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# *Developing energy use and savings indices for Michigan dairy operations*

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**ABSTRACT.** *Michigan dairy farmers have little information available that shows how their operations' energy use and milk production compares to other operations of a similar size. The limited data available from other states only shows electricity (not total energy) use per cow or per hundredweight (cwt) of milk produced, and is not separated into different herd size categories. The goal of this study is to fill this information gap by compiling and analyzing certified energy audits of Michigan dairy operations. The Michigan Farm Energy Program has been conducting certified energy audits on Michigan dairy operations and documenting each farms' energy use, herd size, and production numbers as well as proposed energy conservation measures with their potential energy savings. This information was used to create energy use intensity (EUI) and energy savings indices for Michigan dairy farms. The EUI indices are broken down into four different herd size categories, and show four different metrics: total energy consumed per cwt and per cow, and total electricity consumed per cwt and per cow. Total energy consumption per cwt and per cow decreased as herd size increased, while total electricity consumption per cwt and per cow at first decreased but for the largest category of farms increased to levels near those of small dairy farms. The energy savings indices showed that electricity use only comprises 30% of Michigan dairy farm energy consumption. However, 82% of the energy conserved on audited farms was electricity and 81% of the total energy conserved came from improving three areas: manure handling, milking system, and lighting.*

***Keywords.*** *Dairy farms, energy conservation, energy conservation measures (ECMs), energy efficiency, energy use intensity (EUI), Michigan, Michigan Farm Energy Program (MFEP), Michigan State University, milk production*

## Introduction

Before the start of the Michigan Farm Energy Program (MFEP) in 2009, Michigan dairy owners had little way of knowing how their operations' energy usage compared to other similar operations. They also had little analysis available of potential energy conservation measures (ECMs) to show which categories of ECMs typically have the greatest potential for improvement.

Michigan dairy operations are energy intensive operations. The average dairy operation audited by MFEP consumes over 238,000 kWh equivalent of electricity, propane/natural gas, and diesel fuel per year. In addition, these operations have been faced with rising electricity costs, which are the highest in the Midwest (Hankey, Cassar, Liu, & Wong, 2018). Although natural gas prices have been decreasing over the past few years, Michigan still has the second highest natural gas prices in the Midwest (Merriam, Wade, Villar, Little, & Spangler, 2018). Machinery used in dairy farms mainly consumes electricity, diesel, and propane/natural gas. Preliminary data collected from MFEP energy audits of Michigan dairy operations shows that electricity usage is a significant portion of dairy operation energy usage (30%).

Dairy farms use many different pieces of equipment such as large cooling and refrigeration systems, hot water heaters, lights, ventilation systems, compressors, and vacuum/milk pumps. Figure 1 shows dairy farm energy consumption by equipment category from a dairy farm study conducted in New York, and is cited by numerous utility company agricultural energy programs. As can be seen in the NY study, milk cooling, lighting, ventilation, and vacuum pumps are the four top categories of energy consuming equipment on a dairy farm (Ludington & Johnson, 2003). Michigan's energy savings indices will show the frequency and effectiveness of targeting these categories for energy efficiency upgrades.

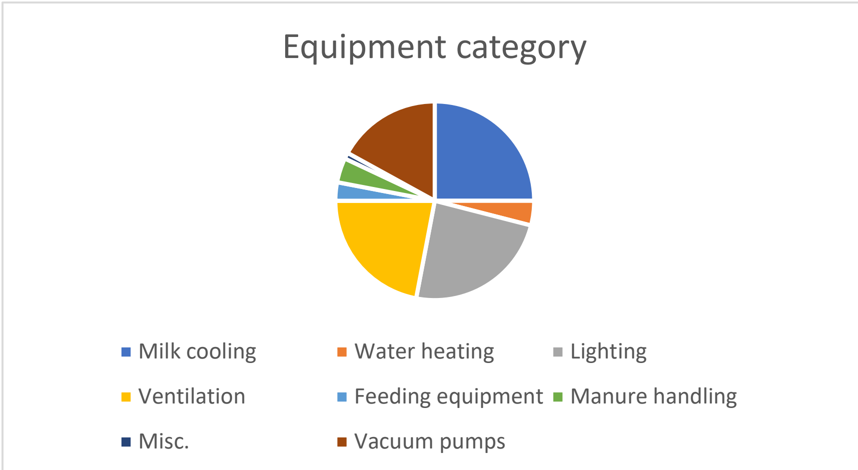


**Figure 1. Dairy farm energy consumption by equipment category for NY dairy farms (Ludington & Johnson, 2003)**

# Literature Review

There is currently very little data available that shows the energy use intensity (EUI) of dairy operations. The Environmental Protection Agency's Energy Star program provides a detailed energy use index report for a variety of property types, such as banking, entertainment, healthcare, education, food sales, and lodging/residential. Energy Star does not have any EUI information for agricultural properties (Energy Star, 2016).

There is some limited dairy farm EUI data available from New York, Minnesota, and Wisconsin, shown in Table 1, but these data sets were not broken down by operation size. In addition, each study in Table 1 used different metrics for reporting EUI. EUI data that is broken down by operation size could help operators in making capital investment decisions based on how their operation's energy use compares to other operations of similar size. In addition, the states listed only give a range or average for farm size. If the data was broken down by farm size, it could be shown to what extent the levels of energy consumption per cow or per hundredweight (cwt) of milk produced varies with farm size.

**Table 1. Dairy farm energy consumption by state (Bolton & Vanderlin, 2009; Ebinger, 2015; Ludington & Johnson, 2003; WiDATCP, 2006)**

| State | Number of milk cows | Year(s) of study | # of farms in study | Electricity used per cwt milk (kWh) | Electricity consumed per cow (kWh) | Avg. yearly milk production per cow (cwt) |
|---|---|---|---|---|---|---|
| New York | 42-860 | 2003 | 32 | 3.5 | 424-1736 | 241 |
| Minnesota | All Farm Sizes | 2013-2016 | 30 | Not Available | 800-1,200 | Not Available |
| Wisconsin | 148 Average | 2007 | 552 | Not Available | 700-900 | 220 |

Finally, farmers and researchers alike have very few tools available to find potential areas for energy efficiency improvements that have the greatest potential for improvement. An energy savings index developed from certified energy audit data would show the ECM categories that are most frequently recommended, as well as each ECM's savings as a percentage of total recommended savings. This would be useful to farmers when making energy saving capital investment decisions. It could also be used by researchers for deciding which new technologies to test or prove on farms based on the type of equipment and energy the technology is meant to replace and save. Overall, these indices would fill an information gap and could be useful across the academic and agricultural community.

## Goal/Objectives

The main goal of this project is to provide an additional tool to dairy farmers to help them become more energy efficient and guide their capital investment decisions. To achieve this goal, the following objectives must be completed:

- Compile all dairy audits conducted by MFEP and extract energy use and savings information as well as operation size and production numbers
- Develop energy use intensity and energy savings indices for Michigan dairy operations using MFEP energy audit data

## Materials and Methods

Certified energy audits conducted by MFEP are a reliable source of dairy farm production, energy use, and energy savings data since they are conducted in accordance with ASABE/ANSI S612 standard for farm energy audits. Therefore, all of the data for Michigan dairy operations was extracted from certified energy audit reports created by MFEP auditors. MFEP was formed in 2009 when Michigan State University's Department of Biosystems and Agricultural Engineering (BAE) and Department of Agricultural, Food, and Resource Economics (AFRE) partnered to develop a training curriculum for farm energy auditors, initially focusing on dairy farms. BAE also developed a state based certification process that follows the recommendations of ASABE/ANSI S612 energy audit standard, which states: "Ideally, there would be a process in-place, provided by non-profit, State or National entities for certification of on-farm energy auditors" (ASABE, 2009). Beginning in 2009, MFEP started training and certifying energy auditors to perform agricultural energy audits that conformed to this standard set forth by the American Society of Agricultural and Biological Engineers (ASABE) and certified by the American National Standards Institute (ANSI) (Van Zweden, Go, & Surbrook, 2017).

As presented in Table 2, MFEP has audited a large variety of agricultural operations between the years 2010 and 2016. Besides traditional types of farms such as dairy or greenhouse operations, MFEP also audits rural businesses and Michigan Department of Natural Resources fish hatcheries. For each type of operation, MFEP has developed technical guides which help the auditors do their jobs more efficiently and effectively (Van Zweden et al., 2017).

**Table 2. 2010-2016 potential energy savings for Michigan (Van Zweden et al., 2017)**

| No. | Operation | Energy Savings (kWh) | % Savings | Annual Savings ($) | Cost to Implement ($) | Payback Time (years) | Average Annual Savings ($) |
|---|---|---|---|---|---|---|---|
| 133 | Dairy Farms | 11,190,946 | 35 | 1,214,725 | 2,741,579 | 2.3 | 9,133 |
| 57 | Grain Drying | 14,302,450 | 28 | 999,482 | 6,836,135 | 6.8 | 17,535 |
| 35 | Greenhouse | 27,762,764 | 34 | 1,106,753 | 4,917,592 | 4.4 | 31,622 |
| 27 | Food Processing | 2,371,934 | 38 | 338,023 | 1,347,791 | 4.0 | 12,519 |
| 19 | Irrigation | 4,433,969 | 51 | 418,839 | 1,560,736 | 3.7 | 22,044 |
| 12 | Crops | 375,529 | 4 | 53,583 | 130,250 | 2.4 | 4,465 |
| 5 | Beef | 69,076 | 14 | 9,913 | 19,476 | 2.0 | 1,983 |
| 4 | Hogs | 198,264 | 14 | 18,002 | 59,718 | 3.3 | 4,501 |
| 2 | Poultry | 12,618,901 | 62 | 567,365 | 2,053,625 | 3.6 | 283,683 |
| 36 | Rural Business | 13,706,260 | 36 | 768,458 | 1,916,983 | 2.5 | 21,346 |
| 1 | Mixed Farm | 11,358 | 94 | 1,693 | 3,480 | 2.1 | 1,693 |
| 3 | Fish Hatcheries | 2,085,817 | 13 | 93,610 | 206,775 | 2.2 | 31,203 |
| 334 | Audit Total | 89,127,267 | 34 | 5,590,446 | 21,794,140 | 3.9 | 16,738 |
| 154 | Renewable Energy | 24,763,113 | 69 | 1,797,018 | 15,636,108 | 8.7 | 11,669 |
| 488 | Grand Total | 113,890,380 | 38 | 7,387,465 | 37,430,248 | 5.1 | 15,138 |

Table 2 also shows that the type of operation individually audited the most is dairy farms. This is partially due to the Michigan Milk Producers Association (MMPA), Michigan's largest milk cooperative, promoting MFEP certified farm energy audits to its members. Finally, all of the results in Table 2 were achieved from auditing less than 2% of all Michigan agricultural operations/rural businesses, showing the large potential future impact MFEP can have on agricultural energy efficiency (Van Zweden et al., 2017).

The only farm energy audits conducted by MFEP are ASABE/ANSI S612 Type 2 audits, which are more comprehensive then Type 1 audits. A Type 2 audit requires more detailed information from the operation and makes recommendations for energy efficiency improvements. Auditors start the audit by establishing a baseline of energy use. The operation provides 2 to 3 years of historical energy use data, usually in the form of monthly utility bills, as well as milk production numbers. The auditor also documents every piece of energy-consuming equipment on the farm with its duration of use. With this information, and the help of technical guides developed by MFEP, the auditor identifies areas for improving energy efficiency and reducing energy costs (Van Zweden et al., 2017).

Once the audit is completed, an audit report is written by the energy auditor. The report contains a detailed analysis of each category of energy consuming equipment, the final energy conservation measures (ECMs) recommended, and the historical energy use and production data. ECMs are usually arranged in the final recommendation table in an audit report by the type of energy conserved. For example, a typical report will have electricity savings and natural gas/propane savings. Under electricity savings will be ECM categories such as lighting, motor controls, cooling compressors, and electric water heaters (Van Zweden et al., 2017).

Based on the calculated cost and energy savings, as well as the operator's management practices, the auditor will recommend upgrades with payback periods that are considered acceptable by the funding agencies that the operation could use to partly fund their energy efficiency improvements. Therefore, each ECM category in the final table is a compilation of all that category's recommendations from the report that have an acceptable payback period and are consistent with the operator's management practices (Van Zweden et al., 2017).

The auditor is required to submit the completed report to MFEP for review by an energy audit reviewer. Once any changes recommended by the reviewer are made, the audit report is certified by MFEP as conforming to the ASABE/ANSI S612 standard for Type 2 farm energy audits. These certified Type 2 audit reports contain all the data that is used to compile energy use and savings indices for dairy farms. Since these reports are confidential, the data is extracted from each report and the farm's name and other identifying information is redacted. (Van Zweden et al., 2017).

There are four pieces of information that are extracted from all dairy audit reports to make the energy use indices: total annual energy consumption, annual milk production, number of milk cows, and annual electricity consumption. This information is used to calculate the total energy and electricity consumed per pound of milk produced, the total energy and electricity consumed per milk cow, and electricity consumed as a percent of total energy consumption for four size categories of Michigan dairy farms. The metric used for classification of dairy farm size was developed by Michigan State University Agricultural, Food, and Resource Economics Department and is as follows: 1-99 milk cows, 100-249 milk cows, 250-449 milk cows, and 450+ milk cows (Wittenberg & Wolf, 2016).

The energy savings indices use data extracted from the final ECM tables in each audit report. The indices show the percent of farms where each ECM category had recommendations, as well as the percent of total proposed energy savings for which each ECM category was responsible. The seven ECM categories used for this index are: lighting, compressors, variable frequency drives (VFDs), weatherization, water heaters, manure handling, and miscellaneous. In addition, ECMs are also categorized by the type of energy conserved, which are electricity, propane/natural gas, and diesel. For each type of energy conserved, the percent of total energy savings is calculated.

## Results and Discussion:

Of the 133 dairy farms audited by MFEP, 113 were selected to be used in this study. The audits not used were missing necessary redacted data such as herd size, energy use, and milk production. Also, several audits were on farms from neighboring states. Table 3 shows four different energy consumption metrics that Michigan farmers can use to see how they compare to other farms. Table 4 shows the average milk production per cow in Michigan for each of the 4 herd size categories.

**Table 3. Energy consumption metrics for Michigan dairy operations**

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

**Table 4. Milk production for Michigan dairy operations**

| Herd Size | Number of Farms | Average Annual Milk Production Per Cow (cwt) |
|---|---|---|
| 20-99 | 22 | 193 |
| 100-249 | 57 | 233 |
| 250-449 | 18 | 250 |
| 450+ | 16 | 274 |
| **Totals:** | **113** | **254** |

Table 4 shows that, on average, the audited dairy farms in Michigan are more productive than the New York and Wisconsin farms shown in Table 1. The studies listed in Table 1 were only able to give an indication of electrical energy consumed per cow and per cwt milk produced, and not total energy. Michigan dairy farms fell within the range of electricity consumed per cow given in Table 1, and had a similar electrical consumption per cwt milk to New York. However, Table 3 has two additional metrics that are not included in the Table 1 studies—total energy consumed per cow and per cwt milk.

Table 3 points out a few important points. The most important metric is total energy consumption per pound of milk produced, since that directly relates to cost and revenue. As farm size increases, energy consumed per pound of milk decreases. However, that does not tell the whole story. Larger farms consume more energy as a whole, but they also produce more milk per cow, as shown in Table 4. Expending less total energy per pound of milk produced means large farms are operating with higher energy efficiency, and have more productive herds. Once farms pass the 100-cow threshold, they are more likely to be milking three times per day, which increases productivity. In addition, since larger farms have more revenue, they tend to be more inclined to invest in better infrastructure, such as newer energy efficient equipment, or better ventilation for their cows which increases production by reducing cow heat stress.

Milking three times per day is the main driver of increased productivity, but this has an impact on electricity usage as indicated in Table 3. As farms get larger, electricity consumption per cwt and per cow at first decreases but for the largest category of farms increases to levels similar to those of small dairy farms. Increased electricity usage that comes from milking three times per day is associated with parlor lights that are never shut off, longer run times for the vacuum and milk pumps due to increased milk volume and additional cleaning cycles, and increased output from the cooling compressors to cool the additional milk. In addition, as farm size increases, living space per cow typically decreases, which necessitates increased ventilation systems in the free stall barns to reduce heat stress.

Ventilation upgrades often consume more energy because older systems tend to be inadequate. However, studies have shown that milk cows that live in poorly ventilated housing tend to have lower productivity in summer months compared to milk cows housed in properly ventilated facilities. Summer heat stress can reduce milk production by as much as 10%, reduce fertility, and reduce feed efficiency (Flamenbaum, 2013).

Although Table 3 indicates that larger farms consume the least amount of energy per cwt of milk produced, there are significant diminishing returns as farm size increases. The largest decrease in energy per cwt is 45% when herd size increases from the smallest category to 100-249 cows. The remaining drops in energy usage per cwt as herd size increases are 21% and 17%, respectively. The case is similar with energy used per milk cow, where the percent drop in energy usage decreases with herd size—34%, 15%, and 9% respectively.

Since electricity consumption is only 30% of total energy consumption on the average Michigan dairy farm, it may seem that equipment that consumes other types of energy, such as propane/natural gas and diesel, would be the primary target of ECMs on energy audits since they comprise most of the energy usage. However, this is not the case. Most of the diesel fuel consumed on a dairy farm is in tractors. Energy auditors do not include tractors in their assessments since the increased fuel efficiency of a newer replacement tractor is never enough to financially justify the upgrade on its own since upgrading typically saves 10-15% in fuel. Virginia Tech University calculated that a 100-horsepower tractor used to farm 350 acres of corn and hay consumes 904 gallons of diesel fuel per year. A farmer that upgraded to a newer tractor of the same size and consumed 15% less fuel would save less than $550 per year if diesel fuel was $4 per gallon. Given that new tractors cost tens of thousands of dollars, the payback period from fuel savings alone would be in the decades (Grisso, Perumpral, Roberson, & Pitman, 2014). Other benefits to tractor upgrades like increased time efficiency, decreased downtime, and less manpower can be hard to quantify, and fall outside the scope of energy audits. During the audit years 2014-2016, MFEP auditors have found that 82% of energy saved in ECMs is electrical energy, while propane/natural gas and diesel collectively account for only 18% of total energy savings, as shown in Figure 2.

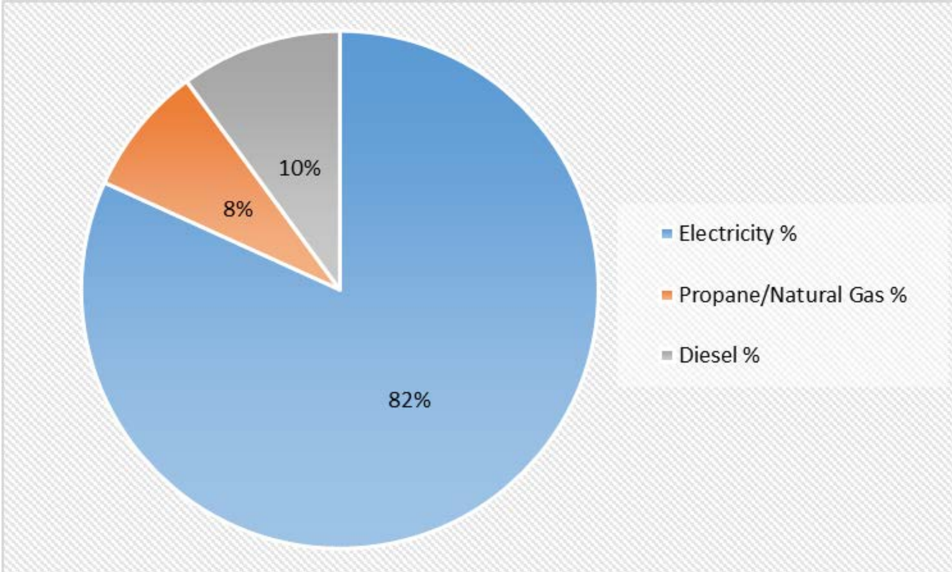


**Figure 2. Proportion of types of energy sources conserved by ECMs on audited farms**

Figure 3 shows the most common energy conservation measures (ECMs) identified on dairy farms audited during the most recent years of 2014-2016, while Figure 4 shows the percent of farms where each ECM category occurred. The ECM categories are lighting, variable frequency drives (VFDs) on the milking system, manure handling, compressor upgrades, water heater upgrades, weatherproofing, and miscellaneous upgrades. Figure 3 shows the proportional energy savings of each ECM category. The top three areas for potential energy efficiency savings were manure handling, lighting, and variable frequency drives (VFDs) on electric motors, especially on vacuum pump motors. Savings for VFDs on milk pumps for milking operations running more than 8 hours per day were also observed.

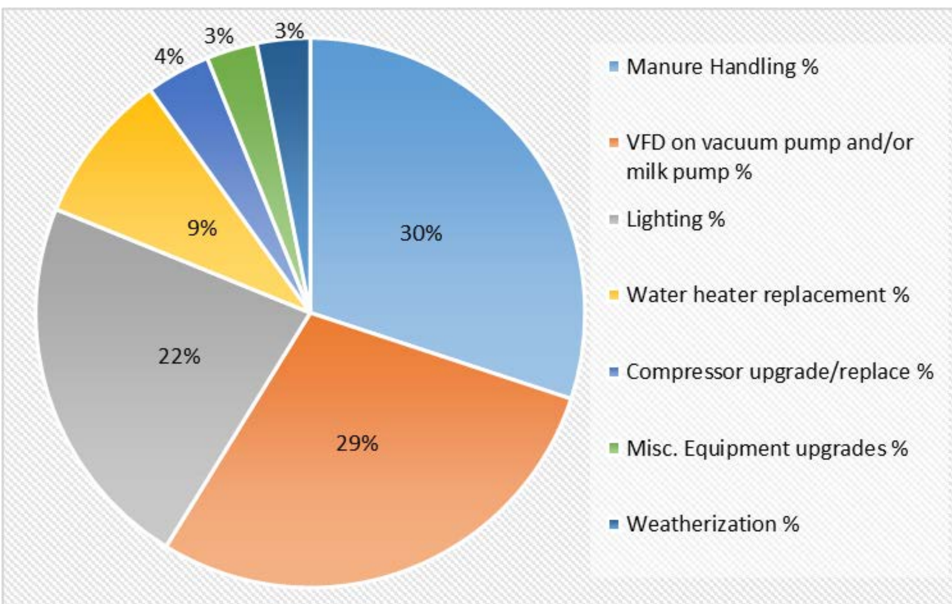


**Figure 3. ECMs and their respective potential percent savings compared to total energy savings**

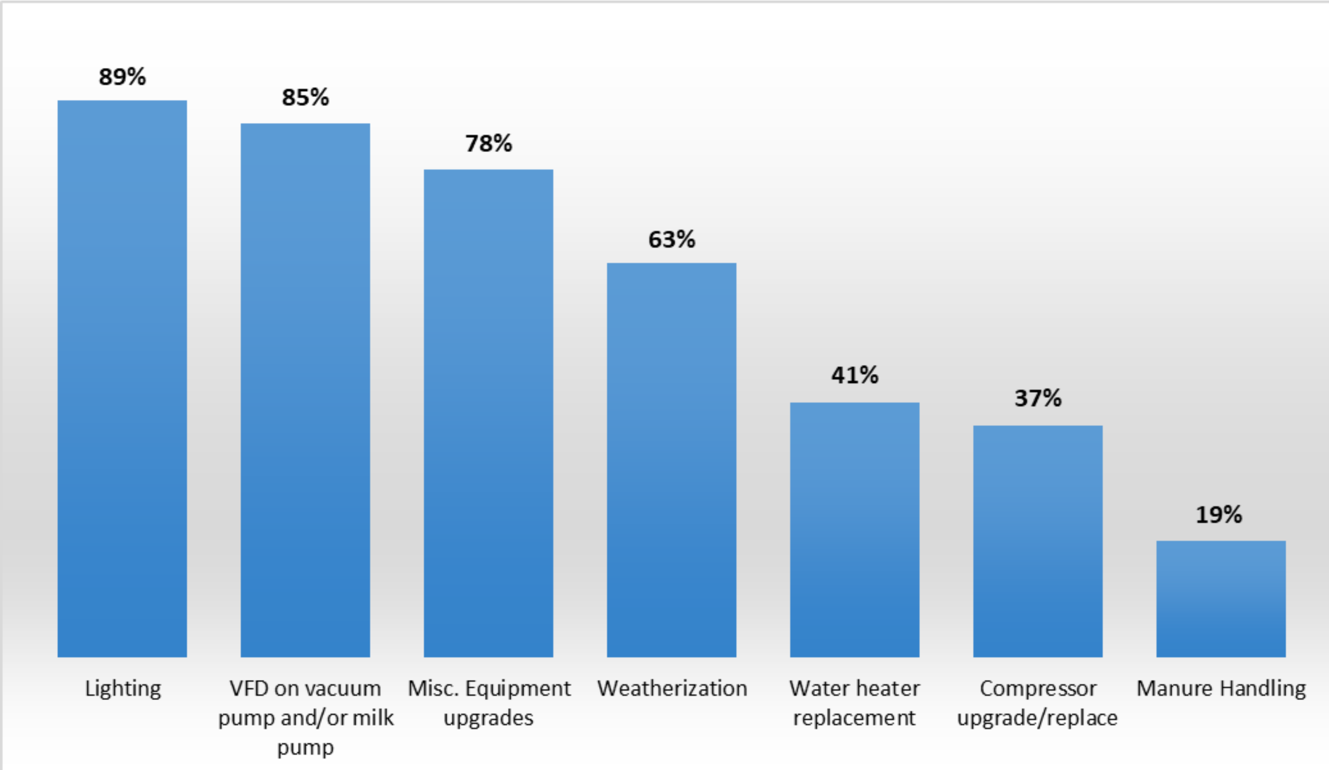


**Figure 4. Percentage of farms audited where each ECM category was recommended**

Figure 2 shows farm electricity use is the largest area for improving energy efficiency. Dairy farms use a lot of electrical equipment, and the payback periods for electricity ECMs are usually less than 5 years. One of the more common and effective ECMs that is almost exclusive to dairy farms is installing variable frequency drives (VFDs) on the vacuum pump motors and the milk pump motors (if operated at least eight hours daily). The vacuum pumps provide the vacuum needed to operate the milking process that extracts the milk from the cows. Once the milk is extracted from the cows, it usually flows to a small collection tank near the parlor floor. The milk pump operates periodically to transfer the milk from the collection tank and usually through a plate cooler before entering the main holding tank. Traditional vacuum pumps operate at close to their maximum power draw for the entire milking session, whether or not they actually need to be running at full capacity. At fixed speed, the vacuum pump is not able to respond to decreased demand for airflow, such as when the farmer is switching milkers between cows, or when switching cows in the milk parlor. During these periods, a relief valve lets air into the system to compensate for the lack of milk entering the system to maintain a constant vacuum level. A non-VFD powered milk pump will turn on and run at full capacity when the collection tank is full, and turn off when it is empty. Warm milk is pumped through the plate cooler in large bursts at a high speed, which makes the plate cooler less effective.

VFD vacuum pump motors fluctuate their speed based on demand for airflow, which means the vacuum regulator is only needed for backup and not for regular use. There is also a potential for savings with VFD milk pumps for farms when milking time exceeds eight hours per day. Between the parlor receiver tank and the main holding tank is the milk plate cooler, which uses cold water to lower the milk temperature before it enters the holding tank. Effectiveness of the plate cooler is increased and less cold water is required when the milk transfer pump is operated with a VFD. The VFD allows the milk to flow through the pre-cooler slowly and continuously, taking full advantage of the heat transfer between the warm milk and the cool flowing water. This will also lessen the load on the cooling compressor for the main tank, since the milk enters the main tank at a lower temperature.

Most of the farms audited still use inefficient incandescent lighting, so energy auditors recommend replacing them with LED lamps. At the start of the program, LED lamps were not considered reliable and cost effective for farm use. However, there have been great advances in LED technology that made LED lamps a more reliable and cost-effective option for improving energy efficiency and increasing light levels. Not all LED lights are suited for outdoor/farm use. Careful consideration must be given to the suitability of the lamp and fixture for the location. In limited circumstances where safety and spatial considerations allow, lighting electricity can also be conserved by installing occupancy sensors, which only turn the lights on when someone enters the space, and turn off when the space is unoccupied.

There has also been great interest by researchers in the use of a control system that will provide milking cows with 16 hours per day of light at a minimum of 15 footcandles, and less than 4 footcandles for the other 8 hours, since there is evidence that proper lighting control for dairy cows can increase milk production and increase the overall well-being of the cows. This concept is called long day lighting (LDL) (Thomas et al., 2017).

To illustrate the massive amount of energy consumed by the diesel manure pumps, and the huge energy savings potential of switching to electric motors to power manure pumps, consider the following: although manure handling ECMs were only made on 19% of the farms audited between 2014-2016, they accounted for 30% of the total energy savings of all ECMs on those farms. Compare this to lighting improvements, which were recommended on 89% of the farms audited, but contributed to 22% of the total savings. This is because almost all of the ECMs for manure pumping were to replace diesel manure pumps with electric pumps. Generally, electric motors are more energy efficient than diesel engines, so a diesel manure pump can usually be replaced with an electric motor to increase efficiency, especially if 3-phase service is available on the farm.

On one third of the dairy farms audited, some type of milk cooling compressor improvement was recommended. Auditors recommend that traditional reciprocating piston compressors be replaced with more efficient scroll compressors. The compressor removes a considerable amount of heat from the milk, which can easily be used to heat the facility as well as pre-heat water used in the milking operation. Therefore, a refrigerant-to-water heat recovery unit is cost effective in most situations.

Weatherproofing, upgrading water heaters, and miscellaneous upgrades did not contribute to a significant percentage of energy savings. Weatherproofing is the addition of insulation in heated spaces and around hot water pipes, or the addition of an insulated blanket around the water heater. Sometimes it was recommended that water heaters be switched between propane/natural gas and electric or switched to tankless water heaters. Miscellaneous upgrades included putting tractor engine block heaters on timers, adding or upgrading a milk plate cooler, or upgrading miscellaneous appliances like washing machines or hot water tanks.

## Conclusion

This study demonstrates the diminishing returns in increased energy efficiency and milk production as herd size increases. This can be a valuable tool to farmers who are considering herd expansion. Past farm energy audit data from other states did not break down energy use intensity data for different ranges of herd size.

The energy savings indices developed in this study helps farmers focus on equipment upgrades that have the greatest potential for improving energy efficiency and reducing operating costs. Based on this study, farm operators can achieve the greatest energy savings by focusing on manure handling, VFDs on their milking systems, and lighting improvements. Lighting and VFDs were recommended as cost-effective energy savings improvements on at least 85% of the farms audited. These indices can also serve as a guide to researchers to focus on technologies and energy types that are most likely to result in significant energy savings. The energy savings indices are important for grant applications as justification for a proposed project that targets a commonly recommended ECM category.

Farmers can use these energy use and savings indices to guide their capital investment decisions, whether for expansion of their operation or for equipment upgrades. Based on this study, Michigan dairy farmers will be able to see how their operations' energy use and productivity compares with other operations within their herd size category. This is especially useful to farmers who have high energy use intensities for their farm size, since it shows them that they should focus on energy efficiency before they expand their herd. This achieves the main goal of the study. The two main objectives to achieve this goal were also completed, since energy use intensity and energy savings indices were created by compiling data from certified Michigan Farm Energy Program audits.

It is important that Michigan dairy farmers remain competitive by improving their energy efficiency, which decreases production costs and reduces greenhouse gas emissions, which also protects the environment. There are even funds available through private, state, and federal organizations to help offset the costs of energy efficiency upgrades, and provide funding for renewable energy projects. Farmers can have access to these funds only after a certified energy audit has been conducted that follows ASABE/ANSI S612 Type 2 energy audit requirements. This index and surrounding discussion should serve as a tool for farm operators to start planning effective energy and cost saving improvements to their operations.

# References


ASABE Standards. (2009). S612 JUL2009 (R2016) Performing on-farm energy audits. St. Joseph, MI: ASABE.

Bolton, K., & Vanderlin, J. (2009). Milk production costs in 2007 on selected Wisconsin dairy farms. Center for Dairy Profitability. Retrieved from http://cdp.wisc.edu/pdf/07cost.pdf

Ebinger, F. (2015). Increasing dairy farm profitability with energy efficiency improvements. Minnesota Department of Agriculture. Retrieved from http://www.mda.state.mn.us/protecting/sustainable/greenbook/~/media/Files/protecting/sustainable/greenbook2015/gb15ebinger.pdf

Energy Star. (2016). U.S. energy use intensity by property type. Energy Star. Retrieved from https://portfoliomanager.energystar.gov/pdf/reference/US%20National%20Median%20Table.pdf

Flamenbaum, I. (2013). The beneficial effects of cooling cows. DeLaval. Retrieved from http://www.milkproduction.com/Library/Scientific-articles/Housing/The-beneficial-effects-of-cooling-cows/

Grisso, R., Perumpral, J. V., Roberson, G. T., & Pitman, R. (2014). Predicting tractor diesel fuel consumption. Publication 442-073. Virginia Tech University. Retrieved from https://pubs.ext.vt.edu/content/dam/pubs_ext_vt_edu/442/442-073/442-073_pdf.pdf

Hankey, R., Cassar, C., Liu, J., & Wong, P. (2018). Electric power monthly. United States Energy Information Administration. Retrieved from https://www.eia.gov/electricity/monthly/current_month/epm.pdf

Ludington, D., & Johnson, E. L. (2003). Dairy farm energy audit summary. New York State Energy Research and Development Authority. Retrieved from file:///C:/Users/Owner/Downloads/dairy-farm-energy.pdf

Merriam, R., Wade, J., Villar, J., Little, J., & Spangler, V. (2018). Natural gas monthly. United States Energy Information Agency. Retrieved from https://www.eia.gov/naturalgas/monthly/pdf/ngm_all.pdf

Thomas, A., Thelen, J., Go, A., Surbrook, T., Vanee, M., & Althouse, J. (2017). *A dairy long day lighting success story: MI dairy increases production and cuts costs*. Paper No. 1700081. St, Joseph, MI: ASABE

Van Zweden, B., Go, A., & Surbrook, T. (2017). *Michigan Farm Energy Program*. Paper No. 1700417. St. Joseph, MI: ASABE

WiDATCP. (2006). Dairy farm energy management handbook. Wisconsin Department of Agriculture, Trade, and Consumer Protection. Retrieved from https://datcp.wi.gov/Documents/DAD/DairyFarmEnergyManagementHandbook.pdf

Wittenberg, E., & Wolf, C. (2016). 2015 Michigan dairy farm business analysis summary. Michigan State University Extension. Retrieved from https://msu.edu/user/steind/2015%20MI%20Dairy%20Farm%20Business%20Analysis%20%232016-01.pdf