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Improved Methods for Identifying, Applying, and Verifying Industrial Energy Efficiency Measures

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Improved Methods for Identifying, Applying, and Verifying Industrial Energy Efficiency Measures

Improved Methods for Identifying, Applying, and Verifying Industrial Energy Efficiency Measures

A thesis submitted in partial fulfillment
of the requirements for the degree of
Master of Science in Mechanical Engineering

By

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Bachelor of Science in Mechanical Engineering, 1999

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This thesis is approved for recommendation to the Graduate Council.

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Abstract

Energy efficiency is the least expensive source of additional energy capacity for today's global energy expansion. Energy efficiency offers additional benefits of cost savings for consumers, reduced environmental impacts, and enhanced energy security. The challenges of energy efficiency include identifying potential efficiency measures, quantifying savings, determining cost effectiveness, and verifying savings of installed measures. This thesis presents three separate chapters which address these challenges. The first is a paper presented at the 2014 industrial energy technology conference (IETC) that details a compressed air system project using the systems approach to identify cost effective measures, energy intensity to project savings, and proper measurement and verification (M&V) practices to prove that the savings were achieved. The second is a discussion of proper M&V techniques, how these apply to international M&V protocols, and how M&V professionals can improve the accuracy and efficacy of their M&V activities. The third is an energy intensity analysis of a poultry processing facility at a unit operations level, which details the M&V practices used to determine the intensities at each unit operation and compares these to previous works.

Acknowledgements

I would like to thank Dr. Darin Nutter, who offered me the opportunity to work and learn alongside him for many years.

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Harding, A.C., and Nutter, D., 2014, "COMPRESSED AIR SYSTEM ANALYSIS AND RETROFIT FOR ENERGY SAVINGS," Proceedings of the 36th annual industrial energy technology conference, New Orleans, Louisiana, May 20-23.

Harding, A.C., and Nutter, D., 2015, "Measurement and verification of industrial equipment: sampling interval and data logger considerations," Energy Engineering, Journal of the Association of Energy Engineers, in press.

Harding, A.C., Nutter, D., and Liang, Y., 2015, "Unit Operation Energy Intensities for a Poultry Broiler Processing Plant," Energy Engineering, Journal of the Association of Energy Engineers, in press.

1 Introduction

Energy efficiency is the least expensive source of additional energy capacity for today's global energy expansion [1]. Energy efficiency offers additional benefits of cost savings for consumers, reduced environmental impacts, and enhanced energy security. The challenges of energy efficiency include identifying potential efficiency measures, quantifying savings, determining cost effectiveness, and verifying savings of installed measures.

As global energy demand increases, countries and companies are relying more and more on energy efficiency as an energy source, since constructing new fossil fuel power plants is expensive and developing new renewable energy technologies is both expensive and time consuming. Energy efficiency measures offer energy savings and corresponding cost savings for the person or company installing the measure, and at the same time freeing capacity on the utility system to meet growing demand. Energy efficiency measures have proven track records of saving significant amounts of energy with short economic paybacks and long measure lives.

Energy professionals have been successful in implementing some common measures and efficient technologies, such as National Electrical Manufacturing Association (NEMA) [2] premium efficiency electric motors and light emitting diode (LED) lighting, throughout the U.S. and the world. Many of these common measures have required simple analysis methods, as they are one-for-one replacements of existing equipment or technologies, and comparing the energy usage of the old and new measures is a simple process. As these measures saturate the market, more complex measures offer great promise of significant savings with good return on investment. Identifying these measures is the first challenge of energy engineering professionals.

The Department of Energy (DOE) has, for many years, offered guidance on some of the largest energy using systems in the industrial sector [3]; namely pumps, fans, steam, compressed air, and process heating. These systems may have dynamic interactions that can be analyzed and exploited to achieve significant savings, but identifying the measures that are required to achieve these savings can be difficult.

Despite the DOE guidance and the significant savings available from whole-system analyses, single component retrofit remains all-to-common in the energy efficiency field. The simplicity of the single-component retrofit (in terms of analysis, cost, and time) make them attractive to energy managers and other decision makers. This is despite the fact that the incremental cost of a whole system analysis versus a single component analysis is small and the potential savings is large. Whole system analysis must become more prevalent in the field for us to achieve the whole potential of energy efficiency as a resource.

For instance, it is common in industry for a vendor to propose a like-for-like retrofit of an existing pump with a more efficient model. The retrofit may provide energy and cost savings that meet the financial requirements of the company, so the measure gets installed. If, at the same time, the whole pump system is assessed, additional measures may be identified that have small incremental costs. These may include throttled control valves, large pressure variations, or changes from initial design conditions. The total savings of replacing the pump and installing the additional measures may far exceed the savings of the pump retrofit alone.

Coincidentally, the measurement and verification (M&V) of retrofit projects should seemingly be simple when compared to more complex projects. Furthermore, measurement and verification of industrial energy savings is an increasingly important topic, specifically as more states are implementing energy efficiency incentive programs. M&V has been important to the commercial sector for many years, and the international protocol for measurement and verification (IPMVP) framework [4], U.S. Federal Energy Management Program (FEMP) [5], and American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) guideline 14 [6] have helped energy professionals perform M&V activities in office buildings and residential dwellings with a high degree of accuracy. Less guidance has been developed for the industrial sector, since industrial processes are much more varied and unique.

Single component retrofit measures should be easily isolated, their energy usage measured, and project savings verified with little ambiguity. Sadly, this is not the case; so, measurement and verification is critical. For the numerous M&V activities taking place throughout the country, many have inappropriate M&V plans through misunderstanding of M&V protocol requirements and/or lack of knowledge regarding M&V equipment, which are all contributing to poor practices in the M&V field. The results are that savings are widely misrepresented, or presented with large uncertainty or unknown uncertainty levels. M&V professionals need further guidance to improve the implementation and accuracy of energy efficiency savings programs.

One of the reasons that savings are sometimes misrepresented is the lack of understanding of the factors that influence savings in dynamic systems. Energy usage is typically only monitored continuously by the utility revenue meters, but energy usage is defined by multiple systems that operate independently. Understanding the independent variables that affect change in the whole plant energy usage can be difficult. By breaking down the whole facility into unit operations, and then monitoring those operations individually, one can learn which unit operations are most important to overall energy usage, and what independent variables affect each unit operation. This can lead to more targeted energy management programs, and higher overall savings.

The first paper (Chapter 2) presented in this thesis shows the use of the whole system approach to analyzing a compressed air system for energy efficiency opportunities. Instead of simply replacing the existing air compressors with more efficient compressors, the whole system was analyzed to determine which additional measures could be implemented to increase overall energy savings. Four measures were identified that increased the total project savings to 17% of annual usage, compared to the 11% that would be achieved with the one-for-one compressor retrofit alone. The paper provides detail on the measurement and verification activities that determined the actual savings achieved by the project.

The second paper (Chapter 3) presented in this thesis attempts to explain the process of industrial M&V using the IMPVP option B framework. Issues regarding proper sampling rate and the cost of M&V activities are discussed. Three different electric energy logging apparatuses are discussed, including some of the benefits and drawbacks of each. Examples are given to show that fast sampling rates on a pulse type energy logger are unnecessary and, in some cases, can be improper. The paper concludes that understanding the option B framework and understanding how the different types of electrical loggers work can lead to improved M&V plans and more accurate estimates of energy savings.

The third paper (Chapter 4) presented in this thesis focuses on energy intensity at the unit operation level in a poultry processing facility. This paper presents the methodology and findings of a study completed at a large poultry processing plant. In this study, the plant energy usage was measured at many individual points in the facility, and those measurements were aggregated to show the usage for different unit operations. Two different measures of production output were used to convert energy usage into energy intensity with units of energy per unit production. These results were then compared to previous studies, conducted in the late 1970's [7, 8]. This paper also presents multiple regression analysis findings regarding the variables that affect energy intensity at the unit operations level. The study found that more automation has led to replacing human energy with electrical and natural gas energy, but this has been mostly offset by energy efficiency.

In summary, the three papers that are presented begin with a presentation of existing energy assessment methods, provide deep insight into some poorly understood or applied principles of M&V, and then progress to a re-invention of similar unit operations energy intensity determinations using modern technologies.

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2 Compressed air system analysis and retrofit for energy savings – an industrial case study

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2.1 Abstract

This case study paper describes energy efficiency improvements to a large sanitary paper products manufacturing facility that underwent a comprehensive compressed air system retrofit. The project was motivated by potential energy savings and better system performance, resulting in improved system reliability, reduced energy consumed by over 240,000 kWh annually, reduced maintenance cost by nearly $7,000 annually, and reduced electric utility bills by nearly $19,000 annually (a 17% savings). This project used a whole-system approach to evaluate both the supply and demand sides of the system to develop the most comprehensive and cost effective solution for providing high-quality compressed air to the manufacturing processes. The project included several actions including piping retrofits, equipment upgrades, pressure control changes, and compressor retrofits.

2.2 Introduction

Compressed air systems are some of the largest energy using systems in a modern manufacturing facility. According to the December 2002 United States Industrial Electric Motor Systems Market Opportunities Assessment, compressed air systems consume almost 10% of all electrical energy used in US manufacturing facilities [1]. Furthermore, according to the 2010 MECS data, the net electricity usage in the US manufacturing sector was over 878,000 Million kWh [2]. This leads to an annual estimated compressed air system energy usage of almost 87,000 Million kWh. At an average cost of $0.0667/kWh [2], this estimate amounts to a very significant $5.8 Billion dollars per year spent on energy for compressed air systems in the US. Clearly, some amount of this energy expenditure is unnecessary and can be cost-effectively eliminated. The current literature offers a range of assertions on the amount of system-specific energy savings that is available, with experts in New Zealand concluding that 15% is a reasonable number [3], while experts in New Jersey think 30% is possible [4]. Studies of compressed air systems around the world have identified similar measures that should be undertaken to achieve this energy savings [5-9], including fixing leaks, implementing new technologies, identifying inappropriate uses, and other measures.

Rockline Industries is one of the largest global producers of consumer products specializing in wet wipes and coffee filters. Their Springdale, Arkansas facility was the location of the study described in this paper. They contacted the Arkansas Industrial Energy Clearinghouse (i.e., the Clearinghouse) after initially identifying their compressed air system as a potential source of significant savings. The manufacturing company then made the decision to replace their air compressors with more efficient units. Experts from the Clearinghouse then engaged and began working with the company, representatives of the electric utility and a local compressed air vendor to perform a more complete evaluation of the system (as described in this paper). The team also provided measurement and verification (M&V) of the overall project savings.

Energy efficiency and reduced utility costs were part of the justification for this detailed study. High maintenance costs were another driver. The existing air compressors had a history of oil carryover into the compressed air system, which caused costly shut-downs and required cleaning of the compressed air piping throughout the facility. Furthermore, the diaphragm pumps are one of the large air users in the manufacturing facility. They are used to move highly viscous fluids such as lotions throughout the facility. These pumps are expensive to operate and maintain, and the plant was experiencing a high failure rate for this type of pump.

Another driver of the project was the recent implementation of energy efficiency incentives in the State of Arkansas [10]. The local electrical utility began offering incentives for energy efficiency projects in 2010. The staff at this company worked closely with the electric utility representatives to obtain significant incentives based on energy savings, which brought down the overall cost of the project. When this incentive was added to the annual savings from the reduced electric bill, it made the project financially viable for the company.

There are many published papers on the general subject of energy cost saving measures which target individual components of compressed air systems; however, a whole-system approach is considered superior, and more comprehensive. The case study paper presented below provides the results of a ‘system approach’ which evaluated both the supply and demand sides of the system to develop the most cost effective solution for providing high-quality compressed air to the manufacturing processes. Overall, the project included several actions including piping retrofits, equipment upgrades, pressure control changes, and compressor retrofits.

2.3 **Methodology**

Because of its ease to quantify the cost and savings, a component level approach is often taken by equipment vendors and system operators. In the component level approach, a specific measure is identified and implemented, and the energy and/or maintenance savings for that measure are quantified and used as justification for the project. These projects are often recommended based on the vendor's prior successful implementation of a similar project, or some other outside influence which may or may not be focused on energy efficiency or cost savings. The Department of Energy and the Compressed Air Challenge; however, advocate a systems approach [11] as the best practice for analyzing and improving a compressed air system. The systems approach is defined as:

> Improving and maintaining peak compressed air system performance requires not only addressing individual components, but also analyzing both the supply and demand sides of the system and how they interact. This practice is often referred to as taking a "systems approach" because the focus is shifted away from individual components to total system performance [11].

The systems approach is a much more comprehensive method of optimizing the performance of the compressed air system. It includes the following steps:

- Establish current conditions
- Determine process needs
- Gather baseline data
- Develop potential energy efficiency measures
- Evaluation of financial and technical conditions
- Implement measures
- Gather verification data
- Continue to monitor and assess system

The component level approach typically involves implementation of a handful of very specific, low cost, short payback measures, or the replacement of an old compressor with a more efficient one. This approach guarantees that each individual measure has quantifiable savings and makes financial sense, if the time is taken to measure and verify the savings. The approach also has the potential to miss significant savings opportunities through the interaction of components and also has the opportunity to overestimate savings based on “rules of thumb” or average savings instead of system specific calculations of savings. The system approach is more costly and time consuming to implement, but has the potential to optimize the performance of the overall compressed air system. The systems approach also offers the opportunity to implement more savings measures, by subsidizing some measures with the savings from others. Since the overall cost savings is the final goal, this should be preferable for most companies.

For this study, the company used the systems approach when they decided that their compressed air system needed to be upgraded. The main goals of the project were to increase the reliability, decrease the required maintenance, and decrease the operating cost of the compressed air system, all while maintaining the quality of the compressed air delivered to the process.

As a major manufacturer of baby wipes and other sanitary wipes, both process reliability and product quality are of upmost concern to the company. Therefore, high quality compressed air is a key component of that objective. The compressed air used in the manufacturing process at this facility is held to ISO (International Organization for Standardization) class 2 air quality standards for particles and class 4 for humidity, since the compressed air is used in almost every stage of manufacturing their sanitary products.

2.4 **System description and analysis**

The project included four distinct changes to the overall system, including a piping retrofit, diaphragm pump retrofits, pressure control changes, and a compressor room retrofit. In addition to a description of the original and new system configurations, each of the four changes is discussed below.

2.4.1 Original System Configuration

Figure 1 provides a schematic of the original system configuration. The existing compressors at the facility were identical, 150hp, single stage, load/unload rotary screw compressors. The specific efficiency of these compressors was rated by the Compressed Air and Gas Institute (CAGI) [12] as 18.7 kW/100 cfm at full load, and each of the compressors was capable of producing 678 acfm. These compressors ran in a configuration where one of the compressors ran at full load, and the other compressor loaded and unloaded as needed to maintain plant pressure.

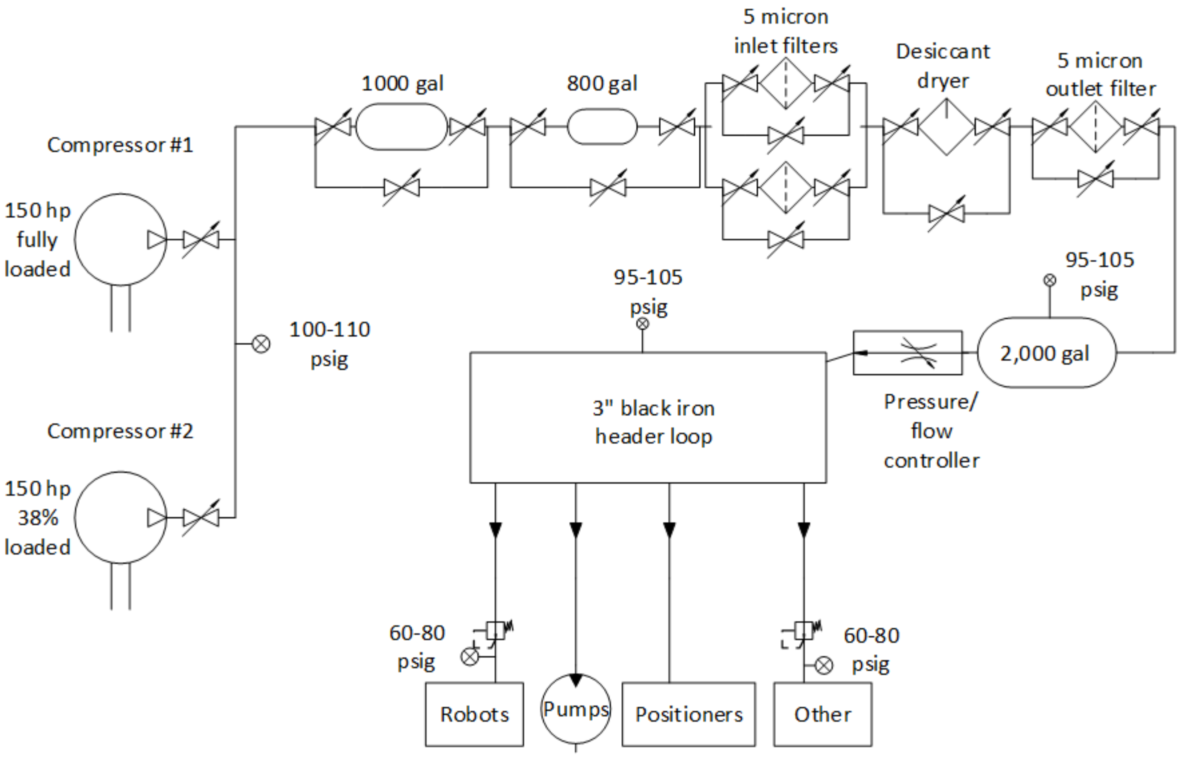

Figure 2-1: Original plant compressed air system configuration

Baseline energy usage data was collected by deploying data loggers on both compressors and measuring the energy usage over a period of about two weeks. The data shows that the lead compressor is nearly fully loaded, and the trim compressor is loading and unloading to control system pressure. The logged data is shown in Figure 2.

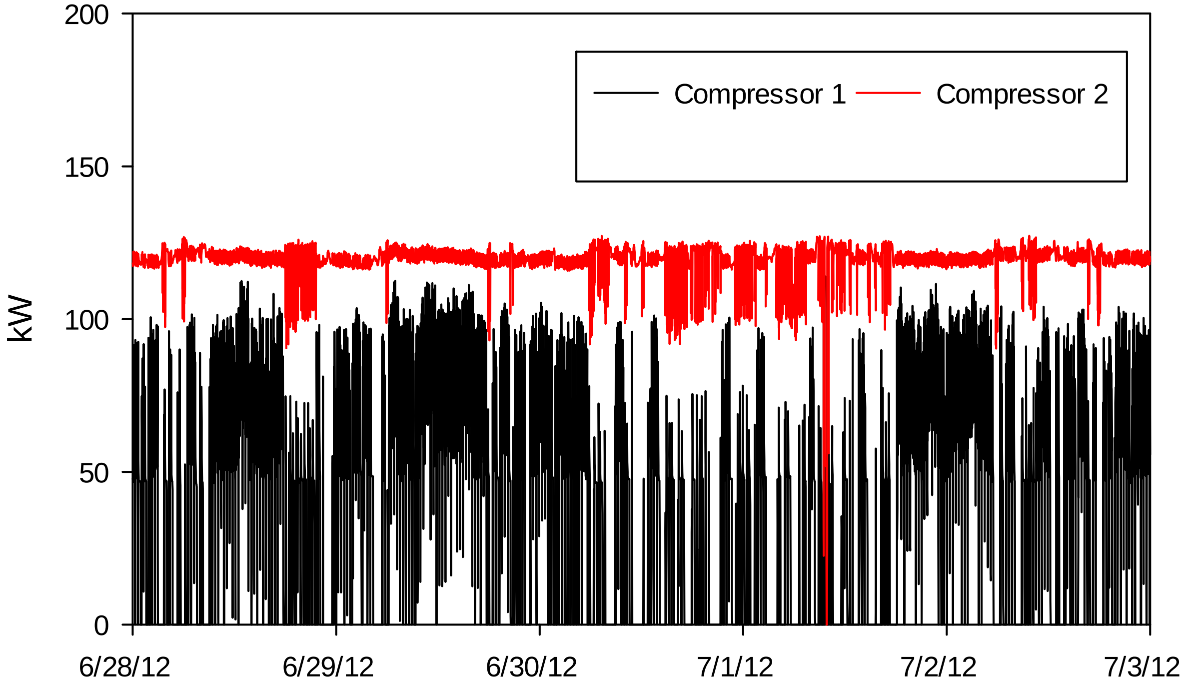

Figure 2-2: Original system measured electrical power data (60 second intervals)

The cut in pressure for the trim compressor was set to 100 psig, and the cut out pressure was set to 110 psig. The compressor room contained two wet storage tanks, with a total capacity of 1,800 gallons. A heated desiccant dryer with associated filters was also located in the compressor room. Dry air was sent into the plant to a 2,000 gallon dry storage tank, which typically remained around a nominal 100 psig.

The distribution system consisted of a 3" cast iron pipe header loop, which supplied air to all of the end uses in the facility. The piping was over 20 years old, and cleaning the header system after an oil event caused significant downtime in the facility.

A pressure/flow controller was present in the system, located between the dry storage tank and header loop, but the pressure controls were set to maintain maximum pressure downstream of the controller, essentially bypassing it. The pressure controller settings likely ended up in this configuration after complaints about low air pressure at specific locations in the facility. Increasing header pressure has the effect of increasing artificial demand [13] throughout the plant, and may or may not correct the low pressure condition that caused the complaints.

The diaphragm pumps that are used to move lotions and other fluids from holding tanks to the process were all connected to the main header with separate, unregulated drops. There are 12 of these pumps, and on average, each pump was being replaced about every 2 months.

2.4.2 **System Piping**

The project began by addressing the piping system. The 3” black iron header was replaced with a 90mm aluminum piping system. The old header was more than 20 years old, and the iron pipe had degraded over time. When a recent air compressor event sent oil into the header, the entire plant was shut down for several hours while the bulk of the oil was drained from the piping. When the system started back up, the plant had to deal with excess oil in the system, which was trapped in the pores and rough surface of the degraded pipe.

The new piping system was selected for several reasons. First, the aluminum pipe will not corrode over time as steel or iron pipe will, so the integrity of the piping system 20 years from now should be significantly better than the condition of the old header. Second, the time to install the aluminum piping system was significantly less than the time it would have taken to install a new threaded or welded steel piping system, since the aluminum piping system uses slip fit connections. Lastly, the design of the slip fit connections, along with the reduction in pipe degradation means that a properly installed aluminum piping system should theoretically never leak, where iron or steel pipe undoubtedly will over time.

The energy savings from the reduced leaks was a small consideration for this part of the project, but the long term benefit may be significant [14]. Figure 3 is an image of part of the aluminum piping system. The aluminum piping is blue, and the slip fit connectors for the system are black.

Figure 2-3: Aluminum piping system. Aluminum pipes are blue in color and slip fit connectors are black. Photograph by A.C. Harding, used with permission.

2.4.3 **End Use Equipment**

The second change of the overall project was to address the diaphragm pumps in the facility. Air operated diaphragm pumps are, by nature, less efficient than motor driven pumps [11], since they use compressed air as a motive force rather than using an electric motor directly. The fluids that are being pumped in this facility are quite viscous and have suspended solids, so the use of centrifugal pumps was not appropriate. The existing diaphragm pumps were fairly new, and all major manufacturers of this style of pump have focused on energy usage in the last decade, meaning that any energy efficiency gains from switching manufacturer's was small. The largest consideration for this stage of the project was to improve reliability of the pumps, and therefore reduce the annual maintenance cost of replacing failed pumps.

The company turned to a local compressed air vendor to assist with the proper sizing and configuration of the pumping system. The existing configuration of these pumps meant that each pump was individually powered from the main header at line pressure. When pumping was called for, 100 psig air was sent to the pumps, which then moved the fluids from holding tanks or vats into smaller day tanks or individual process lines for use. The major issue with the system configuration was identified as the over-pressurization of the pumps.

Diaphragm pumps are typically rated for a maximum pressure input. This is the pressure at which it is safe to operate the pump. The pumps also typically have a minimum input pressure, which is the pressure below which the pump may stall or cease to operate properly. The forces that the pump, and particularly the actual diaphragm, experience at different pressures can be wildly different. The pump speed changes with pressure and the pump flow rate changes accordingly. Since the applications at this facility involve transfer between two tanks, the pumping speed was not a big concern for the company. This meant than the air input pressure and corresponding pump speed could be reduced to near minimum, which in turn reduced the loads on the pumps.

As an example, a typical diaphragm pump may have a maximum pressure rating of 100 psig. At 100 psig, the pump may be capable of pumping 8 gpm of water, and the pump must consume 18 scfm of compressed air to do so. The same pump, with an inlet pressure of 40 psig, may be able to pump a maximum of 6 gpm of water with only 8 scfm of compressed air input, or it may be able to pump 2 gpm of water with only 3 scfm of compressed air.

If the amount of water to be pumped is 500 gallons, then at the 100 psig maximum case, a total of 1,125 scfm of air is consumed, but it only takes 62.5 minutes to complete the action. In the 40 psig, 2 gpm case, the same amount (500 gallons) is pumped in 250 minutes (4 times as long), but only 750 scfm of air is required (a 33% reduction). The pump speed and duty are significantly reduced, the energy savings is significant, and the only penalty is time. If the time penalty is acceptable, then the pressure reduction can yield a significant savings.

The company decided that they could reduce the line pressure to 55 psig with no negative impact on production. The new pump header is shown in Figure 4. The header is regulated to 55 psig.

Figure 2-4: Diaphragm pump header regulated to 55 psig. Photograph by A.C. Harding, used with permission.

2.4.4 Pressure Control

The third aspect of the overall project was the control of pressure in the system. The existing system was run with an average pressure of 100 psig, which included about 5 psig of drop through the treatment equipment, and a 10 psig differential from the load/no load controls on the compressors. This means that while the compressors were modulating between 100 and 110 psig, the header was seeing a pressure range of 95 to 105 psig. The additional pressure drop of 5 (or more) psig from the “last dirty thirty” [15] meant that end uses were receiving about 90 psig before the trim compressor loaded in, and about 100 psig before the trim compressor unloaded.

The DOE and the Compressed Air Challenge have advocated for years that plant pressure should be set to the lowest possible pressure to maintain acceptable operations [11]. The highest pressure end use in this facility is a set of electropneumatic positioners for pneumatically actuated control valves. These positioners become unreliable when the supply pressure drops below about 90 psig. If one the positioners fail on low air pressure, it could cause a production issue that causes a production line to shut down or generate scrap products. The header pressure was apparently set to properly provide a minimum of 90 psig to these controllers.

However, after further investigation, it was discovered that most of the end uses in the facility were regulated in the range of 55 to 80 psig. The intrinsic air consumption of the electropneumatic positioners is zero cfm [16], since their method of operation is to position an actuator. As long as the actuator is in the same position, no air is consumed. This is the definition of a “flow static” application, which makes it a perfect candidate for a pressure booster. A 2:1 pressure booster regulator [17] was installed at the bank of positioners, and set to an operating pressure of 95 psig, ensuring sufficient supply pressure for the devices. This allowed the plant header pressure to be dropped to 85 psig, allowing for 5 psig drop to the end uses regulated to 80 psig.

The plant header pressure was set to 85 psig by using the existing pressure/flow controller at the main receiver tank (shown in figure 5). This device ensures a constant 85 psig, regardless of tank pressure, as long as that pressure remains above 85 psig. The tank pressure is held relatively constant at about 93 psig by the new variable speed drive compressors that were installed as the final system change.

Figure 2-5: Pressure/flow controller regulating plant pressure to 85 psig. Bottom view with tank shown. Photograph by A.C. Harding, used with permission.

2.4.5 **Compressors**

The new compressors consist of two identical, 200hp, 115 psig rated, variable speed drive, single-stage, lubricant injected rotary screw compressors. These compressors were selected by the company after consultation with a local vendor, based on the desire to operate one compressor normally, with the second compressor acting as a 100% redundant backup.

The new compressors each have a specific efficiency as low as 19.0 kW/100 cfm at full operating pressure, with slightly higher values at full flow and full turndown. In the case of specific efficiencies, with units of kW/100 cfm, lower numbers mean higher efficiencies, so these compressors, at full load, are actually slightly less efficient than the old compressors. However, since the new compressors utilize variable speed drives, at part load they are quite a bit more efficient than the original, single-stage, rotary screw compressors.

Analysis of the logged data from the old compressors (Figure 2) shows that the lead/lag control scheme, with the pressure settings described above, yielded an overall specific efficiency of around 21.8 kW/100 cfm. Analysis of logged data from the new compressors shows an overall specific efficiency of 19.4 kW/100 cfm.

The compressor replacement portion of the overall project included some significant piping changes in the compressor room. The two wet storage tanks were removed from the system. This is not a common measure to take when upgrading a compressed air system, and for many years the compressed air industry has held to the old rule of thumb that says more system volume is always better [18]. In the case of variable speed drive compressors, the added system volume does increase the ride-through time available if the main compressor unexpectedly goes offline and the backup has to start [19], but there is no energy efficiency benefit.

In the case of this facility, the added storage capacity also came with a significant number of valves, fittings, and potential maintenance issues. As can be seen in the final system configuration (Figure 7), removing these extra tanks simplified the compressor room piping, eliminating the pressure drop associated with them, and eliminated the need for the two extra ASME pressure vessels to be inspected and certified by the State each year.

The removal of the wet storage tanks also allowed the needed floor space for the addition of a loose-pack, deep-bed filter (so-called mist eliminator filter) (Figure 6). This 10 micron filter has no measurable pressure drop, and removes a significant load from the 5 micron filters that are required upstream of the desiccant dryer. In theory, there is no energy efficiency savings from this measure, but in practice this large filter will reduce the maintenance cost for the 5 micron filters by extending the time between required cartridge replacements. Alternately, if the 5 micron filters are serviced at the same intervals, the pressure drop through them will be reduced due to the reduced loading.

Figure 2-6: Mist eliminator filter and associated piping. Photograph by A.C. Harding, used with permission.

2.5 **Results and discussion**

With the plant distribution piping system upgraded, the end uses evaluated and improved, the plant pressure under control and minimized, and the compressor room fully retrofitted, the project's four changes to the compressed air system project were completed. The final system configuration is shown in Figure 7. The next step of the systems approach was to verify the reduced energy consumption and determine the resulting economics [11]. Data loggers were deployed on the system to measure the energy consumption, and production data was analyzed to determine the energy intensity of the new system.

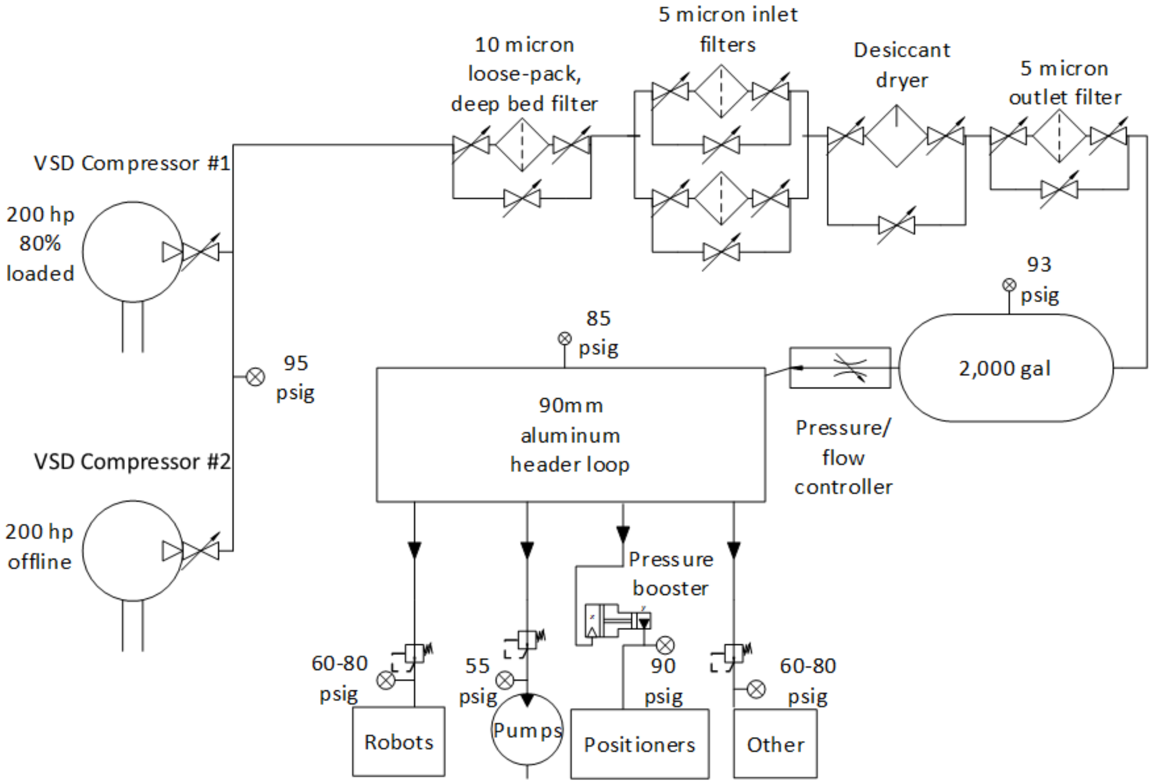

Figure 2-7: Final plant compressed air system configuration

The average power recorded with the old system configuration was 168.8 kW (Figure 2). The average power recorded with the new system configuration was 121.5 kW (Figure 8). This difference in average power is not representative of the actual energy savings, since the production levels during the two logged periods was different by about 2,600 units per hour. The actual energy savings can be more closely estimated by calculating the energy intensity, or energy per unit of production, for each period. The calculated energy intensities were 8.432 kWh/1000 ea. for the old system and 6.982 kWh/1000 ea. for the new system (Figure 9).

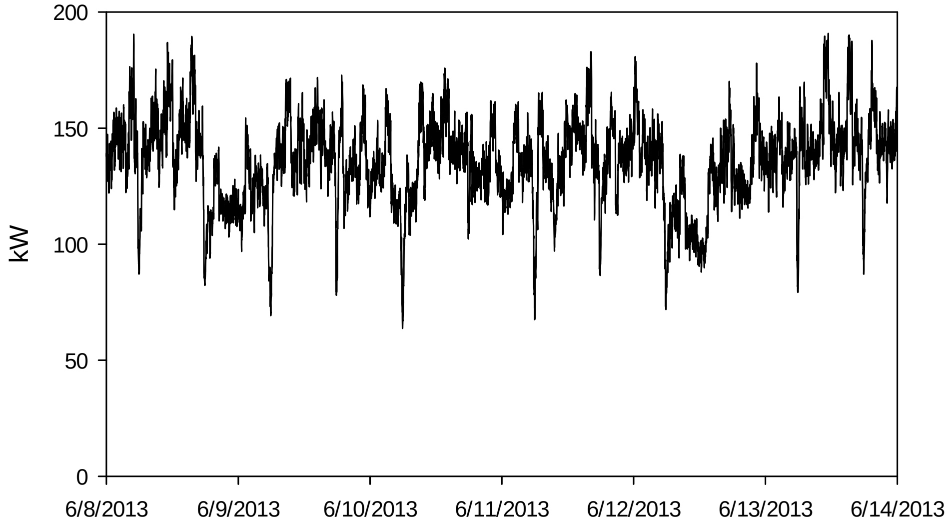

Figure 2-8: Final system measured electrical power data (60 second intervals)

Based on comparison of the old system energy intensity to the new numbers, an annual energy savings of over 242,000 kWh was achieved. This represents about 17.2% of the baseline compressed air system energy usage. This is consistent with similar case studies of industrial compressed air systems that show overall savings of 10% to 18% of baseline compressed air system energy [19-22].

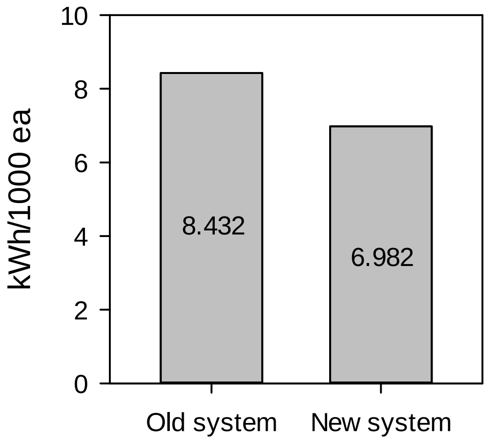

Figure 2-9: Compressed air energy intensity

Additionally, there was some demand savings, but due to the different production levels during the baseline and verification periods, it is difficult to quantify the annual demand savings. We do know that the average power was reduced by 47.3 kW between the two logging periods, so the annual demand savings is likely on the order of 500 to 600 kW-mo/year.

The 17% savings includes the energy efficiency improvement of the compressors, which was about 11%, as well as a reduction in compressed air consumption from the diaphragm pumps, which was about 1.4%. Based on published pump curves for the diaphragm pumps, the 1.4% savings is estimated by comparing the operating points at the old and new pressures. The pump curves show the pump flow rate and the specific air consumption at each pressure. Dividing the total annual volume pumped by the flow rate and then multiplying by the specific consumption gives a measure of air consumed annually. Multiplying this number by the specific efficiency of the air compressor yields an annual energy usage. The published pump curves are based on water at ambient temperature, so there is some error introduced by the fact that the fluid being pumped is actually a series of lotions and other viscous fluids, but the result is a reasonable approximation of the overall energy use. This estimate yielded a compressed air use reduction of about 17%, and an energy savings of about 1.4% of the baseline energy use. The change also reduces the annual pump replacement costs by a projected $4,900 annually.

The other 4.8% of the baseline system energy usage was saved through the combination of the reduction in artificial demand due to the header pressure reduction and the decreased friction in the new aluminum piping. At an average cost of $0.072/kWh, the energy savings reduced the annual utility cost by just over $19,000.

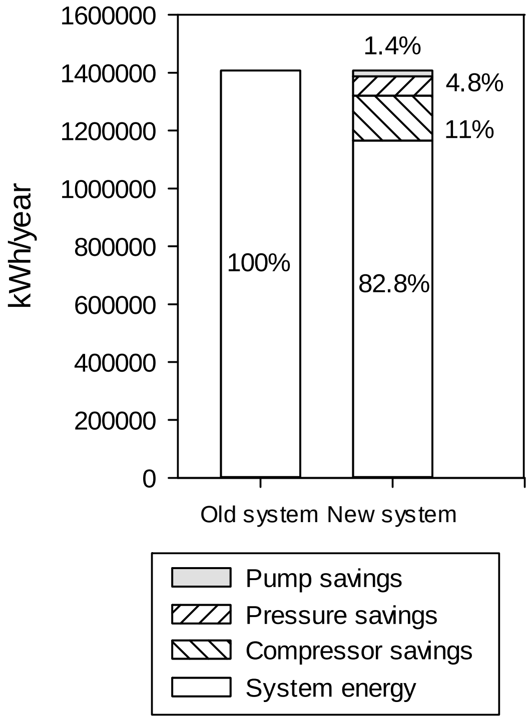

Figure 2-10: System Energy Breakdown

2.5.1 **Economic Viability**

The energy savings, along with the maintenance savings on the diaphragm pumps and compressors, were found to be significant. The overall project cost was reduced by the energy efficiency incentives offered by the local electric utility, which improved the simple payback of the project and helped to make it viable. As a long-term investment in this manufacturing facility, all of the life cycle costs should be included to determine a return on investment of the overall project [23].

The maintenance savings detailed above amounted to an annual savings of nearly $7,000. The energy savings were measured and verified as just over $19,000 annually. When all four stages of the project were considered, and the utility rebate included in the overall project evaluation, the total cash outlay for the company was just over $70,000, which yielded a simple payback of just less than 3 years. Using a 10 year lifespan, and a 15% discount rate, the net present value of the project comes to nearly $70,000. The internal rate of return (IRR) for the entire project was 56%.

2.6 Summary and conclusions

This case study paper described a compressed air system retrofit at a large sanitary paper products manufacturing facility. This project used a system approach to evaluate and implement changes on the supply side and demand side of the system to optimize the compressed air system efficiency, rather than focusing on one or two specific components. The result was an annual energy savings of 17.2% of the baseline system electricity use, which reduced the annual utility cost by just over $19,000 annually. Additionally, the system maintenance cost was reduced by nearly $7,000 annually. The project simple payback was just under 3 years, the Net Present Value of the project was nearly $70,000, and the IRR was 56%.

In conclusion, using a system approach when retrofitting a compressed air system can lead to higher overall energy and maintenance savings by considering the interaction between components rather than simply implementing the energy efficiency measures that have low simple payback periods when considered individually. The interaction of potential measures should be considered in order to guarantee that individual measures will provide the stated benefits and economic viability that are expected. This system approach can and should be applied to other energy consuming systems in industrial and commercial facilities, such as pump systems, fan systems, process heating systems, steam systems, and HVAC systems.

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3 Measurement and verification of industrial equipment: sampling interval and data logger considerations

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3.1 Abstract

Measurement and verification (M&V) of energy efficiency projects is an important activity for energy managers, government agencies, building owners, and utility representatives. Misapplication or misunderstanding of M&V protocol requirements can cause significant error in energy savings calculations. Additionally, incomplete knowledge of how common data loggers function can create confusion around the measurements being taken and the results being reported. This paper seeks to further the understanding of data collection intervals, M&V costs, and M&V plan uncertainty. Additionally, a detailed description of how several types of electrical data loggers function is presented, showing the advantages and potential disadvantages of each.

3.2 Introduction

Measurement and verification (M&V) of energy savings has been an important topic among energy managers, governmental agencies, building owners, and utility representatives since the first energy crisis in the mid-1970s. And, as utility incentive or rebate programs become more ubiquitous across the U.S., more industrial companies are pursuing viable energy efficiency as a way to reduce bottom line costs. The utility incentives can reduce the simple payback of these measures to be competitive with other capital projects within the company, such as new product development and process efficiency improvements. The utility programs require M&V to qualify the projects for the rebates and incentives. Furthermore, these industrial energy efficiency projects include variables which can be more complex than commercial building projects, such as varying production output, work schedules, shift efficiencies, and others. These are added to the common commercial sector variables such as weather and occupancy loads.

Given the abundance of information, it is worthy to note that there is still significant confusion among energy managers regarding data collection methods, development of M&V plans, and errors associated with application of M&V protocols, whether proper or not. This may be due to the fact that M&V is not a common part of day-to-day operations for most energy managers, but rather done possibly once or twice a year to justify a project or procure a rebate. The authors have observed that the infrequency of data logging and M&V techniques lead to improper applications or use of out-of-date information and/or methods. Also, since power and energy measurements typically require some knowledge of electrical and mechanical safety procedures, it is quite common for an energy manager or energy engineers to develop the M&V plan, which in turn is implemented by a technician, such as an electrician. Without good communications between the engineer and technician, the data may not represent the intent of the project. This can either be due to mistakes by the technician in carrying out a properly designed M&V plan, but more commonly can be due to the technician following a poorly designed M&V plan, developed by an engineer with insufficient knowledge of data gathering techniques.

This paper seeks to explain how data logging intervals are commonly misapplied, and what the perceived and actual requirements are within the governing M&V framework. The discussion and guidance provided should lead readers to an understanding that will lead to better M&V plan design and implementation. Further, the paper will provide relevant information on several types of available electrical data loggers, their capabilities, their costs, and the implications of using each for pre- and post-retrofit M&V of energy efficiency projects.

3.3 **Background**

A brief history of M&V is given in the *Energy Management Handbook*, chapter 27 [1]. In the 1980s, M&V of energy savings became important when utility incentive, rebate, and loan programs were prevalent. In addition, several US Department of Energy (DOE) programs targeted residential and commercial buildings. These programs required proof that the implemented energy efficiency measures had performed as expected and achieved the savings that were promised. Successful and not-so-successful energy efficiency projects have been well documented by Waltz [2], Roosa [3], McBride [4], and others. Note that savings cannot be directly measured, since savings is the reduction of usage, so over time performance contractors and energy engineers developed methods that provide a high level of confidence in projections or estimates of savings, often based on measurable quantities.

The North American Energy Measurement and Verification Protocol (NEMVP) was first published in 1996, and later expanded and re-named the International Performance Measurement and Verification Protocol (IPMVP) [5]. This set of measurement protocols gives guidance on the type of M&V required to quantify and report energy or cost savings.

More recently, the International Standards Organization (ISO) released ISO 50001:2011, which is the overarching standard for an energy management system [6]. ISO 50015:2014 “Measurement and Verification of Organizational Energy Performance — General Principles and Guidelines” [7] is a companion standard which addresses M&V. This standard is similar to IPMVP in that it provides an overview or framework of how M&V should be conducted and what M&V plans should include. ISO 50015 includes guidance on M&V plan construction, data gathering, uncertainty, and reporting.

While many examples are given for different types of energy efficiency measures, facilities, and savings goals, no specific M&V plans are defined within the current IPMVP framework or ISO 50015. In fact, the IPMVP preface specifically states that “Each user must establish its own specific M&V Plan that addresses the unique characteristics of the project.” [5]

Specific guidance on M&V plans was offered by the DOE when they published a guide titled “The Uniform Methods Project: Methods for Determining Energy Efficiency Savings for Specific Measures” [8] in April 2013. This guide offers specific guidelines that should be followed for many specific energy efficiency measures, including commercial lighting, residential boilers, and several other measures that are commonly implemented as energy efficiency improvements. The information published in the Uniform Methods Project includes directions for types, levels, and durations of measurement, equipment types, data handling, and metering methods. However, only 7 specific measures are covered in detail, and these measures are largely related to the residential and commercial sectors only. There are no industry specific measures covered. Chapter 9 of that document discusses “Metering cross-cutting protocols” at a high level, but does not include specifics for these types of measures. Related, ASHRAE Guideline 14 [9] addresses the technical aspects of commercial building M&V in great detail.

3.4 **IPMVP options**

IPMVP provides four options for M&V. Option A is “partially measured retrofit isolation,” where many parameters can be stipulated. Option B is “retrofit isolation,” where all parameters are measured. Option C is “whole facility,” where data from the utility revenue meters are used to determine savings from all measures combined. Option D is “calibrated simulation,” where, for example, a building energy modeling program such as eQuest [10] is used to determine the savings from one or more measures.

Good savings estimates of simple measures with constant energy usage, e.g. lighting retrofits, can be determined with single power measurements, taken pre- and post-retrofit, and known annual operating hours. Little guidance is needed on determining savings with these measures which use IPMVP option A; and in fact, some utility programs allow prescriptive rebates, with operating hours, fixture wattage, and other parameters all being stipulated. In these cases, nameplate information and a count of the pre- and post-retrofit units is all that is required.

Multiple measures with system, weather, and production interactions may require multi-variable regression analysis, and metering individual measures may not provide sufficient information. Kissock [11] describes methods to perform this complex analysis with relatively simple inputs. The Department of Energy EnPI tool [12] is another example of such regression based analysis. These models typically conform to use with IPMVP option C, using data from the utility revenue meters.

IPMVP option D is intended for use in commercial building simulation modeling, and doesn't have broad application in industrial energy efficiency. Industrial simulation can be done, and is used for some selected industries where the simulation provides significant benefits to production efficiency, output, and other measures. The complexity of doing industrial process simulation for individual facilities makes the endeavor too costly to be justified for energy efficiency programs, so IPMVP option D is rarely used for industrial facilities.

Other measures require data logging at specific intervals over set periods of time. These measures may be small in comparison to the overall energy usage of the facility, have no influence from weather patterns, or be measures where it is relatively easy to access and measure individual energy usage. These measures will use IPMVP option A or B. As mentioned above, M&V plans that use option A may have some parameters logged and others stipulated, either through the use of spot measurements, facility inputs, engineering experience, or a combination of these. Option B requires that all parameters be measured, so data logging is more prolific in option B M&V.

For all M&V plans that use option A or B, proper application of M&V methods can increase the efficacy of measures by reducing the overall M&V costs associated with the measures. However, the improper application of M&V methods can inaccurately estimate savings, thereby either inflating the claimed savings and providing an improper assessment of the project cost effectiveness, or underestimating the savings which reduces the apparent cost effectiveness of the project.

3.5 **The M&V Plan**

The guiding principles of M&V that are set forth in IPMVP are intended to provide reasonable accuracy in the determination of actual energy savings given the many variables that could take place in any energy efficiency project. These principles include; “M&V costs should normally be small relative to the monetary value of the savings being evaluated,” and “Accuracy tradeoffs should be accompanied by increased conservativeness in any estimates and judgments” [5]. To these ends, the M&V plan should consider the cost of any required M&V activities and determine the level of M&V that reduces uncertainty in the savings estimates without unnecessarily reducing the efficacy of the energy savings project.

3.5.1 **The cost of M&V**

Cost savings is not the only goal of energy efficiency projects, but it is usually the most important driver of the projects in the commercial and industrial sectors, so expensive M&V plans can act to reduce the implementation rates of these projects. Quantitative uncertainty analysis can be used to determine the proper levels of M&V that are acceptable for each project, and Mathew [13] has shown that this can be simple to integrate into the planning stages of any energy efficiency project.

Often times, an M&V method is selected and the M&V plan is developed based solely on the measure being implemented, without regard to the cost of M&V compared to the savings of the project. Consider compressed air efficiency projects for example; it is common to see option B selected, with 2 weeks of data logging required regardless of scale or scope. However, the DOE Compressed Air Sourcebook states, “Energy savings from system improvements can range from 20 to 50 percent or more of electricity consumption" [14]. Clearly the electricity consumption of the system is related to the size of the system and the operating hours of the system, so savings available for a compressed air project is related to those variables.

As an example, consider a fully loaded, continuously operating compressed air system with a single 50-hp air compressor. This system may have the opportunity to reduce operating costs by 50%, with an annual savings of around $15,000 (based on $0.065/kWh and $10/kW-mo). A different compressed air system may have the same opportunity to reduce operating cost by 50%, but if the second system is much larger, with a single 500-hp compressor, the savings could be 10 times as much. In these two systems, the same M&V plan might have exactly the same cost, but its impact on the overall project cost might be 10 times greater.

For the smaller system, this could mean that an expensive M&V plan reduces the efficacy of the project to a level that makes the project untenable to the decision makers. For the larger system, the less expensive M&V plan might provide a very high uncertainty level, in terms of dollars. This high cost uncertainty may equal or outweigh the potential savings of the project, making the M&V plan inadequate for the project. Therefore, measurement uncertainty for any M&V plan should also be determined and both should be considered during the proper selection of the M&V plan for each individual project.

3.5.2 **Methods for estimating energy savings**

There are five methods available for determining the parameters needed to estimate energy savings. These are stipulation, spot checking, current logging, energy logging, and power logging. These methods have increasing accuracy and increasing costs, from stipulation with low accuracy and low cost, to power logging with high accuracy and potentially high costs. Since logging energy and logging power require very similar equipment and have similar accuracies over long periods of time, these are considered equivalent for the purpose of determining uncertainty and cost.

Since savings can't be measured, even the most rigorous M&V plan has some uncertainty. Take the case of an M&V plan where all parameters are logged for a full year before and a full year after the implementation of an energy efficiency project. Even when the data is normalized for production, weather, and all other variables that affect energy intensity, the difference between the two measured periods is still an estimate of savings with some error. That error may come from calibration of devices, unplanned outages, equipment maintenance, other production related effects, or any number of other sources. This is the baseline uncertainty.

Less rigorous M&V plans add uncertainty to this baseline, which is referred to as "additional uncertainty" within this paper. Lee [15] showed that stipulating operating hours can add 30% additional uncertainty. The American National Standards Institute (ANSI) standard for voltage gives an acceptable tolerance for utilization voltages of -13% to +6% [16]. Dooley and Heffington [17] showed that actual service factors of electric motors can range from 6% to 109% of rated horsepower, so spot checking of varying loads, or stipulating electric motor loads based on nameplate ratings can add uncertainty of up to 94%. Baldor electric motor specifications show that the power factor of premium efficient electric motors can vary from 11% to 17% across their normal operating range, so stipulating a power factor or spot checking the power factor on a varying load can add this much uncertainty. Based on these added uncertainties, the cost uncertainty associated with a single measure energy efficiency project can be estimated.

3.5.3 **Proper sampling intervals**

As the M&V plan is being developed per the IPMVP framework, special attention should be given to the measures that will be logged per option B and how the logging will be implemented. This is an area where little expertise and significant opportunity for mistakes may exist. The most common mistakes occur with choices of data logging and sampling intervals.

As an example, logging motor energy usage at 1 minute intervals is often required by utility incentive programs when measures use IPMVP option B. This is usually due to a misinterpretation of the actual IPMVP requirements. Section 4.7.3 states; “The method of measuring electric demand on a sub-meter should replicate the method the power company uses for the relevant billing meter” [5]. Further, it specifically states that if the utility uses a fixed 15 minute demand window “the recording meter should be set to record data for the same 15 minute intervals” [5] This section goes on to discuss sliding demand windows and makes the general statement that if a sliding window is used, the demand window can be estimated “…by recording data on one minute fixed intervals…” [5] and then recreating the sliding window during the data analysis phase. Data logging intervals of one minute are mentioned in two other places in the text, once to describe a spot check of a simple measure, and once in the same context as above. The protocol never specifically states that data must be collected at one minute intervals for any practical purpose of determining actual motor energy usage.

In fact, intervals of 1 minute may or may not actually capture the true operating characteristics of some motor operated systems. For instance, an air compressor with load/unload controls may cycle in less than 1 minute, and the data collected at 1 minute intervals may only record the fully loaded or fully unloaded power for significant periods of time. Rather than specifying a data collection rate, data should be collected at the proper intervals to define the dynamic performance of the system.

Alternately, when fine sampling data is not required, a data logger with the ability to oversample (meaning that data is sampled more times than are recorded) and record averages can be selected. These types of loggers may sample data at very high frequencies, but only record the average of those samples to memory at a specified interval. In the case of the load/unload compressor, some data loggers may be able to oversample at 1 second intervals, and then record the average of those readings at 15 minute intervals, giving true average power or true energy consumption. In this case, a graph of the recorded data will not be truly representative of power over time, but will represent average power over time. This is the same methodology that utility meters use, and will produce the same results as using a utility meter.

Several types of data loggers are available on the market today, with different capabilities, accuracies, and considerations regarding ease-of-use. So, proper application of each type or style of data logger relies on a solid understanding of how they work and how they can be applied to measuring power and energy usage. The next section presents a discussion of three types of data logger systems; current loggers, energy loggers, and power loggers.

3.6 **Equipment considerations**

The specific devices that are used to measure and monitor energy, power, and other necessary data for M&V plans should be installed by knowledgeable technicians per the manufacturer's instructions for each device. Installation instructions are typically quite thorough and complete, and equipment manufacturers typically provide support to end users of their equipment as needed.

A review of the literature shows that applications and uses of data acquisition systems have been well documented since the 1970's [18-20]. Data acquisition systems are often permanently installed in an industrial facility, and these are meant to provide real-time data to plant operations personnel. These systems can typically provide data logs that can be analyzed off-line for different purposes and these data should be used whenever possible for M&V activities, since the data is available and adds no cost to the project budget.

Today, portable data loggers are widely used for M&V. These devices can be inexpensive, easy to install and operate, and provide the necessary precision and accuracy for M&V activities. These devices record and store data, which can later be extracted and analyzed. Modern data loggers have significant storage capacity, high sample rates, small size, and high durability. The large number of manufacturers means that data loggers are readily available for most project needs. State equipment loan libraries, utility plan implementers, and utilities themselves may be able to provide data logging equipment for an M&V project without directly adding cost to the project. The choices are many, so it is up to the M&V professional to ensure that the proper data loggers are selected for the project, and that these are utilized correctly.

3.6.1 **Current logging**

Logging electrical measurements is relatively straightforward, and can be accomplished with non-destructive means at a low cost. Current can be logged with a current transducer (CT) and a data logger. The current transformer has been used to successfully measure electrical current since it was patented by Edward Weston in 1888 [21]. The portable data logger is a more modern construct, having been introduced in the 1980's to replace chart recorders with solid-state devices that could capture voltage and current signals and store them digitally.

Typical current transducers are solid core current transformers, split core current transformers, and Rogowski coils. Solid core CTs are commonly used in permanent installations, since they require the conductor to be passed through the center of the device, requiring the circuit to be open while doing so. Split core CTs are the most common transducer used to temporarily measure and log current. These have reasonable accuracies, but their large size and rigid space limitations are a disadvantage. Additionally, CTs have a strict current limitation, and the output signal saturates at that limit, meaning that any current above the limit cannot be determined.

Rogowski coils are another type of current transducer that have arisen in recent years as the transducer of choice for M&V professionals. The Rogowski coil is a flexible transducer which produces a scaled time derivative of the primary signal [22]. This signal requires the data logger or transducer set to have some computational capabilities in order to reproduce the primary current signal in an understandable form. Modern data loggers have all the computing power necessary to perform this function.

The flexible transducer is a major advantage over rigid CTs and is likely the primary reason that technicians prefer to install Rogowski coils. The other major advantage that should be considered is the fact that error in Rogowski coils is a function of the primary current being measured [23], where error in CTs is a function of full scale rated current. This means that CTs must be selected based on the magnitude of the current being measured; a maximum current to ensure that the CT does not saturate, and a minimum current to ensure that CT error is acceptable. Since Rogowski coils do not saturate, the maximum current is limited only by the diameter of the conductor being measured and the minimum current is not a limiting factor since the error scales with current.

One disadvantage that should be considered is the Rogowski coil's need for power to produce a signal that the logger can record. When the Rogowski coil is used as a stand-alone current transducer, it will likely require either battery or 110VAC source. In an industrial setting, this may require an extension cord to be routed from a wall receptacle to the electrical panel with the transducer, and this may very well be unacceptable to the facility operators, not to mention inconvenient to install.

While current logs are valuable to engineers and maintenance personnel, the goal of most electrical M&V plans is to measure energy usage in kWh. Three phase current is related to energy by the formula:

kWh = V*A*PF*sqrt(3)*OH/1000

When current is logged, the other independent variables voltage (V), power factor (PF) and operating hours (OH) can present significant uncertainty.

The uncertainty related to actual operating hours is difficult to manage, since plant employee working hours and equipment operating hours can differ significantly. Lee [15] showed that incorrect assumptions regarding operating hours can affect savings calculations by up to 30%. Luckily, the data logs will provide a very precise representation of the equipment operating hours during the M&V period, and these can be compared to any stated operating hours. Projecting the recorded operating hours over the course of a year is a simple arithmetic problem, producing an estimate of annual operating hours. Holidays and plant shut downs must be considered, since any interruptions in normal activity during the logged period will reduce the logged operating hours and could produce an unreasonably low estimate of annual operating hours. Conversely, if the equipment normally shuts down for some period outside of the logged period, not taking these shut down hours into account could produce an unreasonably high estimate of annual operating hours. Any assumptions regarding operating hours should be clearly stated and justified in the M&V report.

Voltage, particularly in an industrial facility, can vary during the course of a normal day as plant equipment loads change, HVAC loads change with temperature, or utility grid loads change for various reasons. The Western Systems Coordinating Council (WSCC), a group of 86 western utilities, requirement for utility supply voltage stability [16] gives some tolerance on voltage supplied by the electric utility. Without logging voltage over time, it is impossible to precisely determine the power, and thus energy usage of any piece of equipment. However, if the logged equipment is small relative to the size of the transformer supplying power to it, and if the supply voltage is "stiff,[1]" it is reasonable to check voltage when the data logger is deployed and use that voltage reading for the energy calculation. If additional voltage readings can be taken when the logger is removed or during the logged period, these can be used to estimate the average voltage. Any assumptions regarding voltage should be stated and justified in the M&V report. Note, it is rarely reasonable to assume that the operating voltage is equal to the nominal supply voltage.

Power factor is a measure that is difficult to obtain without the proper measurement. Since this is a derived measurement, a power meter or power monitor that simultaneously measures current and voltage is required to determine power factor. Without this type of meter, current and voltage measurements can be taken separately but simultaneously, and then the power factor can be calculated, but the math involved is difficult and likely beyond the scope of most M&V technicians. Power meters are available from several manufacturers at prices ranging from a few hundred to several thousand dollars, and at least a simple power meter should be part of any electrical M&V technician's toolbox. It is easy to state that power factor is assumed to be 80% or 90%, but this is rarely correct and can introduce significant error into the annual energy calculation, since power factor linearly influences the calculation.   It is sometimes possible to obtain a reasonable estimate of power factor of a specific motor by estimating the load factor and referencing the manufacturer's data sheets for that motor. Motor load, age, and maintenance practices can significantly change the actual power factor from the

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[1] Ieeexplore.ieee.org, IEEE Standards Dictionary: "The ability of an area electric power system to resist voltage deviations caused by a distributed resource or loading."

manufacturer's stated values. A low estimate of power factor is more conservative, and barring any other means to obtain actual power factor, a low estimate should be used.

3.6.2 **Energy logging**

Energy logging began in the late 19th and early 20th century as electric utilities needed a way to charge their customers for the services that they rendered, namely providing cheap, reliable electricity to homes and businesses [24]. Utility grade revenue meters are permanently installed on the electrical service, and provide a measure of energy used. Originally, this meant that a dial would increment as a unit of energy was consumed, and this dial had to be manually read for billing purposes. Modern smart meters can transmit data, which can be read in real time, and have the ability to measure energy, power, and other parameters.

Logging energy "directly" actually means logging volts and amps, and using those measurements to calculate power factor and power, and then calculating energy based on power over time. The energy logger apparatus will include, at a minimum, a current transducer, a voltage lead, and a data logger. On three phase systems, there will be 3 or 4 sets of transducers and leads, and these can either be attached directly to the logger, or attached to an "integrator box" that does all of the math and sends out energy measurements as "counts" or "pulses." Energy or "kWh" logger sets with Rogowski coils typically use the voltage leads not only to measure voltage, but also to power the Rogowski coil wave form generator circuit, eliminating the need for an external power source. The energy used by this circuit is usually very small compared to the energy being logged, and can therefore be neglected, or compensated for in the energy measurements [23].

This type of logger/transducer can be very accurate over long durations, but can be very inaccurate over short durations. It is common for these transducer sets to have selectable dipswitches that can be set to record a “count” or pulse at 1kWh, .5kWh, .25kWh, or .1kWh intervals. When using this type of device to measure data at 1 minute data intervals the individual data points can be wildly inaccurate.

For example, if a continually operating, fully loaded 20-hp load is logged at 1 minute intervals with a pulse type kWh meter that is set to record 1 pulse per 1 kWh, the data set does not accurately represent the actual energy usage. In fact, the data appears to show that during many of the 1 minute intervals, no energy is used. This obviously is not the case, since we know that 20-hp, or 14.92 kW is being constantly required. Figure 3.1 shows the pulse type meter data overlaid with the actual energy consumed.

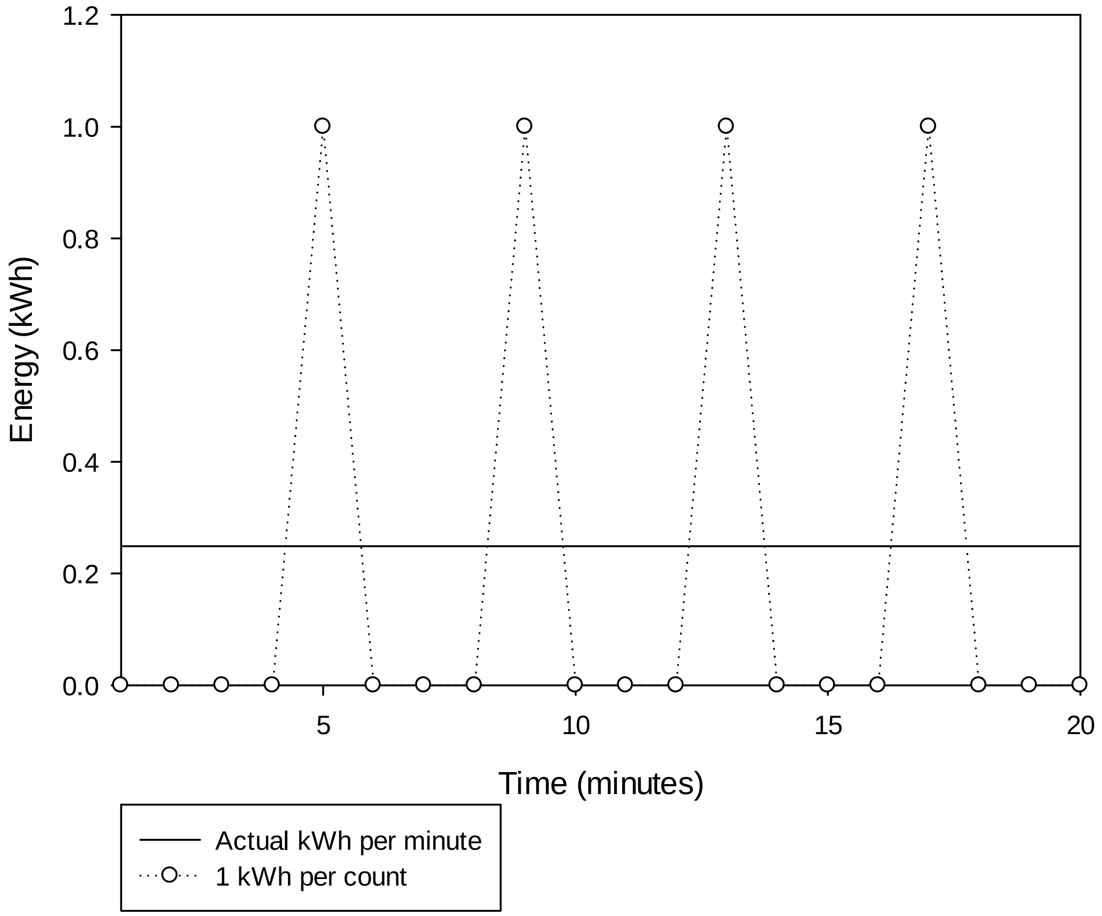

Figure 3-1: 20 hp_e constant load energy consumption. Actual versus 1 kWh/pulse metered data.

The actual energy consumption during each 1 minute interval is 0.249 kWh. For this configuration, the pulse type meter only increments the count after a full kWh is consumed, so during the first four intervals the reported energy usage is zero. At the conclusion of the 5th interval, the actual energy usage has been 1.243 kWh, so a count of 1 is recorded during this interval. The 0.243 energy usage is carried over to the next interval, and zeros continue to be recorded until the 9th interval, when the 2nd kWh is consumed and another 1 count is recorded. The process continues, recording 1 count each time a full kWh is consumed.

Many of these pulse type energy transducer sets have the ability to report counts in finer increments. For instance, it is common to see dip switches on the current transformer that allows energy to be reported as 1.00, 0.50, 0.25, or 0.10 kWh per pulse. At the highest setting of 0.10 kWh per pulse, the data for the above case would show 1-minute interval usage of 0.2, 0.2, 0.3, 0.2, and 0.2 kWh for the first 5 intervals. This data is shown in Figure 3.2.

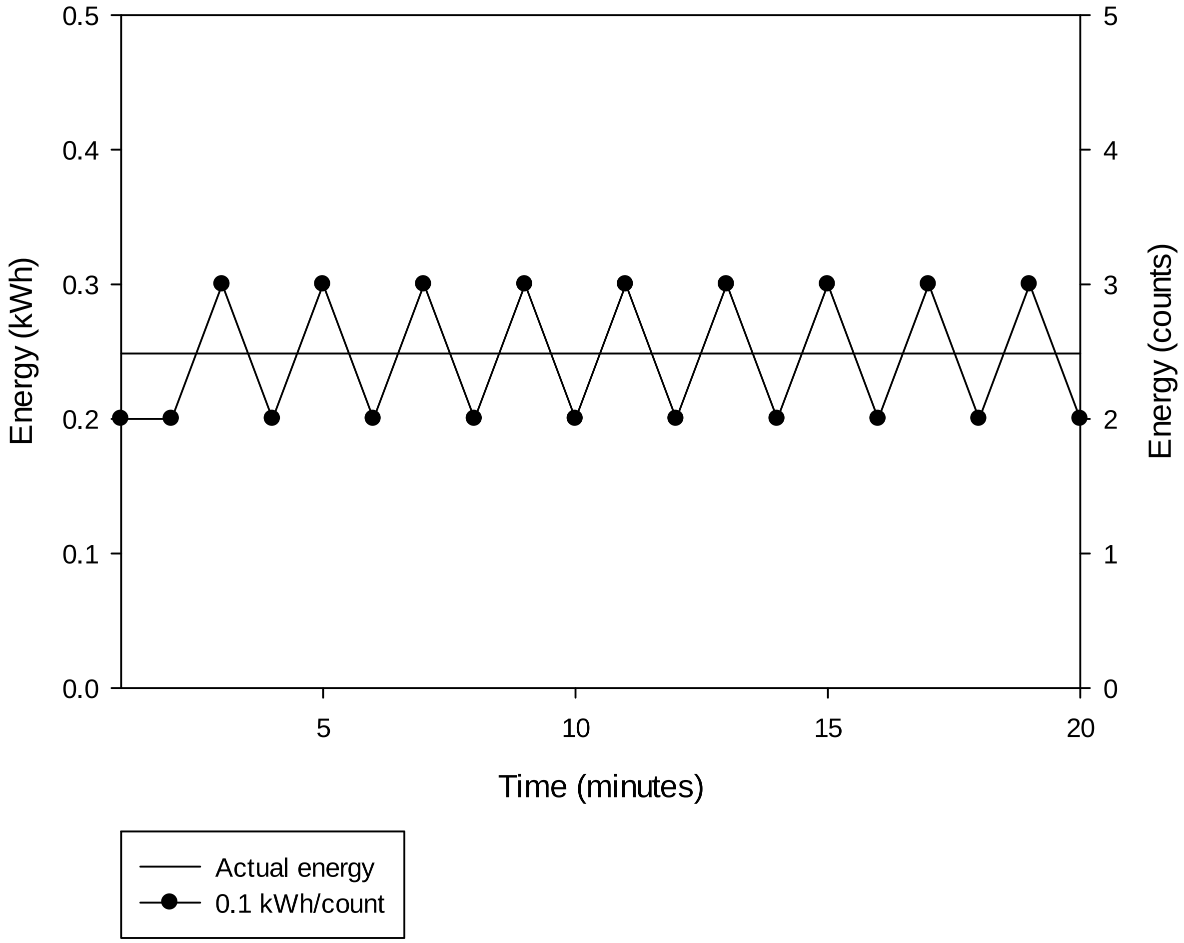

Figure 3-2: 20 hp constant load energy consumption. Actual versus 0.1 kWh/pulse metered data.

Since no additional data is recorded by this style of transducer, it is easy to mistake this data for being representative of power over time. If the data above is mistakenly converted from the apparent unit of kWh/minute to kW, the resultant power curves do not accurately reflect the true power being consumed. The three cases are shown in figure 3.3.

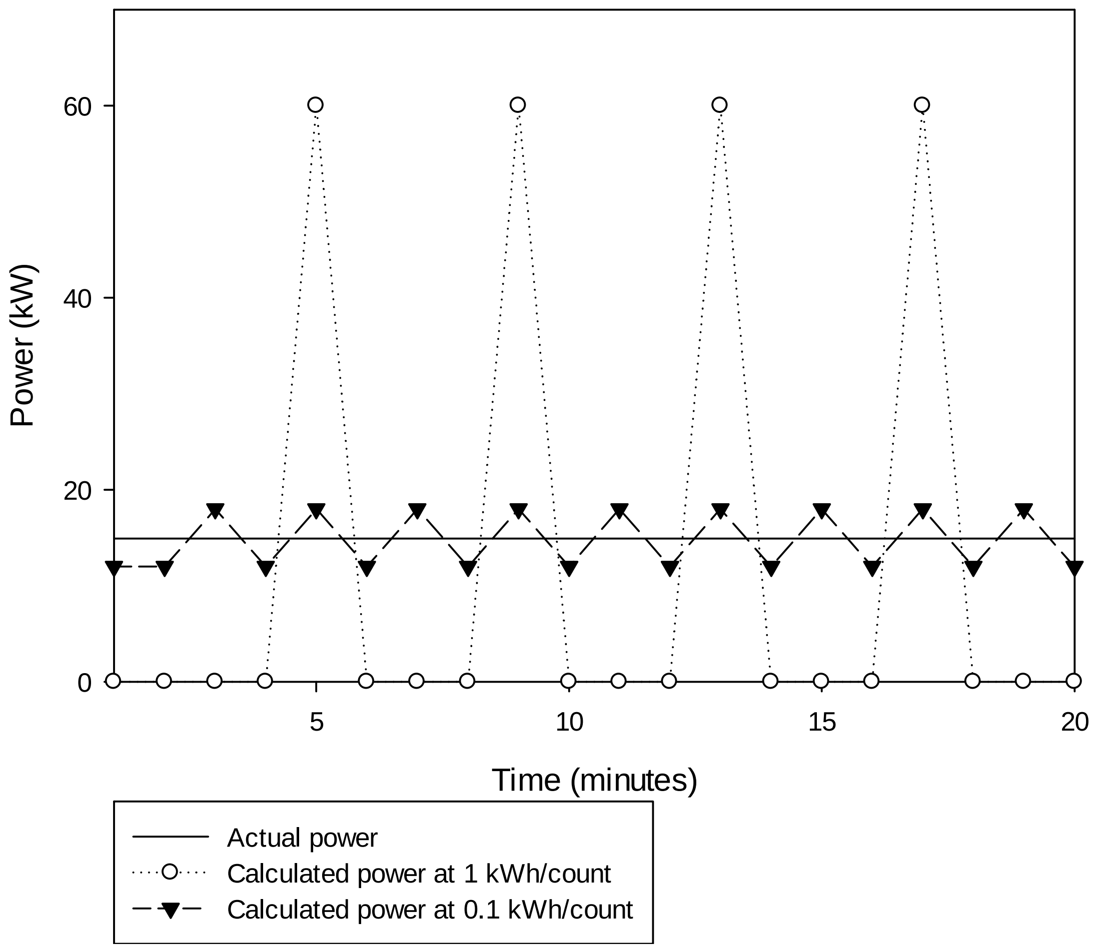

Figure 3-3: Power versus time for 20 hpe constant load.

The 20 hp constant load presented above is provided for illustrative purposes only, and is not intended to represent a real world example. Let us consider the real case of a 100 hp air compressor being data logged for M&V purposes. This compressor may have a varying load that peaks at around 78 kW when the compressor is fully loaded, and may have a low load condition of around 30 kW when the compressor is idling. This compressor may also shut down on nights and weekends. A possible log of the actual power versus time, in 15 second intervals, over a period of 2 hours is shown in figure 3.4.

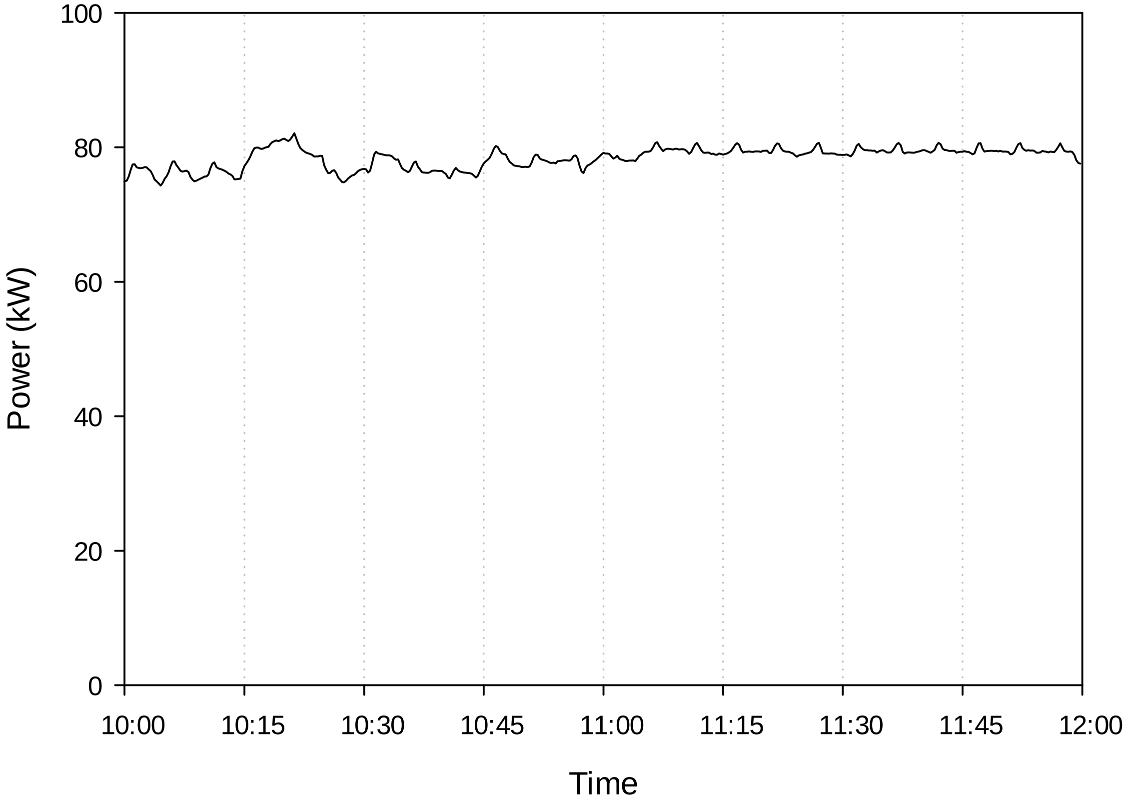

Figure 3-4: Directly logged power for a theoretical 100 hp air compressor over a 2 hour time period.

A counting meter, set to record 0.10 kWh per count at the same 15 second intervals, would provide the following data log for the same period (Figure 5):

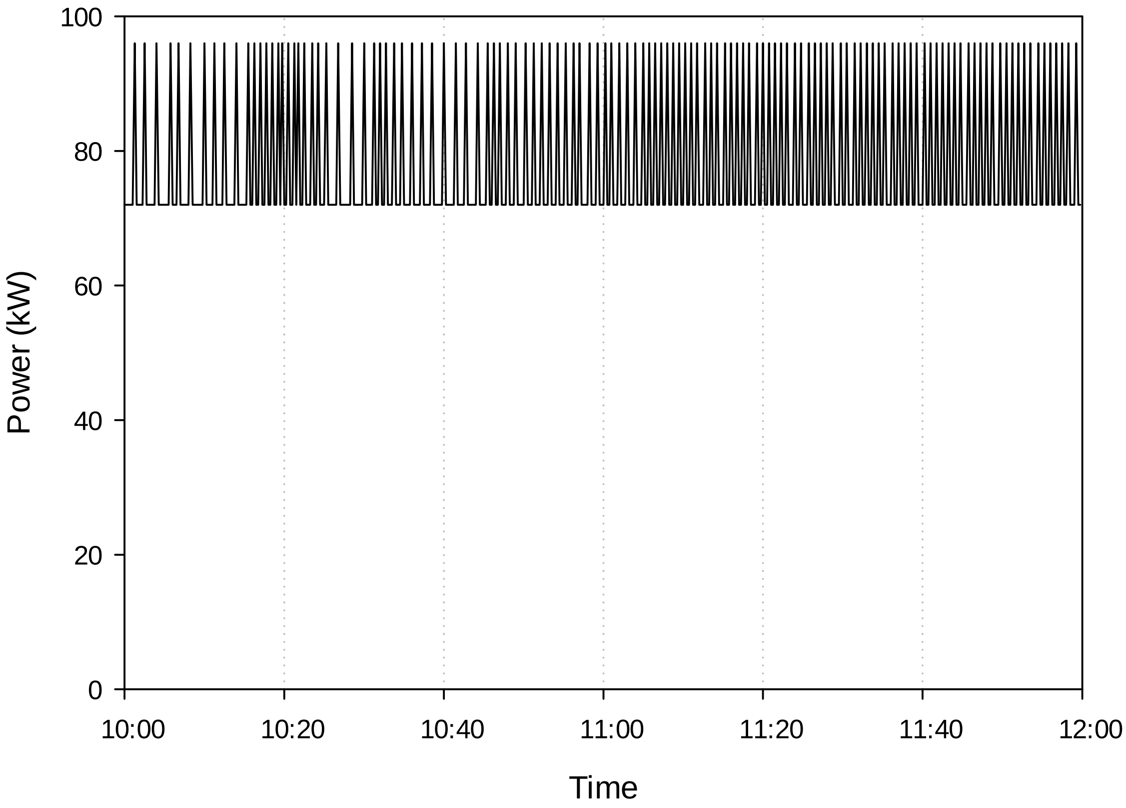

Figure 3-5: Indirectly logged power data for the same compressor, converted from a pulse type logger recording at 0.1 kWh/pulse at 15 second intervals.

The energy calculated from the power data in the 2 hour period is 157 kWh. The energy calculated from the pulse type energy logger is also 157 kWh, showing that over time the two methods are equivalent. However, looking at 1 minute intervals the story is much different, with the power logger showing an average kW for the first minute of 75.6 kW (which is correct), and the energy logger counting 12 pulses, which is equivalent to 1.2 kWh/minute or 72 kW average power. This is a difference of 4.7%,

Longer time intervals of 5 and 15 minutes can be analyzed to show that the pulse type meter is more accurate over longer intervals. In the first 5 minute interval, the kW logger shows an average power of 76.1 kW, and the pulse meter records 63 pulses which is equivalent to 75.6

kW, a difference of 0.7%. In the first 15 minute interval (a common utility demand window), the kW logger shows an average power of 76.2 kW, and the pulse type logger records 190 pulses which is equivalent to 76.0 kW, a difference of 0.3%. Data for the various logger types and settings are presented in Figure 6 for comparison.

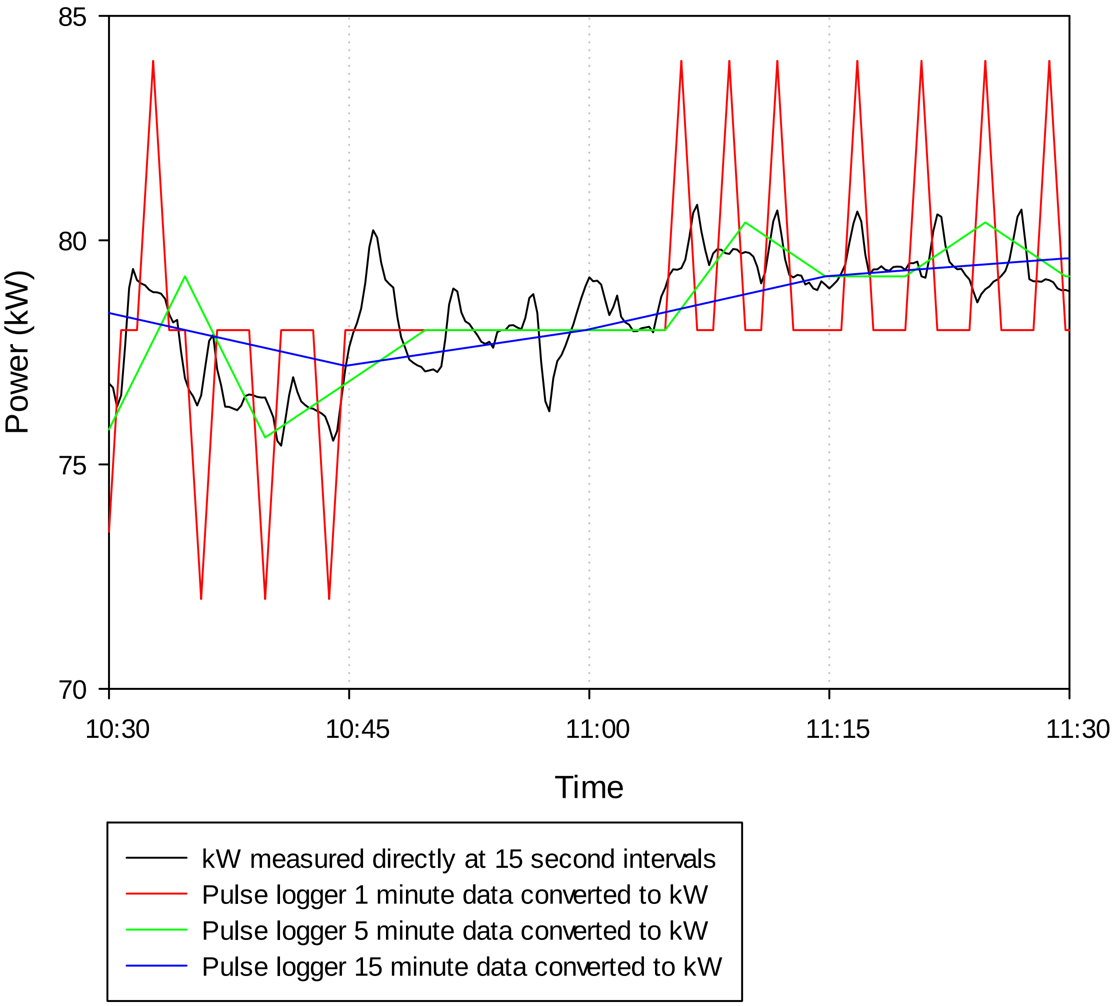

Figure 3-6: The same data from figures 4 and 5 overlaid with 5-minute and 15-minute pulse logger data converted to kW. The data period in this figure is one hour of the total data from the other figures above.

If the data is to be used for simply estimating energy usage over the course of a year, the error in each short time interval is inconsequential, since the total energy over the logging period is very accurate. If the data is to be used for additional energy auditing and analysis purposes, the short time data provided by a pulse type logger may provide very little insight and may not be useful to the auditor at all.

3.6.3 **kW logging**

Directly logging power is a third option, which is preferred in almost every scenario, if economically feasible. Power loggers are relatively new, and have arisen as computing power and storage have increased dramatically while costs have dropped in the modern computing era. While energy loggers store kWh readings, power loggers store instantaneous kW readings, as well as kWh and other useful information that is calculated from volts and amps.

The kW logger set up is similar to the kWh logging apparatus, with a current transducer, voltage leads, and a data logger. The exception is that these loggers typically do not have an integrator box or other electronics that are separate from the data logger, so the current and voltage information is logged directly without the use of “counts” or other representative measures. Since power in kW is derived from voltage and current, this type of logger can produce a very accurate representation of power over time as well as total energy used.

Power loggers that can record multiple channels, including measured voltage, measured current, calculated power factor, calculated power, calculated reactive power, and other measures are useful. These loggers have only recently become available, due to the memory requirements of logging multiple channels. The benefit is that the actual current over time data is stored in the logger, which is exactly the same as that recorded by a simple current logger described previously, as well as the actual measured voltage over time. This reduces any uncertainty introduced by spot checks of voltage, or assuming a constant voltage.

Since the data points used to calculate the derived values of PF, kW, kVAR, and other measures are stored directly, the data can be much more accurate over short intervals. One tradeoff is that the number of recorded data points is multiplied by the number of channels, so data sets can be much larger and require more computing power to analyze. Modern desktop and even laptop computers should have the ability to handle large amounts of data, so with relatively inexpensive updates to computing hardware this should not be an issue.

Another consideration is that the cost of these modern kW loggers may be many times higher than a comparable current logger. Organizations that perform significant M&V activities should find that this increase in first cost will reduce the long-term cost of data analysis, since all of the relevant data is collected and available.

3.6.4 **Equipment and deployment costs**

The logging equipment types described above are rapidly evolving, with data storage capacity and wireless data transfer capabilities increasing dramatically over the last few years. The costs of the individual pieces of equipment may be subject to change, and certainly will not remain constant over time. To the extent that equipment cost factors in to the cost of M&V, several observations are warranted. First, measuring devices are essential for the M&V professional, and while cost is important, no M&V can be performed without these devices. The minimum M&V professional toolkit must include devices that can measure voltage, current, and power factor; or power directly, as well as some type of data logger with the same capabilities. The data logger types discussed above can have a wide range of prices, with current loggers (including small battery powered data logger and current transformer) costing a few hundred dollars, and energy/power loggers costing at least three times as much (since 3 current transducers are required). These costs may be factored in to the cost of an M&V plan, if necessary equipment is not available. Additionally, if logging energy or power directly reduces uncertainty, then the purchase of more advanced data logging equipment may be warranted. Since this equipment is durable, the cost of equipment may be amortized over several M&V projects.

The long term cost of M&V activities should include labor costs, as qualified technicians (such as electricians) must deploy the devices in a safe and effective manner. The cost of M&V activities should also include engineering time, since calculations are required to determine the annual energy usage of the equipment before and after the measure is installed. Table 3-1 below shows the estimated additional cost of M&V activities, using the case where all parameters are stipulated as the lowest cost scenario. In other words, M&V cannot cost less than the case where everything is stipulated and nothing is measured. This baseline (stipulated) also presents the highest amount of uncertainty. The estimates assume that the technician already has basic tools for measuring volts and amps. The cost of purchasing a device to measure power factor and any data loggers is added to the M&V cost for the project. Technician time is estimated as $50 per hour, and engineering time is estimated as $100 per hour.

Table 3-1: Estimated cost for different M&V activities and equipment. The stipulated value scenario represents the baseline case with no added cost. This does not imply that the activity is free of cost, but that no additional costs are incurred.

Category	Stipulate	Spot check	Current log	Power/Energy log
Equipment cost	-	$900 power meter	$900 power meter + $200 current logger with transducer	$2,500 power logger with transducers
Technician time	-	$50	$100	$100
Engineering time	-	-	$200	$200
Total	-	$950	$1,400	$2,800

Since measurements are taken on plant equipment, often while the equipment is operating, the time required to obtain any necessary permissions, dress in the appropriate protective gear, open electrical panels or cabinets, and restore the work area to a safe state afterwards can be significant. The actual time to install the measurement device(s) is small in comparison. While it may take substantial planning to schedule and prepare for a data logger installation, the actual installation typically only takes a few minutes. This is true for spot checks, single phase current logging, and three phase energy/power logging alike. In Table 3-1, this is estimated as 1 technician labor hour to perform all of the necessary functions to acquire one spot checked power measurement. Assuming that the technician did not already own a power meter, this activity would cost $950 more than stipulating all paramaters, but may reduce the additional uncertainty by a great amount.

The cost difference between spot checking of measurements and deployment of data loggers, from a labor perspective, is due to the need for the data logger to be both deployed and be removed once the logging period is complete. Again, the time to actually remove the device is very small in comparison to the time the technician must take to do it safely and properly.

Engineering calculation also requires some minimum, or baseline, amount of time and effort regardless of the method used to determine the parameters. Stipulating all of the parameters, therefore, represents the zero added cost scenario. Spot checking of measurements provides single values for the parameters (such as volts, amps, etc.), so the calculation time for this scenario is similar to stipulation of parameters. Data logging typically requires analysis of large data sets, which can take several hours to several days, depending on the amount of data. For the purpose of comparison, a single measure project with a single data logger deployment should generate a single data set, which may take two hours to interpret. In Table 3-1, a scenario where one current data logger is deployed would cost an estimated $1,400 more than the case where all parameters are stipulated. The case where one power logger is deployed would cost $2,800 more than the case where all parameters are stipulated

These estimated additional costs can then be used, along with the estimated additional uncertainties presented previously, to determine which M&V method is most cost effective for a particular energy efficiency project.

As an example, consider a compressed air project with an estimated savings of 100,000 kWh annually. At $0.10/kWh, this represents an annual savings of $10,000. Stipulating all parameters may have additional uncertainty that is very high. Simply stipulating operating hours can add 30% uncertainty to the savings estimate, or $3,000, which should rule out stipulation of all parameters as well as spot checking, which requires stipulation of operating hours. Data logging current requires that voltage and power factor be spot checked, which adds 16.5% to 22.9% additional uncertainty, representing up to $2,290, for a cost of $1,400.

Logging power (or energy) reduces additional uncertainty to zero, for a cost of $2,800, or about $1,400 more than logging current. In this case, logging power directly reduces uncertainty by $2,290 for a cost of $1,400. Determining if the benefit is worth the cost is left to the reader, recognizing that the cost of purchasing some of the required equipment might be neglected or amortized over several projects.

3.7 **Conclusions**

Measurement and verification of energy savings has been and will continue to be an important activity for energy managers, government agencies, building owners, and utility representatives. Understanding the M&V process, the importance of the M&V plan, the limitations of the M&V equipment, and the process of determining energy savings are keys for a successful energy efficiency project.

M&V plans should follow the IPMVP framework, taking into consideration the cost of M&V activities and the potential reductions in uncertainty related with different levels of M&V. Estimates and judgments should be sufficiently conservative with regards to the accuracy of the M&V methods that are specified.

Finally, logging electrical data as part of IPVMP option A and option B M&V plans can be accomplished with several available styles of data loggers, and each of these styles has advantages and limitations. Current loggers are inexpensive, but care should be taken to measure voltage and power factor appropriately. Pulse style energy loggers can provide simple long term measurements of consumed energy, but should not be used to collect short-time interval data, as their accuracy in short intervals can be poor. Loggers that measure and record current and voltage, and then calculate other measures such as power factor, power, and kVAR are more expensive, but can provide accurate data for both short and long intervals.

Understanding these complex but necessary concepts can provide a high degree of confidence in energy savings projects.

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4 Unit Operation Energy Intensities for a Poultry Broiler Processing Plant

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4.1 **Abstract**

Energy use for poultry broiler processing plant was analyzed using available monthly utility bill information, utility-provided 15-minute interval data, and short-term 30-second submetered data at the unit operation level. Energy intensities were determined in terms of the whole plant and unit operations, and both compared to three broiler processing plants operated in the late 1970s. It was found that secondary utilities, including water chilling, ice making, and compressed air, are the largest energy consumers in the process, followed by Offal, RKP, and Evisceration. On a total energy (MMBtu) basis, natural gas usage for steam generation by boilers was higher than site electricity consumption. Overall, the total annual energy intensity was found to be 2.46 MMBtu/1000 head of broilers processed. The largest opportunities for reducing energy intensity exist in the process refrigeration and hot water generation systems. Finally, it was concluded that measuring and tracking energy intensity on a unit operations level provides valuable insight into how energy is used, how that compares to similar facilities, and potentially where to target energy efficiency efforts.

4.2 **Introduction and Background**

Growing concern for resource management and climate change has led to focus on energy use and conservation in energy-intensive industries, such as steel, aluminum, petroleum refining, glass, etc. In the United States, about one third of all energy is used by the industrial sector [1]. Food-related energy use has remained a substantial share of the total national energy budget, with a significant increase from 12.2 % in 1997 to 15.7% in 2007, representing an annual average increase rate of 8.3 % [2].

Poultry production and processing has grown steadily over the past 5 decades, with the domestic consumption of chicken meat per capita increase of 200% from 1960 to 2011 (from 19.2 pounds in 1960 to 58.5 pounds in 2011)[3]. Vertical integration and the uniformity of commercial poultry have allowed poultry processing plants to develop into highly automated facilities characterized with larger plants and faster processing line speeds. By 1992, more than 80 percent of all chicken products were produced in large plants employing more than 400 workers [4]. Energy represents the third or fourth largest operating expense in poultry processing plants, behind labor, chickens to be processed and possibly the interest on money [5]. The energy efficiency in the production cycle, as well as the cost of energy, consequently has a large impact on not only the competitiveness of the individual company, but also the environment, including greenhouse gas emissions and air pollutants.

Despite the production efficiency, the broader implication of the material and energetic intensity of US broiler production from a supply chain perspective is largely unaddressed. Data for the relevant material and energy inputs associated with the production of poultry feed ingredients, feed milling, on-farm production, hatchery chick production, processing and transportation are either limited or outdated [6, 7]. Significant literature has been produced in recent years regarding the energy intensity of other industries [8-13]. The energy intensity of agriculture and food systems has been researched at a global level recently [14], but broiler production energy intensity is not found in recent literature.

Energy consumption and costs in broiler processing were reported in numerous studies in the 1970s and 1980s [6, 15, 16]. Electrical usages were determined based on equipment survey of three processing plants, with name plate data and operating times of each piece of electrical equipment collected, ampere readings obtained on selected motors (Whitehead and Shupe, 1979). Refrigeration, used for chilled water and ice making, and other mechanical drives accounted for more than 80% of the total calculated electrical use.

Using multiple regression techniques, Jones and Lee (1978) analyzed monthly utility bills of 11 broiler processing plants in Georgia and Alabama with different plant size, machinery components and operating procedures. The results showed that volume of poultry processed, contributed by the size of the plant and capacity utilization, was the most important factor affecting electricity consumption (inverse relationship), while ambient temperature was inversely correlated with the fuel consumption.

Brown and Lee (2007) reported the operating efficiency of five southern processing plants, ranging from 498 Btu/lb to 1,761 Btu/lb of processed weight. They also identified chillers, water heater and boilers as the largest energy users, and opportunities to reduce refrigeration and other process improvement, such as burner maintenance, heat recovery, more efficient lighting.

Energy conservation opportunities were evaluated and/or demonstrated in areas such as shell-and-tube heat recovery system from a refrigeration system[17] , heat pump/heat recovery system from a refrigeration system[18] , economizer on flue gas of steam boilers (AlQdah, 2010), etc.

Poultry processing consists of live bird holding, hanging, slaughtering, scalding, defeathering, eviscerating and chilling, grading, cut-up and packaging. Some processing plants conduct further processing to prepare value-added, convenience foods for consumers. Electricity is used for refrigeration, conveyors, lighting, air conditioning, pumps, compressed air and other mechanical drives. Fossil fuels are used for production of steam or hot water for processing and sanitation, as well as space heating. General diagrams of unit operations with their energy input and outputs are shown in Figure 4-1.

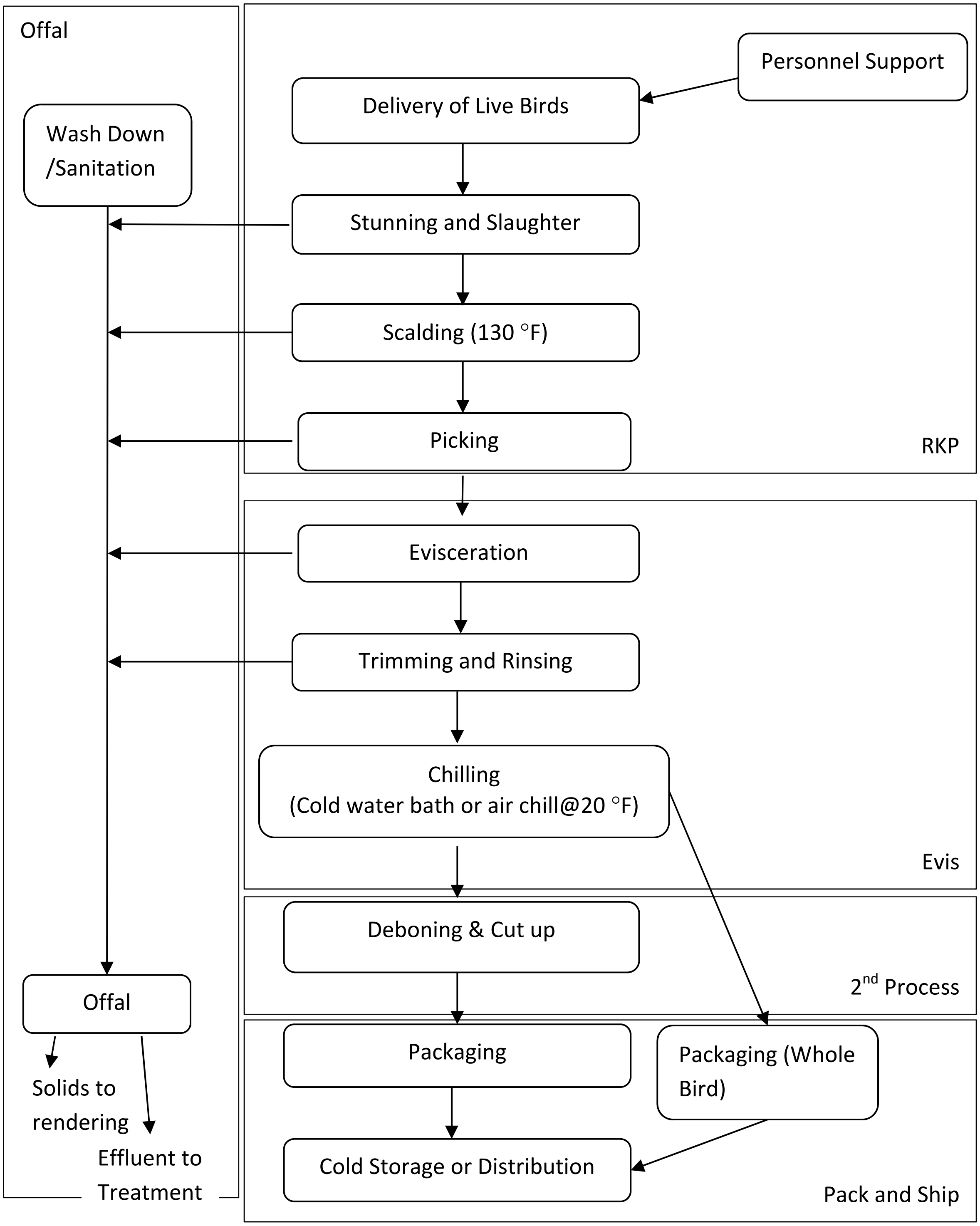

Figure 4-1: Unit operation flow chart of a typical broiler processing plant.

Efforts have been made to quantify energy use and greenhouse gas emissions from food production sectors [19-21]. Before significant reductions in energy consumption can be realized, it is necessary to have a complete understanding of the operations from an energy use perspective.

This paper describes, in detail, the process of characterizing energy use at a typical broiler processing plant via energy intensity metrics at the unit operations level. This study included six steps, which were: 1). perform a whole plant assessment to gather operations data/information; 2). perform a utility analysis for both energy sources – electricity and natural gas; 3). collect and review, from local electrical utility, available metered interval data; 4). develop a unit operation level sub-metering and implementation plan; 5). perform sub-metering data analysis, and 6). compute unit operations level energy intensities.

Further, the paper compares, when possible, the energy intensities discovered in this study to previous studies in the literature. The primary objective of this study was to survey and characterize energy uses in a typical poultry processing plant.

4.3 **Materials and Methodology**

In June 2012, a poultry processing company agreed to participate in the study. After consultation, one of the company’s poultry processing plants was selected for the study. The plant processes live birds and packages front halves, saddles, and leg quarters for finish processing at a nearby plant. Approximately 12 trips were made to the plant during the study period of June 2012 through October 2013.

4.3.1 **Utility Analysis**

Utility bills for this facility were gathered for a recent 12 month period directly preceding the study. These bills were re-calculated and analyzed for several purposes. First, the investigators understand the need to verify the accuracy of the bills. While billing errors are rare, these could impose a significant error to the data analysis presented in this paper. Second, the investigators needed a baseline understanding of the scale of energy and power being used in this facility, in order to develop the data logging methodology and deploy the equipment. Finally, in order to calculate costs and dollar savings from energy efficiency measures, the investigators must understand the average and marginal costs of energy and demand at the facility.

4.3.2 **Unit Operations and Schedule**

The next task included a detailed discussion with plant engineers regarding plant operations. This also included a review of plant drawings and processes. This step defined the plant operating schedule (Figure 4-2) and processing operations. Furthermore, this review helped define the scope of the portable data logger deployment, by locating the boundaries of service for electricity and fuels throughout the facility.

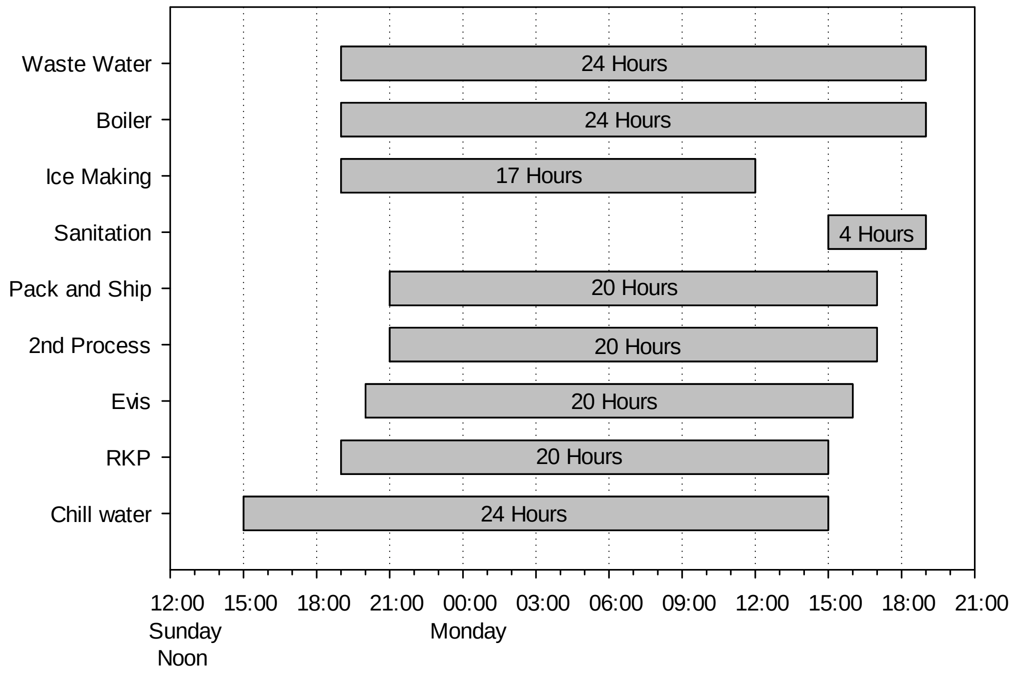

Figure 4-2: Typical production schedule for each primary unit operation and other support systems. Note that RKP is Receiving, Killing, and Picking.

Based on the above described discussions, physical layout, and other factors, distinct processing operations were grouped into unit operations. Each are defined below.

<u>RKP</u> – Receiving, Killing, and Picking. This includes energy from the time the birds enter the building until the feathers are removed from the carcass. This includes live hanging, stunning, killing, bleed out, removal of head and feet, scalding, and removal of feathers. Only electrical energy is included in this unit operation, as steam and hot water used for scalding is included in utilities.

Evis – Evisceration. This is the removal of internal organs from the carcass, including the hock, heart, lungs, liver, gizzard, kidneys, intestines, and all other internal organs. When the carcass leaves Evis, it is ready to be packaged as a whole broiler. This also includes separating the heart, liver, and gizzard for use as a food product, and moving the carcass through the bird chiller. This does not include the energy required to produce chilled water for bird chilling.

Offal – Pronounced as one word, but meaning "off fall," this operation refers to everything that "fell off" the bird. This is the transport of waste from the previous operations. Waste products are moved out of the RKP and Evis areas and either sent to rendering or waste water treatment. Vacuum pumps, water pumps, augers, and conveyors are major energy users in this operation.

2nd Process – This is the sorting and partial cut-up of carcasses. Whole carcasses are moved from Evis, weighed, then sorted for size. The front half is cut from the carcass and sent to another facility for further processing. The saddles are either sent out whole, or cut into halves or quarters before being packed for shipping.

Pack and Ship – The cut up carcasses are packed in totes with ice for transport to further processing facilities located off-site.

Utilities – This includes all boiler, chiller, and compressed air energy required for the other unit operations. The steam required for making hot water, scalding, and other uses are included in this operation. The ammonia chillers required for bird chilling, space conditioning, freezing, and ice making are included in this operation. The air compressors and other auxiliary equipment are included as well.

4.3.3 **Electricity and Natural Gas Supplies, Meters, and Interval Data**

Fifteen minute interval data were provided for the master electrical meter for the months of August 2012 and January 2013. A sample plot of these data is provided in Figure 4-3. The monthly electricity use data for this facility was provided to the investigators as well. The monthly average demand for this facility was about 2.6 MW, with some seasonality based on outdoor temperature, which can be primarily attributed to the cooling load of the facility. Winter month peak demand was around 2.2 MW, where summer peak demand approached 3.0 MW. Energy usage was highly dependent on production load, with periods of low production coincident with lower monthly energy usage, as could be expected. The facility consumed approximately 14.3 Million kWh during the 12 consecutive month period that was analyzed.

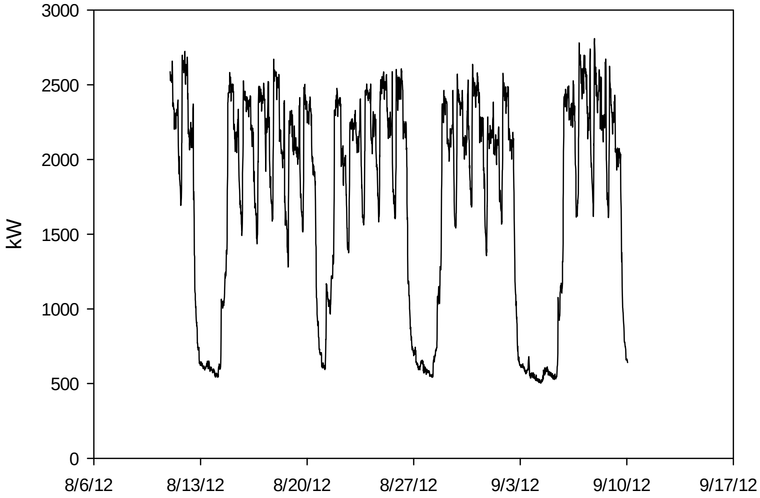

Figure 4-3: Whole-plant summertime electricity demand interval data, August and September 2012.

The natural gas meter for the processing facility is also a master meter. It provides natural gas to the space heating furnaces in the main processing building as well as the equipment in the boiler room. Some additional space heating equipment is also served by this master meter, but the scale of this equipment is very small compared to the boilers and large air handlers, so these were neglected. No short-time interval data were available for natural gas consumption; only monthly utility usage was provided. Average monthly natural gas usage was 9,500 MMBtu, with a strong seasonality correlation to outdoor air temperature. Natural gas usage in the summer months was about 50% of peak natural gas usage in the winter months. The facility consumed approximately 114,000 MMBtu of natural gas during the 12 consecutive month period that was analyzed.

4.3.4 **Submetering Data Plan and Analysis - Electricity**

A detailed review of plant electrical drawings was performed by the facility engineering group, and a list of main taps, their capacities, and locations was provided to the investigators. The logging equipment was sized to handle the maximum load of each of the main taps. Based on the cost of the equipment and the number of necessary data logging locations, the electrical submeter logging process was split into three separate measurement intervals. Each interval was scheduled for two weeks in duration.

Once the data logging equipment was available, field engineers and plant electricians installed these loggers. At each main tap, while the facility was running at near full capacity, a power monitor was also used to determine the actual full load current, voltage, and power factor. Voltage taps that had a current imbalance of more than a 5% were logged with three phase loggers. Taps that were balanced were logged with single phase loggers. Figure 4-4 is an image of current transducers deployed on an electrical subpanel.

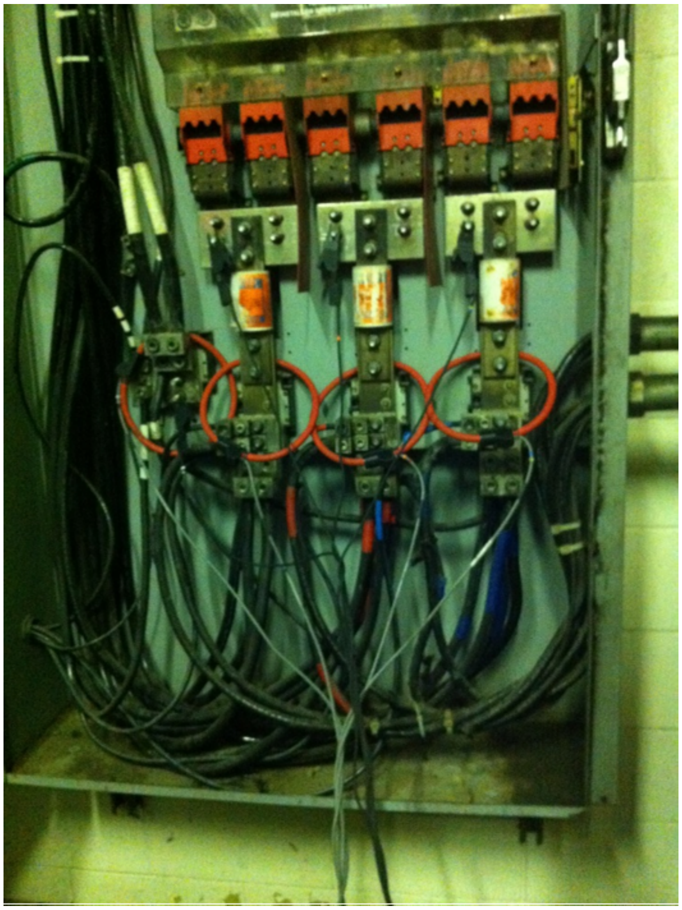

Figure 4-4: Data logger transducers deployed at electrical panel. Photograph by A.C. Harding, used with permission.

Data loggers and transducers were selected based on the maximum current carrying capacity of the circuit being measured. Each main tap has a maximum current rating, and transducers were selected or procured to handle the maximum current of each circuit. For Instance, if a tap had a maximum current rating of 2,000 Amps, the transducer that was selected for that circuit also had a current rating of 2,000 Amps or higher. Upon deployment of the data loggers, it was noted that the actual peak current of many of the circuits was significantly lower than the maximum current rating of the circuit. This allowed the use of smaller physical transducers, which was preferred, due to limited space inside electrical panels.

The loggers were first deployed onto the largest capacity taps. The largest equipment in the facility, as a group, was the ammonia chillers. The load on these chillers varies somewhat (e.g., seasonally) and the average temperatures during the first logging period was a reasonable representation of the average yearly temperature of 60.3 F[2], with daytime temperatures in the 70's F and nighttime temperatures in the 50's F. This deployment captured most of the utility unit operations which included water chilling, ice making, and space cooling.

When the two week logging period concluded, the second deployment commenced, which included the taps for much of the Receiving, Killing and Packing (RKP) unit operations, and all of the Evisceration (Evis) and Offal unit operations. The second data collection interval concluded 2 weeks later.

The third data logging interval commenced several weeks after the second interval concluded. This interval included logging the remaining RKP unit operations (cooling shed), all of the second processing operations, all of the pack and ship operations, and the remaining utility operations (waste water treatment and boiler room).

At the conclusion of the third data logging interval, the operating voltage, current, and power factor were again checked with a power monitor to ensure accuracy and to estimate the effect of temperature on the electrical readings. These measurements were taken in late January, when the daytime high temperatures were in the 30's F and the overnight lows were in the low

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[2] http://www.weather.com/weather/wxclimatology/monthly/72761

20's F. These measurements were consistent with the first set of measurements, showing that seasonal temperatures have little effect on operating electrical energy, with the exception of the chillers. Therefore, the logged data were combined across the whole plant as submetered data.

4.3.5 **Submetering Data Plan and Analysis – Natural Gas**

The boilers at this facility are three similar 300hp fire tube package boilers. Two boilers are normally running, with the third boiler on standby. Measurements of natural gas usage were taken over the course of several production days and one weekend. Figure 4-5 shows the measured boiler input energy in 15 minute intervals.

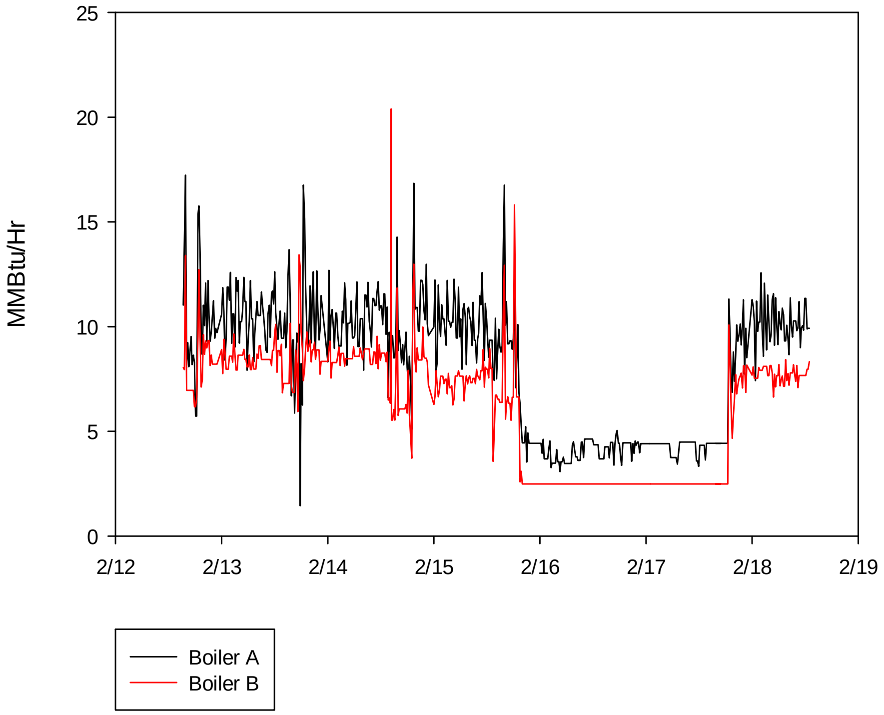

Figure 4-5: Natural gas consumption rates every fifteen minutes for the two operating steam boilers.

The natural gas fired furnaces were monitored as well. As a non-intrusive data logging measure, temperature/relative humidity loggers were placed inside the heating ducts of each furnace. When the burners were off, the temperature and relative humidity were equal to the ambient conditions. When the burners were turned on, there was a corresponding rise in temperature, and a drop in relative humidity as the air was heated. This data allowed the team to estimate each furnace's duty cycle (on and off time).

Direct quantification of natural gas usage for the furnaces was not available with this data analysis method. The total natural gas usage of the furnaces is taken to be the total natural gas usage minus the calculated natural gas usage of the boilers, since there are no other significant natural gas uses at the facility.

4.3.6 **Submetering Data Plan and Analysis – Interval Data Versus Submetered Data**

The electric utility for this facility provided 15-minute interval data for the master meter. The utility data were overlaid with the logged data at the main taps. Overall, inspection of Figure 4-6 shows that the submeter data is a reasonable representation, since it closely corresponds to the utility data. Over a two week period, there is about 7% difference in the utility data versus our data. If the atypical production days are excluded, the difference is only about 3%. Atypical production days are defined as days when abnormal levels of production occurred, such as production on Saturdays, or weekdays with partial production shifts.

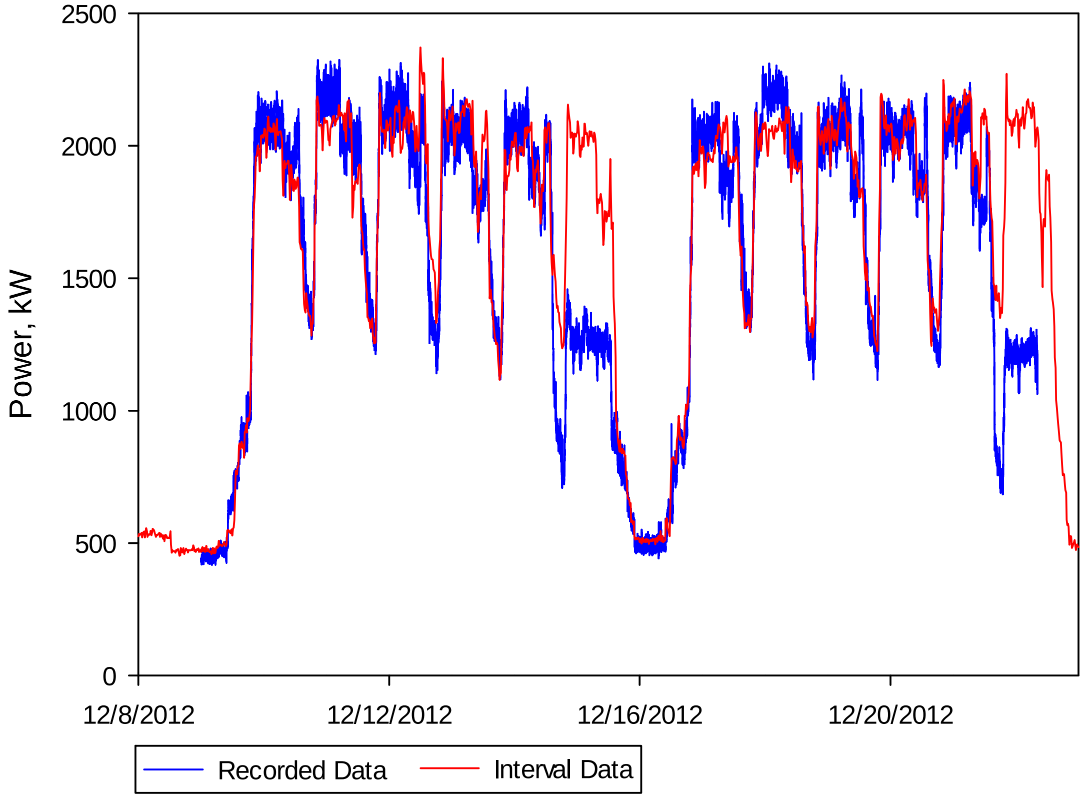

Figure 4-6: Side-by-side comparison of utility provided interval data and combined submetered data.

4.4 Results and Discussion

To account for expected variation in production levels, it is common to normalize energy use with company tracked production metrics (i.e., energy use per unit of production). It was found that this plant tracks production performance based on two metrics, either the number of birds processed each day (called 'headcount') or the number of hours the process line operates each day (called 'line hours').

So, discussed below are the resulting energy intensities for both electricity (kWh/headcount and kWh/line hour) and natural gas (MMBtu/headcount and MMBtu/line hour).

4.4.1 **Electrical Energy Intensities**

Daily electrical energy intensity values are shown in Figures 4-7 – 4-8. The computed average daily electrical energy intensities and coefficients of variation are shown in Tables 4-1 – 4-2.

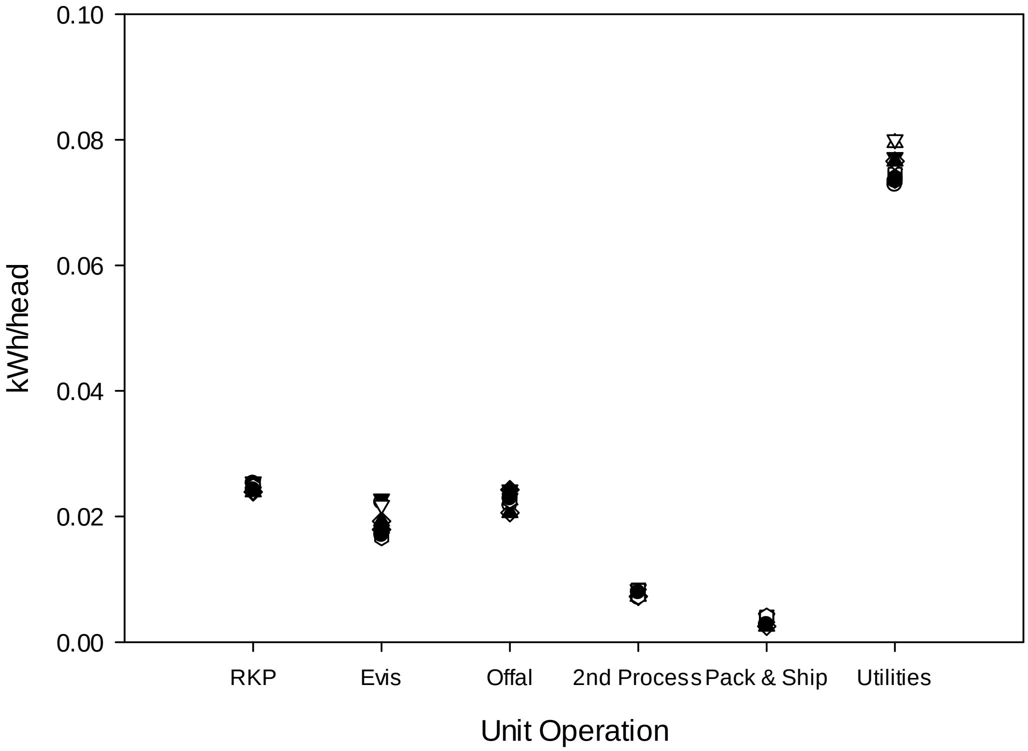

Figure 4-7: Daily electrical energy intensity values by headcount (kwh/head) for each unit operation. Each unit operation contains 10 data points except Evis and Offal which contain an extra Saturday production day (so 11 data points). Typical non-production days of Saturday and Sunday are not included.

Table 4-1: Electrical energy intensity by headcount.

Unit operation	RKP	Evis	Offal	2nd Process	Pack & Ship	Utilities
Intensity (kWh/1000 head)	24.6	19.0	22.8	7.8	3.4	75.6
Coefficient of Variation (%CV)	2%	12%	5%	6%	16%	3%

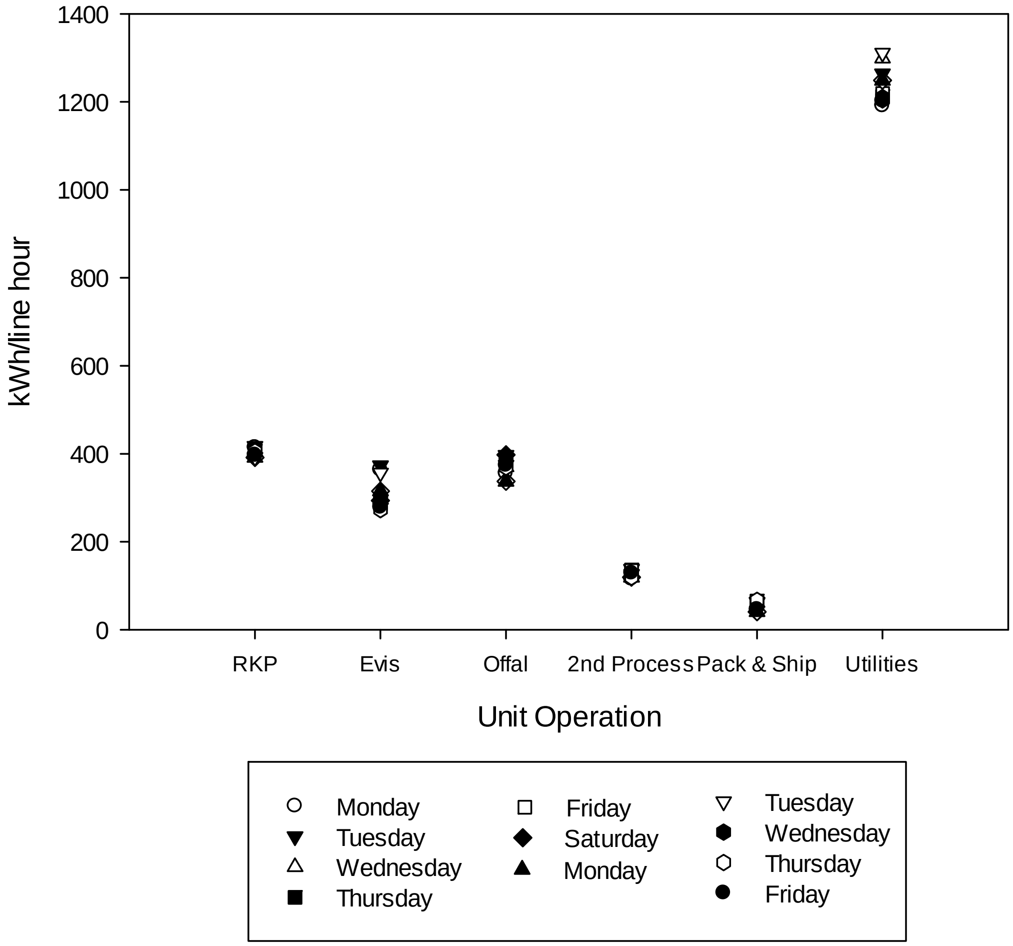

Figure 4-8: Daily electrical energy intensity values by line hour (kwh/line hour) for each unit operation. Each unit operation contains 10 data points except Evis and Offal which contain an extra Saturday production day (so 11 data points). Typical non-production days of Saturday and Sunday are not included.

Table 4-2: Electrical energy intensity by line hour.

Unit operation	RKP	Evis	Offal	2^{nd} Process	Pack & Ship	Utilities
Intensity (kWh/line hour)	403.2	311.3	375.6	126.8	56.3	1,236.3
Coefficient of Variation (%CV)	2%	12%	5%	6%	16%	3%

Values are given for both intensity types for a combined two weeks within the submetering data collection period. Each unit operation contains either 10 or 11 data points. Inspection of the data shows very tight groups for RKP, Offal, 2nd processing, and Packing/Shipping. Very little variation among days, with Pack & Ship having the largest coefficient of variation of 16%, indicates constant daily process line loading and steady operations. The Evis unit operation values have some data spread, 12% CV, while all other unit operations have a %CV of 6% or less. Utility unit operation variation could be due to weather and/or bird size mix. Processing of different bird sizes (i.e., mix) could result in refrigeration load changes. Similarly the variation in Evis could be due to equipment loading or cycling and/or processing different bird sizes. Review of the South Engine Room portion of the Utility unit operations also showed less steady operation (as expected with load depended ammonia compressors).

4.4.2 **Natural Gas Energy Intensity**

Daily intensity values of boiler natural gas were found to be fairly flat (Table 4-3), indicating that operational variations are not significant.

Table 4-3: Boiler natural gas energy intensity.

		Btu/head	MMBtu/line hour
Wednesday	2/13/12	1,761	28.6
Thursday	2/14/12	1,729	28.3
Friday	2/15/12	1,807	29.6
Coefficient of Variation	(%CV)	1.8%	1.9%

The steam produced by the boilers is used to make hot water for the scalders as well as hot water for sanitation. During the normal sanitation hours of 3pm -7pm, the average boiler energy on the monitored days was 17.4 MMBtu/hr, or 69.7 MMBtu/day. During the normal production hours of 7pm until 3pm the following day, the average boiler energy was slightly higher, at 18.6 MMBtu/hr, or 371.3 MMBtu/day. This shows that the natural gas energy used for sanitation is about 15.8% of the total boiler energy. The steam system at this facility had significant opportunities for energy efficiency improvements, and could be characterized as having below average overall system efficiency.

The remainder of the natural gas, about 2%, is used for space heat.

4.4.3 **Energy Intensity at Unit Operation Level**

The computed daily total plant (natural gas and electrical) energy intensities are shown in Figures 4-9 and 4-10. Natural gas used by the boiler was only monitored for three of the five shown production days and are given for both headcount and line hours. Measured electricity use by the primary unit operations is also shown, but the units were converted from the kWh to MMBtu to provide consistency. It can be seen that the natural gas energy use is large compared to electricity. This is typical for manufacturing plants that use significant thermal energy. It should also be recognized that the electrical values are calculated as “site-energy” intensities, and therefore, do not include upstream conversion factors, transmission losses, and/or efficiencies.

The energy intensities discussed to this point include the electricity and natural gas energy recorded for specific unit operations during the production week. These energy intensities do not include the energy used in auxiliary operations. In addition these energy intensities also do not include any weekend energy used for maintenance operations or other non-production work in the production facility. Even though they are relatively small energy users, these auxiliary operations are vital to the operation of the business, so they should be considered during any analysis of the overall energy intensity of the business.

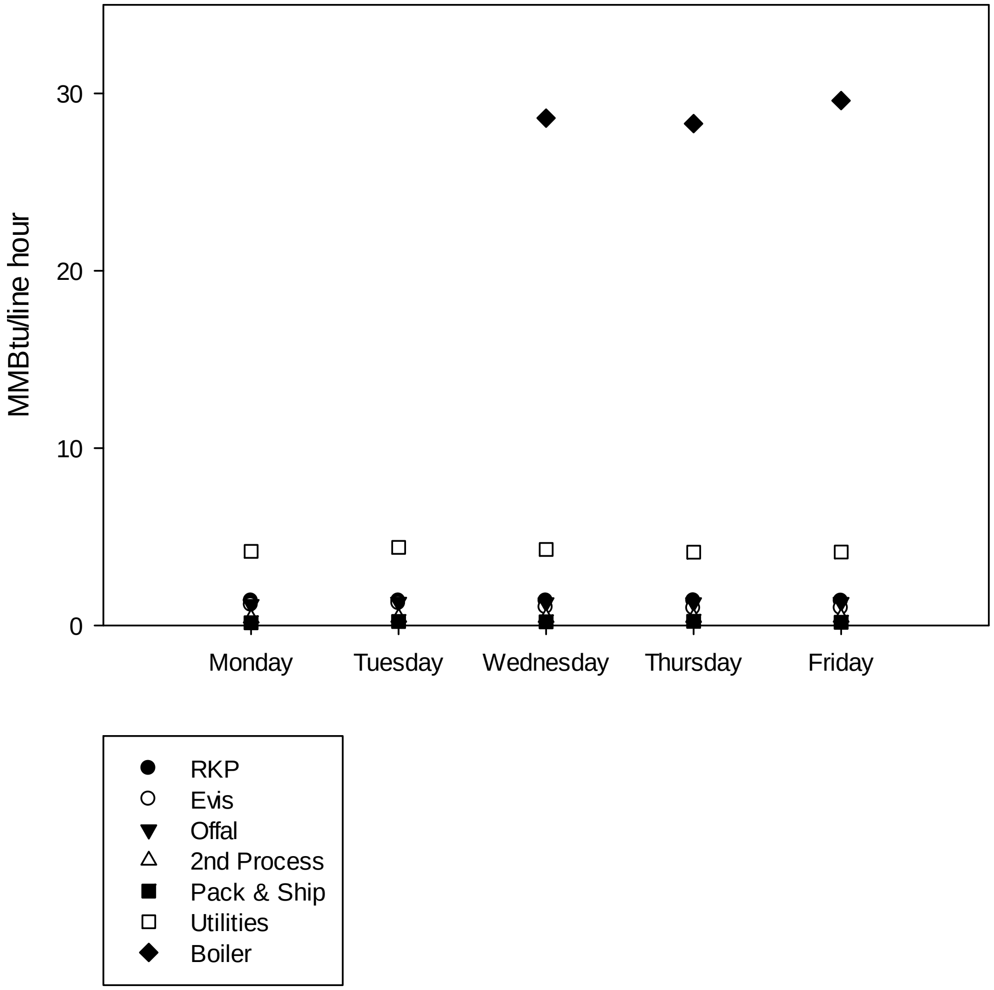

Figure 4-9: Daily total (natural gas and electrical) energy intensity values by line hour (MMBtu/line hour) for each unit operation. Note that the steam boiler values are only Wednesday, Thursday, and Friday.

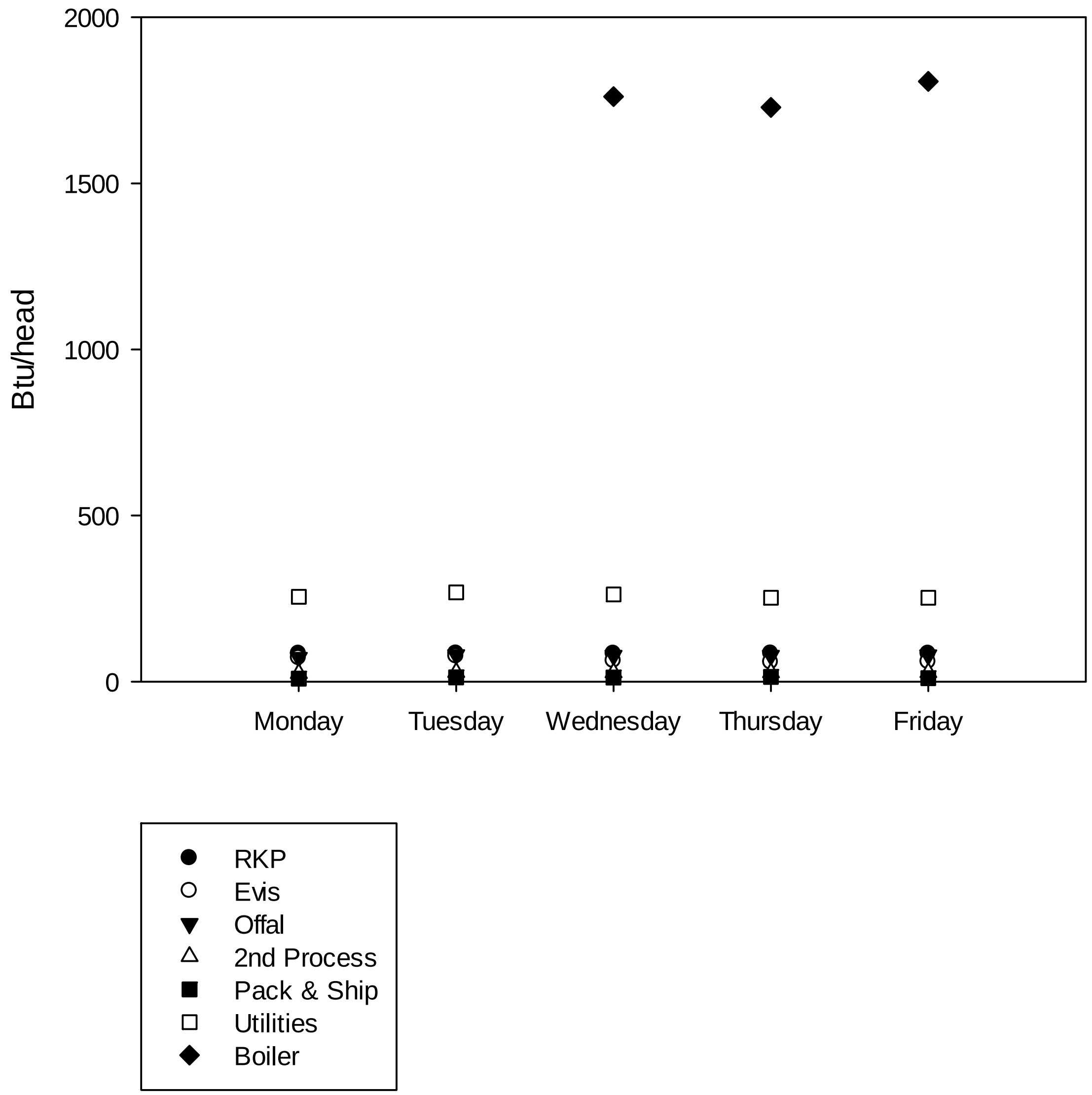

Figure 4-10: Daily total (natural gas and electrical) energy intensity values by headcount (MMBtu/headcount) for each unit operation. Note that the steam boiler values are only Wednesday, Thursday, and Friday.

4.4.4 **Modeling energy intensity**

The determination of independent variables that influence energy intensity may be useful for plant operations personnel, energy managers, or others at the facility. The knowledge of which independent variables affect energy intensity can help determine which systems or measures may have significant impact on overall energy consumption and cost. This can lead to a more targeted energy management plan for individual facilities.

The DOE EnPI tool [22] was used to perform regression analyses on the metered data for each unit operation. The results are presented in Table 4-4. The independent variables that were considered are headcount, line hours, heating degree days (HDD), and cooling degree days (CDD). Data for other potential variables were not available.

The general formula for a multiple linear regression model is:

$$y=b_0+b_1x_1+b_2x_2+\dots b_px_p$$

The ENPI tool runs multiple models using many possible combinations of independent variables, and then selects the best model(s) based on two criteria. First, the model p-value must be below 0.010. Next, the models that satisfy the first criteria are sorted based on best coefficient of determination, R^2.

The analysis showed that Evis, Offal, 2nd Processing, and Pack and Ship were significantly influenced by both headcount and line hours. 2nd processing was also affected by HDD, showing that space heating in this part of the building was significant.

Table 4-4: Multiple linear regression model significant variables, coefficients, constants, and statistical significance information for unit operations, as determined by the DOE EnPI tool version 4.0. Models with the highest R^2 values are shown. Electric energy has been converted from kWh to source MMBtu using a site-to-source factor of 3. All unit operations are electric energy only unless denoted otherwise. Results of the general formula will be in units of MMBtu.

Unit Operation	**Separated unit operations**	**Model is Appropriate**	**Variables ($x_1,x_2,…$)**	**Coefficients ($b_1,b_2,…$)**	**Constant (b_0)**	**R^2**	**Model p-Value**
RKP	RKP without cooling shed	TRUE	Head count	2.132E-04	8.9044	0.9910	0.0000
	cooling shed	**FALSE**	Head count	-5.050E-06	1.4207	0.2747	0.3855
			Line hours	1.106E-01			
			HDD	-2.678E-02			
EVIS	All EVIS	TRUE	Head count	-1.764E-02	19.4217	0.8877	0.0000
			Line hours	2.907E+02			
Offal	All Offal	TRUE	Line hours	3.288E+00	10.8427	0.9685	0.0000
2nd Process	All 2nd Process	TRUE	Line hours	4.648E-01	16.8039	0.7942	0.0004
			HDD	-1.483E-01			
P&S	All P&S	TRUE	Line hours	3.163E-01	4.0199	0.7265	0.0002
Utilities	Engines	TRUE	Head count	5.753E-04	40.4568	0.9897	0.0000
	Boiler *natural gas only	TRUE	Line hours	1.048E-01	3.1740	0.8912	0.0000
			HDD	-2.292E-02			
	Waste water treatment	TRUE	Head count	1.527E-05	2.2606	0.9505	0.0000

The RKP unit operation did not produce a model that was acceptable until the cooling shed energy was separated from the rest of the energy for that unit operation. Afterward, RKP without cooling shed energy produced an acceptable model using the headcount variable. The cooling shed by itself still did not produce an acceptable model, showing that the factors driving energy usage are not known. This may be explained by the unpredictable occupancy times and levels in the cooling shed, as well as the fact that fans are run based on an operators experience rather than some measureable criteria, such as bird temperature or outside conditions.

The utilities unit operation similarly did not produce an acceptable model when all of the unit operation components were considered together. Engines (including ammonia chillers and air compressors), boiler, and waste water treatment electricity were separated to determine that engines and waste water treatment were highly influenced by headcount, and the boiler was affected by line hours and HDD.

4.4.5 **Lessons learned from modeling energy intensity**

The regression analyses presented above are useful in predicting the energy intensity of various unit operations based on independent variables. Beyond simply generating formulas, several lessons can be learned from the coefficients and constants that are generated from the analyses. These lessons can lead to a better understanding of what changes in the production process might have the greatest effects on energy intensity at the facility.

First, the production measures of line hours and headcount produce very similar results, because these measures are closely related. The facility in the study took great care to ensure that the production line ran when birds were available to process at a pre-determined rate.

When fewer birds are available, or when fewer birds are needed to fill production orders, the plant runs fewer line hours rather than spreading out production over the same amount of line hours. This has a significant effect on energy intensity, since processing fewer birds over a given shift would result in higher energy intensity. As an example, Figure 4-11 shows headcount and line hour energy intensity data on the same graph, demonstrating the close relationship between the two.

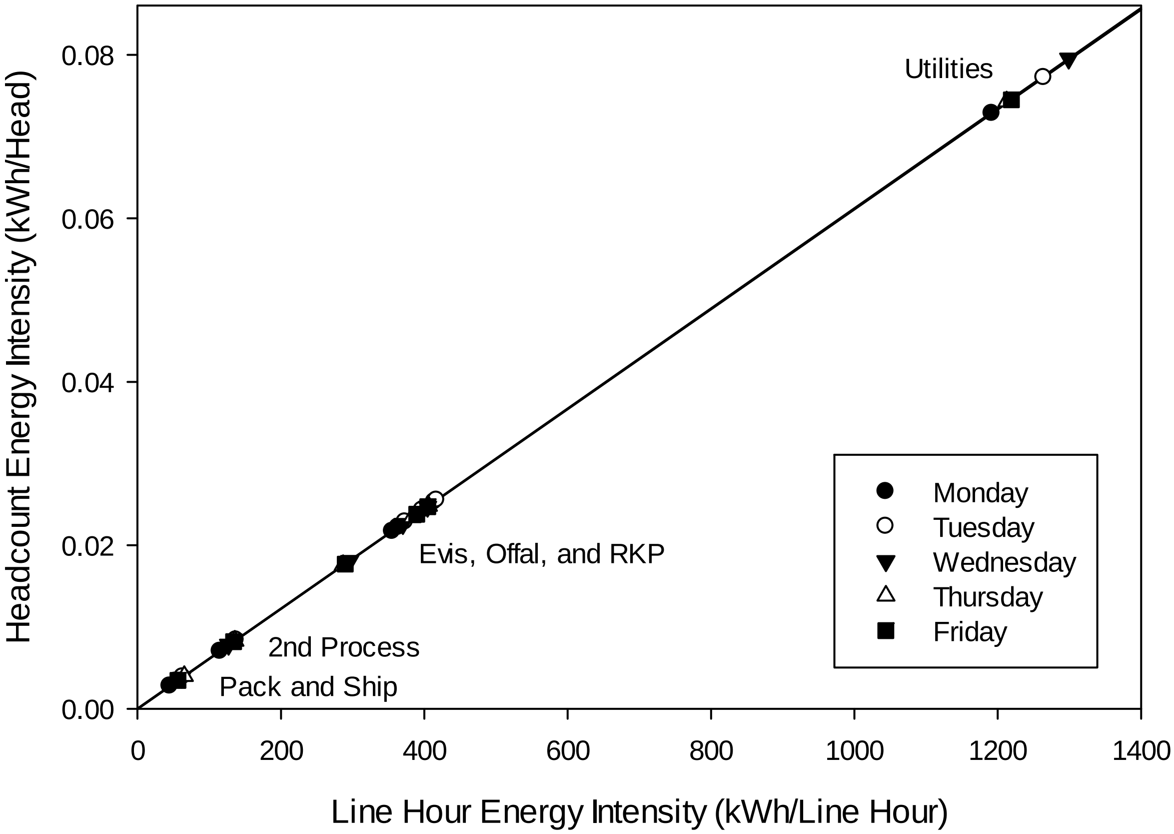

Figure 4-11: Line Hour Energy Intensity versus Headcount Energy Intensity for unit operations over five production days. Close grouping of data for each unit operation shows strong relationship between Line Hours and Headcount.

Second, the weather conditions during the data collection period in this study were rather mild, with temperatures ranging from 20F for nighttime lows to about 70F for daytime highs. The average annual temperature at the facility is around 58F. The lack of extreme high or low outdoor temperatures may require further study, but at least for mild weather conditions, the effects of HDD and CDD on energy intensity was minimal. When HDD did have some effect on energy intensity, it was at least an order of magnitude smaller than the factors such as headcount or line hours.

4.4.6 **Total Energy Intensity**

The calculation of overall annual energy intensity (Table 4-5) requires only the utility revenue meter information, which is easily found on utility bills, and a measure of production. In this case, annual headcount was used. The energy intensity measure reported is the annual energy usage divided by the annual headcount.

Table 4-5: Annual energy intensities for the plant (computed as the sum of all revenue energy meters divided by annual headcount). The total energy intensity is based on site-energy and a conversion of 3,412 Btu/kWh.

	Amount	Unit
Electric Energy Intensity	216	kWh/1000 head
Natural Gas Energy Intensity	1.72	MMBtu/1000 head
Total Energy Intensity	2.46	MMBtu/1000 head

The calculated energy intensity values can be compared to the 1979 paper of Whitehead and Shupe (1979). In this study, the authors measured data for three broiler processing facilities ranging from 60,000 head/day to 200,000 head/day, and calculated the energy intensity. The unit operation definitions differ slightly from what has been presented above, but in general the approach was the same. The average live weight of broilers in the late 1970's was much lower than the current average live weight of broilers, so it is possible that the total energy intensity per processed weight has improved. Data was not available to calculate the live weight or processed weight in the Whitehead and Shupe study. The high-level results are shown in Table 4-6.

Table 4-6: Whole plant energy intensity comparisons per head. Electricity was converted by 3,412 Btu/kWh (site-energy).

	Plant A (Whitehead and Shupe, 1979)	Plant B (Whitehead and Shupe, 1979)	Plant C (Whitehead and Shupe, 1979)	This study
Electricity (kWh/head)	0.3204	0.3123	0.2136	0.216
Electricity (Btu/head)	1,093	1,066	729	737
Heating Fuels, primarily natural gas (Btu/head)	4,476	1,444	1,284	1,720
Total (Btu/head)	5,569	2,509	2,013	2,457

The energy used in the late 1970's was higher, on average, than found in this study. However, one of the plants, Plant C, actually used slightly less electricity and significantly less fuel energy than the plant in this study. Plant B also used less fuel energy than the plant in the current study. Plant A had an on-site rendering operation which increased fuel use. It would be expected that today's broiler processing plants would have a greater amount of automation. Thus, more manual processing in the 1970's, particularly within the RKP and Evisceration unit operations, required a larger workforce to perform the tasks which are now automated. The added electrical equipment increases the electrical energy intensity, with a portion of this being offset by energy efficiency gains. Similarly, reduced fuel energy in the previous study might be attributed to more human labor or changes in sanitation procedures over the years.

For the purpose of comparing the results more directly, the data collected in this study has been re-categorized to more closely match the unit operations as categorized by Whitehead and Shupe. Table 4-7 shows the energy intensity data as presented in Table 1 of Whitehead and Shupe, with corresponding values from this study.

Table 4-7: Energy intensity values from the current study presented side-by-side with values found in Table 1 of Whitehead and Shupe. (kWh/1000 head)

Area	Plant A	Plant B	Plant C	Current study
Live holding	5.84	26.52	3.97	0.44
Hanging, scalding, slaughtering, and defeathering	21.47	28.99	28.91	25.82
Eviscerating and chilling	15.75	21.84	10.21	15.83
Packing and shipping	4.34	4.65	2.51	11.83
Box and lid construction	1.66	0.82	1.74	3.44
Cut-up	3.75	-	2.44	7.75
Offal, waste handling and treatment	23.50	47.28	19.31	37.84
Process refrigeration	119.08	88.33	96.06	59.78
Shops, services, offices, employee facilities	56.66	38.24	21.32	42.17
Total	252.05	256.67	186.47	204.90

4.5 Discussion of current electric energy uses compared to Whitehead and Shupe, 1979

Obviously, many technological and operational industrial energy efficiency improvements have been made in the United States in the last 35 years. For example, the adoption of the Energy Policy Act (EPACT) in 1992 and the Energy Security and Independence Act (EISA) in 2007 have implemented and improved energy efficiency standards on industrial equipment including electric motors and other significant end users. These energy efficiency gains are sometimes counteracted with increases in automation that replaces human energy. Some of these effects are seen when comparing the 1979 energy intensity values with the current ones.

The live holding area energy intensities cannot be directly compared without knowledge of the time of year and loading conditions of the live holding areas. In general, these are typically sheds with lighting and fans that are run when the outside air temperature warrants the need for cooling the birds. In the case of this study, the data was collected during the winter, when fans were not often required. In the case of the Whitehead and Shupe study, the authors state "Plant B used much more electricity for live holding since it had larger fans that operated more hours per day."

The hanging, scalding, slaughtering, and defeathering operations, as well as eviscerating and chilling likely have more efficient electric motors, more automation, and fewer humans involved today when compared to the earlier period. The chilling operation, in this sense, does not include the energy required by the ammonia chillers, as that energy is included in the process refrigeration operation. Several operations, such as packing and shipping, box and lid construction, and cut-up at the facility in the current study are highly automated, where this was not likely the case in the earlier study, where manual labor was the norm. Waste water treatment energy is significantly different between facilities, since some plants have on-site waste water treatment facilities, such as the plant in this study and Plant B of the Whitehead and Shupe study, while other plants send their waste water to municipal facilities for processing. This has the effect of offsetting energy use at the plant with higher waste water treatment costs.

Process refrigeration, the largest portion of electricity usage in both studies, is an area where energy efficiency has been a major focus over the last several decades [23-25] . The facility in the current study uses energy efficient, variable volume screw compressors where the most common type of ammonia compressors in the 1970s was the reciprocating compressor. Advances in ice making, cooling towers, and auxiliary equipment also contribute to the lower energy intensity of these operations today.

Shops, services, offices, and employee facilities vary widely between processing facilities today, much as they did in the 1970s. The facility in the current study housed corporate offices, a full service truck shop, and several other services that are sometimes completely separate from processing facilities. Because of the various sizes and purposes, a direct comparison to the three facilities in the earlier study was not made.

4.6 **Energy Efficiency Opportunities**

The energy intensity values shown in Table 4-6 indicate that process refrigeration is the most energy intensive operation in poultry processing, consuming 29% to 52% of the total energy for each facility. By far the most common process refrigeration system uses ammonia as the refrigerant. Ammonia refrigeration systems have been a focus of energy efficiency improvements throughout the industry due to their significant impact on overall energy usage (and cost), as well as the significant safety impacts of these systems. A typical process refrigeration system in the US today uses variable volume screw compressors, tube or sheet ice makers, and state-of-the-art controls. Older systems may be retrofitted with electromagnetic bearings, de-superheat recovery systems, and various control systems.

The chilled water side of the process refrigeration system can see significant energy efficiency gains from variable speed drives on condenser and cooling tower fans and circulating water pumps. In some US regions, free cooling may be practical by using plate-and-frame or other heat exchangers to take advantage of low average outdoor temperatures, but relatively low chilled water temperature requirements will make this opportunity impractical in most regions. Other common Heating, Ventilation, Air Conditioning, and Refrigeration (HVAC&R) energy efficiency measures include floating head pressure and optimizing system loop pressure(s) based on cooling loads [26].

The best opportunities for natural gas reductions will be either load reductions (e.g., reduced process heating or adding steam line insulation) or system efficiency improvements (e.g., tuning combustion efficiency or heat recovery). Most of the natural gas used in a typical broiler processing facility is used to make hot water for scalding and sanitation, with a maximum temperature of about 140 F. Efficiency of direct hot water heating systems can be around 15% higher than a steam-to-hot-water system, but this likely will not be a practical retrofit if the plant currently generates steam, due to the cost of piping, pumping, and equipment. Direct hot water systems should be considered in new construction. Typical boiler measures will apply to steam systems.

Broiler processing facilities can benefit from new lighting technologies similar to any commercial building, so all of the standard opportunities are available for lighting. One specific lighting measure that should be considered is the use of LED lights coupled to occupancy sensor controls in coolers and freezers. The low occupancy rates in these areas, as well as LED technologies' reaction to cold temperatures, can make these measures very attractive when properly specified with wash-down fixtures and low-temperature sensors.

Broiler processing facilities also have typical compressed air systems, which can benefit from common industrial compressed air system measures. Care must be taken to ensure that compressed air is sanitary in many areas of these facilities, and compressed air lines that run through or come into contact with freezers must have appropriate pressure dew points, heat tracing, or other measures to ensure that ice does not form inside the compressed air piping.

A list of common energy efficiency opportunities for each unit operation for broiler poultry processing systems can be found in Table 4-8.

Table 4-8: Common energy efficiency opportunities for unit operations including expected savings and payback.

Unit Operation	System	Measure	Expected savings	Expected payback
RKP	Boiler	Use lowest possible temperature water for scalding	1-3%	immediate
	Motors and drives	Replace worm gear drives with more efficient hypoid or cycloid drives	3-10%	Less than 1 year
		Match hydraulic pumps to load	5-10%	1 to 3 years
Evis	Motors and drives	Match vacuum pump capacity to load	5-25%	2-3 years
		Replace v-belts with more efficient synchronous belts	3-10%	Less than 1 year
Offal	Pumping	Match pump capacity to load	10-30%	Immediate to 2 years
		Optimize system performance with proper size piping	3-10%	3-5 years
		Use an energy efficient centrifugal pump	Up to 20%	1-5 years
2nd Process	Compressed air	Use vacuum pumps in place of compressed air vacuum generators	2-5%	1-2 years
Pack and Ship	Lighting	LED lighting in coolers and freezers	5-10%	3-5+ years
	Demand side management	Produce ice during non-peak periods	5-10%	Immediate to 5 years

Table 4-8: Common energy efficiency opportunities for unit operations including expected savings and payback. (Cont.)

Unit Operation	**System**	**Measure**	**Expected savings**	**Expected payback**
Utilities	Compressed air	Implement leak management program	Up to 50%	Less than 1 year
		Stage compressors for most efficient operation	10-20%	Less than 1 year
		Purchase more efficient compressor(s)	10-25%	2-5 years
	HVAC&R	Float head pressure	Up to 3%	immediate
		Use variable speed drives on cooling tower fans	10-30%	1-2 years
		Use variable speed drives on chilled water pumps	5-10%	3-5 years
		Reduce cooling load of people, equipment, lights, infiltration, defrost time	2-10%	immediate
		Elevate suction pressure	2-15%	immediate
		Stage/sequence compressors for more efficient operation	10-20%	Immediate to 3 years
	Boilers	Utilize direct hot water heating	5-10%	3-5+ years
		Tune boilers for most efficient operation	1-5%	Less than 1 year
		Automatic top blowdown based on conductivity	2-10%	1-2 years
		Recover waste heat from stack and/or blowdown	5-15%	2-5 years

4.7 **Summary and Conclusions**

Energy is a significant part of the total cost of broiler production. The goal of this project was to understand, measure, and document the energy uses in a broiler processing facility. This study started in June 2012 with the collection and analysis of utility bills from the electricity, natural gas, water, and sewer utilities. This utility analysis helped in understanding the overall usage and cost of energy for the facility.

A process map was developed and split into individual unit operations. Electrical energy for each of the individual unit operations was monitored over several separate data collection intervals between November 2012 and January 2013. Natural gas energy was measured during February 2013. The data were presented in distilled form that utilizes production information to normalize the data.

The normalized data were used to calculate energy intensity values for each unit operation. These were presented in a useful form that shows the energy used to process a single bird, as well as the energy used for each line hour of production. The total plant energy intensity was also calculated using annual production data and metered utility data. In comparison to similar plants in the literature, this plant was found to have lower than average electricity and fuel energy intensities; however, significant energy efficiency opportunities do exist.

It can be noted that poultry processing steps have not changed significantly in the past 35 years, but the processing plants have become more automated, replacing human energy with electrical energy. Gains in energy efficiency have helped to offset some of those electrical energy increases. Significant opportunities still exist to minimize energy usage in a facility;

specifically a robust energy management program with a focus on continuously reducing energy usage can help the poultry processing industry control costs and remain competitive. This study found that the largest opportunities for reducing energy intensity are in the areas of process refrigeration and hot water generation. In conclusion, this study shows that measuring and tracking energy intensity on a unit operations level can provide valuable insight into how energy is used in the facility, where an overall utility meter analysis cannot. This approach can lead to better comparison of energy usage between facilities, and can help to guide energy efficiency programs and the implementation of energy efficiency measures.

4.8 **References**

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5 Summary and conclusions

Energy efficiency is important to the residential, commercial, and manufacturing sectors. As demand for energy grows, energy efficiency offers the lowest cost source of additional capacity for utility grids. As energy engineers and energy managers design and implement energy efficiency programs, there are several main concepts that should be considered.

First, systems with dynamic interactions should be evaluated as whole systems rather than focusing on single components. The paper entitled “Compressed Air System Analysis and Retrofit for Energy Savings” presented a case study of a compressed air system where retrofitting the air compressors would have yielded a savings of 11%, but using the system approach increased that savings to 17% for little additional cost. This approach can be applied to pump, fan, process heat, steam, and other systems with dynamic interactions.

Second, M&V activities can provide reasonable certainty that energy efficiency projects have delivered the promised savings, in terms of both energy and cost. Understanding the requirements of IPMVP is critical to designing a good M&V plan. The paper entitled “Measurement and Verification of Industrial Equipment: Sampling Interval and Data Logger Considerations” presented detailed explanations of how sampling intervals are commonly misapplied, and how different data loggers function within those intervals. Proper understanding of these complex concepts will aid the M&V professional in designing an M&V plan for their project that provides reasonable accuracy, implementation cost, and cost uncertainty.

Finally, energy intensity is a useful metric at many levels. Overall energy intensity can be helpful to building energy managers, industrial operations personnel, and management alike. A deeper understanding of energy usage, specifically in the industrial sector, may require determination of energy intensity at the unit operation level. This level of detail may help industrial energy managers and stakeholders more easily find the operational and equipment aspects of their business that will lead to greater energy efficiency and project efficacy. The determination of unit operation energy intensity is detailed in the paper entitled "Unit Operation Energy Intensities for a Poultry Broiler Processing Plant," and the process can be replicated at any industrial operation, and potentially at commercial operations.

These three papers separately address the main concepts. The papers together represent a body of work that demonstrates a deep understanding of industrial energy efficiency.

The whole system approach can be used for any system with dynamic interactions. These include compressed air systems, fan and pump systems, steam systems, process heating systems, and many more. Using the whole system approach, rather than simply retrofitting a single system component, can provide significant additional savings with little additional cost. Even single component retrofit projects require some understanding of the dynamic effects of the system, so the further exploration of the system has a small incremental cost. Where dynamic effects can be exploited, additional measures may be free to implement, or incur only small costs.

Regardless of the scale or scope of the energy efficiency project, proper M&V practices can reduce the uncertainty associated with calculating the savings obtained by the project. This is important to building owners, utility rebate programs, and other stakeholders, since real money is involved in the implementation of the project and the subsequent operation of the equipment. Improper M&V practices can provide high levels of uncertainty around an energy efficiency project, and may cause the project to fail, or cause similar projects to be disregarded in the future. M&V professionals should seek to deepen their understanding of protocols, practices, and equipment.

Understanding how weather, production levels, and other variables affect energy usage in an industrial facility can be difficult. Overall energy intensity is a useful metric, but further insight can be gained from determining energy intensity at the unit operation level. Any industrial facility can break down their operation into several unit operations. These can be monitored to determine which unit operations have the greatest effect on overall energy usage, and which variables have the greatest effect on energy intensity.

In conclusion, the combination of using the whole system method to analyze a system, using proper M&V techniques to determine savings, and using unit operation energy intensity to determine where to focus efforts, represent some of the best practices of industrial energy management. These are all areas where additional guidance is needed within the industrial energy efficiency field.