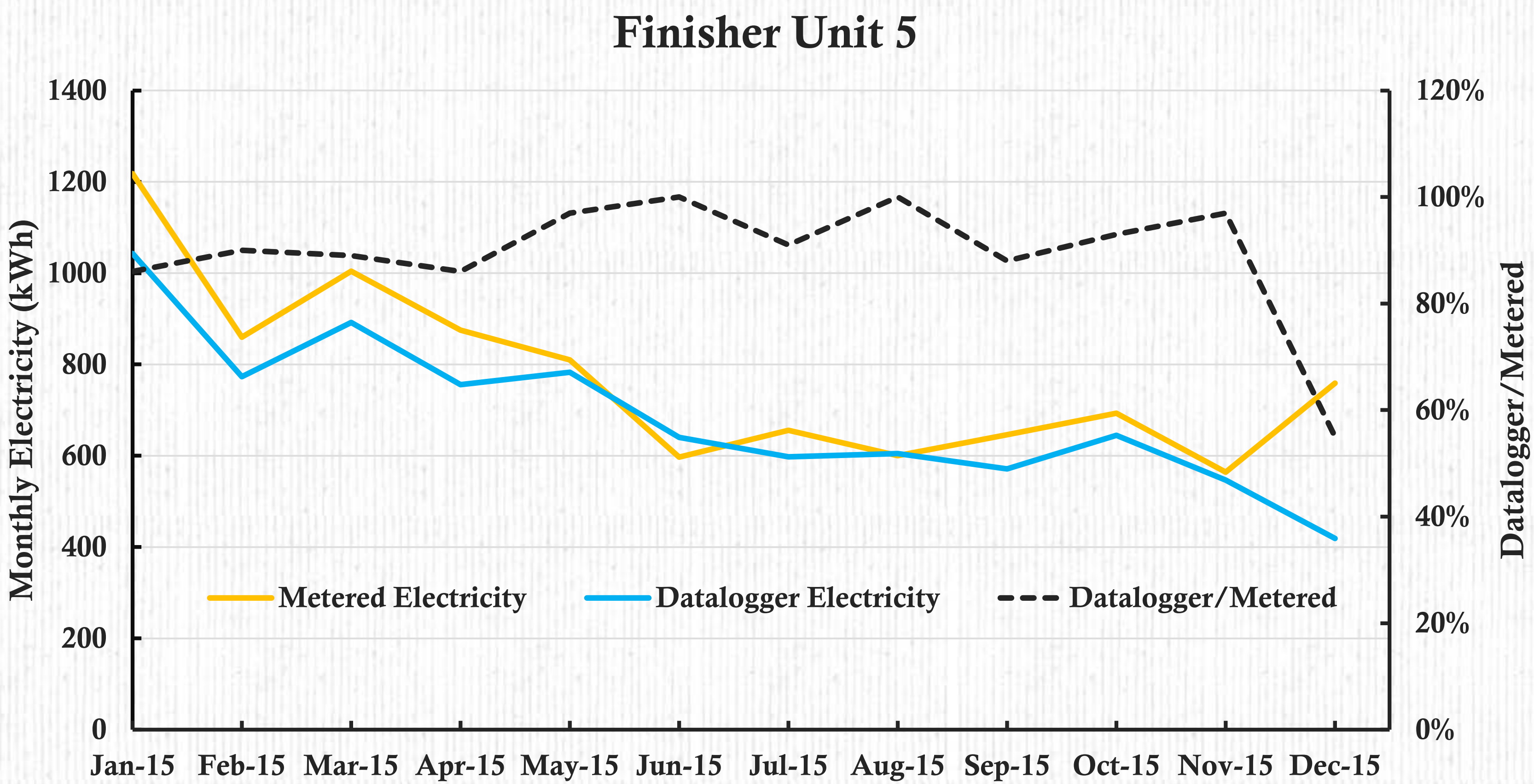
- Finish barn #4
  - Pig rooms are tunnel ventilated
- Electrical usage
  - Uses 7,500 kWh/month on ave.
  - 5,837 pigs per year
  - **15.4 kWh per finished pig**

- Finish barn #5
  - Pig rooms are curtain sided
- Electrical usage
  - Uses 770 kWh/month on ave.
  - 3,000 pigs per year
  - **3.1 kWh per finished pig**

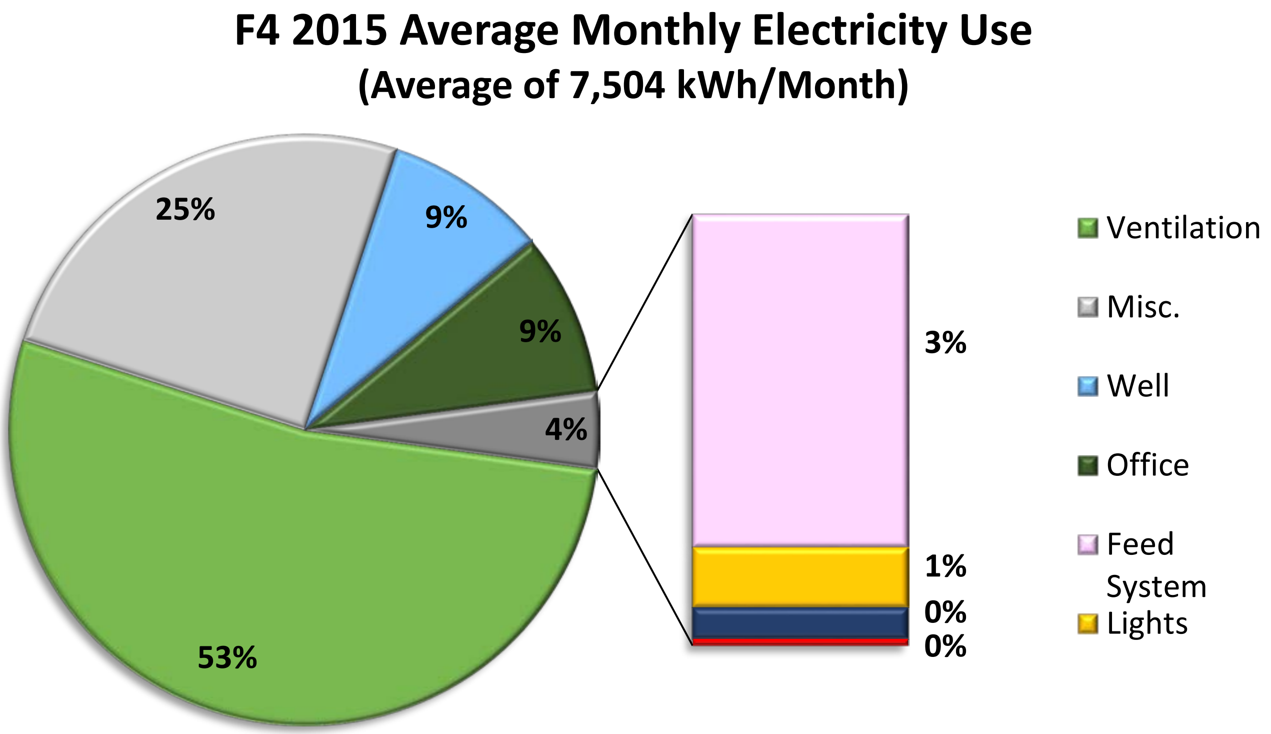
Proportion of Electrical Loads Recorded



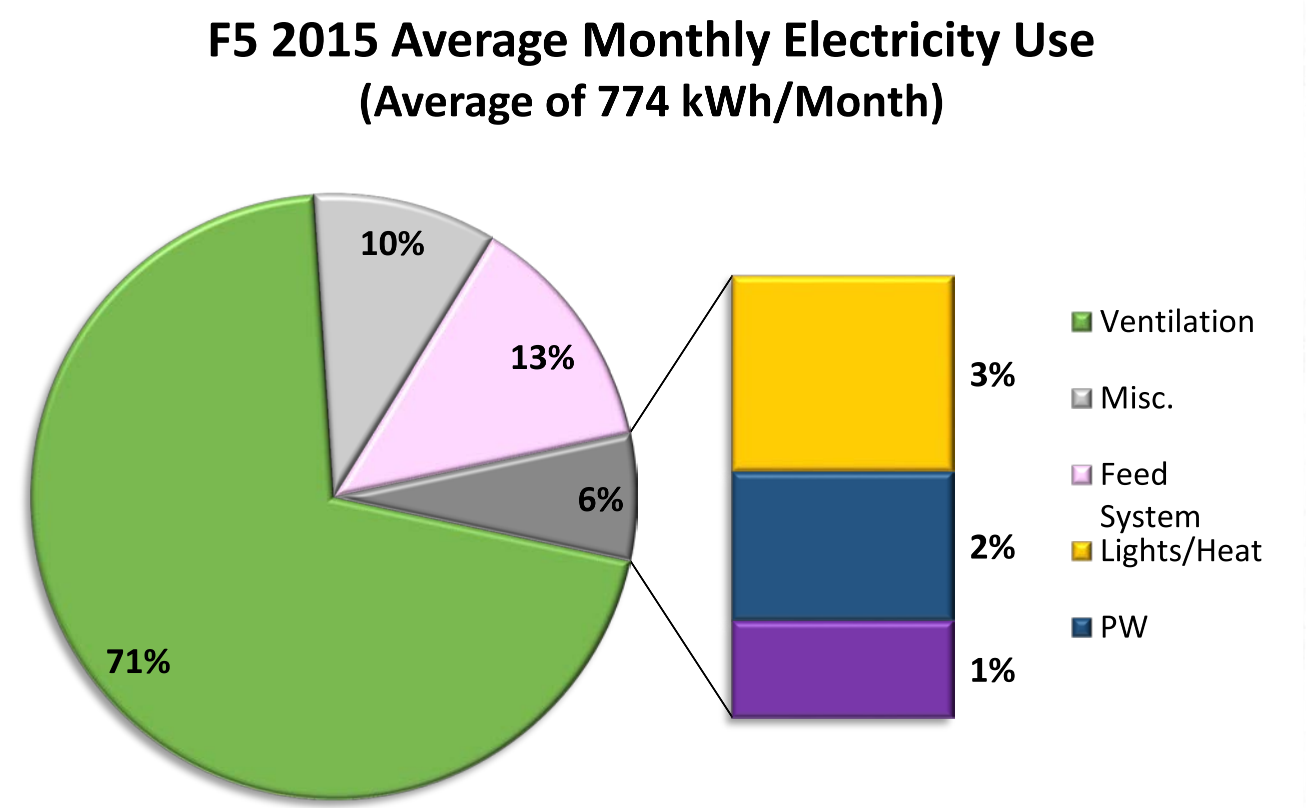
Proportion of Electrical Loads Recorded



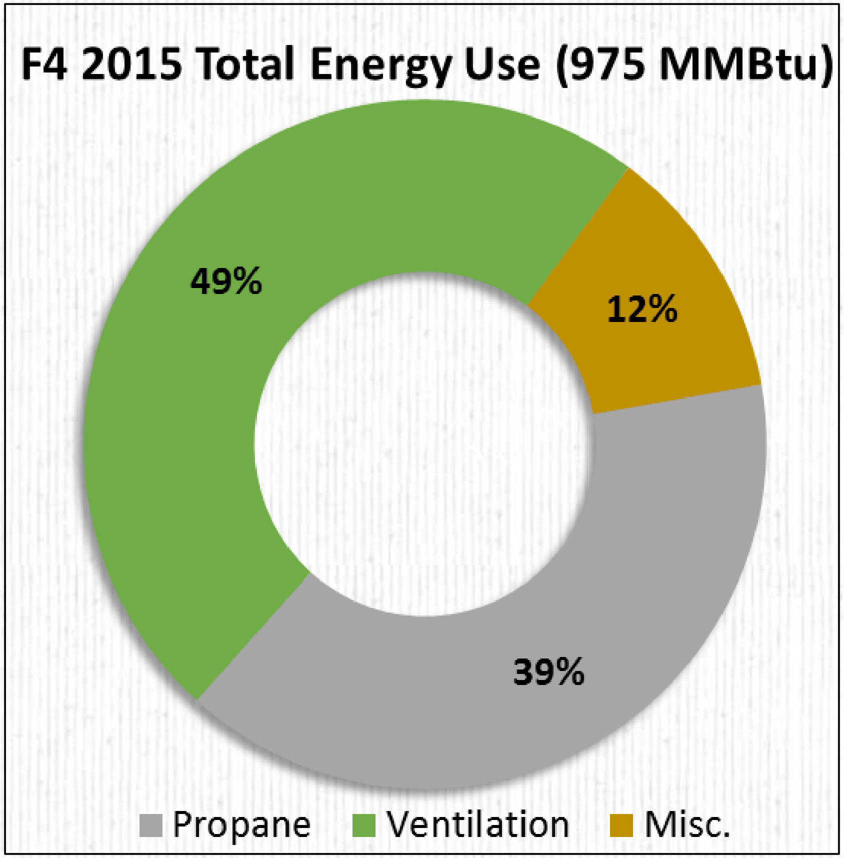
Monthly Electricity Use - Finisher

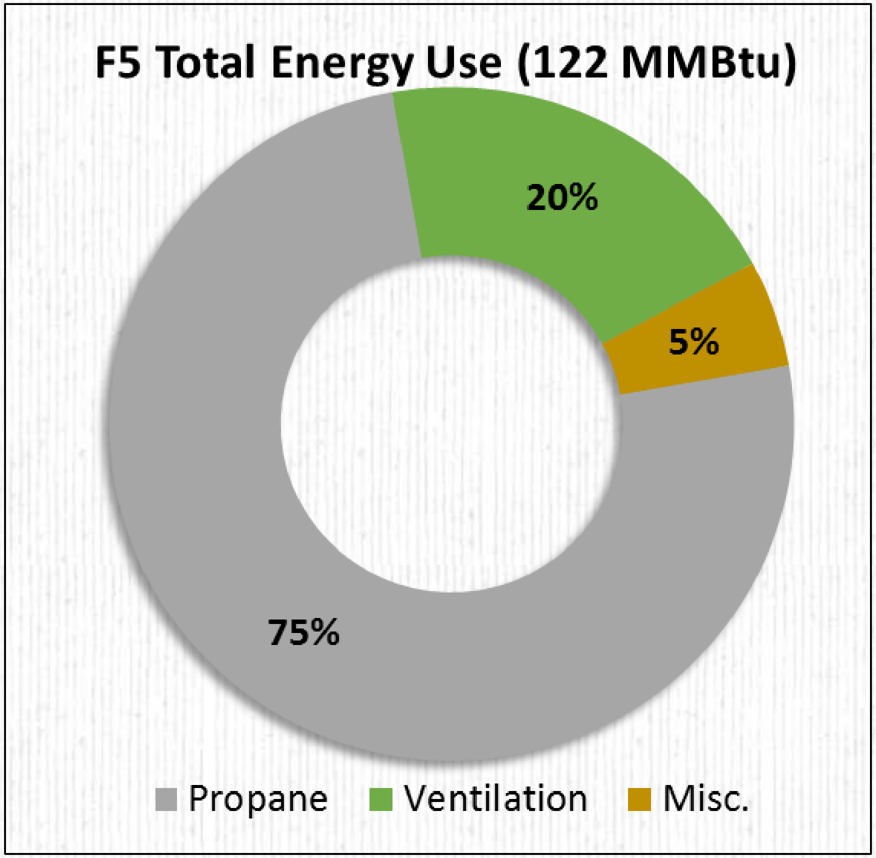


Monthly Electricity Use - Finisher



Total Fossil Energy Use (Heat + Elec): Finishers



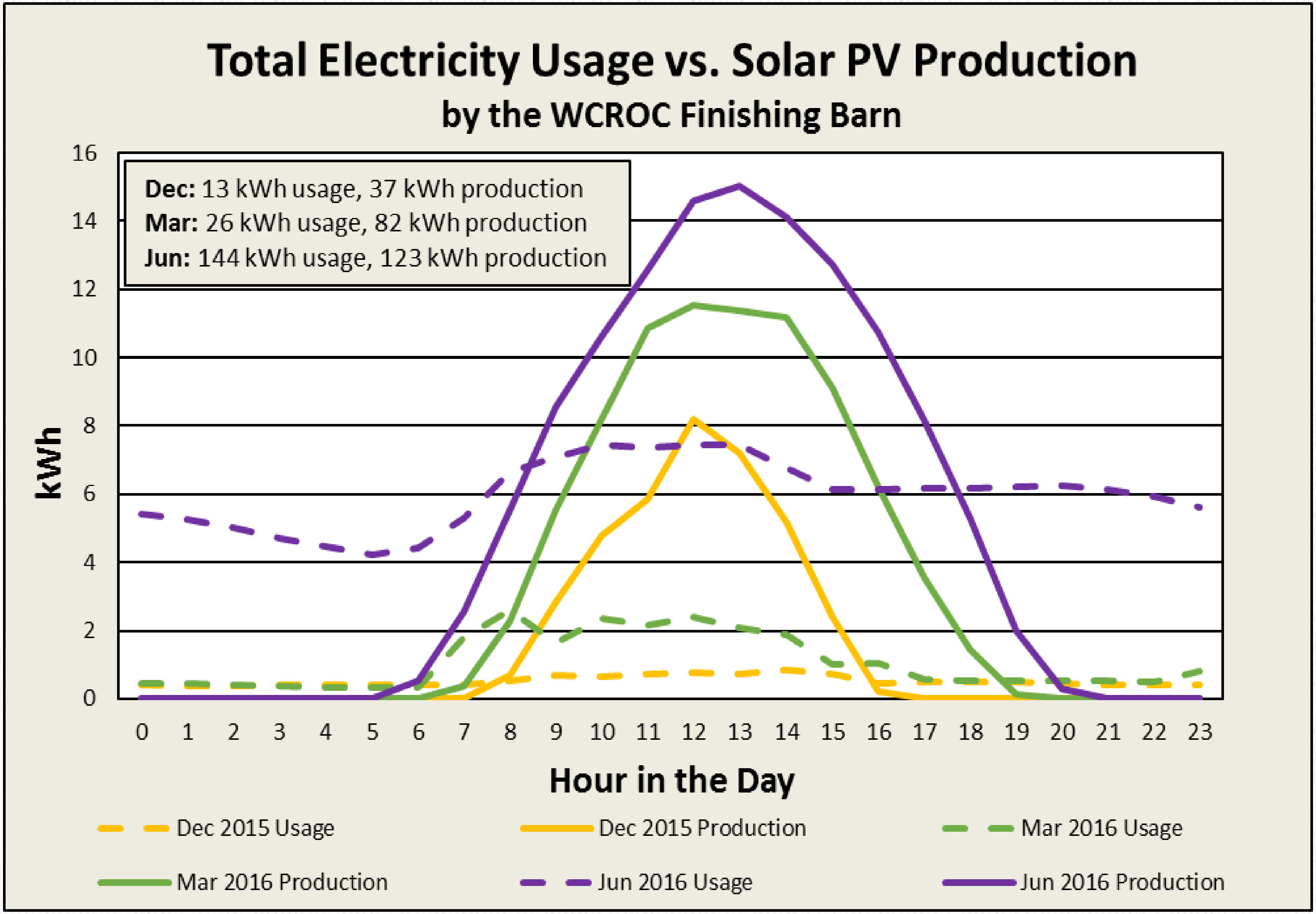


WCROC Solar PV Installation

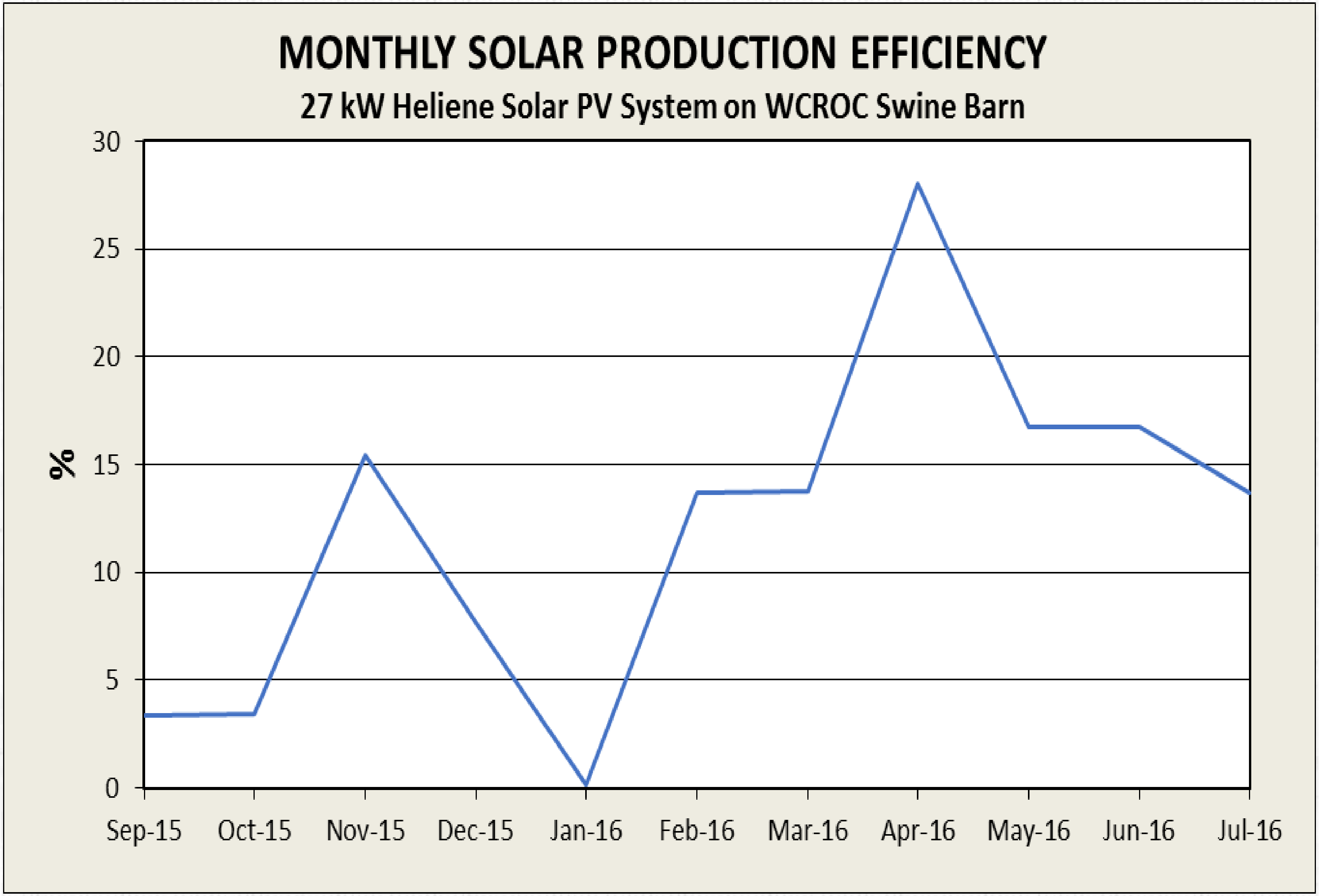
UNIVERSITY OF MINNESOTA

WCROC Solar PV Installation

SolarEdge inverters



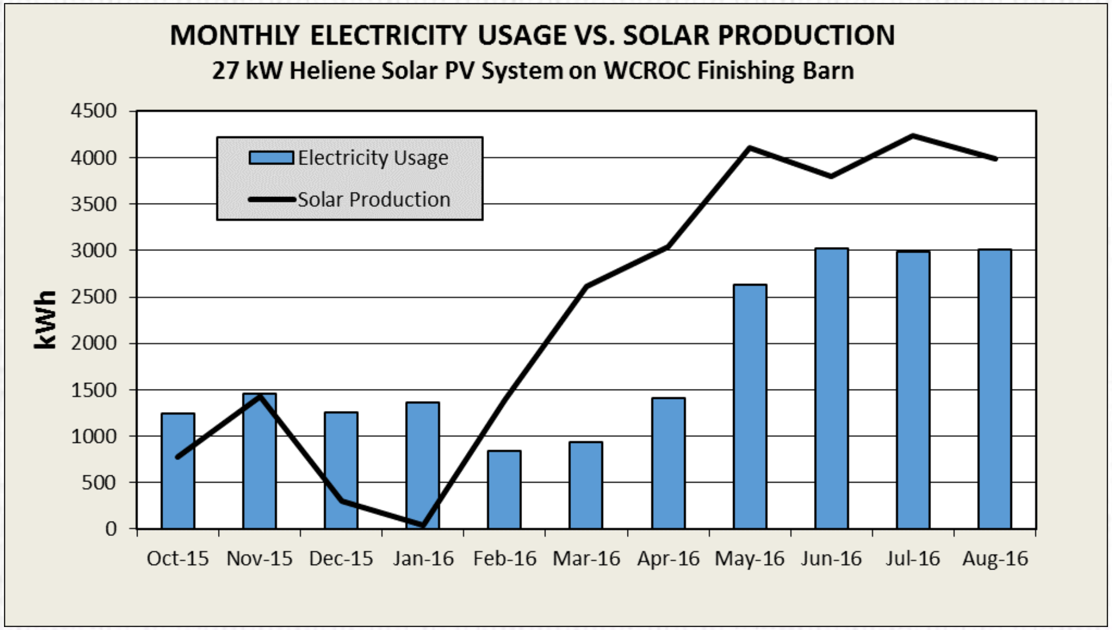
UNIVERSITY OF MINNESOTA



UNIVERSITY OF MINNESOTA

Swine Barn Energy Systems

- Morris Example (finishing barn roof)
  - Use PVwatts to predict performance (easy)
    - Predicted annual production = 35,480 kWh
    - Cost = $86,000 ($3.20/Watt)



Over 25 years

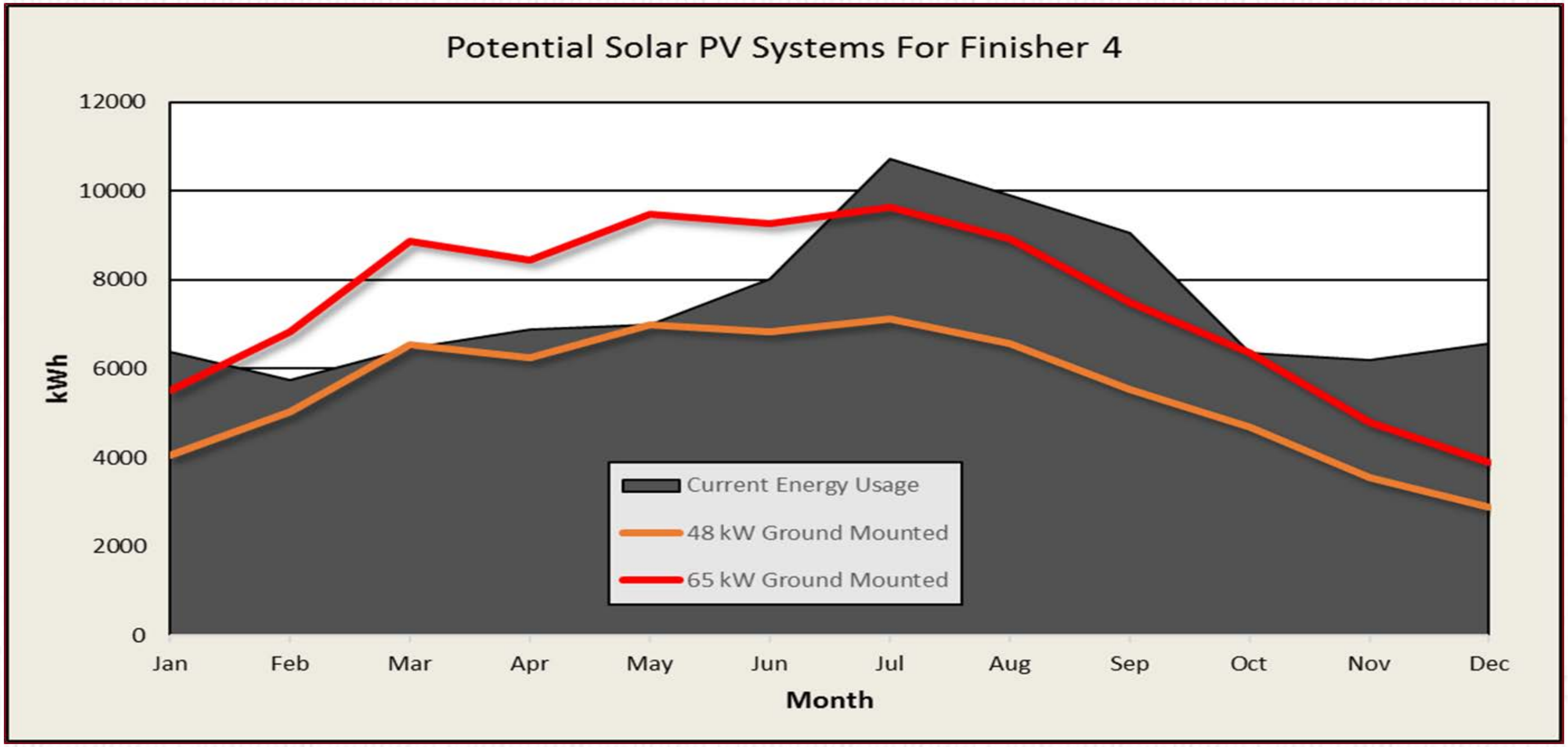
- 9.7₵/kWh (no incentives)
- 6.8₵/kWh (fed tax credit)
- 1.6₵/kWh (FTC & MiM)

Might have maintenance costs with inverters

Projected Solar PV Installation

Finisher #4

- Used PVwatts to predict performance
- Ground mounted due to barn orientation



Lowering Energy Consumption by Reduction of Temperature in Swine Facilities

L. J. Johnston*[1], M. C. Brumm[2], S. Moeller[3], S. Pohl[4], M. Shannon[5], and R. Thaler[4]

[1] University of Minnesota, West Central Research and Outreach Center, Morris
[2] Brumm Swine Consultancy, Mankato, MN
[3] The Ohio State University, Columbus
[4] South Dakota State University, Brookings
[5] University of Missouri, Columbia

pork checkoff

UNIVERSITY OF MINNESOTA

Heating Fuel and Electricity Costs to Produce Pigs

Phase of production	Heating fuel ($/pig)	Electricity ($/pig)	Total cost ($/pig)
Farrow-to-finish	1.37	2.30	195.91
Wean-to-finish	1.92	0.76	181.97
Feeder-to-finish	1.42	1.23	184.97

MnSCU Adult Farm Business Mgt. (2014)

Pigs Prefer Cooler Nights

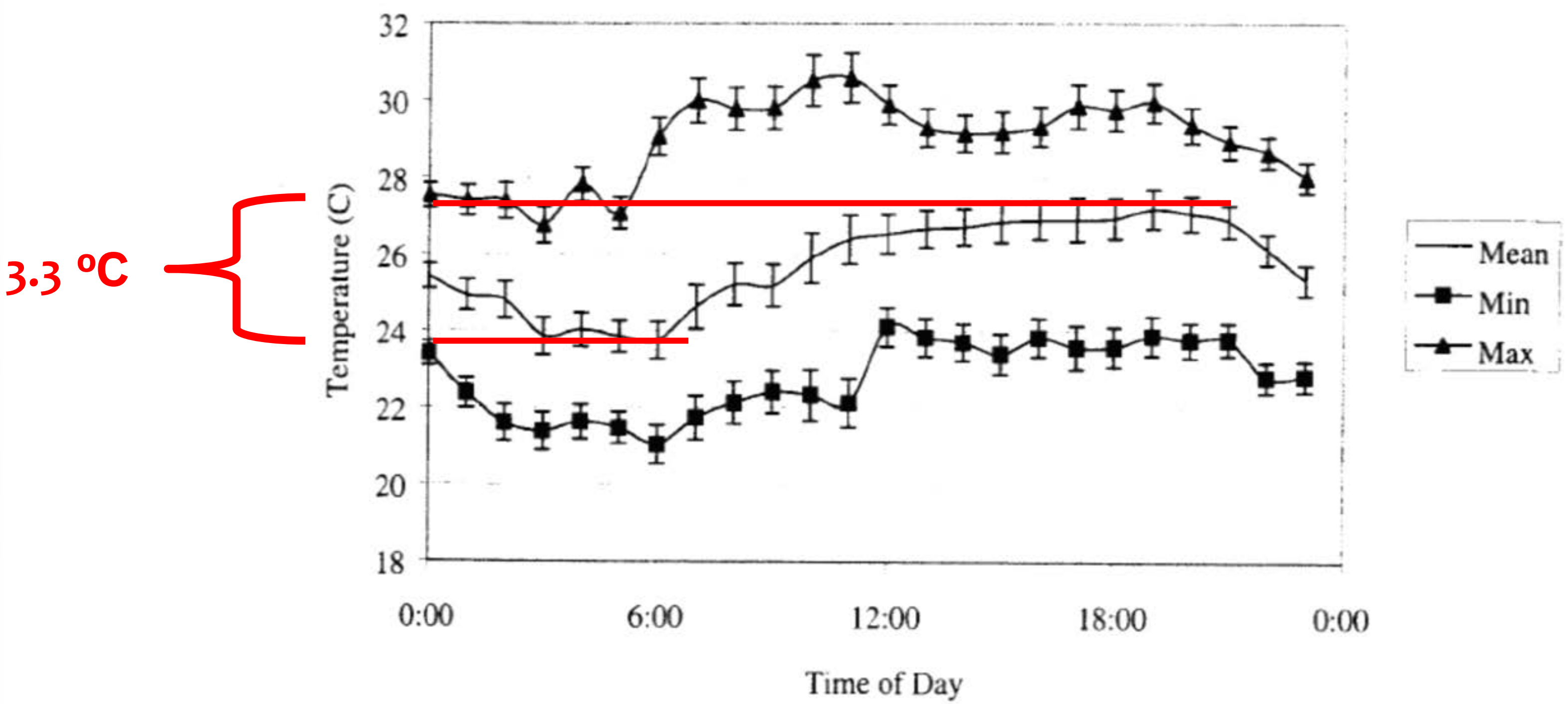


Fig. 1. Mean preferred temperatures (± SE), selected by early-weaned pigs, for a 24-h circadian cycle (averaged for all replicates; $P < 0.001$). P value represents differences in mean temperature data per hour of the day.

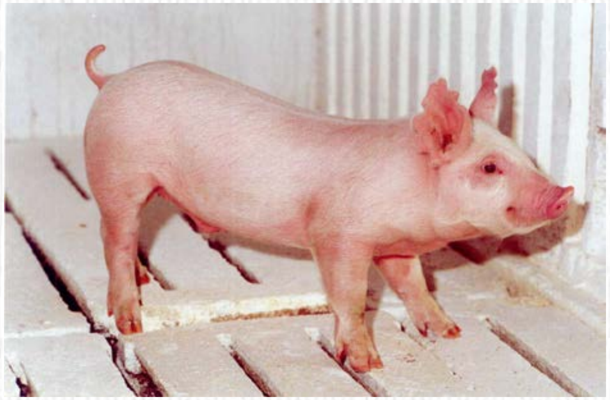
Bench and Gonyou, 2007

So why re-evaluate RNT?

- Commercial implementation of RNT was impractical in the 1990's
- Design of nursery facilities has improved
- Heating costs can be significant (remember $7 propane?)
- Heat production of pigs has increased
  - 60 Btu/h at 15 lb bodyweight
  - 137 Btu/h at 24 lb
  - 240 Btu/h at 48 lb

Objectives (XP 1)

- To determine if a RNT regimen:
  - Influences pig performance
  - Decreases consumption of fossil fuels



Cooperating Universities

UNIVERSITY OF Nebraska Lincoln

SDSU
South Dakota State University

UNIVERSITY OF MINNESOTA
Driven to Discover℠

Mizzou
University of Missouri - Columbia

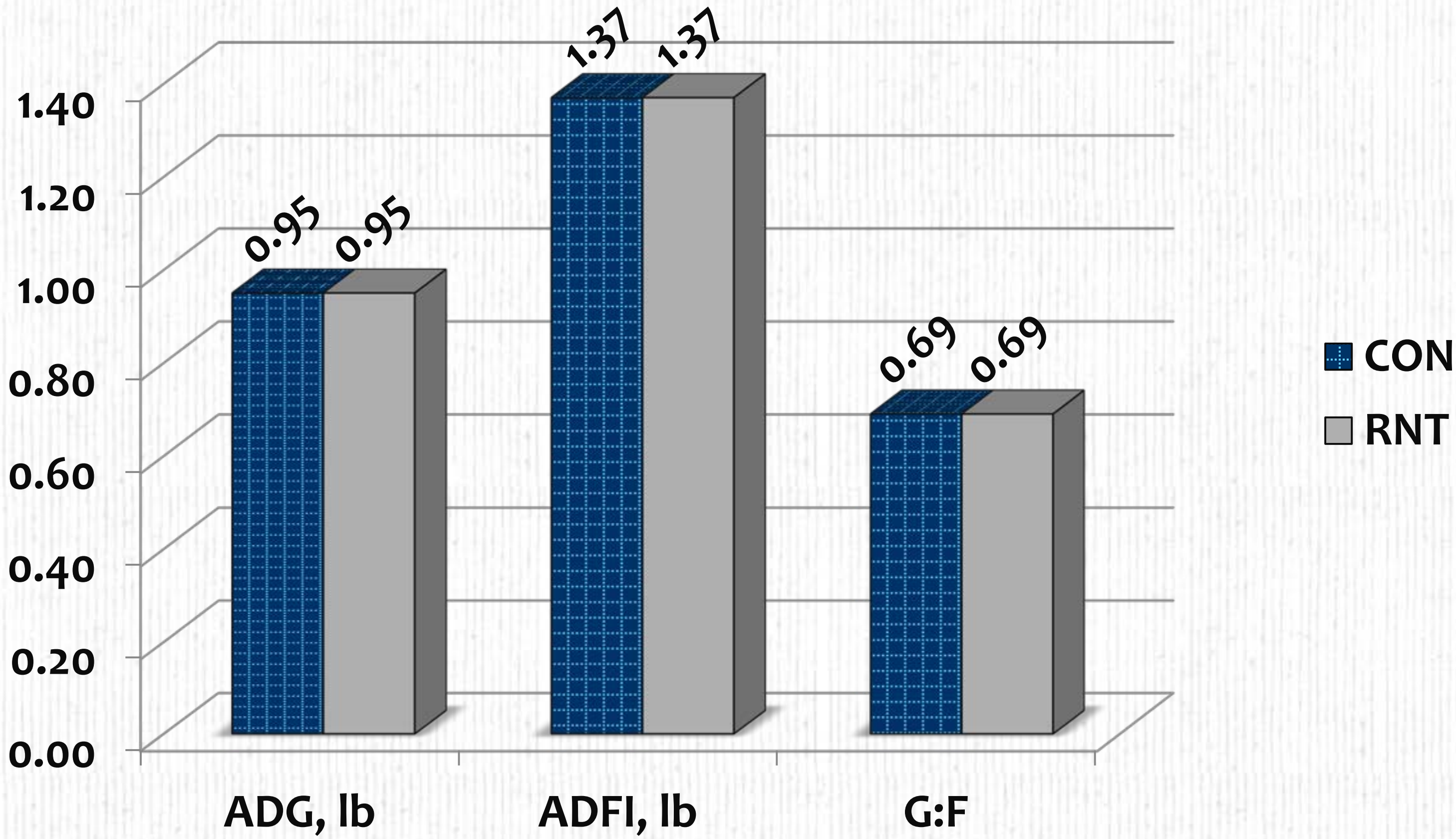
Room Treatments

- Control
  - 86 °F at pig height
  - Lowered temperature 3.5 °F per week (5-6 wk)
- RNT
  - Same as Control in week 1
  - Beginning week 2, reduced temperature 11 °F 1900 to 0700 hours daily
  - Reduced daytime temperature 3.5 °F per week

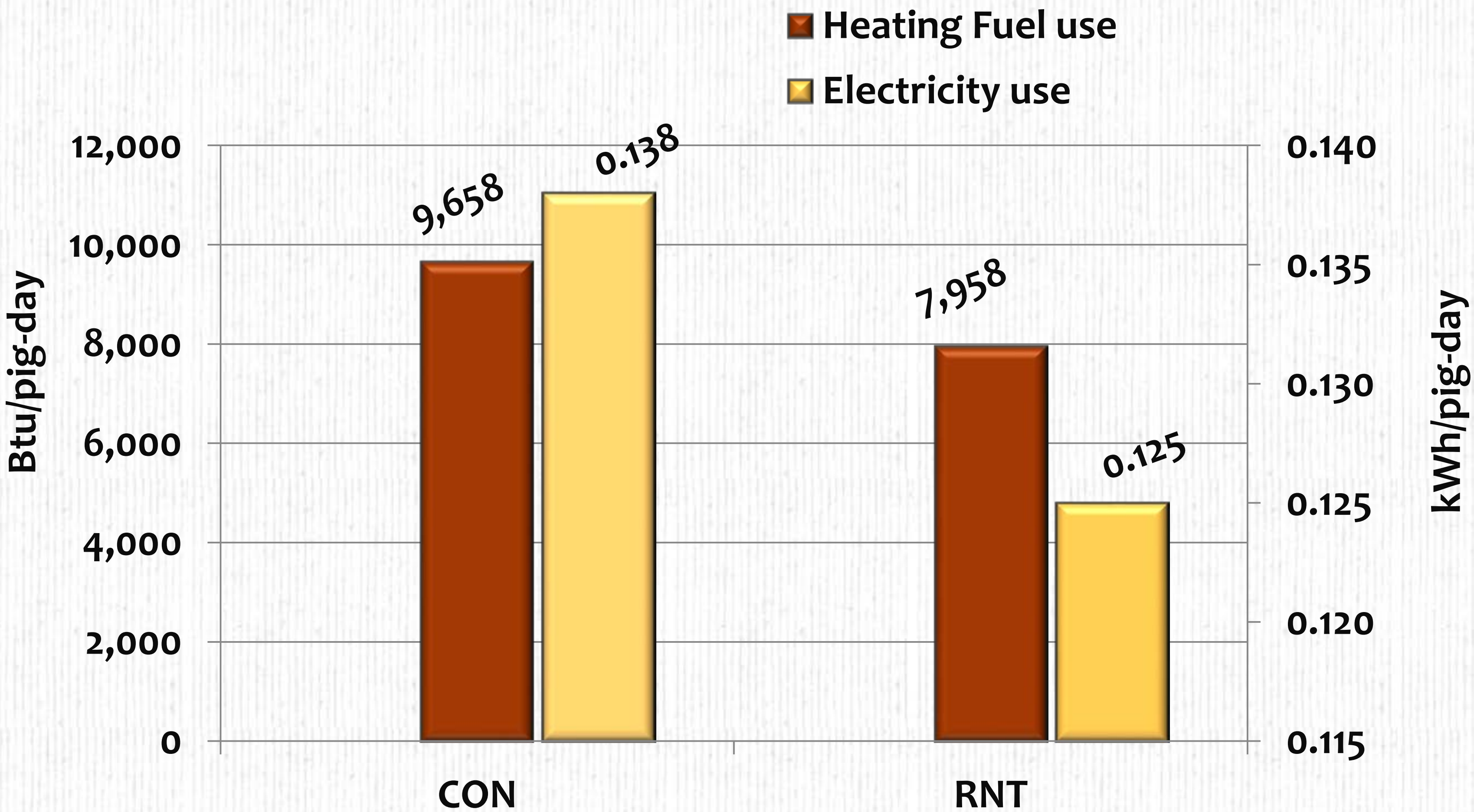
Procedures

* Animals
  * 1,638 weaned pigs weighing 13.7 lb
  * Trial lasted 35 to 42 days
* Facilities
  * Mirror-image nursery rooms used at each site
  * 6 trials conducted at 3 stations
    * NE (2 trials; 238 pigs)
    * MO (2 trials; 480 pigs)
    * MN (2 trials; 920 pigs)
* Measurements
  * Pig performance
  * Weekly heat/electricity use by room

Overall Pig Performance (XP 1)



Use of Heating Fuel and Electricity (XP 1)



Use of Heating Fuel and Electricity Across all Stations *(XP 1)*

	Trait			
	Heating fuel (Btu/pig)		Electrical use (kWh/pig)	
Station	CON	RNT	CON	RNT
NE	2,307	2,307	3.28	3.03
MO	1,070,833	875,000	10.9	9.45
MN	143,200	124,841	2.54	2.50

Summary (XP1)

- The RNT regimen imposed:
  - Had no effect on pig performance
  - Had no effect on morbidity or mortality of pigs
  - Numerically reduced heating fuel and electricity use by 18 and 9%, respectively.

Objectives (XP 2)

- To determine if a more aggressive RNT regimen:
  - Influences pig performance
  - Increases magnitude of fossil fuel savings

Cooperating Universities

OHIO STATE

SDSU

South Dakota State University

University of Minnesota

Driven to Discover℠

Mizzou

University of Missouri - Columbia

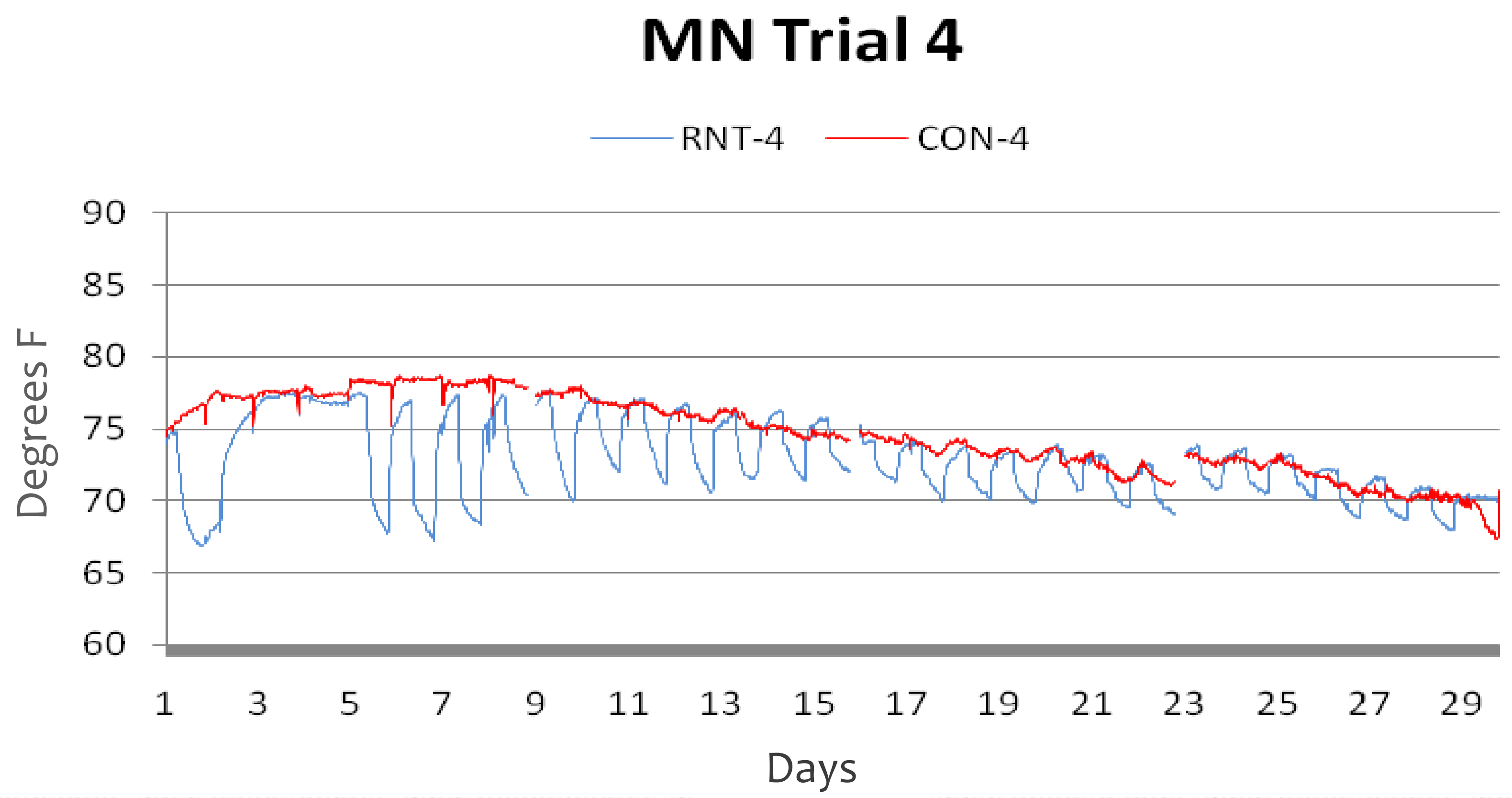
Procedures

- Animals
  - 4,298 weaned pigs weighing 13.7 lb
  - Trial lasted 28 to 42 days
- Facilities
  - Mirror-image nursery rooms used at each site
  - 10 trials conducted at 4 stations
    - OH (2 trials; 1,420 pigs)
    - MN (4 trials; 2,368 pigs)
    - MO (2 trials; 360 pigs)
    - SD (2 trials; 150 pigs)
- Measurements
  - Pig performance
  - Weekly heat/electricity use by room

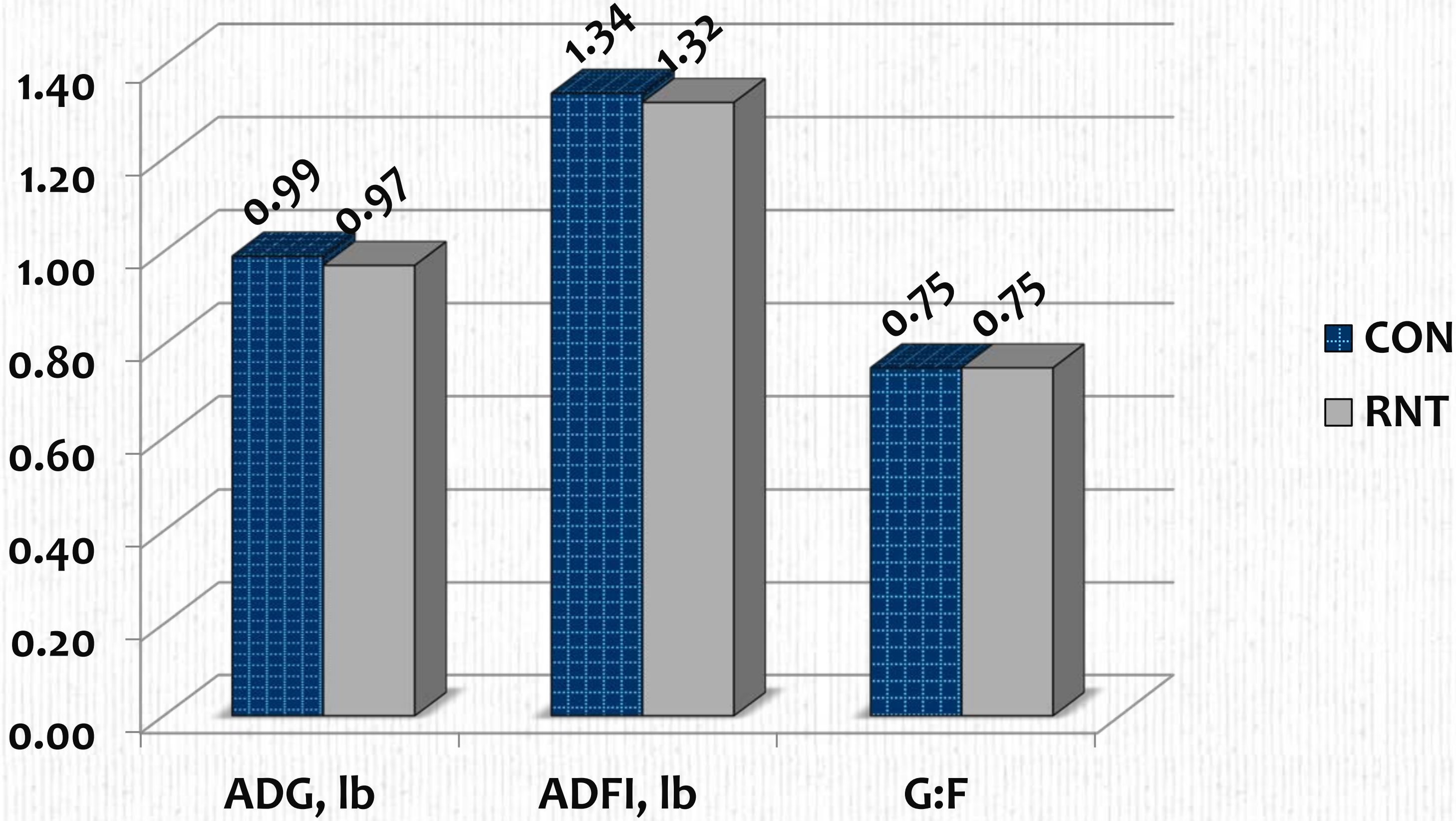
Room Treatments (XP 2)

- Control
  - 86 °F at pig height
  - Lowered temperature 3.5 °F per week (5-6 wk)
- RNT
  - Same as Control during days 1 to 4
  - Beginning day 5, reduced temperature 15 °F 1900 to 0700 hours daily
  - Reduced daytime temperature 3.5 °F per week

Example Temperature Profile in a MN Nursery Room (XP 2)

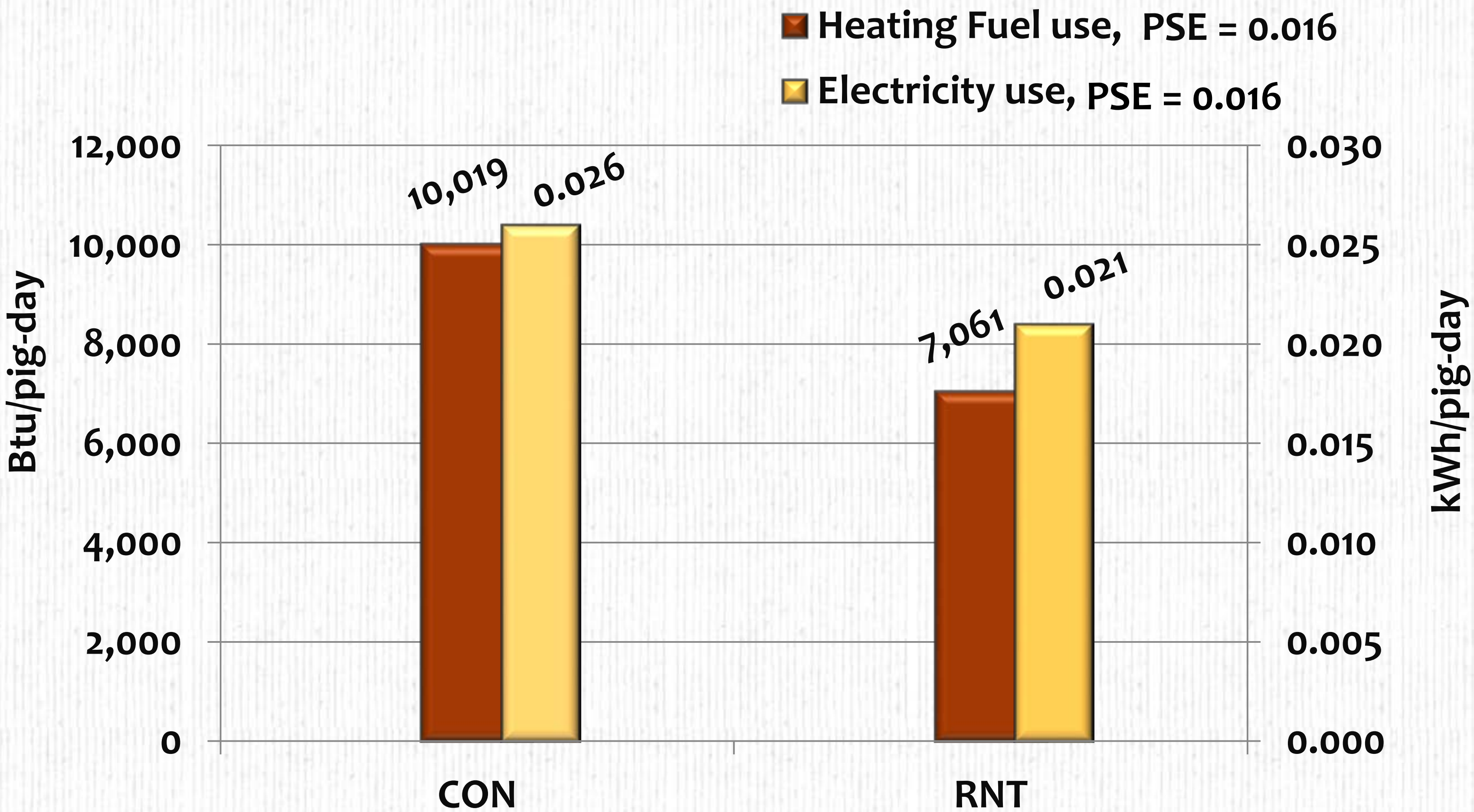


Overall Pig Performance (XP 2)



UNIVERSITY OF MINNESOTA

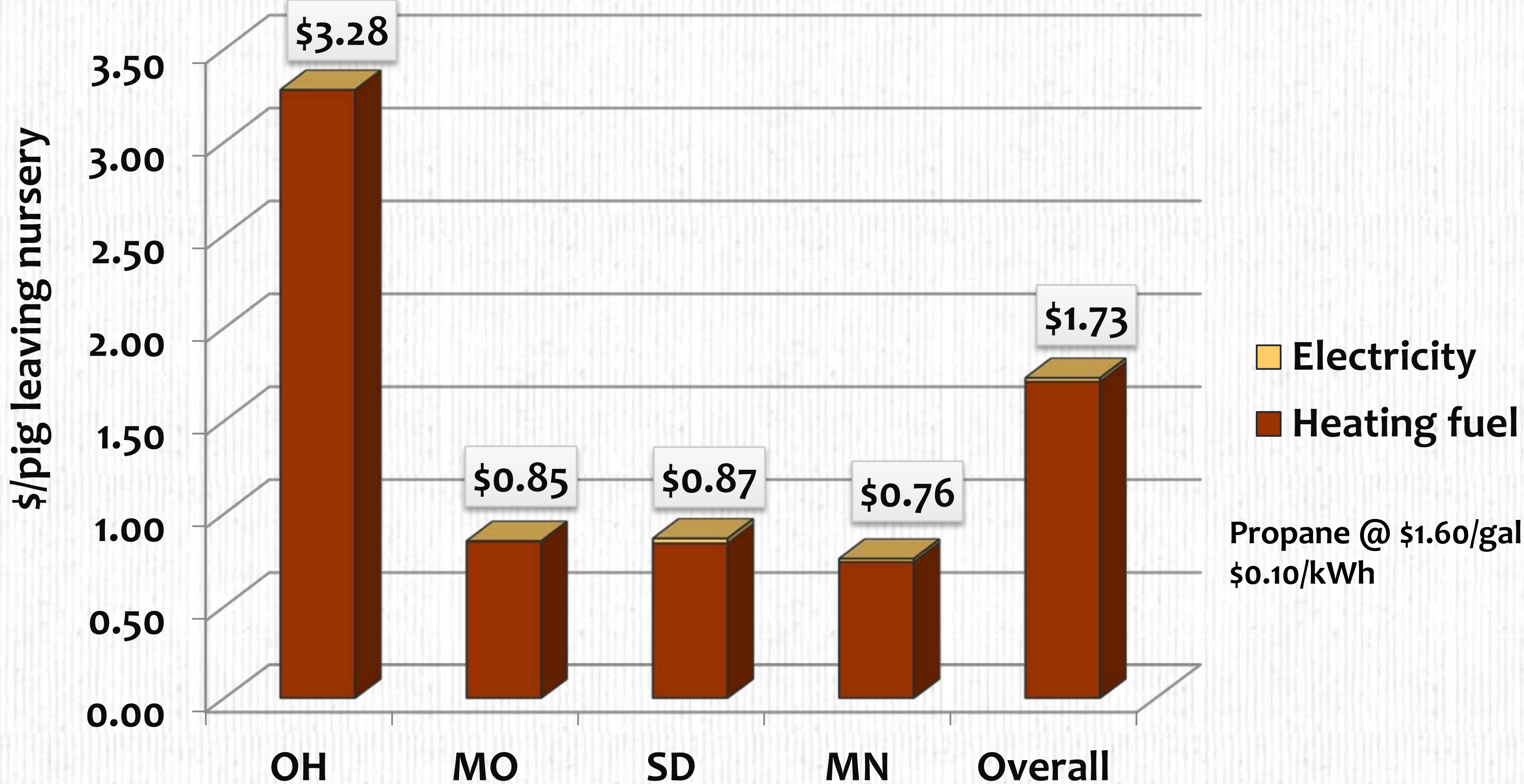
Use of Heating Fuel and Electricity
(XP 2)



Use of Heating Fuel and Electricity Across all Stations (XP 2)

	Trait			
	Heating fuel (Btu/pig-day)		Electrical use (kWh/pig-day)	
Station	**CON**	**RNT**	**CON**	**RNT**
OH	14,307	8,943	-	-
MO	14,104	12,030	0.020	0.019
SD	7,935	5,714	0.043	0.036
MN	3,009	1,557	0.032	0.026

RNT Cost Savings in Heating Fuel and Electricity



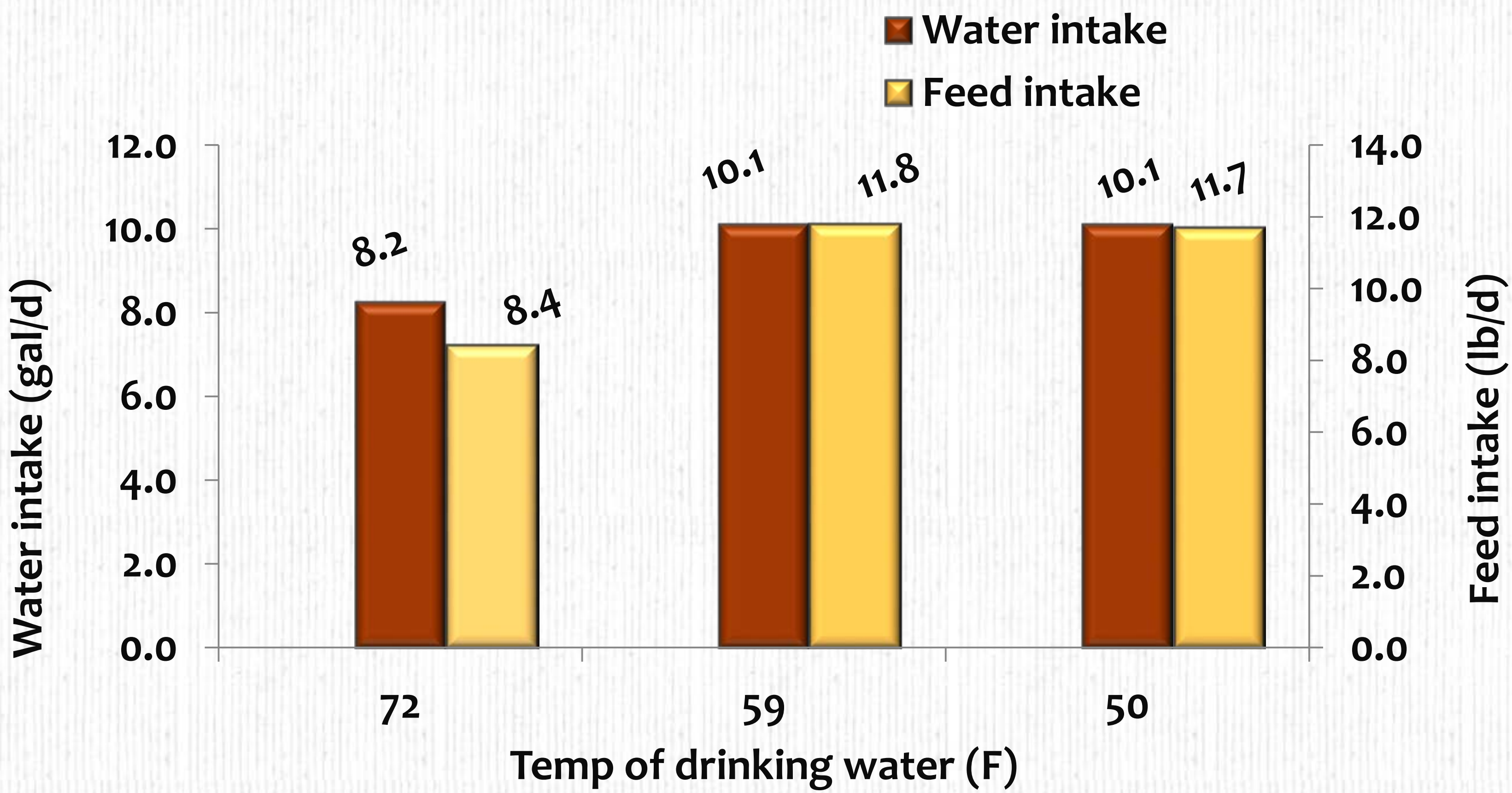
Estimated Reduction in GHG Emissions

- Propane
  - 2,958 Btu/pig/d saved x 35 d = 103,530 Btu saved
  - 103,530 Btu = 1.13 gallons saved
  - 15.2 lb CO_2 equivalents saved/pig
- Electricity
  - 0.005 kWh/pig/d saved x 35 = 0.175 kWh saved
  - 0.3 lb CO_2 equivalents saved/pig
- Total: 15.5 lb CO_2 equivalents saved/pig

Conclusions

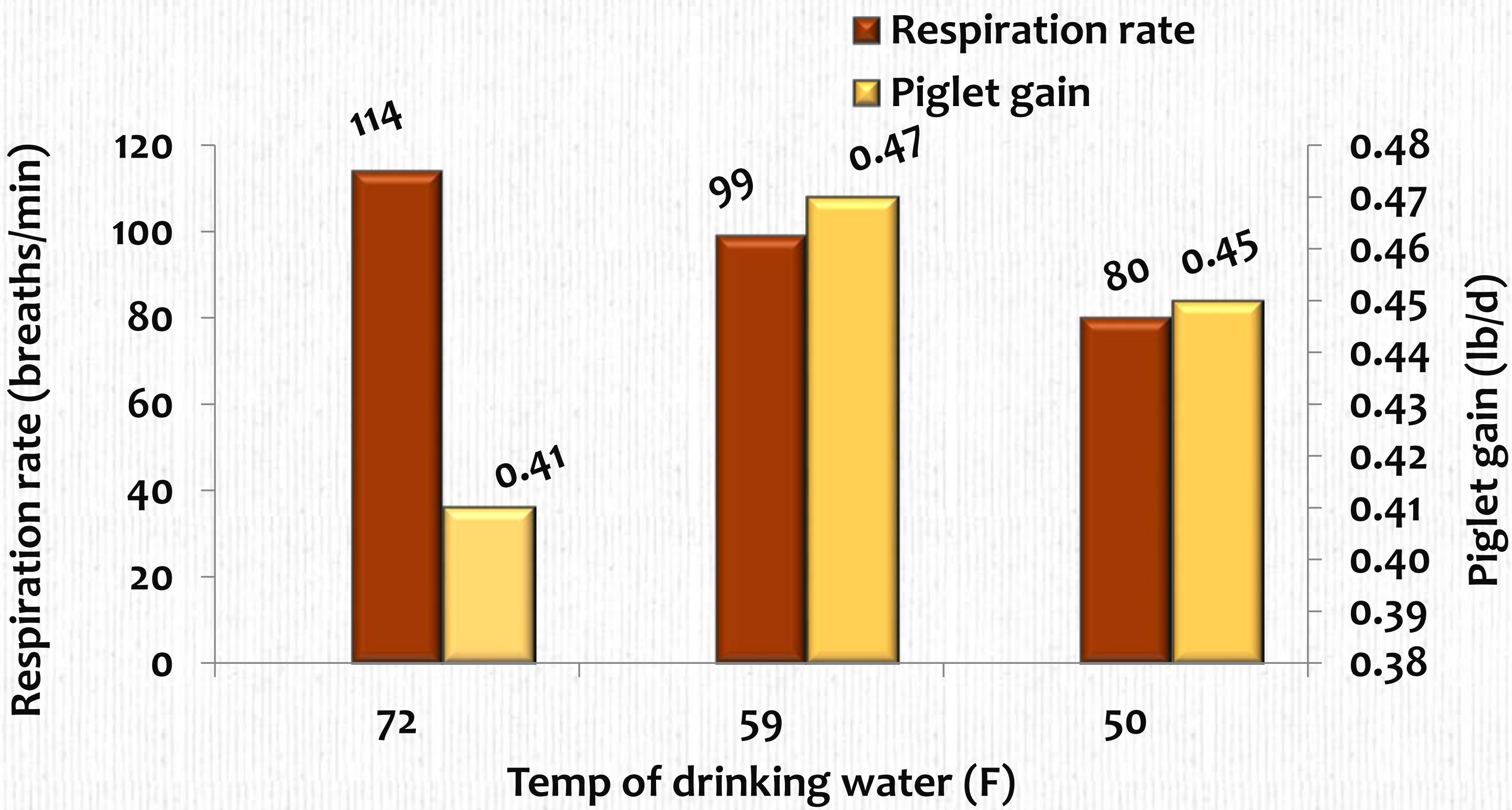
- Reducing room temperature furnace set point by 15 °F at night beginning the 5th day after arrival:
  - Did not influence pig performance or health
  - Reduced heating fuel and electrical use by 29 and 19%, respectively
  - Reduced GHG emissions by 15.5 lb CO_2 -e

Effect of Water Temperature on Performance of Lactating Sows



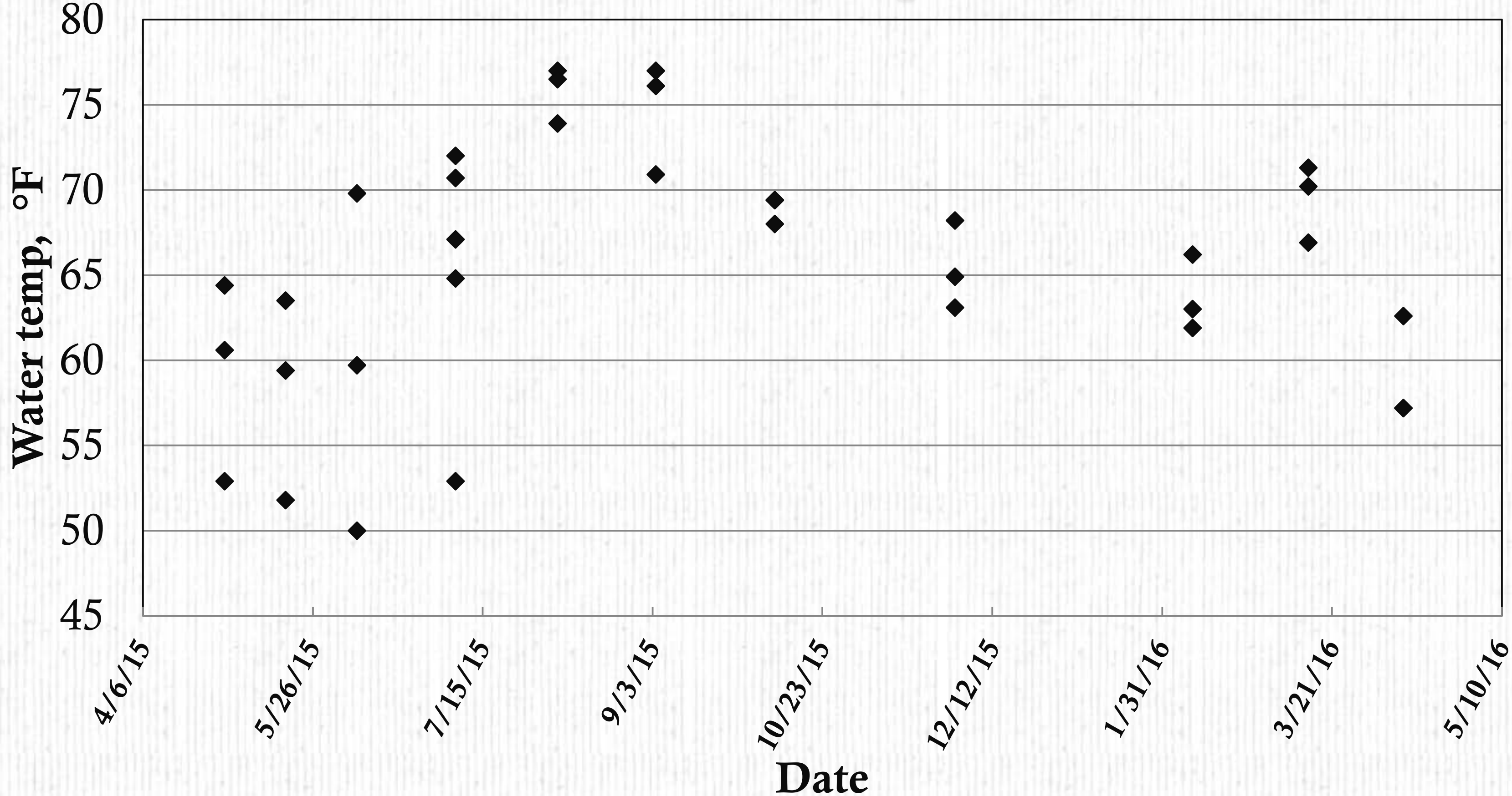
Jeon et al. (2006)

Effect of Water Temperature on Performance of Lactating Sows



Jeon et al. (2006)

Water Temperature in Farrowing Stall
Water Cups



Johnston et al. unpublished

Cooling Sows with Solar Energy?

- Solar PV panels on roof of WCROC farrowing barn
- Use air-source heat pumps or chillers to cool water
- Circulate water under sow for cooling
- Supply cooled drinking water to sows

Cooling Sows with Solar Energy

Nooyen Manufacturing, Netherlands

ECM	Barn	Electrical Savings (kWh/yr)	Natural Gas Savings (therms/yr)	Propane Savings (gallons/yr)	Energy Savings (MBtu)	Energy Cost Savings ($)	Energy Cost Savings Propane ($/yr)	Installed Cost Opinion* ($)	Natural Gas Payback (yrs)	Propane Payback (yrs)
LED Lighting										
	Nursery	6,173	(88)	(97)	12.3	530	430	6,000	11.3	14.0
Daylight Harvesting										
	Nursery	4,999	(70)	(77)	10	430	351	1,500	3.5	4.3
Solar Chimney										
	Nursery	2,100	-	-	7.2	202	202	6,000	29.7	29.7
Curtain Sided Barn										
	Finishing	10,607	(224)	(246)	13.8	856	603			
Earth Tube Pre-conditioning										
	Farrowing	(1,736)	1,349	1,482	129.0	823	2,353	10,000	12.2	4.3
	Nursery	(4,388)	1,899	2,087	174.9	944	3,125	20,000	21.2	6.4
	Finishing	(1,873)	493	542	42.9	181	741	10,000	55.2	13.5
Variable Speed Fans										
	Nursery	1,979	-	-	6.8	191		1,000	5.2	
	Finishing	347	-	-	1.2	33		1,000	29.9	
Heat Lamp Controllers										
	Farrowing	7,431	(194)	(213)	6.0	573	353	3,000	5.2	8.5
Night Temperature Setback										
	Nursery	-	928	1,020	92.8	690	1,734	500	0.7	0.3
	Finishing	-	471	518	47.1	340	880	500	1.5	0.6
Water to Water Heat Pump										
	Farrowing	7,500	-	-	25.6	722		50,000	69.2	
Air Conditioning (Traditional)										
	Nursery	2,593	(17)	(19)	7.2	237	218	80,000	337.6	367.1
	Finishing	3,265	33		14.5	338	314	80,000	236.7	254.4
Air Conditioning (Geothermal)										
	Farrowing	(30,671)	4,607	5,063	356.0	427	5,653	175,000	409.8	31.0
	Nursery	(34,711)	4,634	5,092	345.0	59	5,314	200,000	3,389.8	37.6
	Finishing	(4,780)	1,229	1,351	106.6	441	1,836	150,000	340.1	81.7

Summary

- Consumers and market chains will likely continue demanding:
  - Reduced carbon footprint
  - More environmental sustainability
- Producers have tools to reduce fossil fuel use without compromising animal performance and comfort
- Changes will likely be driven more by consumer demands than economic benefit to producers

Acknowledgements

- Swine: Adrienne Hilbrands, Mark Smith, farm staff
- Renewable energy: Mike Reese, Eric Buchanan, Kirsten Sharpe, Curt Reese, George Nelson, Rachael Acevedo, crops staff
- Funders:
  - MN Pork Board
  - Excel Energy
  - UM Institute on the Environment
  - UM Rapid Ag Response Fund
  - MN Environment and Natural Resource Trust Fund through the Legislative Citizen's Commission on MN Resources

Commercial Swine Barn Baseline Energy Audit

June 30, 2017

Eric Buchanan, Kirsten Sharpe, Lee Johnston, Ph.D., Michael Reese, and Joel Tallaksen, Ph.D.

*University of Minnesota's West Central Research and Outreach Center, Morris, MN, 56267

*With special acknowledgment to Anderson Farms, Hillside Hogs, Moore Lean, and Moser Farms

Project funding provided by the Minnesota Environmental and Natural Resources Trust Fund through the Legislative-Citizen Commission on Minnesota Resources (LCCMR)

CONTENTS

1. Introduction

Interest in energy use for all sectors of society is increasing because of rising energy prices, uncertainty about access to fossil fuel reserves, and scientific consensus about the deleterious implications of fossil fuel use for the global climate (Lammers et al., 2012). Within agricultural systems, there is potential to reduce the fossil energy consumption in livestock production systems. Greenhouse gas emissions from the agricultural sector account for approximately 22% of total global emissions, and livestock production (including transport of livestock and feed) accounts for nearly 80% of the agricultural sector's emissions (McMichael et al., 2007). By 2050, global livestock production is expected to double- growing faster than any other agricultural sub-sector (FAO, 2006a). Meat production and demand is increasing throughout the world, and pork is the most widely consumed meat globally, accounting for 40% of meat consumption worldwide (FAO, 2006b). The U.S. is currently the second largest supplier of pork after China (FAO, 2014), and within the U.S., the largest share of pork production resides within the Midwest region (74% as of September 1, 2015; USDA, 2016). Most of the U.S. swine industry now consists of large, energy-intensive and concentrated production systems.

Commercial pork production systems typically consist of three separate phases: breed-to-wean, nursery, and finishing. The breed-to-wean phase includes housing of mature sows during gestation, lactation, and of piglets from birth to weaning. Typically, a sow will enter the birthing room one week before farrowing and remain in the room for approximately three weeks with the piglets. The piglets, which are about 12 pounds and 21 days old, are moved at weaning onto trailers and transported to nursery facilities. The sows are moved back to gestation rooms for mating and pregnancy and the cycle repeats.

The nursery phase includes housing of the newly weaned, approximately 12 pound pigs until they are generally 9 weeks old and 50 pounds. The finishing phase houses and grows the pigs from 50 pounds to their market weight of approximately 280 pounds when they are about 25 weeks of age.

During each of these phases, pigs have very different environmental requirements, which in turn require differing fossil fuel inputs. In the breed-to-wean phase, sows require extensive cooling during the summer, which is typically supplied by exhaust fans and hanging fans. The piglets in this phase require extensive heating especially during the first week of life which is supplied by propane heaters and heat lamps. In the nursery phase, the pigs require both heating and cooling provided by propane heaters and fans, respectively. Pigs in the finishing phase typically require year-round cooling due to internal heat gains from body heat.

One of the University of Minnesota West Central and Outreach Center's (WCROC) strategic goals is to research methods of reducing fossil energy consumption within production agriculture systems. The purpose of the study, reported herein, is to provide actual baseline energy consumption data for commercial pork production systems in the Upper Midwest. There have been previous studies which report energy use in these systems, however these studies estimate energy use theoretically by relying on scientific literature and brief audits. Information on how much energy is used, and on the relative amounts of energy used for each purpose, is far from complete and the differences among production units are large (Barber et al., 1998). There are opportunities for reducing fossil energy consumption; however, the opportunities are different for each production phase. Therefore, this study will be one of the first studies to specifically measure the energy consumption of operating commercial pork production systems and the various loads within these operations, providing data which will give insight into lowering fossil fuel inputs.

The data from this study will be used in a Life Cycle Assessment (LCA), energy efficiency studies, economic feasibility studies, renewable energy feasibility studies, and energy/agriculture policy development. The data is also invaluable to researchers and producers that seek to improve the energy efficiency of pork production systems or are interested in integrating renewable energy systems into their facilities. The data will be useful in targeting specific areas of pork production that have potential for improved energy efficiency. Energy monitoring was performed from November 2014 to April 2017 which was essential in understanding the influences of seasons and patterns on energy usage.

2. Materials and Methods

2.1. Facility Information

To collect baseline energy data, two commercial facilities from west central Minnesota that are representative of typical Upper Midwest swine production systems were selected from each phase of production (Table 1.): two breed-to-wean barns (BWA & BWB), two nursery barns (NBA & NBB), and two finishing barns (FBA & FBB). At each of these facilities, researchers recorded and analyzed monthly consumption of electricity and heating fuel. In addition, monthly pig inventories and monthly pig production of each facility were recorded. All barns were located in west central Minnesota.

Breed-to-Wean Barn A (BWA) was a 2,600 sow facility. The farrowing and north gestation rooms in this barn were power-ventilated, while the south sow gestation rooms were curtain-sided with stirring fans for air movement. The floors were fully slatted with shallow manure pits and scrapers for manure management. The north gestation room consisted of 763 stalls and 8 pens. The south east gestation room consisted of 756 stalls, and the south west gestation room consisted of 612 stalls. The north farrowing barn consisted of four rooms with 52 stalls in each room, which were identical in size, structure, and electrical loads. The south farrowing barn was different than the aforementioned barn and was made up of 9 rooms with 24 stalls in each room. The 9 rooms in the south barn were identical in size, structure, and electrical loads. There were several miscellaneous rooms within the unit used for pressure washers, mechanical rooms, wash rooms, and storage rooms. The unit had a central office area with showers, bathrooms, laundry area, and a kitchen. Lastly, an additional gilt developer unit (GDU) was commissioned during January of 2015 and was dedicated to providing replacement gilts to the main sow unit.

Breed-to-Wean Barn B (BWB) was a 3,300 sow facility. The farrowing rooms in this facility were power-ventilated, and the gestation room was tunnel-ventilated in the summer and power-ventilated in the winter. The floors were fully slatted over deep manure pits for manure management. There were 10 farrowing rooms which were identical in size, structure, and electrical loads. Each room consisted of 48 farrowing stalls. There was one additional farrowing room that was half the size of the other rooms and consisted of 24 stalls. The unit had several miscellaneous rooms that served as a pressure washer room, storage rooms, work room, and refrigerator and wash rooms. The unit had a central office area with showers, bathrooms, laundry area, and a kitchen. During late June of 2015, a new GDU was added to provide replacement gilts for the main gestation unit.

Nursery Barn A (NBA) was a 3,000 head, power-ventilated facility. There were 3 nursery rooms that housed 1,000 pigs each and had fully-slatted floors and were identical in size, structure, and electrical loads. The unit also consisted of a load out and storage area, office and laundry area, and shower room.

Nursery Barn B (NBB) was a 10,200 head, power-ventilated facility. There were 8 nursery rooms that housed 1,000 pigs each and had fully-slatted floors and were identical in size, structure, and electrical loads. There were two additional 1,100 head nursery rooms which also had fully-slatted floors and were identical to each other in size, structure, and electrical loads. The unit had several miscellaneous rooms including a pressure washer room, mechanical room, and storage room. There was also a central office area which had showers, a bathroom, laundry area, and kitchen.

Finishing Barn A (FBA) was a 2,400 head, tunnel-ventilated facility. There were 2 finishing rooms that housed 1,200 pigs each and had fully-slatted floors and were identical in size, structure, and electrical loads. The unit also consisted of a load out and storage area, office and laundry area, and shower room.

Finishing Barn B (FBB) was a 1,060 head, curtain-sided facility. There were 2 finishing rooms that housed 530 pigs each and had fully-slatted floors and were identical in size and structure and consisted of the same electrical loads. The unit also had a central storage room and pressure washer room and a load out hallway.

Table 1. Commercial swine barn details

Barn	Barn Capacity	Barn Type
Breed-to-Wean Barn A (BWA)	2,600 sows	Power-ventilated farrowing and north gestation rooms, curtain-sided south gestation rooms
Breed-to-Wean Barn B (BWB)	3,300 sows	Power-ventilated farrowing rooms and tunnel/power-ventilated gestation room
Nursery Barn A (NBA)	3,000 feeder pigs	Power-ventilated
Nursery Barn B (NBB)	10,000 feeder pigs	Power-ventilated
Finishing Barn A (FBA)	2,400 finishing pigs	Tunnel-ventilated
Finishing Barn B (FBB)	1,060 finishing pigs	Curtain-sided

Figure 1. An example of a power-ventilated pig barn.

Figure 2. An example of a curtain-sided pig barn.

Figure 3. An example of a tunnel-ventilated pig barn with ventilation fans on the far end and an inlet curtain on the near end.

2.2. Biosecurity

Preventing the introduction of potentially devastating disease agents has always been a challenge for pork producers. Typically, strict biosecurity programs are put into effect on pig farms to maintain the health and welfare of the swine and to protect the farmer's financial interests. Renewable energy scientists from the University of Minnesota West Central Research and Outreach Center (WCROC) followed the biosecurity protocols for all commercial facilities and complied with any adjustments throughout the monitoring period.

Most breed-to-wean, nursery, and finishing facilities are operated on a continuous basis, therefore they always contain pigs of different ages and weights. To combat the spreading of diseases and sicknesses through a production system, producers follow an All-In/All-Out (AIAO) production method which involves grouping pigs of similar age and weight together. Pigs are farrowed in specific rooms. Weaned pigs from each specific room are kept together and moved to a nursery room and eventually to a finishing room without commingling pigs from other rooms. Marketing is done one room at a time, and rooms are pressure washed and disinfected between groups of pigs to minimize the transmission of disease and sickness (Clark et al., 1995).

2.3. Data collection

In each swine facility, data were collected from two general categories of energy used in pork production: electrical energy and thermal energy provided by heating fuel (propane or natural gas).

2.3.1. Electrical energy

In this study, we measured energy of loads directly related to the pigs. However, to determine if an adequate amount of these loads were being monitored, researchers compared the monthly data recorded by sensors located in the barn (in kilowatt hours) to the electricity provider's billed kilowatt hours used per month. In some facilities where the collected data were not representative of the entire barn, we measured loads that were not directly related to pigs, such as outbuildings not related to the production units, but powered from the same utility meter. Researchers monitored these circuits separately to subtract the usage of these outbuilding loads from the swine barn data.

For BWA and BWB, gilt development units (GDUs) were added in 2015 after monitoring of the barns began. A GDU supports breed-to-wean units but is not directly involved in weaned pig production. So, electrical and thermal energy used in these units was subtracted from the total use of the breed-to-wean barns.

Stand-alone HOBO (HOBO UX120-006M, Onset Computer Corporation, Bourne, MA) data loggers were installed to monitor key individual electric loads. These loads were chosen based on categories known to consume the most energy (e.g. ventilation fans, heat lamps, feed lines) and other loads that are representative of swine production systems (see Table 2). Electrical energy monitoring required access to the barn's circuit breaker boxes to install the data loggers and apply current sensors to specific loads. No wiring was added or altered, and the current sensors simply snapped around existing electrical wiring (Figure 4). CR Magnetic CR9580-10, 20, and 50 ampere (amp) sensors (CR Magnetics, St. Louis, MO) were connected to input adapter cables (CABLE-ADAP10, Onset Computer Corporation, Bourne, MA) using wire nuts and were then plugged into one of the 4 available channels in the data logger. Magnelab DCT 25, 50, 100, 250, and 500 amp sensors (Magnelab Inc., Longmont, CO) were also used. The Magnelab sensors connected directly to input adapter cables which were then plugged into the data logger. The adapter cables were strung through cable gland joints which were installed on the side of the electrical box and the data loggers attached to the side of the boxes using magnets (Figure 5). The self-powered, split core current sensors generate a 0-5 volts direct current (DC) signal proportional to the input alternating current (AC) current. The output signal is average sensing (as instantaneous power varies from one moment to the next) and calibrated to Root Mean Square (RMS) (CR Magnetics).

Each data logger was programmed to collect a current reading every 30 seconds and an average recording from each 30 second recording was stored on the logger every 10 minutes. Data was collected using a laptop equipped with "HOBOware" software (HOBOware Pro Version 3, Onset Computer Corporation, Bourne, MA) and a USB cable connecting the data logger to the laptop. The data were collected monthly and exported from the HOBOware Program into Microsoft Excel (2013). Each 10 minute average value of electric current was converted into power using the power equation described below and multiplied by 1/6 of an hour to determine energy usage in kilowatt hours. The resulting 10 minute average energy usage values were then summed for each load each day to obtain a total energy usage per day.

The measured current is used to calculate the power (kilowatts) and energy (kilowatt hours) consumed by the measured load using the following equation (U.S. Department of Energy, 2001):

$$P = V * I * \ phase * PF$$

Where: *P*= Power in watts

V= Voltage, line to ground, in volts

I= Current, on one phase, in Amperes (Amps)

Phase= Number of phases in the circuit, unitless

PF= Power Factor, unitless

An instantaneous power measurement requires instantaneous measurement of the current and voltage on all phases of the supply lines to every load measured. This would require 6 sensors on a three phase load and would make the number of sensors and data loggers needed for a typical barn cost prohibitive. Several reasonable assumptions were made to simplify the measurement set-up without significantly sacrificing measurement accuracy.

In calculating power, it is important that the voltage is measured between one phase line and neutral. The voltage was measured once when the sensors were installed and was considered to remain constant. This is a reasonable assumption since supply voltage changes very little in a properly wired electrical system. Multi-phase loads were assumed to be balanced meaning the same amount of current flows in each phase line. All multi-phase loads measured in the swine barns were AC motors which, theoretically, produce balanced loads. Assuming balanced loads means only one current sensor is required for each load and that the measured current is multiplied by the number of phase lines to calculate the total current.

The final element in the power equation is the power factor (PF) which varies between zero and one. A purely resistive load like a heating element or incandescent light bulb has a power factor equal to one. An AC motor has a power factor that varies with the load on the motor; higher loading produces a higher power factor. The power factor accounts for the fact that some of the supplied power to a motor is not consumed by the motor, but instead creates the magnetic field that allows the motor to operate. Adding the power factor to the power equation allows the calculation of the power actually consumed by the motor. Operating motors at a low power factor is undesirable, so motors are typically sized so they are at least 70% loaded under normal conditions. A study by the U.S. Department of Energy (U.S. Department of Energy, 1997) shows that a typical motor loaded between 70% and 100% of its rated load will operate with a power factor generally between 80% and 90%. For this study the power factor of all motor loads was set at 85%. These assumptions allow a reasonable estimate of power consumption with a manageable amount of sensor and data logging equipment. . The power factor of loads which had mixed resistive and inductive loads combined into one sensor, for example when measuring a whole electric sub feed panel, were estimated based on the ratio of resistive to inductive loads within the sensor.

Additionally, as measuring the current on all of the loads in each barn was not feasible, other assumptions were made to compare the utility meter data to data collected by researchers. In each barn in this study, the loads from only one whole room in the facility were measured. There were 2 to 11 identically sized rooms within a facility, each containing identical loads. The data recorded from the loads in the measured room were multiplied by the appropriate number of identical loads in the other rooms in the barn. Pig flow through each barn is a continuous process with each period or turn occurring multiple times per year in each room. Therefore, the energy used by each load in a monitored room is representative of all other similar rooms in the facility on an annual basis even though the actual size and weight of pigs is not the same in each room at any given time.

Thirty four total data loggers were installed and 133 total loads were monitored across all 6 commercial swine barns (Table 2). The shaded loads are categories that were monitored across all six barns.

Table 2. Loads measured across all commercial barns

Electric Loads	BWA	BWB	NBA	NBB	FBA	FBB
Feed Motors/Augers	X	X	X	X	X	X
Lights	X	X	X	X	X	X
Ventilation/Stirring Fans	X	X	X	X	X	X
Pit Fans	X	X	X	X	X	X
Manure System[a]	X		X			
Pig Heater Fans	X	X	X	X	X	X
Well	X	X	X	X	X	
Cooling Cell	X					
Pressure Washer	X	X	X	X	X	X
Actuators[b]	X		X			
Curtains						X
Heat Lamps	X	X				
Water Heater	X		X		X	
Generator Heat/Controls[c]	X		X	X		
Office/Mechanical	X	X	X	X	X	X
Controller				X	X	
Gilt Developer	X	X				
Miscellaneous Loads[d]			X	X		

[a] Comprised of under-slat scrapers, lift pumps, and water pump
[b] Feed system actuator for movement of feed down a feedline
[c] Comprised of generator engine block heater and backup system controls
[d] Examples include hallway heaters and unrelated outbuildings

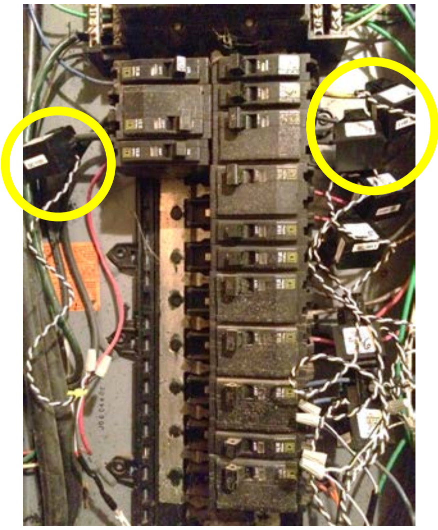


Figure 4. Current sensors snapped around different circuits within the circuit breaker panel

Figure 5. Data loggers attached to side of electric circuit breaker panel

2.3.1.1. Equipment uses

Feed system- actuators are a component of a feedline which control the switching on of motors within the feed system to move feed down the line. Feedline motors and feed auger motors are used to move pig feed from feed bins, down the feedline, and into pig feeders. The horsepower (HP) of these motors typically range from 1/4 HP to 2 HP.

Lighting- lighting is used in all areas of a barn. The way lights are used varies across each individual facility due to management practices. Lights might be left on all day in some barns or only used for a short amount of time in other barns. The type of lighting can vary across barns as well. For example, in BWA, compact fluorescent lights (CFLs) were used, whereas light-emitting diodes (LEDs) were used in BWB.

Ventilation- one of the most important components of all pig barns, mechanical ventilation can include different types of fans which can serve different purposes. Ventilation systems are used to control the moisture and heat produced by the animals in the barn. In addition, ventilation systems remove air contaminants produced from manure, feed, and the pigs themselves (Jacobson, 2004). Basket/stirring fans are typically hung inside a room and are used for supplemental cooling and air distribution. Pit fans are mounted on manure pit access ports of deep-pitted barns to remove gases generated by manure. Pit fans are typically used for minimum ventilation. Wall/exhaust fans are used to exchange the desired amount of air in a pig housing unit (Jacobson, 2004). The primary function of a cool cell is to cool the pigs, and air needs to be drawn through the cool cell by ventilation fans. Therefore, cool cells are part of a ventilation system. Cooling cells work by evaporating water into incoming air which decreases the incoming air temperature.

Manure system- there are different ways in which producers manage their manure. Monitoring in this study included under-slat manure scrapers, which push the manure into a storage system. Water pumps are used to flush shallow manure pits into a manure storage system. Lift pumps are used to lift slurry from the facility into a manure storage system.

Heat (for pigs)- heaters for pig rooms consist of propane, or in some instances, natural gas- fired heaters. The electric load being measured is the heater fan.

Pressure washer- pressure washers are used to clean rooms after a group of pigs has left the room. This minimizes the spread of disease and sickness through the production system.

Curtains- although this is a form of ventilation, curtain ventilation is different than mechanical ventilation, as buoyancy and wind forces are used to naturally ventilate the barn. Curtains can be adjusted to let more outside air through the barn while using minimal electricity.

Heat lamps- as piglets require higher temperatures, especially during the first several days after birth, heat lamps are typically used in breed-to-wean barns to provide supplemental heating. Heat lamps can range from 100 watt bulbs to 250 watt bulbs, depending on management style of the barn.

Controllers- controllers in pig barns rely on sensors in the pig rooms to provide optimal environmental conditions for pigs. Controllers regulate ventilation, heating, and humidity within a room.

Office (human use)- office use includes electrical loads such as space heaters, washing and drying machines for clothes, refrigerators, computers, stoves, lighting, bathroom and shower rooms, water heaters, etc.

Gilt developer- gilt developer units (GDUs) are facilities dedicated to raising replacement females for the sow herd. In the case of both breed-to-wean barns in this study, GDUs were located on the same site. However, the GDUs were managed separately from the breed-to-wean units and could therefore be monitored separately from the sow unit.

Miscellaneous loads- miscellaneous loads included hallway heaters and lights, workrooms, storage rooms, etc.

2.3.2. Thermal energy

For the purpose of this study, data from both electrical and heating fuel consumption was obtained. Heating fuel consumption was obtained from the producer's records and receipts from gas utility companies. Each of the six commercial buildings used propane to heat their buildings and pressure wash. However, BWA and NBA switched from propane to natural gas during the summer of 2016 and FBB used diesel for pressure washing. At each swine facility, propane tank fill reports and natural gas consumption reports were obtained from the producers and analyzed to observe monthly and yearly use. Due to fluctuations of oil prices throughout the year and variations in costs to each barn, the yearly average price of propane across the six commercial barns was $1.21 per gallon in 2015 and $1.20 per gallon in 2016. These costs were used to calculate the cost of propane per pig produced.

2.3.3. Pig inventories

Monthly pig inventories were reported by each producer, because these numbers can drastically affect energy used in the barn and help in identifying daily routines in the barn. Pig production records were also collected to calculate amount of energy (both electric and thermal) used to produce one pig from each phase of production.

3. Results and Discussion

The objective of this commercial swine energy monitoring task was to understand how much energy is used to produce weaned piglets, feeder pigs, and market weight hogs, and to determine where, specifically, that energy is used within each production stage. This energy use data can then point to areas where both cost and energy consumption might be reduced.

3.1. Breed-to-Wean Barn A and Breed-to-Wean Barn B (BWA and BWB)

3.1.1. Electric and thermal energy was calculated using $ .10/kWh for both years (average price per kWh across the Midwest) and $1.21/gal in 2015 and $1.20/gal in 2016 (using the average price per gallon across all units in this study). The kWh used per pig and the associated costs per pig remain fairly constant over the course of both 2015 and 2016 (Table 3). This can be expected, as electricity is used to maintain production and facility management throughout the building and to power fixed and constant loads. Both facilities used comparable amounts of electrical energy to produce one weaned piglet, regardless of barn size and structure.

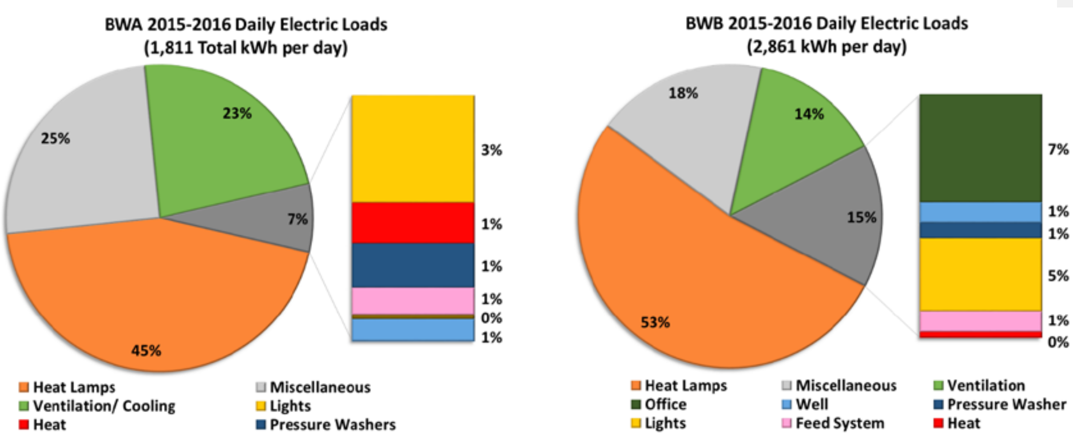
Commented [KTS1]: The data for BWB is found taking the utility meter data and generator produced data, MINUS the house/shop data logger data AND the GDU data measured by data loggers. From January 2015 to April 2015, the house/shop use was estimated simply using the average of all the months' data we have so far on the house/shop (May 2015 through May 2016), as there really wasn't any specific seasonal correlation to the data.

The daily average electricity distribution across loads in BWA and BWB is shown in Figures 6 and 7. The largest electric load across both units were heat lamps followed by miscellaneous loads. Heat lamps accounted for about 50% of the total electricity used in each facility. Miscellaneous loads are the difference between the facility utility electric meter and the total of all loads monitored during this study. As these breed-to-wean units were extensive in size and complexity, it was simply not feasible to have sensors installed on every single load within the unit. Loads in the miscellaneous category are comprised of loads not directly related to pig care such as hallway heaters and lights, workroom heaters and lights, storage rooms, etc.

Table 3. Electric and thermal consumption and total costs per weaned pig produced across both BWA and BWB in 2015 and 2016.

Year	Barn	Total pigs weaned	Total electricity used by facility (kWh)	kWh/ pig	$ electricity/ pig	Total propane used by facility (gal.)	Gal. propane/ pig	$ propane/ pig	Total therms natural gas used by facility	Therms natural gas/ pig	$ natural gas/ pig	Total energy cost/pig
2015	BWA	57,965	658,558	11.36	$1.14	19,668	0.34	$0.41	X	X	X	$1.55
	BWB	85,874	1,045,541	12.18	$1.22	27,016	0.31	$0.38	X	X	X	$1.60
2016	BWA	58,872	663,751	11.27	$1.13	4,168	0.07	$0.09	4,774	0.08	$0.07	$1.29
	BWB	89,469	1,043,038	11.66	$1.17	27,008	0.30	$0.36	X	X	X	$1.53

*In August 2016, BWA transitioned heating fuels from propane to natural gas. The natural gas lines and meter which supplied fuel to the unit also supplied natural gas to the onsite GDU. There was no way to separate out natural gas supplied to the GDU, so these values are included in the 2016 natural gas usage and cost for BWA.



Figures 6 and 7. The average daily electricity use across electrical loads in BWA and BWB.

3.2. Nursery Barn A and Nursery Barn B (NBA and NBB)

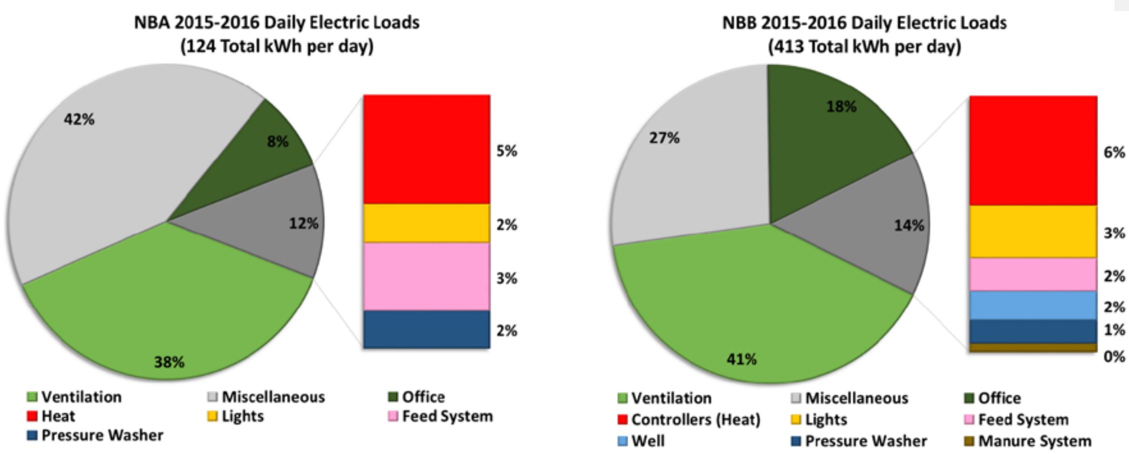
3.2.1. Electric and thermal energy

The kWh used per pig and the associated costs per pig remain fairly constant over the course of both 2015 and 2016 (Table 4). This can be expected, as electricity is used to maintain production and facility management throughout the building and to power fixed and constant loads. Both facilities used comparable amounts of electrical energy to produce one weaned piglet regardless of barn structure and, most notably, regardless of the fact that NBB was 4 times as large as NBA.

Table 4. Electric and thermal consumption and total costs per feeder pig produced across both NBA and NBB in 2015 and 2016.

Year	Barn	Total feeders produced	Total electricity used by facility (kWh)	kWh /pig	$ electricity / pig	Total propane used by facility (gal.)	Gal. propane / pig	$ propane / pig	Total therms natural gas used by facility	Therms natural gas/ pig	$ natural gas/ pig	Total energy cost/pig
2015	NBA	19,596	44,354	2.26	$0.23	8,434	0.43	$0.52	X	X	X	$0.75
	NBB	71,522	157,313	2.20	$0.22	31,175	0.44	$0.53	X	X	X	$0.75
2016	NBA	18,609	46,428	2.49	$0.25	4,192	0.23	$0.27	4,830	0.26	$0.24	$0.76
	NBB	71,778	143,882	2.00	$0.20	26,975	0.38	$0.45	X	X	X	$0.65

The daily average electricity distribution across loads in NBA and NBB is shown in Figures 8 and 9. The largest electric load across both units was ventilation, which used about 40% of the electricity used by the whole unit. Miscellaneous loads used the second-most amount of electrical energy. Specifically, in NBA, there was an additional shed onsite which contained several smaller electrical loads and a back-up generator equipped with an engine block heater. Monitoring an engine block heater at another site revealed that a block heater can use a significant amount of electricity- up to 36 kWh per day.



Figures 8 and 9. The average daily electricity use across electrical loads in NBA and NBB.

3.3. Finishing Barn A and Finishing Barn B (FBA and FBB)

3.3.1. Electric and thermal energy

In comparing FBA and FBB (Table 5), a relatively large difference is seen in the electrical use of each barn. As FBA was a tunnel-ventilated barn and FBB was a curtain-sided barn, FBA was expected to use (proportionally) more electrical energy than FBB due to the increased ventilation requirements. There was also a slight rise in the amount of electricity used at FBB from 2015 to 2016. This can be attributed to the fact that during 2016, the pigs entered the barn at a lower weight which required heater fans to be used more to provide adequate heating for the smaller pigs. Another reason FBB saw a rise in electricity use was because from May 2015 to March 2016, one pit fan motor was not working. When the fan was fixed in March 2016, a rise in ventilation occurred.

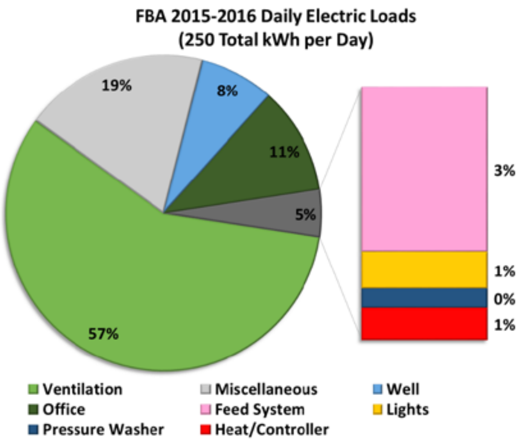
Comparing propane use of FBA and FBB in Table 5, FBB used slightly more propane per market pig than in FBA. This result was expected due to the fact that FBB was a curtain-sided barn, meaning there is typically less insulation on the curtains than there would be on a solid-walled barn such as FBA. Another result to note is that propane use in FBB was higher during 2016 than 2015. Again, propane use increased due to the fact that the pigs in this barn were placed in FBB when they were at a lower weight compared to 2015. The smaller pigs therefore required more heating to maintain pig performance and comfort.

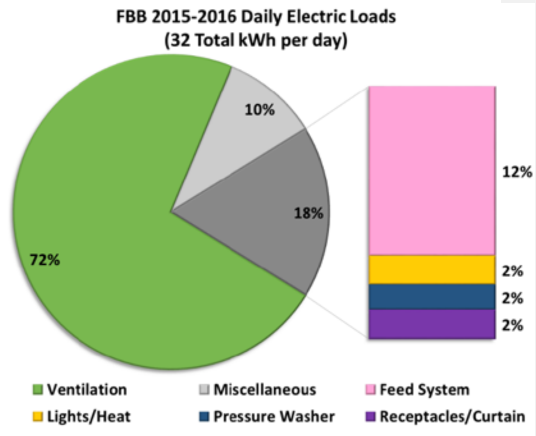
Table 5. Electric and thermal consumption and total costs per finished pig produced across both FBA and FBB in 2015 and 2016.

Year	Barn	Total Market Hogs produced	Total electricity used by facility (kWh)	kWh/pig	$ electricity/ pig	Total propane used by facility (gal.)	Gal. propane/ pig	$ propane/ pig	Total energy cost/pig
2015	FBA	5,837	90,048	15.43	$1.54	1,440	0.25	$0.30	$1.84
	FBB	2,970	9,282	3.13	$0.31	996	0.34	$0.41	$0.72
2016	FBA	6,819	92,231	13.53	$1.35	2,990	0.44	$0.53	$1.88
	FBB	2,655	13,928	5.25	$0.52	1,695	0.64	$0.77	$1.29

*FBB used diesel to provide fuel to a pressure washer. As the diesel tank is located on the farm site and is used for other machinery, an estimate of 75 gallons of diesel per year was used by the pressure washer as estimated by the producer.

The daily average electricity distribution across loads in FBA and FBB is shown in Figures 10 and 11. The largest electric load across both units was ventilation, which used over 50% of the electricity used by the entire barn. In the case of FBA, there was an additional shed onsite which was powered from the same utility meter. The shed had several smaller electrical loads as well as a generator engine block heater. Through monitoring of an engine block heater on another site, researchers concluded that the block heater may have used a significant amount of electricity- up to 36 kWh per day if running all hours of the day (during winter, for example). We are confident that in both units, electrical energy used directly for the care of the pigs was adequately captured.





Figures 10 and 11. The average daily electricity use across electrical loads in FBA and FBB.

The overarching goal of this study was to provide actual baseline electric and thermal energy consumption within pork production systems in the Upper Midwest. Previous studies have reported energy use within these systems, however, this is the first study of its kind to parcel out individual electric use past the utility meter. This unique aspect allows insight into where electrical energy is specifically being used within each phase of pork production and where there is potential to reduce usage.

The findings from this study are comparable to other industry reported measures. Anecdotal evidence from a breed-to-wean production system of 70,000 sows, indicates average electrical use per weaned pig was 9.7 kWh across the whole system. Units within this system ranged from 5 kWh to 12 kWh per weaned pig, the 5 kWh per weaned pig unit having put various efficiency measures into place. Comparing these industry findings to this study where results ranged from 11.27 to 12.18 kWh per weaned pig produced, the findings from this study are comparable with those of the previously mentioned measures. As electric energy was further parceled out among various loads within the breed-to-wean units, the findings of this study point to areas within barns where there is a potential to reduce usage such as in heat lamps, which were found to be the top users of electrical energy by far across breed-to-wean units.

Nursery findings from this study are also comparable to other industry measures. Brumm (2015) reported industry measures of about 1.8 kWh and 0.31 gallons of propane per feeder pig produced. These measures are comparable to our findings, which ranged from 2.0 kWh to 2.49 kWh per feeder pig produced and from 0.38 to 0.44 gallons of propane per feeder pig produced.

Finishing industry measures from Brumm, (2015) also report 11.2 kWh per finished pig produced in a tunnel-ventilated unit. Our findings, which ranged from 13.53 kWh to 15.43 kWh per finished pig produced in FBA, are comparable with the aforementioned measure. The differences may arise from several factors such as overventilation (especially during the winter), additional space heating, or geographical location.

All barns are unique based on barn size and structure, ventilation systems, manure systems, climate and geographical location and management style. Therefore, it was expected that there may be some differences within this study from unit to unit. However, differences are minimal, and we are fully confident that our results capture an accurate depiction of Midwest pork production units and point to areas with production phases where there is potential to reduce both electric and thermal energy consumption.

References

Barber, E.M., H.L. Classen, and P.A. Thacker. 1989. Energy use in the production and housing of poultry and swine- an overview. Can. J. Anim. Sci. 69: 7-21.

Brumm, M. 2015. Production Contracts [PowerPoint slides]. Retrieved from personal source.

Clark, K., C. Hurt, K. Foster, J. Hale. 1995. Positioning your pork operation for the 21st century- Chapter Nine: All-In/All-Out Production. Purdue University Cooperative Extension Service, West Lafayette, IN. Accessed May 24, 2017. http://www.ansc.purdue.edu/swine/porkpage/21stcentury/chapter09.pdf.

FAO, 2006a. Livestock a major threat to the environment. Food and Agriculture Organization of the United Nations, Rome, Italy. Accessed July 19, 2016. http://dicaveggie.com/wp-content/uploads/2014/10/Livestock-a-major-threat-to-environment.pdf.

FAO, 2006b. World Agriculture: Towards 2030/2050, Interim Report. Food and Agriculture Organization of the United Nations, Rome, Italy.

FAOstat, 2014. United Nations Food and Agriculture Organization Statistical Databases and Datasets. Accessed July 19, 2016. http://faostat3.fao.org/browse/Q/QA/E

Jacobson, L.D. (2004). Mechanical Ventilation for Pig Housing. Retrieved from http://www.thepigsite.com/articles/186/mechanical-ventilation-for-pig-housing/

Lammers, P.J., M.D. Kenealy, J.B. Kliebenstein, J.D. Harmon, M.J. Helmers, and M.S. Honeyman. 2012. Energy use in pig production: An examination of current Iowa systems. J. Anim. Sci. 90: 1056-1068.

McMichael, A.J., J.W. Powles, C.D. Butler, and R. Uauy. 2007. Food, livestock production, energy, climate change, and health. The Lancet. 370: 1253-1263.

USDA. 2016. Quarterly Hogs and Pigs. USDA National Agricultural Statistics Service, Washington, DC. Accessed July 19, 2016. http://usda.mannlib.cornell.edu/usda/current/HogsPigs/HogsPigs-06-24-2016.pdf.

U.S. Department of Energy. 1997. Determining Electric Motor Load and Efficiency. 1st ed. Accessed June 27, 2016.http://infohouse.p2ric.org/ref/40/39569.pdf.

U.S. Department of Energy. 2001. Improving Fan Performance- A Sourcebook for Industry. Accessed June 27, 2016. https://energy.gov/sites/prod/files/2014/05/f16/fan_sourcebook.pdf.

Appendix

A.1. Breed-to-Wean Barn A (BWA):

BWA Biosecurity

Researchers were required to remain out of contact with pigs from other sites for 48 hours and 2 showers before arrival. Protective plastic boots were worn into the facility upon arrival, personnel showered upon entry to the unit, and wore clothing that was provided by the producer. All equipment that was needed by researchers was shipped to the unit at least one week before visiting so that it could sit in isolation before use.

A.1.2. Electrical Data

The electricity provider of Breed-to-Wean Barn A, Stearns Electric Association (Melrose, MN), provided researchers with daily data taken from the meters. This barn had two meters that fed electricity to the barn, so the data from both meters was added together to obtain a total for the month. This metered total was then compared to the data collected from the installed sensors and data loggers to determine the proportion of total load that was monitored.

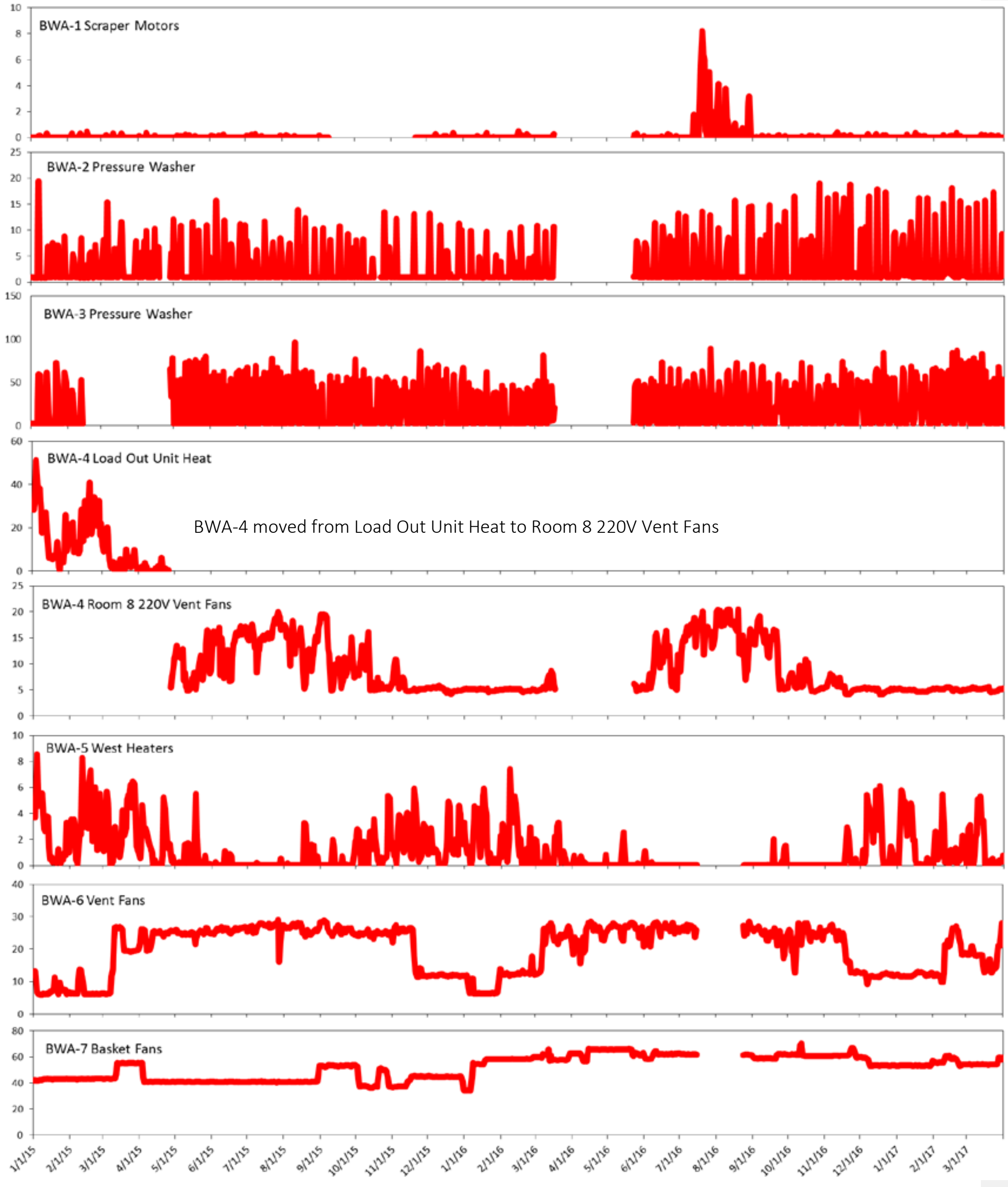
Table A1. Breed-to-wean Barn A loads monitored, location of the load, size of the sensor monitoring the load, the sensor name and number, and the data logger ID. Loads that have been starred indicate that the sensor was moved from one load to a different load.

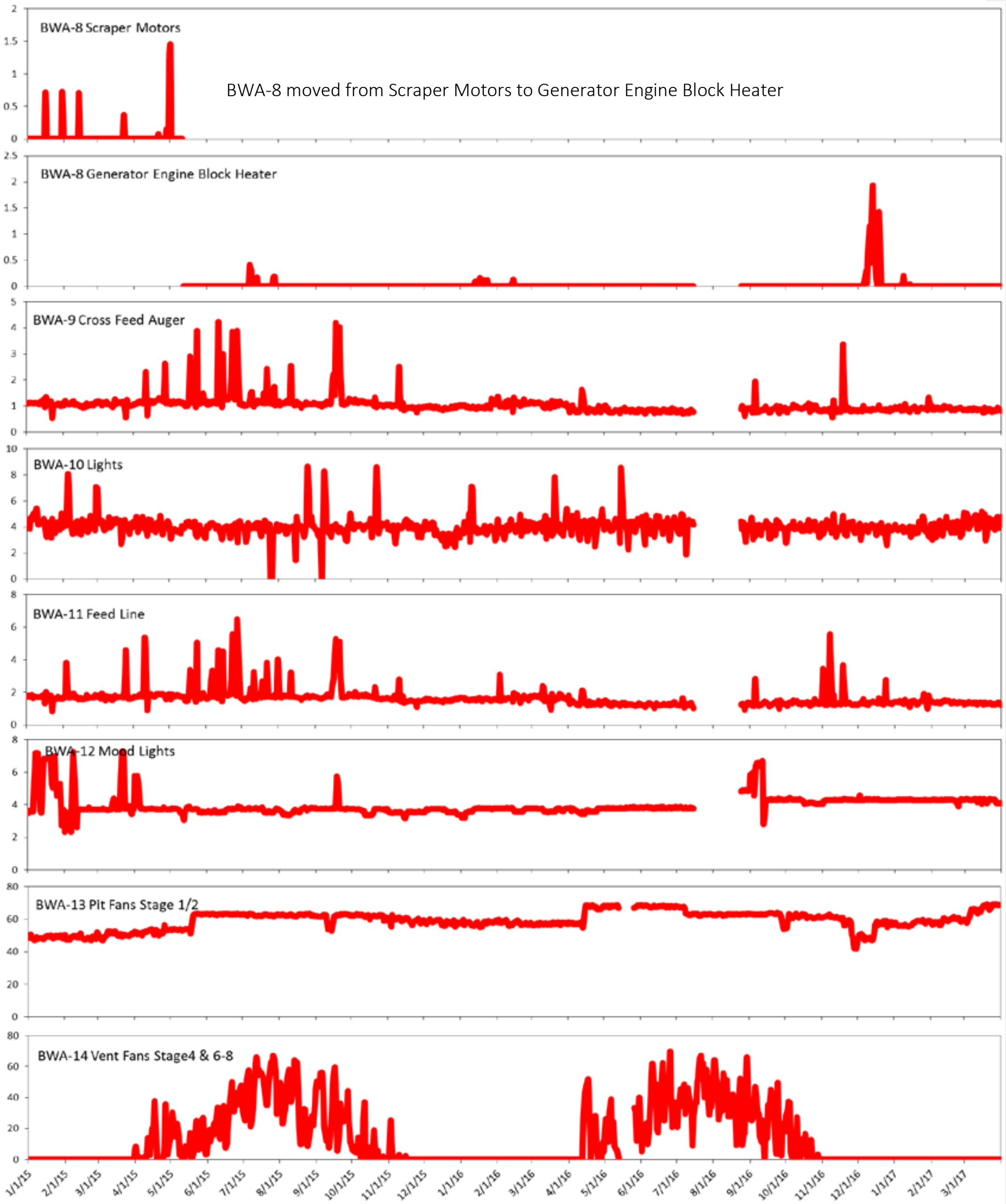
Breed-to-Wean Barn A (BWA)				
Load Description	**Location of Load**	**Sensor Size (AMPS)**	**Sensor ID**	**Data Logger ID**
Scraper Motors	South Farrowing Rooms	20	BWA-1	BWA-D1
Pressure Washer	Load Out Room	50	BWA-2	
Pressure Washer	Load Out Room	50	BWA-3	
*Load Out Unit Heat	Load Out Room	20	BWA-4	
*Farrowing Room 8 220V Vent Fans	South Farrowing Room 8	20	BWA-4	
West Heaters	South West Gestation	20	BWA-5	BWA-D2
Vent Fans	South West Gestation	20	BWA-6	
Basket Fans	South West Gestation	20	BWA-7	
*Scraper Motor	South West Gestation	20	BWA-8	
*Generator Engine Block Heater	Generator	20	BWA-8	
Cross Feed Auger	South West Gestation	20	BWA-9	BWA-D3
Lights	South West Gestation	20	BWA-10	
Feed Line	South West Gestation	20	BWA-11	
Mood Lights	South West Gestation	20	BWA-12	
Pit Fans Stage 1/2	North Gestation Room	50	BWA-13	BWA-D4
Vent Fans Stage 4 & 6-8	North Gestation Room	20	BWA-14	
*Feed Actuator	North Gestation Room	20	BWA-15	
*Water Heater	Office	20	BWA-15	
Well	Whole Facility (except South Gestation)	20	BWA-16	
South Feedline/North Feedline/Cross Auger	Farrowing & Gestation	50	BWA-17	BWA-D5
Lights	North Gestation Room	20	BWA-18	
Vent Fans Stage 3-7 & 9-5	North Gestation Room	20	BWA-19	
*Heaters Stage 10	North Gestation Room	20	BWA-20	
*Cool Cell	North Gestation Room	20	BWA-20	
West Feed Line	North Farrowing	20	BWA-21	BWA-D6
North Farrowing Room 2 Heat	North Farrowing Room 2	20	BWA-22	
North Farrowing Room 2 Heat Lamps	North Farrowing Room 2	20	BWA-23	
North Farrowing Room 2 Lights	North Farrowing Room 2	20	BWA-24	
North Farrowing Room 2 36" Vent Fan	North Farrowing Room 2	20	BWA-25	BWA-D7
North Farrowing Room 2 Pit Fan	North Farrowing Room 2	20	BWA-26	
Incoming Feed Auger	North Farrowing	20	BWA-27	
Pit Slurry Water Pump	North Farrowing	20	BWA-28	
Gilt Developer Unit (GDU) Electric Service	GDU	250	BWA-29	BWA-D8
GDU Electric Service	GDU	250	BWA-30	
GDU Electric Service	GDU	250	BWA-31	
GDU Electric Service	GDU	250	BWA-32	BWA-D9
GDU Electric Service	GDU	250	BWA-33	
GDU Electric Service	GDU	250	BWA-34	

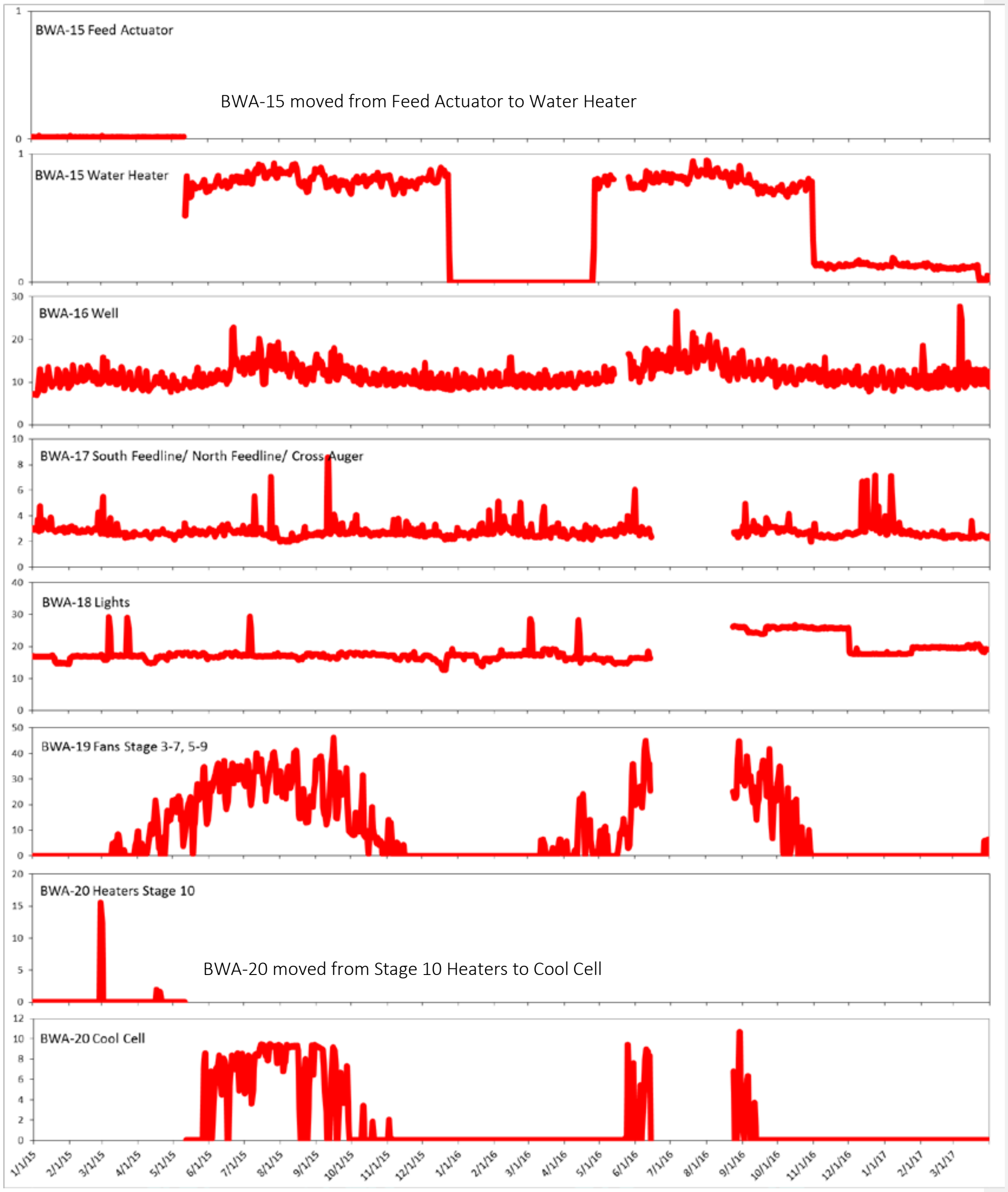
A.1.3. Materials

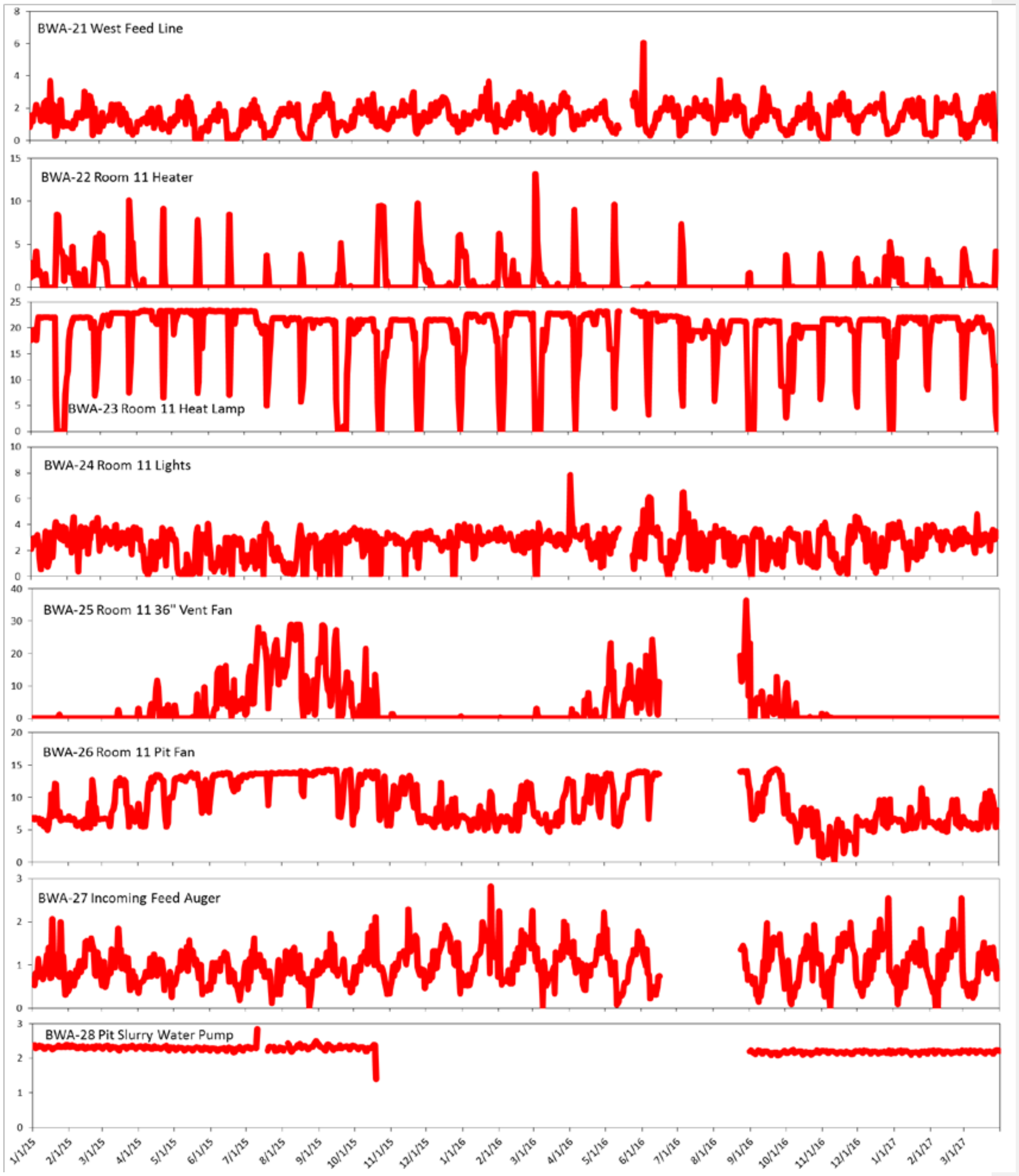
- Nine HOBO UX120-006M Data Loggers
- 24 CR Magnetic CR9580-20, 20 amp sensors
- Four CR Magnetic CR9580-50, 50 amp sensors
- Five Magnelab DCT-0024-250, 250 amp sensors
- One Magnelab DCT-0036-500, 500 amp sensor
- Nine USB cables
- 34, 0 to 10V DC input adapter cables

A.1.4. Data logger and sensor information




BWA-8 Scraper Motors
BWA-8 moved from Scraper Motors to Generator Engine Block Heater
BWA-8 Generator Engine Block Heater
BWA-9 Cross Feed Auger
BWA-10 Lights
BWA-11 Feed Line
BWA-12 Mood Lights
BWA-13 Pit Fans Stage 1/2
BWA-14 Vent Fans Stage4 & 6-8
1/1/15
2/1/15
3/1/15
4/1/15
5/1/15
6/1/15
7/1/15
8/1/15
9/1/15
10/1/15
11/1/15
12/1/15
1/1/16
2/1/16
3/1/16
4/1/16
5/1/16
6/1/16
7/1/16
8/1/16
9/1/16
10/1/16
11/1/16
12/1/16
1/1/17
2/1/17
3/1/17


BWA-15 Feed Actuator
BWA-15 moved from Feed Actuator to Water Heater
BWA-15 Water Heater
BWA-16 Well
BWA-17 South Feedline/ North Feedline/ Cross Auger
BWA-18 Lights
BWA-19 Fans Stage 3-7, 5-9
BWA-20 Heaters Stage 10
BWA-20 moved from Stage 10 Heaters to Cool Cell
BWA-20 Cool Cell
1/1/15
2/1/15
3/1/15
4/1/15
5/1/15
6/1/15
7/1/15
8/1/15
9/1/15
10/1/15
11/1/15
12/1/15
1/1/16
2/1/16
3/1/16
4/1/16
5/1/16
6/1/16
7/1/16
8/1/16
9/1/16
10/1/16
11/1/16
12/1/16
1/1/17
2/1/17
3/1/17


BWA-21 West Feed Line
BWA-22 Room 11 Heater
BWA-23 Room 11 Heat Lamp
BWA-24 Room 11 Lights
BWA-25 Room 11 36" Vent Fan
BWA-26 Room 11 Pit Fan
BWA-27 Incoming Feed Auger
BWA-28 Pit Slurry Water Pump
1/1/15
2/1/15
3/1/15
4/1/15
5/1/15
6/1/15
7/1/15
8/1/15
9/1/15
10/1/15
11/1/15
12/1/15
1/1/16
2/1/16
3/1/16
4/1/16
5/1/16
6/1/16
7/1/16
8/1/16
9/1/16
10/1/16
11/1/16
12/1/16
1/1/17
2/1/17
3/1/17

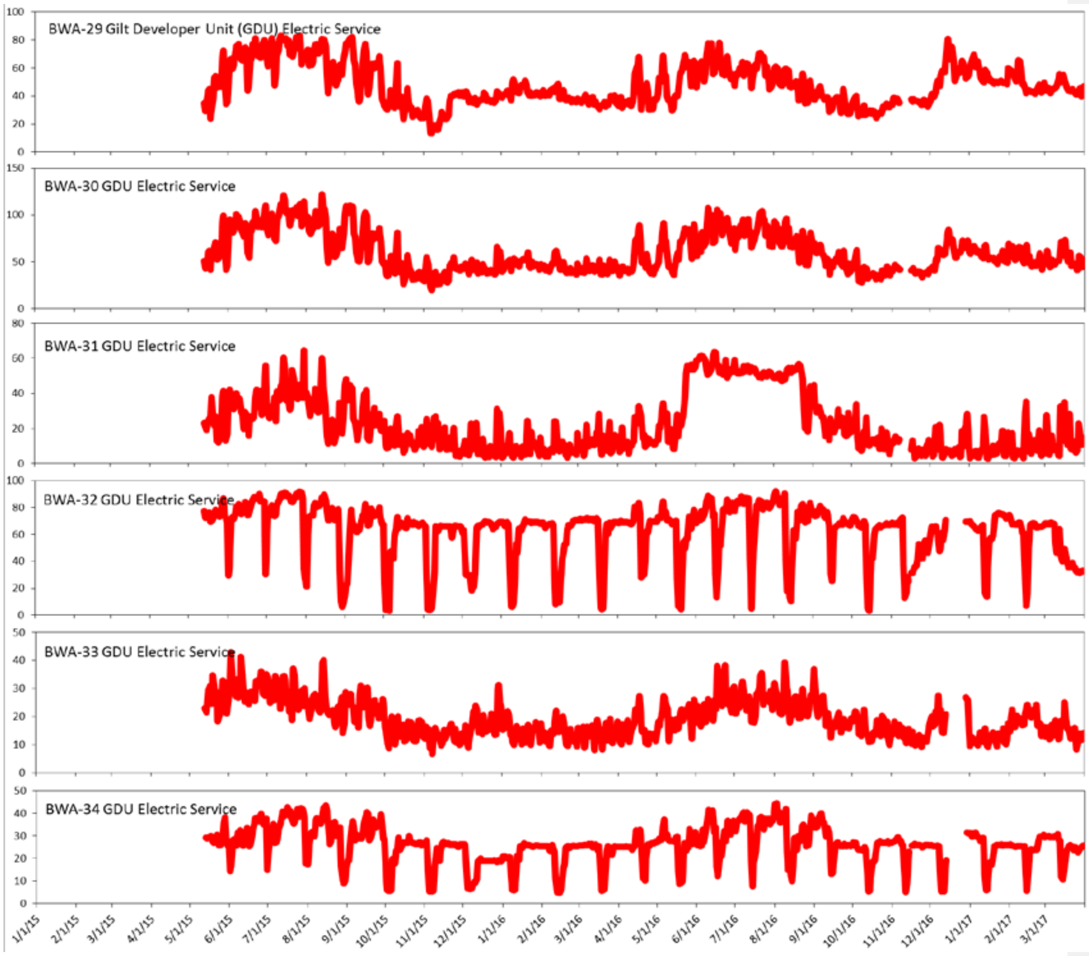


Figure A1. Timeline of sensors from beginning of installation to sensor and data logger removal. Gaps in data represent areas where data was lost due to equipment failure. All data is in kWh.

BWA-D1- "Entry" (installed 11/8/15):

- BWA-1- Scraper motors (all scraper motors in the "S. Farrowing Rooms")
  - This sensor had been unplugged from the data logger from 9/10/15 to 11/20/15. However, as this load uses an insignificant amount of energy, the data was estimated to be 0 kWh during this time frame.
- BWA-2- Pressure washer
  - This sensor was not reading any usage after the first data collection on 12/15/15, and it was discovered that the circuit was no longer used for the pressure washer.
  - This sensor was moved to another pressure washer circuit on 12/15/15 at approximately 3:15 PM.

  - On 4/20/15, this sensor came unplugged from the data logger and was not plugged back in until 4/27/15. The missing data was filled in with data from the same sensor earlier in the month, as the pressure washer is used in a cyclical pattern.
- BWA-3- Pressure washer
  - This circuit was multiplied by two in the energy calculations, as there were three pressure washers, but only two pressure washers were being monitored. Multiplying this load by two allows for the use of the third pressure washer to be accounted for.
  - On 2/14/15, at approximately 10:00 AM, the adapter cable on this sensor came unplugged. On 4/27/15, the cable was plugged back in. Therefore, data from 2/14/15 to 4/27/15 is invalid. To estimate the use of the pressure washer, the average daily use was calculated from months with complete data (January, May, and July 2015), and then multiplied by the number of days the pressure washer cable was unplugged (72 days).
- BWA-4- Load out unit heat until 4/27/15 then sensor was moved to S. Farrowing Room 8 220 volt fans
  - On 4/27/15, it was discovered that the data logger had been programmed incorrectly for this sensor- the data logger was programmed to scale BWA-4 as a 50 amp sensor instead of a 20 amp sensor. In the energy calculations, the equation for this sensor was multiplied by 0.4 to correct the scaling issue.
  - After the sensor was moved to Room 8 220 volt fans, the data from this load was multiplied by 9, as there were a total of 9 farrowing rooms in the old building, each having the same number of 220 volt fans.

BWA-D2- "W. South Gestation" (installed 12/15/14):

- BWA-5-West heaters
  - There were two heaters on this circuit. The data from this circuit was divided by two to obtain the usage of one heater. The remainder was then multiplied by 7 to account for all heaters in the "South Gestation" rooms (both the west and east sides).
- BWA-6-Vent fans
  - 4 of 13 total vent fans in the "South West Gestation" were being monitored. The data from this load was multiplied by 3.25 to account for all 13 fans in both the west and east sides (3.25 x 4 = 13).
- BWA-7-Basket fans
  - 11 basket fans on 2 two phase circuits were being monitored. The data was divided by 11 to obtain the usage of one fan. The remainder was then multiplied by 27 to account for all basket fans in both the west and east sides.
- BWA-8-Scraper motors until 5/12/15 then the sensor was moved to engine block heater.
  - When the sensor was monitoring the scraper motors, the data was multiplied by two, as there were two scraper motors in the "South Gestation" rooms.
  - When the sensor was moved to the engine block heater, the power factor in the energy calculation was changed to 1, and the calculations were run beginning on 5/12/15.

BWA-D3- "South West Gestation", (installed 12/15/14):

- BWA-9-Cross feed auger
  - The data was multiplied by 2, as the east room had similar augers.
- BWA-10-Lights
  - The data was multiplied by 2, as the east room had similar lighting.
- BWA-11-Feed line
  - The data was multiplied by 2, as the east room had a similar feed line.
- BWA-12- Mood lights

    - 20 of 24 bulbs on this circuit were being measured. Therefore, the data was multiplied by 0.2, which was then added back to the original data to account for the 4 unmeasured bulbs.
    - The total data was then multiplied by 2, as the east room had similar lighting.

BWA-D4- "N. Gestation", (installed 11/8/14):

- BWA-13- Pit fans (stage 1 and stage 2)
- BWA-14- Vent fans (stage 4 and stage 6-8)
- BWA-15- Feed actuator until 5/12/15, then moved to hot water heater
    - After the sensor was moved to the hot water heater, the phase and power factor were changed to 1 in the energy calculations.
- BWA-16- Well
    - This well fed the whole facility, except for the "South Gestation" rooms.

BWA-D5- "N. Gestation", (installed 11/8/14):

- BWA-17-South feed line/ north feed line/ cross auger
- BWA-18-Lights
    - One of seven single circuits was being monitored, so to account for all seven circuits, the energy calculations multiplied the data by 7.
- BWA-19- Fans (stage 3-7 and stage 9-5)
- BWA-20- Heaters (stage 10) until 5/12/15, then sensor moved to cool cell
    - Moving the sensor required changing the power factor to 1 in the energy calculations.

BWA-D6- "N. Farrowing Room 2" (installed 11/8/15):

- BWA-21-West feed line
    - The data from this load was multiplied by two, as there was an east feed line as well that was not monitored.
- BWA-22-"N. Farrowing Room 2" heaters
    - To "scale up" data to compare measured data to the utility meter: the data from this load was first divided by two, as there were two heaters on this circuit. The remainder was then multiplied by 17 to account for the total number of heaters in both the old and the new farrowing rooms.
- BWA-23- "N. Farrowing Room 2" heat lamp
    - This circuit was multiplied by 7 in the energy calculations, as there were 6 additional heat lamp circuits which were used identically.
    - To "scale up" data to compare measured data to the utility meter: the monitored circuit had 10 heat lamps on it, so the data from this circuit was divided by 10 to obtain the usage of one heat lamp. The remainder was then multiplied by 424, the total number of heat lamps (farrowing crates) in the whole facility.
- BWA-24- "N. Farrowing Room 2" lights
    - To "scale up" data to compare measured data to the utility meter: the data was divided by 28, as there were 28 bulbs on this circuit. The remainder was then multiplied by 252, the total number of lights in both the "Old" and "New Farrowing Rooms".

BWA-D7- "N. Farrowing Room 2" (installed 11/8/15):

- BWA-25- "N. Farrowing Room 2" 36" fan

- o To "scale up" data to compare measured data to the utility meter: there were 3, 36" fans on the measured circuit. There were 12 total 36" fans in the newer farrowing rooms, so the data from this circuit was multiplied by 4 to account for the fans in the other 3 "N. Farrowing" rooms.
- BWA-26- "N. Farrowing Room 2" pit fan
  - o To "scale up" data to compare measured data to the utility meter: there was one pit fan on the monitored circuit. Each new farrowing room had one pit fan, so the data was multiplied by four to account for all four "N. Farrowing" room pit fans.
- BWA-27- Incoming auger
  - o This load fed all of the new barn, however, the data was multiplied by two, as there was an incoming feed auger in the "S. Farrowing" rooms that was not being measured.
- BWA-28- Pit water pump

Gilt Developer Unit- data loggers BWA-D8 and BWA-D9 were installed to capture a large portion of energy that would have otherwise been missing. The whole Gilt Developer Unit electric service was being measured, so that it could be accounted for when comparing utility meter data to measured data.

BWA-D8- Gilt Developer (GDU) (installed on 5/12/15):

- BWA-29- Whole GDU electric service
- BWA-30- Whole GDU electric service
- BWA-31- Whole GDU electric service

BWA-D9- Gilt Developer (GDU) (installed on 5/12/15):

- BWA-32- Whole GDU electric service
- BWA-33- Whole GDU electric service
- BWA-34- Whole GDU electric service

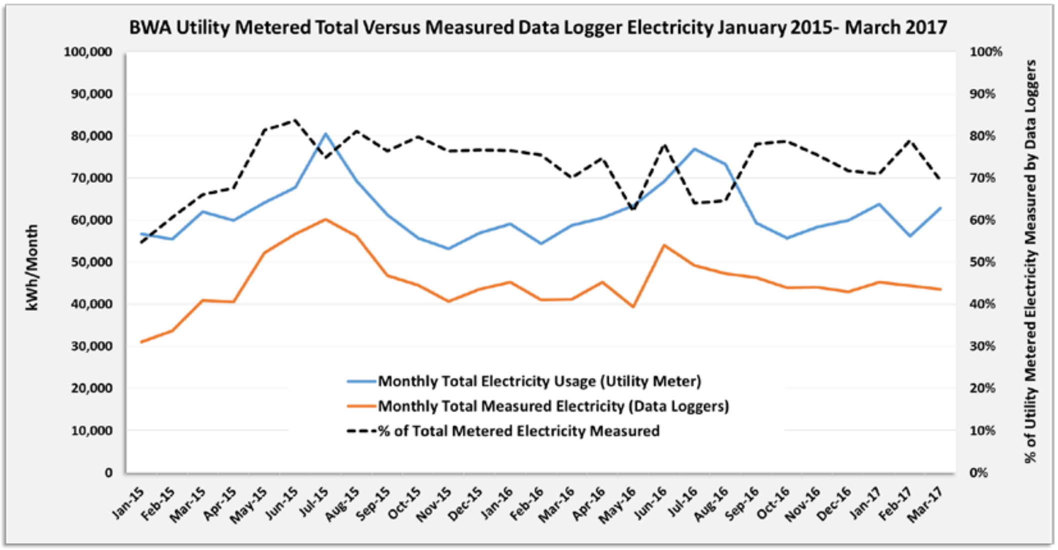


Figure A2. Total monthly electric usage of BWA as obtained from the facility's electric bill, the total monthly amount of electric usage captured by installed data loggers and sensors, and the percent of electricity measured compared to the metered total.

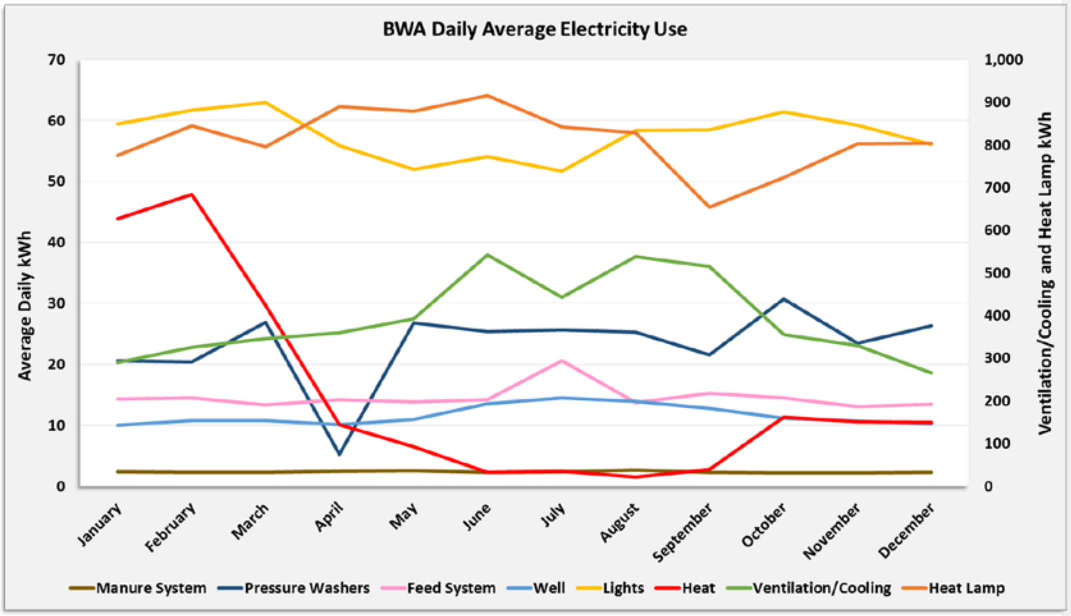


Figure A3. The monthly averages of daily energy use by various electrical loads measured at BWA from January 2015 to March 2017. It should be noted that there were data logger failures that resulted in data lost from "Pressure Washers" and "Ventilation/Cooling" during April and from "Heat" from May to December. The data that was available is reflected in this figure.

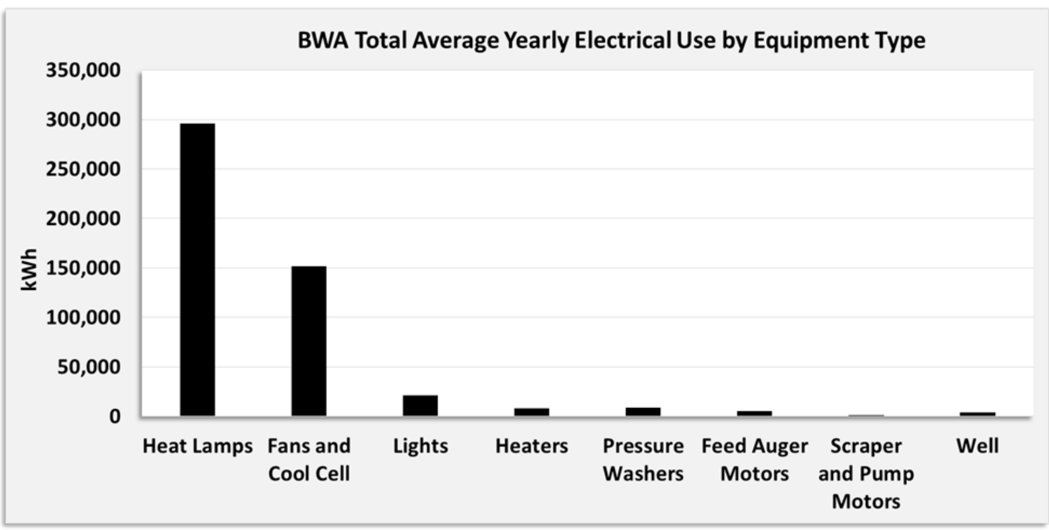


Figure A4. The average yearly electricity use (2015-2016) by equipment type in BWA.

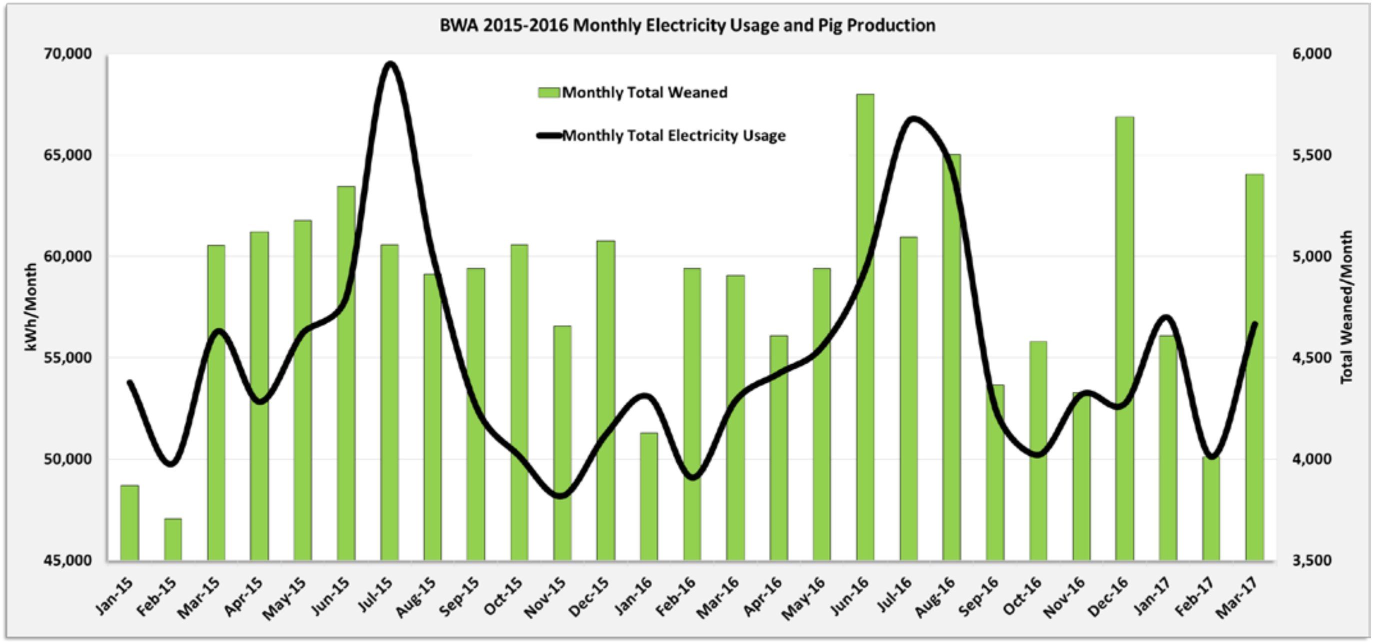


Figure A5. The total number of weaned pigs produced per month and the total electricity use per month for January 2015- March 2017 at BWA.

A.1.5. Thermal data

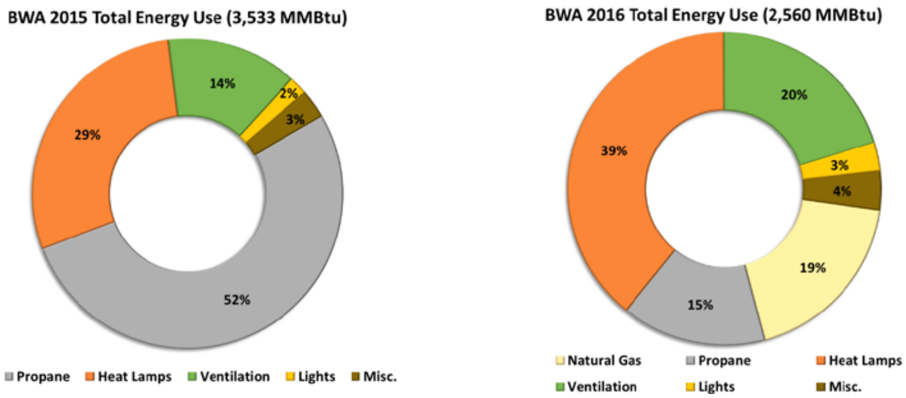


Figure A6 and A7. Total energy use converted into MMBtu across several larger electrical loads and propane/natural gas consumption in BWA in 2015 and 2016. (1 kWh= 3412.14 btu, 1 therm= 91,600 btu)

Propane Tank Fill History Reports recorded by the gas utility, Belgrade Cooperative (Belgrade, MN), were collected from the producer and analyzed to represent monthly totals and yearly totals of propane used. Propane was used for both heating and pressure washing at Breed-to-Wean Barn A up until August, 2016, when the barn switched to natural gas. Natural gas records were collected from the natural gas utility, Dooley's Petroleum (Clara City, MN). It is noted that the GDU for BWA is included in the natural gas used in 2016 as it was not possible to separate out use from this unit from the breed-to-wean unit.

A.1.6. Additional Information

Applies to: the total kWh used in 2015 (658,558 kWh), the total kWh used in 2016 (663,751 kWh), and Figure A5. "BWA 2015-2016 Monthly Electricity Usage and Pig Production". The loads included in the "Miscellaneous" category include loads not monitored by the data loggers. These data are found by taking the data obtained from the utility meter and generator produced data, minus the Gilt-Developer Unit (GDU). As monitoring of the GDU did not begin until mid-May 2015, and the GDU started up mid-January 2015, January 2015 to mid-May 2015 GDU data was estimated. As the data appears seasonal, January, February, and March 2015 GDU data were estimated using the average of January, February, and March 2016 GDU data. This average was divided in 2 for January, as the GDU started up midway through Jan 2015. To estimate April 2015 GDU data, the average of May 2015 and April 2016 GDU data was used. To estimate the GDU usage from May 1, 2015 to May 13, 2015, the daily average of May 2016 was found and multiplied by 12 days (the number of days missing in May). From November 8, 2016 to November 15, 2016 and from December 14, 2016 to December 28, 2016, the data loggers experienced battery issues and data was not recorded. The data during these times was estimated by using the daily average use from November 2015 for the missing days in November 2016 and the daily average use from December 2015 for the missing days in December 2016.

A.2. Breed-to-Wean Barn B (BWB):

BWB Biosecurity

BWB: Researchers were required to remain out of contact with pigs from other sites for 48 hours and 2 showers before arrival. Shoes were left in the designated area, showering in was required, and clothing was provided by the producer. Equipment was required to have had adequate downtime (or days of no contact with pigs outside of the facility) of at least one week and was sanitized both before arrival and upon arrival.

A.2.1. Electrical data

The electricity provider of Breed-to-Wean Barn B, Agralite Electric Cooperative (Benson, MN), provided researchers with 15 minute data taken from the electric utility meters. The metered data was compiled into daily and monthly data and was then compared to the data collected from the installed sensors and data loggers to determine if an adequate amount of loads were being monitored.

Table A2. Loads monitored, location of the load, size of the sensor monitoring the load, the sensor name and number, and the data logger ID. Loads that have been starred indicate that the sensor was moved from one load to a different load.

Breed-to-Wean Barn B (BWB)				
Load Description	**Location of Load**	**Sensor Size (AMPS)**	**Sensor ID**	**Data Logger ID**
Lights	Gestation Room	20	BWB-1	BWB-D1
Feed Motors	Gestation Room	50	BWB-2	
*Heat	Gestation Room	20	BWB-3	
*Vent Fans	Gestation Room	20	BWB-3	
*Heat	Gestation Room	20	BWB-3	
*Vent Fans	Gestation Room	20	BWB-3	
*Heat	Gestation Room	20	BWB-3	
Vent Fans	Gestation Room	50	BWB-4	
VS Pit Fans Stage 1/2	Gestation Room	20	BWB-5	BWB-D2
Vent Fans	Gestation Room	50	BWB-6	
VS Pit Fans Stage 1/2	Gestation Room	50	BWB-7	
Vent Fans	Gestation Room	50	BWB-8	
Farrowing Room 2 Lights	Farrowing Room 2	20	BWB-9	BWB-D3
Farrowing Room 2 36"/24" Vent Fans/Pit Fans	Farrowing Room 2	20	BWB-10	
Farrowing Room 2 Outlets (Heat Lamps)	Farrowing Room 2	50	BWB-11	
*Farrowing Room 2 Heat	Farrowing Room 2	20	BWB-12	
*Generator Heater/Off-Peak Controls	Generator	20	BWB-12	
*Farrowing Room 2 Heat	Farrowing Room 2	20	BWB-12	
*South Well	Whole Facility	50	BWB-13	BWB-D4
*South Well & North Well	Whole Facility	100	BWB-13	
Farrowing Room 2 Feed Motor	Farrowing Room 2	20	BWB-14	
Main Loop Feed Motor Controller Power & Main Input Feed Motor	Whole Facility	50	BWB-15	
Pressure Washer	Whole Facility	100	BWB-16	
Farrowing Room 2 Outlets (Heat Lamps)	Farrowing Room 2	25	BWB-17	BWB-D5
Farrowing Room 9 Outlets (Heat Lamps)	Farrowing Room 9	25	BWB-18	
Farrowing Room 9 Outlets (Heat Lamps)	Farrowing Room 9	25	BWB-19	
Farrowing Room 2 & Room 9 Control Panel	Farrowing Rooms 2 & 9	25	BWB-20	
Heat NW/SW Room	Misc. Heating	25	BWB-21	BWB-D6
*North Well	Whole Facility	25	BWB-22	
*Panel 1 Electric Feed	Misc. Loads	250	BWB-22	
Pressure Washer Room Heater	Misc. Heating	25	BWB-23	
*Pressure Washer/Electric Room Lights/Outlets	Misc. Lighting	25	BWB-24	
*Panel 1 Electric Feed	Misc. Loads	250	BWB-24	
Gilt Developer Unit (GDU) Electric Service	GDU	250	BWB-25	BWB-D7
Gilt Developer Unit (GDU) Electric Service	GDU	250	BWB-26	
Gilt Developer Unit (GDU) Electric Service	GDU	250	BWB-27	
Gilt Developer Unit (GDU) Electric Service	GDU	250	BWB-28	
House & Shop	House & Shop	250	BWB-29	BWB-D8
House & Shop	House & Shop	250	BWB-30	
Office Electric Subpanel #1	Office & Farrowing Room 11	250	BWB-31	
Office Electric Subpanel #1	Office & Farrowing Room 11	250	BWB-32	

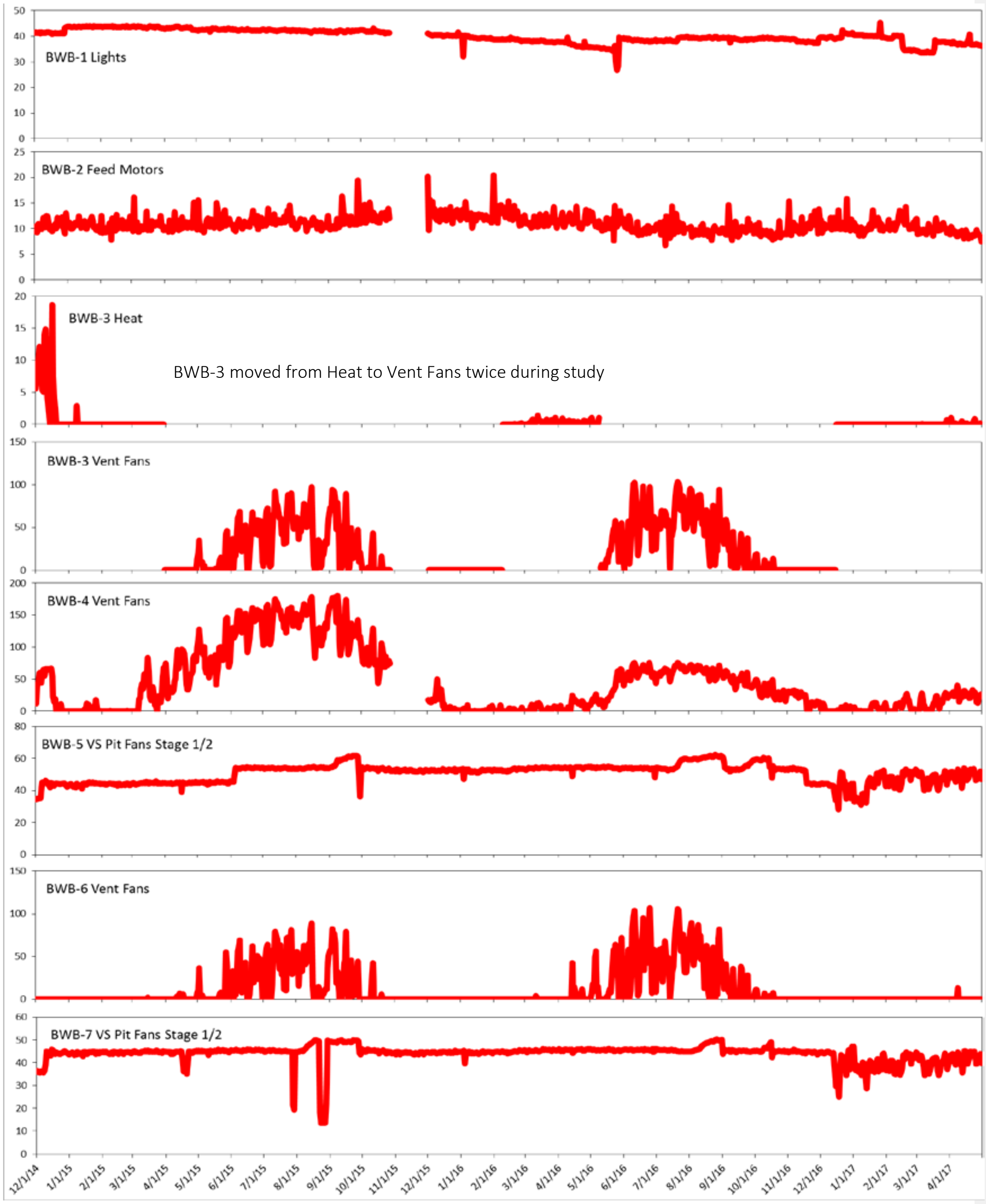
A.2.2. Materials

- Eight HOBO UX120-006M Data Loggers
- 7 CR Magnetic CR9580-20, 20 amp sensors
- 8 CR Magnetic CR9580-50, 50 amp sensors
- 5 Magnelab, DCT-0010-025, 25 amp sensors
- 2 Magnelab, DCT-0016-100, 100 amp sensors
- 10 Magnelab, DCT-0024-250, 250 amp sensors
- Seven USB cables
- 32, 0 to 10V DC input adapter cables

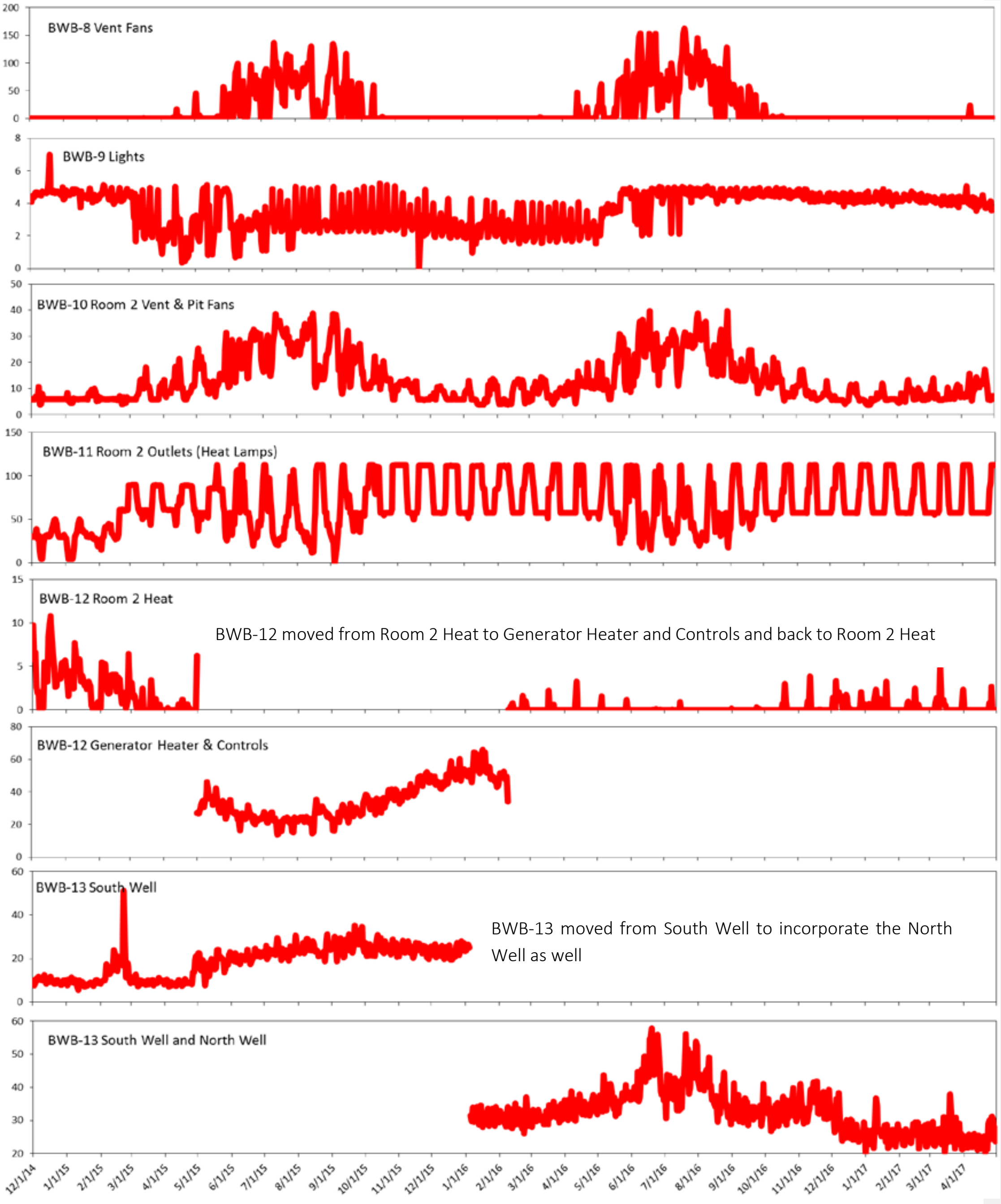
A.2.3. Data logger and sensor information

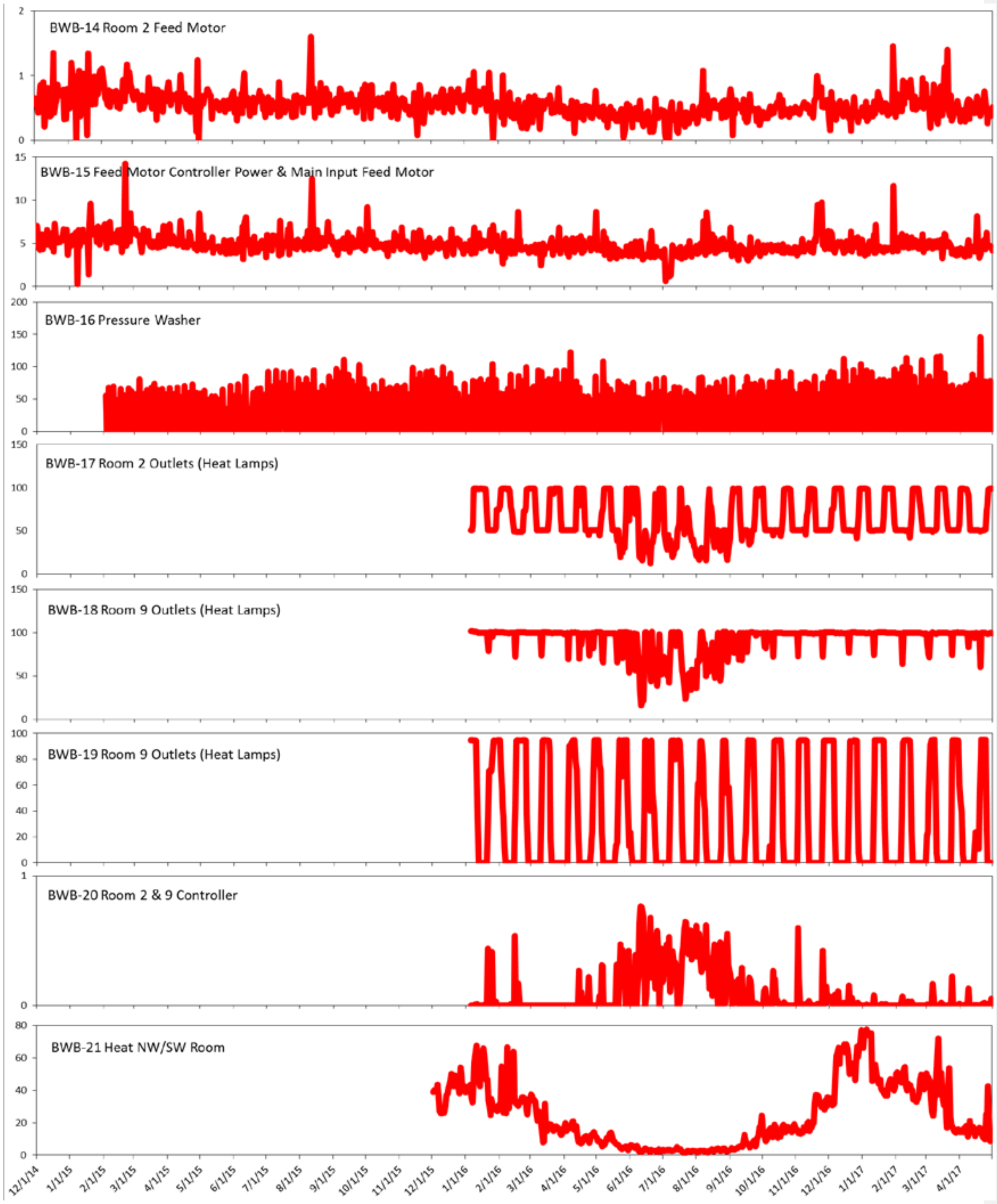
All data loggers in this facility, except BWB-D8, were programmed incorrectly, scaling each sensor from 10 volts to the maximum sensor output, instead of from 5 volts to the sensor output. Therefore, in the energy calculations, each equation that was tailored to each sensor was divided by 3000 instead of the typical 6000, in order to correct for the incorrect scaling. It was decided to simply correct for the error in the energy calculations, rather than restart and reprogram each logger, which would cause some data to be lost. Below is the equation used in the energy calculations:

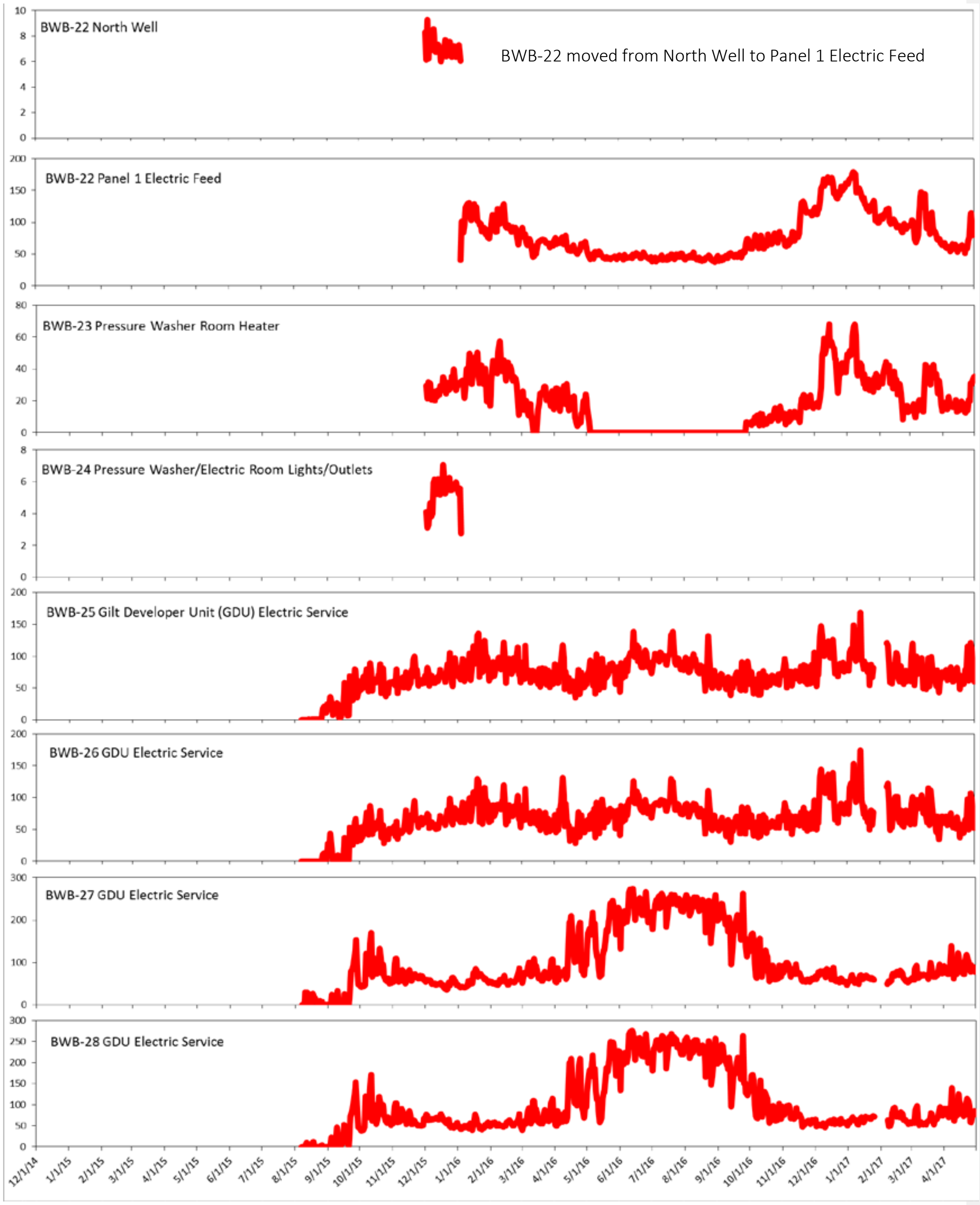
$$kWh = \frac{Volts\ x\ Amps\ x\ phase\ x\ power\ factor}{3000}$$



BWB-1 Lights
BWB-2 Feed Motors
BWB-3 Heat
BWB-3 moved from Heat to Vent Fans twice during study
BWB-3 Vent Fans
BWB-4 Vent Fans
BWB-5 VS Pit Fans Stage 1/2
BWB-6 Vent Fans
BWB-7 VS Pit Fans Stage 1/2
12/1/14
1/1/15
2/1/15
3/1/15
4/1/15
5/1/15
6/1/15
7/1/15
8/1/15
9/1/15
10/1/15
11/1/15
12/1/15
1/1/16
2/1/16
3/1/16
4/1/16
5/1/16
6/1/16
7/1/16
8/1/16
9/1/16
10/1/16
11/1/16
12/1/16
1/1/17
2/1/17
3/1/17
4/1/17


BWB-8 Vent Fans
BWB-9 Lights
BWB-10 Room 2 Vent & Pit Fans
BWB-11 Room 2 Outlets (Heat Lamps)
BWB-12 Room 2 Heat
BWB-12 moved from Room 2 Heat to Generator Heater and Controls and back to Room 2 Heat
BWB-12 Generator Heater & Controls
BWB-13 South Well
BWB-13 moved from South Well to incorporate the North Well as well
BWB-13 South Well and North Well
12/1/14
1/1/15
2/1/15
3/1/15
4/1/15
5/1/15
6/1/15
7/1/15
8/1/15
9/1/15
10/1/15
11/1/15
12/1/15
1/1/16
2/1/16
3/1/16
4/1/16
5/1/16
6/1/16
7/1/16
8/1/16
9/1/16
10/1/16
11/1/16
12/1/16
1/1/17
2/1/17
3/1/17
4/1/17


BWB-14 Room 2 Feed Motor
BWB-15 Feed Motor Controller Power & Main Input Feed Motor
BWB-16 Pressure Washer
BWB-17 Room 2 Outlets (Heat Lamps)
BWB-18 Room 9 Outlets (Heat Lamps)
BWB-19 Room 9 Outlets (Heat Lamps)
BWB-20 Room 2 & 9 Controller
BWB-21 Heat NW/SW Room
12/1/14
1/1/15
2/1/15
3/1/15
4/1/15
5/1/15
6/1/15
7/1/15
8/1/15
9/1/15
10/1/15
11/1/15
12/1/15
1/1/16
2/1/16
3/1/16
4/1/16
5/1/16
6/1/16
7/1/16
8/1/16
9/1/16
10/1/16
11/1/16
12/1/16
1/1/17
2/1/17
3/1/17
4/1/17


BWB-22 North Well
BWB-22 moved from North Well to Panel 1 Electric Feed
BWB-22 Panel 1 Electric Feed
BWB-23 Pressure Washer Room Heater
BWB-24 Pressure Washer/Electric Room Lights/Outlets
BWB-25 Gilt Developer Unit (GDU) Electric Service
BWB-26 GDU Electric Service
BWB-27 GDU Electric Service
BWB-28 GDU Electric Service
12/1/14
1/1/15
2/1/15
3/1/15
4/1/15
5/1/15
6/1/15
7/1/15
8/1/15
9/1/15
10/1/15
11/1/15
12/1/15
1/1/16
2/1/16
3/1/16
4/1/16
5/1/16
6/1/16
7/1/16
8/1/16
9/1/16
10/1/16
11/1/16
12/1/16
1/1/17
2/1/17
3/1/17
4/1/17

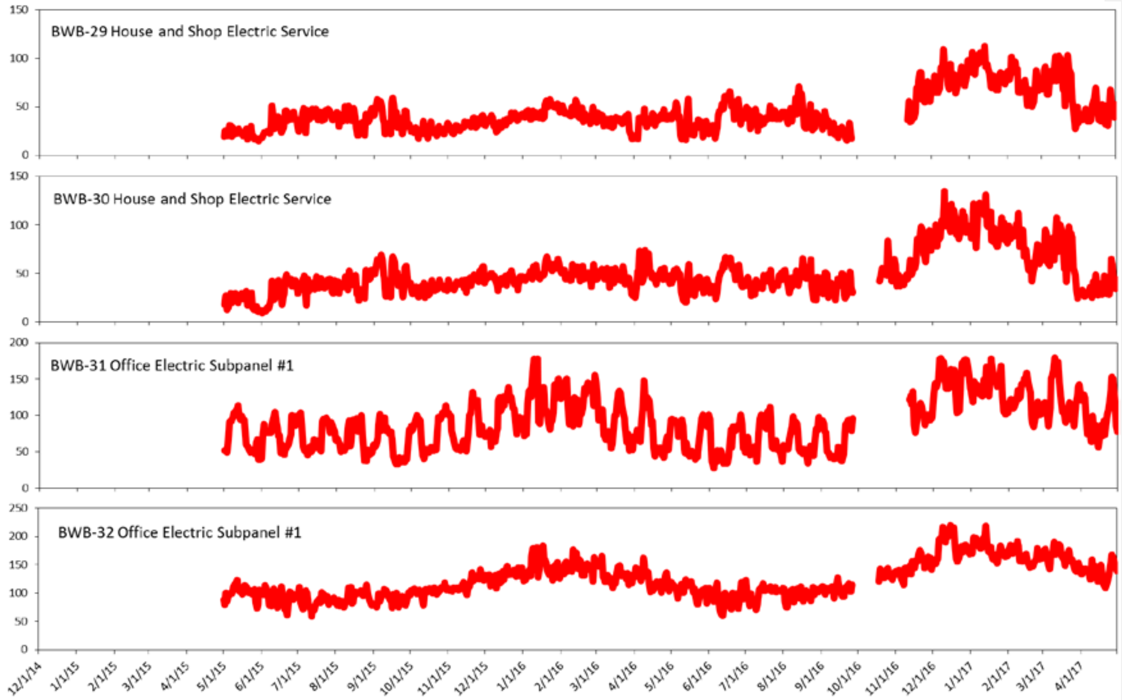


Figure A8. Timeline of sensors from beginning of installation to sensor and data logger removal. Gaps in data represent areas where data was lost due to equipment failure. All data is in kWh.

BWB-D1- "Gestation Room" (installed 11/18/14):

Data loggers BWB-D1 and BWB-D2 were monitoring loads in the facility's "Gestation Room". This room was one large air space, which housed gestating sows in both individual crates and group pens. Data logger BWB-D1 experienced battery issues and data was lost from this logger from 10/28/15-12/1/15.

- BWB-1- "Gestation Room" lights
  - The data from this sensor was multiplied by 2, as only 3 of 6 total two phase circuits were being measured.
- BWB-2- "Gestation Room" feed motors
  - The data from this sensor was multiplied by 2 as only 3 of 6 total two phase circuits were being measured.
- BWB-3- "Gestation Room" heaters until 3/30/15, then moved to "Gestation Room" vent fans on 3/30/15.
  - While the sensor was on the "Gestation Room" heaters, the data was multiplied by 4, as only 2 of 8 two phase circuits were measured.
- BWB-4- "Gestation Room" vent fans

BWB-D2- "Gestation Room" (installed 11/18/15):

- BWB-5- "Gestation" variable speed pit fans, stage 1&2
- BWB-6- "Gestation" vent fans
- BWB-7-" Gestation" variable speed pit fans, stage 1&2
- BWB-8-" Gestation" vent fans

Figure X. Timeline of sensors from beginning of installation to end. Gaps in data represent areas where data was lost due to battery issues

Data loggers BWB-D3 and BWB-D4 were monitoring loads in one of the facility's farrowing rooms, "Farrowing Room 2". There were 11 total farrowing rooms in the building with 48 farrowing crates in each room. "Farrowing Room 11" was half the size of the other rooms, with 24 farrowing crates. The farrowing rooms housed gestating sows approximately five days before farrowing and lactating sows and piglets for 21 days after farrowing.

To "scale up" data to compare measured data to the utility meter: electricity for "Farrowing Room 11" was fed by "Office Subpanel #1", which was a subpanel that fed all of the office loads plus "Farrowing Room 11". "Office Subpanel #1" was monitored by data logger BWB-D8. In order to obtain the usage for "Farrowing Room 11", each of the loads specific to "Farrowing Room 2" were divided in half, and the remainder was then added to the "Farrowing Room 2" loads and also subtracted out from the monthly totals obtained by data logger BWB-D8. For example: the monthly total of "Farrowing Room 2" lights was divided by two to obtain "Farrowing Room 11's" light usage. This remainder was subtracted from the "Office Subpanel #1" loads and then added back on to "Farrowing Room 2" lights.

Commented [ESB2]: I cannot follow this.

BWB-D3- "Farrowing Room 2" (installed 11/18/14):

- BWB-9- "Farrowing Room 2" lights
  - To "scale up" data to compare measured data to the utility meter:
    - All loads specific to "Room 2" were first divided by 2, to obtain the usage of "Farrowing Room 11". The remainder was then added back to "Room 2" lights and subtracted from BWB-31 and BWB-32.
    - After dividing the data for "Room 2" lights by 2, the total of BWB-9 was multiplied by 10, as there were 10 other farrowing rooms that were identical to "Room 2".
- BWB-10- "Farrowing Room 2" 36" and 24" vent fans and pit fans
  - All loads specific to "Room 2" were first divided by 2, as the 11th farrowing room was half the size of "Room 2". The remainder was then added back to "Farrowing Room 2" and subtracted from BWB-31 and BWB-32.
  - After dividing the data by 2, the monthly total was multiplied by 10 to account for the fans in all 10 identical farrowing rooms.
- BWB-11- "Farrowing Room 2" outlets (heat lamps)
  - All loads specific to Room 2 were first divided by 2, as the 11th farrowing room was half the size of "Farrowing Room 2". The remainder was then added back to "Farrowing Room 2" and subtracted from BWB-31 and BWB-32.
  - After dividing the monthly total by 2, the data was multiplied by 10 to account for all of the outlets in the other 10 identical farrowing rooms.
  - After being multiplied by 10, the product was then multiplied by 2, as only 4 of 8 total single phase outlet circuits were being measured.
- BWB-12-"Farrowing Room 2" heat until 4/30/15, then moved to generator heater and off-peak controls until 2/9/16 when it was moved back to "Farrowing Room 2" heat.
  - When the sensor was on "Farrowing Room 2" heat, the data was divided by 2 to obtain the usage for "Farrowing Room 11".
  - After the "Farrowing Room 2" heat data was divided by two, the original data total was multiplied by 10 to account for all of the other same-sized rooms.
  - After the sensor was moved to generator heaters and off-peak controls, the phase was changed in the energy calculations to two phase, and the power factor was changed to 1.

BWB-D4- "Farrowing Room 2" and misc. (installed 11/18/14):

- BWB-13-South well
  - There was a north well as well, so the data was multiplied by two in the energy calculations to obtain the usage for both identical wells up until 12/1/15 when sensor BW6-22 was installed on the north well.

- On 1/4/16, the north well was added to sensor BWB-13, to free up a sensor for placement on an additional load.

- BWB-14-"Farrowing Room 2" feed motor
  - All loads specific to "Farrowing Room 2" were first divided by 2, as the 11th farrowing room was half the size of "Farrowing Room 2". The remainder was then added back to "Farrowing Room 2" and subtracted from BWB-31 and BWB-32.
  - After the data was divided by two to obtain the usage of "Farrowing Room 11", the data was multiplied by 10 to account for all 10 rooms.
- BWB-15- Main loop feed motor controller power and main input feed motor from bins

- BWB-16- Pressure washer (sensor installed on 2/1/2015)

BWB-D5- "Farrowing Room 2 and 9" (installed 1/4/16):

- BWB-17- "Farrowing Room 2 Outlets" (Heat Lamps)
- BWB-18- "Farrowing Room 9 Outlets" (Heat Lamps)
- BWB-19- "Farrowing Room 9 Outlets" (Heat Lamps)
- BWB-20- "Farrowing Rooms 2 and 9" Control Panel

BWB-D6- Miscellaneous (installed 12/1/15):

- BWB-21- Heat NW/SW room
- BWB-22- North well
- BWB-23- Power washer room heater
- BWB-24- Power washer and electric room lights and outlets

BWB-D7- Gilt Developer Unit (installed 8/7/15):

- BWB-25- Gilt developer electric service 2A (from automatic transfer switch 2)
- BWB-26- Gilt developer electric service 2B (from ATS2)
- BWB-27- Gilt developer electric service 3A (from ATS3)
- BWB-28- Gilt developer electric service 3B (from ATS3)

BWB-D8- Main Panel (installed 4/30/15):

This data logger was programmed correctly, scaling each sensor from 5 volts to the maximum sensor output. Therefore, in the energy equations, each equation that was tailored to each sensor was divided by 6,000, to factor in time into the equation.

$$kWh = \frac{Volts\ x\ Amps\ x\ \sqrt{phase}\ x\ power\ factor}{6000}$$

- BWB-29- House and Shop
  - This load was monitored so that it could be subtracted out from the metered data, as this load was not related to swine production.
- BWB-30- House and Shop
  - This load was monitored so that it could be subtracted out from the metered data, as this load was not related to swine production.
- BWB-31- Office Subpanel #1 (this includes "Farrowing Room 11")

- This subpanel fed the office of BW6 and “Farrowing Room 11”. Therefore, the loads monitored in “Farrowing Room 2” that were identical to all farrowing rooms were divided in half, as “Farrowing Room 11” was half the size of “Farrowing Room 2”. The loads were then subtracted out from the office subpanel and added back to the farrowing loads.

- BWB-32- Office Subpanel #1(this includes “Farrowing Room 11”)
    - This subpanel fed the office of BW6 and “Farrowing Room 11”. Therefore, the loads monitored in “Farrowing Room 2” that were identical to all farrowing rooms were divided in half, as “Farrowing Room 11” was half the size of “Farrowing Room 2”. The loads were then subtracted out from the office subpanel and added back to the farrowing loads.

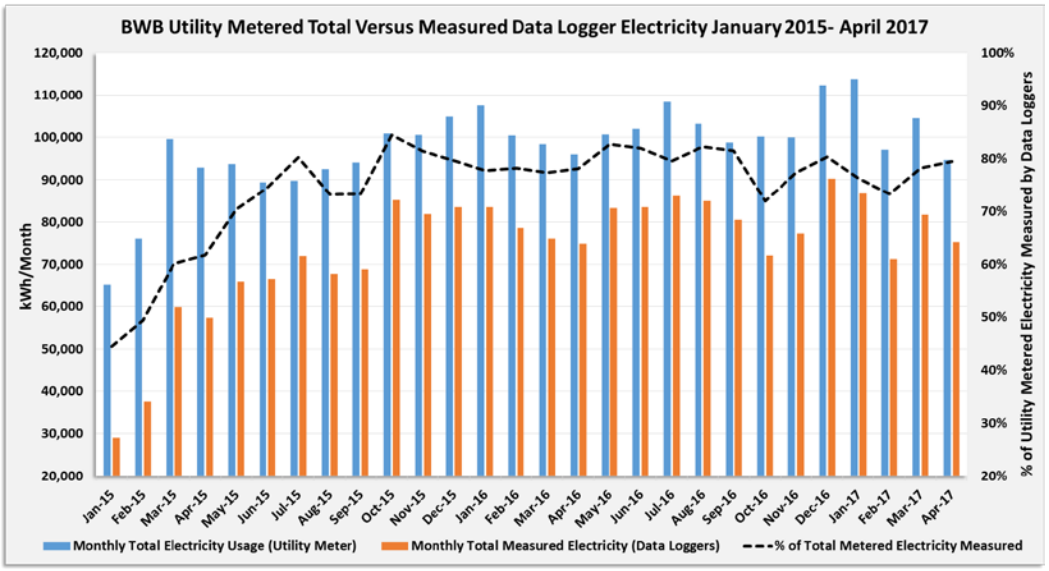


Figure A9. Total monthly electric usage of BWB as obtained from the facility’s electric bill, the total monthly amount of electric usage captured by installed data loggers and sensors, and the percent of electricity measured compared to the metered total.

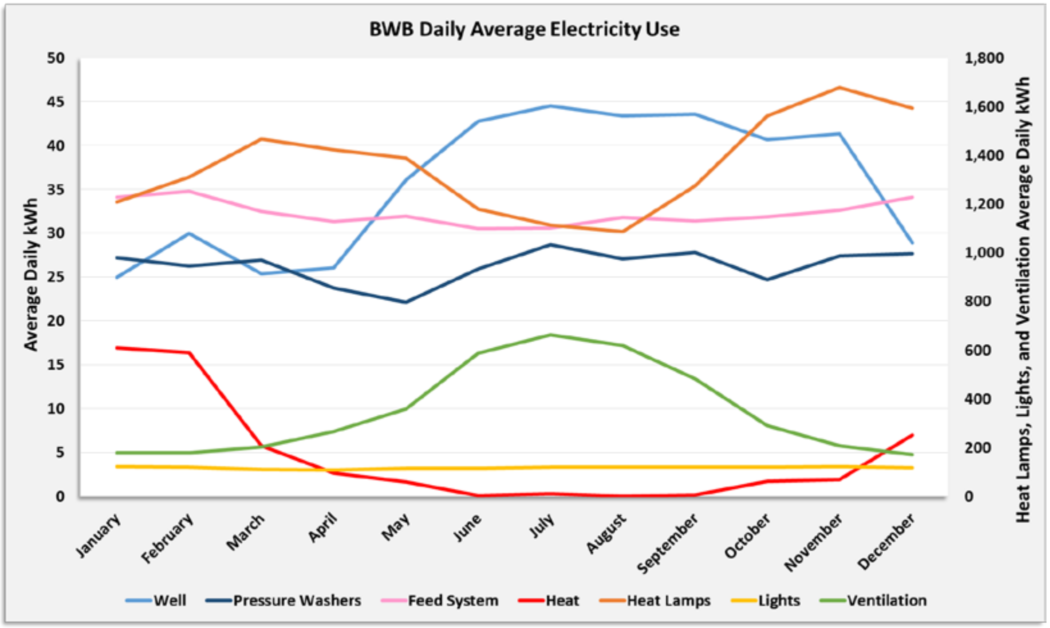


Figure A10. The monthly averages of daily energy use by various electrical loads measured at BWB from January 2015 to April 2017. It should be noted that there were data logger battery issues during all years that resulted in some data lost for “Heat” from May to December and data lost from “Ventilation” in March. The data that was available is reflected in this figure.

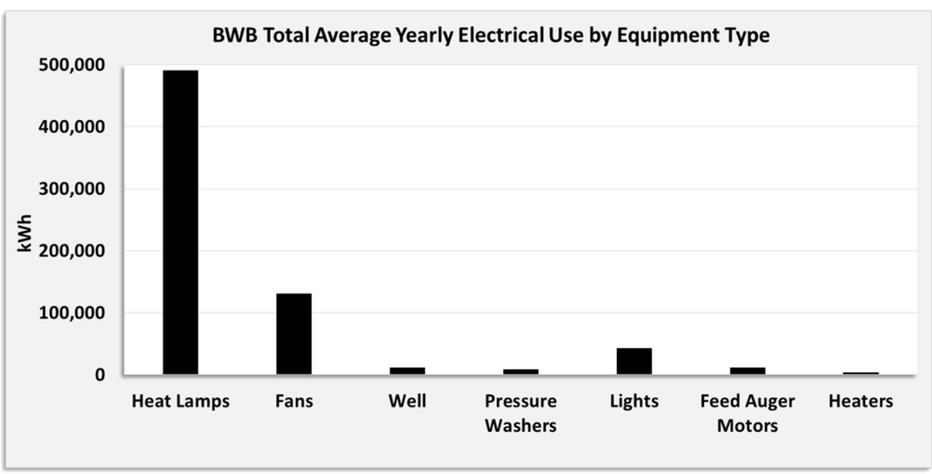


Figure A11. The average yearly electricity use (2015-2016) by equipment type in BWB.

Thermal Data

Propane Tank Fill History Reports recorded by the gas utility, Dooley's Petroleum (Murdock, MN), were collected from the producer and analyzed to represent monthly totals and yearly totals of propane used. Propane was used for both heating and pressure washing at Breed-to-Wean Barn B.

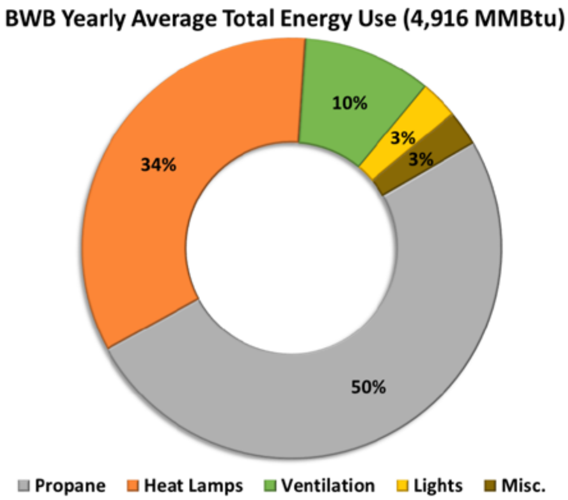


Figure A12. The total average energy use averaged across 2015 and 2016 and converted into MMBtu across several larger electrical loads and propane consumption in BWB. (1 kWh= 3412.14 btu, 1 therm= 91,600 btu)

A.3. Nursery Barn A (NBA):

NBA Biosecurity

Researchers were required to remain out of contact with pigs from other sites for 48 hours and 3 showers before arrival. Personnel put on protective plastic boots provided at the entrance to facility, left shoes with protective boots on in the entrance, and walked through the shower and office areas with socks only. Equipment that was needed in the facility had at least three days of downtime and was sanitized before arrival.

A.3.1. Electrical Data

The electricity provider of Nursery Barn A, Stearns Electric Association (Melrose, MN), provided researchers with daily data taken from the meters. The monthly metered total was then compared to the data collected from the installed sensors and data loggers to determine if an adequate amount of loads were being monitored.

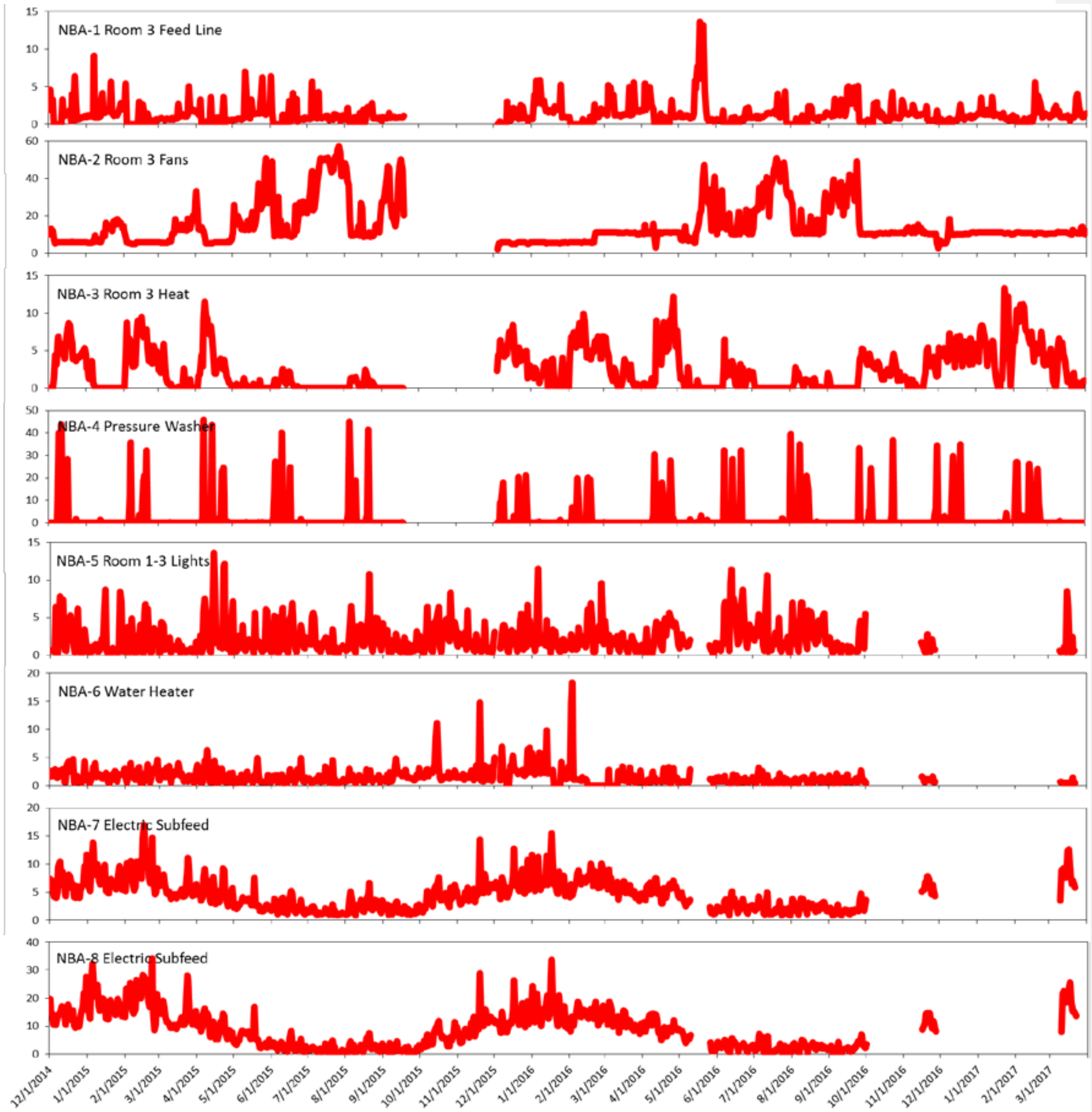
Table A3. Loads monitored, location of the load, size of the sensor monitoring the load, the sensor name and number, and the data logger ID.

Nursery Barn A (NBA)				
Load Description	Location of Load	Sensor Size (AMPS)	Sensor ID	Data Logger ID
Feed line Room 3	Nursery Room 3	50	NBA-1	NBA-D1
Fans Room 3	Nursery Room 3	50	NBA-2	
Heat Room 3	Nursery Room 3	50	NBA-3	
Pressure Washer	Whole Facility	50	NBA-4	
Room 1-3 Lights	All Nursery rooms	50	NBA-5	NBA-D2
Water Heater	Office	50	NBA-6	
Electric Subfeed	Office	50	NBA-7	
Electric Subfeed	Office	50	NBA-8	
Cattle Shed Electric Service	Outbuilding	250	NBA-9	NBA-D3
Cattle Shed Electric Service	Outbuilding	250	NBA-10	
Well	Whole Site	50	NBA-11	

A.3.2. Materials

- Three HOBO UX120-006M Data Loggers
- 9 CR Magnetic CR9580-50, 50 amp sensors
- Two Magnelab DCT-0024-250, 250 amp sensors
- Three USB cables
- 11, 0 to 10V DC input adapter cables

A.3.4. Data logger and sensor information



NBA-1 Room 3 Feed Line
NBA-2 Room 3 Fans
NBA-3 Room 3 Heat
NBA-4 Pressure Washer
NBA-5 Room 1-3 Lights
NBA-6 Water Heater
NBA-7 Electric Subfeed
NBA-8 Electric Subfeed
12/1/2014
1/1/2015
2/1/2015
3/1/2015
4/1/2015
5/1/2015
6/1/2015
7/1/2015
8/1/2015
9/1/2015
10/1/2015
11/1/2015
12/1/2015
1/1/2016
2/1/2016
3/1/2016
4/1/2016
5/1/2016
6/1/2016
7/1/2016
8/1/2016
9/1/2016
10/1/2016
11/1/2016
12/1/2016
1/1/2017
2/1/2017
3/1/2017

Figure A13. Timeline of sensors from beginning of installation to sensor and data logger removal. Gaps in data represent areas where data was lost due to battery issues or unplugged cables. All data is in kWh.

NBA consisted of three identical rooms, each having the same electrical loads and each having a capacity of 1,000 head. As the rooms were identical, it was determined that the data obtained from the room monitored by the data logger could be multiplied by the total number of rooms in this facility (3) to compare monitored data to metered data. After multiplications, the data was compared to the metered data provided by Stearns Electric Association. NBA-D3 was a data logger that was added in May of 2015 to an additional and unrelated building which was powered from the same meter as the nursery. Monitoring the additional building allows for those data to be subtracted from the metered data to focus solely on the nursery building.

NBA-D1- "Room 3" (installed 11/8/14):

NBA-D1 experienced battery issues from 9/19/15-12/4/15 when a new data logger was made to replace the old. Therefore a significant amount of data was lost during this timeframe.

- NBA-1- Feed line in "Nursery Room 3"
    - To "scale up" data to compare measured data to the utility meter- the data from this sensor was multiplied by three to account for feed lines in all three rooms.
- NBA-2- Fans in "Nursery Room 3"
    - To "scale up" data to compare measured data to the utility meter- the data from this sensor was multiplied by three to account for fans in all three rooms.
- NBA-3- Heat in "Nursery Room 3"
    - To "scale up" data to compare measured data to the utility meter- the data from this sensor was multiplied by three to account for heaters in all three rooms.
- NBA-4- Pressure washer

NBA-D2- Miscellaneous (installed 11/8/14):

NBA-D2 experienced battery issues from 5/11/16-5/25/16, 10/2/16-11/15/16, and from 11/28/16- 12/31/16. Therefore, data from these time periods was lost.

- NBA-5- All nursery room lights
  - These light circuits are located in the subfeed which was already being monitored. Therefore, the usage of the light circuits was subtracted from the sub feed total to observe separate usage of the lights.
  - This adapter cables for this sensor were unplugged from 12/2/15-12/5/16. Therefore, data from these four days is missing.
- NBA-6- Water heater
  - This circuit was located in the subfeed which was already being monitored. Therefore, the usage of the water heater circuit was subtracted from the sub feed total in order to observe separate usage of the water heater.
  - The adapter cables for this sensor were unplugged from 12/2/15-12/5/16. Therefore, data from these four days is missing.
- NBA-7- Subfeed
  - The subfeed contained miscellaneous and office circuits.
- NBA-8- Subfeed
  - The subfeed contained miscellaneous and office circuits.

NBA-D3- Cattle shed (installed 5/23/15):

- NBA-9- Cattle shed electric service
- NBA-10- Cattle shed electric service
- NBA-11- Well
  - The well fed the whole site and was located in the cattle shed subfeed. Therefore, the usage of the well could not be specifically correlated to swine use, so water for pigs in NBA was not accounted for.

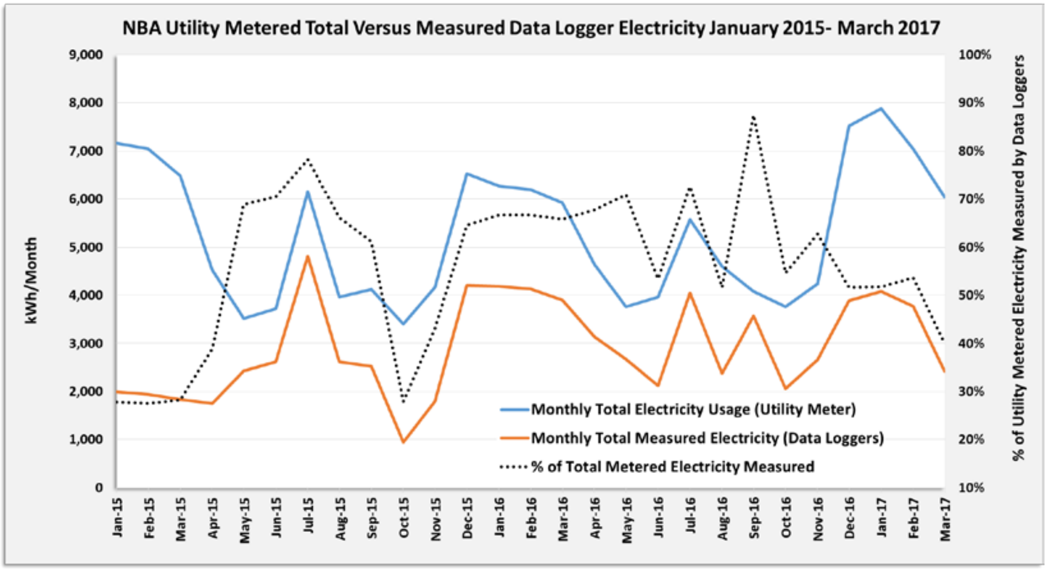


Figure A14. Total monthly electric usage of NBA as obtained from the facility's electric bill, the total monthly amount of electric usage captured by installed data loggers and sensors, and the percent of electricity measured compared to the metered total.

The drastic decrease in percent of electricity recorded during the fall of 2015, May 2016, October-March 2017 can be attributed to data loggers experiencing battery issues. Another reason overall as to why the percent measured was not higher was due to the fact that there was a generator shed on the site that could not feasibly be measured. This shed contained a 1,500 watt block heater (which could have potentially used 1,000 kWh per month).

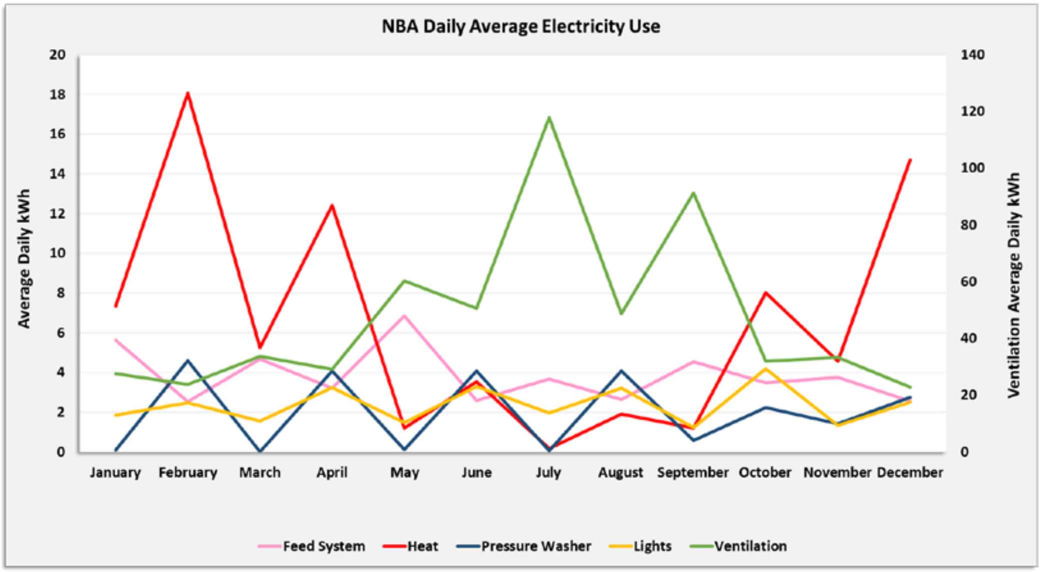


Figure A15. The monthly averages of daily energy use by various electrical loads measured at NBA from January 2015 to March 2017. No data is estimated.

Ventilation and heating use was as expected, with ventilation usage higher in the summer and heater fan use higher during the winter. Other loads such as the pressure washer were not used every month and were only used when rooms needed to be cleaned. The lighting usage reflects when the building was used more- during cleaning and when transitioning pigs.

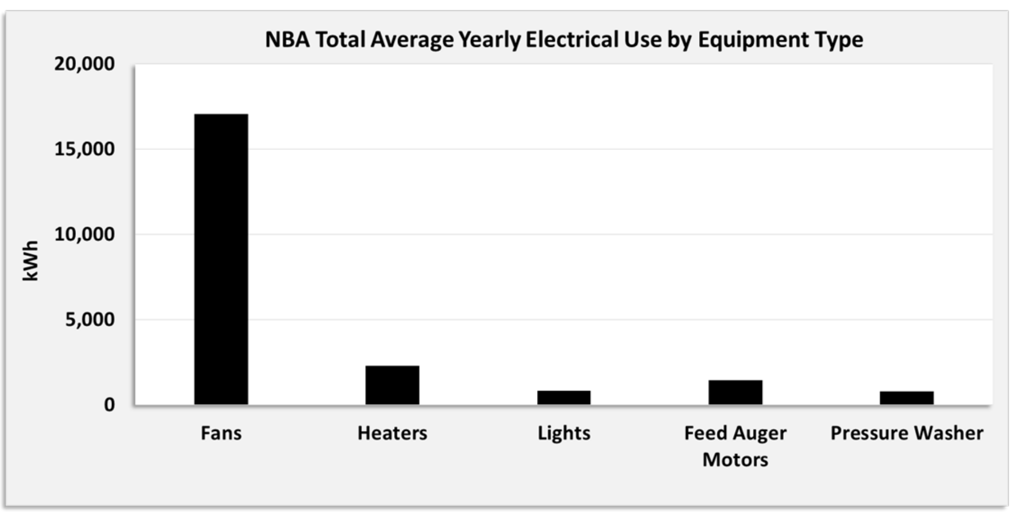


Figure A16. The average yearly electricity use (2015-2016) by equipment type in NBA.

Thermal Data

Propane Tank Fill History Reports obtained from the gas utility, Belgrade Cooperative (Belgrade, MN), were collected and analyzed to represent monthly totals and yearly totals of propane used. Propane was used for both heating and pressure washing at Nursery Barn A.

During August 2016, NBA switch over from propane to natural gas. The natural gas bills were obtained from the supplier, Dooley's Natural Gas (Clara City, MN), and were collected and analyzed to represent monthly natural gas total use.

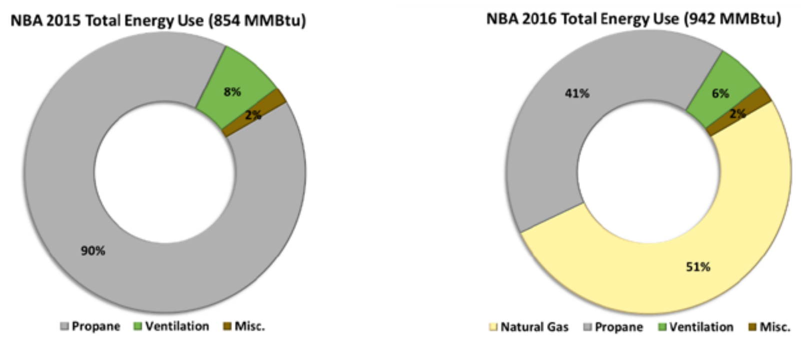


Figure A17 and A18. Total energy use converted into MMBtu across several larger electrical loads and propane/natural gas consumption in NBA in 2015 and 2016. (1 kWh= 3412.14 btu, 1 therm= 91,600 btu)

A.4. Nursery Barn B (NBB):

NBB Biosecurity

Researchers were required to remain out of contact with pigs from other sites for 48 hours and 2 showers before arrival. Shoes were left in the designated spot, researchers showered in to the facility and wore clothing provided by the producer. All equipment needed by researchers had at least 48 hours of downtime and was sanitized before arrival and upon arrival.

A.4.1. Electrical data

The electricity provider of Nursery Barn B, Agralite Electric Cooperative (Benson, MN), provided researchers with 15 minute data taken from the meters. The metered data was compiled into daily and monthly data and was then compared to the data collected from the installed sensors and data loggers to determine if an adequate amount of loads were being monitored.

Table A4. This table represents loads monitored, location of the load, size of the sensor monitoring the load, the sensor name and number, and the data logger ID. Loads that have been starred indicate that the sensor was moved from one load to a different load.

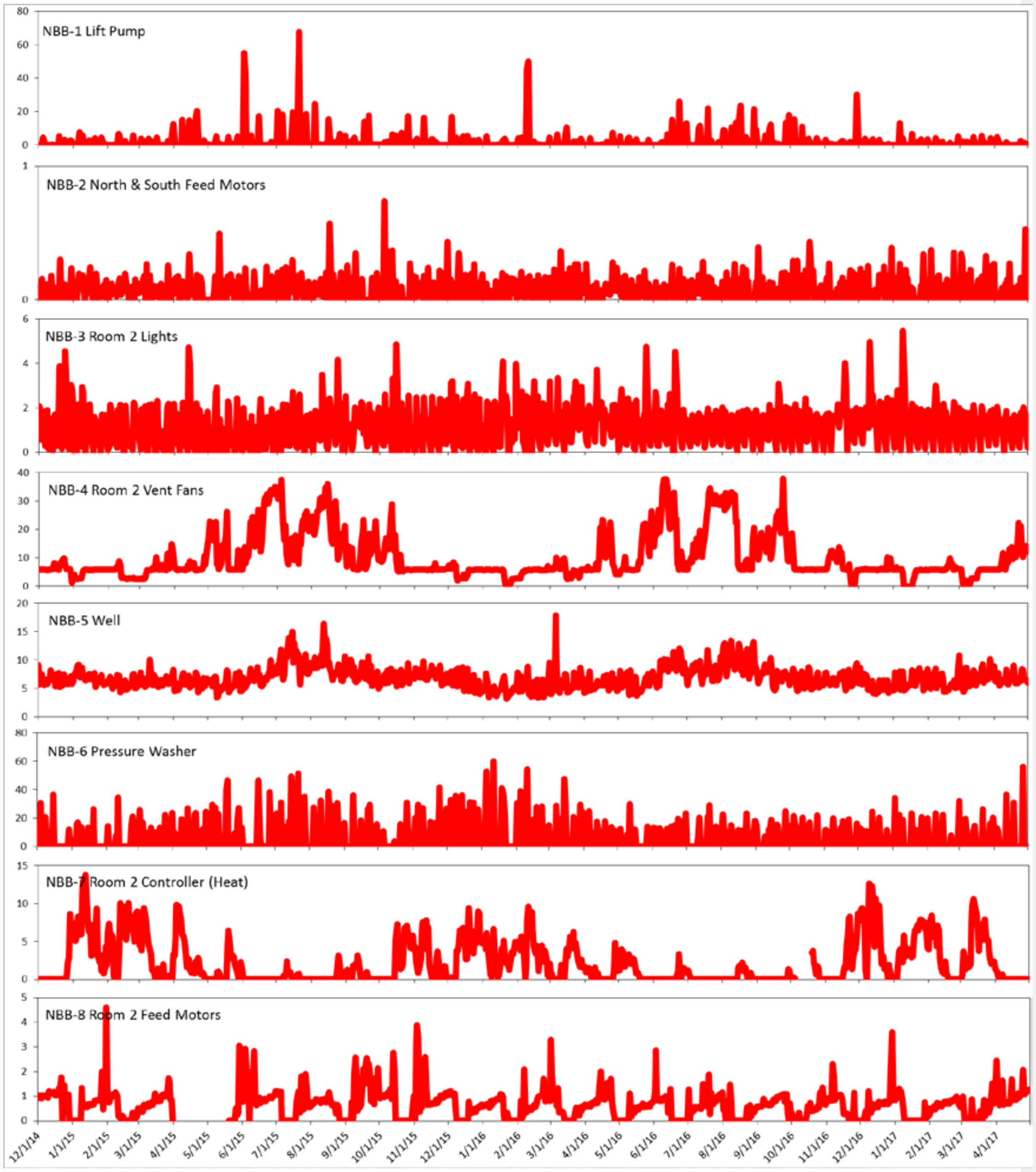
Nursery Barn B (NBB)				
Load Description	**Location of Load**	**Sensor Size (AMPS)**	**Sensor ID**	**Data Logger ID**
Lift Pump	Whole Facility	50	NBB-1	NBB-D1
North & South Feed Motors	Whole Facility	50	NBB-2	
Room 2 Lights	Nursery Room 2	10	NBB-3	
Room 2 Vent Fans	Nursery Room 2	50	NBB-4	
Well	Whole Facility	20	NBB-5	NBB-D2
Pressure Washer	Whole Facility	50	NBB-6	
Room 2 Controller (Heat)	Nursery Room 2	50	NBB-7	
Room 2 Feed Motors	Nursery Room 2	50	NBB-8	
Generator Room	Generator	20	NBB-9	NBB-D3
*Outside Lights	Office	20	NBB-10	
*Panel 1 Electric Feed	Office	250	NBB-10	
*Clothes Dryer	Office	50	NBB-11	
*Panel 1 Electric Feed	Office	250	NBB-11	
Medicine Refrigerator	Office	50	NBB-12	
Room 9 Fans	Nursery Room 9	100	NBB-13	NBB-D4
Room 9 Feed Motors	Nursery Room 9	100	NBB-14	
Room 9 & 10 Basket Fans	Nursery Rooms 9 & 10	100	NBB-15	
Room 9 Lights	Nursery Room 9	100	NBB-16	
Room 9 Controller/ Acuator/ Heat/ Water Solenoid	Nursery Room 9	25	NBB-17	NBB-D5
Electric Hallway Heat by Rooms 9 & 10	Hallway	50	NBB-18	
Electric Hallway Heat in Entry	Office	20	NBB-19	
Unlabeled 60 AMP Circuit	Unknown	100	NBB-20	

A.4.2. Materials

- Five HOBO UX120-006M Data Loggers
- 1 CR Magnetic CR9580-10 amp sensor
- 4 CR Magnetic CR9580-20 amp sensors
- 6 CR Magnetic CR9580-50 amp sensors
- 1 DCT Magnelab 25 amp sensor
- 3 DCT Magnelab 50 amp sensors
- 4 DCT-0016-100 Magnelab 100 amp sensor
- 2 DCT-0024-250 Magnelab 250 amp sensors

- Five USB cables
- 19, 0 to 10V DC input adapter cables

A.4.3. Data logger and sensor information


NBB-1 Lift Pump
NBB-2 North & South Feed Motors
NBB-3 Room 2 Lights
NBB-4 Room 2 Vent Fans
NBB-5 Well
NBB-6 Pressure Washer
NBB-7 Room 2 Controller (Heat)
NBB-8 Room 2 Feed Motors
12/1/14
1/1/15
2/1/15
3/1/15
4/1/15
5/1/15
6/1/15
7/1/15
8/1/15
9/1/15
10/1/15
11/1/15
12/1/15
1/1/16
2/1/16
3/1/16
4/1/16
5/1/16
6/1/16
7/1/16
8/1/16
9/1/16
10/1/16
11/1/16
12/1/16
1/1/17
2/1/17
3/1/17
4/1/17

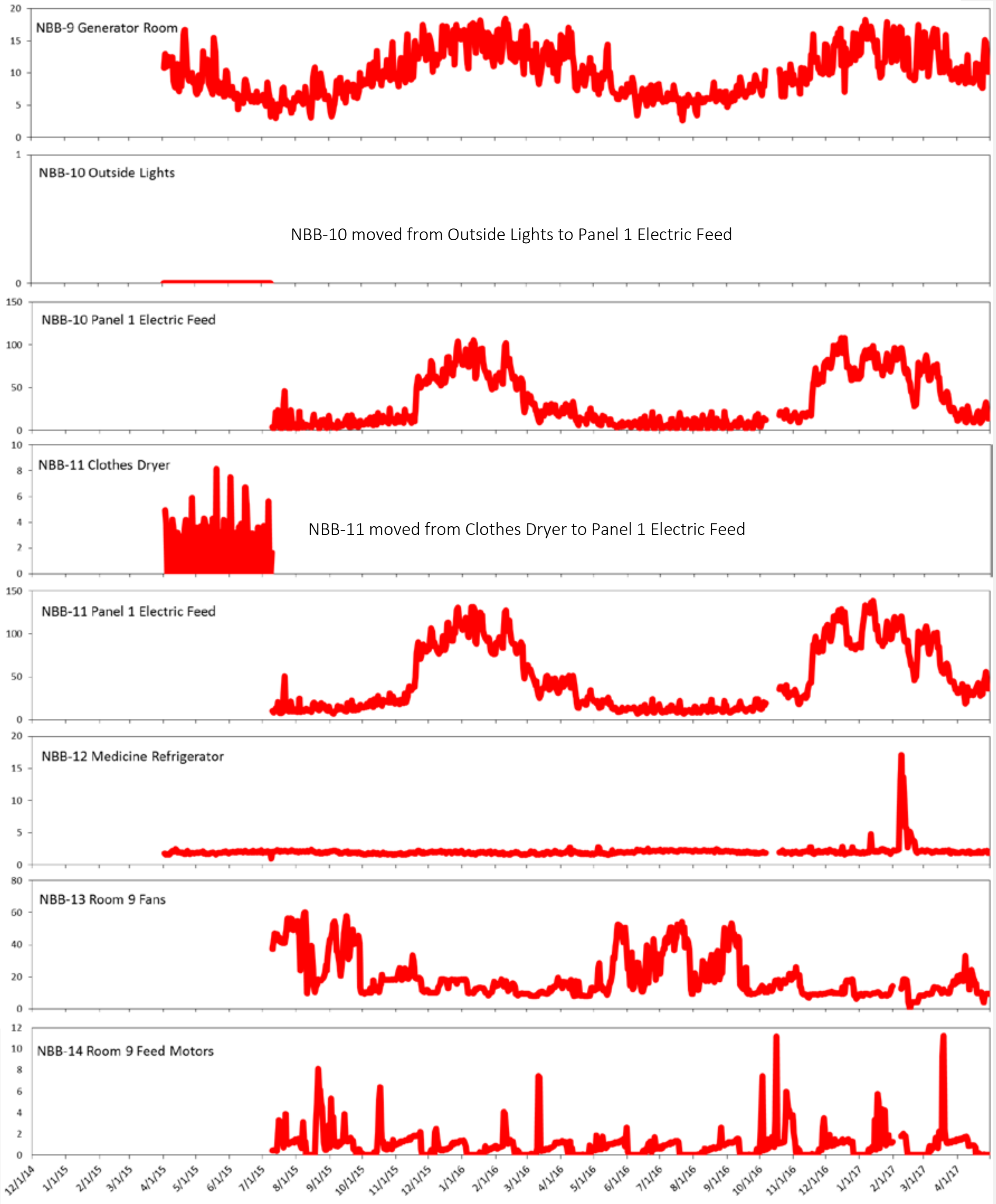

NBB-9 Generator Room
NBB-10 Outside Lights
NBB-10 moved from Outside Lights to Panel 1 Electric Feed
NBB-10 Panel 1 Electric Feed
NBB-11 Clothes Dryer
NBB-11 moved from Clothes Dryer to Panel 1 Electric Feed
NBB-11 Panel 1 Electric Feed
NBB-12 Medicine Refrigerator
NBB-13 Room 9 Fans
NBB-14 Room 9 Feed Motors
12/1/14
1/1/15
2/1/15
3/1/15
4/1/15
5/1/15
6/1/15
7/1/15
8/1/15
9/1/15
10/1/15
11/1/15
12/1/15
1/1/16
2/1/16
3/1/16
4/1/16
5/1/16
6/1/16
7/1/16
8/1/16
9/1/16
10/1/16
11/1/16
12/1/16
1/1/17
2/1/17
3/1/17
4/1/17

Figure A19. Timeline of sensors from beginning of installation to end. Gaps in data represent areas where data was lost due to battery issues or unplugged cables. All data is in kWh.

NBB consisted of ten total nursery rooms. Eight of the ten rooms were identical to each other, each having the same electrical loads and each having a capacity of 1,000 head. As the rooms were identical, it was determined that the data obtained from the room monitored by the data logger could be multiplied by the total number of identical rooms in the facility (eight) to compare monitored data to metered data. NBB also had an additional two nursery rooms that were differently sized than the other eight, but were identical to each other. These two rooms had a capacity of 1,200 head each. As these rooms were only identical to each other, the data obtained from one of the rooms was multiplied by two and the data was added to the rest of the data from the facility to compare to the metered data provided by Agralite Electric Cooperative.

NBB-D1- “Room 2” and misc. (installed 11/18/14):

- NBB-1- Lift pump
- NBB-2- North and south feed motors
- NBB-3- “Room 2” lights
  - The data from this sensor was multiplied by 10 up until 7/10/15, when monitoring began on the lights in “Room 9”. This was to account for the lights in rooms 9 and 10 that went unmeasured until 7/10/15. After 7/10/15, the data was multiplied by 8 (the number of rooms identical to “Room 2”).
- NBB-4- “Room 2” vent fans
  - The data from this sensor was multiplied by 10 up until 7/10/15, when monitoring began on the fans in Room 9. This was to account for the fans in Room 9 and 10 that went unmeasured until 7/10/15. After 7/10/15, the data was multiplied by 8 (the number of rooms identical to “Room 2”).

NBB-D2- “Room 2” and misc. (installed 11/18/14):

- NBB-5-Well
- NBB-6-Pressure washer
  - There were two pressure washers in this nursery, so it was programmed in the energy calculations to multiply this data by 2 to account for both pressure washers.
- NBB-7- Room 2 controller (heat)
  - This sensor was originally monitoring “Room 2” heat, however, it appeared that this circuit was not being used as current was never measured going to this circuit. Therefore, the sensor was moved on 12/18/15 to the “Room 2” controller, which was determined to be the circuit supplying power to the heater fans in this room.
  - The data from this sensor was multiplied by 10 up until 8/6/15, when monitoring began on the controller in “Room 9”. This was to account for the controller in rooms 9 and 10 that went unmeasured until 8/6/15. After 8/6/15, the data was multiplied by 8 (the number of rooms identical to “Room 2”).
- NBB-8- “Room 2” feed motors
  - This sensor came unplugged from the data logger on 4/1/15 and was plugged back in on 5/19/15.
  - The data from this sensor was multiplied by 10 up until 7/10/15, when monitoring began on the feed motors in “Room 9”. This was to account for the feed motors in rooms 9 and 10 that went unmeasured until 7/10/15. After 7/10/15, the data was multiplied by 8 (the number of rooms identical to “Room 2”).

NBB-D3- Miscellaneous (installed 4/1/15, reprogrammed 7/10/15):

- NBB-9- Generator Room
  - The generator room included loads such as lights and the generator block heater
- NBB-10- Outside lights until 7/9/15, then moved to “Panel 1 Feed” (office lights/AC/heat, hallway lights, hallway heat, hall feed motors)
  - This data logger was reprogrammed, as the sensor was switched from a 20 amp sensor to a 250 amp sensor
  - Sensors NBB-1, NBB-2, NBB-9, and NBB-12 were located within the “Panel 1 feed”. These loads were subtracted from the “Panel 1 Feed” to obtain separate usage data.
- NBB-11- Clothes dryer until 7/9/15, then moved to Panel 1 Feed (office lights/AC/heat, hallway lights, hallway heat, hall feed motors)

- Data logger was reprogrammed, as the sensor was switched out from a 20 amp sensor to a 250 amp sensor
  - Sensors NBB-1, NBB-2, NBB-9, and NBB-12 are located within the “Panel 1 feed”. These loads were subtracted out from the “Panel 1 Feed” to obtain separate usage data.
- NBB-12-Medicine refrigerator

NBB-D4- “Room 9” (installed 7/10/15):

- NBB-13- “Room 9” fans
  - This data was multiplied by 2 to account for “Room 10” fans.
- NBB-14- “Room 9” feed motors
  - This data was multiplied by 2 to account for “Room 10” feed motors.
- NBB-15-Rooms 9 and 10 stirring fans

- NBB-16-“Room 9” lights
  - This data was multiplied by 2 to account for “Room 10” lights.

NBB-D5- “Room 9” and misc. (installed 8/6/15):

- NBB-17- Room 9 controller/actuator/heat/H2O solenoid
  - This data was multiplied by 2 to account for “Room 10” loads.
- NBB-18- Electric heat in hallway near room 9 and 10

- NBB-19- Electric heat in entry hallway

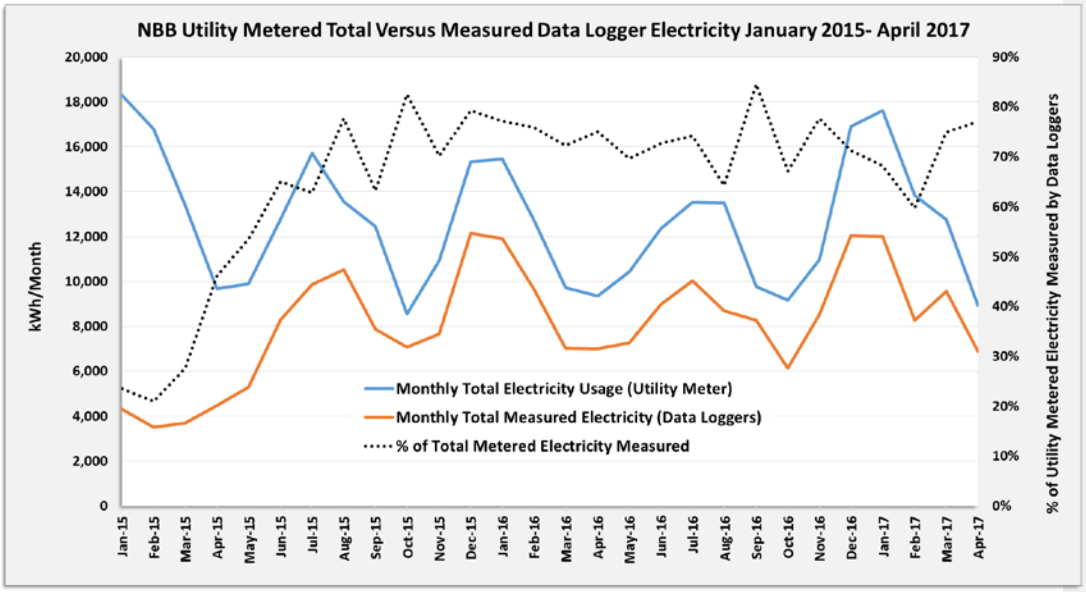


Figure A20. Total monthly electric usage of NBB as obtained from the facility’s electric bill, the total monthly amount of electric usage captured by installed data loggers and sensors, and the percent of electricity measured compared to the metered total. As additional data loggers were added to this facility, the percentage of electricity captured by loggers can be seen to increase.

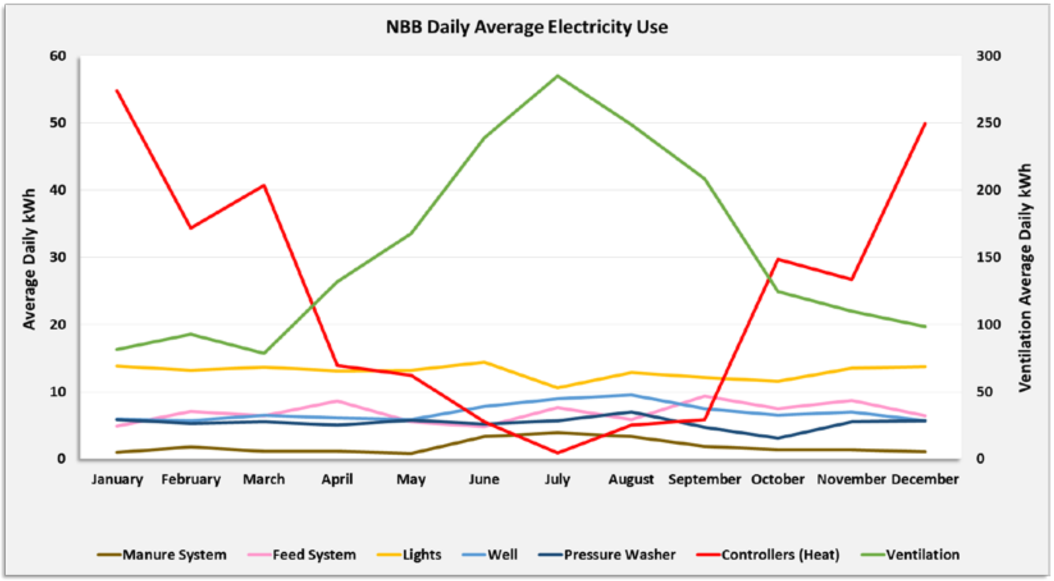


Figure A21. The monthly averages of daily energy use by various electrical loads measured at NBB from January 2015-March 2017.

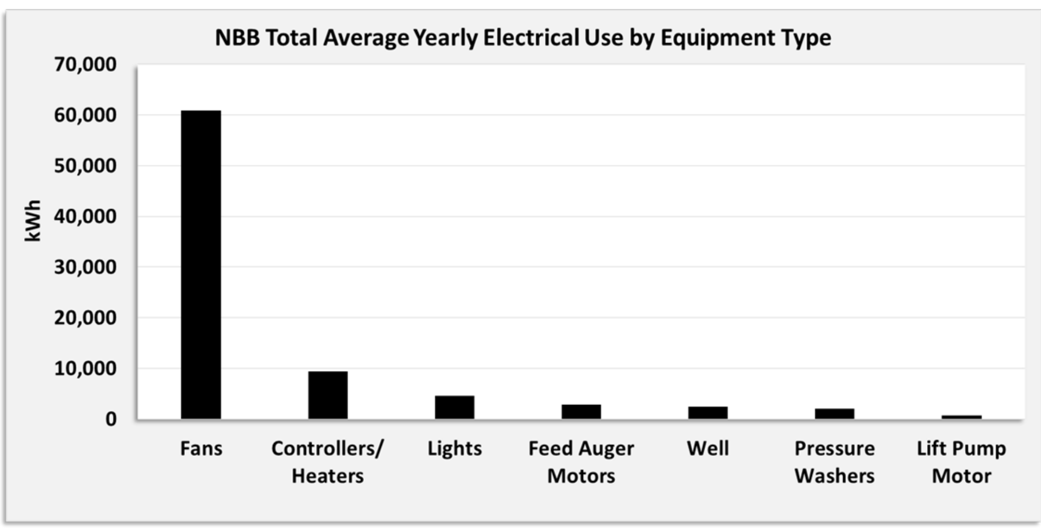


Figure A22. The average yearly electricity use (2015-2016) by equipment type in NBB.

Thermal Data

Propane Tank Fill History Reports recorded by the gas utility, Jerry's U-Save (Morris, MN), were collected from the producer and analyzed to represent monthly totals and yearly totals of propane used. Propane was used for both heating and pressure washing at Nursery Barn B. Diesel from Jerry's U-Save (Morris, MN) is also used at this nursery in an incinerator used for carcass disposal.

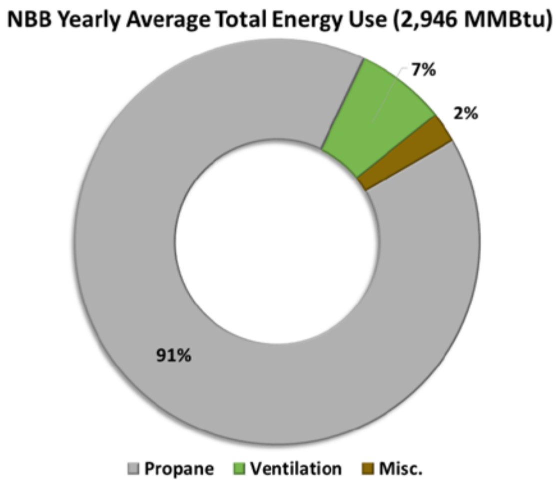


Figure A23. The total average energy use averaged across 2015 and 2016 and converted into MMBtu across several larger electrical loads and propane consumption in NBB. (1 kWh= 3412.14 btu, 1 therm= 91,600 btu)

A.5. Finishing Barn A (FBA):


N
West and East Finishing Rooms
FBA-D1, FBA-D2, & FBA-D3
Office/Load Out
Generator Shed

Researchers were required to remain out of contact with pigs from other sites for 48 hours and 2 showers before arrival. Researchers wore protective plastic boots into barn and made sure all equipment that was needed had at least 48 hours of downtime and was sanitized before arrival.

A.5.1. Electrical data

The electricity provider of Finishing Barn A, Agralite Electric Cooperative (Benson, MN), provided researchers with daily data taken from the meters. The metered data was compiled into monthly data and was then compared to the data collected from the installed sensors and data loggers to determine if an adequate amount of loads were being monitored.

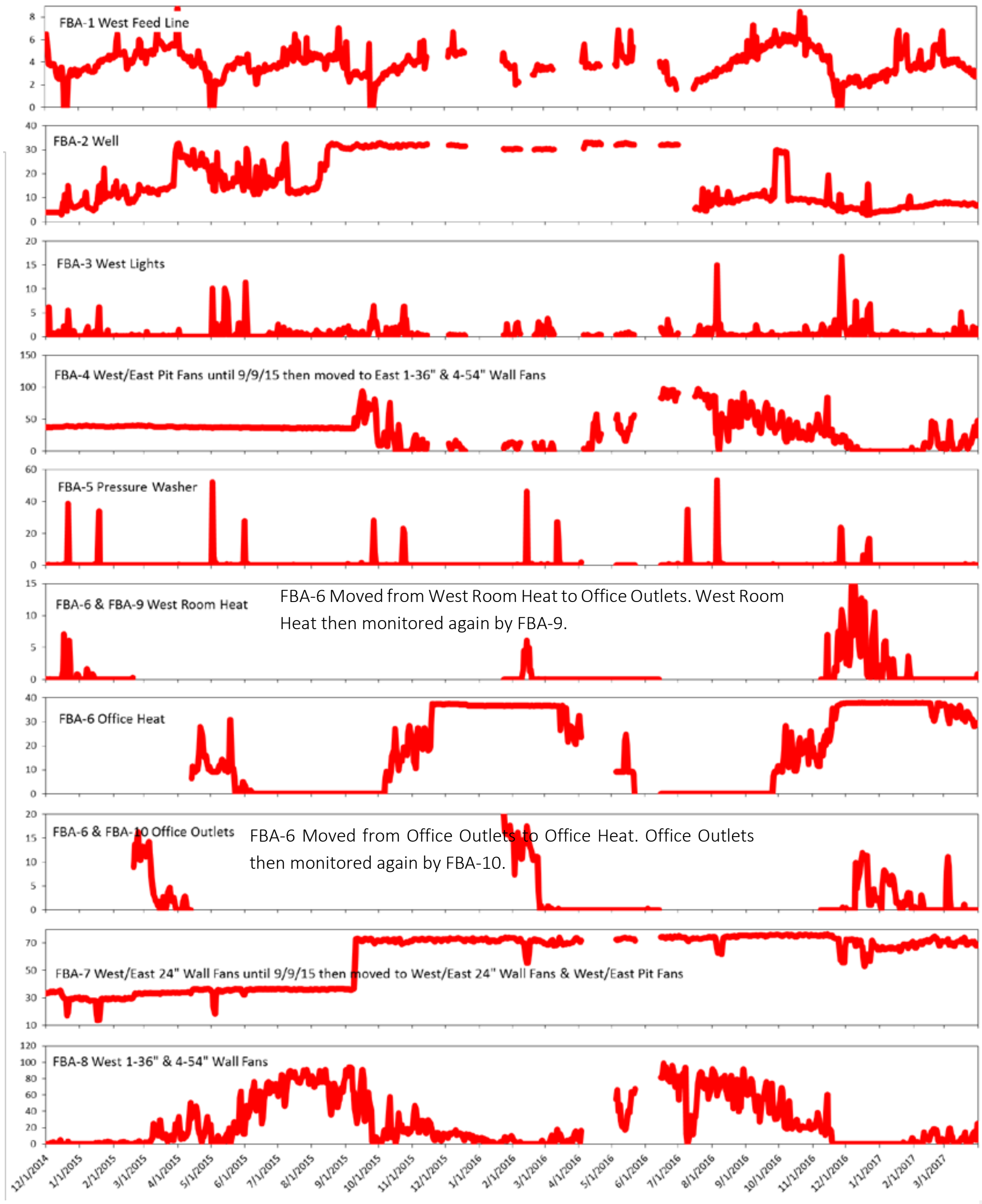
Table A5. Loads monitored, location of the load, size of the sensor monitoring the load, the sensor name and number, and the data logger ID. Loads that have been starred indicate that the sensor was moved from one load to a different load.

Finishing Barn A (FBA)				
Load Description	Location of Load	Sensor Size (AMPS)	Sensor ID	Data Logger ID
West Feed Augers	West Room	20	FBA-1	FBA-D1
Well	Whole Site	20	FBA-2	
West Lights	West Room	20	FBA-3	
*West/East Pit Fans	West/East Rooms	20	FBA-4	
*East 1-36" & 4-54" Wall Fans	East Room	20	FBA-4	
Pressure Washer	Whole Barn	50	FBA-5	FBA-D2
*West Heat	West Room	50	FBA-6	
*Office Outlets	Office	50	FBA-6	
*Office Heat	Office	50	FBA-6	
*West/East 24" Wall Fans	West/East Rooms	20	FBA-7	
*West/East 24" Wall Fans & West/East Pit Fans	West/East Rooms	20	FBA-7	
West 1-36" & 4-54" Wall Fans	West Room	50	FBA8	
West Heat	West Room	25	FBA-9	FBA-D3
Office Outlets	Office	50	FBA-10	
West Controller	West Room	25	FBA-11	
Water Heater	Office	100	FBA-12	

A.5.2. Materials

- Two HOBO UX120-006M Data Loggers
- Five CR Magnetic CR9580-20 amp sensors
- Three CR Magnetic CR9580-50 amp sensors
- Two USB cables
- 8 0 to 10V DC input adapter cables

A.5.3. Data logger and sensor information



FBA-1 West Feed Line
FBA-2 Well
FBA-3 West Lights
FBA-4 West/East Pit Fans until 9/9/15 then moved to East 1-36" & 4-54" Wall Fans
FBA-5 Pressure Washer
FBA-6 & FBA-9 West Room Heat
FBA-6 Moved from West Room Heat to Office Outlets. West Room Heat then monitored again by FBA-9.
FBA-6 Office Heat
FBA-6 & FBA-10 Office Outlets
FBA-6 Moved from Office Outlets to Office Heat. Office Outlets then monitored again by FBA-10.
FBA-7 West/East 24" Wall Fans until 9/9/15 then moved to West/East 24" Wall Fans & West/East Pit Fans
FBA-8 West 1-36" & 4-54" Wall Fans

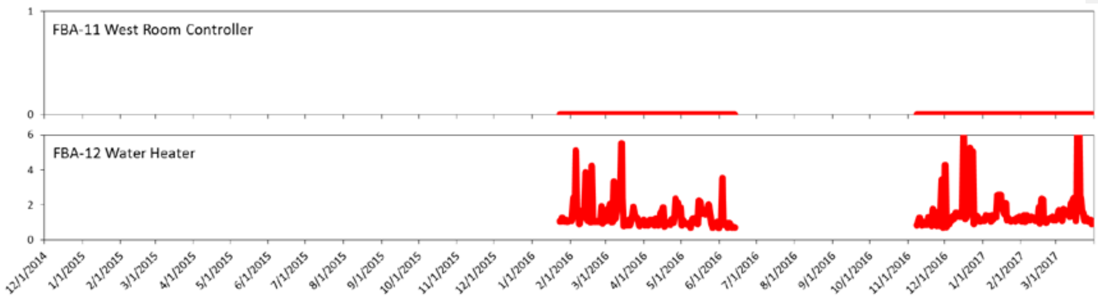


Figure A24. Timeline of sensors from beginning of installation to end. Gaps in data represent areas where data was lost due to battery issues or unplugged cables. All data is in kWh.

FBA consisted of two identical rooms, each having the same electrical loads and each having a capacity of 1,200 head. As the rooms were identical, it was determined that any data obtained from a single room could be multiplied by the total number of identical rooms in the facility (two) to compare monitored data to metered data provided by Agralite Electric Cooperative. However, in some cases, the same loads from each side of this barn were being monitored together, so not all loads are multiplied by two.

FBA-D1- West and east rooms (installed on 11/15/14):

During the following dates, FBA-D1 experienced battery issues and data was lost: from 11/15/15-12/3/15, 12/20/15-1/22/16, 2/8/16-2/19/16, 3/10/16-4/4/16, 4/22/16-5/4/16, 5/22/16-6/14/16, and from 7/1/16-7/15/16.

- FBA-1- West feed auger motors
    - This monthly total consumption was multiplied by 2 after the energy calculations have been run, as the east feed auger was not being monitored.
- FBA-2- Well
    - After the first data collection, it was observed that this sensor was not reading any current. The sensor was adjusted and fixed on 12/15/14. Therefore, data is missing from this load from 11/15/14 to 12/15/14.
- FBA-3- West lights
    - This load was multiplied by two in the energy calculations, as only two of four single phase circuits were being measured. After the energy calculations were run, the data was again multiplied by two to account for the "East Room".
- FBA-4- West and east pit fans until 9/9/15, then moved to east 1, 36" and 4, 54" vent fans

FBA-D2- West and east rooms (installed on 11/15/14):

During the following dates, FBA-D2 experienced battery issues and data was lost: from 4/4/16-5/4/16 and from 5/23/16-6/15/16. On 6/15/16, FBA-D2 was replaced with FBA-D3.

- FBA-5- Pressure washer
    - The pressure washer adapter cable came unplugged from the data logger between 2/19/15 to 3/13/15. Therefore, data in between these dates is missing. However, this was discussed with the producer, which decided that during these times, the pressure washer was most likely not used, and if it had been used, it would not significantly contribute to the monthly totals.

- FBA-6- “West Room” heat until 2/19/15, then moved to office outlets (1200W Duraflame heater) until 4/13/15, then moved to office heat (electric wall heat)
    - The sensor was first installed to monitor the “West Room” heat (the monthly total was then multiplied by two after the energy calculations had run to account for the use in the “East Room”).
    - On 2/19/15, the sensor was moved to “Office Outlets/Outside Office Outlets” to capture the use of the office Duraflame heater
    - On 4/13/15, the sensor was then moved to “Office Heat” which is electrical heat for the office. The power factor was changed to 1 and the phase became a two phase circuit.
- FBA-7- West and east 24” wall fans until 9/9/15 then added additional west and east pit fans to the sensor

- FBA-8- West 1 36” and 4 54” vent fans
    - The data from this sensor was multiplied by two after the energy calculations to account for the east vent fans up until 9/9/15, when monitoring began on the east vent fans as well.

FBA-D3- Miscellaneous (installed on 1/22/16):

This data logger was moved to replace FBA-D1 on 7/15/16. So, data from this logger is missing from 7/15/16 until a new data logger was installed on 11/7/16.

- FBA-9- West heater
- FBA-10- Office outlets
- FBA-11- West controller
- FBA-12- Water heater

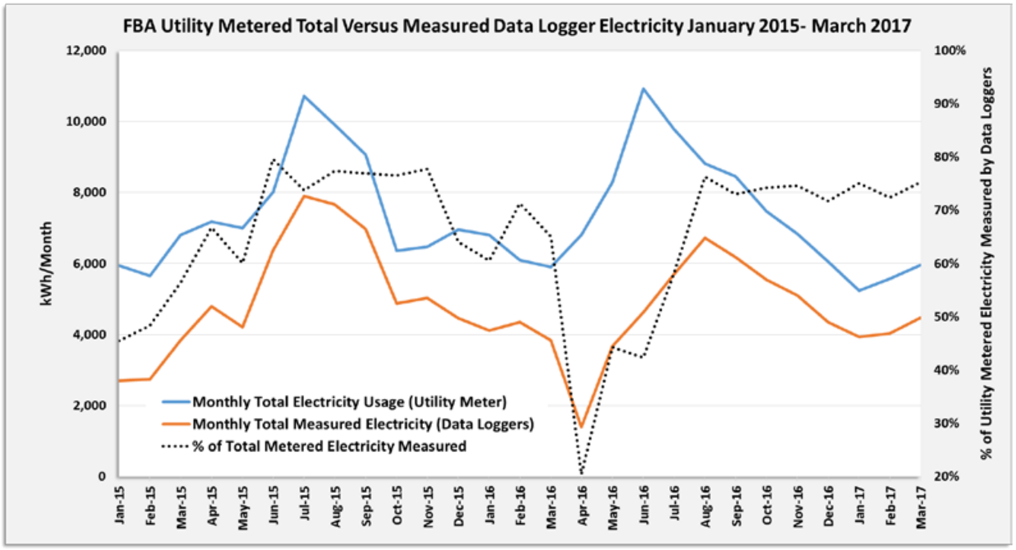


Figure A25. Total monthly electric usage of FBA as obtained from the facility’s electric bill, the total monthly amount of electric usage captured by installed data loggers and sensors, and the percent of electricity measured compared to the metered total.

From December 2015 to June 2016, FBA-D1 and FBA-D2 both had issues resulting in a loss of data.

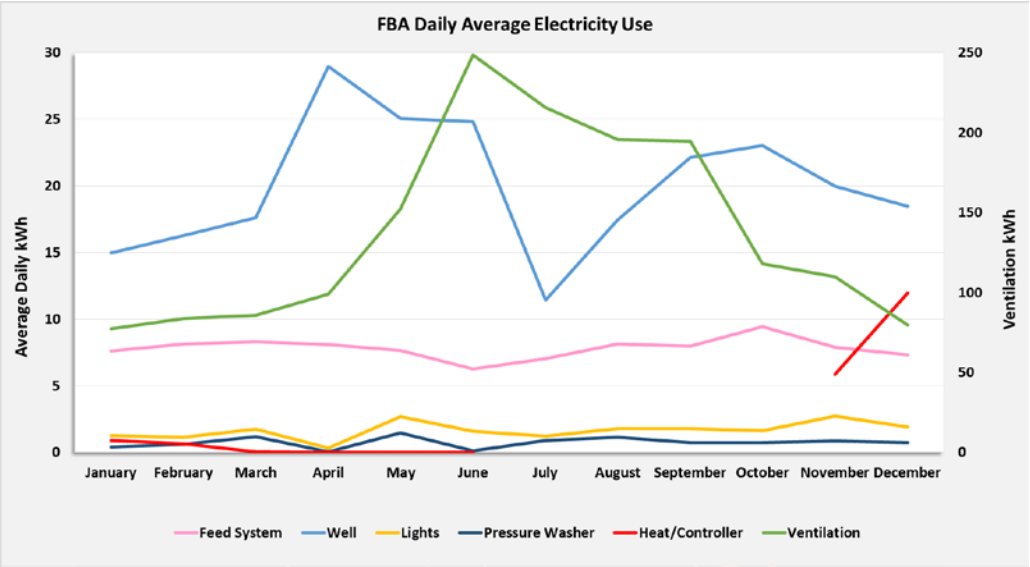


Figure A26. The monthly averages of daily energy use by various electrical loads measured at FBA from January 2015 to March 2017. It should be noted that there were data logger battery issues during both years that resulted in some data lost for "Heat/Controller" from July to October. The data that was available is reflected in this figure and no missing data was estimated.

As was expected, the ventilation loads were high in the summer, with heating loads increasing during the winter. One thing to be noted was that from May 2015 to October 2016, there was a herd of cattle drinking from the same well as the pigs. There was no way to partition off separate use for the pigs versus the cattle.

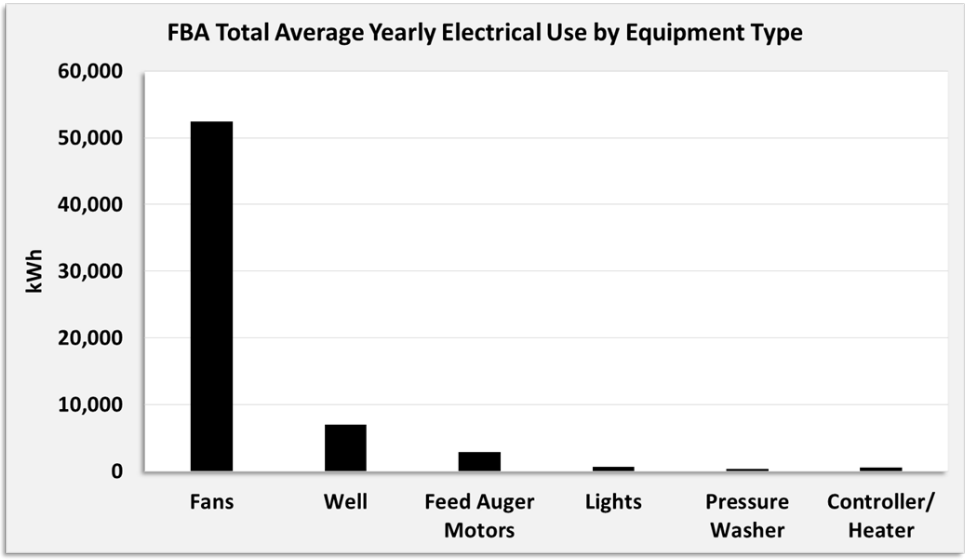


Figure A27. The average yearly electricity use (2015-2016) by equipment type in FBA.

Thermal Data

Propane Tank Fill History Reports obtained from the gas utility, Fauskee Oil Company Incorporated (Brooten, MN), were collected and analyzed to represent monthly totals and yearly totals of propane used. Propane was used for both heating and pressure washing with hot water at Finishing Barn A.

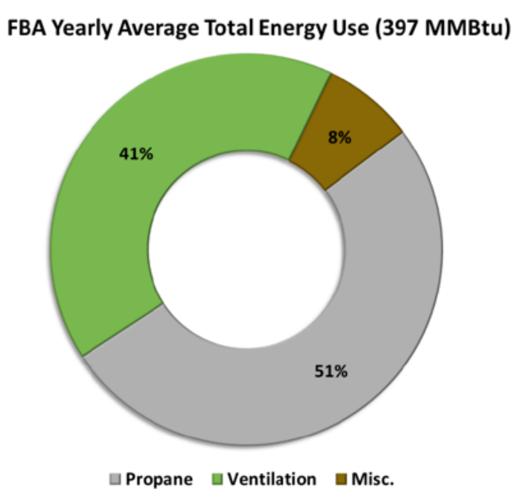


Figure A28. The total average energy use averaged across 2015 and 2016 and converted into MMBtu across several larger electrical loads and propane consumption in FBA. (1 kWh= 3412.14 btu, 1 therm= 91,600 btu)

A.6. Finishing Barn B (FBB):

FBB Biosecurity

Researchers were required to remain out of contact with pigs from other sites for 48 hours and 2 showers before arrival. Researchers wore protective plastic boots and stepped into a mat containing a disinfectant powder making sure to thoroughly powder the protective boots before entering the facility. All equipment that was needed had at least 48 hours downtime and was sanitized before arrival.

A.6.1. Electrical data

The electricity provider of Finishing Barn B, Agralite Electric Cooperative (Benson, MN), provided researchers with daily data taken from the meters. The metered data was compiled into monthly data and was then compared to the data collected from the installed sensors and data loggers to determine if an adequate amount of loads were being monitored.

Table A6. Loads monitored, location of the load, size of the sensor monitoring the load, the sensor name and number, and the data logger ID. Loads that have been starred indicate that the sensor was moved from one load to a different load.

Finishing Barn B (FBB)				
Load Description	**Location of Load**	**Sensor Size (AMPS)**	**Sensor ID**	**Data Logger ID**
Pressure Washer	Whole Barn	50	FBB-1	FBB-D1
East Lights/Heaters	East Room	20	FBB-2	
East Receptacles and Curtain	East Room	50	FBB-3	
East Fans/Pit Fans	East Room	20	FBB-4	
East Feed Auger	East Room	20	FBB-5	FBB-D2
West Fans	West Room	50	FBB-6	
*Electric Hall Heat	Hallway	20	FBB-7	
*West Feed Augers	West Room	20	FBB-7	
West Pit Fans	West Room	20	FBB-8	

A.6.2. Materials

- Two HOBO UX120-006M Data Loggers
- Five CR Magnetic CR9580-20 amp sensors
- Three CR Magnetic CR9580-50 amp sensors
- Two USB cables
- Eight 0 to 10V DC input adapter cables

A.6.3. Data logger and sensor information

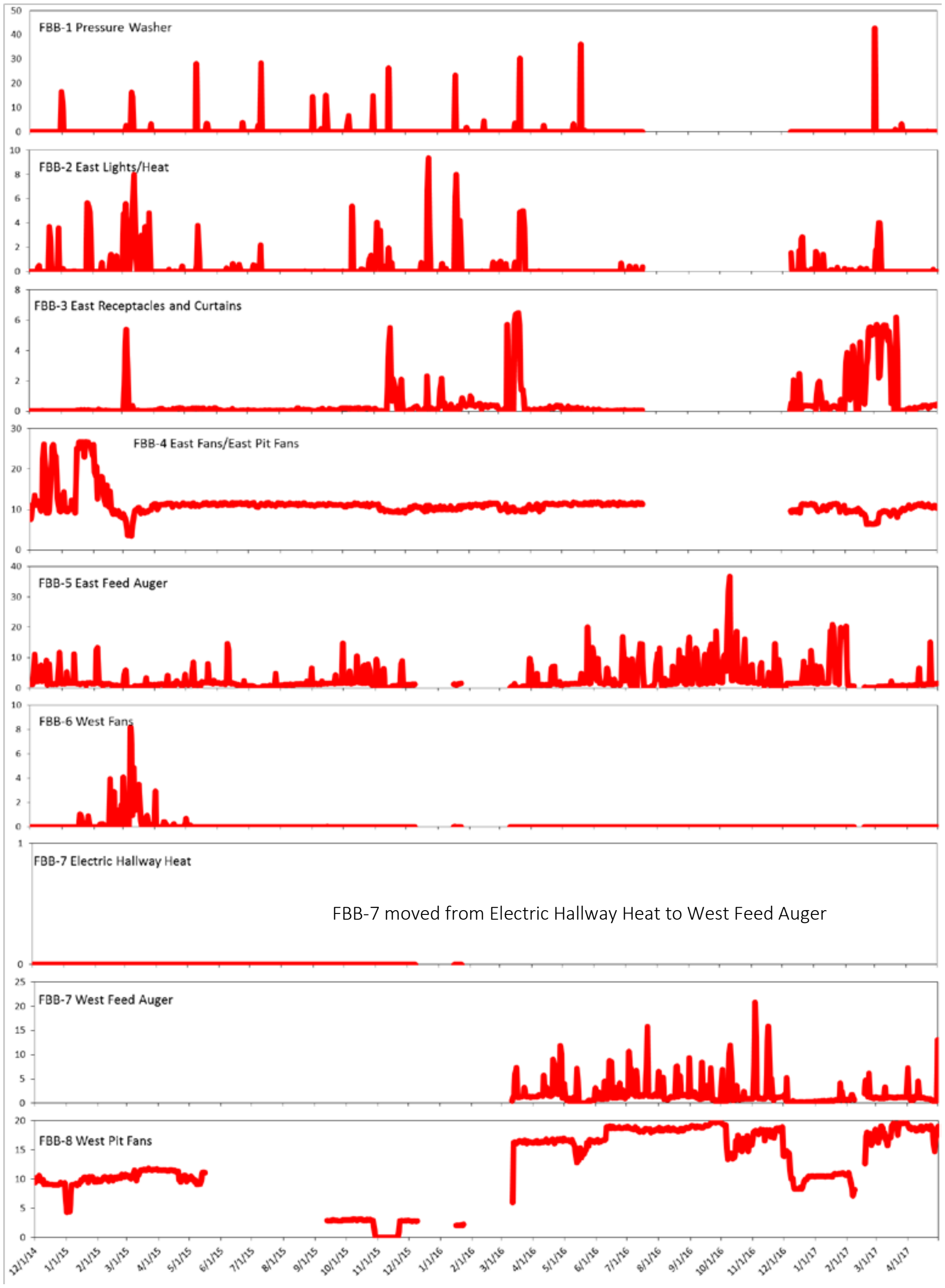


Figure A29. Timeline of sensors from beginning of installation to end. Gaps in data represent areas where data was lost due to battery issues or unplugged cables. All data is in kWh.

FBB consists of two identical rooms, each having the same electrical loads and each having a capacity of 530 head. As the rooms were identical, it was determined that the data obtained from the room monitored by the data logger could be multiplied by the total number of identical rooms in the facility (two) to compare monitored data to metered data provided by Agralite Electric Cooperative. However, in some cases, the same loads from each side of this barn were being monitored, so not all loads are multiplied by two.

From July of 2016 to April 2017, researchers were unable to access this barn. During the time of inaccessibility, both FBB-D1 and FBB-D2 experienced battery issues, and data was lost.

FBB-D1- (installed 11/15/14):

During the following dates, FBB-D1 experienced battery issues and data was lost: from 7/19/16-12/31/16.

- FBB-1- Pressure washer
- FBB-2- East lights and heaters
  - This circuit fed both the lights and heaters in the "East Room"
  - The data was multiplied by two after the energy calculations were run to account for the use of the west lights and heaters.
- FBB-3- East receptacles and curtain
  - The data was multiplied by two after the energy calculations were run to account for the use of the west receptacles and curtain.
- FBB-4- East basket and pit fans

FBB-D2- (installed 11/15/14):

During the following dates, FBB-D2 experienced battery issues and data was lost: from 12/10/15- 1/14/16 and 1/24/16-3/10/16. A new data logger was installed on 3/11/16 to replace the faulty FBB-D2.

- FBB-5- East feed auger
  - Although the west feed auger was not monitored until 2/5/16, the east feed auger was not multiplied by two, as this auger had a tendency to become hung up and would run for an excessive amount of time. It was therefore not representative to multiply this load by two.
- FBB-6- West basket fans
  - On approximately 5/6/15, FBB was equipped with a new controller. After the controller was installed, the producer had not been able to get the west basket fans to run.
- FBB-7- Hall electric heat
  - This load was monitored from 11/15/14-2/5/16. As this load used no electricity between those monitoring dates, the sensor was moved over to the west feed auger on 2/5/16.
- FBB-7- West feed auger (on 2/5/16)
- FBB-8- West pit fans
  - On 5/17/15, the pit fan on the circuit being monitored blew its motor. As this circuit was a two phase circuit, the sensor was simply moved to the other pit fan on the circuit on 9/11/15. After the sensor was moved, the phase in the calculations was changed to 1.
  - On 3/8/16, the other pit fan on this circuit was fixed, and the phase in the calculations was changed back to 4.

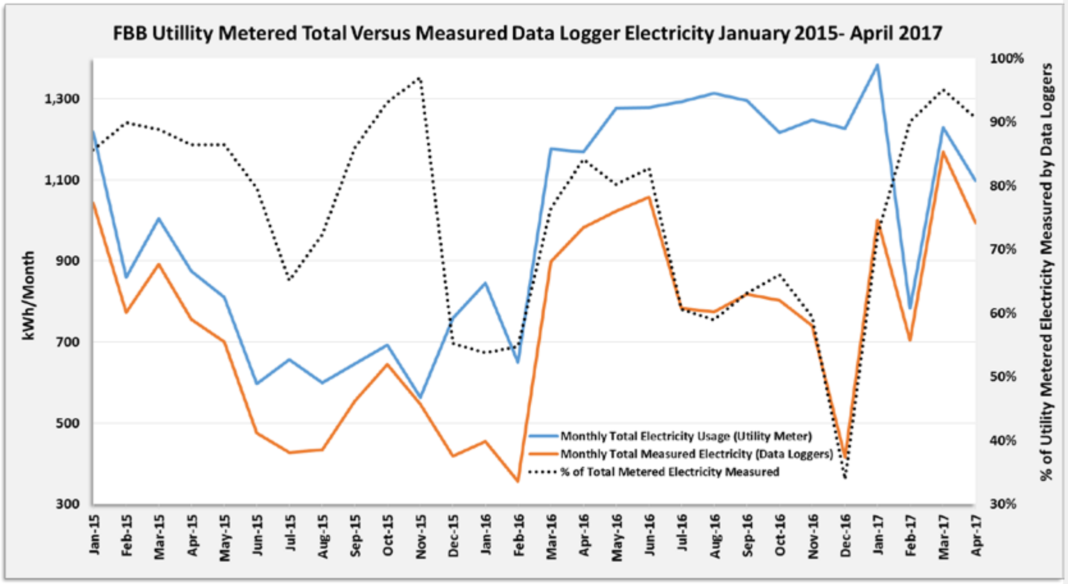


Figure A30. Total monthly electric usage of FBB as obtained from the facility's electric bill, the total monthly amount of electric usage captured by installed data loggers and sensors, and the percent of electricity measured compared to the metered total.

During the winter of 2015-2016, both data loggers began to have issues with their batteries resulting in a significant loss of data which is reflected above. From July 2016 to December 2016, researchers were unable to access the facility. When data was then collected in December 2016, one of the data loggers had experienced battery issues and had died. The data from this logger was unable to be recovered resulting in a loss of data from July 2016 to December 2016.

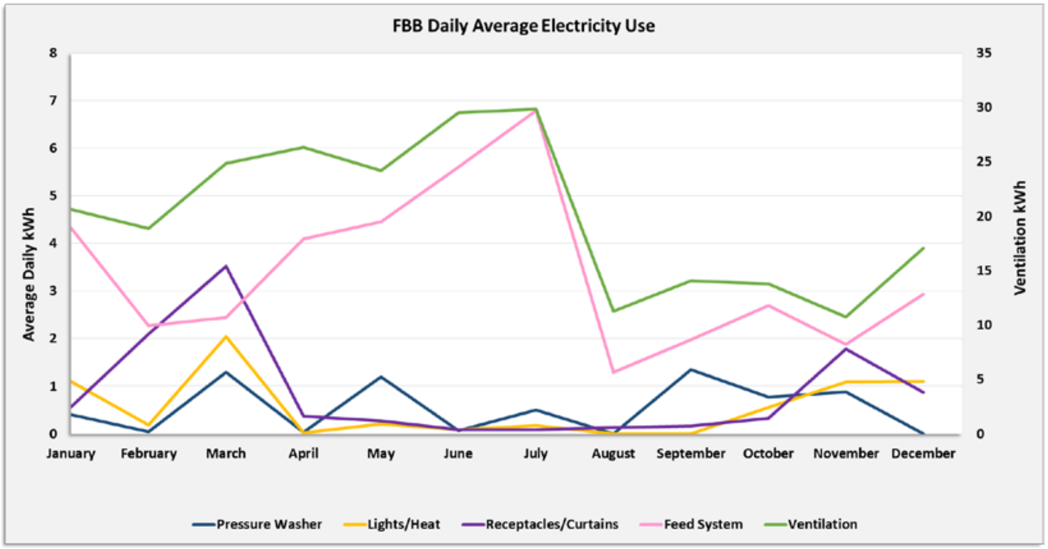


Figure A31. The monthly averages of daily energy use by various electrical loads measured at FBB from January 2015-March 2017. It should be noted that there were data logger battery issues during both years that resulted in some data lost for “Feed System” in January and from August to November and from “Ventilation” from August to November. The data that was available is reflected in this figure and no missing data is estimated.

As can be seen in this figure, the pressure washer is used only during some months pigs left the building and cleaning was required. Lighting use also reflected the transition of pigs out of the building and pressure washer use. During September 2015, one of the pit fans being monitored blew its motor as can be seen in the sharp reduction of the ventilation load.

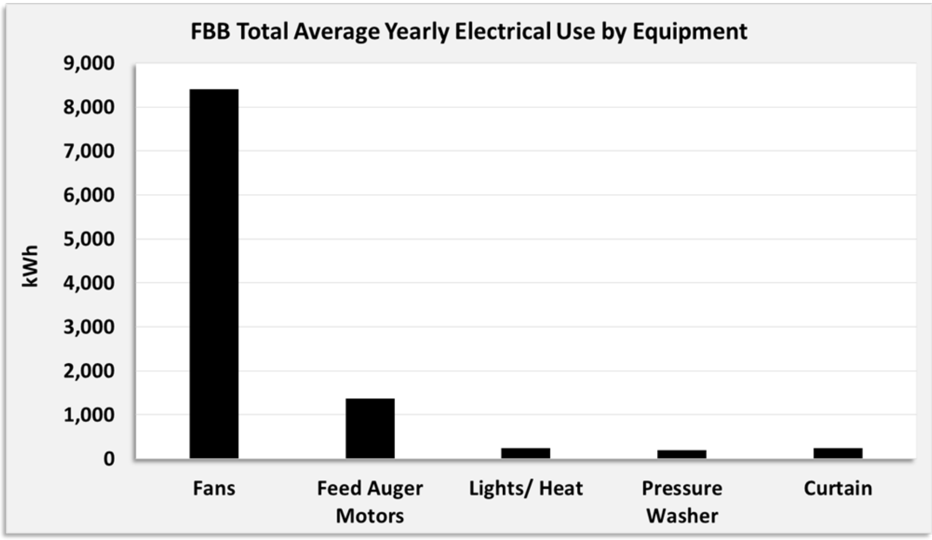


Figure A32. The average yearly electricity use (2015-2016) by equipment type in FBB.

A.6.4. Thermal Data

At Finishing Barn B, propane was used for heating, and diesel was used for pressure washing. Propane Tank Fill History Reports obtained from the gas utility, Jerry's U-Save (Morris, MN), were collected and analyzed to represent monthly totals and yearly totals of propane used. The producer kept no records of diesel used for pressure washing, as a diesel tank is kept on site and provides fuel for various farm equipment. The producer estimated that 75 gallons of diesel per year are used for pressure washing at Finishing FBB.

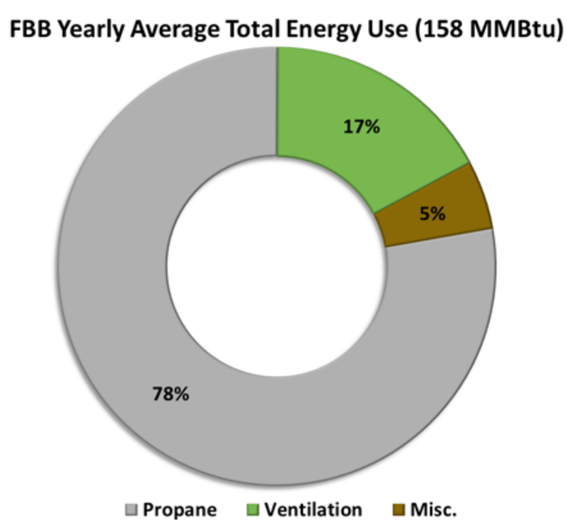


Figure A33. The total average energy use averaged across 2015 and 2016 and converted into MMBtu across several larger electrical loads and propane consumption in FBB. (1 kWh= 3412.14 btu, 1 therm= 91,600 btu)

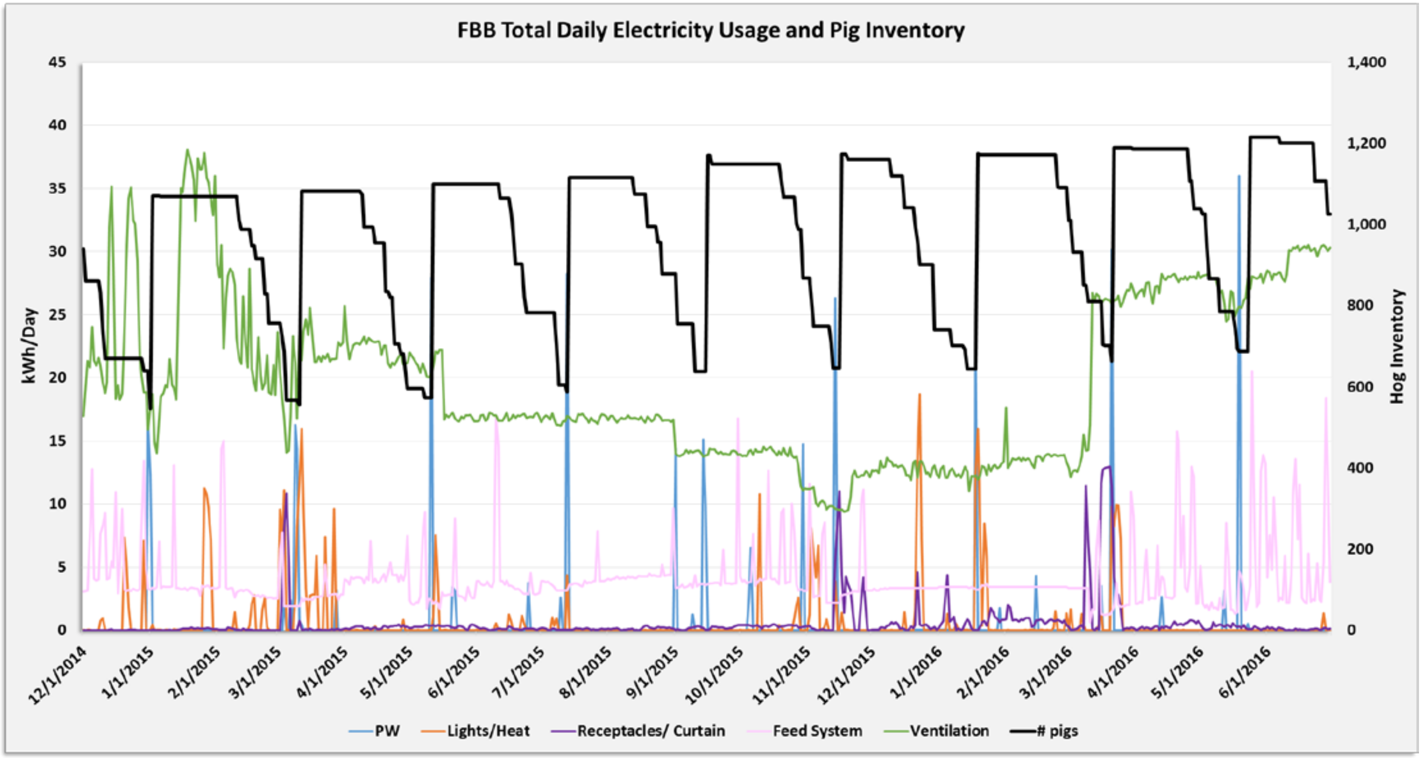


Figure A34. The total daily electricity used and pig inventory in FBB.

Return on Investment for Energy Conservation Measures in Swine Production Systems

Justin Miller

West Central Research and Outreach

Center August 11, 2016

Contents

1 Literature Review

1.1 Swine Production Overview

Swine production is one of the largest livestock industries in the world. Forty percent of the meat produced worldwide comes from the swine industry (Stone et al. 2011). The United States is one of the highest producing and the second most consuming country of pork in the world (Schaffer et al.). In March of 2016, the U.S. swine industry was reported to contain 67.6 million head of pigs (United States Department of Agriculture et al. 2016). Swine production systems raise these pigs from when they are born until they are ready to be taken to market to be processed for meat.

Three of the most common types of swine operations are Farrow to Finish, Farrow to Feeder, and Feeder to Finish (Kephart et al. 2001). A three-site Farrow to Finish production is the most common. Farrow to Finish involves three main steps of production: farrowing, feeder/nursery, and finishing. In farrowing, sows are brought in to give birth to a litter of pigs. The sow is usually put in the farrowing barn one week before giving birth. She and her litter typically stay in the barn another three weeks for a total occupancy of four weeks. At the end of the four weeks, the piglets are around 10-15 pounds and are moved to the feeder/nursery stage. There is usually a three-day window in between each cycle in the farrowing barn to allow for cleaning of the pens. During the feeder/nursery step in production, the pigs are grown for six weeks until they are around 50-60 pounds. Then the pigs are moved to the finishing stage where they stay in the finishing barn for around three and a half months. The pigs are then sent off to market after they reach somewhere between 250-300 pounds. In between each group of finishing pigs, there is typically a one-week gap before the next group comes in.

According to Kephart et al. (2001), Farrow to Finish operations tend to have the largest labor and capital costs, but also can have the largest potential in the swine market. A Farrow to Feeder operation involves the same first steps as Farrow to Finish but eliminates the finishing stage. Once the piglets reach 50-60 pounds, they are sold to swine operations that do finishing. Farrow to Feeder operations have a lot less capital and feed expenses compared to Farrow to Finish, but the market for feeder pigs is not always very stable (Kephart et al. 2001). Feeder to Finish are the operations that buy feeder pigs from other swine operations. The pigs come in at 30-60 pounds and are raised until they are ready to be sent to market. This operation type tends to have the lowest labor expenses among the three options (Kephart et al. 2001).

Most of the U.S. swine industry is concentrated in large production farms, a trend that has taken place over the last twenty years. Schaffer et al. discuss how small swine farms have been stopping production while larger swine farms are taking over the market. In the 1950's there were approximately three million swine farms, but by 2002 only 79,000 swine farms were in operation, which is a trend that has continued to today. Additionally, the total number of pigs in production on average per year did not significantly fall, leading to more pigs being produced in smaller areas (Schaffer et al.). While larger and more concentrated production can lead to increased production and efficiency, there are problems that can result, as is the case of the swine industry. Many of these problems end up being negative environmental externalities. Most of these externalities are due to some form of pollution in the swine industry.

1.2 Environmental Effects of the Swine Industry

Two major forms of negative environmental externalities that occur due to swine production systems are water pollution and air pollution. Both of these primarily result from manure and waste in swine production. Since today's industry has about the same amount of pigs as in past years, but concentrated on fewer farms, all the manure from those pigs tends to be gathered in smaller areas and in larger quantities. Much of this is a result of Concentrated Animal Feeding Operations (CAFOs), which are industrialized livestock operations that group large amounts of animals in smaller places in order to produce greater numbers of output. Having greater amounts of manure in smaller places also leaves less room for error in manure handling practices. However, many in the general public, especially those living near these operations, argue that CAFOs in the swine industry pose significant risks to health, quality of life, property value, and local economies (Schaffer et al.). Osterberg and Wallinga (2004) discuss how water and air pollution occur from manure in swine production. One way that water pollution to occurs is when microbes create nitrate from breaking down the nitrogen contained in manure. Normal groundwater nitrate levels then increase when manure is assimilated into wells and streams. These increased nitrate levels can produce diseases when groundwater is ingested by humans, some of which can be fatal. Microbes in manure can enter the groundwater and lead to diseases as well (Osterberg and Wallinga 2004). For air pollution, Osterberg and Wallinga (2004) state that decomposing manure creates "dust particles, bacteria, endotoxins, hundreds of volatile organic compounds including hydrogen sulfide and ammonia, and odors" that all can create health problems.

1.3 Energy Usage

Another major negative environmental externality resulting from swine farms becoming larger is energy usage. One of the biggest uses of energy in the swine industry is in feed production (Thoma et al. 2011). However, this use of energy does not occur in the swine operations themselves but is used to grow and process the feed for the pigs. Within the swine production process itself there is still a lot of energy being used. The West Central Research and Outreach Center (WCROC) swine production system, which is much smaller than the largest commercial swine operations, has a projected annual usage of around 1500 million Btu of energy. In comparison, the U.S. Energy Information Administration (2013) reported that an average U.S. household uses around 90 million Btu of energy annually.

While the amount of money spent on electrical and fuel energy in swine production only accounts for around 3-5% of total production costs, the amount of energy used is substantially higher than what residential houses are using (Kephart et al. 2001). Where there is major energy usage, there is always the conversation about making that energy use more efficient or "greener". Government organizations and the local populations put pressure on energy-using industries to lower their energy usage or be more environmentally friendly, such as the swine production industry. With swine production, there is the discussion of what does the "carbon footprint" of the swine industry exactly look like? A report by Thoma et al. on the "National Life Cycle Carbon Footprint Study for Production of US Swine" (2011) states that the average carbon footprint for a pig in U.S. swine production is 2.87 lb. CO2e per lb. live weight. If an average pig is around 270 lbs., then this equates to 775 lb. CO2e per pig. If a 5000 head farrow to finish operation is used as an example, the carbon footprint of the operation would be around 3,875,000 lb. CO2e per year. While this is a huge number, the initial value of 2.87 lb. CO2e per lb. live weight takes into account all steps of the pork cycle including pig production, processing, retail, consumption, and packaging. The actual pig production process only accounts for 62% of the carbon footprint. Within the portion of the carbon footprint from the pig production process, only about 3% is due to fuel and electricity. This means that electricity and fuel energy use from swine production only puts out about 72,075 lb. CO2e per year. Manure, feed, and piglets account for the other 97% of the pig production process' carbon footprint (Thoma et al. 2011). Another factor to consider is that electricity from the grid and fossil fuels are non-renewable resources. This means that at some point in the future, these sources of energy and the way they are produced will run out.

1.4 Becoming Greener

Even though energy from electricity and fuel use account for a small percentage of the carbon footprint from swine production, it is still important to look at how to make energy use more efficient and better for the environment. Although the carbon emissions in electricity and fuel usage for pig production are much less than in feed production, Robert Chambers notes in "Energy Management" (2011) at the London Swine Conference that swine producers are already taking measures to properly allocate feed usage based on needs of the pigs. He proposes the argument that swine producers should do the same for energy usage and find ways to produce energy savings. Chambers lists all the areas where energy is concentrated in swine production as being "electrical loads, ventilation fan motors, lighting, heating such as creep heaters, and feed motors, pumps and other miscellaneous loads." According to Chambers, the biggest area out of these energy uses is ventilation. Harry Huffman, in "Ventilation Management" (2011) at the

London Swine Conference, discusses how air quality is one of the most important performance factors affecting pig production. Air quality is largely dependent on ventilation and temperature management. If ventilation and temperature control are not managed properly, energy can be wasted and excessively used. An example is that over ventilating during winter months not only uses more electricity for airflow than needed but also will end up using more heating energy to counter the over ventilation (Huffman 2011). This means that properly managing energy use in areas such as heating and ventilation not only will make swine production more efficient and better for the environment, but could also increase pig performance. Many studies and analyses have been done on ways to save energy in swine production to be more environmentally friendly, more efficient, increase pig performance, and lower energy costs.

1.5 Studies on Alternative Energy Usage/Management in Swine Production

1.5.1 *Energy Management- Robert Chambers (2011)*

Chambers looks at how swine producers can better manage energy usage in different areas of swine production. First he discusses how energy can be managed in ventilation. Chambers states that producers should pay close attention to design, sizing, and make of fans. He also remarks that they should be properly maintained and set to an efficient set point. An example is given of changing set points from 22.2-20.0 degrees Celsius (72.0-68.0 degrees Fahrenheit) to 21.1-14.4 degrees Celsius (70.0-57.9 degrees Fahrenheit) which can save 56-60% of heating energy needed.

Lighting was also an area that Chambers found possible energy savings in. Using compact fluorescent lighting instead of incandescent bulbs can cut electricity usage by 75%, and using T8 fixtures can cut down the electricity usage again by 40%. Chambers also presents the idea of using heat mats instead of heat lamps for farrowing. According to his data, this could reduce electrical usage by 66%.

Other things that Chambers notes are making sure buildings have proper levels of insulation to minimize heat loss, planting tree windbreaks to reduce heating loads, using solar walls to help with heating, and using heat exchangers to precondition the air entering barns. Chambers finishes by stating that all of these energy management measures could lower energy costs for swine producers by 75% or more.

1.5.2 *Ventilation Management- Harry Huffman (2011)*

Huffman focuses on ventilation in swine production. His main argument is that ventilation systems must not over ventilate or waste feed energy, heat energy, and electrical energy. Huffman's reasons for heat waste in current swine barns are that stage 1 fans tend to be oversized, minimum fan speeds can be set too high, heater shut-off set points are usually too high, and heaters could be oversized. In order to counter these causes of heat waste, Huffman maintains to have two fans at lower speed instead of one at high speed for stage 1 ventilation, don't let stage 2 fans run before stage 1 is at full power, and always use newer, more efficient fans when possible. Along with these suggestions are maintenance and management ideas. Huffman states to keep fans and temperature sensors clean, check heating units yearly or more, insulate and cover fans in winter, and ascertain that buildings are well insulated. Huffman believes energy can be saved and pig performance can be improved by measuring air quality regularly and using set points appropriate for each type and size of pig.

1.5.3 *Energy and Ventilation Management Issues in U.S. Pig Buildings- Larry Jacobson (2011)*

Jacobson discusses many different ways to reduce energy usage in traditional swine production barns. Some ventilation ideas he presents are keeping up with fan maintenance, using larger fans, using minimum ventilation fans that will not over ventilate, and to use proper temperature set points. An interesting thing to note is that Jacobson argues smaller fans are less efficient than larger fans. The optimal temperatures he uses are 85-75 degrees Fahrenheit (F) for 12-30 lb. pigs, 75-70 degrees F for 30-75 lb. pigs, and 70-55 degrees F for 75-265 lb. pigs. Another thing Jacobson has found is that wind pressure is a factor that reduces efficiency in ventilation and can also cause under ventilation. He suggests using fan baffles and cones, having fans exhaust vertically through the ceiling and roof, and to have an east to west fan layout if in the Midwest. The east to west layout is an important factor because the common summer wind direction in the Midwest is south.

In order to save heating energy, Jacobson has found that many farms have over sized heaters which should be replaced by more efficient and appropriately sized heaters. The temperature that a heater comes on should be at least 2 degrees F below the set point to help with ventilation efficiency. Jacobson also suggests using radiant heaters that heat surfaces instead of air, which will cut energy usage in half. He goes on to say that proper insulation is an important component of efficient heating. Average poorly insulated barns have an R value of 1, but by increasing the R value to 2, 5, or 10 the swine producers could see fuel savings of 30%, 50%, and 65% respectively.

Finally, Jacobson provides many different guidelines for saving energy plus ventilation management for curtain sided and tunnel ventilated barns. Some of these include using bubble wrap to insulate curtains, moving pit fans to side or end walls, pumping manure twice a year, and using the fewest number of exhaust fans possible. For curtain sided barns he suggests increasing the ventilation capacity so that the ventilation season can be extended longer in fall and spring to save gas usage for heating. Jacobson also suggests using sprinklers, evaporative cooling pads, and misting of air for additional cooling.

1.5.4 *Reducing the Environmental Footprint of Pig Finishing Barns- Jacobson et al. (2011)*

Jacobson et al. propose the idea of creating a new "Greener Pig Barn" (GPB). They state that this idea is in response to demand for the swine industry to decrease the environmental effects of swine production. The goal of the GPB is to produce "greener" designs, along with management techniques, to reduce fossil fuel and energy use. Another goal is to reduce air emissions such as greenhouse gases and odors. For this study the group modeled four different GPB designs. All four have shallow gutters, mechanical scrapers, and an in-ground, covered, concrete manure storage tank. The major differences are the type of flooring, cooling systems, and heating systems.

Each design was assigned a letter: A, B, C, and D. Design A had partially slatted flooring, a ground source heat pump for heating and cooling, and evaporative cooling pads. Design B also had partially slatted flooring but with a complete geothermal exchange system for heating and cooling. Design B included a boiler using fin tubes to provide additional heating. Design C utilized a fully slatted floor with evaporative cooling pads and direct fire heaters for extra heat. Design D also used fully slatted floors and direct fire heaters but had a geothermal cooling system and some infrared radiant heaters for young pigs.

Jacobson et al. then calculated how the electrical energy use, fuel use, and air emissions would be affected for each proposed design. All GPB designs resulted in decreases in air emissions. Designs B and D both had decreases in electrical energy and fuel use. Design A had an increase in electrical energy and decrease in fuel use. Design C saw almost no change in electrical energy and fuel use. Jacobson et al. determined that the costs to design their GPBs would be 1.3 to 2 times higher than normal swine barns, but average daily gain would increase 3-7% and feed consumption per pound of pork produced would decrease 5-10%. Those factors plus the calculation that each design has the potential decrease electricity usage, fuel usage, and/or air emissions should be enough to offset the increased costs. The increase in profit per pig from the GPB designs ranged from $1.22-$4.45 and the payback periods ranged from 6-12.8 years. The group also noted that if increased production costs cannot be recovered from increased performance, then consumers would have to be willing to spend more on pork to purchase pork from swine production systems that are more environmentally friendly.

1.5.5 *Field Performance Evaluation of a Ventilation System: A Swine Case Study- Harmon et al. (2012)*

Harmon et al. set out to develop a procedure for evaluating swine ventilation systems. They also discussed common problems in swine buildings and wanted to provide lessons to help educate swine producers. For their study, a finishing building was evaluated in Iowa that held 2,000 pigs. The ventilation system was fully evaluated with measured parameters of temperature, relative humidity, air speed, static pressure, gas concentrations, and voltage. Some concluding suggestions they made were that minimum ventilation fan speed should be increased as animal size increases, stops should not be used on inlets, and a temperature curve should be used to adjust the set point as the pigs grow. Harmon et al. also stated that fans should be staged with smaller steps during colder weather and larger steps during warmer weather.

1.5.6 *Effects of reduced nocturnal temperature on pig performance and energy consumption in swine nursery rooms- Johnston et al. (2013)*

Reduced nocturnal temperature (RNT) studies in swine production had previously been done in the 1980s and 1990s, but swine producers had not reacted to those studies by implementing the method in their production systems. Johnston et al. decided to conduct a new reduced nocturnal temperature study on pig performance and energy use in swine nurseries. They wanted to see how the RNT method would perform in today's facilities with the pigs in production now compared to those in the 1980s and 1990s. Two different studies were conducted in facilities from various universities in the Midwest. The first study was conducted at the University of Minnesota, University of Missouri, University of Nebraska, and South Dakota State University. However, there were issues with data from South Dakota State University, so their data was not used in the first study.

Pigs at each university were randomly put in two identical rooms at ages 16-22 days old. One room was a control room that started at around 86 degrees F for the first week and then decreased by 3.6 degrees each week for the rest of the study. The other room was the RNT room which had the same schedule as the control room except that each night after the first week, from 7 p.m. to 7 a.m., the temperature was lowered by about 10.8 degrees F. To achieve this temperature setback at night, the ventilation was not increased. Instead heating was reduced and the room was allowed to cool down to the desired temperature. The pigs were allowed access to feed and water as they pleased. The study was conducted for 35 days in Nebraska and 42 days in the other states. A second similar study was then conducted by the University of Minnesota, University of Missouri, The Ohio State University, and South Dakota State University. This study followed the same methods as the previous study, but the RNT room used the original temperature only for the first 4 days before the nighttime temperature, from 7 p.m. to 7 a.m., was reduced by around 14.9 degrees F. This study lasted from around 28-42 days depending on the university.

Johnston et al. hypothesized that an RNT method of swine production would lower the amount of energy used and would not negatively affect pig performance. Their hypothesis seems to be correct in this study that an RNT regimen would not lower pig performance. The group had looked at energy usage along with average daily gain, average daily feed intake, gain to feed ratio, and final pig body weight. All these pig performance measures were the same in both the control and RNT groups. The heating fuel use was reduced by 30% and the electrical use saw a decrease by 20%. The conclusion of the studies was that using RNT schedules in swine nurseries reduces energy and does not negatively affect pig performance. This leads to reduced costs of production and a reduced carbon footprint. With savings found in the nursery barns using a reduced nocturnal temperature regimen, there is a possibility for RNT to be applied in other barns to produce energy savings.

1.6 Return on Investment

All of these previous studies show that there is definite potential for energy savings in swine production and making swine production "greener". Saving energy and being "greener" is better for the environment, but is it better for producers? Financial feasibility is a main factor that needs to be considered when changing the way swine producers manage their production systems. For retrofits or implementations that require initial upfront costs, a projected Return on Investment (ROI) is needed for the producers to implement these ideas. Steve Cotter (2014) states that an ROI analysis is used as a comparison between the expenses or initial costs and the revenue or benefits of a business type decision. Cotter writes there are three general approaches for an ROI to be used. The first approach is to choose among options and determine how to distribute resources that are in high demand. The second is for evaluating and studying different ideas or decisions and the third is as a way of obtaining quantitative evidence to support whatever is being considered for implementation. According to Cotter, the ROI calculation equation is economic gains minus investment costs all divided by investment costs. This calculation results in a percentage value used to measure the ROI. He then goes on to describe two major steps to calculating the ROI. The first step is to design the ROI calculation. This involves finding out what the decision being evaluated will affect, the time line for the decision to be performed or enacted, and figuring out what baseline to compare the decision to. The second step is to actually calculate the ROI by using the calculation equation. The values in the equation will have to be calculated and estimated where needed.

An ROI analysis generally can be pretty simple and easy to communicate to others. However, some of the problems with an ROI are that it does not account for the time value of money or risk of decisions, tends to over value investments by overlooking costs down the road, and can be inconsistent because an

ROI can be evaluated in many different ways (Cotter 2014). To counteract some of these problems, Cotter suggests using the ROI analysis along with net present value, internal rate of return, and payback period for the decision or implementation being evaluated. Net present value is defined as the current value of cash at the necessary interest rate in respect to the initial costs of making a decision or implementation (Gallo 2014). The internal rate of return is the interest rate from the new present value needed to make the net present value equal zero, based on the initial costs and yearly returns of the project (Gallo 2016 "A Refresher on Internal Rate of Return"). The amount of time needed to fully cover the initial costs of a decision or project is the payback period and can be calculated by dividing the total initial costs by the returns per year (Gallo 2016 "A Refresher on Payback Method"). By using the basic calculation along with these other methods, a Return on Investment analysis should be a strong indicator of the economic feasibility for any project and determine how worthwhile that project is for whoever is implementing it.

1.7 Conclusion

With U.S. swine production being concentrated in larger farms than ever before, energy use for large swine production systems has become a significant expense. The high levels of energy use have put pressure on agricultural industries, such as swine production, to become more environmentally friendly and reduce emissions. There are many measures that swine production systems can implement to reduce and optimize energy usage that have been studied and tested by experts. These measures may reduce and optimize energy use, but do they save money and cut energy expenses? Energy conservation measures need to be analyzed from a financial perspective to determine if they should be implemented. Some metrics that can be used for a financial analysis of energy conservation investments are return on investment, net present value, payback period, and internal rate of return. If an energy conservation measure produces a positive result in both optimizing energy use and the financial analysis, then it is something that a swine production system can feasibly consider implementing.

1.8 References

AKF Group LLC. 2016. "Swine Barn Energy Modeling Narrative." Unpublished report commissioned by the University of Minnesota West Central Research and Outreach Center.

Chambers, Robert. 2011. "Energy Management." *London Swine Conference-Exploring the Future.* 109-111.

Cotter, Steve. 2014. "Return on Investment." *EMS World. Expanded Academic ASAP.*

Gallo, Amy. 2014. "A Refresher on Net Present Value." *Harvard Business Review.* https://hbr.org/2014/11/a-refresher-on-net-present-value.

Gallo, Amy. 2016. "A Refresher on Internal Rate of Return." *Harvard Business Review.* https://hbr.org/2016/03/a-refresher-on-internal-rate-of-return.

Gallo, Amy. 2016. "A Refresher on Payback Method." *Harvard Business Review.* https://hbr.org/2016/04/a-refresher-on-payback-method.

Harmon, Jay D., Michael C. Brumm, Larry D. Jacobson, Stephen H. Pohl, and David R. Stender. 2012. "Field Performance Evaluation of a Ventilation System: A Swine Case Study." Digital Repository @ Iowa State University.

Huffman, Harry. 2011. "Ventilation Management." *London Swine Conference-Exploring the Future.* 113-116.

Jacobson, L. D., D. R. Schmidt, W. F. Lazarus, and R. Koehler. 2011. "Reducing the Environmental Footprint of Pig Finishing Barns." 2011 ASABE Annual International Meeting.

Jacobson, Larry D. 2011. "Energy and Ventilation Management Issues in U.S. Pig buildings." *London Swine Conference-Exploring the Future.* 117-123.

Johnston, L. J., M. C. Brumm, S. J. Moeller, S. Pohl, M. C. Shannon, and R. C. Thaler. 2013. "Effects of reduced nocturnal temperature on pig performance and energy consumption in swine nursery rooms." American Society of Animal Science. http://www.journalofanimalscience.org/content/91/7/3429.

Kephart, Kenneth B., George L. Greaser, Jayson K. Harper, and H. Louis Moore. 2001. "Agricultural Alternatives: Swine Production." The Pennsylvania State University Agricultural Research and Cooperative Extension.

Osterberg, David, and David Wallinga. 2004. "Addressing Externalities from Swine Production to Reduce Public Health and Environmental Impacts." Iowa Research Online. American Journal of Public Health. 94:1703-1708.

Schaffer, Harwood D., Pracha Koonnathamdee, and Daryll E. Ray. "Economics of Industrial Farm Animal Production." Pew Commission on Industrial Farm Animal Production.

Stone, James J., Christopher R. Dollarhide, Jennifer L. Benning, C. Gregg Carlson, and David E. Clay. 2011. "The life cycle impacts of feed for modern grow-finish Northern Great Plains US swine production." *Agricultural Systems.* 106:1-10. doi:10.1016/j.agsy.2011.11.002.

Thoma, Greg, Darin Nutter, Richar Ulrich, Charles Maxwell, Jason Frank, and Cashion East. 2011. "National Life Cycle Carbon Footprint Study for Production of US Swine." *Porkcdn.s3.amazonaws.com.* https://porkcdn.s3.amazonaws.com/sites/all/files/documents/NPB%20Scan%20Final%20-%20May%202011.pdf

U.S. Energy Information Administration. 2013. "Newer U.S. homes are 30% larger but consume about as much energy as older homes." http://www.eia.gov/todayinenergy/detail.cfm?id=9951&src=%E2%80%B9%20Consumption%20%20%20%20%20Residential%20Energy%20Consumption%20Survey%20(RECS)-b3.

United States Department of Agriculture, National Agricultural Statistics Service, and Agricultural Statistics Board. 2016. "Quarterly Hogs and Pigs." http://usda.mannlib.cornell.edu/usda/current/HogsPigs/HogsPigs-03-25-2016.pdf.

2 Materials and Methods

2.1 Swine Barn Energy Modeling Narrative- AKF Group LLC (2016)

In an unpublished report, AKF Group (AKF) analyzed the swine production system at the WCROC to model its energy use. The current systems at WCROC were modeled and evaluated and baseline energy usage was calculated. All data for the energy systems was provided by WCROC. AKF developed a list of various retrofits that WCROC could implement to lower its energy usage in swine production. These retrofits were analyzed and modeled by AKF to predict their effects on energy usage. The modeling software used by AKF was a program called eQUEST, version 3-64, and used an engine called DOE-2.2 which was developed by the United States Department of Energy. The program uses a calculation system that projects hourly energy usage for 8,760 hours per year. AKF's model projected energy usage based on typical commercial swine production schedule and occupancy.

AKF's model used maximum capacity numbers reported from WCROC for each of the three buildings. The farrowing barn used a maximum capacity of 32 sows and 32 litters of piglets. Each litter was estimated to be around 11 piglets. The nursery had 4 rooms that held 288 pigs each at maximum capacity and the finishing barn had 2 rooms holding a max of 216 pigs each. AKF also took into account the schedules of energy usage in areas such as heating, lighting, hot water, and ventilation based on data reported from WCROC. Weather was another factor in the model that was important to predict future heating and ventilation loads. The simulation model used a file called Typical Meteorological Year 3, which was published for Morris, MN by the National Renewable Energy Lab and National Climatic Data Center. This file predicts a typical weather pattern for a year by using an algorithm called The Sandia Method. For the buildings, AKF took into account building performance qualities such as thermal properties, R-value, and assembly U-value. These qualities were necessary for modeling heating and ventilation usage.

For baseline energy usage in the model, AKF looked at major sources of energy usage in the current swine production system at WCROC. For lighting, the farrowing and nursery barns used standard T12 fluorescent lighting while the Finishing barn used LED lighting. Miscellaneous equipment in the buildings that used electricity included feed augers, power washers, a clothes washer and dryer, and a medicine fridge. The existing heating, ventilation and air conditioning (HVAC) for each WCROC building was used for the model as well. The farrowing barn has three gas furnaces: one for the office in the building and two for the actual barn itself. There is no mechanical cooling in the building. Instead, fans are controlled based on temperature and pit fans are also used for ventilation. The piglets in the farrowing barn also need heat provided by heat lamps. The nursery and finishing buildings also have no mechanical cooling and use temperature controlled fans along with pit fans for ventilation and air quality control. Each building has gas fired heaters as well. Internal heat output from pigs housed in the barns was also used in the model.

2.2 WCROC Data Acquisition

Data collected for the initial basis of study comes from the West Central Research and Outreach Center, Morris, MN. The WCROC has a swine production system consisting of a farrowing barn, nursery barn, and a finishing barn. Energy usage in these barns is monitored and recorded. Heating fuel usage was recorded through the use of purchase orders. WCROC purchases natural gas from CenterPoint Energy. For electricity usage data in the barns, WCROC uses data loggers and sensors. CR Magnetic 20 and 50 Amp sensors are used to measure the current in the wires. The sensors are clipped on to the main circuit wires to monitor different loads of electricity. Each sensor is able to measure the current flowing through the wire by surrounding a cross section of the wire and measuring the magnetic field. This is possible because a flow of charges through a wire will always produce a magnetic field that is directly dependent on the magnitude of the current in the wire. The sensors then send the current data to data loggers. The data loggers are Campbell Scientific CR800s and have an attached Campbell Sci AM 16/32B Multiplexer. There is one data logger in each barn that records current data from the sensors every 10 minutes. This data is then sent to a computer to be organized so that WCROC can analyze their electricity usage. In total, WCROC collects data from 17 loads in the farrowing barn, 17 in the nursery, and 14 in the finishing barn. WCROC used this data from electricity, along with their natural gas data, to have AKF Group model their swine production energy usage.

2.3 Energy Conservation Measures

The baseline energy usage modeled from WCROC data was evaluated by AKF to determine Energy Conservation Measures (ECMs). These ECMs were then put through AKF's model using the same modeling software to produce predicted performance data. ECMs were only modeled in swine barns that made practical sense or were applicable to the WCROC production system.The ECMs are divided into three main areas of energy usage: lighting, ventilation, and heating and cooling. Two ECMs are for lighting in the swine barns. One of these is LED conversion. LED lights produce 50% more light using the same amount of power as fluorescent lighting. For example, in the WCROC nursery barn, this would cut the power used by the lights from 4,560 watts to 1,200 watts. LED lights also have a longer lifespan compared to fluorescent lights. LED lighting could be applied to any barn but was only applied in AKF's model to the WCROC nursery barn. The other lighting ECM is daylight harvesting. This idea proposes either implementing windows or using existing ones as a natural lighting source to lower the electricity load from other lighting sources.

Many ventilation ECMs were modeled, the first being a solar chimney. This idea uses solar energy from the sun to heat the chimney that creates a "stack effect drawing air out of the barn (AKF 2016)." AKF noted that fans would still be needed to provide enough airflow and ventilation during non-sunny times, but that this ECM should be able to offset around one third of the total fan energy. Another ventilation ECM modeled is implementing curtain sided barns. These would decrease the energy needed by fans, but AKF also noted that the heating demand will be greater. Also, curtain sided ventilation is not practical as a retrofit for an already constructed barn. Earth tube preconditioning was also modeled as a ventilation ECM. This ventilation method takes outside air and pulls it through underground ducts to precondition the air coming into the barns. Heat is absorbed underground in the winter by the air and released underground in the summer. According to AKF, using an earth tube would see an increase in fan energy used by about 2.5 times the baseline due to a pressure drop, but the ECM would cut heating energy usage by anywhere from 23 to 33%. AKF also suggested using variable speed fans as an ECM instead of single speed fans. This is because a variable speed fan can save about 7% of energy used at times when less than full fan speed is needed for ventilation. There are also two other ventilation ECMs that were initially modeled, exhaust air energy recovery and high volume, low speed, overhead fans, but AKF explained problems with each and why they are not the best ideas to implement in this situation.

The first heating and cooling ECM produced in AKF's model is a controller for the farrowing heat lamps. A controller would allow the heat lamps to turn on and off based on an ideal set point temperature for the piglets. This ECM should be able produce energy savings of around 40%. Night temperature setback is another heating ECM modeled. This ECM involves setting the temperature 15 degrees Fahrenheit lower from 7p.m. to 7 a.m. overnight in nursery and finishing barns. Depending on the type of barn, AKF believes this could produce energy savings from anywhere between 17 and 37%. AKF also proposes that barns use a traditional air conditioning system if they do not have any form of cooling other than fans and outside air. Using an air conditioning system should be able to save energy by limiting the usage of fans. However, in AKF's model, they found that this ECM ends up having relatively low energy savings. A similar ECM option was also modeled but instead of traditional air conditioning it was a geothermal heat exchange air conditioning system. This system expends heat to the ground during warm seasons and takes in heat from the ground in cold seasons by pumping a liquid mixture through underground loops of piping. The geothermal heat exchange air conditioning saves heating energy but results in an increase in electrical energy use. AKF Group also mentions a possible ECM of solar air heating, however this method ends up not being very feasible due to expensive installation costs and low efficiency. A water to water heat pump was another proposed ECM but AKF's modeling software could not provide an accurate direct model.

2.4 Return on Investment Calculation

This report takes the projected ECM data provided by AKF through their model to analyze the return on investment for each of the ECM's to determine if they are financially viable options. The data provided by AKF for the ECM's included baseline energy load for each barn, installation costs, electricity savings, natural gas savings, and propane savings. This data was used to put each ECM for each type of barn through a 25-year projection table. These projection tables took into account the data provided by AKF along with lifespans and maintenance costs for each. The only investment cost not found in data from AKF was for curtain sided barns. Instead, an average price was found for a barn curtain of $3 per foot and multiplied by the length of the WCROC finishing barn for two sides. This value was found by looking at barn curtain sales websites called FarmTek* (www.farmtek.com) and Celina Tent** (www.gettent.com). Maintenance costs were assumed to only be needed for the solar chimney, earth tube, traditional air conditioning, and geothermal heat exchange. The maintenance requirements for each are generally just inspections and regular cleaning. For each of these ECMs, a reasonable estimate of 500 dollars per year was used. The only ECMs that had a lifespan of less than 25 years that needed to be accounted for were LED lighting and curtain sided barns. LED lights are rated for an expected life of 50,000 hours (Electronics Weekly Staff 2009). If these lights are used, on average, for 8 hours per day then they would have a lifespan of around 17 years and would have to be replaced once during the 25-year period. The curtains on a curtain sided barn are expected to last around 5 to 10 years (Johnson et al. 2002). Consequently, the curtains would have to be replaced twice during the 25-year period.

The 25-year projection tables were divided into three groups based on swine barn type. Since a swine production operation would typically use either natural gas or propane, two projections were done for each ECM in each barn using each of the heating fuel options. All annual savings numbers and annual expenses were kept constant over the 25-year period. The electrical, natural gas, and propane savings were provided by AKF in units of kilowatt hours (kWh), therms, and gallons respectively. Natural gas prices are reported by the U.S. Energy Information Administration in units of dollars per thousand cubic feet, so data from AKF for natural gas was converted from therms to thousand cubic feet. Baseline energy loads were provided in million British Thermal Units (MMBTU). To find the new energy load from each ECM, all energy sources were also converted to MMBTU in the projection tables.

Energy prices were determined based on data from the U.S. Energy Information Administration (EIA). Electricity prices were reported in cents per kWh. Minnesota commercial monthly average retail electricity prices were analyzed from January 2001 to February 2016. A linear fit was observed for the electricity price data and an average annual percent increase was determined to be 3.35%. The average electricity price in 2015 of 9.5 cents per kWh was used in year 0 in the projection table with each consecutive year being 3.35% more than the previous.

$$P_Y = P_0 * (1 + I)^Y \tag{1}$$

Equation 1 shows the formula used to achieve this percentage increase where Y is the year, P_Y is the price at year Y, P_0 is the price at year 0, and $\boldsymbol{I}$ is the inflation rate (or average annual percent increase). Natural gas and propane prices were each determined using the same method as electricity prices. Natural gas pricing was reported by the EIA in dollars per thousand cubic feet. Monthly Minnesota commercial natural gas prices were analyzed from January 1989 to February 2016. The average annual percent increase in price was found to be 3.76%. The 2015 average natural gas price of $7.48 per thousand cubic feet was used as the initial price at year 0 in the projection table. The price data from the EIA for propane was reported in dollars per gallon on a weekly basis for Minnesota residential pricing from October 1, 1990 to March 28, 2016. The linear trend in the data showed an average annual percent increase in price of 4.56%. Average pricing calculated from purchases reported by commercial swine farmers to WCROC was $1.20 per gallon of propane and used as initial pricing for year 0 in the projection. Both natural gas and propane initial prices and inflation rates were used in equation 1 for the projection table.

Yearly cost savings in dollars were determined for each energy category in each ECM projection table by multiplying each energy savings value by its corresponding price. The dollar energy savings were added together along with maintenance costs subtracted out to calculate a net savings value for each year. The net savings were also discounted to show their value in present day dollars.

$$S_D = S_N/(1+R)^Y \tag{2}$$

Equation 2 shows the formula used to calculate the discounted value of net savings each year where S_D is discounted savings, S_N is net savings, R is the discount rate, and Y is the year. In this calculation, a discount rate of 3% was used. Most economic analyses use discount rates of 3-5% and the present rate for a 30-year U.S. Treasury Bond is around 3%.

The data from the 25-year projection tables were totaled to create values for the entire 25-year period. These totals were used to calculate the return on investment and other metrics for each ECM in each barn that they could be applied to and for each fuel type. First the total electricity cost savings, and natural gas/propane savings were added together, with total maintenance expenses subtracted, to get the net energy cost savings. Average yearly savings was calculated by dividing the net energy cost savings by 25 years. The return on investment (ROI) was then calculated with the following equation.

$$ROI = (NetEnergyCostSavings - InvestmentCosts)/(InvestmentCosts) \tag{3}$$

Equation 3 results in a percentage that is the return on investment for the ECM. The net present value (NPV) of the investment was then calculated by subtracting the investment costs from the total discounted value of savings from the 25-year period (equation 4).

$$NPV = \sum_{Y=1}^{25} S_N/(1+R)^Y - InvestmentCosts \tag{4}$$

Next, the internal rate of return was calculated using the Microsoft Excel function IRR. This function takes equation 4 and sets the NPV equal to 0. It then takes a series of cash flows and an initial investment and uses them in equation 4 to solve for the discount rate (R). This discount rate when the NPV is set equal to 0 is the internal rate of return for the investment. Another metric calculated was payback period, found by dividing the initial investment costs by the average yearly savings. The investment cost per each million BTU of energy saved was also calculated by dividing investment costs by the annual energy reduction (MMBTU). After the 25-year projections and ROI calculations were done for each ECM in each appropriate barn, the same projections and calculations were performed for each ECM with all barns combined.

2.5 References

Electronics Weekly Staff. 2009. "LED Life Expectancy." *Electronics Weekly.* Retrieved 30 May 2016, from http://www.electronicsweekly.com/blogs/led-luminaries/led-life-expectancy-2009-02/

Johnson, Dexter, G.R. Durland, and Gary Anderson. 2002. *College of Agriculture and Biological Sciences, South Dakota State University and the USDA.* "Plastic Curtain Wall Use for Barn Venting." http://pubstorage.sdstate.edu/AgBio_Publications/articles/ExEx1011.pdf

2.6 Appendix

2.6.1 *Full Links to Barn Curtain Sales Websites*

*https://www.farmtek.com/farm/supplies/cat1;ft_barn_curtain;ft_livestock_barn_curtain.html

**http://www.gettent.com/general-merchandise/barn-curtains-agricultural-ventilation.asp?st-t=Google_Agri_Barriers&gclid=CPqXqMOOwc0CFQiqaQodbHECoQ

3 Data

3.1 Farrowing Barn

Farrowing ECM Information

ECM	Investment Costs	Maintenance Expenses	Annual Energy Reduction (MMBTU)	Investment Costs per Annual MMBTU Saved
Earth Tube	$10,000.00	$12,500.00	129.0	$77.52
Heat Lamp Controllers	$3,000.00	-	5.9	$505.38
Geothermal Heat Exchange	$175,000.00	$12,500.00	356.0	$491.57

Farrowing ECM Savings

ECM	Annual Electricity Savings (kWh)	Annual Natural Gas Savings (Therms)	Annual Propane Savings (Gallons)	Net Energy Cost Savings Natural Gas (25-year)	Net Energy Cost Savings Propane (25-year)
Earth Tube	(1,736)	1,349	1,482	$23,212.14	$64,541.87
Heat Lamp Controllers	7,431	(194)	(213)	$21,785.60	$15,849.11
Geothermal Heat Exchange	(30,671)	4,607	5,063	$16,707.40	$157,954.33

Farrowing Return On Investment Metrics (Electricity + Natural Gas)

ECM	Average Annual Energy Cost Savings	Payback Period (Years)	Return on Investment (25-year)	Average Annual Return on Investment	Net t Presen Value	Internal Rate of Return
Earth Tube	$928.49	10.8	132%	5.3%	$4,778.41	5.9%
Heat Lamp Controllers	$871.42	3.4	626%	25.0%	$11,452.63	22.3%
Geothermal Heat Exchange	$668.30	261.9	-90%	-3.6%	$(164,933.37)	-11.4%

Farrowing Return On Investment Metrics (Electricity + Propane)

ECM	Average Annual Energy Cost Savings	Payback Period (Years)	Return on Investment (25-year)	Average Annual Return on Investment	Net t Presen Value	Internal Rate of Return
Earth Tube	$2,581.67	3.9	545%	21.8%	$31,356.65	17.0%
Heat Lamp Controllers	$633.96	4.7	428%	17.1%	$7,635.06	17.5%
Geothermal Heat Exchange	$6,318.17	27.7	-10%	-0.4%	$(74,099.81)	-0.6%

3.2 Nursery Barn

Nursery ECM Information

ECM	Investment Costs	Maintenance Expenses	Annual Energy Reduction (MMBTU)	Investment Costs per Annual MMBTU Saved
LED Lighting	$12,000.00	-	12.3	$975.61
Daylighting	$1,500.00	-	10.0	$150.00
Solar Chimney	$6,000.00	$12,500.00	7.2	$833.33
Earth Tube	$20,000.00	$12,500.00	174.9	$114.35
Variable Speed Fans	$1,000.00	-	6.8	$148.15
Night Temperature Setback	$500.00	-	93.1	$5.37
Traditional Air Conditioning	$80,000.00	$12,500.00	7.2	$11,111.11
Geothermal Heat Exchange	$200,000.00	$12,500.00	345.0	$579.71

Nursery ECM Savings

ECM	Annual Electricity Savings (kWh)	Annual Natural Gas Savings (Therms)	Annual Propane Savings (Gallons)	Net Energy Cost Savings Natural Gas (25-year)	Net Energy Cost Savings Propane (25-year)
LED Lighting	6,173	(88)	(97)	$20,387.13	$17,672.79
Daylighting	4,999	(70)	(77)	$16,549.40	$14,399.23
Solar Chimney	2,100	-	-	$(4,627.54)	$(4,627.54)
Earth Tube	(4,388)	1,899	2,087	$30,483.85	$88,707.77
Variable Speed Fans	1,979	-	-	$7,418.86	$7,418.86
Night Temperature Setback	92	928	1,020	$29,388.77	$57,848.78
Traditional Air Conditioning	2,593	(17)	(19)	$(3,311.44)	$(3,850.53)
Geothermal Heat Exchange	(34,711)	4,634	5,092	$2,407.31	$144,444.12

Nursery Return On Investment Metrics (Electricity + Natural Gas)

ECM	Average Annual Energy Cost Savings	Payback Period (Years)	Return on Investment (25-year)	Average Annual Return on Investment	Net t Presen Value	Internal Rate of Return
LED Lighting	$815.49	14.7	70%	2.8%	$1,513.29	4.0%
Daylighting	$661.98	2.3	1003%	40.1%	$9,469.34	32.3%
Solar Chimney	$(185.10)	(32.4)	-177%	-7.1%	$(9,492.64)	-
Earth Tube	$1,219.35	16.4	52%	2.1%	$(473.69)	2.8%
Variable Speed Fans	$296.75	3.4	642%	25.7%	$3,913.51	22.5%
Night Temperature Setback	$1,175.55	0.4	5778%	231.1%	$18,849.19	149.6%
Traditional Air Conditioning	$(132.46)	(604.0)	-104%	-4.2%	$(82,618.88)	-
Geothermal Heat Exchange	$2,407.31	2,077.0	-99%	-4.0%	$(199,407.67)	-16.0%

Nursery Return On Investment Metrics (Electricity + Propane)

ECM	Average Annual Energy Cost Savings	Payback Period (Years)	Return on Investment (25-year)	Average Annual Return on Investment	Net t Presen Value	Internal Rate of Return
LED Lighting	$706.91	17.0	47%	1.9%	$(232.38)	2.8%
Daylighting	$575.97	2.6	860%	34.4%	$8,086.57	29.2%
Solar Chimney	$(185.10)	(32.4)	-177%	-7.1%	$(9,492.64)	-
Earth Tube	$88,707.77	5.6	344%	13.8%	$36,969.17	12.4%
Variable Speed Fans	$296.75	3.4	642%	25.7%	$3,913.51	22.5%
Night Temperature Setback	$2,313.95	0.2	11470%	458.8%	$37,151.41	262.3%
Traditional Air Conditioning	$(154.02)	(519.4)	-105%	-4.2%	$(82,965.71)	-
Geothermal Heat Exchange	$5,777.76	34.6	-28%	-1.1%	$(108,066.43)	-2.0%

3.3 Finishing Barn

Finishing ECM Information

ECM	Investment Costs	Maintenance Expenses	Annual Energy Reduction (MMBTU)	Investment Costs per Annual MMBTU Saved
Curtain Sided	$2,628.00	-	13.8	$190.43
Earth Tube	$10,000.00	$12,500.00	42.9	$233.10
Variable Speed Fans	$1,000.00	-	1.2	$833.33
Night Temperature Setback	$500.00	-	47.1	$10.62
Traditional Air Conditioning	$80,000.00	$12,500.00	14.5	$5,517.24
Geothermal Heat Exchange	$150,000.00	$12,500.00	106.6	$1,407.13

Finishing ECM Savings

ECM	Annual Electricity Savings (kWh)	Annual Natural Gas Savings (Therms)	Annual Propane Savings (Gallons)	Net Energy Cost Savings Natural Gas (25-year)	Net Energy Cost Savings Propane (25-year)
Curtain Sided	10,607	(224)	(246)	$32,752.85	$25,894.85
Earth Tube	(1,873)	493	542	$(4,091.92)	$11,034.50
Variable Speed Fans	347	-	-	$1,300.83	$1,300.83
Night Temperature Setback	-	471	518	$14,741.02	$29,202.96
Traditional Air Conditioning	3,265	33	-	$772.62	$(260.19)
Geothermal Heat Exchange	(4,780)	1,229	1,351	$8,045.14	$45,745.24

Finishing Return On Investment Metrics (Electricity + Natural Gas)

ECM	Average Annual Energy Cost Savings	Payback Period (Years)	Return on Investment (25-year)	Average Annual Return on Investment	Net Present Value	Internal Rate of Return
Curtain Sided	$1,310.11	2.0	1146%	45.8%	$19,091.95	36.2%
Earth Tube	$(163.68)	(61.1)	-141%	-5.6%	$(13,199.00)	-
Variable Speed Fans	$52.03	19.2	30%	1.2%	$(138.46)	1.9%
Night Temperature Setback	$589.64	0.8	2848%	113.9%	$9,204.61	76.9%
Traditional Air Conditioning	$30.90	2,588.6	-99%	-4.0%	$(79,920.21)	-16.1%
Geothermal Heat Exchange	$321.81	466.1	-95%	-3.8%	$(145,251.82)	-13.6%

Finishing Return On Investment Metrics (Electricity + Propane)

ECM	Average Annual Energy Cost Savings	Payback Period (Years)	Return on Investment (25-year)	Average Annual Return on Investment	Net Present Value	Internal Rate of Return
Curtain Sided	$1,035.79	2.5	885%	35.4%	$14,681.77	30.6%
Earth Tube	$441.38	22.7	10%	0.4%	$(3,471.35)	0.5%
Variable Speed Fans	$52.03	19.2	30%	1.2%	$(138.46)	1.9%
Night Temperature Setback	$1,168.12	0.4	5741%	229.6%	$18,505.01	134.5%
Traditional Air Conditioning	$(10.41)	(7,686.6)	-100%	-4.0%	$(80,600.15)	-17.5%
Geothermal Heat Exchange	$1,829.81	82.0	-70%	-2.8%	$(121,007.35)	-6.6%

3.4 All Barns Combined

ECM Information

ECM	Investment Costs	Maintenance Expenses	Annual Energy Reduction (MMBTU)	Investment Costs per Annual MMBTU Saved
LED Lighting	$(12,000.00)	-	12.3	$(975.61)
Daylighting	$(1,500.00)	-	10.0	$(150.00)
Solar Chimney	$(6,000.00)	$(12,500.00)	7.2	$(833.33)
Curtain Sided	$(2,628.00)	-	13.8	$(190.43)
Earth Tube	$(40,000.00)	$(37,500.00)	346.8	$(115.34)
Variable Speed Fans	$(2,000.00)	-	8.0	$(251.57)
Heat Lamp Controllers	$(3,000.00)	-	5.9	$(505.38)
Night Temperature Setback	$(1,000.00)	-	140.2	$(7.13)
Traditional Air Conditioning	$(160,000.00)	$(25,000.00)	21.7	$(7,373.27)
Geothermal Heat Exchange	$(525,000.00)	$(37,500.00)	807.6	$(650.07)

ECM Savings

ECM	Annual Electricity Savings (kWh)	Annual Natural Gas Savings (Therms)	Annual Propane Savings (Gallons)	Net Energy Cost Savings Natural Gas (25-year)	Net Energy Cost Savings Propane (25-year)
LED Lighting	6,173	(88)	(97)	$20,387.13	$17,672.79
Daylighting	4,999	(70)	(77)	$16,549.40	$14,399.23
Solar Chimney	2,100	-	-	$(4,627.54)	$(4,627.54)
Curtain Sided	10,607	(224)	(246)	$32,752.85	$25,894.85
Earth Tube	(7,997)	3,741	4,111	$49,604.07	$164,284.14
Variable Speed Fans	2,326	-	-	$8,719.69	$8,719.69
Heat Lamp Controllers	7,431	(194)	(213)	$21,785.60	$15,849.11
Night Temperature Setback	92	1,399	1,538	$44,129.80	$87,051.74
Traditional Air Conditioning	5,858	16	(19)	$(2,538.82)	$(4,110.73)
Geothermal Heat Exchange	(70,162)	10,470	11,506	$27,159.86	$348,143.69

Return On Investment Metrics (Electricity + Natural Gas)

ECM	Average Annual Energy Cost Savings	Payback Period (Years)	Return on Investment (25-year)	Average Annual Return on Investment	Net Present Value	Internal Rate of Return
LED Lighting	$815.49	14.7	70%	2.8%	$1,513.29	4.0%
Daylighting	$661.98	2.3	1003%	40.1%	$9,469.34	32.3%
Solar Chimney	$(185.10)	(32.4)	-177%	-7.1%	$(9,492.64)	-
Curtain Sided	$1,310.11	2.0	1146%	45.8%	$19,091.95	36.2%
Earth Tube	$1,984.16	20.2	24%	1.0%	$(8,894.28)	1.3%
Variable Speed Fans	$348.79	5.7	336%	13.4%	$3,775.05	13.7%
Heat Lamp Controllers	$871.42	3.4	626%	25.0%	$11,452.63	22.3%
Night Temperature Setback	$1,765.19	0.6	4313%	172.5%	$28,053.80	113.2%
Traditional Air Conditioning	$(101.55)	(1,575.5)	-102%	-4.1%	$(162,539.10)	-
Geothermal Heat Exchange	$1,086.39	483.2	-95%	-3.8%	$(509,592.86)	-13.4%

Return On Investment Metrics (Electricity + Propane)

ECM	Average Annual Energy Cost Savings	Payback Period (Years)	Return on Investment (25-year)	Average Annual Return on Investment	Net Present Value	Internal Rate of Return
LED Lighting	$706.91	17.0	47%	1.9%	$(232.38)	2.8%
Daylighting	$575.97	2.6	860%	34.4%	$8,086.57	29.2%
Solar Chimney	$(185.10)	(32.4)	-177%	-7.1%	$(9,492.64)	-
Curtain Sided	$1,035.79	2.5	885%	35.4%	$14,681.77	30.6%
Earth Tube	$6,571.37	6.1	311%	12.4%	$64,854.46	11.2%
Variable Speed Fans	$348.79	5.7	336%	13.4%	$3,775.05	13.7%
Heat Lamp Controllers	$633.96	4.7	428%	17.1%	$7,635.06	17.5%
Night Temperature Setback	$3,482.07	0.3	8605%	344.2%	$55,656.42	198.4%
Traditional Air Conditioning	$(164.43)	(973.1)	-103%	-4.1%	$(163,565.86)	-
Geothermal Heat Exchange	$13,925.75	37.7	-34%	-1.4%	$(303,173.60)	-2.5%

4 Analysis

4.1 LED Lighting

LED lighting data was from the nursery barn. With a total investment cost of 12,000 dollars, the projected return on investment to implement the LED lights was 70% in a swine production system using natural gas and 47% in a system using propane. This major difference in return on investment percentages is due to an increase in fuel use from this ECM and the fact that propane is more expensive than natural gas. While both ROI percentages indicate a positive return, having propane as a fuel may cause this ECM to not be worth the expense. The internal rates of return also seem to show this. Using LED lighting in a natural gas system produces a projected internal rate of return of 4%, which is better than the ideal interest rate of 3% and produces a positive net present value for the investment. LED lighting with a propane system projects to have an internal rate of return of 2.8%, which is less than the ideal interest rate and produces a negative net present value. A drawback of the LED lighting as an ECM is that is produces one of the highest costs per million Btu saved. The investment still saves about the same amount of energy per year whether the system uses natural gas or propane, but the return only seems to be substantial enough in a system that uses natural gas. If a system uses propane, it will be more worthwhile to invest the money elsewhere if a 3% interest rate will be achieved. However, if lowering energy usage is an important goal for a swine producer, this investment will lower energy usage while still generating a positive return whether propane or natural gas is used.

4.2 Daylighting

A low investment cost of 1,500 dollars produced a great projected return on investment for utilizing daylighting. The projected ROI in a natural gas system is 1,003% and 860% in a propane system. The internal rates of return are also both very high at 32.3% and 29.2% respectively, resulting in positive net present values for both. On paper, daylighting is definitely a sound and worthwhile investment. However, it is not very practical to retrofit an existing barn with new windows where they didn't previously exist. For this reason, using daylighting as an energy conservation measure can only really be applied to barns with existing windows or in construction of new barns. If a new barn is being constructed, daylighting is a very positive investment that has a payback period of only 2-3 years.

4.3 Solar Chimney

The solar chimney does not have an effect in the model on heating fuel usage, so both the natural gas and propane systems are the same. This ECM had a negative projected return on investment and does not project to have positive savings during any year of operation. This results in a payback period that is negative which means that the investment will never pay for itself. Investment costs per annual million Btu saved is also pretty high. All of this makes for a bad investment projection to implement a solar chimney in a swine production system. Major problems with the outlook of this ECM are that a solar chimney would need to be large enough to properly ventilate a barn and is difficult to implement and operate.

4.4 Curtain Sided Barns

Similar to daylighting, this ECM cannot easily be applied to an existing barn. Instead it would be applied to construction of a new barn. The ROI percentages are highly positive for a natural gas system and for a propane system. The investment cost is relatively low at $2,628 along with a low payback period of 2-3 years. The internal rate of return is projected for natural gas to be 36.2% and 30.6% for propane. With such a low payback period and a high internal rate of return, installing curtains seems to be a great investment when constructing a new swine barn. However, this assumes that pig performance is the same in a curtain sided barn when compared to a tunnel ventilated barn. A producer must first evaluate pig performance based on barn type.

4.5 Earth Tube

The earth tube ECM has higher installation costs than the other ECMs but presents an opportunity to produce high savings in fuel use. The barn that presents the best return for an earth tube is the farrowing barn, with the finishing barn being the worst. In the farrowing barn, an earth tube in a natural gas system has a projected return on investment of 132% with a payback period of 10.8 years and an internal rate of return of 5.9%. In a propane system, the numbers for an earth tube are even better with an ROI of 545%, payback period of 3.9 years, and an internal rate of return of 17.0%. This ECM saves a substantial amount of energy per year with one of the lowest investment costs per annual million Btu saved. An earth tube in the farrowing barn is a great investment both from an energy standpoint and financial outlook. Not only does it project to have high annual energy savings and the same low investment cost per million Btu saved, but it projects to generate a great return. The nursery projected return is very good for an earth tube as well. However, in the finishing barn an earth tube has a negative return in a natural gas system and a very low return on investment with a high payback period in a propane system. This leads to an earth tube not being a great measure to implement in a finishing barn.

4.6 Variable Speed Fans

Variable speed fans did not project to affect fuel usage, so both natural gas and propane systems have the same outlook. For a low investment cost of $1,000 in either barn, this ECM has a great ROI at 642% in the nursery barn but only 30% in the finishing barn. The payback periods for each barn are 3.4 and 19.2 years respectively. As far as from a financial standpoint, implementing variable speed fans is a good investment, although it is much better in the nursery than the finishing barn. The biggest drawback with this ECM is that it saves less than 10 million Btu per year. In a finishing barn, the relatively low return on investment may not be large enough to justify implementation of variable speed fans in the barn. If the energy reduction is enough to justify the investment, then there is definitely a substantial return to be made on each dollar invested for variable speed fans in the nursery barn.

4.7 Heat Lamp Controllers

The heat lamp controller ECM has the lowest projected annual energy savings of all measures at 5.9 million Btu. However, it projects to be a good financial investment. The installation cost is only $3,000 and has an ROI of 626% for natural gas systems and 428% for propane systems. Both paybacks are under 5 years and the internal rates of return are 22.3% and 17.5% respectively. Using heat lamp controllers is a good investment, but if money is not readily available then there may be better options with similar financial gains that also have better energy savings.

4.8 Night Temperature Setback

Implementing a night temperature setback in a swine production system has the lowest estimated investment cost out of all the ECMs at $500 per barn. The projected return on investment is extremely high for both the nursery and finishing barns at 5,778% or 2,848% respectively for a natural gas system and 11,470% or 5,741% respectively for a propane system. The payback periods are all under one year and the internal rates of return are all above 76.9%. The investment cost per million Btu saved is only around $7-10. This ECM projects to be the best investment and value among all options. As long as there are no detrimental effects to the pigs in the barns (see section 1.5.6), then a night temperature setback should definitely be considered for implementation in a swine production system.

4.9 Traditional Air Conditioning

This ECM does not save a considerable amount of energy compared to its initial investment cost. The investment costs are very high and the annual energy reduction is only around 7.2-14.5 million Btu depending on the barn. Whether the system is natural gas or propane, implementing traditional air conditioning results in a projected ROI that is negative, which meant that the internal rate of return could not be calculated for this investment. Overall, this ECM is not a good investment due to no positive return over the entire 25-year period. This ECM is not recommended to be pursued at this time.

4.10 Geothermal Heat Exchange

A geothermal heat exchange system has the highest investment costs for implementation out of all of the ECM options. All of the projected ROIs for this measure are negative and all the payback periods are over 25 years. This ECM does save anywhere from 100-350 million Btu per year depending on the barn, but payback periods of 450-2,000 years make this investment not feasible in a natural gas system. With propane, a geothermal heat exchange system projects to have a better ROI but the payback periods are all over 25 years. This indicates that the geothermal heat exchange ECM is not an ideal investment even in a swine production system that uses propane instead of natural gas. The installation costs are just too high with this ECM. In the future this could be a good energy conservation measure to implement, due to its high energy savings, if installation costs go down or energy prices drastically rise.

4.11 Comparisons

For lighting ECMs, both LED lighting and daylighting are different types of measures. It is conceivable that they could both be used together in a production system. If a new barn is being built and the better ECM needs to be determined, from a financial standpoint it would be daylighting. This ECM is very inexpensive and projects to have a greater return on investment than compared to LED lighting. LED lighting is projected to save a little more than twice the amount of energy as daylighting but the investment cost is at least 15 times greater.

The best ventilation ECM from a purely financial standpoint seems to be using a curtain sided barn. The investment costs are one of the lowest and the return on investment is projected to be at least 1,000%. No other ventilation ECM projects to have that large of a return on every dollar invested. The issue with this ECM is that it is not a practical retrofit, so it would mostly apply for construction of a new barn. There also could be effects on the performance of the pigs that would need to be factored into any decision to use this ECM. As far as energy savings are concerned, an earth tube is definitely the best option. However, the ROI for an earth tube is low in a natural gas system, so there may be too much risk. In a propane system, an earth tube is the best option for energy savings and also projects to have a great return on investment in the farrowing and nursery barns. A solar chimney is not a good ECM to pursue based on negative projected returns on investment. Variable speed fans could also be used but may not be ideal for energy reduction. They have a projected ROI that is good but the energy savings are considerably less than other ventilation ECM options. Overall, the best ventilation ECM is an earth tube in a propane system, if implemented in the farrowing or nursery barns, due to the high amount of energy savings and the ROI.

The heating and cooling ECM's are difficult to directly compare, as they all have large differences. The night temperature setback ECM is the best option compared to all the rest. The energy savings are relatively high, the investment cost is the lowest, and the ROI is projected to be the highest among all the ECM options. A night temperature setback ECM should seemingly be used in every swine production system if there are no detrimental effects on the pigs. A traditional air conditioning system projects to not generate a return, so it is not a feasible investment. Heat lamp controllers have a good projected ROI, but are not the best energy savings option as they have very low energy savings compared to all other ECMs. A geothermal heat exchange system also may not be a good investment. The investment costs are too high compared to the expected amount of return. However, depending on the importance of energy reduction, a geothermal heat exchange system would have the greatest amount of energy saved each year.

5 Conclusion

The results of the data definitely show that there is potential for implementing energy conservation measures and other technologies in the swine production industry. One thing to remember is that the data in this study was all based on projections. The energy usage and savings were also modeled just for the WCROC swine production system assuming that the WCROC barns would have full occupancy and typical usage schedules. Most commercial swine production systems will be larger and will most likely have different energy usage and potential savings from each ECM if they were to be implemented. However, all the energy conservation measures in this study will at least save energy in some way. As far as financial feasibility, some of these are not practical investments. These are the most expensive ECMs being traditional air conditioning and a geothermal heat exchange system. At some point these systems could become cheaper to install, but for now they have too high investment costs. Yet, the rest of the ECMs should generate some sort of return on the investment and some returns are very substantial. This means that investing in energy conservation measures is feasible and a good idea for swine producers from both an energy and economic standpoint. Using ECMs such as LED lights or an earth tube ventilation system instead of current swine production technologies will lower energy usage while also helping to make swine production better for the environment. Many studies have also showed that some of these technologies also can result in better production environments for the pigs. Even though there is not heavy pressure on swine production directly to become more environmentally friendly, swine producers can use energy conservation measure to be proactive about how their systems affect the environment while also saving money from a reduction in energy usage.

6 Acknowledgments

Funding for this project was provided by the Minnesota Environment and Natural Resources Trust Fund as recommended by the Legislative Citizen Commission on Minnesota Resources (LCCMR). The Trust Fund is a permanent fund constitutionally established by the citizens of Minnesota to assist in the protection, conservation, preservation, and enhancement of the state's air, water, land, fish, wildlife, and other natural resources. Currently 40% of net Minnesota State Lottery proceeds are dedicated to growing the Trust Fund and ensuring future benefits for Minnesota's environment and natural resources. Special thanks to the West Central Research and Outreach Center, Mike Reese, Eric Buchanan, Lee Johnston, and Kirsten Sharpe for direction and support on this project.

Return on Investment for Energy Conservation Measures in Swine Production Systems

ENVIRONMENT AND NATURAL RESOURCES TRUST FUND

Justin Miller

West Central Research and Outreach Center (WCROC)

Renewable Energy Intern

Summer 2016

Swine Production and the Environment

- Swine Production has been increasing in size and becoming more concentrated
- Could create environmental problems
  - Public perception that agricultural industries are heavily contributing to environmental problems
  - Leads to pressure on agricultural industries to become “greener”

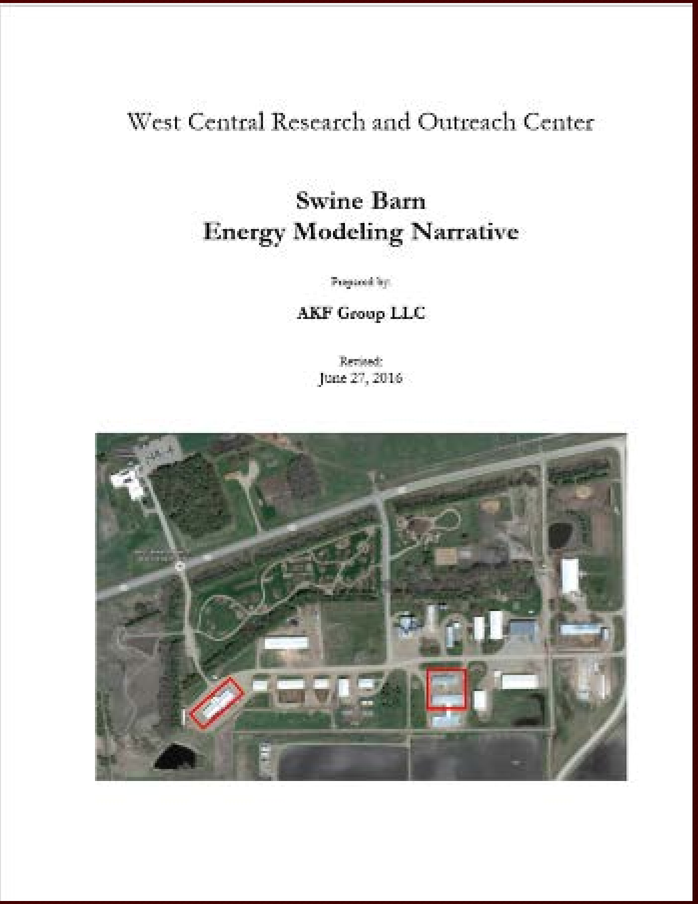
Image from Jeff Quitney at www.youtube.com

Image from Smithfield Foods at www.youtube.com

Swine Barn Energy Modeling Narrative- AKF Group LLC (2016)

- Report commissioned by WCROC
  - Modeled current energy use for WCROC swine production
  - Determined energy conservation measures (ECMs)
  - Modeled energy usage and savings with ECMs in place
    - Model assumed typical commercial schedule and occupancy

- Energy data for AKF model collected from WCROC swine facilities
  - Using sensors on electrical loads and fuel billing statements


West Central Research and Outreach Center

Swine Barn
Energy Modeling Narrative

Prepared by:

AKF Group LLC

Revised:
June 27, 2016

AKF Report Title Page

Return on Investment Study

- AKF found many energy conservation measures that project to reduce energy usage at WCROC

- Objective of this study:
  - Energy conservation measures can reduce energy usage, but are they feasible economic investments?

Image from halalfocus.net

Energy Conservation Measures

- Lighting
  - LED Lighting Conversion
- Ventilation
  - Solar Chimney
  - Earth Tube
  - Variable Speed Fans

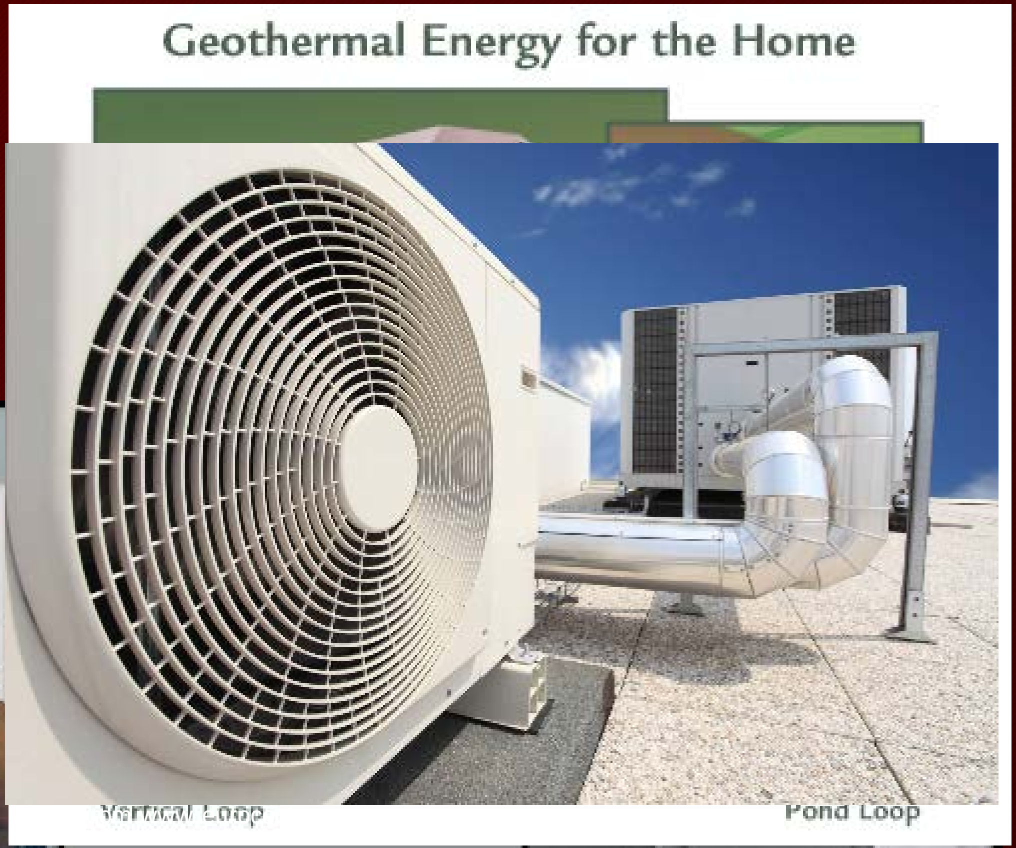
Image from www.exter

Solar Chimney diagram from AKF report

Earth Tube picture from www.homeintheearth.com

Energy Conservation Measures

- Heating and Cooling
  - Heat Lamp Controllers
  - Night Temperature Setback
    - Effects of reduced nocturnal temperature on pig performance and energy consumption in swine nursery rooms- Johnston et al. 2013
  - Traditional Air Conditioning
  - Geothermal Heat Exchange



Geothermal Heat Exchange system diagram from ericsenergy.com

Image from www.automatedproduction.com

Energy Conservation Measures

	Farrowing	Nursery	Finishing
LED Lighting	X	X	
Solar Chimney		X	
Earth Tube	X	X	X
Variable Speed Fans		X	X
Heat Lamp Controllers	X		
Night Temperature Setback		X	X
Traditional Air Conditioning		X	X
Geothermal Heat Exchange	X	X	X

Return on Investment Calculation

- 25-year projections
  - Used AKF energy usage and savings data
  - Initial costs, lifespans, and maintenance costs included as well
  - Energy cost inflation was based on data from U.S. Energy Information Administration

Energy Type	Initial Energy Price (2015 Avg)	Inflation Rate
Electricity (per kWh)	$ 0.095	3.35%
Natural Gas (per therm)	$ 0.75	3.76%
Propane (per therm)	$ 1.10	4.56%

Return on Investment Calculation

- Payback Period
  - Amount of time needed for returns to cover initial investment costs

- Return on Investment (ROI)
  - $ROI = \frac{Net\ Savings}{Investment\ Costs}$

- Other metrics, such as internal rate of return and net present value, were calculated in full analysis but are not in this presentation

Data and Results Summary (Electricity+**Natural Gas**)

			Electricity + Natural Gas	
Energy Conservation Measure	**Barn Applied to**	**Investment Costs**	**Payback Period (years)**	**Annual Return on Investment**
Night Temperature Setback	N	$ 500.00	**0.4**	**231.1%**
Variable Speed Fans	N	$ 1,000.00	**3.4**	**25.7%**
Heat Lamp Controllers	Fa	$ 3,000.00	**3.4**	**25.0%**
Earth Tube	Fa	$ 10,000.00	**10.8**	**5.3%**
LED Lighting	N	$ 12,000.00	**14.7**	**2.8%**
Geothermal Heat Exchange	Fa	$ 175,000.00	**261.9**	**-3.6%**
Traditional Air Conditioning	Fi	$ 80,000.00	**2,588.6**	**-3.96%**
Solar Chimney	N	$ 6,000.00	**-**	**-7.1%**

Data and Results Summary (Electricity+**Propane**)

Energy Conservation Measure	Barn Applied to	Investment Costs	Electricity + Propane: Payback Period (years)	Electricity + Propane: Annual Return on Investment
Night Temperature Setback	N	$ 500.00	**0.2**	**458.8%**
Variable Speed Fans	N	$ 1,000.00	**3.4**	**25.7%**
Earth Tube	Fa	$ 10,000.00	**3.9**	**21.8%**
Heat Lamp Controllers	Fa	$ 3,000.00	**6.1**	**17.1%**
LED Lighting	N	$ 12,000.00	**17.0**	**1.9%**
Geothermal Heat Exchange	Fa	$ 175,000.00	**27.7**	**-0.4%**
Traditional Air Conditioning	Fi	$ 80,000.00	**-**	**-4.01%**
Solar Chimney	N	$ 6,000.00	**-**	**-7.1%**

Data and Results Summary (Electricity+**Natural Gas**)

Energy Conservation Measure	Barn Applied to	Investment Costs	Electricity + Natural Gas Payback Period (years)	Electricity + Natural Gas Annual Return on Investment
Night Temperature Setback	N	$ 500.00	0.4	231.1%
Variable Speed Fans	N	$ 1,000.00	3.4	25.7%
Heat Lamp Controllers	Fa	$ 3,000.00	3.4	25.0%
Earth Tube	**Fa**	**$ 10,000.00**	**10.8**	**5.3%**
LED Lighting	N	$ 12,000.00	14.7	2.8%
Geothermal Heat Exchange	Fa	$ 175,000.00	261.9	-3.6%
Traditional Air Conditioning	Fi	$ 80,000.00	2,588.6	-3.96%
Solar Chimney	N	$ 6,000.00	-	-7.1%

Data and Results Summary (Electricity+**Propane**)

Energy Conservation Measure	Barn Applied to	Investment Costs	Electricity + Propane Payback Period (years)	Electricity + Propane Annual Return on Investment
Night Temperature Setback	N	$ 500.00	0.2	458.8%
Variable Speed Fans	N	$ 1,000.00	3.4	25.7%
Earth Tube	**Fa**	**$ 10,000.00**	**3.9**	**21.8%**
Heat Lamp Controllers	Fa	$ 3,000.00	6.1	17.1%
LED Lighting	N	$ 12,000.00	17.0	1.9%
Geothermal Heat Exchange	Fa	$ 175,000.00	27.7	-0.4%
Traditional Air Conditioning	Fi	$ 80,000.00	-	-4.01%
Solar Chimney	N	$ 6,000.00	-	-7.1%

Data and Results Summary (Electricity+**Natural Gas)**

Energy Conservation Measure	Barn Applied to	Investment Costs	Electricity + Natural Gas Payback Period (years)	Electricity + Natural Gas Annual Return on Investment
Night Temperature Setback	N	$ 500.00	0.4	231.1%
Variable Speed Fans	N	$ 1,000.00	3.4	25.7%
Heat Lamp Controllers	Fa	$ 3,000.00	3.4	25.0%
Earth Tube	Fa	$ 10,000.00	10.8	5.3%
LED Lighting	**N**	**$ 12,000.00**	**14.7**	**2.8%**
Geothermal Heat Exchange	Fa	$ 175,000.00	261.9	-3.6%
Traditional Air Conditioning	Fi	$ 80,000.00	2,588.6	-3.96%
Solar Chimney	N	$ 6,000.00	-	-7.1%

Data and Results Summary (Electricity+**Propane**)

Energy Conservation Measure	Barn Applied to	Investment Costs	Electricity + Propane: Payback Period (years)	Electricity + Propane: Annual Return on Investment
Night Temperature Setback	N	$ 500.00	0.2	458.8%
Variable Speed Fans	N	$ 1,000.00	3.4	25.7%
Earth Tube	Fa	$ 10,000.00	3.9	21.8%
Heat Lamp Controllers	Fa	$ 3,000.00	6.1	17.1%
LED Lighting	**N**	**$ 12,000.00**	**17.0**	**1.9%**
Geothermal Heat Exchange	Fa	$ 175,000.00	27.7	-0.4%
Traditional Air Conditioning	Fi	$ 80,000.00	-	-4.01%
Solar Chimney	N	$ 6,000.00	-	-7.1%

Implications

- Energy Conservation Measures can be good financial investments
  - Some are feasible today
  - Others could become feasible in near future
- Energy modeling is important when considering energy conservation measures
- Lowering Carbon footprint is a way to improve public perception of swine and agricultural industries

Image from www.newsknowhow.org

Acknowledgements

- Funding for this project was provided by the Minnesota Environment and Natural Resources Trust Fund as recommended by the Legislative-Citizen Commission on Minnesota Resources (LCCMR).
- Thanks to Mike Reese, Eric Buchanan, Kirsten Sharpe, Joel Tallaksen, Lee Johnston, and Cory Marquart for direction and support on this project.

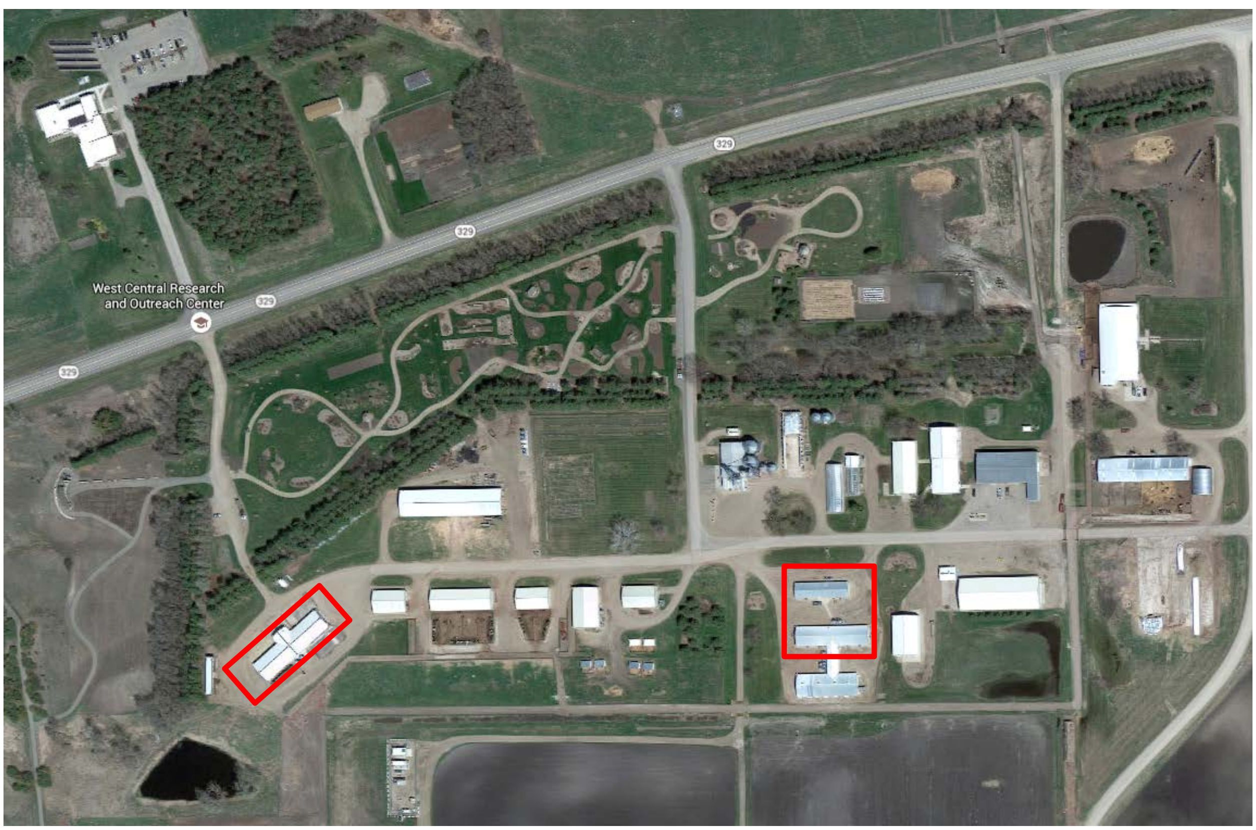
West Central Research and Outreach Center

Swine Barn
Energy Modeling Narrative

Prepared by:

AKF Group LLC

Revised:
December 15, 2016



Whole Building Energy Model

Summary

The WCROC swine program consists of barns for each of the three major swine production stages. These barns are representative of typical commercial operations for gestation/farrowing, nursery, and finishing. The barns are located at the WCROC facility in Morris, MN.

AKF Group has prepared energy models to determine the energy cost impacts of the proposed design and renovations. The existing buildings were calibrated using owner provided energy use data as well as data collected from typical commercial barns serving the same functions. The calibrations are intended to represent the actual facilities at the WCROC with commercial production operating schedules. The calibrated models were then used to analyze the results of potential energy conservation measures (ECMs). The ECM's were determined prior to developing the energy models using a decision matrix for each barn type. These are attached in Appendix A.

Overview

The energy models being used to estimate and compare annual energy use have been created with the software program eQUEST, version 3-64, using the DOE-2.2 simulation engine developed by the US Department of Energy. The program calculates building energy use on an hourly basis for 8,760 hours per year (full year) and utilizes typical meteorological year (TMY) weather data.

A. Occupancy

i) Farrowing –

Occupant (animal) density in the model is based on owner provided data using the peak occupancy of the WCROC facility. The existing barn has a maximum capacity of 32 sows plus 32 litters of piglets. Typical litters are 11 piglets. The sows are typically in the farrowing pens for 4 weeks and there is a 3 day window for cleaning before the next sow is brought in. This results in an average sow occupancy of about 91%.

The sows are brought in to the barn about 1 week prior to farrowing and then the litter remains with the sow for the remaining 3 weeks before being moved to the nursery. This means there is typical piglet occupancy of approximately 75%.

The farrowing sows weigh approximately 400 lbs with the piglets averaging 7 to 8 lbs from birth to leaving the farrowing barn.

ii) Nursery –

Occupant (animal) density in the model is based on owner provided data using the peak occupancy of the WCROC facility. The building has 4 nursery rooms as well as a central support area. Each nursery room can hold 288 pigs. They are brought in from the farrowing barn in the 10-15 lbs range and leave after 6 weeks reaching an average weight of 50-60 lbs.

iii) Finishing –

Occupant (animal) density in the model is based on owner provided data using the peak occupancy of the WCROC facility. Swine in the finishing barn go through a 3.5 month growth phase. The finishing barn has two rooms that can hold a maximum of 216 pigs each. There is typically 1 week of down time after a group of pigs have left a room and the second room will usually be filled 2 weeks after the first is filled.

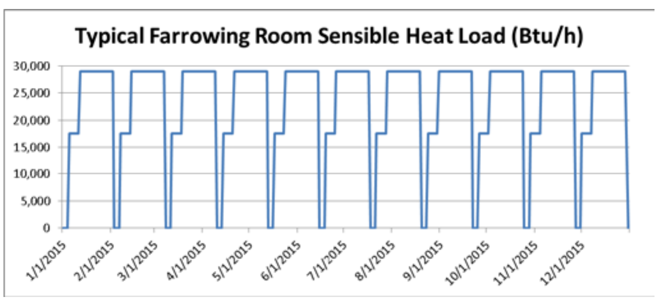
Pigs are brought in from a nursery barn weighing about 50 to 60 pounds and weigh about 260 pounds or more after 3.5 months.

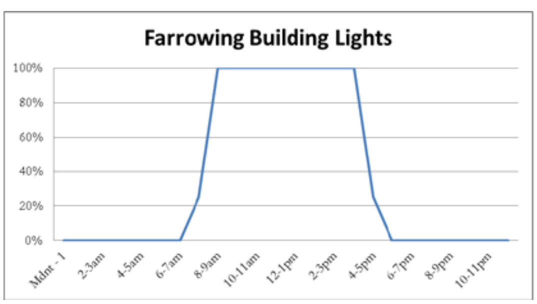
B. Schedules of Use

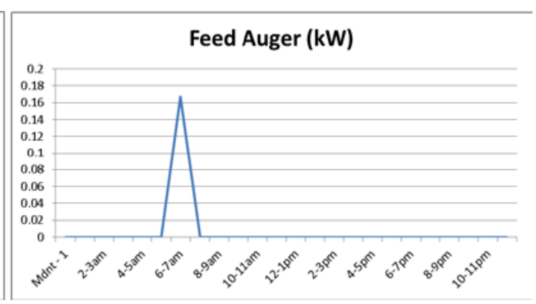
i) Farrowing –

The schedules of use for pit fan operation, lighting, feed augers, and domestic hot water are defined according to owner provided data in order to develop the calibration of annual energy use.

The heating and cooling setpoints for heating and fan control are also based on owner provided information. Graphical views of each space type category are shown below to illustrate the lighting and miscellaneous electrical equipment patterns. The sensible heat load graph shows the typical annual farrowing cycles and the heat output from the pigs during each cycle.



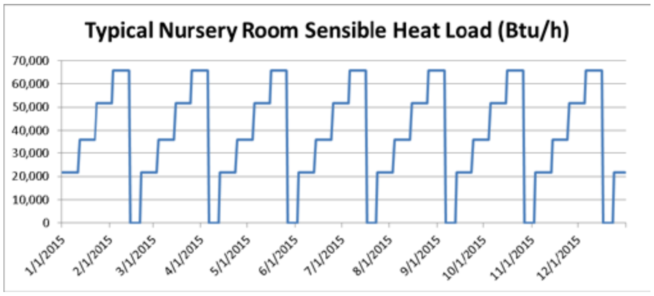


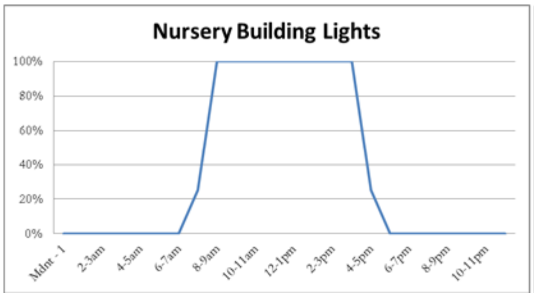


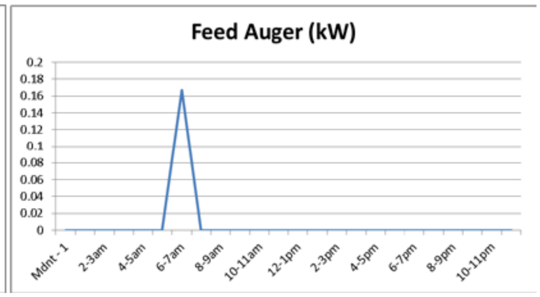
ii) Nursery –

The schedules for animal occupancy have been created to represent the typical growth during the 6 weeks the pigs are in the nursery. This can be seen in the sensible heat load graph below. The current temperature schedule maintains the room at 90°F when the pigs are first brought in and decreases the temperature setpoint by 4°F per week until the temperature is at 70°F when the pigs are over 50 lbs.

The interior lighting and equipment schedules are also based on owner provided information. This includes the feed augers, refrigerators, power washers, etc.





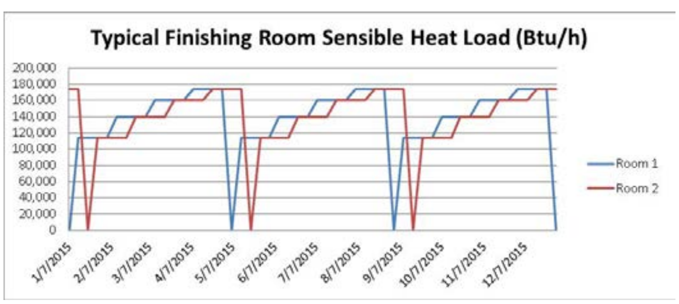


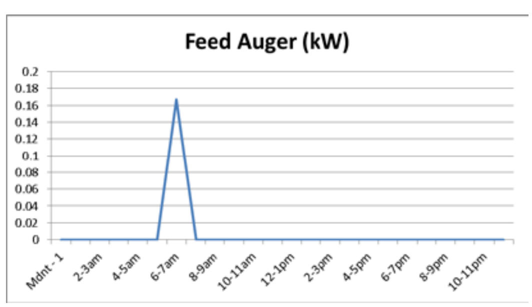
iii) Finishing –

The schedules of use for fan operation, occupancy, and domestic hot water are defined according to owner provided data in order to develop the calibration of annual energy use.

The heating and cooling setpoints, interior lighting, and general equipment loads are also based on owner provided information. Graphical views of each space type category are shown below to illustrate the occupancy, lighting, and miscellaneous electrical equipment patterns. The rooms are fully occupied with increased heat output from the pigs represented by the sensible heat load graph.

A reduced lighting load is maintained during the time between cycles, assuming that some lights will be on while the rooms are being cleaned.





C. General Methodology

The existing building areas have been modeled according to owner provided drawings and owner compiled data on motor sizes, lighting, etc.

D. Weather

The weather file used during simulation is the Typical Meteorological Year 3 (TMY3) file for Morris, MN Municipal Airport as published by the National Renewable Energy Lab and National Climactic Data Center. The TMY3 file for this location uses an algorithm referred to as The Sandia Method to create a typical year using 12 years of site specific meteorological data.

The Sandia method is an empirical approach that selects individual months from different years of the period of record. For example, this site contains 12 years of data, all 12 Januarys are examined, and the one judged most typical is selected to be included in the TMY. The other months of the year are treated in a like manner, and then the 12 selected typical months are concatenated to form a complete year. Because adjacent months in the TMY may be selected from different years, discontinuities at the month interfaces are smoothed for 6 hours on each side. The Sandia Method selects a typical month based on nine daily indices consisting of the maximum, minimum, and mean dry bulb and dew point temperatures, the maximum and mean wind velocity, and the total global horizontal solar radiation. Final selection of a month includes consideration of the monthly mean and median and the persistence of weather patterns.

E. Utility Rate Structure

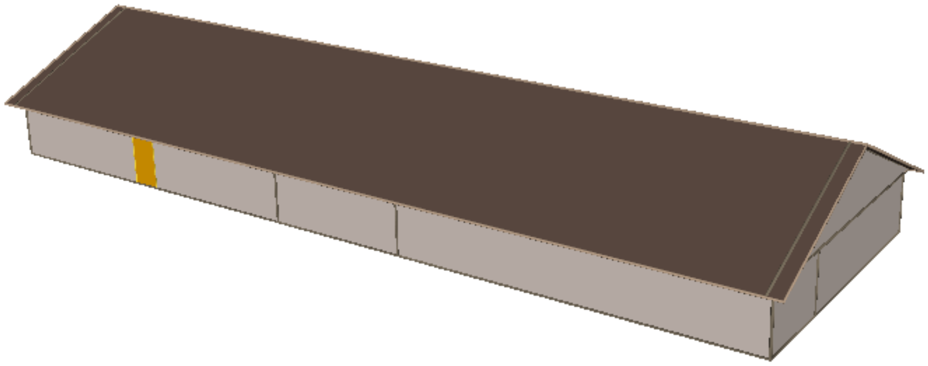
The utility rates used in the energy models are per the historical utility data from 2014 provided by the owner. The annual average utility costs are 0.096 $/kWh and 0.73 $/therm. In addition to the utility rate structure for the WCROC, the final summary includes the impact of propane being a common heating fuel using $1.70/gallon.

Architecture

A. Geometry

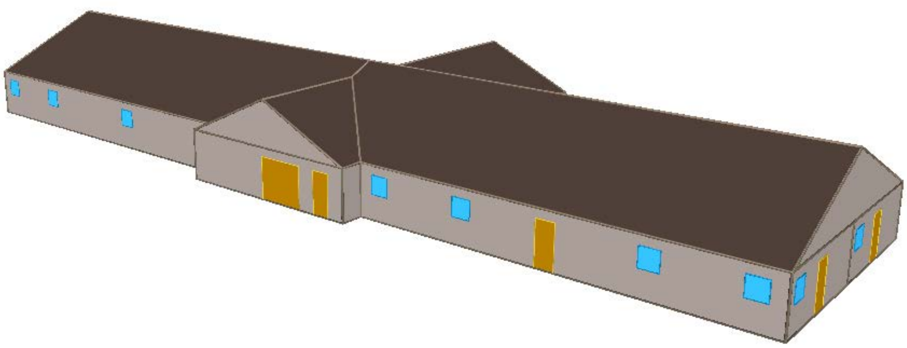
i) Farrowing –

The farrowing barn is an existing building that is approximately 3600 square feet. The building is 128 feet long and 28 feet wide. It is oriented with the length running east to west and is split into two main rooms. The model matches the existing geometry per owner provided drawings.



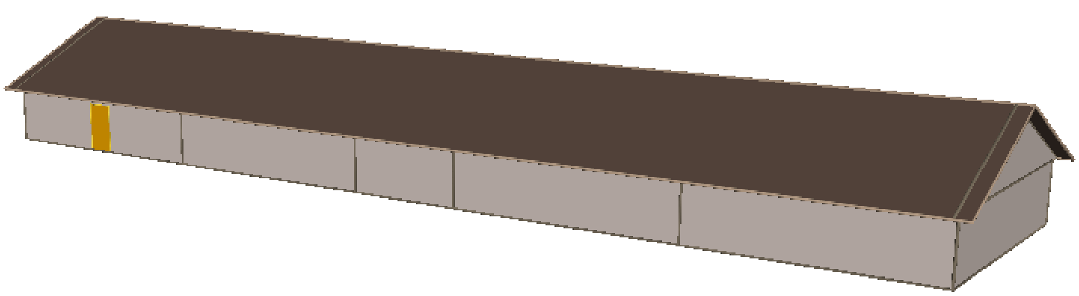
ii) Nursery –

The nursery barn consists of an existing building that is approximately 7,500 square feet. The model matches the existing geometry per owner provided drawings. The building is approximately 165 feet by 45 feet and consists of 4 swine rooms as well as a central office and support area.



iii) Finishing –

The finishing barn consists of an existing building that is approximately 5,200 square feet. The model matches the existing geometry per owner provided drawings. The barn is about 146 feet long, east to west, by 36 feet wide and has two independent rooms.



B. Material Performance

Envelope performance values are based on existing drawings provided by the owner.

i) Farrowing –

Envelope Properties				
Surface	Description	Thermal Properties	R-Value	Assembly U-Value
Below Grade Walls	8" concrete with 2 1/2" extruded polystyrene insulation	R-5 per inch (est)	12.5	0.080
Above Grade Walls	Structural Insulated Panel (SIP); 4" rigid foam bonded to 3/4" plywood both sides, exterior steel siding	Insulation at R-5 per inch (est)	24.00	0.042
Roof	Wood roof trusses, 48" O.C. with 2" fiberglass insulation draped over purlins and 12" fiberglass attic insulation	R-30 per ASHRAE 90.1 Table A2.4	30.00	0.034

ii) Nursery –

Envelope Properties				
Surface	Description	Thermal Properties	R-Value	Assembly U-Value
Below Grade Walls	8" concrete with 2 1/2" extruded polystyrene insulation	R-5 per inch (est)	12.5	0.080
Above Grade Walls	2x6 Wood framing with 5 1/2" cavity fiberglass insulation	R-19 (Effective R-18 installed) cavity insulation per ASHRAE 90.1 Table A3.4	15.00	0.067
Roof	Wood roof trusses, 48" O.C. with 2" fiberglass insulation draped over purlins and 12" fiberglass attic insulation	R-30 per ASHRAE 90.1 Table A2.4	30.00	0.034
Windows	Glass with wood framing	ASHRAE 90.1 Appendix A Table A8.2: Wood frame, double glazing. 0.59 SHGC, 0.64 VLT	-	0.600

iii) Finishing –

See Farrowing materials.

Electrical and Miscellaneous

A. Interior Lighting

i) Farrowing –

The lighting in the farrowing barn has been modeled based on the information received from the owner. Farrowing barn lighting has a total power of 1,460 watts using standard T12 fluorescent fixtures.

ii) Nursery –

The lighting in the nursery barn has been modeled based on the information received from the owner. Nursery barn lighting has a total power of 4,560 watts using standard T12 fluorescent fixtures.

iii) Finishing –

The lighting in the existing building has been modeled based on the information received from the owner. Finishing barn lighting has been mostly converted to LED fixtures and has a total power of 616 watts.

B. Miscellaneous Equipment

i) Farrowing –

Miscellaneous electrical equipment for the building includes 2 feed augers, a medicine fridge, and a power washer. These are modeled per owner provided usage and power information.

- Feed auger
  - ¾ hp motors
  - ~10 minute per day total runtime
  - 2 total augers
- Medicine fridge
  - ~175 watts
  - ~25% duty cycle
- Power washer
  - ~8.4 kW
  - Used to clean pens before new sow is brought in, ~4hrs per month
- Domestic hot water (DHW)
  - 40,000 Btu/h domestic water heater, primary use is for showering which is estimated by the WCROC to be used once per day on average

ii) Nursery –

Miscellaneous electrical equipment for the building includes 4 feed augers and a power washer. These are modeled per owner provided usage and power information

- Feed auger
  - ¾ hp motors
  - ~10 minute per day total runtime
  - 4 total augers
- Clothes washer/dryer
  - Used about every two weeks
- Power washer
  - ~8.4 kW Used to clean pens before new pigs are brought in, ~10hrs per month
- Domestic hot water
  - 75,000 Btu/h domestic water heater serves the showers, restroom fixtures, and clothes washer, approximately 20 gallons per day estimated by WCROC

iii) Finishing –

Miscellaneous electrical equipment for the building includes feed augers and power washers. These are modeled per owner provided usage and power information.

- Feed auger

    - ¾ hp motors
    - ~10 minute per day total runtime
    - 2 total augers
- Power washer
    - ~8.4 kW
    - Used to clean pens before new pigs are brought in, ~4hrs per month

Mechanical Systems

A. General Heating Ventilating and Air Conditioning (HVAC)

i) Farrowing –

The HVAC in the farrowing barn has been modeled based on information provided by the owner. Two 60,000 Btu/h gas fired furnaces provide heat to the farrowing areas with an additional 120,000 Btu/h furnace heating the office. Controller setpoints for heating are 72°F.

No mechanical cooling is provided for the building. Tempering of the space temperature is done using thermostatically controlled fans capable of up to 100 air changes per hour. These fans stage on as the temperature increases to maintain the space temperature within 2 to 3° F of the outdoor temperature. Direct evaporative cooling of the sows is employed when temperatures get above 80° F. Pit fans operate continuously for ventilation and humidity control. The pit fans are sized for 2,800 cfm total which equates to 4 air changes per hour at 50% speed.

125W heat lamps provide heat to the newborn pigs during the winter months for the first 15 to 20 days after birth. The heat lamps are used for 7 to 10 days after birth during summer months.

ii) Nursery –

The HVAC in the nursery barn has been modeled based on existing drawings and information provided by the owner. Nursery barn temperatures are kept at 90°F for the first week when the piglets are introduced and then reduced by 4°F per week to 70°F. The office area's gas fired furnace keeps the office at 72°F. The nursery facility has gas fired unit heaters for the heating season. No mechanical cooling is provided for the building. Cooling is accomplished by thermostatically controlled fans. These fans stage on as the temperature increases to maintain the space temperature within 2 to 3° F of the outdoor temperature. Pit fans operate continuously for ventilation and moisture control.

Pit exhaust fan operation is defined according to owner provided data and is sized for 1,600 cfm per room. They operate at 50% during winter months to maintain the required 4 air changes per hour for moisture control and 100% during summer months for moisture control and cooling.

iii) Finishing –

The HVAC in the existing building has been modeled based on existing drawings and information provided by the owner. Finishing barn thermostat setpoint is in the high 60's to low 70's year round. The current facility has gas fired unit heaters for the heating season. No mechanical cooling is provided for the building. Cooling is accomplished by thermostatically controlled fans as well as direct evaporative cooling of the pigs when temperatures get above 80° F. These fans stage on as the temperature increases to maintain the space temperature within 2 to 3° F of the outdoor temperature.

Pit exhaust fan operation is defined according to owner provided data and is sized for 1,400 cfm per room. They operate at 50% during winter months to maintain the required 4 air changes per hour for moisture control and 100% during summer months for moisture control and cooling.

B. Internal heat gains

Heat load from the pigs is based on owner provided reports from the American Society of Animal Science and Iowa State University on heat and moisture production of swine. The values used in the simulations are shown in the table and chart below. The reports use different equations for calculating typical heat output for piglets, nursery pigs and finishing pigs. Each phase was treated independently without attempting to normalize the heat output between the different stages.

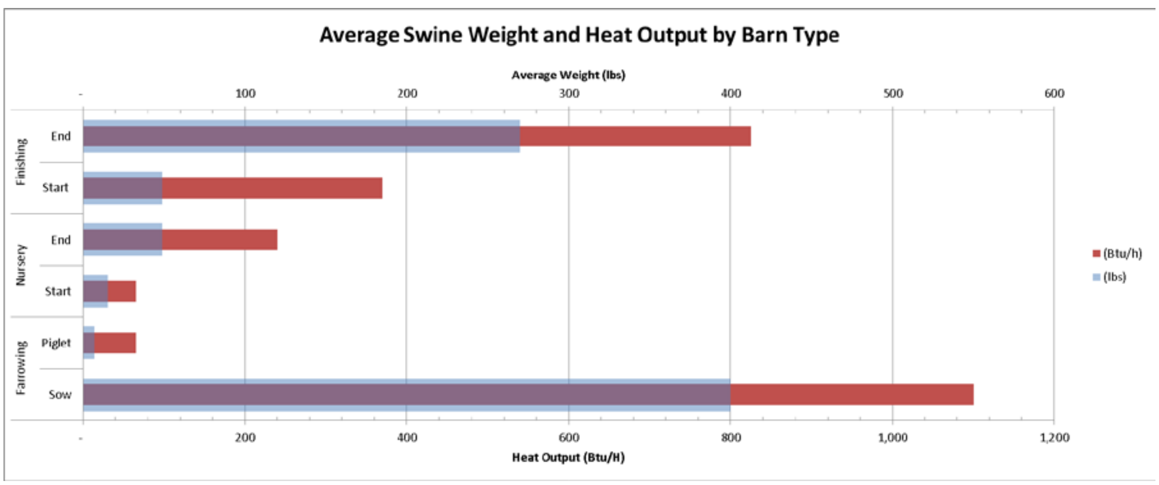
Effects of reduced nocturnal temperature on pig performance and energy consumption in swine nursery rooms

November 25, 2014 American Society of Animal Science - L.J. Johnston, M. C. Brumm, S. J. Moeller, S. Pohl, M. C. Shannon, and R. C. Thaler

Heat and Moisture Production of Growing-Finishing Gilts as Affected by Environmental Temperature

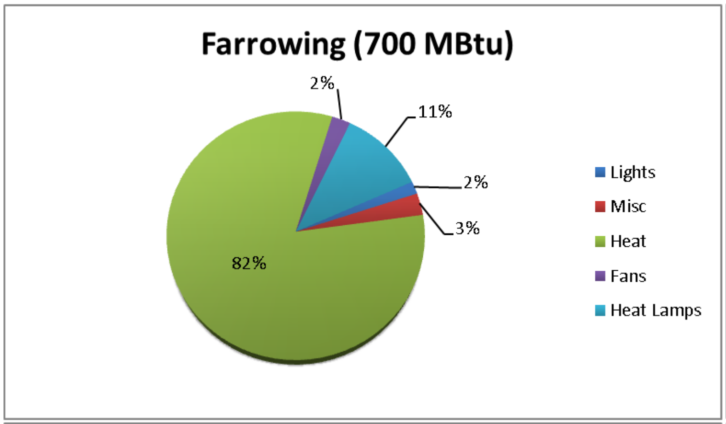
Iowa State University - Tami M. Brown-Brandt, John A. Nienaber, Roger Eigenberg, Hongwei Xin

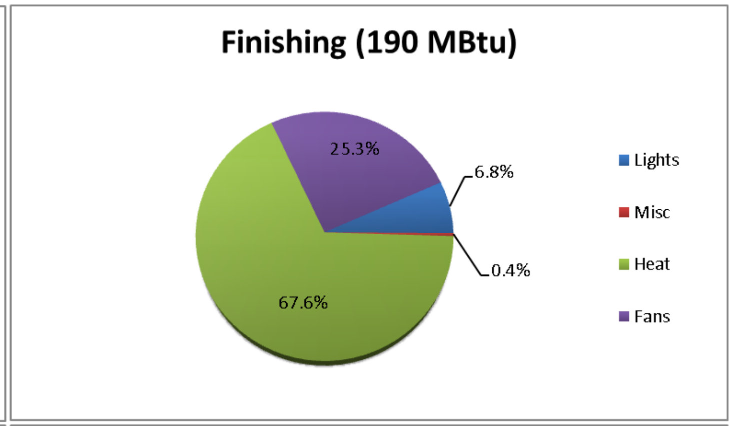
Barn Type		(lbs)	(Btu/h)
Farrowing	Sow	400	1,100
	Piglet	7	65
Nursery	Start	15	65
	End	49	240
Finishing	Start	49	370
	End	270	825

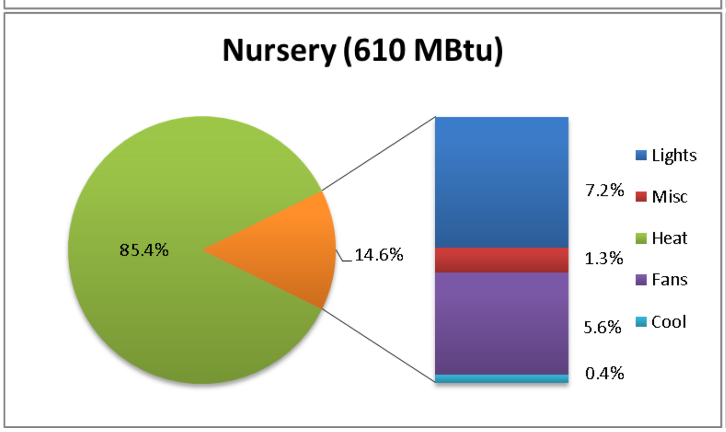


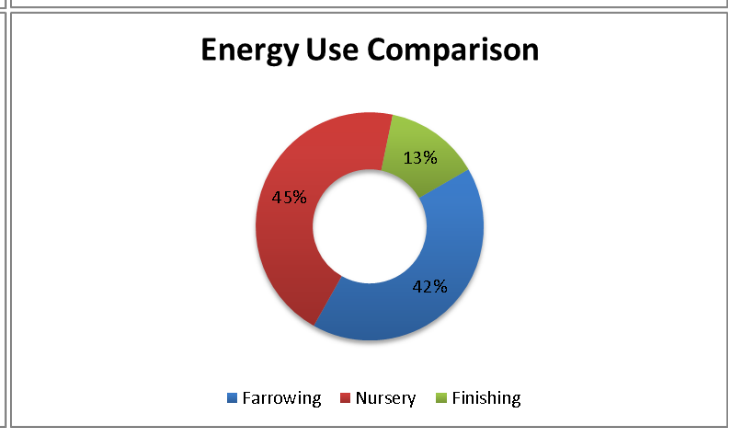
Baseline Building Calibration Results[1]

The charts below demonstrate the total annual energy use, in millions of Btu's (MBtu), of each of the three barn types and the breakdown by percentage of their end use energy. The predominant energy use for each barn is natural gas heating. The comparison chart shows the percent energy use by barn out of the total energy used by the swine program facilities.
The following calibration graphs show the average daily temperature and total heating energy requirement for each barn as well as the total daily fan power all in relation to the average outdoor ambient temperatures.



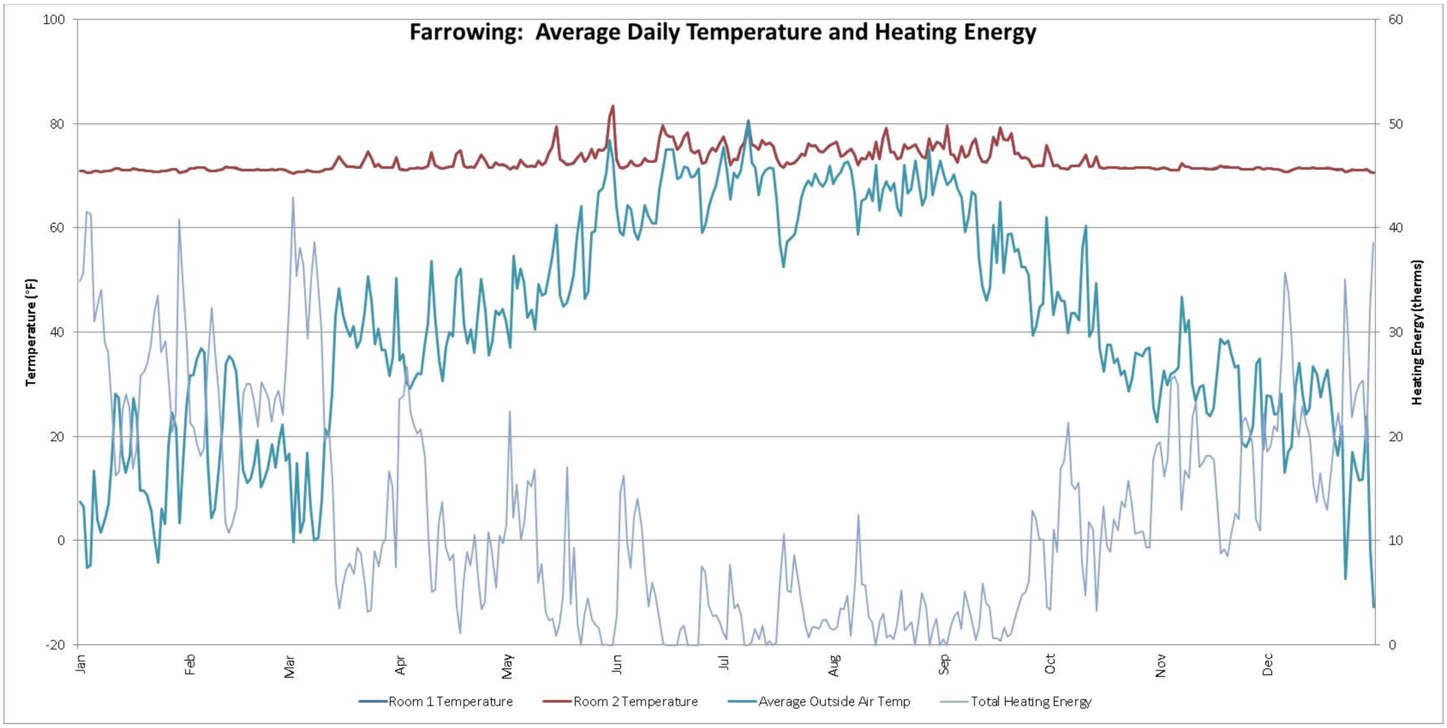


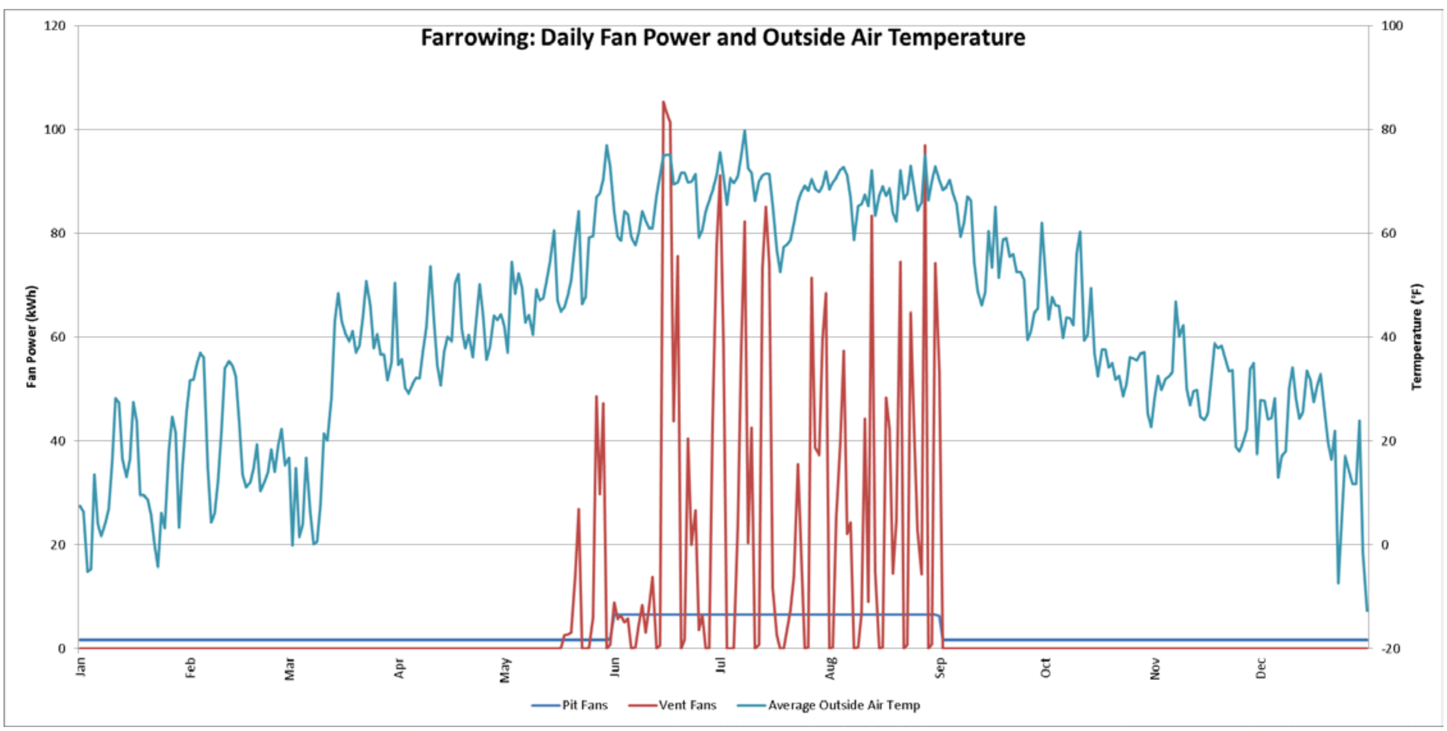




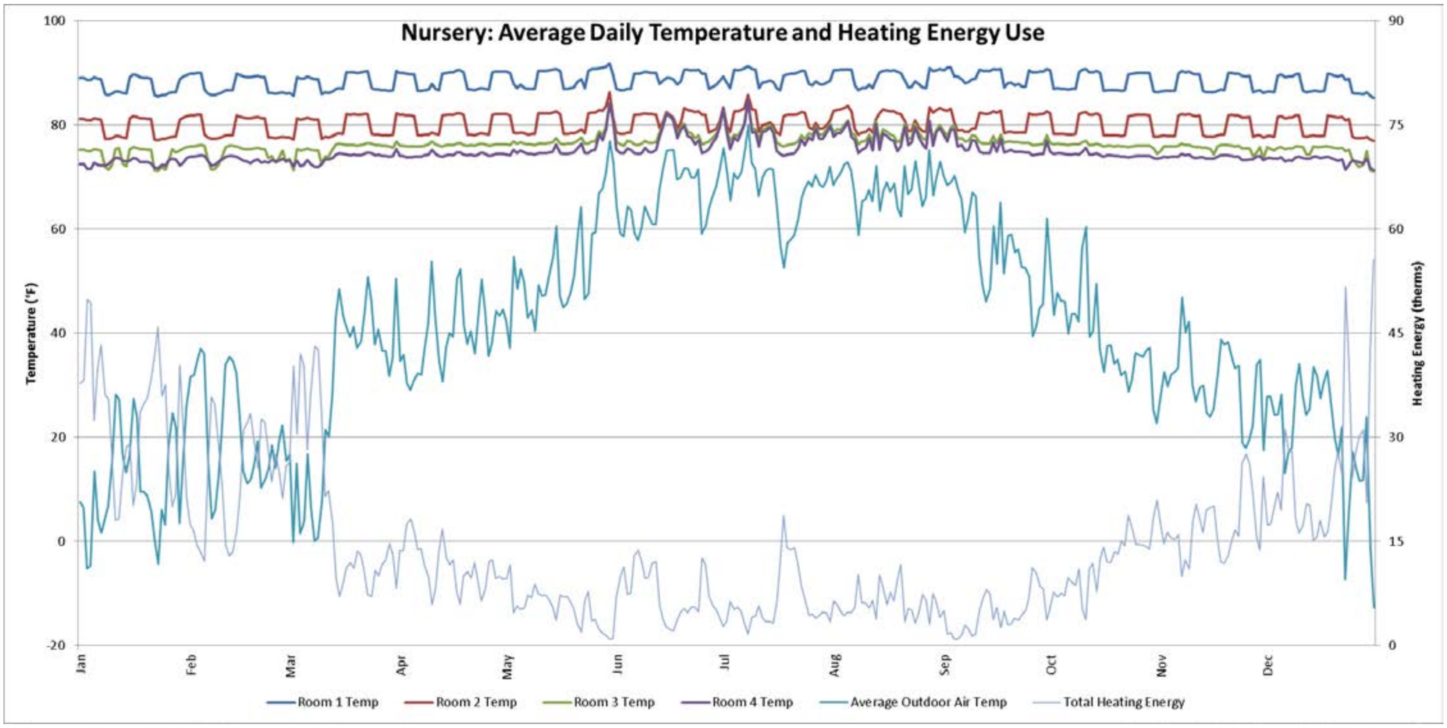
[1] Building energy modeling is a comparative tool used for understanding the relative impact of alternate strategies and systems on annual energy use and cost. Energy modeling is not an absolute predictor of actual energy use or cost and shall not be relied on to predict actual building performance. Changes in construction, variable weather conditions, operational characteristics, end-user input, miscellaneous electrical and gas loads, controls alterations and other unpredictable metrics prevent energy models from predicting the actual annual energy consumption of any facility.

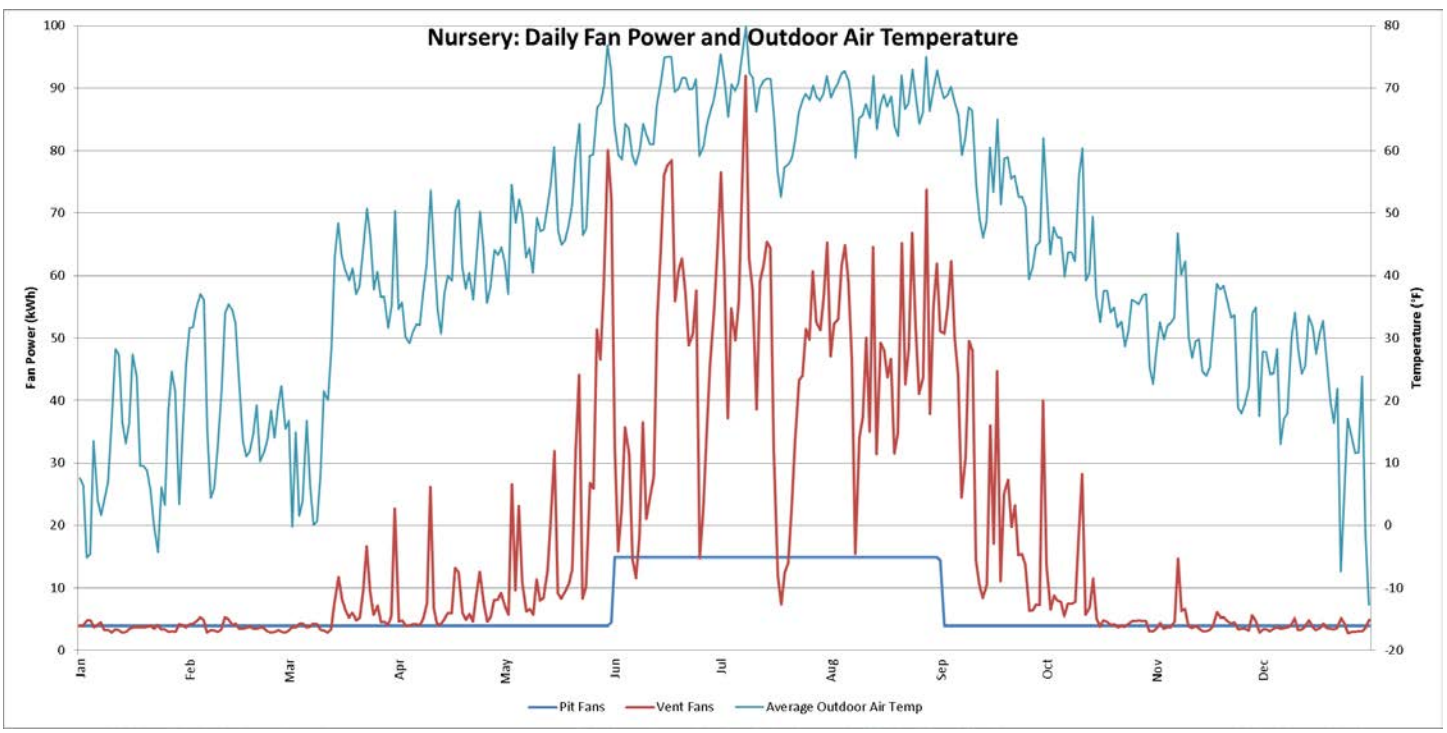
1) Farrowing barn baseline calibration graphs



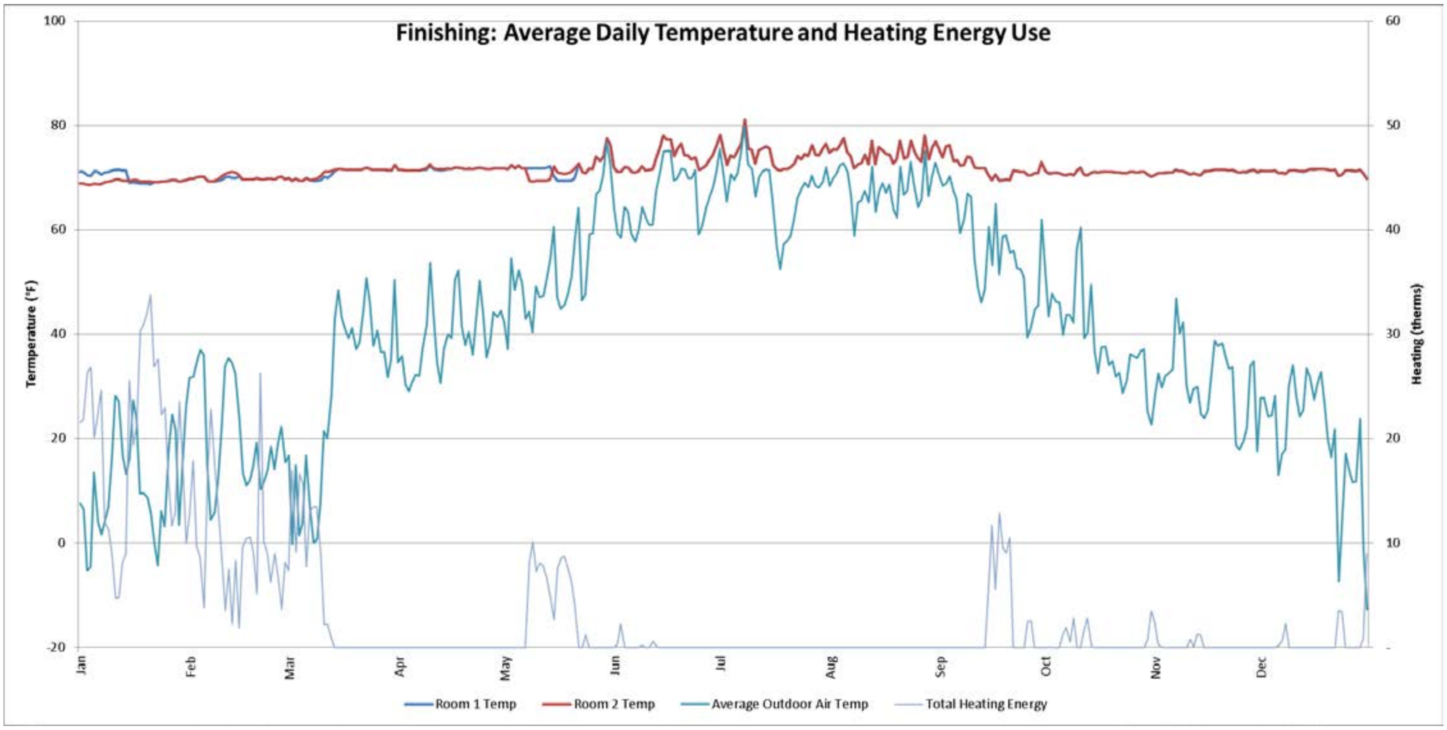


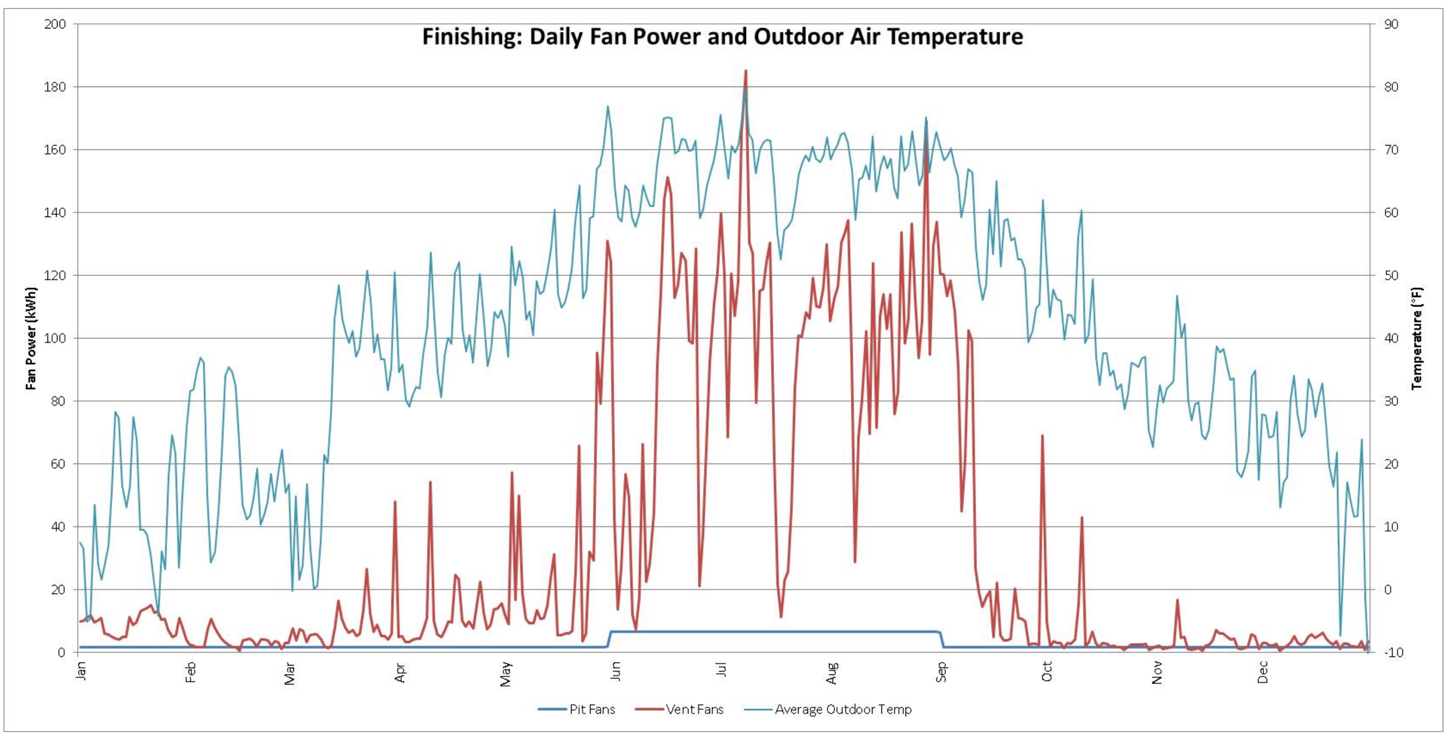
2) Nursery barn baseline calibration graphs





3) Finishing barn baseline calibration graphs





Energy Conservation Measures[2]

Energy conservation measures (ECMs) will be reviewed based on their return on investment, contribution to a net zero building and on their ability to improve the space conditions for the building occupants (swine and humans).

The energy conservation measures that were modeled are as follows:

1. Lighting
    a. Lighting
        i. LED conversion
        ii. Photo sensors (daylight harvesting)
2. Ventilation
    a. Natural ventilation
        i. Solar chimney
        ii. Curtain sided barns
    b. Mechanical ventilation
        i. Earth tube outside air pre-conditioning
        ii. Exhaust air energy recovery
        iii. Variable speed fans
        iv. High volume low speed (HVLS) overhead fans
3. Heating and cooling
    a. Heat lamp controllers (Farrowing)
    b. Night temperature setback
    c. Renewable energy
    d. Mechanical energy
        i. Water-to-water heat pumps
        ii. Air conditioning (traditional)
        iii. Air conditioning (geothermal)

Lighting

- **Lighting ECMs**

  LED conversion - Nursery

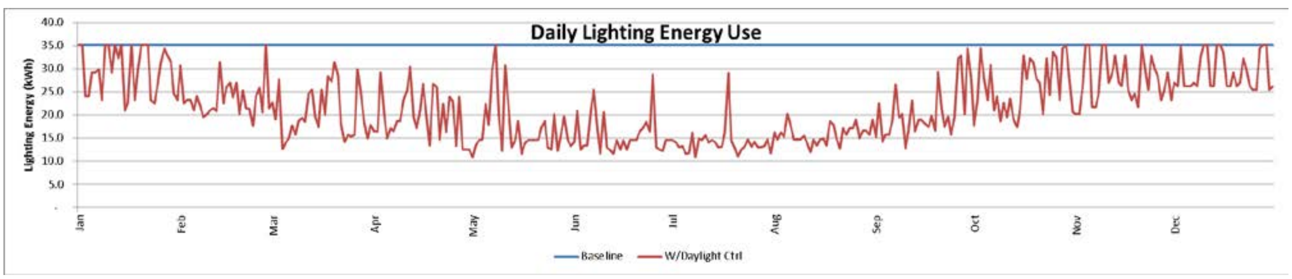
  Lighting power for the nursery comprises nearly half of the total electrical use on an annual basis. The lights are simulated as running for 8 hours per day, every day of the year. The current lighting is fluorescent with a total wattage of 4,560 watts with all lights running. The existing barn lighting is from T-12 fluorescent fixtures. A T-12 typically produces about 60 lumens per watt as opposed to LEDs that are about 90 lumens per watt.

  According to the 2002 Swine Care Handbook, the recommended lighting level for a nursery is 10 foot candles (fc). Based on this value an LED lighting design with an efficiency of 90 lumens/watt would result in a total lighting power for the nursery of about 1,200 watts. There is a larger savings in this barn based on the existing lighting being oversized. In addition to the energy savings, LEDs typically have a lifespan of 2 to 3 times that of fluorescent bulbs which would reduce the labor and replacement costs.

  The farrowing barn has similar potential for energy savings from an LED conversion. The finishing barn has already been converted to LED under a previous project.

[2] Building energy modeling is a comparative tool used for understanding the relative impact of alternate strategies and systems on annual energy use and cost. Energy modeling is not an absolute predictor of actual energy use or cost and shall not be relied on to predict actual building performance. Changes in construction, variable weather conditions, operational characteristics, end-user input, miscellaneous electrical and gas loads, controls alterations and other unpredictable metrics prevent energy models from predicting the actual annual energy consumption of any facility.

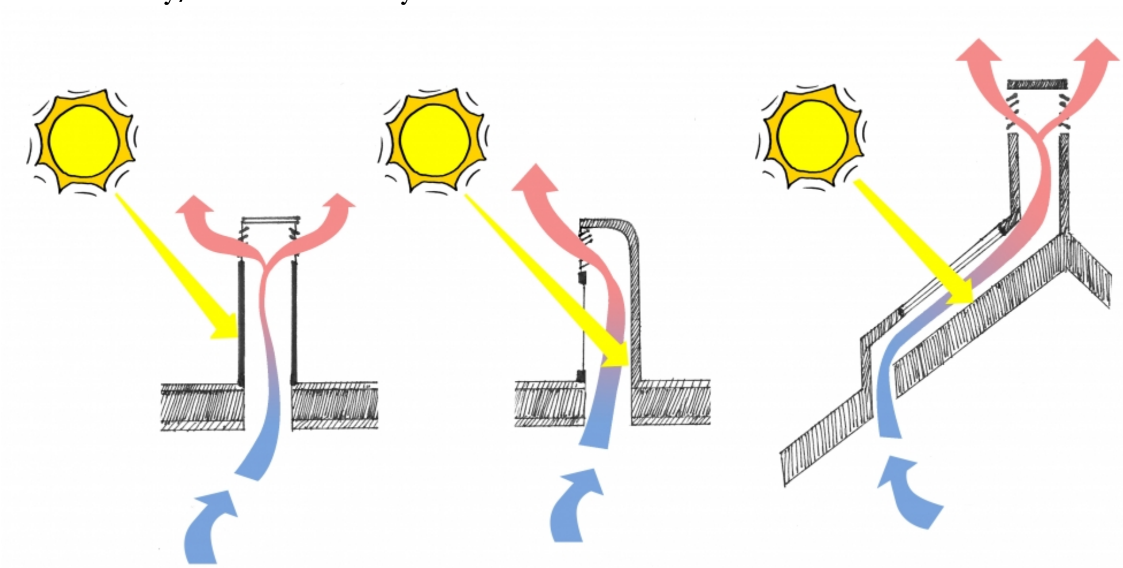
Daylight harvesting - Nursery
The existing lighting is controlled either manually or by automated scheduling. The building has windows that allow natural light into the spaces and the addition of a photometric controller would reduce the total energy consumed by the lighting over the course of the year. Based on the 2002 Swine Care Handbook, a value of 10 foot candles was used as the minimum lighting level desired for a nursery barn. The lighting energy was reduced by nearly 40% or about 400 dollars per year for this facility. This is using a basic on/off control strategy that utilizes inexpensive individual room controllers. The Daily Lighting Energy Use graph shown below shows the energy use of the lights as they are currently controlled vs with daylight sensor control.
This ECM currently applies to only the nursery because it is the only one of the three barns with existing windows. Any facility that has existing windows would be eligible for this ECM. As the heating load is primarily driven by the winter ventilation air, the reduction in envelope thermal value due to windows would not represent a significant change in the heating requirement in order to achieve daylighting savings. The peak heating load for the nursery occurs in the simulation at midnight in December with an outdoor temperature of negative eighteen degrees (-18° F). At this time, the total heating required is 215 kBtu/h. Of this, the building envelope load contributes about 6.5 kBtu/h with the windows representing about one quarter of that amount.



Ventilation

- **Natural Ventilation**

  Solar chimney/Thermal chimney-



Solar/thermal chimneys use the sun's heat to increase the stack effect drawing air out of the barn. A solar chimney could be sized to induce outdoor air into the barns without the use of fans. Ventilation is required 24 hours per day, so fans would still be required to supplement and back up the flow of the chimney when there is not sufficient temperature differential between the interior space and the chimney to maintain flow.

The nursery has a max ventilation rate of 74,000 cfm. In order to achieve this, a thermal chimney would require about 240 square feet of chimney cross sectional area that is about 10 feet tall and maintains a 50° F temperature rise vs the interior barn temperature. At a typical depth of one foot, the length of the chimney would be more than the full length of the barn. These values were derived from formulas in the 1997 ASHRAE Fundamentals handbook. If the temperature difference is less than 50° F there may still be airflow but it would be reduced from the desired rate.
The total fan energy use is 6,400 kWh at a cost of $615/year. Because of the size of the chimney required, the cost to retrofit, even with basic materials, would be at least $6,000, and at best would offset about 1/3 of the total fan energy resulting in a payback of around 30 years. There are other issues with the controllability of the air flow rate and the impact on the space temperature.

Curtain sided construction-
Curtain sided construction can eliminate a large percentage of the fan energy used for a barn but also increases the heating demand due to the reduced insulation value of the curtains. The nursery and farrowing barns require year round heating for the piglets and would not be well suited for curtain sided construction. This ECM was only modeled for the finishing barn.

- **Mechanical Ventilation**

Earth tube pre-conditioning-
This is a method of tempering the outside air that is required for ventilation and moisture control by drawing it through ductwork buried in the ground. The air will absorb or reject heat to the ground, and the reduced winter heat load is the primary benefit along with moderate summer cooling. This is at the expense of increased fan power due to the pressure drop caused by the required buried ductwork.
Data used for analysis of this ECM was taken from the article "Earth Tempering of Ventilation Air" from the Pork Industry Handbook, September 1985. The article was authored by Warren Goetsch from the University of Illinois, Larry Jacobson from the University of Minnesota, Randall Reeder from Ohio State University, and Dennis Stombough from Ohio State University. Per this paper, the required piping for each barn was determined using 10" diameter pipe at 300 cfm per 150 foot length and buried at a minimum starting depth of 6' below grade and sloped to a common sump location to handle condensation. The duct sizing indicated in this ECM is only intended to be used as a starting point for investigating the potential benefit of this strategy.

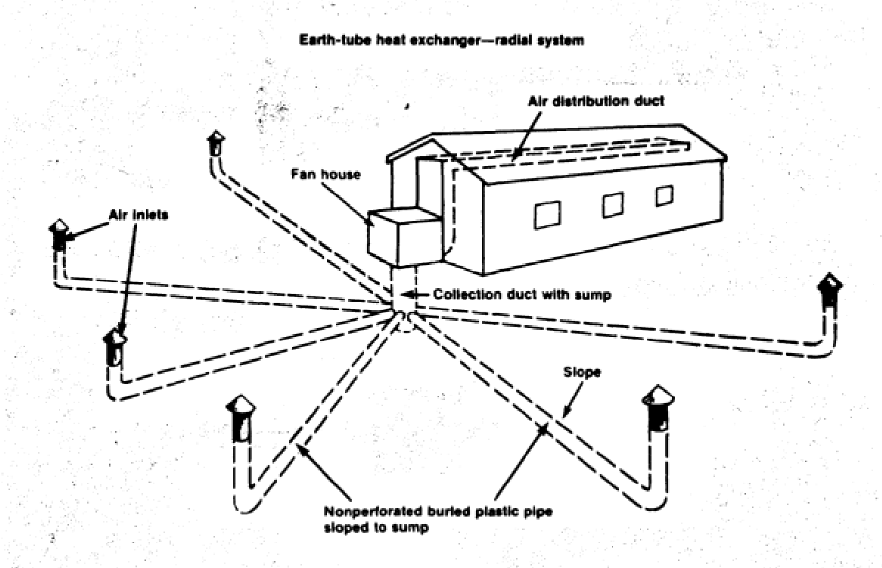
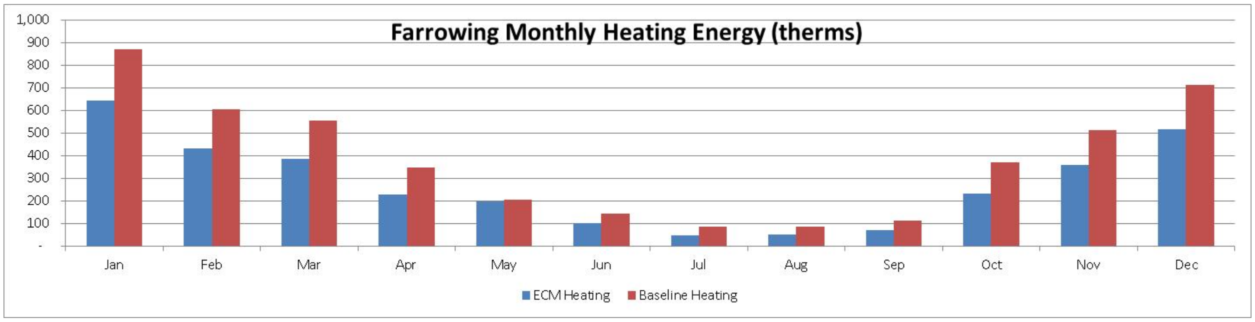


Figure 4. System layout using the wagon wheel or radial pattern.

i) **Farrowing –**

The total heating energy requirement is reduced by about 28% from 4,600 therms to 3,250 therms. The pit fan energy use increases by a little more than 2.5 times from 1,100 kWh to 2,800 kWh due to the increase in pressure drop from the earth tube ducting.

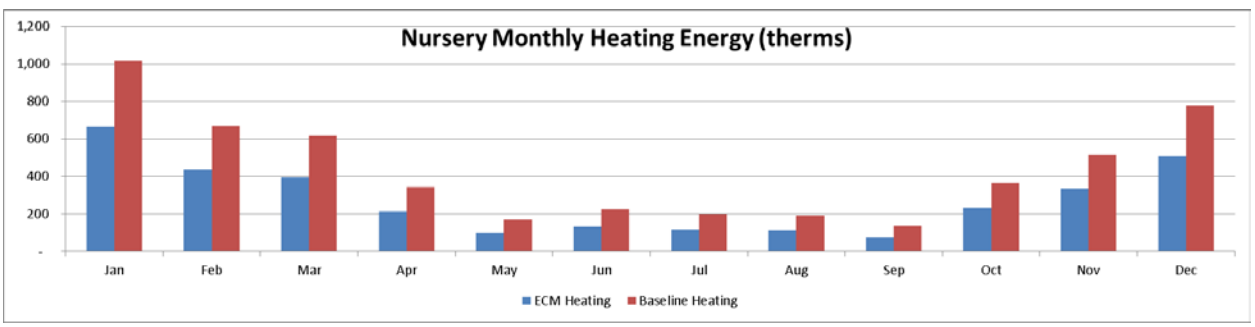
The winter minimum outside air flow rate to achieve 4 air changes per hour is 1,400 cfm. This would require a minimum of five 10" pipe runs with a rough cost of between $10,000 and $15,000 based on 2014 RS Means Mechanical Cost Data.



ii) **Nursery –**

The total heating energy requirement is reduced by about 36% from 5,200 therms to 3,300 therms. The pit fan energy use increases by a little more than 2.5 times from 2,500 kWh to 6,500 kWh due to the increase in pressure drop from the earth tube ducting.

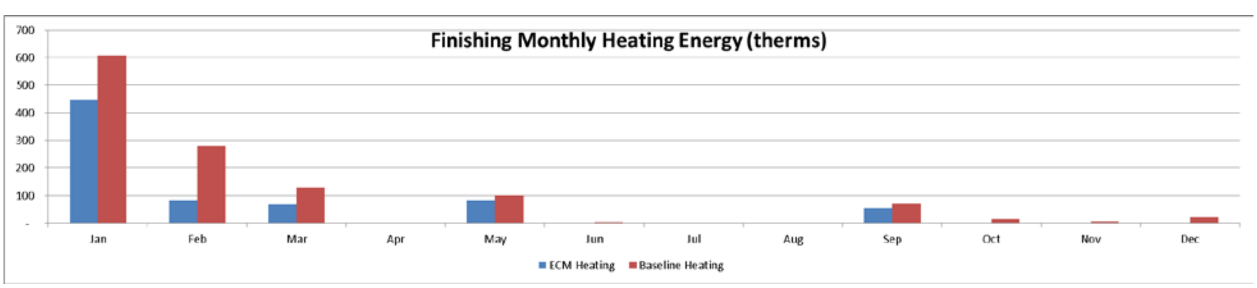
The winter minimum outside air flow rate to achieve 4 air changes per hour is 3,200 cfm. This would require a minimum of eleven 10" pipe runs with a rough cost of between $20,000 and $30,000 based on 2014 RS Means Mechanical Cost Data.



iii) **Finishing –**

The total heating energy requirement is reduced by about 40% from 1,200 therms to 700 therms. The pit fan energy use increases by a little more than 2.5 times from 1,100 kWh to 2,800 kWh due to the increase in pressure drop from the earth tube ducting.

The winter minimum outside air flow rate to achieve 4 air changes per hour is 1,400 cfm. This would require a minimum of five 10" pipe runs with a rough cost of between $10,000 and $15,000 based on 2014 RS Means Mechanical Cost Data.



Construction of the earth tube heat exchanger system requires deep trenches to be excavated representing the majority of the cost of this ECM. As long as the geology around the barn is favorable and the cost to excavate is not too high there is large potential for heating savings that could result in paybacks as low as 10 years.

Exhaust air energy recovery-
For the majority of the year the indoor temperatures are higher than the outdoor ambient temp and there is constant ventilation requirement that has a net cooling effect on the space as cooler air is drawn in and warm air is exhausted out. Recovering the heat from the warm pit exhaust air stream would help to reduce the heating demand on the space. There is greater potential to recover heat from an exhaust air energy recovery heat exchanger than with the earth tube system previously discussed due to the barn exhaust temperature being higher than the ground temperature as well based on the efficiency of the heat exchange material.
The downsides of this method are increased fan power due to the added pressure drop of the heat exchanger as well as reduced heat exchanger life due to the corrosive air that is exhausted from the building. An added constraint is that the typical exhaust air paths would have to be rerouted to facilitate energy recovery as well as implementation of daily or weekly cleaning and maintenance.
The article "Heat Exchangers in Swine Facilities" written by Larry D. Jacobson, University of Minnesota; Martin L. Hellickson, Oregon State University; Jay D. Harmon, Iowa State University was referenced during the investigation of this ECM.
Exhaust air energy recover was not modeled or included in the final summary primarily due to the maintenance required to operate.

Variable speed fans-
This ECM had initially been designed to analyze the use of a single central fan with variable speed control as a replacement for the distributed wall mounted fans currently in use. Due to the extensive conversion that would be required to the exhaust/ventilation system, the ECM was changed to look at control of the existing fans.
The use of a variable speed drive or a fan that has an electrically commutated motor can help to save energy when less than 100% of fan flow is required. The fans can be controlled to run at reduced RPM based on the interior temperature. Reducing the fan speed as opposed to cycling the fans on and off can show positive savings. To evaluate this, the finishing barn was tested by switching the calibration fan control from "cycling" to "variable speed" and there was a savings of about 7% of the total fan power.
There are drawbacks to this strategy including reduced static pressure, which can be an issue in high wind conditions as well as poor mixing of air in the space.

High volume low speed overhead fans-
This ECM is not being pursued based on physical space constraints and reduced life expectancy of equipment due to being located in corrosive environments.

<u>Heating and Cooling</u>

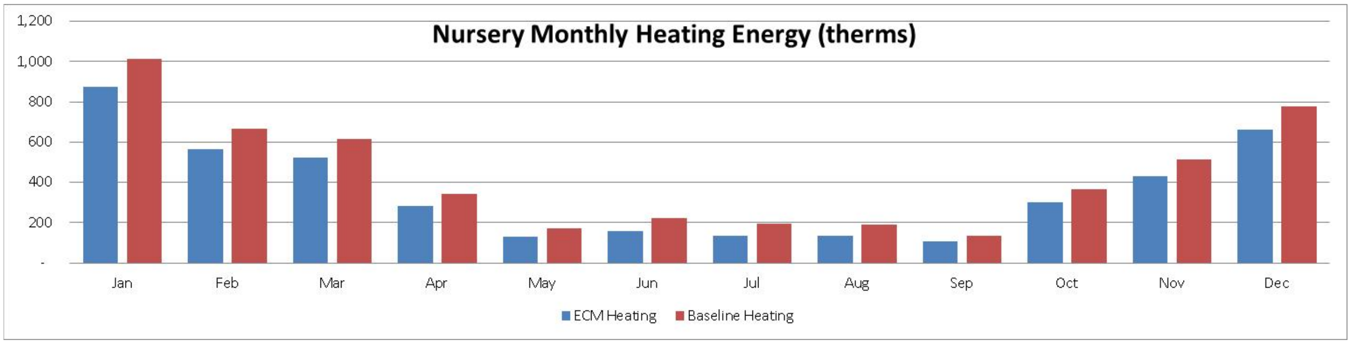
- **Heat Lamp Controllers (Farrowing barn only)**

  Heat lamps are used in the farrowing barn to keep the new born piglets warm. These are currently uncontrolled and run 24 hours per day when switched on.
  Several options exist for thermostatic control of heat lamps including the HerdStar MicroZone controller which can automatically adjust heat lamp output based on ambient conditions and piglet growth. HerdStar's literature states that when implemented in facilities without any automatic controls they typically see savings of around 40% with payback periods of less than one year in most cases.

- **Night Temperature Setback**

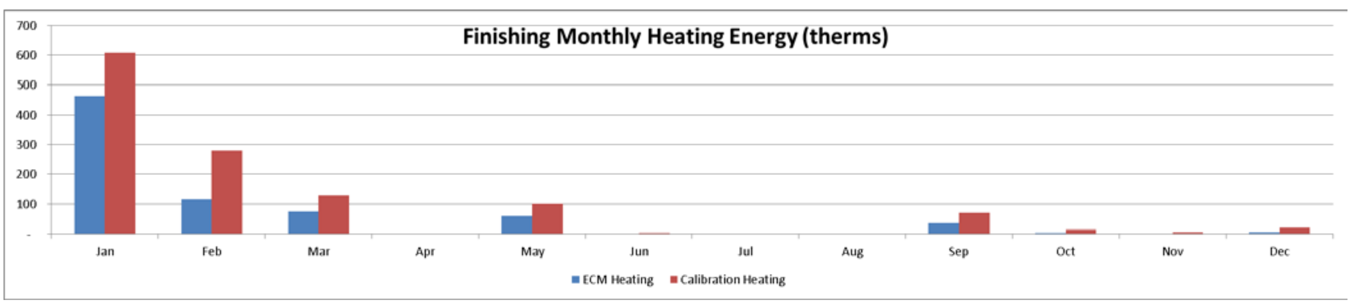
  i) Farrowing – N/A
  ii) Nursery –

This ECM uses a 15 degree temperature setback at night from 7pm to 7am. The setback temperature would vary depending on the size of the pigs in the room from no setback for the first week to 55° F during the last week they are in the nursery. The overall savings is about 18% and due to the relative low cost of adjusting temperature setpoint schedules, this is an effective ECM that helps reduce heating energy use. At the WCROC facility, this reduces natural gas usage by about 930 therms per year.



  iii) Finishing –

This ECM uses a 15 degree temperature setback at night from 7pm to 7am. The overall savings is about 38% and due to the relative low cost of adjusting temperature setpoint schedules this is an effective ECM that helps reduce heating energy use. The minimum setback temperature is 53° F. At the WCROC facility, this reduces natural gas usage by about 470 therms per year. The higher savings for the finishing barn is due to the higher heat output by the larger pigs as well as the whole barn being setback to 53° F as opposed to the higher temperatures required during setback in the nursery.

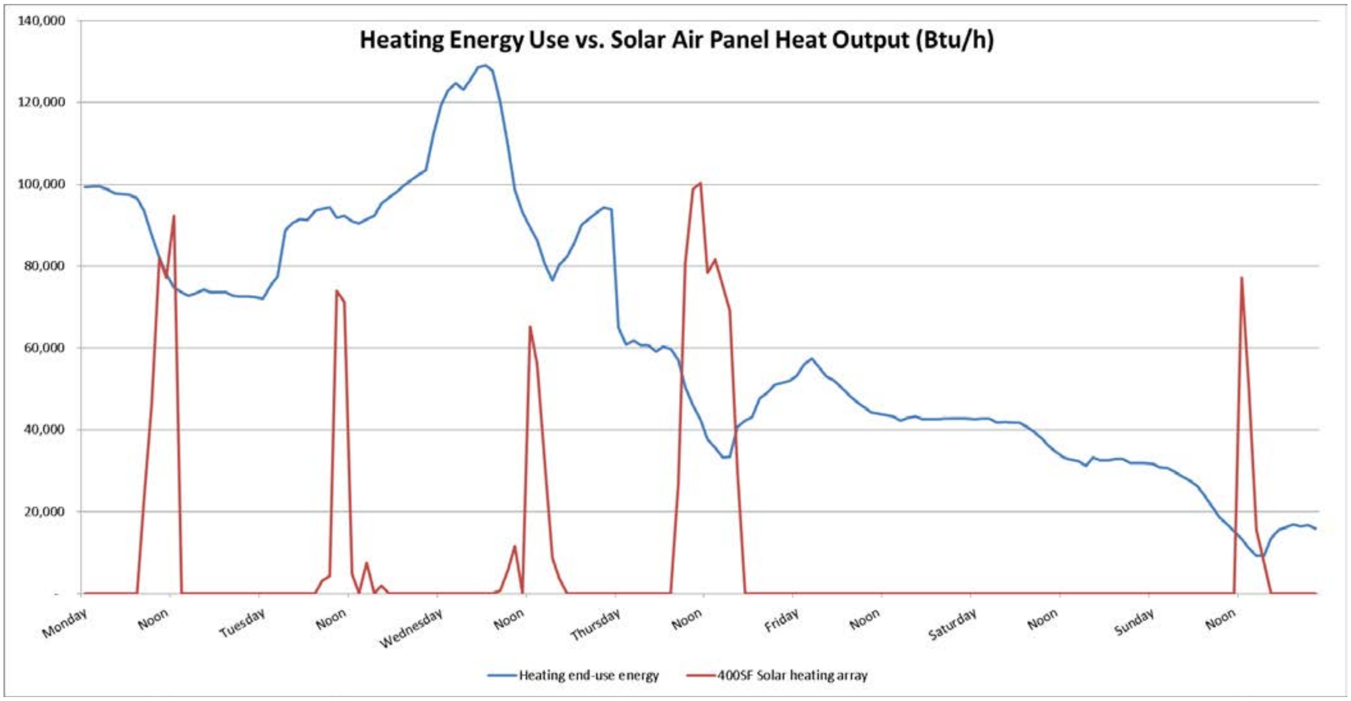


The simple paybacks of this ECM are less than one year due to the low cost of implementation. The cost associated with this was assumed to be a single visit from a controls contractor.

- **Solar Air Heating**

The barns require a large amount of outside air that is required for moisture and contaminant control. Solar air heating panels can provide free heating but only during daylight. Outside air is required 24 hours per day, so there is only a partial offset to the heating requirement. It does have the potential to be constructed on site for a lower cost than commercially available panels, but at the cost of efficiency which is already quite low due to the heat capacity of air.

The following graph shows a typical week in February. The window for free heat is about 8 to 9 hours and this correlates with the time of day with the lowest heating demand. This is based on a 400 SF south facing solar collector.



- **Water-to-water Heat Pump (Simultaneous heat/cool)**
  This ECM is being specifically targeted toward the farrowing barn due to the need for simultaneous heating and cooling of the piglets and sows. The system would consist of a water to water heat pump that would supply approximately 90-100° F water to hydronic heating pads in the piglet crates and 70° F water to cooling pads in the sow crates. The system would be sized to replace the existing infrared electric heat lamps that serve the piglet areas. The system would be controlled to maintain a desired surface temperature for the piglets and any available cooling capacity would be sent to the sow crates.
  In addition to eliminating the need for the heat lamps, this system would allow lower overall space temperatures in the barns, reducing the natural gas heating load.

  i) Farrowing –

  The heating lamps total 4 kW of total power which is about 13,500 Btu/h. This would mean that about 1 ton of cooling would be available for the sows. As part of a previous proposal, AKF sized a cooling only sow pad system at 7.5 tons, so it is not anticipated that this approach would significantly benefit the sows. The smallest commercial water-to-water units available are 2 tons and at the required temperatures the heat pump would use a little under 2 kW. The two circulation pumps would each have fractional horse power motors and would use less than 1 kW total. A temperature controller would be used to maintain the surface temperature of the heating pads so that the system would not be required to run continuously as the existing heat lamps are being controlled.

  Due to the limitations of the modeling software, this ECM is not able to be directly modeled. A conservative estimate for the savings would be to reduce the energy use of the existing heat lamps by one third. Due to the high cost of implementing this ECM, it may not be feasible based on the long payback timeframe but may be worth further investigation if there is a higher priority on animal comfort and net zero energy use.

ii) Nursery – N/A
iii) Finishing – N/A

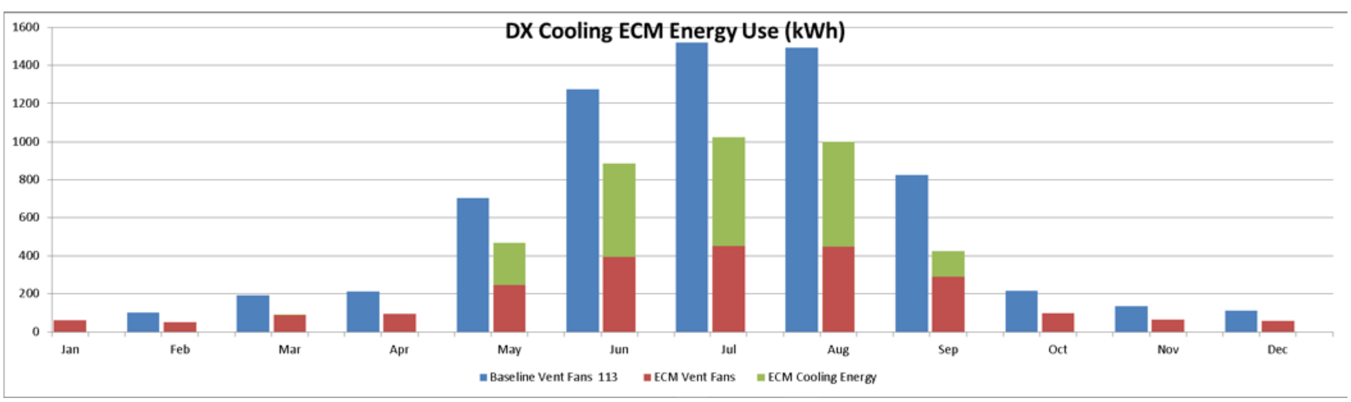
- **Air Conditioning - Traditional air cooled direct expansion (DX)**
  The barns currently do not have any cooling capability other than drawing large volumes of outside air through the space to remove heat. Based on the existing fans and typical design for enclosed barns a maximum air flow rate of 100 air changes per hour is possible. During a peak design condition the swine rooms will be approximately 2 degrees F warmer than the outdoor temperature during that hour.
  Adding mechanical cooling with air cooled equipment is not directly an energy conservation measure but done more as a way to improve the environmental conditions for the swine and farmers. The addition of cooling does allow for the peak outside airflow rate to be reduced while still maintaining reduced indoor temperatures. Limiting all fans to 50% of their peak flow rate saves enough fan power to offset the added power of the DX cooling equipment.
  In order to avoid issues with reduced equipment life and intensive cleaning and maintenance of the equipment, this ECM is modeled as conditioning outdoor air only with no recirculation of air from the space.

i) Farrowing –

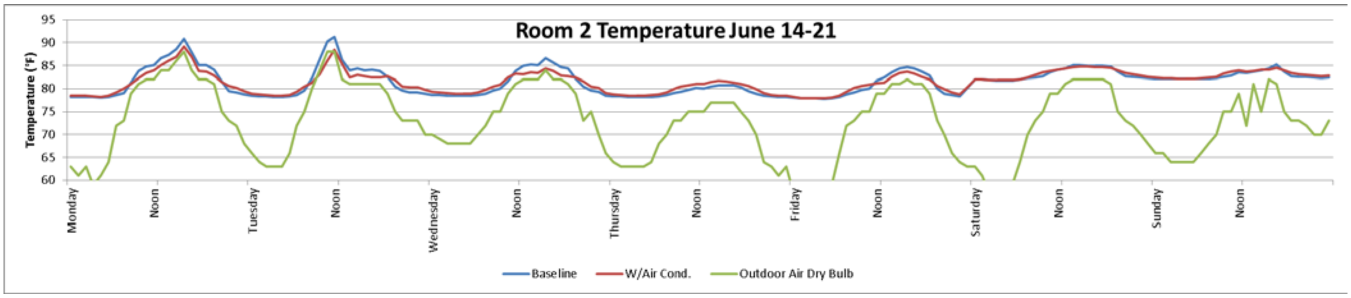
Air conditioning was not analyzed for the farrowing barn due to the heating requirement of the piglets.

ii) Nursery –

Eight tons of air conditioning was added to the nursery and used to reduce the temperature of the incoming ventilation air.

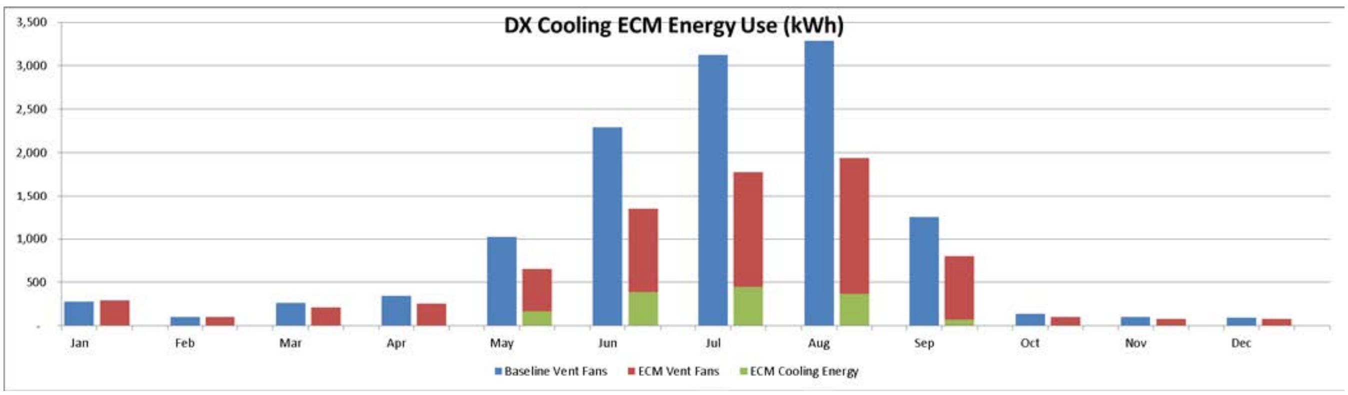


The following graph shows the effect of the air cooled DX system on the peak space temperature of one of the rooms in the nursery barn in the middle of June. The use of the air conditioning keeps the room up to 3 degrees cooler during peak conditions than by using a high air exchange rate only.

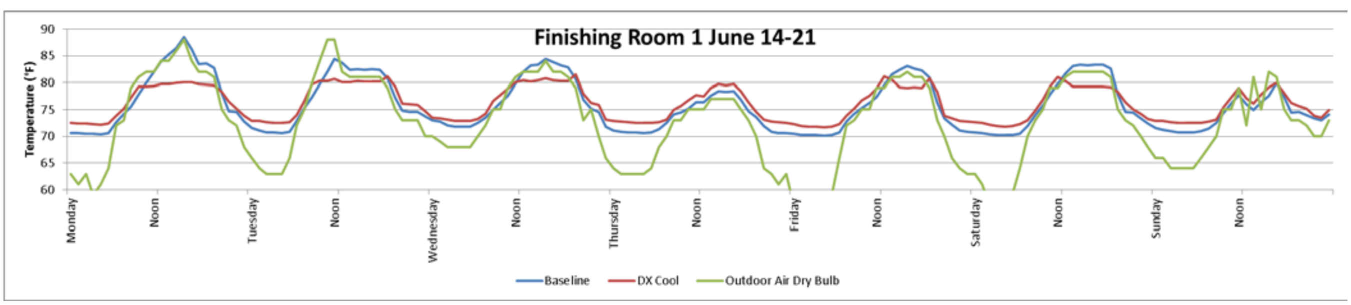


iii) Finishing –

Ten tons of air conditioning was added to the finishing barn and used to reduce the temperature of the incoming ventilation air.



The DX air conditioning system has a similar effect on the finishing barn while showing greater fan power savings.



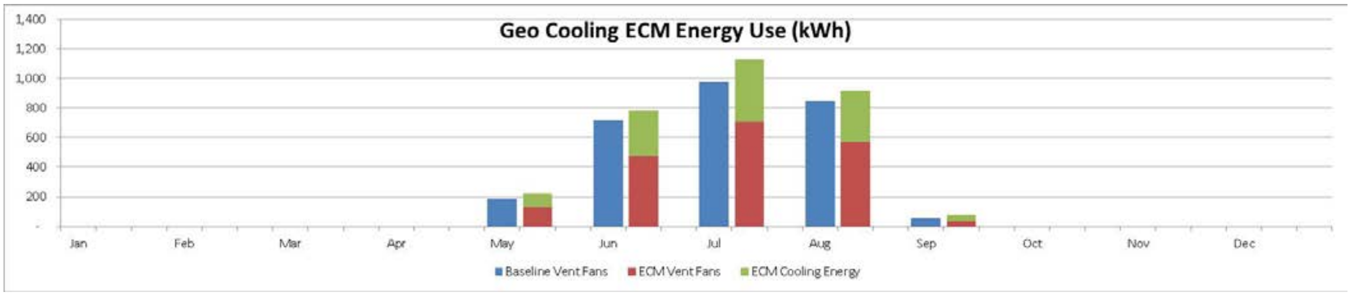
While traditional air conditioning has a positive effect on stabilizing and lowering the peak indoor temperatures of the barns as well as reducing the required fan power, there is very little savings in energy cost or energy use. This equates to long payback periods that do not justify this ECM unless the goal is to provide better thermal comfort for the pigs which may have positive results in health and growth.

- **Air Conditioning - Geothermal heat exchange**
  Similar to the air source DX cooling ECM, this option would add cooling capacity to the swine rooms and help to maintain the room temperatures closer to setpoints during warmer summer conditions. Due to the use of the well field, the system is also capable of heating the barn. The geothermal heat exchange system rejects heat to the ground during the cooling season and extracts heat from the ground during the heating

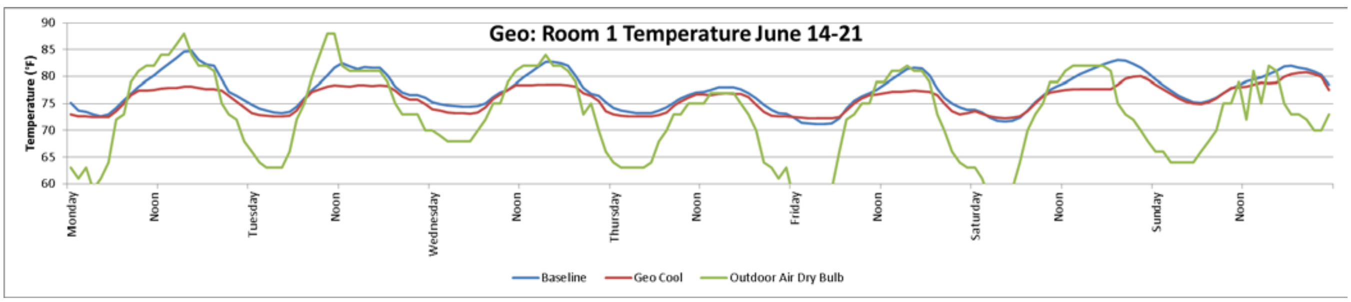
season. Due to an imbalance in the heating and cooling profile, the well field must be oversized to prevent possible freezing conditions.

i) Farrowing –

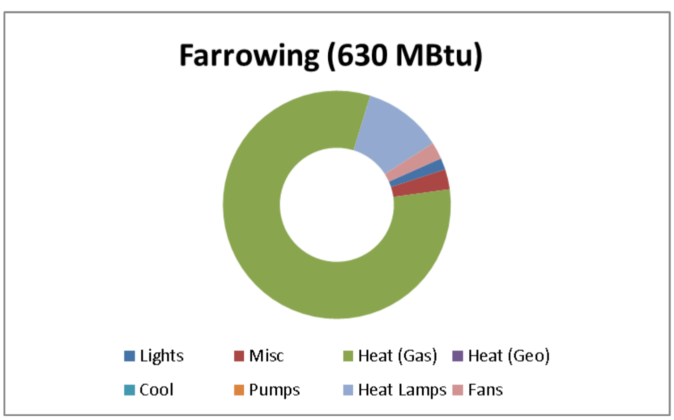
The geothermal air conditioning would be sized to both heat and cool the entire barn. This would require about 7.5 tons of capacity per room in order to offset the full heating load. A typical installation would require one 200 foot deep vertical well for each ton of cooling. The HVAC system would consist of air handling units that would heat or cool the ventilation air.

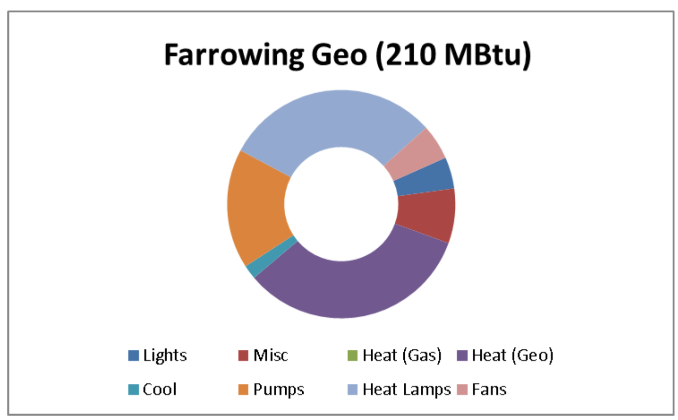


The following graph shows the effect of the geothermal system on the peak space temperature of one of the rooms in the farrowing barn in the middle of June. As the geothermal system has been sized for heating capacity, this means there is additional cooling capacity that keeps the peak indoor temperature lower than with the air cooled DX system.



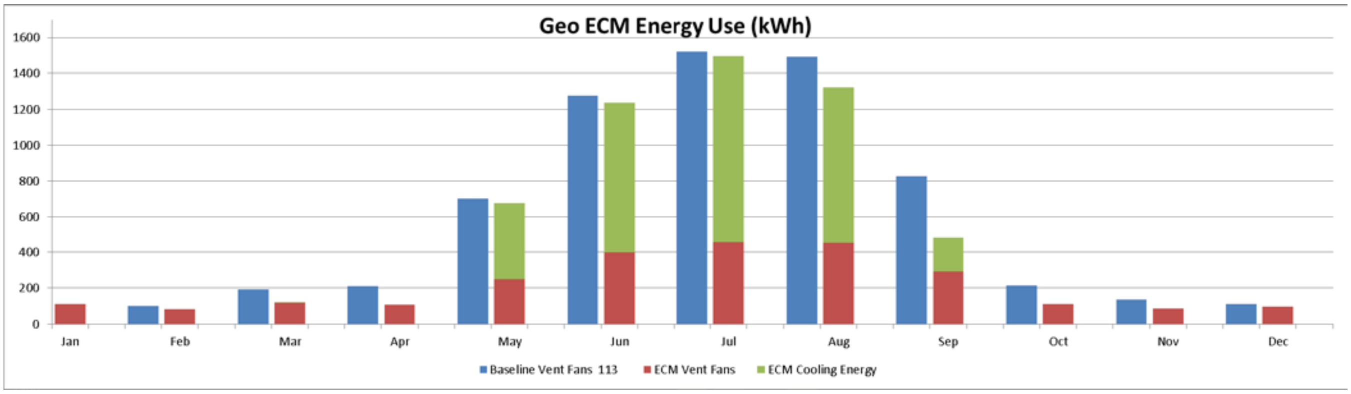
These charts show the effect of converting the full heating load over to the geothermal system as well as adding cooling. The result is a large reduction in total energy use as the primary benefit.



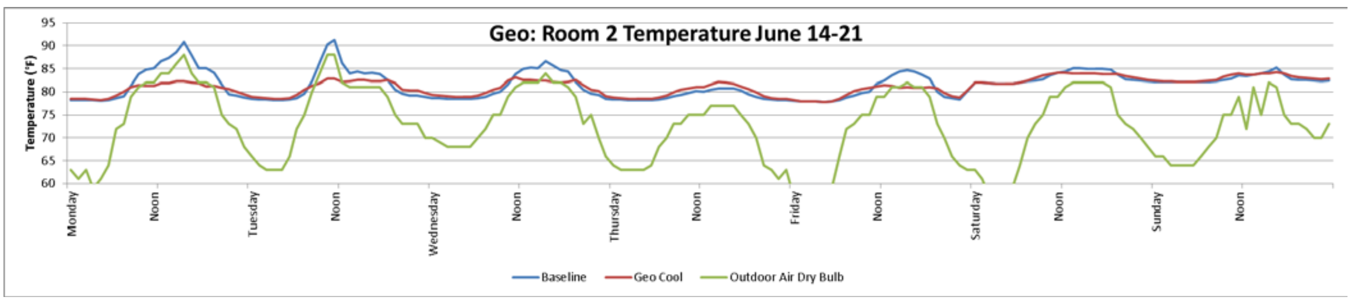


ii) Nursery –

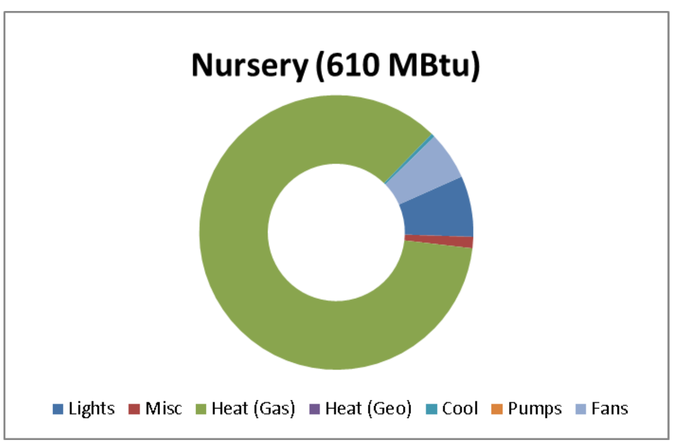
The geothermal air conditioning would be sized to both heat and cool the entire barn. This would require about 10 tons of capacity per room in order to offset the full heating load. A typical installation would require one 200 foot deep vertical well for each ton of cooling. The HVAC system would consist of air handling units that would heat or cool the ventilation.

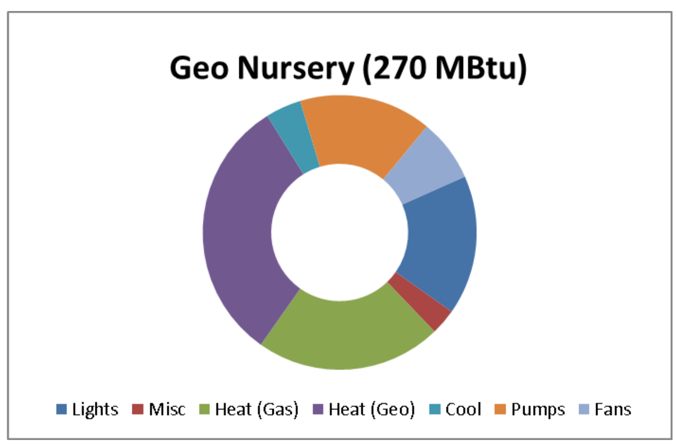


The following graph shows the effect of the geothermal system on the peak space temperature of one of the rooms in the nursery barn in the middle of June. As the geothermal system has been sized for heating capacity, this means there is additional cooling capacity that keeps the peak indoor temperature lower than with the air cooled DX system.



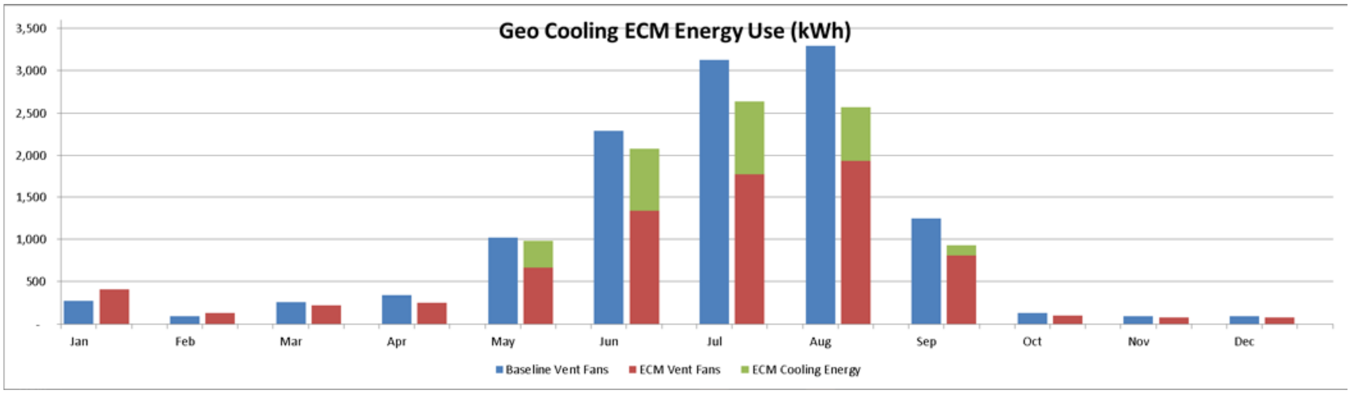
These charts show the effect of converting the full heating load over to the geothermal system as well as adding cooling. The result is a large reduction in total energy use as the primary benefit.



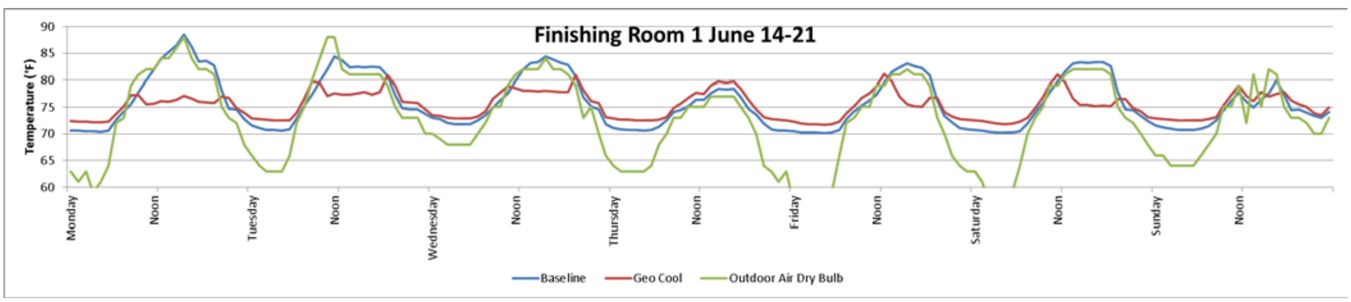


iii) Finishing –

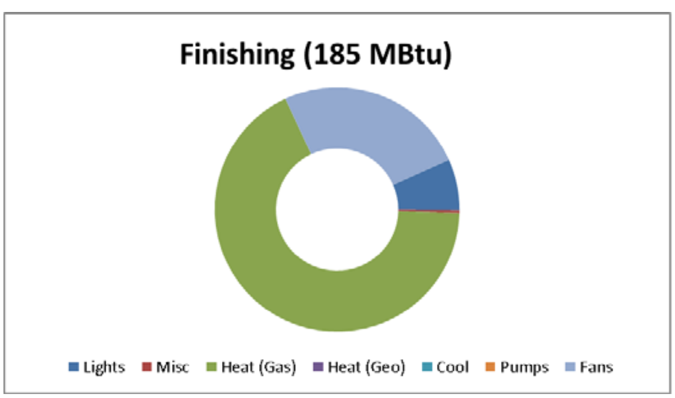
The geothermal air conditioning would be sized to both heat and cool the entire barn. This would require about 8 tons of capacity per room in order to offset the full heating load. A typical installation would require one 200 foot deep vertical well for each ton of cooling. The HVAC system would consist of air handling units that would heat or cool the ventilation air.

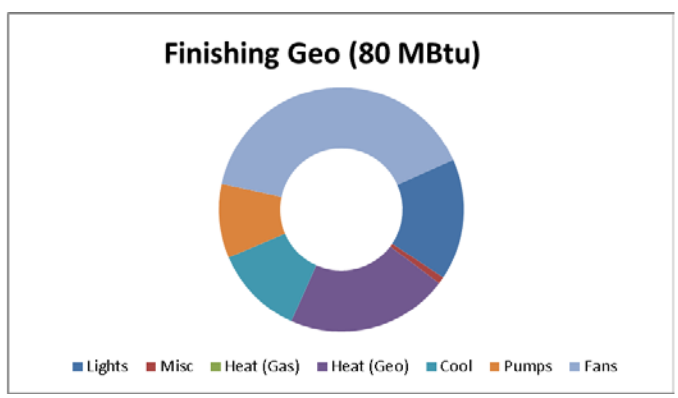


The following graph shows the effect of the geothermal system on the peak space temperature of one of the rooms in the finishing barn in the middle of June. As the geothermal system has been sized for heating capacity, this means there is additional cooling capacity that keeps the peak indoor temperature lower than with the air cooled DX system.



These charts show the effect of converting the full heating load over to the geothermal system as well as adding cooling. The result is a large reduction in total energy use as the primary benefit.





While the geothermal option represents an overall energy use reduction, the cost of electricity is higher so there are not large energy cost savings to go along with it. In addition, the installation cost of the vertical wellfield means that the simple payback for this ECM would be well over 100 years for all three barns. It would be possible to downsize the systems to reduce the installed cost, but this would still require the use of the natural gas heaters and there would be less of an energy savings. Unless the projects are seeking net zero energy use or had more favorable utility costs, such as propane for heating, this ECM may have too long of a payback timeframe to be considered further.

Summary Table –

ECM	Barn	Electrical Savings (kWh/yr)	Natural Gas Savings (therms/yr)	Propane Savings (gallons/yr)	Energy Savings (MBtu)	Energy Cost Savings ($)	Energy Cost Savings Propane ($/yr)	Installed Cost Opinion* ($)	Natural Gas Payback (yrs)	Propane Payback (yrs)
LED Lighting [Total fixture replacement]										
	Nursery	6,173	(88)	(97)	12.3	530	430	6,000	11.3	14.0
Daylight Harvesting										
	Nursery	4,999	(70)	(77)	10	430	351	1,500	3.5	4.3
Solar Chimney										
	Nursery	2,100	-	-	7.2	202	202	6,000	29.7	29.7
Curtain Sided Barn [New construction only]										
	Finishing	10,607	(224)	(246)	13.8	856	603			
Earth Tube Pre-conditioning										
	Farrowing	(1,736)	1,349	1,482	129.0	823	2,353	10,000	12.2	4.3
	Nursery	(4,388)	1,899	2,087	174.9	944	3,125	20,000	21.2	6.4
	Finishing	(1,873)	493	542	42.9	181	741	10,000	55.2	13.5
Variable Speed Fans										
	Nursery	1,979	-	-	6.8	191		1,000	5.2	
	Finishing	347	-	-	1.2	33		1,000	29.9	
Heat Lamp Controllers										
	Farrowing	7,431	(194)	(213)	6.0	573	353	3,000	5.2	8.5
Night Temperature Setback**										
	Nursery	-	928	1,020	92.8	690	1,734	500	0.7	0.3
	Finishing	-	471	518	47.1	340	880	500	1.5	0.6
Water to Water Heat Pump										
	Farrowing	7,500	-	-	25.6	722		50,000	69.2	
Air Conditioning (Traditional)										
	Nursery	2,593	(17)	(19)	7.2	237	218	80,000	337.6	367.1
	Finishing	3,265	33		14.5	338	314	80,000	236.7	254.4
Air Conditioning (Geothermal)										
	Farrowing	(30,671)	4,607	5,063	356.0	427	5,653	175,000	409.8	31.0
	Nursery	(34,711)	4,634	5,092	345.0	59	5,314	200,000	3,389.8	37.6
	Finishing	(4,780)	1,229	1,351	106.6	441	1,836	150,000	340.1	81.7

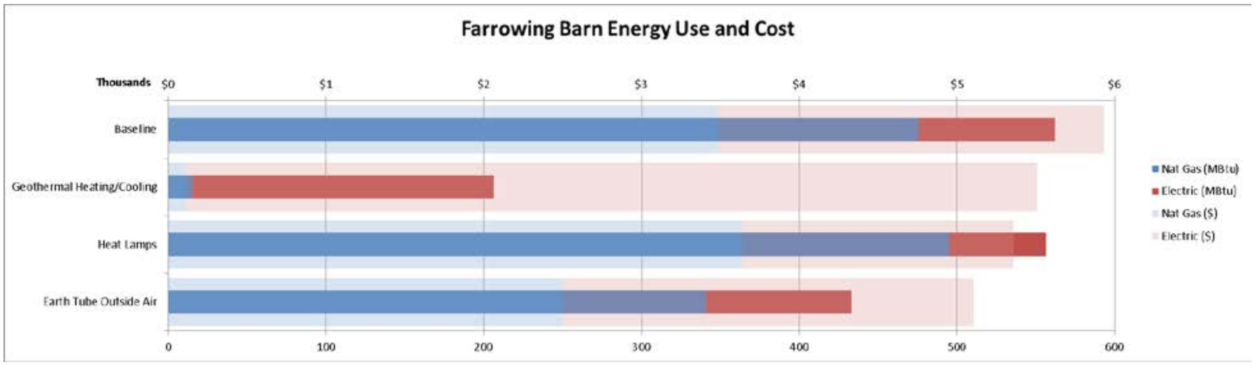
*Based on other recent projects or using RS Means data

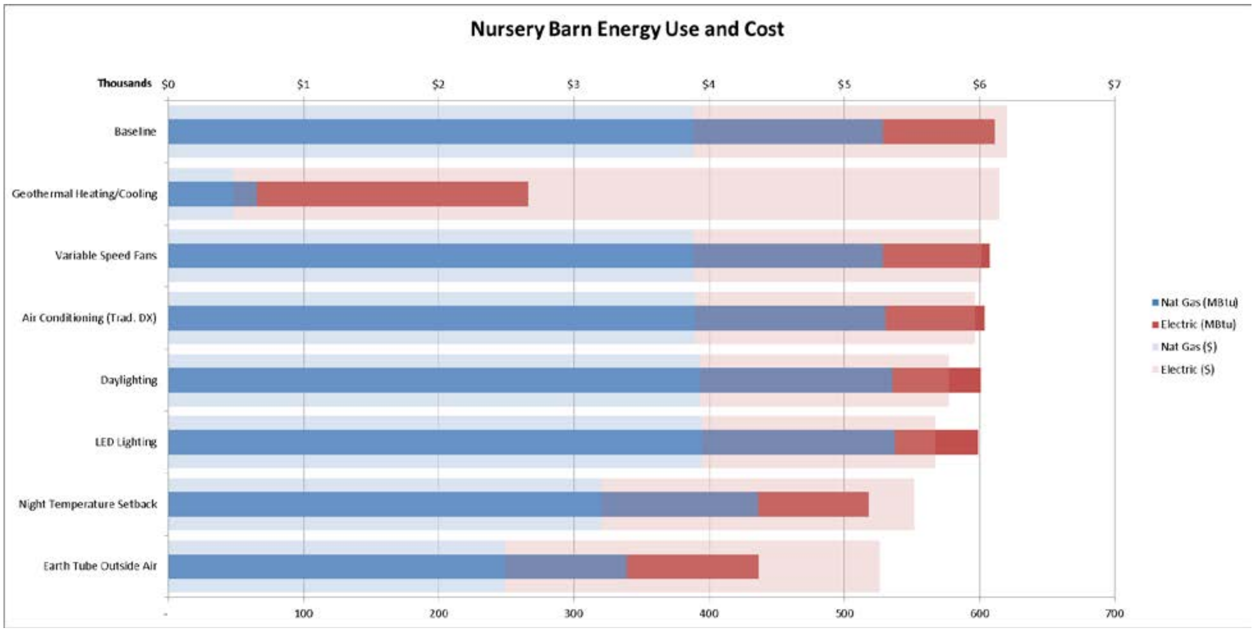
**This ECM would realize electrical energy use savings from reduced heating unit fan run time but is not shown due to modeling software limitations

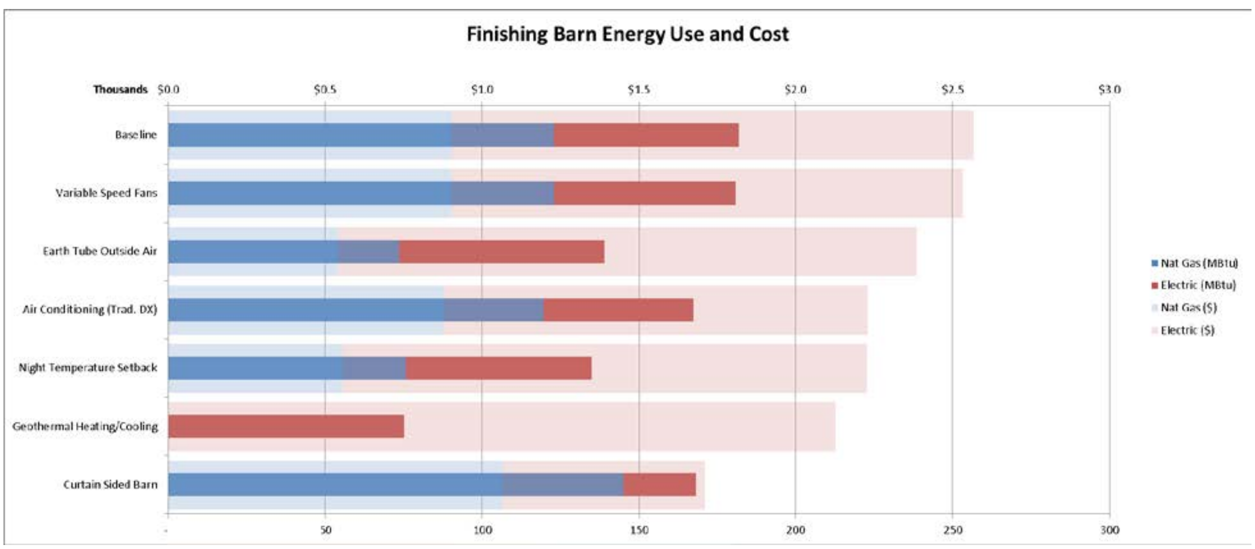
The following charts compare the annual energy use and energy cost for the calibrated baseline model against the ECM's that were simulated for each barn type. There are two sets of charts – one set showing natural gas as the heating fuel and one set showing propane as the heating fuel. The charts DO NOT consider the installation costs of the various ECMs, only the annual costs from fuel use.

The solid bars in the charts show the annual gas and electric energy usage while the wider translucent bars show the associated costs of that usage. Electricity usage and costs are shown with red bars and fuel (natural gas or propane) usage and costs are shown with blue bars. The charts show at a glance if a reduction in energy usage results in a reduction in energy costs.

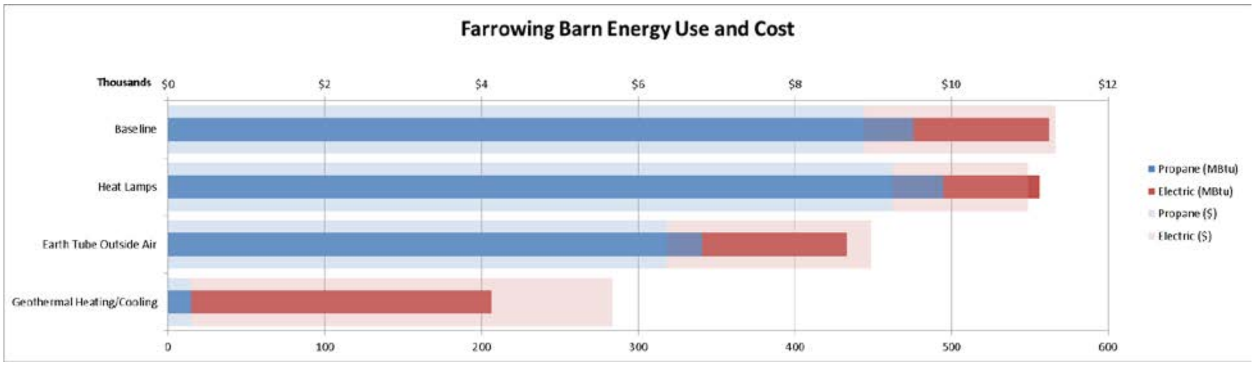
ECM Annual Energy Use and Cost Comparison Charts – Natural Gas Heating

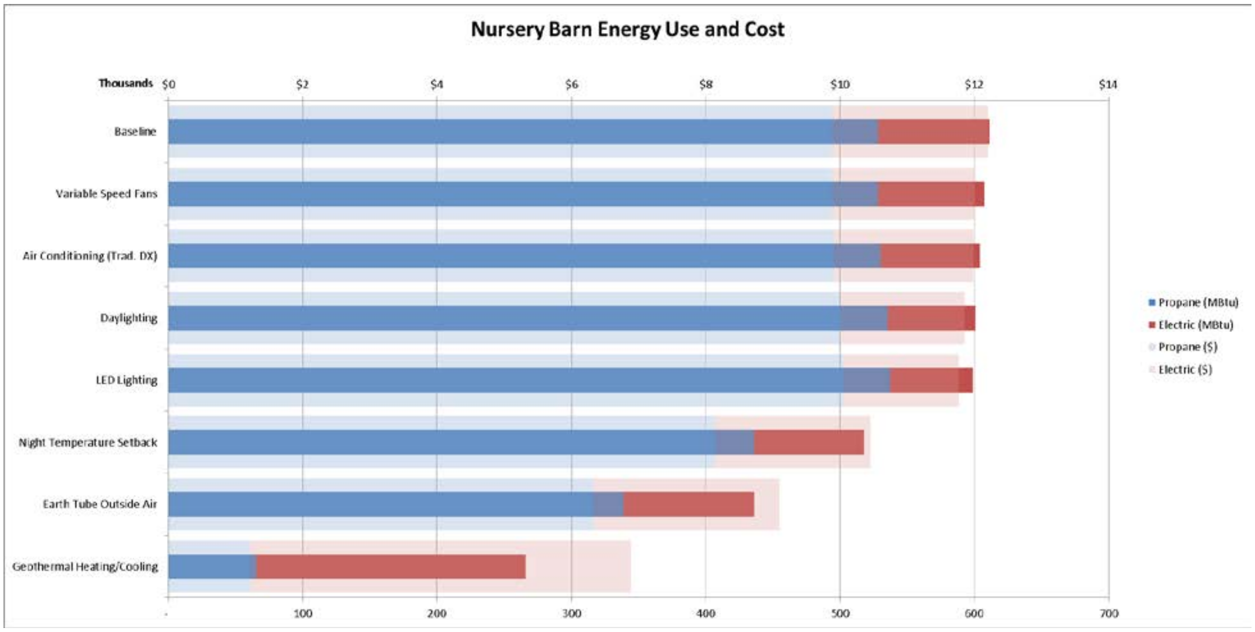


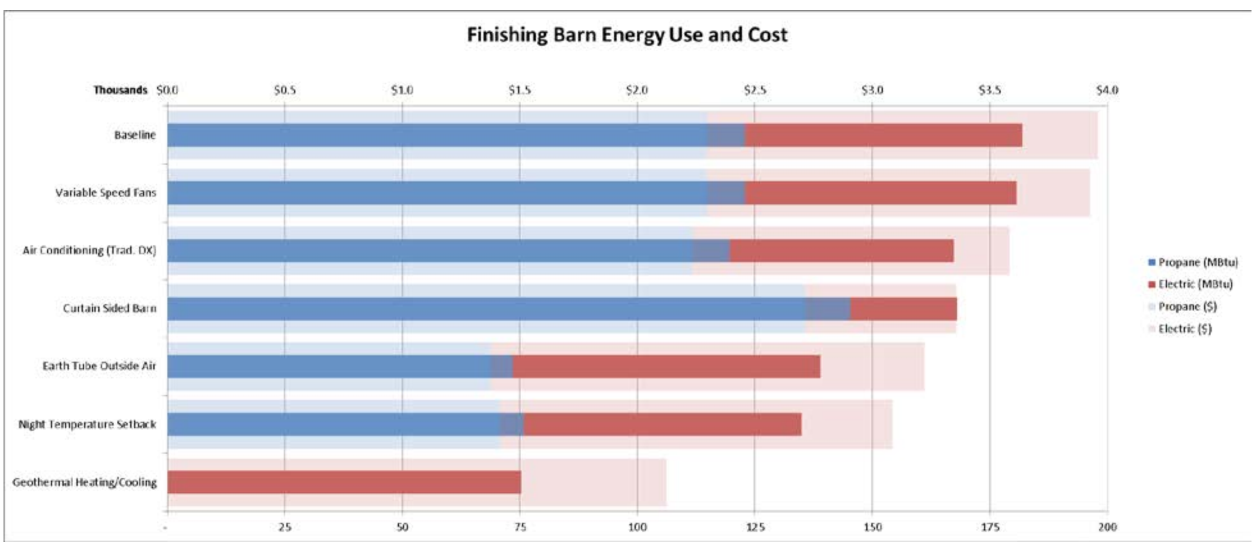




ECM Annual Energy Use and Cost Comparison Charts – Propane Heating







Conclusions

Outdoor air ventilation is required 24 hours per day in all swine barn types to control moisture and odor from the manure pits below the pens. This heating load caused by the ventilation is the largest energy user in the barns. ECMs that reduce the heating load of the required ventilation, such as earth tube pre-conditioning, can be very effective in reducing the energy use and cost of swine barns.

The decision to implement any of the above ECMs will largely depend on the goals of the owner. Options like LED lighting and night temperature setback are relatively simple to install and could provide value regardless of the goals. Other ECMs, like geothermal, have large energy and cost savings but will have high initial capital costs and the simple payback on investment may be too high to be effective on a cost saving basis. However, if the goal were to eliminate natural gas/propane usage and to have a Net Zero facility that could run on renewables, then geothermal may be worth the investment.

Combining ECMs will reduce the impact of some of the individual measures but can result in a final product that has a great savings and shorter simple payback. This would require further energy modeling to determine the value of the different combinations of options. The driving factor in the cost of the geothermal option is the heating load it is sized to handle. As this load is reduced through ECMs like earth tube pre-conditioning and night temperature setback the size and cost of the geothermal wellfield will decrease and make it a more attractive solution.

Funding Acknowledgment

LCCMR-This project was supported by The Minnesota Environment and Natural Resources Trust Fund as recommended by the Legislative - Citizen Commission on Minnesota Resources (LCCMR) Project #: FY 2014 - 122E Michael Reese Project Manager.

The Trust Fund is a permanent fund constitutionally established by the citizens of Minnesota to assist in the protection, conservation, preservation, and enhancement of the state's air, water, land, fish, wildlife, and other natural resources. Currently 40% of net Minnesota State Lottery proceeds are dedicated to growing the Trust Fund and ensuring future benefits for Minnesota's environment and natural resources.

Joel Tallaksen

West Central Research and Outreach Center

University of Minnesota

Version 1.1

Summary Activity 3 of LCCMR Project FY14 122E: Life Cycle Assessment of Swine Production

2013-2017

Table of Contents

Funding Acknowledgment

LCCMR-This project was supported by The Minnesota Environment and Natural Resources Trust Fund as recommended by the Legislative - Citizen Commission on Minnesota Resources (LCCMR) Project #: FY 2014 - 122E Michael Reese Project Manager.

ENVIRONMENT AND NATURAL RESOURCES TRUST FUND

The Trust Fund is a permanent fund constitutionally established by the citizens of Minnesota to assist in the protection, conservation, preservation, and enhancement of the state's air, water, land, fish, wildlife, and other natural resources. Currently 40% of net Minnesota State Lottery proceeds are dedicated to growing the Trust Fund and ensuring future benefits for Minnesota's environment and natural resources.

Disclaimer

All data, models, and predictions contained in this report are solely works of the authors. Neither the University of Minnesota nor the funding agency(ies) have reviewed these statements for accuracy or completeness. For comments or questions, please contact the author.

LCA Subsection Author:

Dr. Joel Tallaksen, Research Scientist, University of Minnesota

1 Introduction

Over the last decade, a prevailing trend in agriculture research and marketing is to examine the sustainability of agricultural products and the commodities used to make them. On the producer's part, these concerns are centered on avoiding the excess use of fossil energy and other costly resources. From the marketing standpoint, there is more demand from consumers and regulators for products that use less natural resources or have less impacts on the environment. This can be seen in press releases from companies such as McDonald's and Wal-Mart, which are adding environmental reporting requirements for their suppliers and for the products they purchase from those suppliers.

Although many companies have greatly improved the sustainability of their manufactured food products, they have done so mostly by making the changes that they can make at their manufacturing, packaging, and retail facilities. At their core, these products are agricultural products and are produced on farms across the country. Therefore, these companies need to drive changes in farming practices in order to continue to improve the sustainability of their products.

In terms of agricultural production, sustainability can have many different meanings. It can include factors such as animal welfare, environmental impacts, and social impacts. Many of the sustainability policies that companies are implementing are centered on environmental impacts of product production. Depending on the product and location, this can include issues like air, water, and soil pollution or other factors such as energy use or global warming potential. Probably the largest measure of sustainability in manufacturing is global warming potential. Global warming potential (GWP) is a measure of how much a product or process impacts global climate change and is usually expressed as the amount of carbon dioxide emitted by making a product. When a company states that their product is carbon neutral or has a low carbon footprint, it refers to a product that emits no or little carbon dioxide during its production, meaning it has zero or low GWP.

In a 2012 study by Thoma et al, swine production was found to have a GWP of 2.48 lbs of CO_2 equivalents per 4 ounce pork delivered to the consumer. Although a percentage of this was from energy used in meatpacking, packaging, and retail areas of the pork supply chain, the initial production of hogs on the farm was approximately 63% of the overall GWP. Thoma's study looked at swine production using a very high level national analysis of the swine supply chain. Unfortunately, this information is difficult to use for targeted improvements at the farm level. In addition, the study didn't report energy use for the swine system.

The work in this study was conducted to identify areas where farm operations could be changed to improve the downstream sustainability of the pork supply chain. In order to engage more pork producers at the farm level, a key focus was on areas where sustainability improvements would improve swine production economics. Therefore, much of the work looked at energy use in the swine production system. A typical Midwestern swine production system uses fossil-based electricity for ventilation and heating, natural gas for heating and hot water, and diesel fuel for tractor and vehicle use. Energy is a significant cost in swine production and has a notable impact on the global warming potential of swine farms. Additionally, indirect energy used to grow feed ingredients greatly increases the overall GWP of pork.

The study employed lifecycle assessment (LCA) methodology to track resource inputs and outputs of the system and to analyze the amount of fossil energy used by and carbon dioxide (GWP) emitted during the swine production cycle. The specific goal of the work was to develop a model for understanding how energy use and greenhouse gas emissions could be reduced using energy conservation techniques or the addition of renewable electricity. To get a broader sampling of data, energy use information from commercial operations was compiled and analyzed alongside energy consumption data from the University of Minnesota, West Central Research and Outreach Center (WCROC) swine research system. In addition to examining the amount of energy consumed in pork production systems, the analysis looked at energy use for production of swine feed ingredients.

Alternative scenarios were modeled to explore changes to both the University's research system and commercial operations to identify areas of high energy use and high impact that could be altered to reduce energy expenses and improve sustainability. Specifically, the model was also used to examine the impacts of solar PV electricity on both the commercial and University swine production systems.

2 Methods

The LCA methodology used in this study is essentially an organized method of tracking inputs and outputs of the swine production system and assigning impacts to them. In addition to energy data, cropping system data was used from the WCROC research farm. This model was designed as a 'Swine Stage Centric' model, where individual stages correspond to discrete parts of the animal production systems and which are linked to the specific inputs and outputs at each of the growth stages. This makes it easily to change the model based on different animal management assumptions, different inputs, or different scenarios being modeled. For example, the question could be asked, "what is the impact on global warming potential of a 5% reduction in protein content for grow-finish hogs if it adds 5 days to that stage of growth"? This results can easily be calculated by changing a few variables for the diet and number of days in the grow-finish stage.

Current commercial swine production practices have animal production spread among different farm types based on animal growth stage. Most hogs are born on one farm (farrowing), moved to a second farm to be raised to roughly 75 pounds (nursery), then moved to a final farm where they are raised to market weight at around 275 pounds (grow-finishing). Breeding stock may also be raised on a totally separate farms or be part of the farrowing operation.

2.1 Life Cycle Assessment

The LCA work done for this project was conducted using ISO 14000 standard methodology as a general guide. SimaPro (7.2) software was used for modeling swine systems and calculating result data. Background databases used in conjunction with the SimaPro work included Ecoinvent (2.0), US LCI, and Agri-footprint. For global warming calculations, GWP 100a (IPCC 2013) was used to calculate impacts. Fossil energy impacts were calculated using the CED 1.08 method with the addition of United States-based fossil energy sources.

2.2 LCA Model Scope and Goals

This analysis is focused on two key areas of environmental impact, GWP and fossil energy resource depletion. The study used a 'cradle gate to gate' analysis of lifecycle impacts of the swine system, which includes all of the swine production system from the production of crops until the hogs are at market weight and ready to be loaded onto a truck at the farm gate. The main focus of the study was on activities occurring on the swine farm. Boundaries of the foreground system focus on the swine system activities related to (Figure 1).

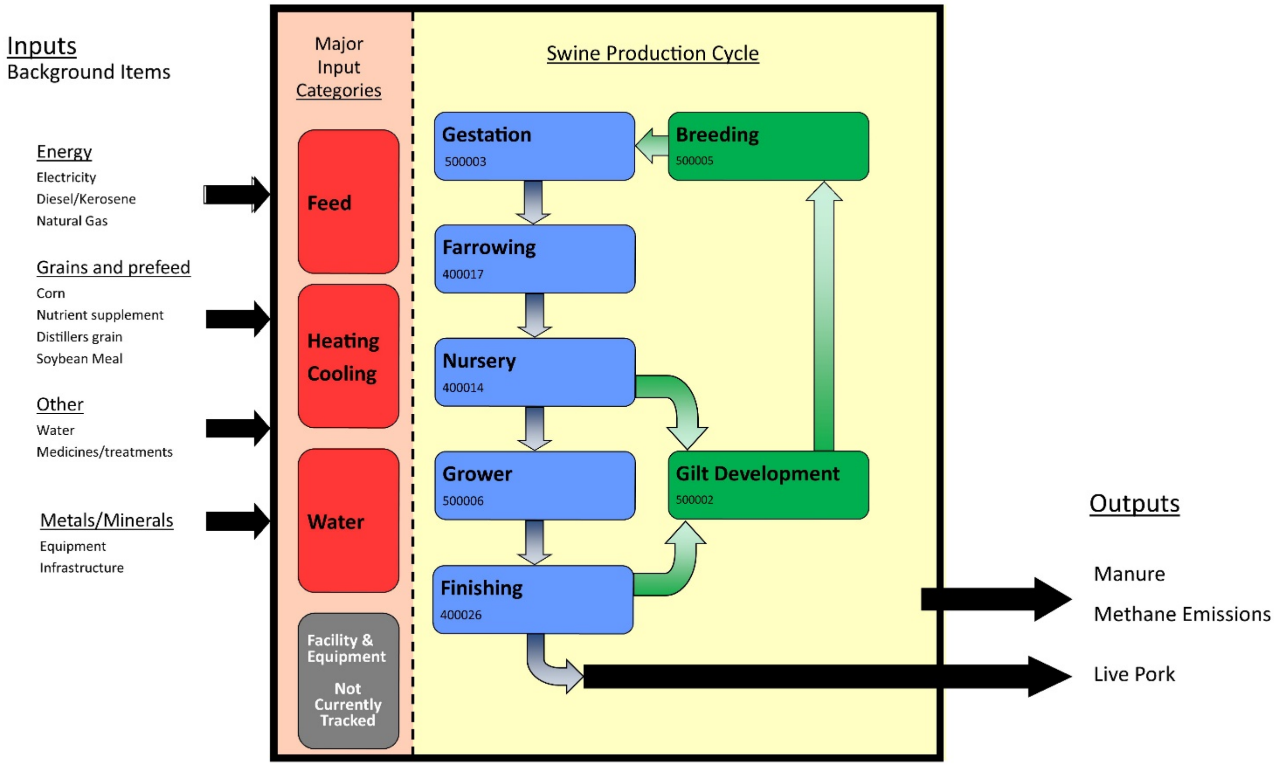


Figure 1 LCA Overview and Boundaries for the Swine Production System. The schematic shows the foreground and background components of the swine systems being analyzed. Items within the foreground system boundaries (peach and yellow areas) are considered the main focus of the study. Items in the background system (outside the black boundary lines) are items that are considered secondary and can't be varied as part of the main system.

2.2.1 Foreground System Items

Life cycle assessment is often divided into two areas of study, the foreground system and the background system. The foreground system is typically the area where the model focuses most of its effort and it is assumed that is the area where those using the LCA results are interested in making changes. In this LCA work, the foreground system includes the activities where swine production is directly occurring. As seen in the peach and yellow colored areas of Figure 1, this includes the different stages of swine production and the direct inputs needed for those areas. Mixed feed, heating, cooling, and ventilation are major inputs into the swine production stages. In addition, several other activities and energy resources are needed to operate the swine production system. These include things like lighting, office heating, worker showers, and laundry facilities.

At this time, infrastructure items, such as buildings, are not included in the LCA efforts for this project. The capacity has been added to models to allow for inclusion of infrastructure should accurate building data become available. Similarly, water and energy for water pumping are not fully implemented in the model.

2.2.2 Background System Items

The background system refers to items that are generally not in the control of those managing the main foreground system or within the scope of research of those analyzing the foreground system. On Figure 1, these are the items under the heading inputs on the left. For this study, this meant activities such as crop production, electricity generation/transmission, and natural gas extraction/delivery were in the background system.

2.3 Examining The Swine Production System

To evaluate a variety of swine systems, different sets of data were used to observe the specific systems used at WCROC and hypothetical systems designed based on data from commercial farms. It was intended that using the different data would allow researchers to assess high performing and lower performing systems from the sustainability standpoint. The data was used to examine both the impacts on individual growth stages and on the complete cradle to gate modeled swine production systems. The following systems were designed based on energy audits.

- WCROC Conventional System

  The conventional swine system used for research at WCROC includes a standard crated farrowing system, nursery building, a standard finishing barn, and hoop barn gestation pens. Due to the research nature of WCROC and the smaller scale of production, it is expected that the system would be less efficient than current large-scale industry facilities. Energy data needed to be scaled up to represent facilities running at near capacity, which is uncommon for research activities.

- WCROC Alternative Systems

  The swine researchers at WCROC are continually testing alternative housing, climate, and behavioral systems. These alternative systems represent potential future swine management techniques to improve animal welfare, health, or economics in swine production systems. The current alternative systems included in this research were the Swedish style farrowing unit, the hoop barn grow-finish system, and the outdoor gilt development unit. As with the WCROC conventional system, alternative production systems at WCROC are small-scale and thus likely to be somewhat less efficient than is seen in the commercial operations.

- Commercial Farm Average

  For each growth stage, the commercial farm data for the two paired growth stage (i.e. nursery) farms was averaged to come up with a combined measure for data on energy use in commercial swine production. It should be noted that there were significant differences between many of the farms depending on the type of equipment and technologies employed by the commercial operators.

- Commercial Farm Best Energy Technology

  The total energy use was analyzed for each of the paired commercial farms, and the farm using the least energy on was analyzed for impacts at each stage and then used to create an ideal best technology full production system model.

- Renewable Electricity Scenarios

  All of the above systems were tested with solar energy replacing the grid energy being used at the farms. This was done at the system level looking at complete cradle to gate use of renewable electricity in each of the different systems.

2.4 Data Collection

A number of different sources of data are used in this study. Priority was given to data generated by WCROC staff from work done on the WCROC swine production research systems or collected at local commercial operations. However, some information was outside the ability or scope of staff to collect and, therefore, was found in databases or literature. This was primarily background data for items brought into the swine and the cropping system.

Data collection at WCROC included all stages of a standard swine production system; farrowing, nursery operations, grow-finish production, gilt development, and gestation. Also included in the WCROC information was data on feed use, the length and conditions of each growth stage, natural gas use, and continuously logged electricity data. Commercial system auditing analyzed electricity and natural gas/propane use. Each commercial system focused on a single stage of production. However, for commercial systems, farrowing, gestation, and replacement gilt development were considered a single operation (breed-to-wean).

2.5 Feed Systems

The feed mixes used for this LCA analysis of all production stages are based on feed guidelines from the US Center for Pork Excellence, as applied at WCROC. For very young animals (nursery stages 1 & 2), pre-made pellets were purchased that conformed to these guidelines. All older stages received feed mixes produced on-site that met these nutritional recommendations. The majority of each mix is corn, with a high percentage of ground corn grain (starch source) and some dry distiller's grain (protein and fat source). Alternatively, soybean meal is used as a protein source. There are a number of other nutrients and minerals required at low levels, these are mixed with corn and soybean meal to make a complete feed. Throughout the production process, a number of different feeds and feed ingredients are provided at different stages to promote swine growth and health as they progress to market weight.

2.6 Energy Sources

Swine production uses a number of different energy types; electricity, propane, and diesel fuel are the most common. However, natural gas and gasoline use is also common. For this study, the impacts of electricity were studied using a Minnesota grid electricity mix calculated using the 2011 Minnesota electricity production mix data collected by EIA (Energy Information Agency). The EIA based percentage of each type of electricity production (coal, nuclear, wind…) was used in conjunction with data on database literature on the production of each energy type. This Minnesota mix was used for all on farm and regional energy demands. Since most of the feed and other products used on the swine farm were produced regionally, the large majority of electricity used was the Minnesota mix. For renewable scenarios, infrastructure and background energy was not included in the LCA for solar PV system. Therefore, they were considered to be carbon neutral and fossil energy free sources of electricity.

Natural Gas data in this model were derived from the Ecoinvent database, which used NREL (National Renewable Energy Lab) data to assess the impacts of natural gas supplied to consumers across North America. Propane data were assessed using the US LCI database, which unfortunately was modeled at a US based refinery and not the consumer. Similarly, impacts of diesel energy on the farm were modeled at the point of production at the US refinery.

2.7 Manure Management System

Although not an important component of energy in these systems, manure management is an important part of the carbon emissions during pork production. After manure is excreted from livestock, microorganisms continue to break it down into methane and carbon dioxide. Since methane is a chemical with high global warming potential, examining the breakdown of the manure is important part of looking at global warming potential in livestock systems. Direct measurements of manure emissions are very difficult, expensive, and require fairly significant changes to livestock system. Therefore, manure emissions for this project are based on standardized calculations developed by ASABE. Using a number of previous studies on manure breakdown, they have modeled how much methane is released depending on what manure management system, diet, and temperatures are being used for a given livestock system.

3 Results & Discussion

3.1 Model Development

The initial LCA model developed as part of this project has been continually updated with new data on growth stages, inputs and outputs as the data has become available. The current model (Figure 5) includes data on all major inputs and outputs including; feed systems, building systems, and manure systems. By its nature, LCA models are designed to allow continual improvements and refinements. With the model that we have developed, we plan to examine individual heating, cooling, and ventilation system changes in newly funded grant projects. In addition, there are a number of improvements that we hope to make in the model as new data becomes available. Appendix A list some of the areas that we are working on to collect data for revisions. Therefore, this model will move continue to be used for swine production energy and GWP research into the future.

3.2 Model Output Energy vs. GWP

For this summary report, much of the output data presented explores the input energy component of swine production. The GWP results are expressed only for the final emissions impact data, but not individual growth stages of the system. This is not to imply that the GWP component of the study is less important. However, it is important to recognize that fossil input energy is much more easily changed by altering swine management practices. Global warming potentials includes many factors that are difficult for pork producers to change such as manure emissions or that occur in the background system that are not directly managed by pork producers.

3.3 Production System Inputs

In terms of total energy, one of the largest requirements for energy in the entire system is the production of animal feed ingredients. Figure 2 shows the relative amount of energy needed to produce the ingredients for feeding one market ready hog. Production of corn is the single most energy intense ingredient needed for feed, requiring almost 50% of the total energy needed for producing swine feed. An examination of the inputs into corn production show that nitrogen fertilization and grain drying are the two most significant energy uses in production of corn. Needing neither nitrogen fertilizer nor drying, soy products are the second most energy intense input into swine feed. Most of this energy is for tillage, harvest, and transportation. The last inputs listed are amino acids produced artificially. Production of these amino acids is complex and requires a significant amount of energy. Even though they are added to feed mixes at very low levels, they significantly increase the energy embodied in the final feed product. Several other ingredients are used in feed production. However, they were not significant in the overall amount of energy being used in swine production.

In terms of fossil energy sources used for entire swine production system (base on WCROC data), natural gas and crude oil and lignite coal were the most used primary energy sources (Figure 3). In addition to being used in the grain production system (for grain drying), natural gas was used for electricity generation, building heat, and hot water. Much of the crude oil was used for vehicles and tractors for growing and transporting feed. Lignite coal was used in production of electricity, with the Minnesota based grid using more than 50% coal-based electricity. Commercial swine operations were slightly different in terms of natural gas use as rural farms are often not connected to a natural gas utility. These farms typically use propane as a heating source and for grain drying.

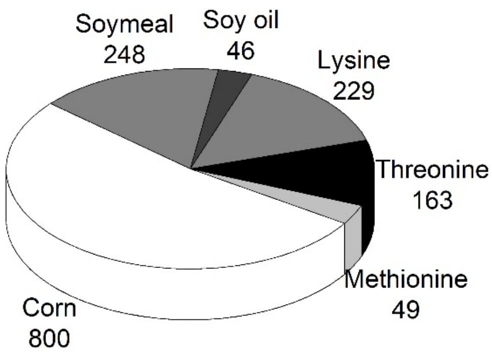


Figure 2. Fossil Energy for Major Feed Ingredients. Each of the feed ingredients is listed with the amount of fossil energy (in MJ) required to produce of the ingredients required to grow a single 120 kg market weight hog.

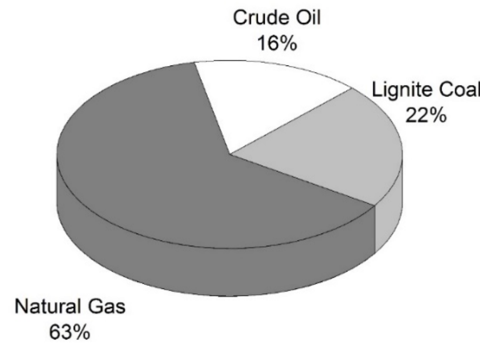


Figure 3. Key Sources of Fossil Energy for The Swine Production System. The primary energy sources for the production of pork and the relative percentage of each used.

3.4 Growth Stage & Building Systems Fossil Energy Results

The initial analysis of the swine production system looked at individual growth stages and the fossil energy needed for each of the different stages (Figure 6). Each stage was examined in terms of one unit of output as indicated panels in the figure, in most cases one animal. Comparisons were made between the WCROC swine production system and commercial systems. If an alternative system was being used at WCROC, it was included as well. To more closely look at areas where swine producers may have more ability to reduce fossil energy use, a second analysis was done looking more specifically at the building systems (Figure 7).

For comparing the different swine systems, (commercial vs. WCROC), it is important to understand that the feed and animal management are modeled after WCROC operations. Only building energy use from commercial and alternative production systems is changed. For example, in all systems the length of time a piglet is assumed to stay with a sow before weaning is 28 days. Current commercial practices are often 21 day, which improves turnaround time for facilities and cycles sows through faster. Specific animal husbandry data for commercial operations is not available, but will be added in the future.

3.4.1 Gestation

The gestation stage for swine is just short of 4 months. During this time the sows are fed a balanced diet to promote healthy litters of piglets. The WCROC system is a bit different in that gestation is done in an unheated hoop barn. Thus, the only energy used is to heat waterers in winter. Looking at Figure 6A, one can see that total fossil energy in the WCROC gestation system is slightly lower in commercials systems. When comparing only the building system energy (Figure 7A), one can see a significant fossil energy consumption for the unheated WCROC gestation hoops.

3.4.2 Farrowing

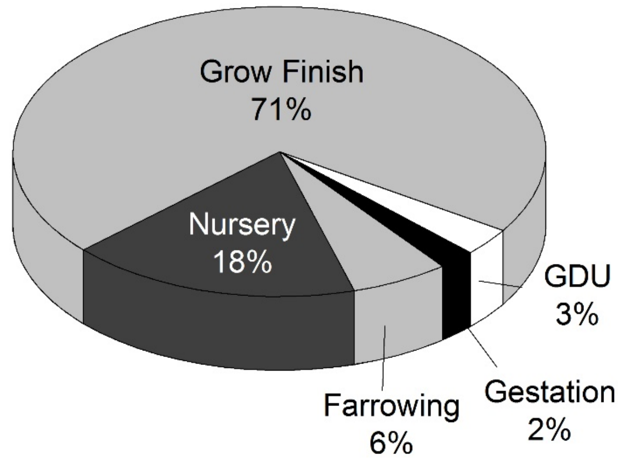


Figure 4. Relative Fossil Energy Contribution of Each Growth Stage. The relative contribution of the building system energy is shown for each stage is shown for the WCROC swine production system.

The farrowing stage is a fairly short stage of between 21 to 30 days where animals are confined in a heated space to give birth and raise the young until they can eat solid food. Fossil energy for the farrowing was difficult to calculate for WCROC because the research farm only farrows when hogs are needed for research. That limited data set was extrapolated to estimate the amount of energy needed to fully utilize the farrowing facilities on a continuous basis. It is highly doubtful that WCROC's system is as efficient as indicated in Figure 6B and Figure 7B. The WCROC alternative system data is more likely to have yielded realistic data, as it showed the expected increase in fossil energy use due to a higher demand per animal for space, heating, and straw. The commercial barn data in Figure 6B is probably much more representative of real-world farrowing system energy use. Upcoming rotations of large groups of sows through the farrowing system at WCROC will provide a better set of baseline data for analysis.

3.4.3 Nursery

Piglets brought into the nursery system usually spend a short time (45 days) in the climate controlled facility as then transition to a higher starch based diet, gain strength, and increase their disease resistance. The WCROC nursery is fairly typical of modern swine systems, although the number animals produced in the facility is lower than could be produced under commercial production. Both in terms of total fossil energy (Figure 6C) and building system energy (Figure 7C), all three systems were comparable.

3.4.4 Grow finish

During the grow-finish stage, hogs increase in size from roughly 27 kg to 120 kg, with feed available at all times. This stage lasts roughly 90 days and is typically in a heated/ventilated facility. In addition to a conventional facility, WCROC uses an alternative system where animals are housed in a sheltered hoop barn. The hoop barn is unheated and uses electricity only for heating waterers in cold weather. Because of the length of this stage and amount of feed consumed, it is a fairly fossil energy intense stage of the production system (Figure 6D). However, relatively little building system energy is used when the number of days spent in the stage is considered. (Figure 7D). In the case of the WCROC conventional system, the building system fossil energy use is significantly higher. One of the likely reasons for this is the small scale of production at WCROC. The overhead energy demand for operating small barns makes them much more energy intense per head raised. On the other hand, the outdoor alternative system at WCROC used almost no building system energy.

3.4.5 Gilt Development

Replacement sows are produced in the gilt development units of swine production systems. In most modern farms, breeding stock is separated from the market animals early in production and raised somewhat differently to promote animals that can more successfully produce piglets. For this study, animals were put into the gilt development unit after the nursery stage. They are fed diets similar to the grow finish stage animals. However, the diet is modified to reduce growth of fat as the animals approach market weight and continue to grow to breeding weight. For this model, gilts spent an extra 30 days in the development unit (total of 120 day) above what grow-finish hogs spend in that stage. WCROC has a standard gilt development unit (GDU) in a heated and ventilated building, but also has a temperate seasonal GDU that is unheated. Typical commercial barns will have heated indoor slatted floor GDU's. The energy use of WCROC's conventional GDU system was similar to the commercial systems (Figure 6E), with a significant amount of the fossil energy being used for feed. In terms of building system energy (Figure 7E), the WCROC conventional GDU was similar to the commercial systems. However, the WCROC outdoor GDU used almost no building systems energy.

3.5 Total System Impacts

So far, this analysis has focused mostly on the individuals production stages and how fossil energy intense they are. However, it is important to look at the overall performance of the system as well. By combining the different stages at WCROC and the average and best systems at commercial operations, a better understanding of how differences in the stages impact the system as a whole.

3.5.1 Energy

The total fossil energy for the modeled production systems is shown in Figure 8A, which is expressed in terms of the energy used for producing one market hog when combining these systems. The large impact that feed production has on the overall system is visible in the systems shown. A more detailed assessment of energy needed specifically for housing or building systems (Figure 8B) shows that there are differences in the amount of fossil energy needed between the different production systems. This figure also shows how the use of renewable electricity can decrease the amount of fossil energy needed. Depending how much fossil based electricity was used in the swine production building system, solar PV electricity reduced the fossil energy demand by between 42% (alternative) and 68% (commercial best).

3.5.2 Global Warming Potential

The analysis showed a similar situation in management of swine GWP as with swine fossil energy use, very little of the GWP emissions are able to be directly controlled by swine producers. The major areas of GWP impacts are feed production and manure management (Figure 9A). Though there are some methods of reducing manure emissions with feed additives, these are not economically feasible and are not all that effective. As with fossil energy, carbon emissions in feed production are also difficult for farmers to influence. This leaves the building system part of swine production as the major area for pork producers to manage for GWP reduction, which accounts for only about 10% of the total GWP impacts. However, our work with renewable energy does show that greenhouse gases can be significantly reduced in the building systems area (Figure 9B).

3.6 Implications

The findings of this work indicate that there are some areas that could be more heavily targeted by producers wishing to reduce their environmental impacts. Activities of the on-farm hog operations are within their control and can be impacted by farm manager decisions. Unfortunately, because grain and feed ingredient production is such a large part of the impacts, it is difficult for swine producers to directly reduce the majority system sustainability impacts.

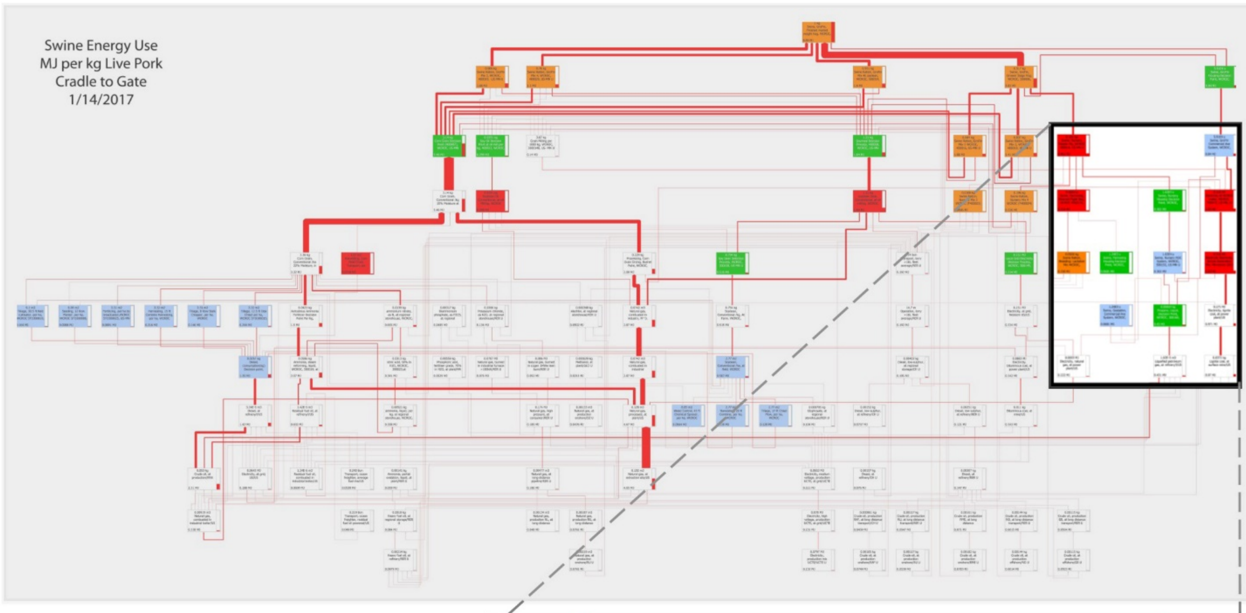
To continue reducing the environmental impacts monitored (fossil energy and GWP), a combination of conservation and other renewable technologies will be needed. On the conservation side, changing buildings, heating and cooling, ventilation, and lighting can all lower fossil electricity use. One solution that would both decrease fossil energy use and lower the GWP from manure emissions is the use of an anaerobic digester. Anaerobic digestion systems capture methane and use it to make electricity or heat, which are both needed at different points in swine production systems. In some areas of the U.S., anaerobic digestion could also be a source of additional revenue.

3.7 Future Work and Areas For Refining LCA

The swine life cycle model was designed as a tool to investigate a wide variety of issues related to the sustainability of pork production. It is able to be customized and expanded to meet many needs for swine sustainability research and is an important asset for Minnesota researchers. It was anticipated that the model would be used for new research efforts, and new funding has been secured to examine other swine production issues. As with all LCA models, the data collected on swine production is the key to making an accurate model. Going forward, WCROC will continue to collect new data, both on the farm and off, to improve model results. Appendix A lists some of the changes that will be made, but is only a small part of the continual improvements and additions the model is expected to have in the future.

4 Conclusions

- A model was developed that can track energy use and greenhouse gas emissions (GWP) though the swine production system at a moderate resolution, with the ability to be refined as more data becomes available. This model is designed and already committed for further research that examines questions regarding swine life cycle energy and carbon footprints with potential new technologies and organic production.
- Energy use and GWP emissions in the broader swine lifecycle were highest for feed production, which accounted for almost 60% percent of fossil energy and 50% of greenhouse gas emissions.
- The fossil energy portion of the production system that can be directly controlled by the hog growers is roughly 25% of the energy of producing pork. Renewable energy replacements for fossil based electricity, such as solar PV, can significantly lower fossil energy use for swine production. However, replacements for natural gas/propane, diesel, and gasoline will be needed to further reduce fossil energy use.
- The fossil energy and GWP impacts for feed crop production and feed ingredients are an important area that must be addressed to continue reductions in environmental impacts of swine production systems.



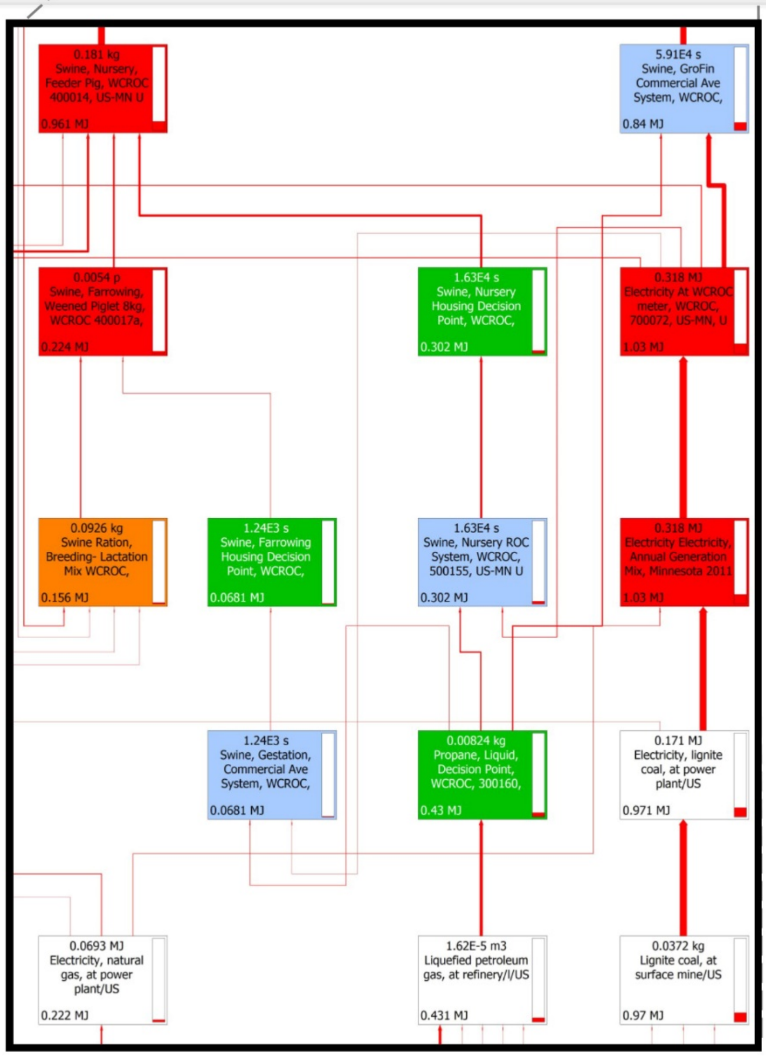
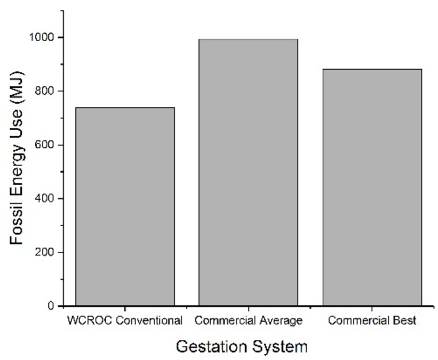
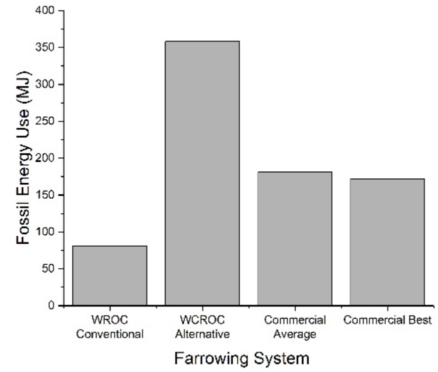


Figure 5. Schematic of the LCA Model as displayed by SimaPro. The image at the top is a Sankey diagram of the key processes using fossil energy in the swine production model. Drawn by the SimaPro LCA software, all the activities in the system are linked by lines indicating energy flow. The highlighted section on the top drawing is expanded in the image on the right to show a more detail look at some of the activities in the production model. Each process (box) in the expanded view has a process name, the amount of material- time- or energy moving on to the next stage and the cumulative amount of energy used at that process. The size of the lines linking the processes represent the relative amount of energy being used. These drawings are used to help visualize the large tables of data the software produces. The same method is used to diagram GWP models.

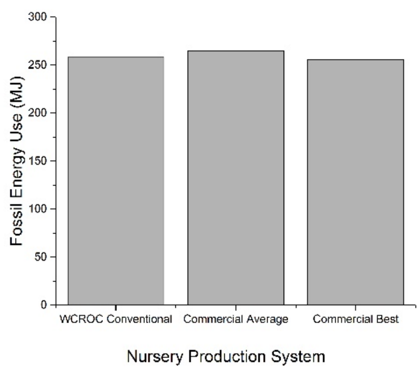
A). Gestation (Per Bred Sow)



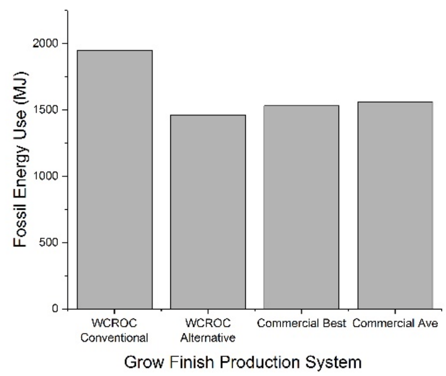
B.) Farrowing (Per Liter)



B.) Nursery (Per Pig)



C.) Grow Finish (Per Pig)



D.) Gilt Development (Per Pig)

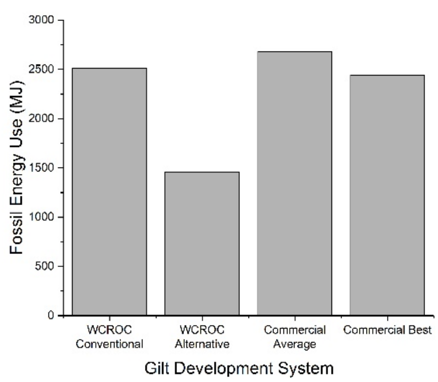
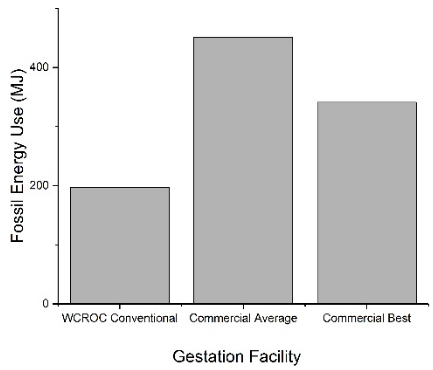
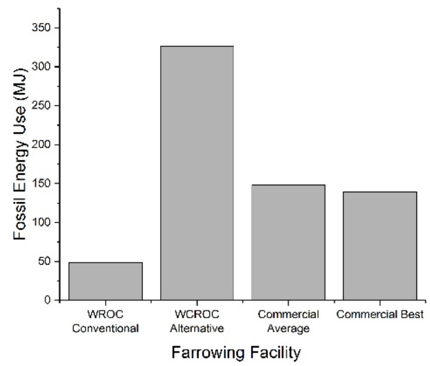


Figure 6. Total Fossil Energy Required for Individual Growth Stages. For each stage, the fossil energy needed for the commercial average and best systems were compared with the WCROC research farm conventional system and alternative system if one existed for the stage. Results are the total fossil energy used in producing one unit of output (output unit for each stage is shown in parenthesis). These graphs include all fossil energy for feed and other inputs needed for the given stage.

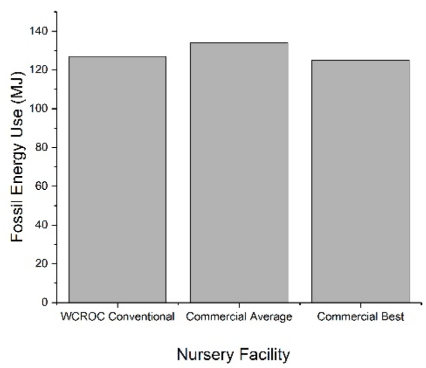
A.) Gestation (Per Bred Sow)



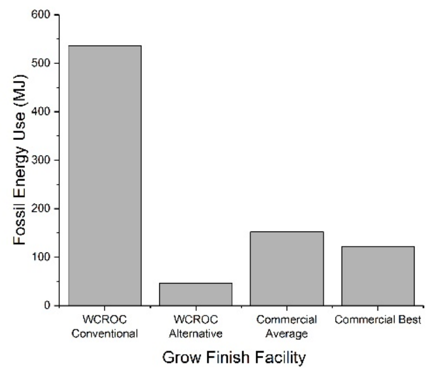
B.) Farrowing (Per Liter)



C.) Nursery (Per Pig)



D.) Grow Finish (Per Pig)



E) Gilt Development Unit (Per Pig)

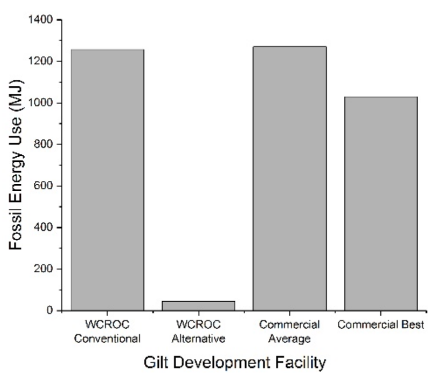
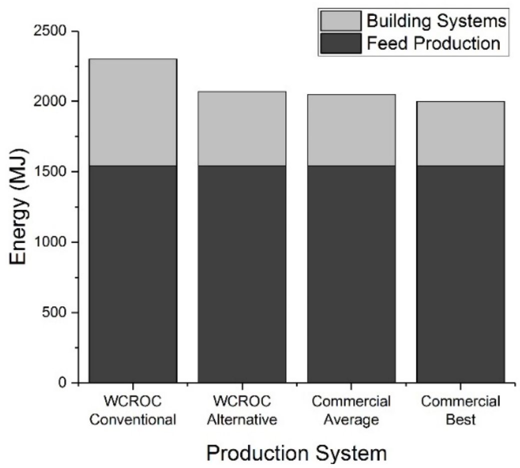


Figure 7. Building System Fossil Energy for Individual Growth Stages. For each stage, the fossil energy needed for the building system for commercial average and best systems were compared with the WCROC research farm conventional system and alternative system if one existed for the stage. Results are the total fossil energy used in producing one unit of output (output unit for each stage is shown in parenthesis). The graphs only include energy for heating, cooling, ventilation and other fossil energy use in the building system.

A) Total Swine System Fossil Energy



B) Building Energy With Renewable Production

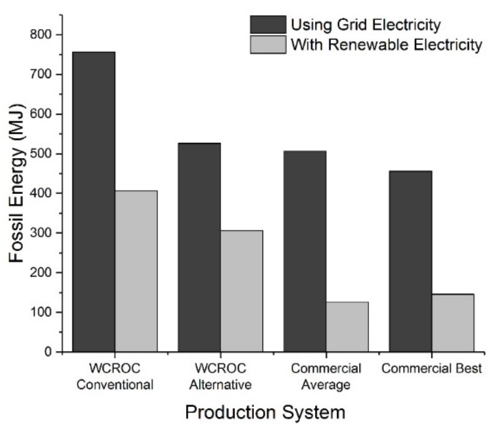
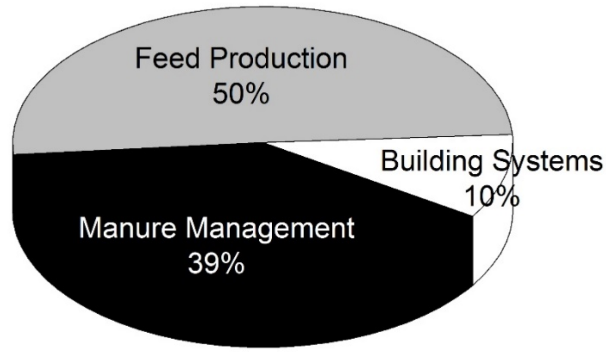


Figure 8. Fossil Energy For Swine Production Systems These figures show the fossil energy needed for A) the entire swine production system and B) building system. Data is based on the energy needed for one market weight hog (120kg)

A) GWP Emissions from Swine System Components



B) GWP Emissions With Renewable Energy

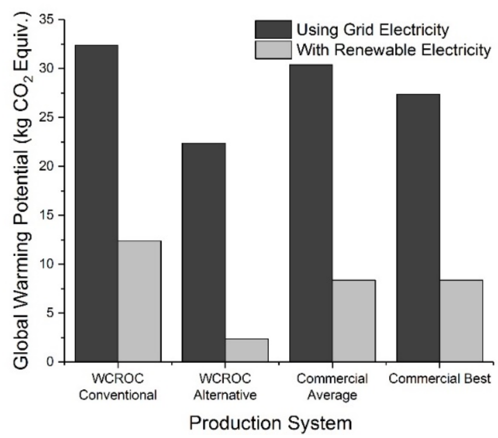


Figure 9. Global Warming Potential for the Swine Production System. The Global Warming Potential (kg of CO_2 Equivalents) for the system is shown A) as a comparison of the major GWP emitters and B) by the potential reduction using renewable energy.

Appendix A Future Model Revisions

Issue	Impact	Information Needed/Solutions
WCROC Farrowing Energy Accuracy	This has a significant impact on the energy used for WCROC farrowing in the model. However, it is likely of only a minor impact to the system as a whole.	More information is needed about the energy use when farrowing barns are full. The estimates used in the model were based on only a few periods where data was not precise. There was likely error in extrapolating to full barns.
On farm vehicle use	It is not likely to be a large impact at a typical farm. However, WCROC has a large number of vehicles in use on our research farm.	Need to develop better WCROC vehicle data, which factors out vehicle use for research or other animal systems. Or, data could be collected at outside commercial operations.
Water energy and inputs	Inconsistent use of water data in the current model may have some impact on the final results. However, is not likely to be a major factor in the system.	It is difficult to get accurate water data at WCROC due to a lack of water meters for individual buildings and little information on total water being pumped.
Updated Minnesota Grid Energy Data	Grid power is used as the regional electricity source. This is likely to impact the system as coal based electricity is used less than in the past. Wind and natural gas are a much higher percentage.	Data from IEA for energy mix and databases for power plant impacts can be used in revisions.
Specific Data Needed for stage length and feed use at commercial farms	Commercial farms may be more efficient than indicated by the findings of this report. The level of change is hard to gauge.	Commercial farms would have to be willing to provide more data, depending on the farm this may be easy or difficult to get

IMPLEMENTING SOLAR ELECTRIC SYSTEMS ON SWINE FACILITIES

Rachael Acevedo, Renewable Energy Intern

University of Minnesota West Central Research & Outreach Center

This project was sponsored through a grant from the Minnesota Environmental and Natural Resources Trust Fund through the Legislative Citizens Commission on Minnesota Resources

---

Pork Production

On June 1, 2016, the United States hogs and pigs market possessed 62 million pigs (USDA 2016). In Minnesota alone, 7.44 million pigs were on the market on June 1, making Minnesota rank third for the number of pigs raised and second for the value of the pigs (USDA 2016). Not only is pork production essential economically, but the industry has made great steps in becoming environmentally progressive as well. In the past fifty years, the pork production industry in Minnesota has reduced water usage by 41%, land usage by 78%, and its carbon footprint by 35% overall (Minnesota Pork Producers Association 2016). Despite these advances, raising swine is still an incredibly energy intensive process, requiring a lot of electricity and fuel to transpire.

Facility construction, operation and management, grain cultivation, feed processing, breeding and birthing, and manure management are six processes that occur in swine systems (Gensch 2014). Grain cultivation uses almost half of the energy required in this system; however, many swine farmers are not involved in this process. Facility operation, which includes heating, cooling, and ventilation, is the second largest energy user at 25% (Figure 1).

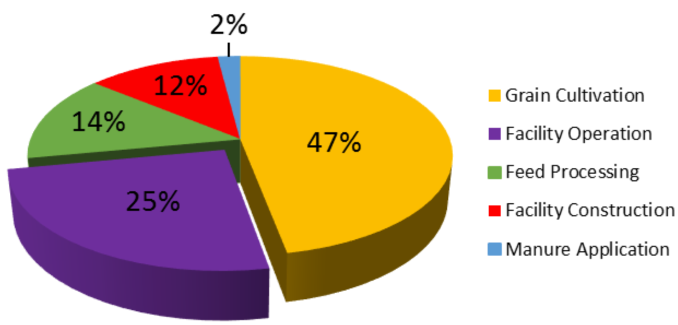


Figure 1: Percentage of Total Energy Used by the Main Processes in Pork Production (Gensch 2014)

Operation provides a great opportunity to start minimizing energy costs and usage due to the large amount of control a farmer has on building and barn design and operation (Gensch 2014). While one pig normally requires the equivalent of 7-12 gallons of gasoline, these values can be significantly reduced, but only after understanding how the fuel and electricity is being used (Gensch 2014).

There are four phases of swine production: gestation, farrowing, nursery, and finishing (Gensch 2014). In the gestation phase, pregnant sows are housed and develop their litters. Until weaning at about 11 lb., piglets are born and raised with their mother in the farrowing phase. The young pigs are then moved to the nursery phase where they are raised to approximately 55 lb. Lastly, in the finishing phase, the pigs are grown until they reach market weight, or approximately 250 to 300 lb.

Just because humans may be comfortable in the barn does not mean the pigs are. Although pigs are able to adapt to their environment within reason, swine tend to be very sensitive to the smallest of environmental stresses, which may cause depressed growth, reproduction, or lactation or impair disease resistance (Baker 2004). They give off heat, water vapor, urine, feces, and disease-causing organisms that impact their environment, and as the temperature difference between the body and cooler environment increases, so does a pig's heat loss.

The temperature of a barn must always be kept between the lower and upper critical temperatures, the effective temperatures below or above which swine are unable to maintain productivity (Baker 2004). These critical temperatures, between which is known as the thermoneutral zone, change with body weight, type of housing, amount and composition of feed, presence of bedding, and use of cooling systems. For example, John E. Baker at the Warrick Veterinary Clinic in Chandler, IN found that piglets have a lower critical temperature of 84°F as they are small and become cold easily (Baker 2004). Swine approximately 8 weeks old, or 40 lbs, have a lower critical temperature of about 63°F whereas finishing barn swine (>100 lb.) and breeding or gestating sow require a lower critical temperature of 54°F. Fortunately, temperature controls in barns do exist; unfortunately, heating and cooling depends upon a great deal of energy to use these necessary controls. Dr. Lee Johnston, Director of Operations at the WCROC and a professor of swine nutrition and management, has done considerable research on lowering the nocturnal temperature of swine facilities (Johnston and Li 2011). Specifically, in swine nurseries, extensive amounts of supplemental heating are required to keep pigs within their thermoneutral zone. By lowering the temperature for a portion of the day and allowing the pigs to huddle close together to conserve heat, the amount of energy required to operate the barn may be lowered significantly.

Another concern in raising healthy swine indoors is the production of more than 130 fixed gases and odorous vapors, especially as manure decomposes (Ni et al. 2000). Hydrogen sulfide, ammonia, and carbon dioxide are some of the most common gases that need to be properly exhausted from the pig space using ventilation, another environmental control system that depends on electricity to run. Hydrogen sulfide can be tolerated by swine up to 10 ppm but can be lethal at concentrations as low as 50 ppm. Ammonia can be present up to 100 ppm in a swine barn. At 50 ppm, ammonia hinders a young pig's ability to clear bacteria from its lungs; at 75 ppm, ammonia depresses pig growth (Kim et al. 2007). Carbon dioxide can be allowed up to 3,000 ppm for swine and often determines the minimum ventilation rate required for a barn (Ni et al. 2000). To prevent the buildup of noxious gases, two to four air changes are required per hour, varying from 1.5 ft^3/min per nursery pig to 3.5 ft^3/min per growing pig to 10 ft^3/min per sow and litter in a farrowing barn (Jones and Friday 1980).

Pork production is a large economic benefactor in Minnesota, but the amount of electricity or fuel required for operation can lead many farmers to seek supplemental sources of energy to offset costs of traditional fuel sources. Solar energy has become a leading solution, but it is important to understand how electric load (i.e. amount of electricity) is affected by the swine and their environmental requirements as well as how the amount of available solar energy changes with its own conditions. By first knowing what electric loads are required, the proper type of solar system can be chosen to fit those needs.

What is solar energy?

Without fail, the sun rises and sets whether we notice it or not. Earth receives about 1,366.1 watts per square meter of energy from the sun (Gueymard 2003). New technologies are being invented constantly with the sole purpose of harnessing the sun's power and turning it into electricity or heat. In fact, approximately the same number of solar systems was installed from 2012 to 2014 that had been implemented since its inception (Roney 2014). This makes solar technology the most rapidly growing energy technology by a wide margin.

Direct, diffused, and reflected are all types of solar energy (Kalogirou 2014). Direct radiation passes through the atmosphere and strikes the earth without being deflected and constitutes 85% of solar radiation. Diffused radiation means that water vapor, dust, carbon dioxide, or other compounds in the air are able to scatter the radiation, making it the only radiation able to reach the ground when skies are completely overcast. Unfortunately for those trying to harness solar energy, diffused radiation is comprised of significantly less energy than direct radiation. Finally, reflected radiation "bounces" off a surface, such as snow. Reflected radiation contains less energy than direct radiation but more than diffused radiation. As a result, cloud cover, air pollution, reflection, atmospheric absorption, and other atmospheric and weather conditions can greatly affect the amount of solar energy able to be received by a solar collector.

Another characteristic of solar energy that affects the amount of energy received is the angle of incidence, or the angle between the solar collector and the sun's rays (Kalogirou 2014). When the sun is directly above the solar collector (i.e. at noon above a horizontal panel), the sun's rays intercept the panel at 0°. The greater that angle becomes, the more radiation is reflected, and the less radiation is intercepted (Figure 2).

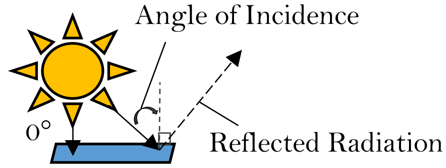


Figure 2: Sun's rays reflecting off of a horizontal panel (Made by author).

Despite the simplicity of the concept, the angle of incidence can significantly reduce the amount of energy received by a collector (Kalogirou 2014). Throughout the day, the sun is moving across the sky, constantly changing the angle at which its rays hit the surface. Longitude also plays a role on what angle and direction the sun is most efficient at. For example, the sun is directly above the equator. This means that a person in the northern hemisphere receives more solar radiation to the south, and someone in the southern hemisphere gets more solar radiation to the north. The final major consideration is the time of year as the sun is much lower in the sky in the winter when compared to summer.

When discussing solar energy, one of the most important concepts to understand is energy efficiency. Energy efficiency involves minimizing energy use while maximizing productivity (Brown and Elliott 2005). In regards to solar systems, efficiency is the effectiveness with which a solar collector absorbs and retains energy (Kalogirou 2014). Mathematically, energy efficiency is shown in Figure 3.

$$Efficiency = \frac{Solar\ energy\ collected}{Total\ solar\ energy\ striking\ collector\ surface} * 100\%$$

Figure 3: Equation to calculate efficiency of a solar system (Kalogirou 2014).

When choosing the size of a solar system for a swine barn, efficiency of the system is a major factor. Efficiency changes with the angle of incidence as well as type of solar radiation being received. As a result, time of day when a high electric load is required, longitude, and season all affect the type and size of the system needed to make a swine barn a net zero system. A net zero system means that no supplemental electricity would have to be purchased as the farm is self-sufficient and can produce the same amount of electricity as is being used at any point in time. In other words, a higher efficiency is desired when there is a greater need for electricity, such as a need for cooling at noon when the barn is hottest, and the system generally has a high efficiency due to the low angle of incidence. The type of solar system being used can also have an effect on when the electricity is being produced and how large the system may need to be.

Types of Solar Systems

As previously mentioned, solar systems transform solar energy into electricity or heat. There are two main kinds of solar collectors: passive, which has no separate solar collector or medium for the transference of heat, and active, which utilizes a collector unit and fans or pumps to push solar-heated air or liquid to where the heat is needed (Kalogirou 2014). Passive systems, such as a window, often take advantage of seasonal changes by letting little solar radiation in during the summer and a lot in during the winter. However, these same systems that let the heat in during the day tend to let heat out by night, resulting in a drastic cycling of temperatures. The drastic cycling can be reduced by adding insulation to the walls, ceiling, and/or roof, insulating glass to the windows, insulating covers to the windows overnight, or ventilation systems that are controlled by thermostats.

Another type of passive solar system is the transpired solar collector (TSC), which can be further separated into sidewall collectors (A.1a) and transpired solar ducts (A.1b). Sidewall collectors are typically attached on a south-facing wall, where a lot of sunlight is able to be absorbed. They are simple to install and maintain and have a high efficiency in winter, making them ideal for livestock with low tolerance for temperature fluctuations. In order to prevent overheating in the summer, some farms have white, hinged panels that swing up to cover the collector and reduce the amount of radiation able to get through. Similarly, transpired solar ducts use sunlight to heat the barn, but instead of letting the light directly into the barn, the sun's rays warm the air as it passes through a wall or duct (Love and Shah 2011). The air is then drawn through perforations in an unglazed metal sheet, transferring the air to the inside of the barn.

Despite the convenience of passive collectors, active systems are more often necessary to maintain a constant target temperature necessary for swine. A black-painted surface (i.e. the absorber plate) absorbs the sun's rays, causing an increase in temperature on the surface, which subsequently heats up an interlaying transfer medium, usually air or water (Kalogirou 2014). This medium can then be relocated to be used or stored.

More often than not, the absorber is protected by a cover plate so that heat is not lost as a result of wind convection or radiance. Cover plates are primarily made of glass, fiberglass, or plastic (Kalogirou 2014). Glass has a transmissivity of 87%; in other words, 87% of the radiation reaches the black absorber plate rather than being reflected or absorbed by the glass. Greenhouse-grade fiberglass is the most common material for cover plates in the Midwest. Although it has a slightly lower transmissivity of 80%, fiberglass is more resistant to breakage. Plastic often becomes brittle and discolored after only a year or two. Finally, plastic films or sheets have a high transmissivity (92%), but up to 30% of captured radiation can be lost by reflecting back through the cover.

There are three primary types of active collectors: bare plate, covered plate, and suspended plate (Turner et al. 1981). Bare plate collectors draw the transfer medium underneath the absorption plate (A.2a). Although the least efficient, bare plate collectors are also the most common. Covered plate collectors consist of a transparent cover over the absorption plate between which fluid is drawn (A.2b). Lastly, the suspended plate draws the medium between the transparent cover and from under the absorption plate, making it the most efficient but least practical in terms of swine farms due to the efficiency rarely being worth the high capital cost (A.2c).

Countless types of active collectors have been invented, including ground-mounted (A.3a), pole-mounted (A.3b), and roof-mounted (A.3c). Ground-mounted are attached to the ground at an angle, pole-mounted are held above ground by a rod, and roof-mounted are directly attached to a roof. Pole-mounted systems can also be tracking or fixed, meaning the system is able to follow the sun's trajectory throughout the day. While tracking increases the efficiency by 27% on average, they are significantly more complex and expensive (WCROC 2016). In addition, ground-mounted panels are often more efficient than roof-mounted due to a less efficient slope that generally is present on roof-mounted panels. For example, at the West Central Research and Outreach Center, the ground-mounted solar system is at 28°, but the roof-mounted system was installed on a 4/12 pitch roof, or only 18.5°. The steeper angle of the ground-mounted is able to collect solar radiation more consistently throughout the year. When the sun is lower during winter, a more horizontal panel is able to get very little of the radiation. Despite being more efficient, ground-mounted systems cover a lot of potentially valuable land, so roof-mounted is often more economical. Another consideration for choosing between roof- and ground-mounted is that roof-mounted systems are more difficult to access for removing snow or performing maintenance, which can sometimes result in a decrease in efficiency during those times.

One of the most common terms used when discussing solar energy is "solar photovoltaic (PV) systems" (A.4a). Solar PV systems use photons to knock electrons loose from semi-conductor materials and separate free positive and negative charges, which then form an electric field. The electric field pushes the charges toward a load, creating an electric current (Romich 2014). Essentially, solar PV systems convert light into electricity, giving the technology high potential for swine farmers who wish to supplement their electricity needs with an alternate source of energy.

Solar electric systems (e.g. PV systems) contain three components: a solar module, inverter, and Balance-of-System (BOS) (Romich 2014). Solar modules are what actually collect solar rays and are comprised of a number of cells. Furthermore, modules are combined to create a rigid frame called a panel, which can be further adjoined to form an array. This solar array can be connected to an inverter, which converts electricity from direct current (DC) to alternating current (AC). Direct current is generally used for long distance travel, but alternating current is what most equipment, such as lights, ventilation fans, and heating and cooling equipment, requires to operate. Finally, BOS, also referred to as Balance-of-Plant (BoP), includes any meters, safety equipment (e.g. disconnect switches), conduits, cables, combiner boxes, and racking and tracking gear that may be required for the system to operate properly.

Solar thermal collectors are the second most common type of solar system and can be active or passive (A.4b). However, when discussing applications in agriculture, solar thermal collectors are often active. These devices collect heat by absorbing the radiation and distributing it into a transfer liquid, commonly water or air. Sensors that measure the temperature differential between the transfer liquid and the liquid being heated determine when a pump should be turned on, making it more efficient and, by definition, an active system. Active solar thermal systems are common in ventilation systems and/or hot water heaters and can prove to be very useful on swine farms.

Why Should Solar Be Placed on Swine Farms?

Society is very familiar with rising gas and electricity prices, uncertainty about access to fossil fuels in the future, and concern about the implications of fossil fuel use for the global climate (Lammers et al. 2012). The United States spends $9 billion per year, or 13% of all farm expenses, on energy used in agricultural applications (Brown and Elliott 2005). Electricity prices vary widely, but the average was 6.4 cents per kWh in 2013 and is projected to double by 2040 (Romich 2014). As electricity prices increase, the cost of generating agricultural products tends not to be far behind. With an increase in the production costs, farm income generally decreases. As a result, solar energy provides an invaluable opportunity for swine facilities as it has the ability to stabilize energy costs, minimize fossil fuel use, and decrease pollution and greenhouse gas emissions (Xiarchos and Vick 2011).

Solar panels are the most common way to produce on-farm renewable energy (Vilsack and Clark 2011). Often power fences, water pumps, and irrigation systems are built in locations where it is either too costly or not possible to build power lines. Solar power has been historically found to be a great solution for low power needs in these remote locations (Romich 2014). More recently, solar energy has also been used for systems with greater energy demand, such as grain drying or ventilation and cooling systems in livestock production facilities. In 2011, 78 Minnesota farms were equipped with solar systems, which included 51 farms with PV and 34 with thermal systems (Vilsack and Clark 2011). The entire United States has 7,968 farms using solar panels. Ninety-two percent of these systems are PV, and 28% are thermal. The average generating capacity is 4,449 W with an average installation cost of $31,947 per farm; however, there are a wide variety of costs and sizes of solar panels, so it is important to fit the system to the farm.

The growing popularity of solar systems on farms is not unfounded. Rural areas tend to lack in natural gas, and propane is expensive. When using propane for swine barns, carbon dioxide gets trapped in the building even if the combustion is perfect (Figure 4).

$$C_3H_8 + 5O_2 \rightarrow 3CO_2 + 4H_2O + 50.36\ MJ/kg$$

Figure 4: Combustion reaction using propane (Godbout et al. 2004)

More carbon dioxide is produced from using propane over using a solar thermal system. As carbon dioxide can greatly reduce air quality, using propane instead of solar thermal requires greater ventilation, more air changes per hour, and more heating for the new air, requiring even more propane to heat (Godbout et al. 2004). By using solar thermal, less propane can be used, improving air quality and reducing the production of greenhouse gases.

Another benefit to solar is that electric grids are aging and may not be available in remote areas. Encouraging efficiency and renewable energy options is often less expensive than improving on the current grid infrastructure (Brown and Elliott 2005). Solar can also act as a backup in the case of an electrical outage instead of using kerosene, diesel, or propane (Xiarchos and Vick 2011).

In addition to lack of natural gas and aging electric grids, agricultural areas have more options for where to build solar systems than is available in the city. Solar arrays can be placed on marginal land (if available) or rooftops to avoid competing with valuable land. In some cases, solar arrays can be built on floating structures over water. For example, at the Far Niente Winery in Oakland, CA, almost 50% of a 400 kW system floats on a single acre gray water retention pond (Boyd 2008).

If building the solar arrays on land is not an option, these systems can also be placed on a barn's roof. Orientation of a building can help determine if solar is feasible. As wind pressures result in reduced exhaust fan efficiency and improper ventilation, large tunnel fans should be facing east rather than towards the often south-facing summer winds in the Midwest (Jacobson 2011). As a result, swine facilities in the Midwest are often built in an east to west configuration for better ventilation. This also provides a south-facing roof, which is ideal for the installation of solar collection systems.

Other advantages of using solar energy are that solar collectors have no moving parts and as a result, low operational and maintenance costs (Romich 2014). They also provide the ability to harness a free renewable fuel source.

Sometimes the significant initial capital investment stops farmers from looking into it any further. However, there are a vast amount of subsidies and programs that can help recover the cost (Xiarchos and Vick 2011). One such program in Minnesota is net metering. Once the system is installed, net metering provides financial compensation to customers who produce excess electricity using an on-farm solar electric system (Romich 2014). Excess electricity is then diverted back to the grid to be used by other consumers. The Minnesota Revisor of Statutes describes this program in 216B.164, "Cogeneration and Small Power Production". Any system below 40 kW can sell excess electricity back at the "average retail utility energy rate", received in the form of a check or a credit on the customer's bill. If the system is between 40 and 1,000 kW, electricity can be sent to the utility for an "avoided cost rate". Regardless, the net metering program substantially improves the return-on-investment (ROI) and payback period for a solar system. Other federal incentives are available as well, such as the USDA REAP grant, loans, and investment or production tax credit (DSIRE 2016). The SunShot Initiative is a program developed by the U.S. Department of Energy with the goal of reducing solar expenses to $1 per Watt by 2020 (U.S. DOE 2016). In 2010, the average cost of solar energy was $3.80/W, and already costs have gone down to $1.64/W (U.S. DOE 2016).

Energy Use on Swine Barns

The first step in identifying how solar energy can be implemented is to understand how a farm's strategies to raise swine affects its energy use. One such study was conducted in Iowa (Lammers et al. 2012). Six different facility types, diet formulations, and cropping sequence scenarios were examined in relation to energy use. The baseline system produced 15,600 pigs annually using confinement facilities and a corn-soybean cropping sequence and required 206.8 kWh per 300 lb. market pig, similar to most pork production facilities in the upper Midwest. The bedded hoop barn for grow-finish pigs and gestating sows used 3% less energy (200.2 kWh). Diet type alone accounted for 61 and 79% of total energy in conventional and hoop barns respectively. When averaging all size pigs, hoop barns generally used 64% less energy than conventional but 2.4% more feed. Operation of conventional swine buildings make up 25% of the total cost of energy, suggesting that the best way to minimize energy expenditure is by developing strategies to minimize or supplement energy use for heating and ventilation while maintaining pig performance.

Brown and Elliott (2005) attempted to characterize usage patterns of fossil fuel-based energy on farms. However, they concurred that there is not enough information to come to a conclusion and suggested that the state and/or utilities collect data on the amount of energy used for each application, such as drying and curing, heating, cooling, and ventilation, and water heating. This displays a need for knowledge of how and where supplemental energy is needed.

In Athens, Greece, Panagakis and Axaopoulos (2014) were interested more in how building materials affect cooling in Greece's hot and humid climate. Microclimate control was used to maintain air temperature and relative humidity in the area surrounding the swine. Traditional materials, such as fired brick or cement blocks without insulation, provided buildings that needed 18.2% more daily energy than prefabricated cement panels with insulation. Animal weight, housing density, type of floor, and feed energy content all influenced the total annual cooling energy requirements, but no published information could be found on specific or estimated values.

Regardless of location, the information on where and how swine farms are using energy is just not available. In order for farmers to feel they can install solar collection systems on their farms, they first need to know where the energy is needed most, whether on a specific type of barn (e.g. finishing, nursery, gestation, or farrowing) or on a specific application (e.g. ventilation fans or heating or cooling systems). By knowing where the solar system is most needed, the system can be efficiently used, and the farmer can feel more secure about their investment.

Testing Solar Technology on Swine Barns

Once energy use is determined, a properly fitted solar system can be chosen for a particular swine barn. Using solar technology on swine barns is not all that new but has historically been too expensive or impractical to install. However, pork producers are finding themselves more inclined to install them as electricity and propane costs go up and the cost of solar systems go down. As a result, studies and tests have been growing in popularity to determine how solar energy can be utilized on different types of barns with varying needs all around the world.

Weaning typically occurs from three to five weeks of age and demands a suitable environment for young pigs to remain productive (Bodman et al. 1989). This can be done by heating the entire volume of air between 80 and 95°F or by using hovers, infrared heating, and floor heating to create less energy intensive microenvironments. Bodman, Kocher, and DeShazer studied two modified-open-front (MOF) non-mechanically-vented nurseries in Nebraska: one consisted of 22 pens plus an equipment area and a capacity of 550 pigs and the other barn consisted of 12 pens with a capacity of 300 pigs (A.5d). Construction of the facilities cost approximately 2/3 that of conventional nurseries with heating at 1-2% the cost to operate during winter. Despite the lower cost, solar energy was considered to be a beneficial and effective way to heat in the winter. As a result, the two nurseries were fitted with a mono-slope roof design and passive collector panels for warm weather ventilation panels. In addition, a ground-mounted solar collector provided in-floor heat distribution and storage. Between October 1980 and January 1982, an average of 19% of the solar energy was transferred to the floor surface. After thirteen years of operation, the two facilities showed that the passive and ground-mounted solar panels together could be used effectively. However, there was some uncertainty regarding if the reduced heat loss was due to floor heating, solar energy, or some combination of the two.

Another attempt to modify MOF nurseries in Nebraska occurred in the winter of 1988 (Song 1989). A naturally-ventilated, solar-assisted (NVS) swine nursery and a mechanically-ventilated, solar-assisted (MVS) nursery both held up to 96 pigs and installed active solar collectors for in-floor heating and hovers in the sleeping areas (A.5e). The NVS nursey also utilized solar-preheated ventilation while the MVS nursery had double-glazed solar windows for passive solar heating. Unlike the 1980 study, Song compared building environment, energy efficiency, pig performance, and pig behavior during the experimental process. Finally, the NVS nursery was found to use 72% as much energy as the MVS and required 0.60 kWh less energy per pig. In fact, the MVS required 45% more energy than the NVS in winter because of the need for excess ventilation. Also, a conventionally heated nursery was modeled and found to spend 15.2 to 18.2 kWh per pig compared to 1.4 to 2.2 kWh per pig used by either the NVS or MVS barn.

Solar walls have been of particular interest to many swine farmers. In St-Sylvestre de Beaurivage outside of Quebec City in Canada, a solar wall was installed on the south-southeast wall of a 1,000 piglet space that was 28.6 m long and 14.6 m wide (A.5a; Godbout et al. 2004). The Marisol farm consisted of four rooms with twelve stalls each and kept swine from 11.7 to 55.8 lb. For six months, the energy used for heating was measured, varying between 450.8 kWh and 2389.4 kWh monthly; each month, 12.2-47.4% of that was contributed by the solar wall. If the farm had previously used propane as a fuel source and then replaced it with the solar wall, the energy bill would be reduced by as much as 31%.

A swine nursery in eastern North Carolina implemented a transpired solar wall (TSW) for heating in the winter (A.5b; Shah et al. 2016). The building was equipped with a curtained sidewall, which can be lowered for emergency ventilation but can lose a lot of heat in winter. TSWs have the ability to recover heat by acting as a barrier over the wall and absorbing the heat that tries to escape. This was shown in the fact that 50% of the energy collected by the TSW was actually collected at night between 18:00 and 08:00 when normally the most heat would be escaping due to the large temperature differential between the air inside and outside of the barn. However, in this particular facility, the ventilation fans were not normally operating during the day, so a majority of the heat energy being collected by the TSC in the day had no application to be used on and thus was released as waste. With the TSW, the air temperature was able to be increased up to 95°F, and propane use was reduced by 8.5%; however, the system may have caused unwanted heat gain in the summer had it been tested during those months. Regardless, the conclusion was that the TSW was "technically feasible for use" based on energy output, time of energy output, temperature variation, and animal performance. Economics were not really discussed.

In eastern North Carolina, a swine barn and turkey brooder were both analyzed to determine the practicality of TSC ducts on the barns (Love and Shah 2011; A.5c). PV systems were considered to have too high of an installation cost and too low of an efficiency for these barns whereas TSC ducts could convert up to 80% of solar radiation into heat energy that could be easily retrofitted to a swine barn and turkey brooder. The swine barn was made up of two rooms, 7.6 m x 30.5 m each. One room was fitted with a TSC duct; one was not. The barn had a capacity of 950 pigs raised from about 18 days to 8 weeks old and included a thermostatically-controlled insulated drop ceiling (i.e. a secondary ceiling built below the structural ceiling) and curtains on one side, six ventilation fans, and heating via a propane-fired forced-air furnace. From the fall of 2010 to the spring of 2011, the amount of propane replaced with the energy collected from the TSC ducts was recorded, and analyses of animal performance and carbon dioxide levels were continuous. Propane use was reduced by an average of 34% for the two swine herds in the room with the TSC duct; the first herd was placed in the room with the TSC duct from 11/19/2010 to 1/4/2011 and used 65% less propane than the first herd in the room without the duct in the same period of time, and the second herd was placed in the room with the TSC duct from 1/15/2011 to 3/1/2011 and used

12% more than the second herd in the room without the duct in that period of time. The higher usage in the second herd was more than likely due to management error. During the coldest week of the testing period, the minimum ventilation fans were set to run far longer than necessary, and the solar fan was activated before the TSC duct was able to warm the air, resulting in cold air being pushed into the room. Despite this, the TSC duct showed potential for providing supplemental heat to the swine barn. Unfortunately, tests with the turkey brooder showed the amount of heat supplemented by the TSC duct was inconsequential as the brooder used approximately the same amount of propane as it did prior to installation of the duct.

The Purdue University Cooperative Extension Service provided advice on solar heating in homes, farms, and businesses (Turner et al. 1981). With a farrowing house maintained at about 60°F, heating is essential, especially in winter. Turner et al. discussed various methods on when and how to implement solar systems on a farm. However, they come to no clear conclusion on whether solar is the way to do that as the practicality of the system must be determined on a case-by-case basis.

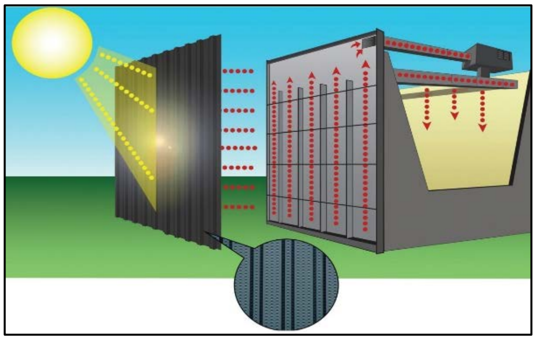
Lastly, a thesis was written in Iowa regarding the economic viability of solar (Sloth 1980). The R factor (e.g. the resistance of structural materials to heat loss) and type of flooring affected heat loss in a swine barn greatly; however, ventilation was by far considered the highest heat loss. The swine act as humidifiers and add moisture to the air, which collect on cold surfaces, reducing the life of the building and its equipment and increasing maintenance costs. As a result, ventilation is essential in maintaining a constant relative humidity and removing any dangerous gases, which is more difficult with solid floors rather than slatted. In this study, Sloth assumed the electrical requirement was solely from ventilation in farrowing and nursery barns. One-cover covered plate collectors were found to be best for swine systems with slatted floors or that are idle for part of the year, and two-cover suspended plate collectors with storage were considered best for systems requiring large amounts of heat or continuous use. Generally, increasing the size of the collector appeared to be more beneficial than improving its efficiency. If dealing with a farrowing and nursery unit, increasing the size of the farrowing unit collector and using any surplus heat in the nursery is more beneficial than using a collector on a nursery with slatted floors. Overall, it was determined that while solar systems are feasible, more work needs to be done to ensure its practicality in the swine industry. While this study was a good comparison among some solar systems in various types of barns, the study did not take into account heating, cooling, or other miscellaneous loads, further emphasizing the need for a better understanding of where energy is being used and can be improved.

Conclusion

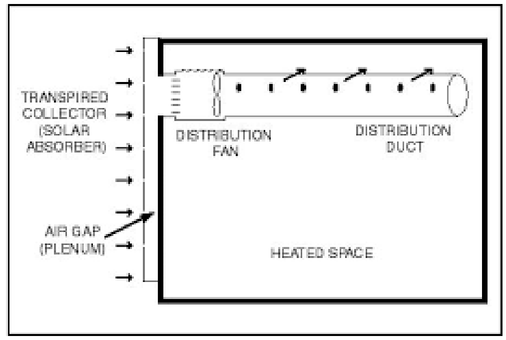
Pork production benefits the economy greatly yet the amount of energy required to operate these systems can be a burden on swine facilities. As a result, some farmers are looking towards the sun as an unlimited source of fuel and way to supplement their energy usage. There are numerous studies and implementations of solar technology and energy that provide information about specific applications and the means to advance solar in the agricultural industry. However, many have found that there just is not enough information out there to make an educated decision on where and how much energy is needed, a crucial first step in deciding if solar energy is the right solution. The WCROC has made steps in determining how best to implement solar on their farm and have found ways to inform pork producers of their findings. By first determining the specific applications of the energy being used, the WCROC was able to choose a suitable roof-mounted solar PV system for their finishing barn and further recommend systems to two other barns in the area. Through this process, solar energy can continue to grow and help farms diminish their electricity bill, reduce their carbon footprint, and overall make their farm a more sustainable and successful business.

Appendix

1. Examples of Passive Solar Systems

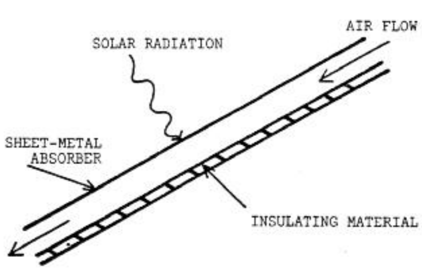


(a) Sidewall collector (Slattery 2014)

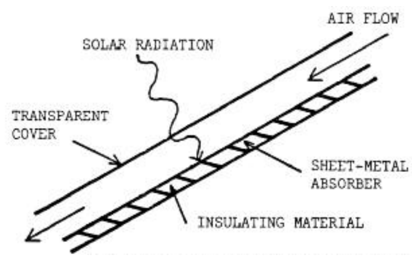


(b) Transpired solar duct (Maurer 2004)

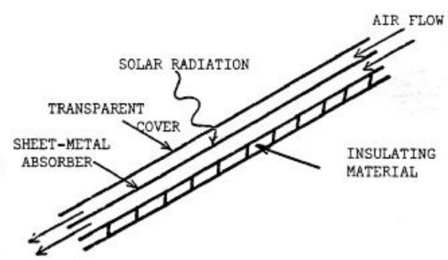
2. Types of Active Solar Systems



(a) Bare plate (Turner et al. 1981)



(b) Covered plate (Turner et al. 1981)



(c) Suspended plate (Turner et al. 1981)

3. Ways to Install Active Solar Systems

(a) Ground-mounted system at University of Minnesota: Morris (Taken by author 2016)

(b) Pole-mounted system at University of Minnesota: Morris (WCROC 2016)

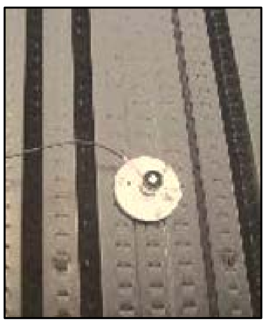
(c) Roof-mounted system on a swine barn at WCROC (Taken by author 2016)

4. Common Types of Active Solar Systems


(a) Solar PV System (Renu News 2015)

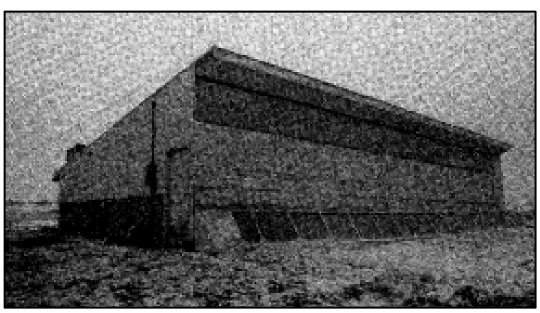

(b) Solar Thermal System (YouGen 2016)

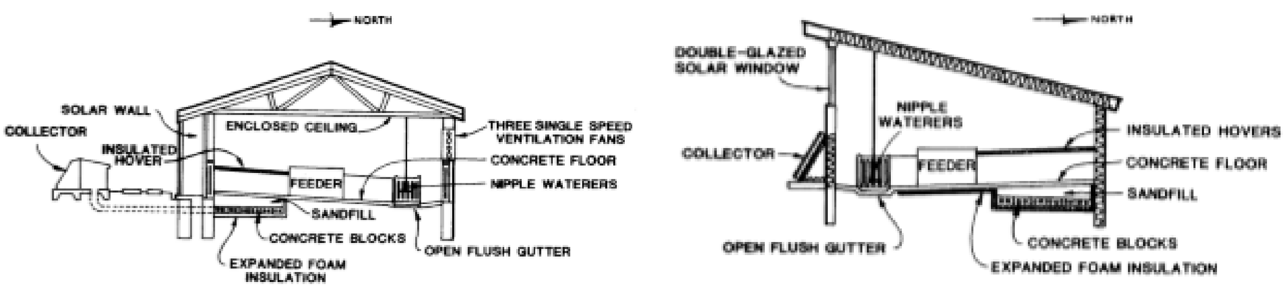
5. Solar Technology Tested on Swine Facilities


(a) Solar wall and radiation sensor in Quebec, Canada (Godbout et al. 2004)

(b) TSW in Clinton, NC (Shah et al. 2016)


(c) TSC ducts at a turkey brooder in Snow Hill, NC (top) and swine nursery in Roseboro, NC (bottom) (Love and Shah 2011)


(d) MOF Solar Nursery near Ceresco, NE (Bodman et al. 1989)



(e) Cross-section of an MVS nursery (left) and NVS nursery (right) (Song et al. 1989)

Bibliography

United States Department of Agriculture. June 2016. "Minnesota Ag News- Hogs & Pigs". Washington D.C: United States Department of Agriculture, National Agricultural Statistics Service.

Baker, John E. 2004. "Effective Environmental Temperature". In *Journal of Swine Health and Production* 12, no. 3: 140-143.

Bodman, G. R., M. F. Kocher, and J. A. DeShazer. 1989. "Performance of solar-assisted modified-open-front swine nurseries". In *Applied Engineering in Agriculture* 5, no. 2: 207-214.

Boyd, Vicky. September/October 2008. "Floating solar power". In *EnerG*. Marlton, NJ: Merco Publishing Inc. http://www.altenerg.com/back_issues/index.php-content_id=84.htm. Accessed June 6, 2016.

Brown, Elizabeth and R. Neal Elliott. March 2005. "On-Farm Energy Use Characterizations". Report IE052. Washington D.C: American Council for an Energy-Efficient Economy (ACEEE).

DSIRE. 2016. "Programs: Minnesota". Raleigh, NC: NC Clean Energy Technology Center. http://programs.dsireusa.org/system/program?state=MN. Accessed June 27, 2016.

Gensch, Alex. August 2014. "Energy Use in Swine Production". http://renewables.morris.umn.edu/biomass/documents/interns/2014/Gensch_video.htm. Accessed June 10, 2016.

Godbout, S., F. Pouliot, I. Lachance, H. Guimont, R. Leblanc, F. Pelletier, and L. Hamelin. 2004. "Feasibility and energy recovery of a solar wall in pig nursery". In ASAE Annual Meeting, paper 044140. St. Joseph, MI: American Society of Agricultural and Biological Engineers.

Gueymard, Christian A. August 2003. "The Sun's Total and Spectral Irradiance for Solar Energy Applications and Solar Radiation Models". Edgewater, FL: Solar Consulting Services.

Jacobson, Larry D. 2011. "Energy and Ventilation Management Issues in U.S. Pig Buildings". In 2011 London Swine Conference: 129-136. St. Paul, MN: University of Minnesota Department of Bioproducts and Biosystems Engineering.

Johnston, Lee and Yuzhi Li. 2011. "Reduced Nocturnal Temperature (RNT) for Nursery Pigs". Morris, MN: University of Minnesota Extension.

Jones, Don D. and William H. Friday. 1980. "Environmental Control for Confinement Livestock Housing". West Lafayette, IN: Cooperative Extension Service, Purdue University.

Kalogirou, Soteris A. 2014. *Solar Energy Engineering: Processes and Systems*. Academic Press: Cambridge, MA.

Lammers, Peter J., M. Douglas Kenealy, James B. Kliebenstein, Jay D. Harmon, Matthew J. Helmers, and Mark S. Honeyman. 2012. "Energy use in pig production: an examination of current Iowa systems." In *Journal of Animal Science* 90, no. 3: 1056-1068.

Love, Chris, and Sanjay B. Shah. 2011. "Transpired Solar Duct for Tempering Air in North Carolina Turkey Brooder Barn and Swine Nursery". In ASABE Annual International Meeting, paper 1110875. St. Joseph, MI: American Society of Agricultural and Biological Engineers.

Maurer, Christine C. 2004. "Field Study and Modeling of an Unglazed Transpired Solar Collection System". North Carolina State University: Raleigh, NC.

Minnesota Legislature. 2015. "216B.164 Cogeneration and Small Power Production." St. Paul, MN: Revisor of Statutes, State of Minnesota.

Minnesota Pork Producers Association. 2016. "MN Pork Production". Mankato, MN: Minnesota Pork Producers Association. http://www.mppainsider.org/mn-pork-production. Accessed June 13, 2016.

Ni, Ji-Qin, Albert J. Heber, Claude A. Diehl, and Teng T. Lim. 2000. "Ammonia, Hydrogen Sulphide, and Carbon Dioxide Release from Pig Manure in Under-floor Deep Pits". In *Journal of Agricultural Engineering Research* 77, no. 1: 53-66.

Panagakis, P., and P. Axaopoulos. 2004. "Comparison of two modeling methods for the prediction of degree-hours and heat-stress likelihood in a swine building." In *Transactions of the ASAE* 47, no. 2: 585-590. St. Joseph, MI: American Society of Agricultural and Biological Engineers.

Renu News. June 2015. "SRP Shipping Durban Installs Solar PV Panels to Benefit from Uninterrupted Power During Grid Outages". Renu News: Durban, South Africa. http://www.renuholdings.co.za/ articles/srp-shipping-durban-installs-solar-pv-panels-to-benefit-from-uninterrupted-power-during-grid-outages. Accessed June 17, 2016.

Romich, Eric. 2014. "An Introduction to On-Farm Solar Electric Systems." Columbus, OH: Ohio State University.

Roney, Matthew J. June 2014. "China Leads World to Solar Power Record in 2013". Washington D.C: Earth Policy Institute. http://www.earth-policy.org/indicators/C47/solar_power_2014. Accessed June 6, 2016.

Shah, Sanjay B., Trapier Marshall, and Steve Matthis. 2016. "Transpired Solar Wall for Tempering Air in a Swine Nursery in a Humid Subtropical Climate." In *Applied Engineering in Agriculture* 32, no. 1: 115-123. St. Joseph, MI: American Society of Agricultural and Biological Engineers.

Slattery, Lee Ann M. September 2014. "Solar Air-Heating Systems 101: Ensuring Efficient and Economical Renewable Energy". In *The Construction Specifier.* Richmond Hill, Ontario, Canada: Kenilworth Media Inc.

Sloth, Darrell Gene. 1980. "The economic feasibility of solar heat in Iowa swine production." In *Retrospective Theses and Dissertation*, paper 17033. Ames, IA: Iowa State University.

Song, A., B. K. Huang, and H. D. Bowen. 1989. "Performance comparisons of naturally-and mechanically-ventilated solar-assisted swine nurseries." *Transactions of the ASAE* 32, no. 1: 216-222. St. Joseph, MI: American Society of Agricultural and Biological Engineers.

Turner, L.W., A.C. Dale, and B.A. McKenzie. 1981. "Solar Heating for Home, Farm, and Small Businesses: Basic Facts About Collection, Storage, and Utilization". West Lafayette, IN: Cooperative Extension Service, Purdue University.

United States Department of Energy. 2016. "About the Sunshot Initiative". Washington D.C: United States Department of Energy. http://energy.gov/eere/sunshot/about-sunshot-initiative. Accessed June 27, 2016.

Vilsack, Tom and Cynthia Z.F. Clark. February 2011. "2007 Census of Agriculture: On-Farm Renewable Energy Production Survey (2009)". Washington D.C: United States Department of Agriculture, National Agricultural Statistics Service.

West Central Research and Outreach Center (WCROC). 2016. "UMM Ground-Mounted Solar PV System". Morris, MN: West Central Research and Outreach Center.

Xiarchos, Irene M. and Brian Vick. April 2011. "Solar Energy Use in U.S. Agriculture Overview and Policy Issues". Washington D.C: United States Department of Agriculture.

YouGen. 2016. "Introduction to Solar Heat and Hot Water". Milton Keynes, Buckinghamshire, England: National Energy Foundation. http://www.yougen.co.uk/renewable-energy/Solar+thermal. Accessed June 17, 2016.

TRANSITIONING MINNESOTA FARMS TO LOCAL ENERGY

Rachael Acevedo, Renewable Energy Intern

University of Minnesota West Central Research & Outreach Center

----

Abstract

The purpose of this study was to determine if solar photovoltaic (PV) systems are feasible options for swine barns to use as a source of electricity and have the ability to produce as much electricity as a swine barn is using at any given time. A 26.88 kW Heliene 60M280 system with three SE9K inverters from SolarEdge Technologies, Inc. was installed in June 2015 on the roof of the West Central Research and Outreach Center (WCROC) swine finishing barn. The system was fully operational in October 2015, at which point the electricity production was recorded. Solar irradiation, or the total solar energy available in a point of time, was measured with a pyronometer at the WCROC weather station and compared to the energy actually being converted into electricity by the solar PV system. In addition, the overall electricity usage in the finishing barn was recorded using the utility meter, and specific applications' electricity usage (e.g. from the pit fans, feed augers, lights, et cetera) was measured with Campbell Scientific CR800 data loggers. The PV system did not provide enough electricity to match the electric load in winter, largely due to snow covering the panels from mid-December through the majority of January, but produced more electricity in summer than the barn was using. Similarly, the system produced more electricity in the middle of the day than was being used, but there was a small load at night that had to be drawn from the grid. Nevertheless, generally the PV system did produce as much electricity as was being used by the finishing barn and proved to be a feasible option for the WCROC swine barn.

Contents

1. INTRODUCTION

The Earth receives about 1,366.1 watts per square meter from the sun (Gueymard 2003). This vast amount of energy can be harnessed using solar technology that can convert the solar radiation into electricity or heat. With the ability to harness this virtually unlimited power source, solar technology is the most rapidly growing energy technology by a wide margin (Roney 2014). The aim of the project, "Transitioning Minnesota Farms to Local Energy", was to determine the viability of using solar photovoltaic (PV) systems on swine farms to supplement or entirely replace electricity usage from the utility grid.

Solar PV systems use photons (i.e. particles of light from the sun) to knock electrons loose from the semi-conductor materials that make up the panels. This separates any free positive and negative charges and allows the formation of an electric current. Through this process, solar PV systems are able to convert light into electricity, which can then be used as an alternate source of electricity for swine barns. Solar PV systems consist of three main components: solar modules, inverters, and Balance-of-System (BOS) components. Solar modules are comprised of numerous cells which collect solar energy. Furthermore, several solar modules can be adjoined to compose a solar array. The array is connected to an inverter, which converts electricity from direct current (DC) to alternating current (AC). Direct current is generated by solar PV panels, but alternating current is what most equipment, such as lights, ventilation fans, and heating and cooling equipment, requires to operate. Finally, BOS components, also referred to as Balance-of-Plant (BoP) components, include any meters, safety equipment (e.g. disconnect switches), conduits, cables, combiner boxes, and racking and tracking gear that may be required for the system to operate properly.

There are numerous benefits to using solar as a source of electricity on a swine barn. First, gasoline, natural gas, and other fuel source prices are unpredictable with a general upward trend. In addition, there is uncertainty surrounding fossil fuels in regards to their availability in the future. In rural areas, natural gas availability is often lacking. Power lines may be failing or non-existent, particularly in remote areas where installing new lines or fixing old ones does not benefit utilities enough to warrant the cost. Using solar energy also reduces greenhouse gas emissions, provides the ability to harness an unlimited and free source of energy, and requires little or no maintenance because PV systems do not need moving parts to function. Finally, there are many programs and grants that give financial support to those installing on-farm solar energy systems. For example, net metering is a Minnesotan program that provides financial compensation to customers who produce excess electricity with a solar PV system (Minnesota Legislature 2015). Any system smaller than 40 kW can sell excess electricity back at its current retail rate, received in the form of a check or a credit on the customer's bill. If the system is between 40 and 1,000 kW, electricity can still be sent to the utility for an "avoided cost rate", or reduced retail rate. Other federal incentives include the Made in Minnesota Solar Incentive Program, USDA REAP grant, investment or production tax credit, and loans (DSIRE 2016).

Solar systems are usually installed in one of three ways. Ground-mounted systems are attached to the ground, as the name suggests. They are easily accessible for doing repair work and removing snow from the panels and can be installed at any angle or direction. In Minnesota, more sun comes from the south at an angle approximately equal to the latitude, which is 45° in Minnesota; ground-mounted systems can always be south-facing and at an ideal angle, making them as efficient as possible. Pole-mounted systems are similar to ground-mounted in that they are attached to the ground, but instead of being low to the ground, they are mounted on poles and can have additional machinery attached, allowing the system to track the sun. Tracking makes the system more efficient, but generally these systems require regular maintenance on the moving components and are too expensive to make them a feasible choice for farms. Lastly, roof-mounted systems are the easiest to install and are most efficient on south-facing roofs with no obstruction (e.g. no trees, chimneys, and other buildings). However, access can be difficult, even dangerous, if snow removal or repair work is required.

In addition to installing the array in different locations, the system can be attached to the grid. If the system is off-grid, benefits include being self-sufficient and potentially being a cheaper option than extending power lines into remote areas. However, off-grid systems require solar batteries to store electricity, which usually makes the system more expensive than a system connected to the grid. Grid-tied systems allow the owner to save money by taking advantage of the net metering program by selling excess electricity back to the utility during times of high production. In addition, at times of low or no solar electricity production, the utility will provide access to back-up power.

Every barn has different electricity needs, meaning that each system requires a different size, location, and type of solar systems. The goal of this project was to determine if solar PV systems can provide as much electricity as a swine barn is using. Actual electricity usage of the WCROC swine finishing barn was compared with the solar production of the 26.88 kW system installed on the barn's roof. In addition, the data was used to help a farm choose what system would be best for them.

2. MATERIALS AND METHODS

a. Location

The West Central Research and Outreach Center (WCROC) in Morris, MN provides opportunities to rural areas by researching innovations or emerging trends in real life scenarios and advising agricultural producers about potentially using these innovations on their own farms. Morris is located in central western Minnesota and part of one of the richest agricultural lands in the country, making it a prime location for testing. The WCROC is specifically located at a latitude of 45 35' N and a longitude of 95 52' W and at an elevation of 1,141 feet above sea level. Currently, the WCROC possesses nursery, gestation, finishing, bedded farrowing, and hoop barns for swine. The focus of this project was on the 146' x 36' finishing barn. The barn consists of one eastern and one western room, housing up to 216 swine each. During this period, the swine were fed a diet mainly consisting of corn and soybean meal. From January 1, 2015 to December 31, 2015, the finishing barn used approximately 3,000 therms of natural gas and 28,000 kWh of electricity.

b. Auditing Electricity Consumption for Pork Production Systems

Swine facilities require large amounts of electricity to function. Up to this point, most research regarding energy consumption to produce pork has been theoretical. To determine the feasibility of solar energy as a source of electricity on a swine farm, actual electricity consumption must be analyzed on the farm in question. Using a Campbell Scientific CR800 data logger with a Campbell Scientific AM 16/32B Multiplexer (Fig. 1), wall ventilation fans, pit fans, heaters, power washer vent fan, feed auger, power washer, and lights (Fig. 2) were monitored at the WCROC finishing barn. The data logger reported the electricity production in electric current consumed by each load in Amperes every ten minutes, and the data of interest was recorded from June 1, 2015 through July 31, 2016. The power consumed, in kWh/day, was calculated using the measured current, voltage, and an estimated power factor.

Figure 1: Campbell Scientific CR800 Data Logger with Campbell Scientific AM 16/32B Muliplexer.

Figure 2: Devices with high electricity requirements at the WCROC finishing barn. From top left, a wall ventilation fan, a pit fan, feed augers, and a heater. From bottom left, the power washer/power washer vent fan and lights.

In addition to measuring the loads of specific applications, overall electricity consumption was measured through an electric meter installed by the electric utility. The Campbell Scientific data loggers were unable to measure some of the miscellaneous loads, so the electric meter gave a better representation of the total need for electrical energy in the barn.

The number of pigs in the barn between June 2015 and May 2016 was also recorded as the electricity consumption can be greatly affected by the amount of pigs. High numbers of pigs require more cooling and ventilation. As the WCROC farm is research-oriented, the finishing barn did not always have pigs, requiring minimal electricity usage.

c. Installing the Solar PV System

An objective of the study was to make the building approach net-zero, meaning the barn would produce as much electricity as the barn would use. By first determining the total electricity usage, PVWatts could be used to estimate the size of the system required to meet that goal of net-zero. PVWatts is a program developed by the National Renewable Energy Laboratory (NREL) that predicts the electricity production of solar PV systems and takes into consideration system size (kW), module type (e.g. standard, premium, or thin film), array type (e.g. open rack, roof mount, tracking, etc.), system losses, tilt (e.g. 4/12 pitch gives an 18.5° tilt), and azimuth (i.e. north, south, east, or west-facing). Finally, the system was sized so that the array could fit on the roof. Using this method, a 26.88 kW DC array was determined to produce about as much electrical energy as the barn required to operate, if not slightly more. As a result, a Heliene 60M280 fixed array comprised of 96 modules was installed on the WCROC swine finishing barn in June 2015 (Fig. 3). The system was roof-mounted at a 20° angle facing south.

Figure 3: Heliene 60M280 Solar PV System Mounted on the Roof of the WCROC Swine Barn.

Electricity from each of the three rows of panels was diverted through one of three inverters, SE9K three phase inverters from SolarEdge Technologies, Inc., and to a transformer for distribution.

Figure 4: SolarEdge SE9K Three Phase Inverters on the WCROC Swine Barn.

The inverters recorded the electricity output of the solar PV system every fifteen minutes, allowing for the daily and monthly kWh produced to be calculated.

d. Comparing Electricity Production to Irradiation and Electricity Usage

Every day a certain amount of irradiation, or power from the sun per unit area, is received in Morris, MN. Irradiation affects the amount of available energy for the solar PV system to collect; therefore, comparing electricity production to irradiation provides the efficiency of the system.

$$Efficiency = \frac{Solar\ PV\ Production\ (W)}{Irradiation\ Available\ \left(\frac{W}{m^2}\right) * Area\ of\ Solar\ System\ (m^2)}$$

Equation 1: Calculation for efficiency of a solar PV system.

Available irradiation was gathered by the pyronometer at the WCROC weather station, and the solar production was collected using the inverter. The area of the 26.88 kW system was known to be approximately 140 m^2, given the number and type of modules. Efficiencies could then be calculated for every hour during a "typical day" in a given month. The typical day was determined by calculating the average daily electricity production. For each month, the date with the production closest to that daily average was chosen as a typical day. The hourly electricity production for the typical day was then compared to the actual irradiation collected from the pyronometer that day. By choosing the production and irradiation from actual days instead of an average of all the days in a given month, the calculated hourly efficiencies were more realistic.

In addition to comparing production to irradiation, the times of electricity production was compared to times of electricity consumption. As described previously, data loggers measured the electric load every ten minutes from the fans, pit fans, heaters, power washer vent fan, feed auger, power washer, and lights in the finishing barn. The data could then be easily compared to the solar electricity production throughout the day as well as on a monthly basis.

e. Case Study

Two farms, Finisher 4 and 5, showed interest in using solar energy to mitigate their grid electricity usage. "Finisher 4" and "Finisher 5" were designations given to the barns by the WCROC to keep their anonymity intact while still allowing the WCROC to monitor their energy usage. Finisher 4 has a tunnel-vented, two room barn with a 2,400 swine capacity (1,200 in each room). The barn's roof has 4/12 pitch and faces east and west, making roof-mounted solar panels much less feasible than ground-mounted. Finisher 5 is a curtain-sided barn with two 530-head rooms. The roof has 4/12 pitch and faces north and south, ideal for a roof-mounted solar PV system. The electricity usage of both barns were being monitored so that a Heliene 60M280 roof-mounted or TenKSolar XT-A ground-mounted solar PV system could be assessed.

After analysis of the two farms' electricity usage, PVWatts was used to estimate what size ground-mounted or roof-mounted arrays would be required to provide Finisher 4 and 5 with a net-zero system. Finally, a report was provided to Finisher 4 and 5, giving them an idea of the solar PV system that would be most beneficial to each barn.

3. RESULTS AND DISCUSSION

a. Electricity Consumption at the WCROC Finishing Barn

First, total electricity consumption of the WCROC finishing barn was analyzed. The electricity usage in the swine barn was recorded by the utility meter (Fig. 5). The meter measured the entire barn's usage and is separate from the Campbell Scientific current sensors, which measured the electricity usage of only specific pieces of equipment.

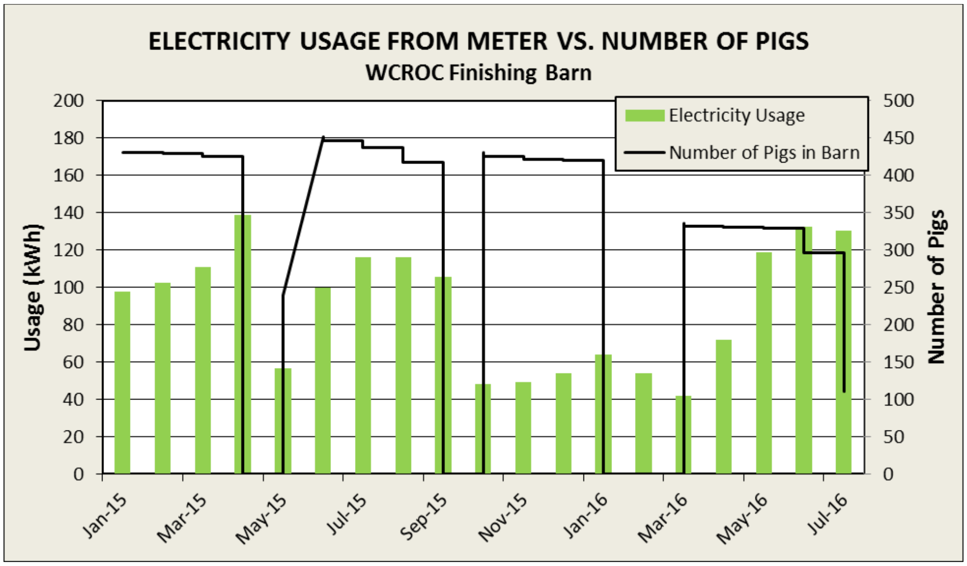
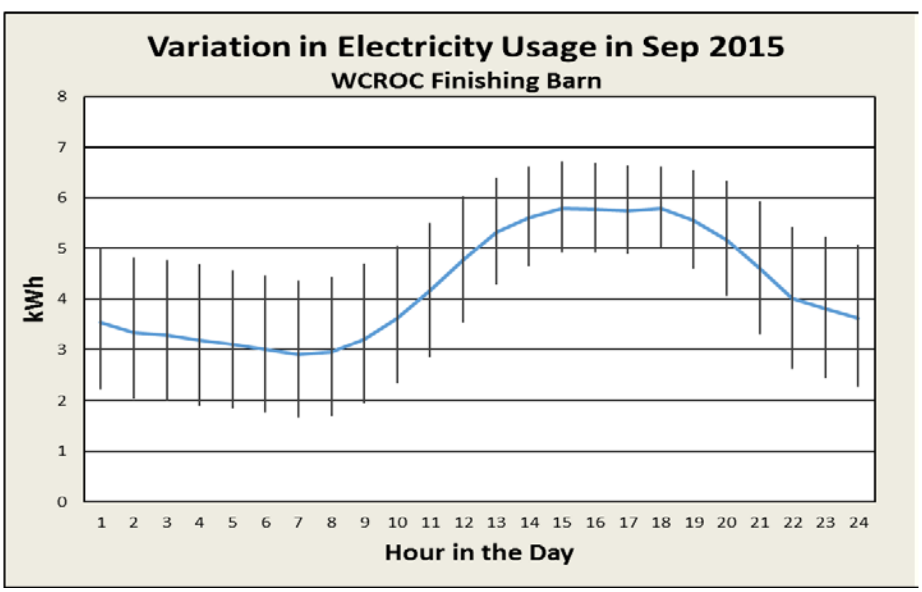


Figure 5: Amount of electricity used by the WCROC swine finishing barn, recorded using an electric utility meter, and the number of pigs in the finishing barn from January 2015 to July 2016.

As the WCROC finishing barn is primarily for research, pigs only resided in the barn during a study. The number of swine affected the load as more pigs residing in the barn required greater electricity usage. In addition, months with more extreme weather, such as January, May, July, and August, had a higher electric load due to higher heating, cooling, or ventilation. While the weather will still affect electricity usage in swine barns, commercial barns typically always have pigs in their barn, so data regarding energy usage in the WCROC finishing barn was only considered for months during which the barn had a significant number of pigs.

Naturally, there was some variation in the amount of electricity used throughout the day. Taken from the Campbell Scientific CR800 data logger with the Campbell Scientific AM 16/32B Multiplexer, the hourly electricity usage from the WCROC swine finishing barn could be shown in Figure 6.



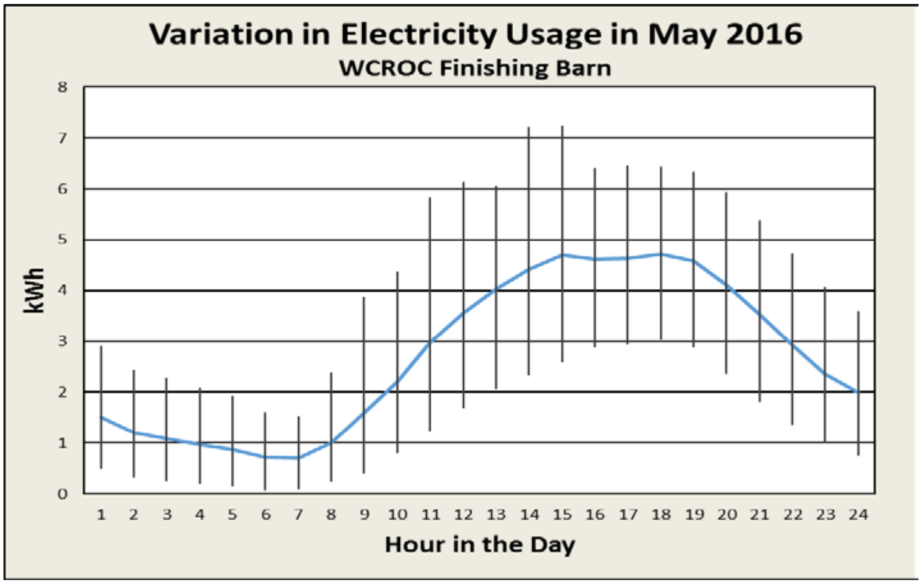


Figure 6: Variation in the total electricity used in an hour, measured using the Campbell Scientific data loggers.

Also, note that in September, the finishing barn had over 400 pigs. In May, there were approximately 330 pigs. Therefore, the barn had less electricity usage in May than it would have had there been seventy more pigs. More mild weather may have also had an effect on this.

Overall, there was a larger electricity usage in the middle of the day. For September, a high variation in electricity usage could be seen at night, and for May, the high variation was in the middle of the day. These high variations were in part due to weather; for example, in Minnesota, weather in May can be very warm, requiring electricity to keep the fans running. However, May weather can also be mild when the sun is high, requiring minimal cooling and some ventilation. This resulted in a high variation from 14:00 to 15:00 when the sun can make a large difference. For September, however, the weather was generally less unpredictable than for May, resulting in less variation in the middle of the day.

Next, average electricity usage and average solar production per month were evaluated (Fig. 7).

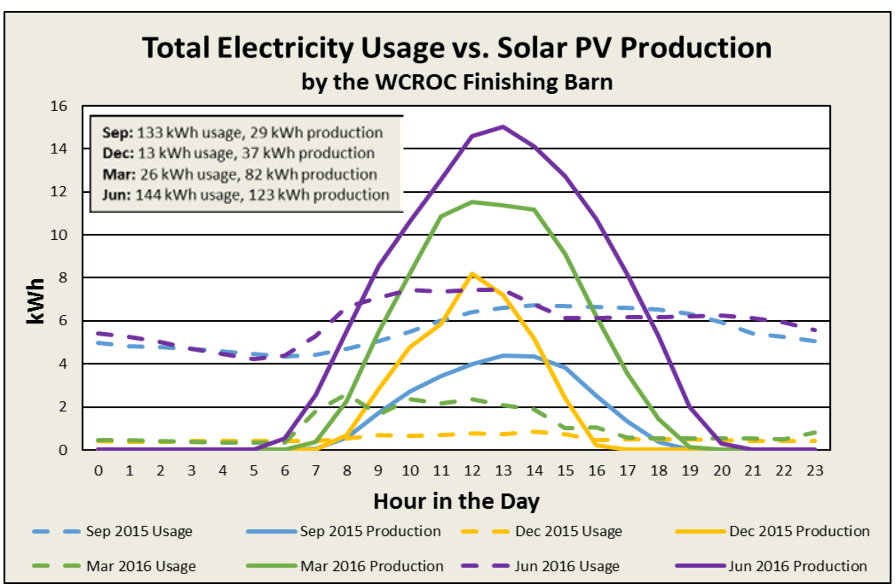


Figure 7: The average hourly electricity usage and solar PV production at the WCROC finishing barn.

Because the solar PV system produced the most electricity during the middle of the day when there is the greatest load, solar energy was a good fit for the swine barn. However, Minnesota winters have a lot of weather variability. When a large amount of heating was required, the weather may have been overcast, preventing enough electricity from being produced. Regardless, there appeared to generally be more production in the middle of the day. Despite this variability being a problem in winter, this trend was beneficial in summer as high ventilation and cooling was required when solar radiation was greatest. The large amount of solar radiation would be able to be converted into a large amount of electricity through the solar PV system, making solar energy ideal in the summer.

Despite the higher load and production in the middle of the day, a small load was typically required at night. In September and June, this average load was actually fairly significant, emphasizing the fact that solar PV systems must either be connected to the grid or attached to a solar battery in order to provide a back-up source of electricity in times of little or no production.

Knowing these trends is important when determining if solar was suitable for use in swine barns. With the WCROC finishing barn, a 26.88 kW roof-mounted system was believed to generally balance the electricity usage and production on an annual basis, but electricity was still required to be purchased from the utility at night and sold to the utility during the day using the Minnesota net metering program.

b. Electricity Production Using the 26.88 kW Solar PV System

Next, monthly production was analyzed. Electricity production from the solar system installed on the roof of the finishing barn was monitored using an online connection with the SolarEdge inverters, where the monthly production and usage were compared (Fig. 8).

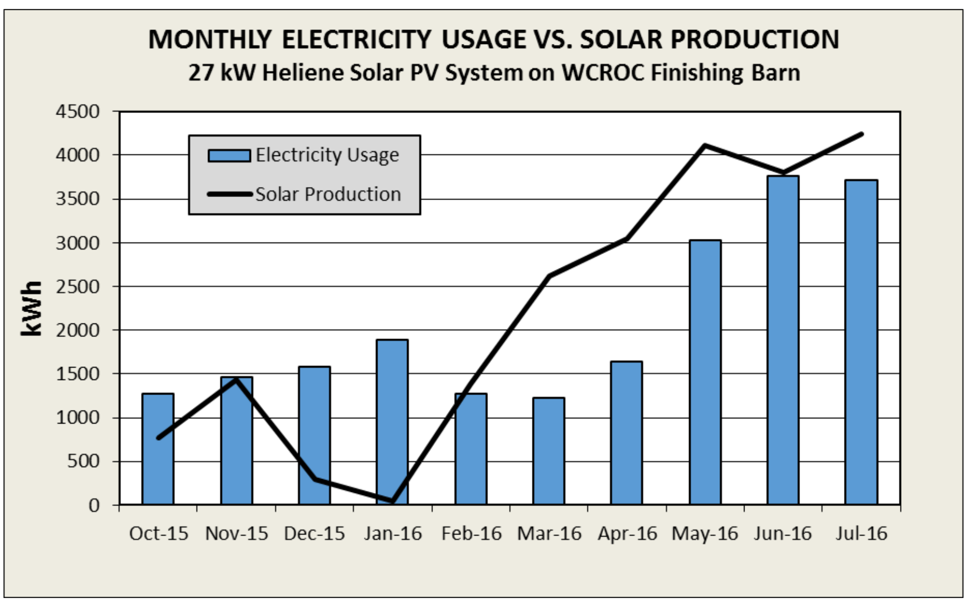


Figure 8: Comparison between the electricity used in the swine barn and produced by the 26.9 kW solar PV system each month.

First, note that the solar system electricity production was much higher in spring than fall. In addition, the load was higher in the late spring than fall. This demonstrates the fact that in the finishing barn, the monthly load was greater during months of high production. However, as the WCROC swine finishing barn is a research barn, the number of pigs residing in the barn fluctuates, another important consideration when looking at the electricity usage. From October

2015 through late January 2016, the barn was almost at full capacity with 212 pigs in each room. On January 26, 2016, the barn was completely emptied until March 11, 2016, explaining why the electricity usage in February and March are so low. The barn was then filled with 167 pigs in each room on March 11.

Another observation is how low solar production was in December and January. This was due to snow covering the panels from December 16, 2015 to January 27, 2016. As a result, about a month and a half of potential production time was lost. While a roof-mounted system was ideal for the finishing barn, cleaning snow off of the panels would be difficult and potentially dangerous. Despite the difficulty, removing the snow regularly is important. In fact, the system was supposed to be able to keep snow off by using solar radiation to melt the snow upon contact. Nevertheless, snow was able to cover the panels quickly enough that all the snow was not able to melt, preventing further heating and electricity production.

Despite the roof-mounted system balancing the annual electricity usage and production, the balance was not as great on a monthly basis. During months of low production, additional electricity needed to be purchased from a utility. During months of high production, the excess electricity was released to the grid. In other words, annual reconciliation is a good goal, but that does not mean no electricity goes into or out of the system on a monthly or even daily basis.

Another way to look at how much electricity being consumed and produced is to look at the daily electricity balance, here defined as the excess electricity being produced by the solar PV system or the total electricity consumption subtracted from the total production (Fig. 9).

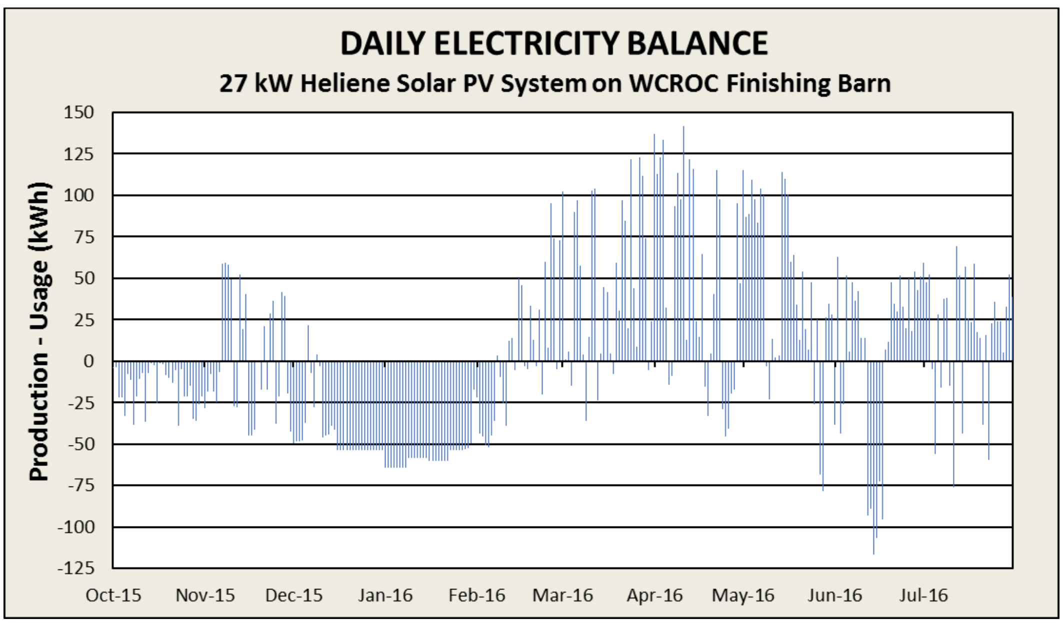
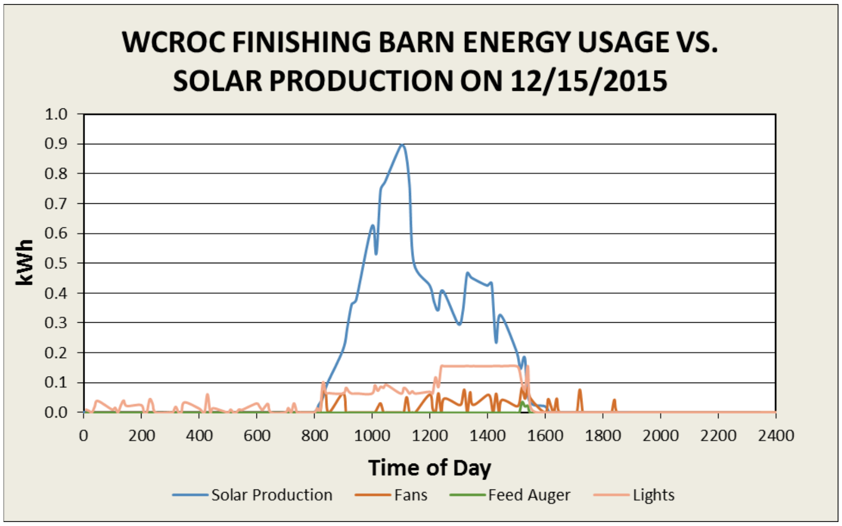
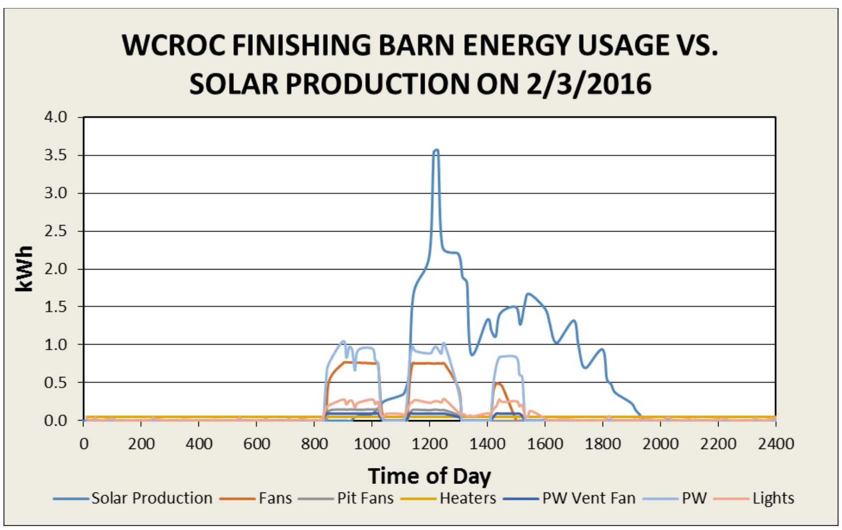


Figure 9: Amount of excess electricity produced from the WCROC solar PV system.

From October 2015 to February 2016, the net electricity balance was negative, meaning that the barn was using more electricity than the PV system was producing. The highly negative section from mid-December through January was explained earlier as being due to snow covering the panel. There was a highly positive net balance from February 2016 through July 2016 with a peak in April. From June 12-17, 2016, there is another very negative balance due to having an exceptionally cloudy week and very low levels of irradiation. Weather fluctuates, and as a result, solar production fluctuates as well. This cannot be prevented, but solar batteries or having a grid connection ensures that the barn will still have a source of electricity despite there being little to no production.

In addition to the total electricity usage, specific applications were measured using data loggers. Hourly electric loads from the ventilation fans, pit fans, heaters, power washer vent fan, feed auger, power washer, and lights were compared to the amount of electricity being produced by the solar PV system during a typical day (Fig. 10).





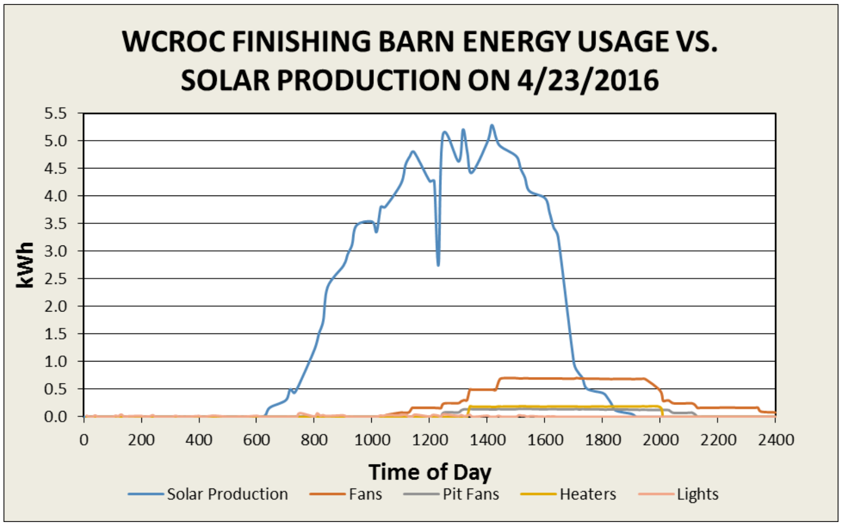


Figure 10: Electricity usage from ventilation fans, pit fans, heaters, power washer (PW) vent fan, feed auger, power washer (PW), and lights compared to the solar PV system's electricity production throughout a typical day in December and April. If the specific application is not shown in a given day, the total load that day from that device was 0 kWh. See the text after Equation 1 for the method for determining the "typical day".

In February, the power washer was in use. The average electricity usage indicated that the power washer was being used a lot due to no pigs residing in the barn; therefore, a day with the power washer and power washer vent fans on was determined to be a good representation of that month. Incidentally, the power washer peaks are relatively in line with the solar production peak. While not necessary, ensuring that high loads, such as the power washer, is used at the same time as high production in the on-farm solar system is one way to ensure the electricity usage is as close to net-zero as possible at any given time.

Overall, specific applications were being used around the same time as electricity was being produced, indicating that solar energy was a good choice for the finishing barn. In December and April, the highest load was slightly later in the day than the greatest production but still usually requiring less electricity than being produced. The same held true in February if the power washer had not been used outside of high production times. A concern with using solar energy would be any loads outside of daylight hours. In this case, there are numerous loads outside of daylight hours, such as the wall ventilation fans, pit fans, heaters, and feed augers; generally, these loads are relatively small and as such do not affect the validity of using a solar PV system to supplement the WCROC finishing barn's electricity usage. However, a grid connection or solar battery is essential to ensuring that electricity is still available during times of no production.

Lastly, a comparison between the actual electricity production of the 26.88 kW Heliene solar PV system on the finishing barn and output predictions from a program called PVWatts was executed (Fig. 11). The goal was to validate this program and determine its practicality for use on a pig farm.

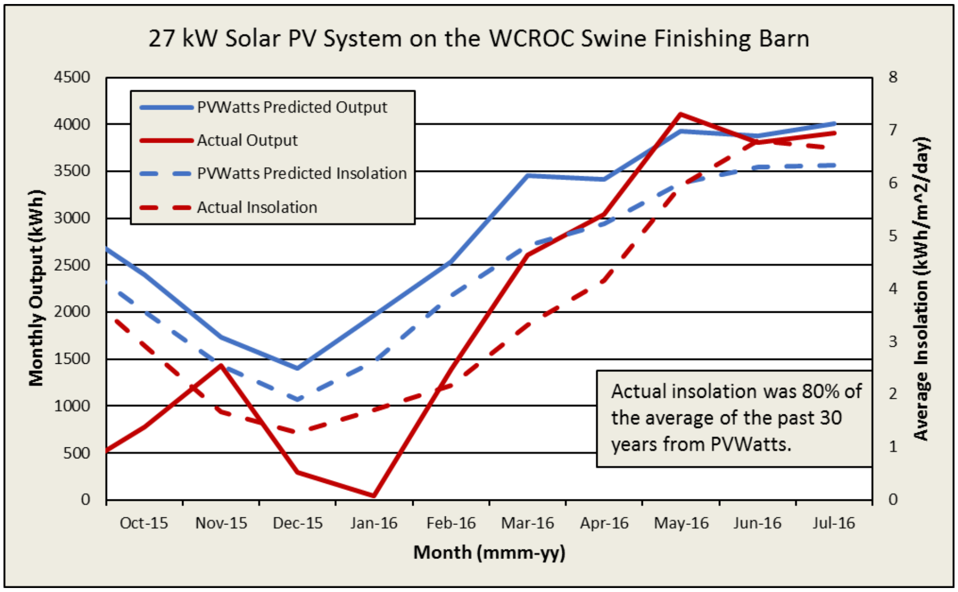


Figure 11: Actual electricity production from the WCROC solar PV system and average monthly insolation from the pyronometer at the WCROC weather station compared with predicted output and insolation from PVWatts.

Overall, PVWatts predicted more output than was actually produced. Specifically, the 26.88 kW Heliene solar PV system produced 74.5% of the electricity production estimated by PVWatts. While the prediction was fairly accurate, remember that December and January had a lack of production due to snow covering the panels, which PVWatts does not take into consideration. Not including these months, the system produced 83.0% of the predicted production from October 2015 to July 2016. However, PVWatts' prediction is based off an average of the solar insolation (i.e. energy received from the sun in a day) over 30 years. As shown in Figure 11, the actual amount of sunlight being received throughout this time period is 80% lower than the 30-year average. As PVWatts does not have the capability to input actual insolation values, a ratio of the average insolation given from PVWatts and the actual insolation in Morris was calculated. By multiplying the actual production by this ratio, the amount of electricity that would have been produced if the actual and predicted insolation were equal was estimated.

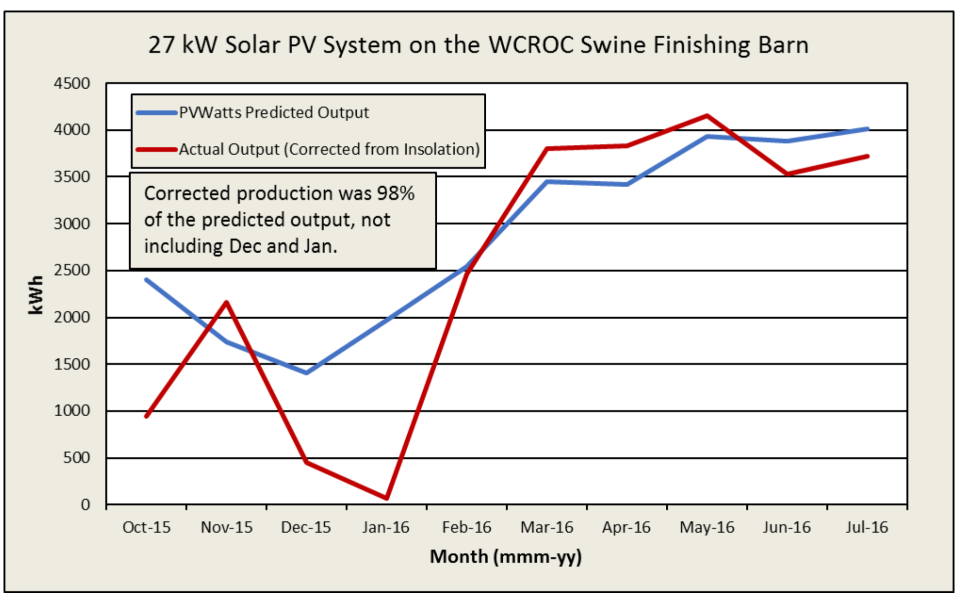


Figure 12: Corrected electricity production from the WCROC solar PV system.

The general trend predicted by PVWatts was much closer when taking into consideration the lower insolation. The actual production was 97.7% of the predicted output without January and December, showing that annual weather variation does occur but can be accounted for. In addition, while PVWatts is not perfect, the program can provide a reasonable estimate of a solar PV system's annual production. By validating this program, farmers can feel more confident about using the program to estimate the size of the array required to produce enough electricity to support their barn while understanding that weather may cause a variation in electricity output within ±10-15% annually.

c. System Efficiency

The efficiency of the solar PV system was calculated using the solar irradiation available as measured by the pyronometer at the WCROC weather station and the solar energy collected by the system (Eq. 1).

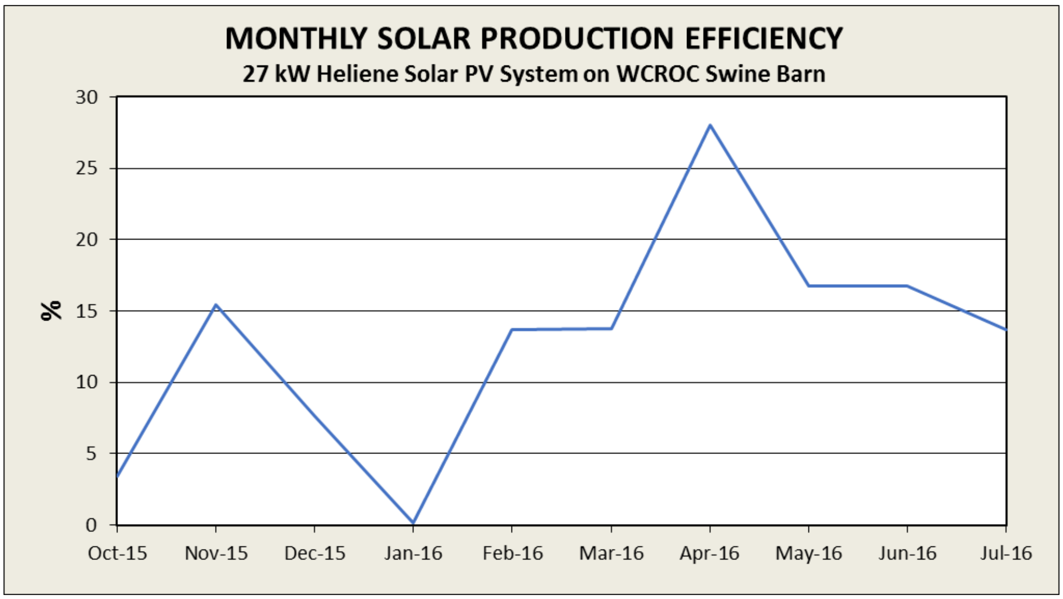


Figure 13: Monthly efficiency of the 26.9 kW solar PV system.

April was the most efficient month. There is a very distinct climb going from October to April as winter is generally less efficient than spring. However, note than January is near zero due to snow covering the panel.

The WCROC solar PV system ranged from an efficiency of 0.17% in January to 28.0% in April with an overall efficiency of 11.9% from September 2015 to June 2016. If snow had been properly removed, the overall efficiency may have been around 13.0%. In addition, one of the theoretically most efficient months, August, was not included in this average as a full year has not yet passed since installation. The average solar PV system typically possesses an efficiency between 11 and 15% (Pure Energies 2014), so this system worked as expected.

d. Determining Solar Options for Finisher 4 and 5

The 26.88 kW solar PV system at the WCROC finishing barn demonstrated the practicality of solar energy as a supplemental source of energy on a farm. Next, two swine barns, Finisher 4 and 5, expressed interest in implementing solar on their farms. PVWatts was used to model several solar PV systems that would fit their electric needs.

Finisher 4 was found to have an electricity need greater than a 40 kW system could provide. Because of this, if the farm were to sell the excess electricity back to the utility, they would receive a reduced compensation, currently around 4 cents per kWh, due to net metering policies. As a result, installing a 40 kW system and purchasing any additional energy from the utility or installing a system slightly larger than 40 kW that does not require Finisher 4 to sell back electricity at any point in time could be more financially beneficial than installing a system that would make the barn net-zero. In addition, due to the roof's orientation, a roof-mounted array would not be economically feasible. A 65 kW ground-mounted array would make the system as close to net-zero as possible but would be much larger than the 40 kW system required by net metering to sell excess electricity at the full retail rate. Therefore, in addition to the net-zero system, a 40 kW ground-mounted system was analyzed as well as one sized to never produce more electricity than needed (Fig. 14).

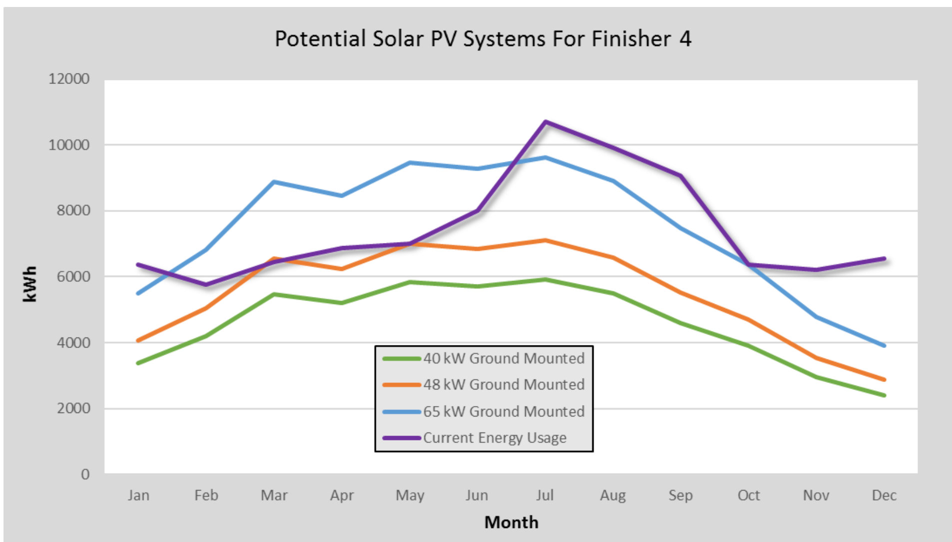


Figure 14: Electricity usage of Finisher 4 and the electricity production of several potential systems to supplement their usage.

All three systems were thought to be good options for Finisher 4 and as such were presented to the owners.

The second set of solar PV systems that were fitted to a swine barn was at Finisher 5. The barn load was small enough that net metering policy was not a concern. In addition, the roof orientation was such that a roof-mounted array was an option. Therefore, a roof-mounted and ground-mounted system were sized such that Finisher 5 would be as close to net-zero as possible.

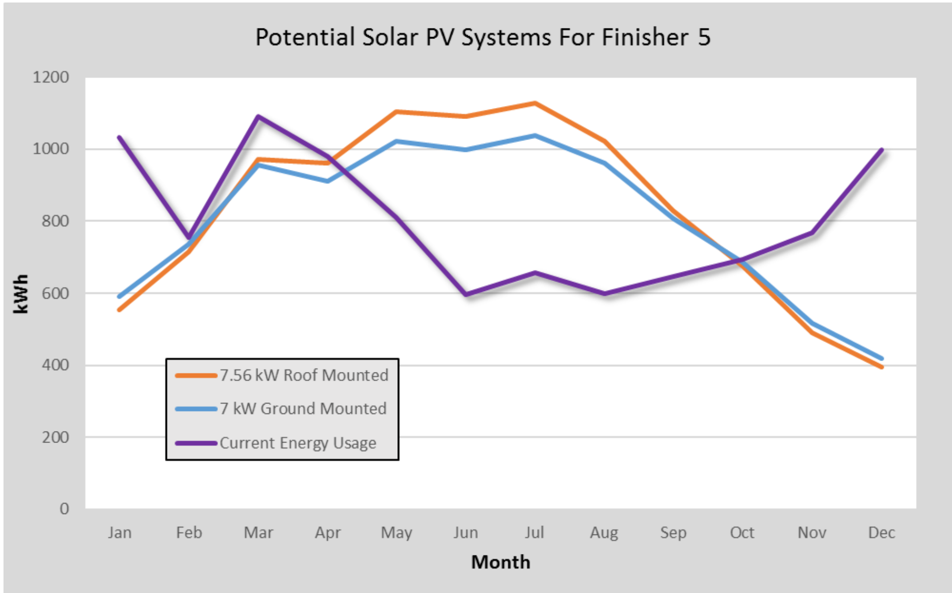


Figure 15: Energy usage of Finisher 5 and the electricity production of several potential systems to supplement their usage.

The roof-mounted array usually produced slightly more over a year than the ground-mounted, but the system was also 7.5 kW compared to 7 kW. As the roof-mounted system was mounted at a lower angle, 18.5°, than the ground-mounted system, the roof-mounted array was less efficient and had to be larger to produce about the same amount of electricity.

Another important step when choosing between roof-mounted and ground-mounted is to ensure that the required roof-mounted system would actually fit on the roof. Finisher 5's roof was measured to be about 6 m tall and 57 m wide. The array required to make the barn net-zero would be comprised of 27 modules, which would require only one row that is 1.65 m tall. Fortunately, the roof-mounted system would fit on the roof, meaning that both the roof-mounted and ground-mounted systems provided opportunities for Finisher 5 to become net-zero, so both were presented to the interested parties.

4. IMPLICATIONS

The objective was to confirm whether or not solar PV systems would be able to provide enough electricity to be a good option for swine barns to supplement their energy usage. At the WCROC finishing barn, a 26.88 kW Heliene model system was installed and proved to be a decent fit for the barn. In winter, the system did not make enough energy, but in summer, there was excess electricity being produced. In addition, the system more than made up for the energy usage during the day throughout most times of the year. Nevertheless, any electric loads at night had to be drawn from the utility grid as well as throughout most of December and January due to snow covering the panels. Solar batteries may provide an alternate option for providing a source of electricity during times of low or no production but add cost to the system.

The agricultural industry should consider implementing solar systems on swine farms. Not only did the WCROC PV system show that enough electricity could be produced to support the barn's electricity usage, but solar PV systems require minimal maintenance costs due to no moving parts, reduce carbon dioxide and other greenhouse gas emissions, and provide the ability to harness an unlimited source of energy. Determining where and how much energy is being used is the first step to choosing a solar system that would best suit a farm. Consider roof-mounted systems as well as ground-mounted depending on cost, land and roof space, and efficiency. In Minnesota, roof-mounted systems are very efficient if facing south but significantly less so if facing east or west. In addition, making a barn net-zero may not always be as economically beneficial as a smaller system due to net metering policies. Larger systems are only able to sell excess electricity at a reduced cost whereas smaller systems will be using all their electricity or selling it back at the full retail price. PVWatts can provide a reasonable estimate of how large a system may need to be to provide a certain amount of electricity within 10-15% depending on the weather that year.

The study of the WCROC finishing barn solar PV system will continue such that more data can be collected. Further studies could involve panel efficiency in winter when snow is manually removed from the panels as well as how the number of pigs, type of barn, or weather fluctuations affect a swine barn's electricity usage and production.

5. ACKNOWLEDGEMENTS

Funding for this project was provided by the Minnesota Environment and Natural Resources Trust Fund as recommended by the Legislative-Citizen Commission on Minnesota Resources (LCCMR). The Trust Fund is a permanent fund constitutionally established by the citizens of Minnesota to assist in the protection, conservation, preservation, and enhancement of the state's air, water, land, fish, wildlife, and other natural resources. Currently 40% of net Minnesota State Lottery proceeds are dedicated to growing the Trust Fund and ensuring future benefits for Minnesota's environment and natural resources.

I would also like to thank Eric Buchanan and Kirsten Sharpe for working with me so closely during the course of the study, Michael Reese for overseeing all tasks, and Lee Johnston for reviewing my papers and presentation.

6. REFERENCES

DSIRE. 2016. "Programs: Minnesota". Raleigh, NC: NC Clean Energy Technology Center. http://programs.dsireusa.org/system/program?state=MN. Accessed June 27, 2016.

Gueymard, Christian A. August 2003. "The Sun's Total and Spectral Irradiance for Solar Energy Applications and Solar Radiation Models". Edgewater, FL: Solar Consulting Services.

Minnesota Legislature. 2015. "216B.164 Cogeneration and Small Power Production." St. Paul, MN: Revisor of Statutes, State of Minnesota.

Pure Energies. 2014. "Solar Panel Efficiency". http://pureenergies.com/us/how-solar-works/solar-panel-efficiency. Accessed July 19, 2016.

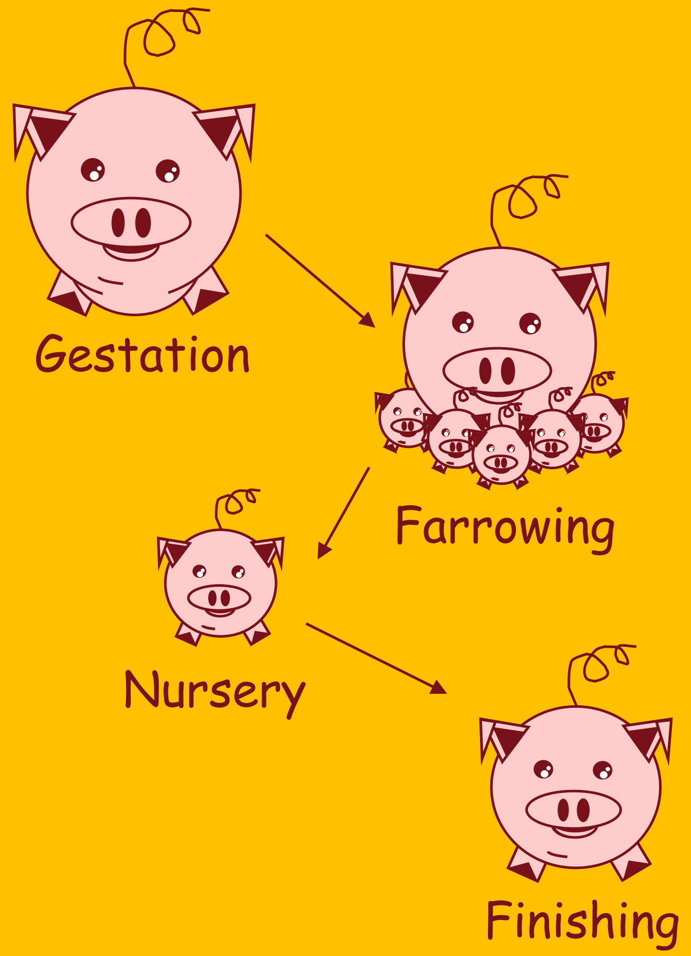
Roney, Matthew J. June 2014. "China Leads World to Solar Power Record in 2013". Washington D.C: Earth Policy Institute. http://www.earth-policy.org/indicators/C47/solar_power_2014. Accessed June 6, 2016.

Transitioning Minnesota Farms to Local Energy

Presented by: Rachael Acevedo, Renewable Energy Intern
University of Minnesota West Central Research and Outreach Center

Objectives

- Determine if a solar PV system can provide as much electricity as a swine barn is using.
- Compare actual electricity usage with solar production for the WCROC solar PV system installed on the roof of a finishing barn.
- Use the WCROC data to help other farms choose what system would be best for them.



Installation Types

Pole-mounted at UMM

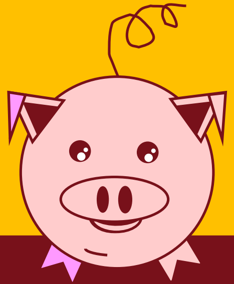
- Track sun
- More expensive

Roof-mounted PV system at WCROC swine barn

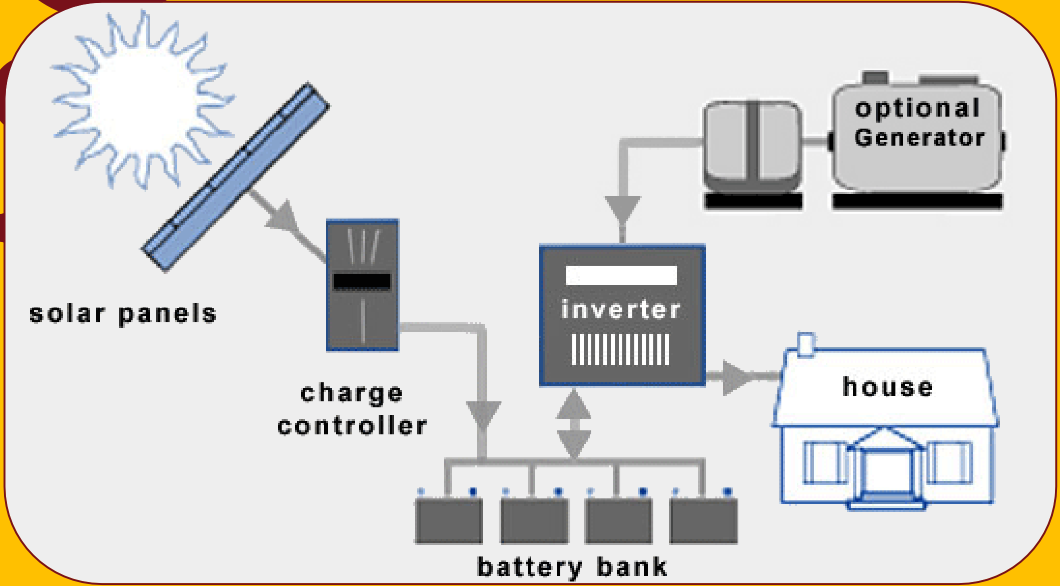
- Works best on south-facing roofs with no obstructions (e.g. no trees, chimneys, etc.)

Ground-mounted at WCROC

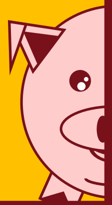
- South-facing
- Easier access for repairs



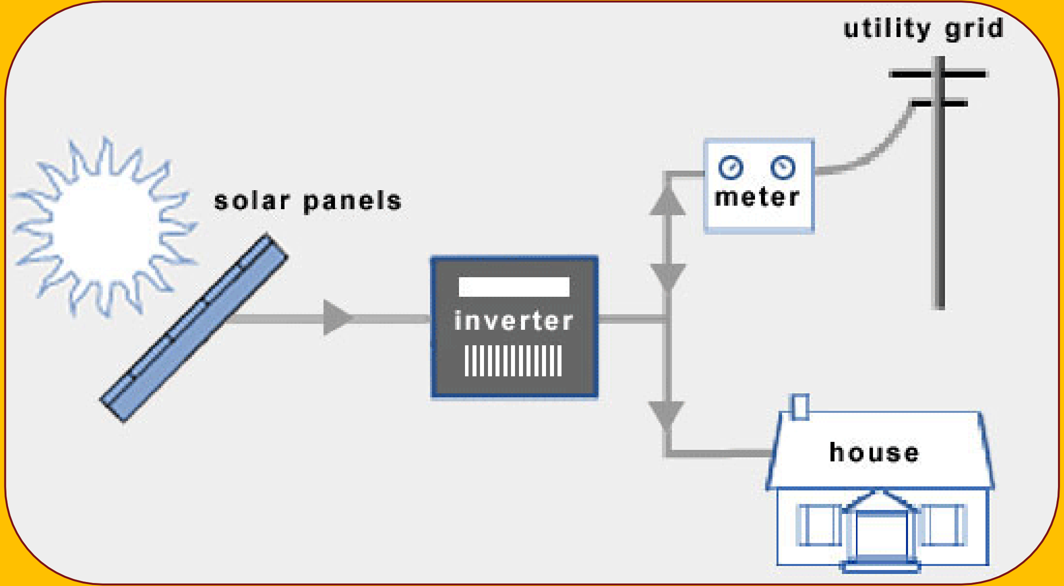
Off-Grid



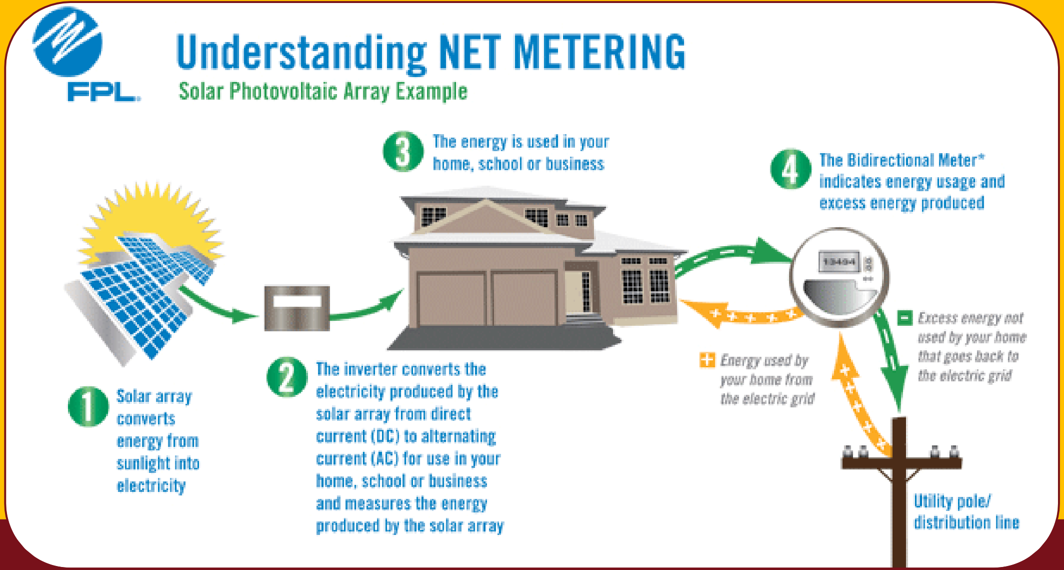
- Self-sufficient
- May be cheaper than extending power lines to remote areas
- Requires solar battery



Grid-Tied

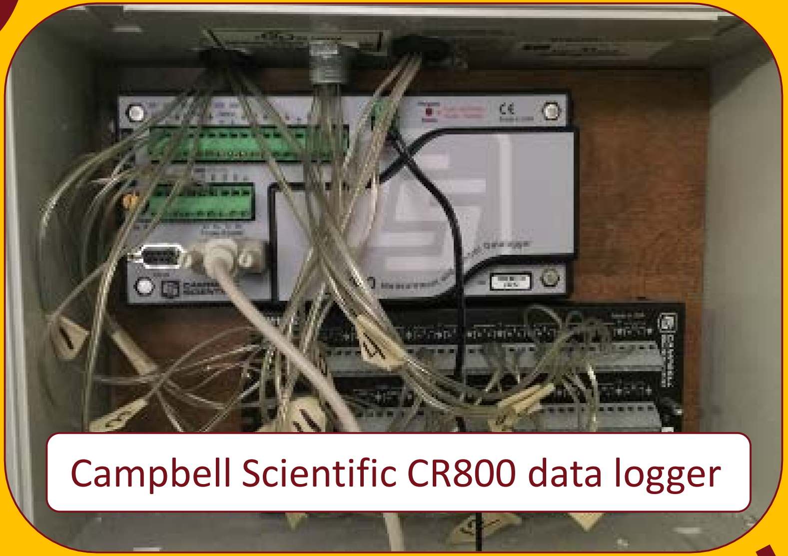


- Save money with net metering
- Access to back-up power



WCROC Finishing Barn

Auditing Energy Usage


Campbell Scientific CR800 data logger


Feed Augers


Pit Fans


Lights


Fans

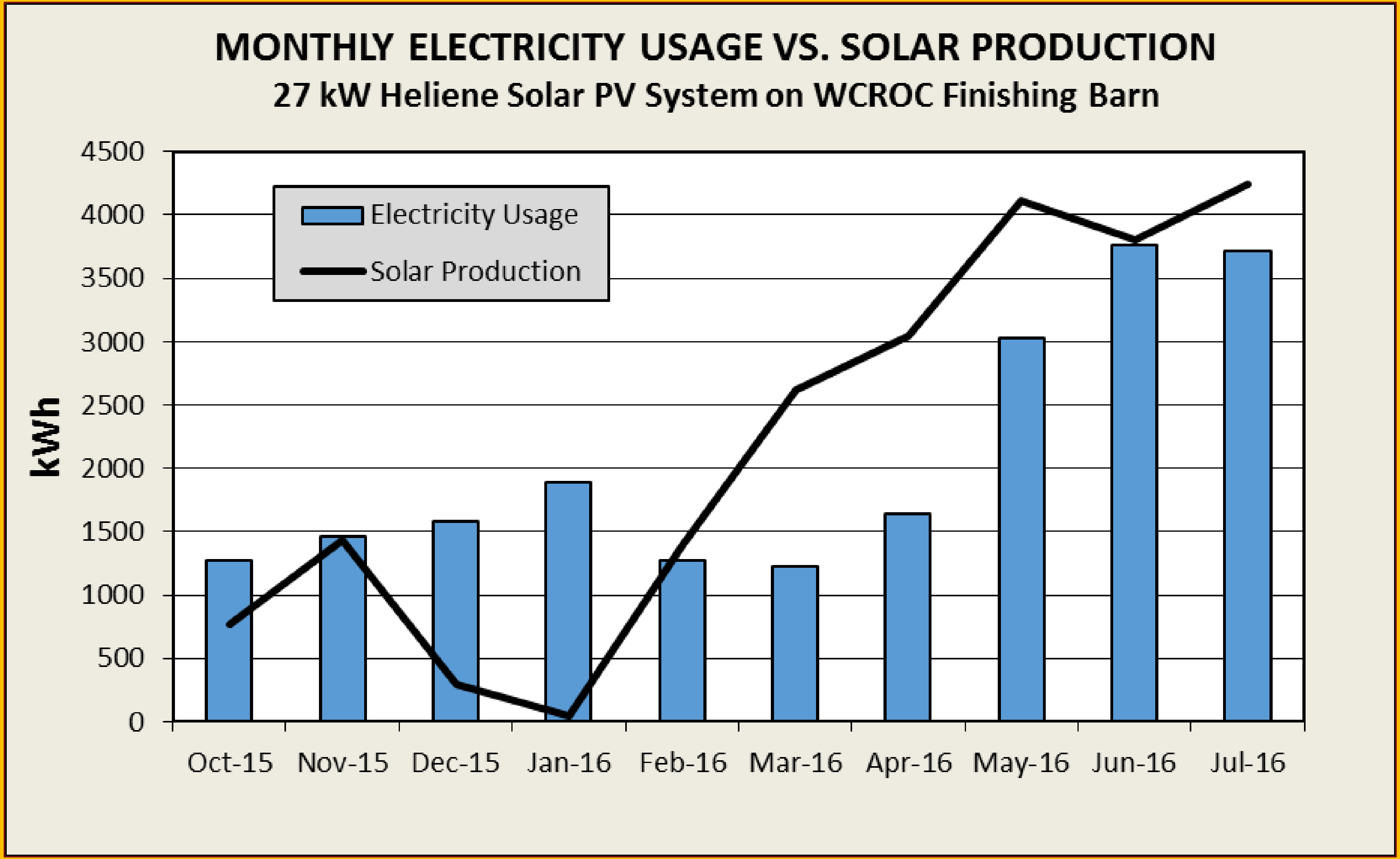

Heaters


Power Washer and Vent Fan

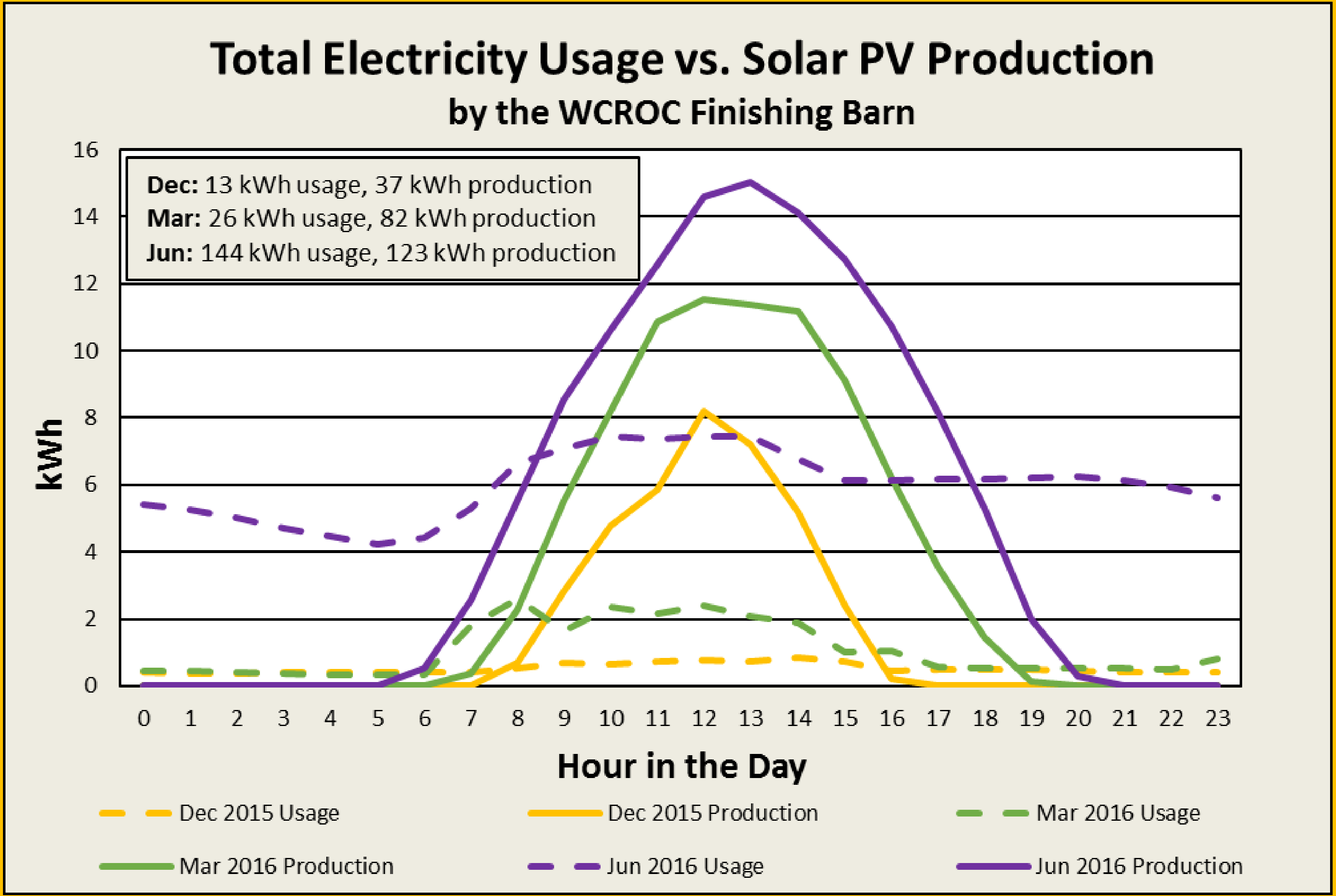
WCROC Solar PV System

- 26.9 kW Heliene 60M280 array installed in June 2015
- Roof-mounted facing south at 20° angle
- 3 SE9K inverters from SolarEdge Technologies, Inc. records power output

Energy Usage vs. Production



Energy Usage vs. Production (cont.)

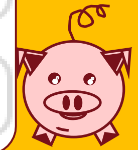


PVWatts Calculator by NREL

SYSTEM INFO

Modify the inputs below to run the simulation.

DC System Size (kW):	26.88
Module Type:	Standard
Array Type:	Fixed (roof mount)
System Losses (%):	14
Tilt (deg):	18.43
Azimuth (deg):	180



RESULTS

Print Results

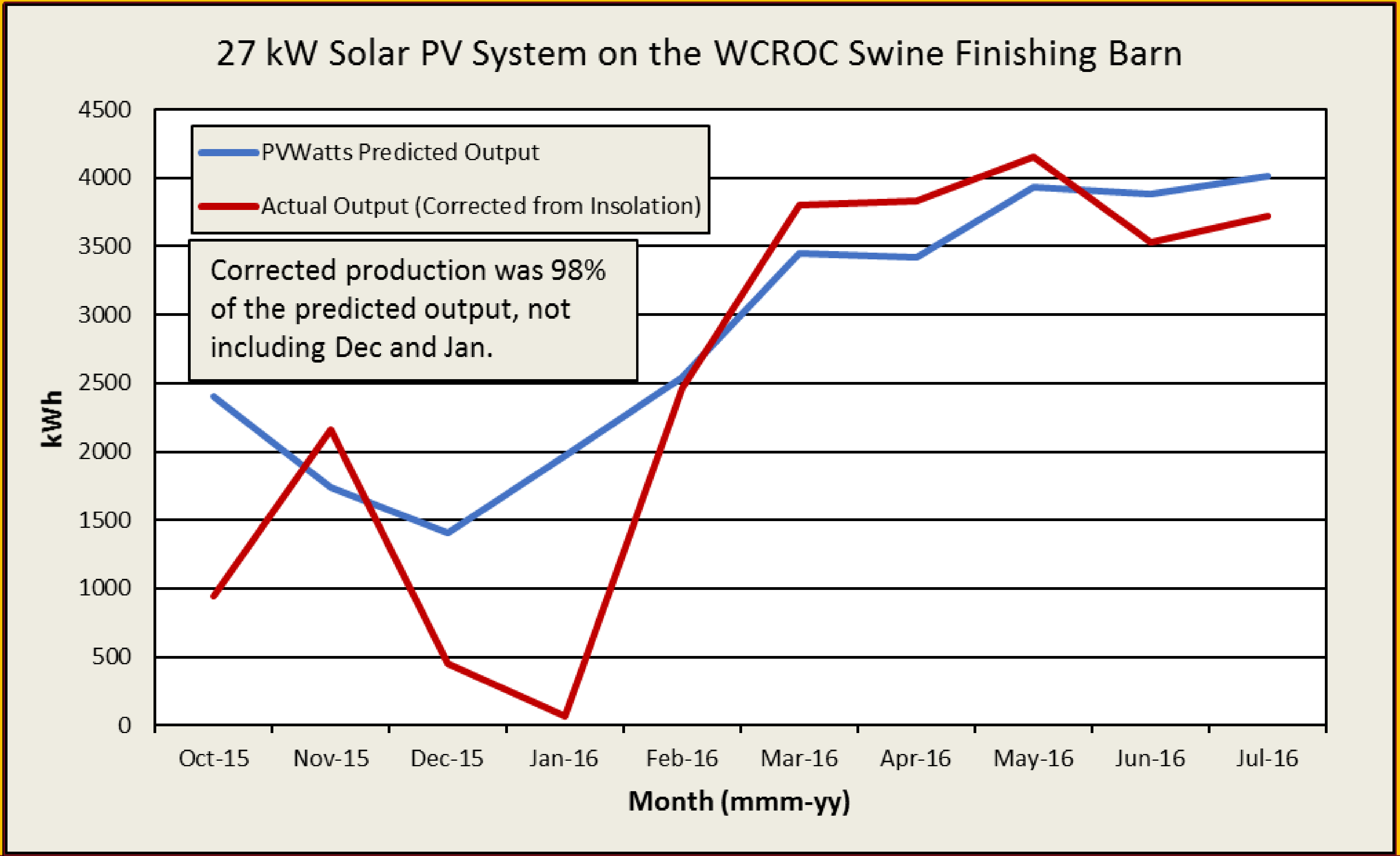
35,317 kWh per Year *

System output may range from 33,777 to 37,337kWh per year near this location. Click HERE for more information.

Month	Solar Radiation (kWh / m^2 / day)	AC Energy (kWh)	Energy Value ($)
January	2.62	1,966	171
February	3.86	2,541	222
March	4.82	3,455	301
April	5.23	3,419	298
May	6.01	3,928	343
June	6.31	3,881	338
July	6.33	4,012	350
August	5.73	3,629	316
September	4.66	2,946	257
October	3.56	2,400	209
November	2.54	1,737	151
December	1.90	1,403	122
Annual	4.46	35,317	$ 3,078

PVWatts is used to determine the size of the ground or roof mounted arrays required to make these barns net-zero.

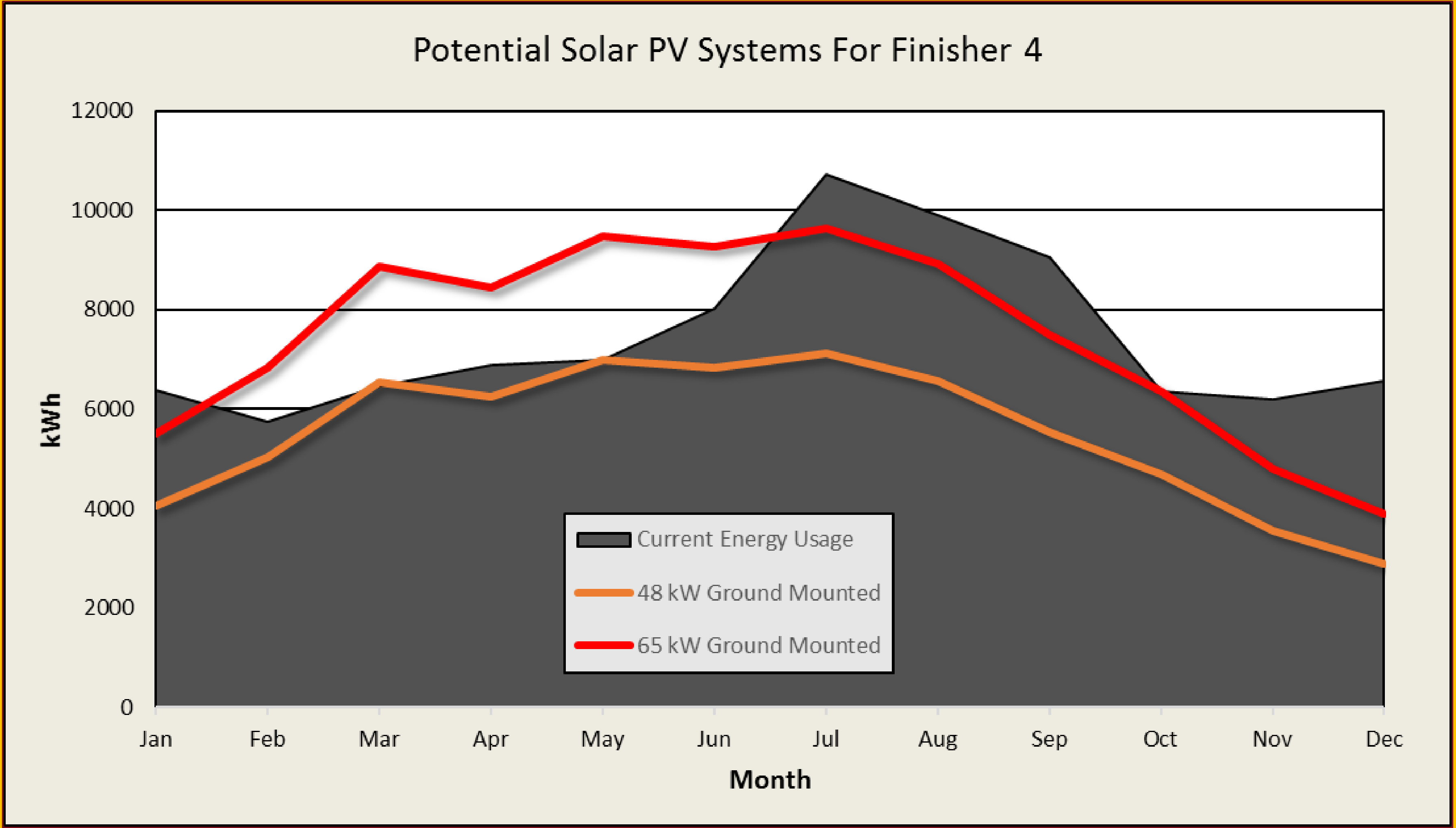
Comparison with PVWatts



Case Study: Finisher 4

- Tunnel-vented, two room barn with a 2,400 pig capacity
- Roof faces east and west, making roof-mounted solar panels much less feasible than ground-mounted

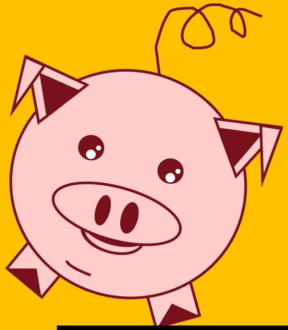
Results for Finisher 4

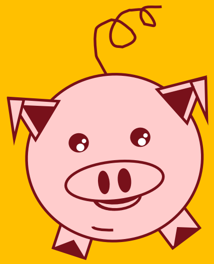


Based on the TenKSolar model XT-A PV system on the UMM campus

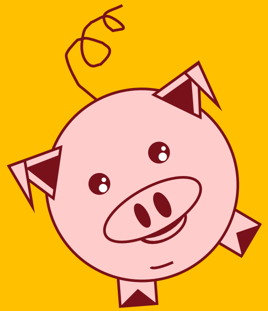
Financial Analysis for Finisher 4

Completed by Justin Miller



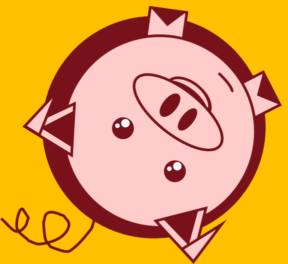


		Before Incentives	
	Total Savings	Payback Period (yrs)	Return-on-Investment
48 kW	$186,492.85	19.5	28%
65 kW	$234,831.98	20.8	20%



		Tax Credit		REAP Grant & Tax Credit	
	Total Savings	Payback Period (yrs)	Return-on-Investment	Payback Period (yrs)	Return-on-Investment
48 kW	$186,492.85	13.6	84%	8.8	186%
65 kW	$234,831.98	14.6	72%	9.4	167%

<u>Assumptions</u>: installation at $3/W and system life is 25 years

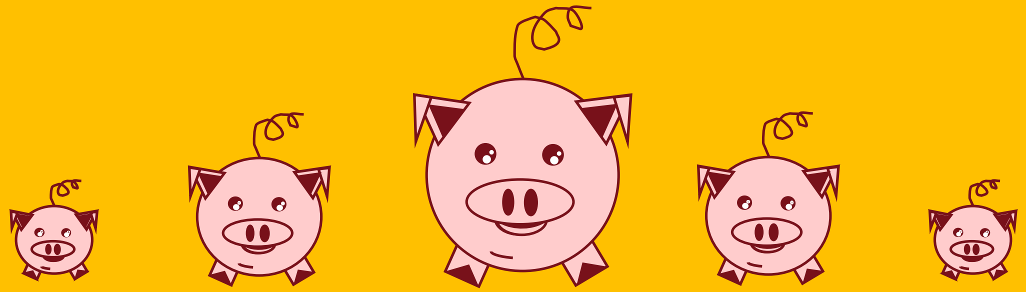


Conclusion

- A solar PV system appears to be a good option for supplementing swine barn energy usage.
- Knowing where and how much energy is being used is the first step to choosing a solar system that fits the farm.
- More electricity is used and produced in the middle of the day. However, a grid connection or solar battery is required during times of no production (e.g. night).
- Making a barn net-zero may not be as economically beneficial as a smaller system due to net metering.
- PVWatts is a simple and free program that provides a reasonable estimate of how much energy can be produced from a particularly sized system.

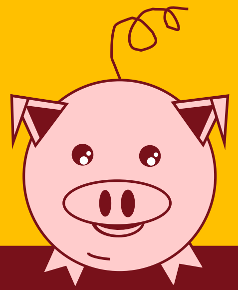
Special Thanks to….

- Michael Reese
- Eric Buchanan
- Kirsten Sharpe
- Lee Johnston
- Minnesota Environment and Natural Resources Trust Fund as recommended by the Legislative-Citizen Commission on Minnesota Resources (LCCMR)
- University of Minnesota WCROC



Bibliography

- energyinformative.org
- energy.gov
- cleantechnica.com
- en.wikipedia.org
- www.thaihorizon.com
- bbe.umn.edu
- sanfrancisco.cbslocal.com
- safeenergy.org
- powersource.post-gazette.com
- gizmodo.in
- kidzworld.com
- flickrhivemind.net
- WCROC
- YouGen
- Renu News
- Kirsten Sharpe
- PVWatts
- Google Earth



Funding Acknowledgment This project was supported by The Minnesota Environment and Natural Resources Trust Fund as recommended by the Legislative - Citizen Commission on Minnesota Resources (LCCMR)

The three systems modeled in electricity production (by Rachael) were solar PV systems of 40, 48, and 65 kW. The 40 kW system was modeled because the maximum size system in Minnesota that allows for net metering compensation at retail is 40 kW. A 48 kW system was modeled as a system that would generally not net meter at any month over the course of a year. The 65 kW system was modeled as the smallest size system in order to have close to net zero electricity usage in the first year.

Each system was modeled to project the amount of electricity it would produce (in kWh). This production was calculated monthly and then yearly. All the systems were then put into a 25-year projection table. The categories used in the projection table were *installation cost, electricity production, baseline load, net electricity/electricity used from solar, electricity price, money saved from solar, maintenance cost, net savings,* and *discounted savings*. The 65 kW system also had some projected months where it produced more electricity than the baseline load. This system was put through a net metering return analysis in order to determine the net metered kWh produced and the kWh purchased from the grid during times where the load demand exceeded system production. Since the system is greater than 40 kW, it receives compensation through net metering as payment from grid electric companies at the avoided cost price. The data from the net metering return analysis was used in the corresponding 25-year projection table. The 25-year projection tables were then used to calculate the return on investment of each system, along with other measurements such as net present value of investment, internal rate of return, and payback period. The return on investment and other measurements were done three different times for each system. These were before incentives, with a federal tax credit, and with the maximum REAP grant and a federal tax credit.

Assumptions/Calculation Methods

- Type of Modules:
  - The module types used for this analysis were TenK solar modules, model XT-A at 410 Watts. These modules are reported by the manufacturer to decline in production by 3% after the first year and then by 0.2% each year afterwards. The warranty for these modules is 25 years and they are not supposed to produce less than 92.2% of their initial energy production at the end of the warranty life.
    - For more information: http://tenksolar.com/wp-content/uploads/2015/12/410W-Nested-Module.pdf
- Actual kW used for each system:
  - Using the 410 Watt modules, the number of modules had to be approximated since a number such as 0.9 or 0.3 of a module cannot be used. This will result in the actual size of each system being 40.2, 48.4, and 65.2 kW if the systems are implemented. The original respective sizes were still used in calculations and assumed to not affect the calculations in a significant way.
- *Installation Cost:*
  - Installation costs for each system were assumed to be 3 dollars per Watt. This equates to $1,230 per module and $3,000 per kW. $3,000 per kW was used in order to find the installation cost for each system.

- *Electricity Production:*
  - An online calculator called "PV Watts" was used to calculate expected production from the solar PV system at each size. These values were used for the first year and the degradation percentages from the TenK manufacturer information were used to calculate each year after.
- *Baseline Load*:
  - Baseline energy usage, both monthly and yearly, was taken from load data from Halls farms. Available data usage was used to project what an "average" electricity load year at Halls would look like. Not all months were available for each actual year of data that was used to make the average year. It was assumed that over the 25-year span that each year would not unreasonably deviate from the average projected year, so the same average projected year load data was used for each year in the 25-year projection.
- *Net Electricity/Electricity Used from Solar:*
  - For systems that had months that produced more than the baseline load, the amount net metered and amount of electricity purchased from the grid were used to find the electricity used from solar. Monthly production values were found each year using the same degradation percentages from the manufacturer. With the other systems the yearly net electricity was used in the same way. For the 48 kW system there was one month in the first year that went over by 90.5 kWh which was subtracted from the net electricity. The returns from avoided cost for 90.5 kWh over production in the system's first year were determined to be insignificant.
- *Electricity Price:*
  - Commercial electricity prices were analyzed from 2001 to present. The linear trend of these prices was an average increase of 3.35% per year. It was assumed that this trend would continue in the future, so an increase of 3.35% in the price per kWh was used for the 25-year projection. 9.5 cents per kWh was used for year 0 which was the average price in 2015.
- *Money Saved from Solar:*
  - Electricity used from solar or electricity production multiplied by the electricity price
- *Money from Net Metering:*
  - Typical avoided cost for electricity production companies is around $0.04 per kWh. This was assumed to be what the electric company would pay each year for any electricity provided to the grid for the 65 kW system. This value was multiplied by the net metered kWh found from the net metering return analysis.
- *Maintenance Cost:*
  - It was assumed that around $1 per Watt would need to be spent over the life of the system in order to fix things such as replacing inverters. This cost was divided evenly among the 25-year life of the system.

- *Discounted Savings:*
  - Discounted savings is the value of net savings in present dollars and takes into account the time value of money. Using the time value of money is the idea with the question of whether having a certain value of money in the future is better than having a lesser amount of money now in order to be able to invest it. Most analyses use discount rates of around 3-5%. For this analysis a discount rate of 3% was used to convert each year's net savings into the value they would have today. For example, this means that discounted savings for the 25th year is the value of the net savings that would equal the net savings if invested at 3% interest for 25 years.
- Return on Investment:
  - Percent of original investment that is gained as revenue. Calculated by taking the difference between net cash flow and investment cost divided by the investment costs. This percentage can be looked at as the percentage of each dollar invested that is collected as a return.
- Net Present Value:
  - This is the sum of the discounted savings with the investment costs subtracted. This value represents the present value of the investment.
- Internal Rate of Return:
  - Discount rate in order to make the net present value equal zero. If this is greater than the ideal discount rate (3%) then the net present value will be positive. It also would mean that the initial investment will internally generate a greater return than if the net present value of the investment was invested at the ideal interest rate over the same period of time.
- Payback Period:
  - Amount of time to generate enough returns to cover the initial investment cost. Found by dividing the investment cost by the average yearly cash flow.
- REAP Grant:
  - REAP stands for the Rural Energy for America Program. This is a federal grant from the U.S. Department of Agriculture that can be applied to Solar PV systems. The maximum amount of the investment cost that can be covered is 25%. The full 25% was used in calculations but the grant could be less than that.
    - For more information: http://programs.dsireusa.org/system/program/detail/917
- Federal Tax Credit:
  - This is the federal Business Energy Investment Tax Credit (ITC) which can be applied to Agricultural industry and solar PV systems. The tax credit is for 30% of the investment cost. Savings from the tax credit were directly applied to lower the investment cost.
    - For more information: http://programs.dsireusa.org/system/program/detail/658

Summary Tables

Before Incentives

	Initial Investment	Savings per year	Payback Period (years)	Total Savings	Return on Investment	Net Present Value	Internal Rate of Return
40 kW	$ 120,540.00	$ 6,216.38	19.4	$ 155,409.52	29%	$ (18,540.54)	1.8%
48 kW	$ 145,140.00	$ 7,459.71	19.5	$ 186,492.85	28%	$ (22,739.71)	1.7%
65 kW	$ 195,570.00	$ 9,393.28	20.8	$ 234,831.98	20%	$ (41,565.15)	1.3%

With Tax Credit

	Initial Investment	Savings per year	Payback Period (years)	Total Savings	Return on Investment	Net Present Value	Internal Rate of Return
40 kW	$ 84,378.00	$ 6,216.38	13.6	$ 155,409.52	84%	$ 17,621.46	4.5%
48 kW	$ 101,598.00	$ 7,459.71	13.6	$ 186,492.85	84%	$ 20,802.29	4.5%
65 kW	$ 136,899.00	$ 9,393.28	14.6	$ 234,831.98	72%	$ 17,105.85	3.9%

With REAP Grant and Tax Credit

	Initial Investment	Savings per year	Payback Period (years)	Total Savings	Return on Investment	Net Present Value	Internal Rate of Return
40 kW	$ 54,243.00	$ 6,216.38	8.7	$ 155,409.52	187%	$ 47,756.46	8.5%
48 kW	$ 65,313.00	$ 7,459.71	8.8	$ 186,492.85	186%	$ 57,087.29	8.5%
65 kW	$ 88,006.50	$ 9,393.28	9.4	$ 234,831.98	167%	$ 65,998.35	7.8%

In order to determine whether installing a solar PV system is worthwhile to Halls, there are factors to initially consider. One of the main factors is payback time. If this project is something that needs to be paid back in under 10 years, then it may be best to not invest in a solar PV system at this time. Even with all possible grants and tax credits, the ideal systems take close to 10 years to pay for themselves. Otherwise all the systems project to say a payback period that is less than the warranty life of the system even without incentives. Another thing to remember is that the returns from this investment are found in the form of savings. This puts even more emphasis on whether or not there is available money because the investment will not generate new monetary returns on its own.

Something else to consider are that these numbers could be the best case scenario. If all the incentives are received, then all systems are good options. The payback periods are just under 10 years, the net present values of the investments are positive, and the investment will be more than doubled after the 25-year period. However, this data is just projections that could be better or worse in reality. The panels will likely produce less than expected and there are also chances of not receiving both incentives or receiving less grant money than 25%. Electricity prices could also drop which would lead to less dollar savings from using the solar PV system. This means that there definitely is some risk involved. A positive outlook though is that there is a chance that electricity prices could spike at any time, leading to greater savings during years that see a spike.

The other question to ask is what the most important outcome of this investment is; generating a substantial return or making the farm more energy efficient and environmentally friendly? If the investment potential of generating a substantial return is most important, then there could be a little too much risk involved with this investment. The net present value is only positive when all incentives are realized. If the net present value of the investment is negative, the investment still could generate a positive return. However, this means that the present value of the returns is less than the initial investment, so an equivalent amount of money to the present value of returns could be invested somewhere else in a better way.

A 25-year projection is a long period of time, so there is definitely some risk involved with this investment, but if there is more emphasis on energy efficiency and being more environmentally friendly then this investment could be made to work. All systems should be able to pay for themselves at some point in the 25-year system life. As far as which system to choose, it would depend on how much the electric bill is desired to be cut down. The 65 kW system will reduce the electric bill the most, but also has a higher starting cost and with less value for every dollar invested. Looking at the return on investment percentages, the 40 kW and 48 kW systems seem to have a better return for each dollar invested than the larger 65 kW system. Since the payback period and other metrics are very similar for the 40 and 48 kW systems, the 48 kW system is probably a better choice. It costs a little more but will cut down the electricity bill more while still seeing the same return for every dollar invested. The farm would be producing electricity at close to net zero and reducing its carbon footprint by using less energy produced from fossil fuels. If most of the incentives are realized, the investment should be able to pay for itself, through savings, in at least around 10 years.