Final Report

Energy Balance Analysis of a Poultry Processing Plant

To:
US Poultry and Egg Association
1530 Cooledge Road,
Tucker, Georgia 30084-7303

From:
Dr. Yi Liang
Biological and Agricultural Engineering Department
University of Arkansas System Division of Agriculture
Dale Bumpers College of Agricultural, Food and Life Sciences
Fayetteville, AR 72701
yliang@uark.edu
479-575-4862 (O)
479-200-6982 (C)
and
Dr. Darin Nutter, P.E.
Mr. Chase Harding, P.E., CEM
University of Arkansas
Mechanical Engineering Department

January 30, 2014

Funded by U.S. Poultry & Egg Association
Industry Summary

The objective of this project was to characterize the energy uses in a broiler processing facility and to identify specific measures to improve energy efficiency. The process of quantifying power requirements and energy usage was separated into two levels, referred to as a high level and a detailed level. The high level included analysis of 12-month energy usage records for the plant and available 15-minute electrical interval data from the utility company, in order to gain an overview of total energy consumption. Electricity was used for refrigeration, conveyors, lighting, air conditioning, pumps, compressed air and other mechanical drives. Natural gas was used for production of steam, and further used to generate hot water for processing and sanitation, as well as for space heating. The production process was split into individual unit operations, which were monitored in the detailed level.

The major processes include RKP (Receiving, Killing, and Picking), Evis (Evisceration), Offal (collection and removal of non-edible parts), 2nd process (sizing, cutting and deboning), pack and ship, utilities (chilled ammonia, compressed air, waste water) and boilers (steam production). Electrical energy for each of the individual unit operations was monitored over three separate data collection intervals, each consisting of two-week periods, between November 2012 and January 2013. Natural gas energy was measured with some novel non-invasive data collection methods during April 2013.

Recorded sub-metered power consumption data on weekdays from individual unit operations matched the 15-minute interval data within 3%, indicating that sub-metering captured the major consumption of electrical usage. Utility usage, including the production of chilled water and compressed air, was the largest energy user of electricity, followed by Offal, RKP, and Evis operations. On total energy (MMBtu) basis, natural gas usage for steam generation by boilers was higher than site electricity consumption.

Energy efficiency recommendations included insulating steam pipes and valves, installing an automatic blowdown system to improve boiler efficiency, adding variable speed motors and drives to the cooling towers of the refrigeration system, upgrading to energy efficient lighting, upgrading to a more efficient air compressor for the plant air system, etc. These measures have guaranteed payback periods of two years, with some leveraging of utility rebate programs.

Several additional energy saving measures were investigated during the course of this project. Although most of the measures in this category represent viable technologies, they are either too costly to implement or are more difficult to estimate the energy savings due to uncertainty. The addition of temperature or occupancy sensors to the cooling shed will allow the automation of the cooling fans with reduced running hours. This measure may warrant further investigation to better determine the magnitude of running hour reduction. Because of the amount of hot water used for scalding and cleanup, it will be more efficient to generate hot water directly and avoid the intermediate step of producing steam. It was difficult to estimate the efficiency improvement of this measure due to the existing boiler system deficiencies. Recognizing that this is a costly system change, it should be considered when a boiler change-out is required.

Results from this project demonstrated that cost-effective energy saving opportunities are available in poultry processing plants and warrant investigation.
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 the energy is used by industrial sector (EIA, 2008). 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% (Canning et al., 2010).

Poultry production and processing has grown steadily over the past five decades, with the domestic consumption of chicken meat per capita increased 200% from 1960 to 2011 (from 19.2 pounds in 1960 to 58.5 pounds in 2011) (USDA ERS, 2012). 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 (Ollinger et al., 2000). Energy represents a significant operating expense in poultry processing plants, behind labor, chickens to be processed and possibly the interest on money. The energy efficiency in the production, 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 polluants.

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 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 (Carr, 1981; Liang et al., 2009).

Energy consumption and costs in broiler processing were reported in numerous studies in 1970s and 1980s (Jones & Lee, 1978; Whitehead and Shupe, 1979; Carr, 1981). 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 sizes, 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 (1980) reported the operating efficiency of five southern processing plants, ranging from 498 Btu/lb to 1,761 Btu/lb. 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 (Boykin, 1977), heat pump/heat recovery system from a refrigeration system (Rowles, citation to be added), 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 1 (ice making, air compressing, boiling, water heating, water chilling).

Efforts have been made to quantify energy use and greenhouse gas emissions from food production sectors (Pelletier, 2008; Tan et al., 2011; Thoma et al., 2012). 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. The primary objectives of this study were to:

1) characterize the energy use via energy intensity metrics of a typical broiler processing plant at the unit operation’s level;
2) investigate and identify specific measures to reduce utility costs through reduced power requirements and energy usage; and
3) disseminate these results and best practices through an appropriate peer-reviewed technical publication.

To meet the primary objects, eight steps were performed. These steps were to:
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’s level sub-metering and implementation plan
5) perform sub-metering data analysis
6) compute unit operation’s level energy intensities
7) analyze and discuss energy reduction and cost savings potential for identified energy efficiency measures (EEMs)
8) document study via this final report and publish within appropriate technical publications
Figure 1. Unit operation flow chart of a typical broiler processing plant.
Materials and Methods

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.

Utility Analysis
Utility bills for this facility were gathered for a 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, the investigators must understand the average and marginal costs of energy and demand at the facility. Figures 2-4 are graphs of the monthly electrical energy usage, electrical power requirements, and natural gas usage.

Electric Energy Consumption

![Graph of Electric Energy Consumption](image)

Figure 2. Monthly electrical energy consumption for the plant from June 2011 through July 2012.
Figure 3. Monthly electrical demand consumption for the plant from June 2011 through July 2012.
Figure 4. Monthly natural gas consumption for the plant from June 2011 through July 2012.
Unit Operations and Schedule
The next task included a detailed discussion with plant engineers regarding the plant operations. This also included a review of plant drawings and processes. This step defined the plant operating schedule (Figure 5) and unit operations. Furthermore, this review helped define the scope of the data logger deployment, by locating the boundaries of service for electricity and fuels throughout the facility.

Figure 5. Typical production schedule for each primary unit operation and other support systems.
Electricity and Natural Gas Supplies, Meters, and Interval Data
The electrical utility meter for the facility is a master meter, which captures the total electricity provided to the entire processing facility, as well as a truck shop and an office building that are separate from the processing facility. The master meter records electrical data for seven transformers within the processing facility. Fifteen minute interval data were provided for the master electrical meter for the months of August 2012 and January 2013. Plots of these data are provided in Figures 6 and 7.

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.

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. This list was used to procure appropriate data logging equipment for this project. 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 (Fluke model 345) 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. Figures 8 and 9 show images of a three phase measurement configuration and deploying data loggers on an electrical subpanel, respectively.

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.
Figure 6. Whole-plant summertime electricity demand interval data, August and September 2012.
15 minute interval data - January 2013

Figure 7. Whole-plant wintertime electricity demand interval data, January 2013.
The loggers were first deployed on November 25, 2012 onto the largest capacity taps. The largest group of equipment in the facility 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 according to The Weather Channel\(^1\), 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 December 9, which included the taps on the main processing building. This building houses much of the RKP unit operations, and all of the Evis and Offal unit operations. The second data collection interval concluded on December 22\(^{nd}\). The data loggers were deployed for the third data collection interval several weeks later in order to avoid the holiday production period.

The third data logging interval commenced on January 13\(^{th}\). 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 and the overnight lows were in the low 20’s. These measurements were consistent with the first set of measurements, showing that seasonal temperatures have little effect on operating energy, with the exception of the chillers.

\(^1\) [http://www.weather.com/weather/wxclimatology/monthly/72761](http://www.weather.com/weather/wxclimatology/monthly/72761)
Figure 8: Data logger transducers deployed at main picking panel

Figure 9: Data logger deployment at cooling shed
Submetering Data Plan and Analysis – Natural Gas

Natural gas monitoring proved to be more difficult than electricity monitoring. Each of the three natural gas-fired, fire tube, 300hp boilers had its own gas meter, but none of these were functional. It was not possible to install water meters on the makeup water to the boilers during the data logging period, so we had to explore alternative, non-intrusive methods of monitoring natural gas usage. The final method used the time lapse photography for the boilers, and logging temperature and relative humidity for the air handlers.

The boilers in use at this facility are packaged fire-tube boilers with fixed linkage controls. The forced draft fans for the burners are constant speed, and their flow is throttled by the controls based on required burner fire rate. The solid linkage on the damper control modulates the gas valve for the burner, which thereby modulates burner firing rate. The mixing valve for the burner is in the center of the boiler end cap, and is easily accessible. A time lapse camera, see Figure 10, was mounted such that pictures of the mixing valve position could be captured at 15 minute intervals for several days (Figure 11). Each boiler was manually set to maximum fire and minimum fire, and the valve positions were marked at each point. As pictures were taken digitally with the boiler operating in automatic, the valve position was recorded. Later, each image was analyzed to determine the mixing valve position. Data from the boiler manufacturer was used to relate mixing valve position to burner firing rate (as %load). Combustion efficiency measurements were made, and these were used to convert burner firing rate to natural gas consumption.

Figure 10: Time lapse camera mounted on boiler #2
Figure 11. Fifteen minute interval data, based on time lapse observation, for a steam boiler.

The natural gas fired furnaces which are associated with the main processing building air handlers also required an alternative method of data logging. These furnaces have no gas metering equipment and the fans run at a continuous constant speed to bring in fresh air to the facility, independent of the need for heat. The furnaces have open ring type burners, which heat the fresh air based on either a thermostat setting, or a manual setting during sanitation periods. During these periods, even when the ambient temperature was high, the furnaces could run at full fire to raise the picking room and evisceration area air temperature as high as possible. This entrains some of the moisture generated by sanitation and helps exhaust it from the building. Additionally, as the heated incoming air picks up the space’s post-sanitation moisture, the cooling air handling units may be operating simultaneously to assist in dehumidifying the space.

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, shown in Figure 12, allowed the team to estimate each furnace’s duty cycle (on and off time). 

The furnace was clearly on for
the whole day on 4/12 and 4/13, as indicated by the high duct temperature and low relative humidity. At 7:48 am on Sunday, 4/14, the furnace was shut off, and duct conditions immediately mimic the outdoor ambient conditions, as indicated by a large drop in temperature and corresponding rise in relative humidity. The furnace came back on at 3:02 pm, on Monday, 4/15, which corresponded to the beginning of the sanitation cycle, and turns off at 7:15 pm, corresponding to the end of the sanitation cycle. A similar sanitation cycle is seen two days later, on 4/17, indicating that either the furnace was not started for every sanitation cycle, or that sanitation did not occur at the normal time on 4/16.

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.

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

The electric utility for this facility provided us with 15-minute interval data for the master meter from 12/8 to 12/22/2012. This data were overlaid, after conversion, with the submetered data that were recorded in Figure 13 below. The data did not exactly match due to the following factors:

1) The utility data includes power used at truck shop and office building, which were not measured as a part of the submetering plan. The utility data should be slightly higher than our recorded data. It is estimated that the truck shop and office building use less than 100kW total.

2) The measured data were recorded over 3 separate logging periods, and then combined to show the total power used on similar days of the week. The interval data shown in the Figure 12 represent only one of the three logged periods. Data from the other two periods were added to the data recorded on the shown dates to determine the total. It should be noted that the outdoor temperature and production headcount and line hours were slightly different on these days.

3) December 15 and December 22 were Saturdays when the plant ran production, which was not typically the case. This time period corresponded to our second submetering recording interval. The utility provided interval data recorded all production operations for these days, but only RKP, Evis, and Offal for these dates were submetered. Our recorded data for the other unit operations included Saturdays when the plant was not running production, making the total noticeably lower for a typical Saturday.

Overall, inspection of Figure 13 shows that the submeter data was a reasonable representation, since it closely corresponds to the utility data. Over the 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%.
Figure 12: Temperature and relative humidity measurements for air heating furnace.
Figure 13: Side-by-side comparison of utility provided interval data and combined submetered data.
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).

Electrical Energy Intensities

The computed daily electrical energy intensities are shown in Figures 14 – 15 and Tables 1 – 2. 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 Offal having the largest amount of data spread - 0.0011 kWh/headcount or 18 kWh/line hour, indicates constant daily process line loading and steady operations. The Evis and Utility unit operations have a small amount of data spread – 0.0022 kWh/headcount and 35 kWh/line hour for Evis, and 0.0026 kWh/headcount and 42 kWh/line hour for Utilities. 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).

Table 1. Electrical energy intensity by headcount (kWh/head).

<table>
<thead>
<tr>
<th></th>
<th>RKP</th>
<th>Evis</th>
<th>Offal</th>
<th>2nd Process</th>
<th>Pack &amp; Ship</th>
<th>Utilities</th>
</tr>
</thead>
<tbody>
<tr>
<td>kWh/head</td>
<td>0.0246</td>
<td>0.0190</td>
<td>0.0228</td>
<td>0.0078</td>
<td>0.0034</td>
<td>0.0756</td>
</tr>
</tbody>
</table>

Table 2. Electrical energy intensity by line hour (kWh/line hour).

<table>
<thead>
<tr>
<th></th>
<th>RKP</th>
<th>Evis</th>
<th>Offal</th>
<th>2nd Process</th>
<th>Pack &amp; Ship</th>
<th>Utilities</th>
</tr>
</thead>
<tbody>
<tr>
<td>kWh/linehour</td>
<td>403.2</td>
<td>311.3</td>
<td>375.6</td>
<td>126.8</td>
<td>56.3</td>
<td>1,236.3</td>
</tr>
</tbody>
</table>
Figure 14: 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.
Figure 15: 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 (hence 11 data points). Typical non-production days of Saturday and Sunday are not included.
Natural Gas Energy Intensity

Daily intensity values of boiler natural gas were fairly flat (Table 3), indicating that operational variations are not significant. 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). These are discussed further in the Energy Efficiency Recommendations section later in this report.

Table 3. Boiler natural gas energy intensity.

<table>
<thead>
<tr>
<th></th>
<th>MMBtu/head</th>
<th>MMBtu/line hour</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wednesday</td>
<td>2/13/2013</td>
<td>0.001761</td>
</tr>
<tr>
<td>Thursday</td>
<td>2/14/2013</td>
<td>0.001729</td>
</tr>
<tr>
<td>Friday</td>
<td>2/15/2013</td>
<td>0.001807</td>
</tr>
</tbody>
</table>

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, or about 1/6th as much as production.

Energy Intensity at Unit Operation Level

The computed daily plant natural gas and electrical energy intensities are shown in Figures 16 and 17. 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 for 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.
Figure 16: Daily 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 17: Daily 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.
Total Energy Intensity

The energy intensities discussed above 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 such as the office building or truck shop. The above 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 small energy users, these auxiliary operations are vital to the operation of the business, so they cannot be neglected when considering the overall energy intensity of the business.

The overall annual energy intensity (Table 4) is calculated based on the utility revenue meter information, 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. 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.

<table>
<thead>
<tr>
<th>Annual Headcount</th>
<th>66,200,000 head</th>
</tr>
</thead>
<tbody>
<tr>
<td>Headcount</td>
<td></td>
</tr>
<tr>
<td>Electricity</td>
<td>14,300,000 kWh</td>
</tr>
<tr>
<td>Natural Gas</td>
<td>113,800 MMBtu</td>
</tr>
<tr>
<td>Total Energy</td>
<td>162,600 MMBtu</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Annual Energy Usage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electricity</td>
</tr>
<tr>
<td>Natural Gas</td>
</tr>
<tr>
<td>Total Energy</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Annual Energy Intensity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electric Energy Intensity</td>
</tr>
<tr>
<td>Natural Gas Energy Intensity</td>
</tr>
<tr>
<td>Total Energy Intensity</td>
</tr>
</tbody>
</table>

The calculated energy intensity values can be compared to the 1979 paper of Whitehead and Shupe. 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 that paper to this one, but in general the approach was the same. The high-level results are shown in Table 5.
Table 5. Whole plant energy intensity comparisons (per head). Electricity was converted by 3,412 Btu/kWh (site-energy).

<table>
<thead>
<tr>
<th></th>
<th>Average of 3 plants (Whitehead and Shupe, 1979)</th>
<th>This study</th>
<th>Percent difference (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electricity (kWh/head)</td>
<td>0.282</td>
<td>0.216</td>
<td>-23%</td>
</tr>
<tr>
<td>Heating Fuels, primarily natural gas (Btu/head)</td>
<td>2,409</td>
<td>1,720</td>
<td>-29%</td>
</tr>
<tr>
<td>Total (Btu/head)</td>
<td>3,372</td>
<td>2,457</td>
<td>-27%</td>
</tr>
</tbody>
</table>

The electrical energy used in the late 1970’s was higher than found in this study, even though 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, which were likely offset by energy efficient operations.

Energy Efficiency Recommendations

One of the goals of this project was to identify and recommend energy saving measures with reasonable implementation costs and return on investment. A separate report was issued to the client company which detailed a total of ten recommendations, each with a simple payback of around three years or less. These recommendations, when implemented, will save about 8% of the current energy costs for the facility. Table 6, on the following page, provides a summary of energy efficiency recommendations.

Four of the recommendations were focused on upgrading the lighting in the facility to a more efficient technology. These included retrofitting T12 fluorescent to T8 fluorescent in areas with low ceilings, or T5 fluorescent in production areas with higher ceilings; replacing metal halide lamps with LED lighting in refrigerated areas; and rebuilding existing probe start metal halide lights with the new pulse start metal halides for outdoor lighting. These three recommendations will save approximately 114,000 kWh or $6,600 per year. The simple payback on these three recommendations ranged from 2.3 to 3.3 years.

Two recommendations were offered that would save natural gas by insulating steam pipes and valves that are currently not insulated. Adding insulation to over 1,500 feet of steam piping will save 6,700 MMBtu or $30,500 each year, with a simple payback of less than one year. Adding removable insulation to 11 un-insulated valves would save an additional 240 MMBtu, or $1,100 each year in natural gas costs.

Two recommendations were offered that will improve the efficiency of the boilers in the facility. These included installing an automatic blowdown system, which would save 1,750 MMBtu per year of natural gas. This would also save water and water treatment chemicals, bringing the total savings to around $19,400 each year with a simple payback that is less than two years. The other recommendation was to install a continuous oxygen trim system to improve the combustion efficiency of the boilers, which will
save 6,000 MMBtu or $27,300 per year in natural gas costs. The simple payback of this recommendation is less than one year.

One recommendation was made to improve the efficiency of the refrigeration system, by adding variable speed motors and drives to the existing cooling towers. This would allow the fans to ramp down in speed when the outdoor ambient temperatures are low, saving significant energy. Based on the current operating parameters for the cooling towers, we estimated an annual savings of nearly 150,000 kWh, or $9,400 each year. Due to the utility rebate structure, this recommendation will have a guaranteed 2 year simple payback.

The final recommendation in the report was to install a more efficient air compressor for the plant air system. The existing compressors are inlet modulating rotary screw compressors, which are not very efficient. Compressors are available that use variable volume, variable speed, or both to control the flow of compressed air to the system much more efficiently. The proposed compressor would save 461,000 kWh or $26,900 each year. Again, due to the utility rebate structure, this would have a guaranteed payback of 2 years.

Several additional energy saving measures were investigated during the course of this project that were not offered in the previously mentioned early-state energy assessment report. These included measures that, although viable technologically, were either too costly to implement, did not produce significant energy savings, or were outside the scope of our energy assessment. The investigated measures included; switching compressed CO2 usage to sanitary compressed air, automating the cooling shed fans, matching refrigeration capacity to load, and additional boiler efficiency measures. Each are discussed below.

The facility has a standard compressed air system, and also has a sanitary pneumatic system that uses CO2 instead of compressed air. The CO2 system is used for all sanitary operations, where food products might be present, to eliminate the possibility of oil contamination from the plant compressed air system. The equipment used in the CO2 system are standard pneumatic components, like air cylinders and valves, and could be used with compressed air instead of CO2 if sanitary conditions could be ensured. In fact, this could easily be done by installing an oil-free air system in the facility. Many compressed air equipment manufacturers produce oil-free air compressors, dryers, and treatment equipment, and these are used extensively in the food production industry. A properly sized oil-free air compressor, with integral dryer, could produce sanitary compressed air for about $18,000 per year that would replace refrigerated CO2 purchases on the order of $100,000 per year. The simple payback for this project is less than 3 years. This project would not reduce energy consumption at the site.

The fans at the cooling shed are a significant source of energy use, even during the winter months. The expectation from the field engineer was that the fans would be turned on when the outdoor temperature approached a level that would be warm for a human body, say around 70F. In fact, it was noted that fans in the cooling shed were actually operated when outdoor temperatures are quite cool, at around 45F or even lower in some cases. The internal heat generated by a trailer loaded with live chickens is quite high, and fans are operated to keep the birds from overheating in the center of the
trailer, rather than the outside. Based on data observations and interviews with plant staff, these fans are run more than 5000 hours per year. Furthermore, fans in the shed must be manually started and stopped, so on days when peak temperatures are high enough to justify running fans, they are turned on and stay on until the end of a shift or the end of a day, regardless of the presence of loaded trailers in the shed. Manual operation of devices in low occupancy areas is proven to be unreliable, and can easily be automated. The addition of temperature, occupancy, proximity, or other sensors would allow the automation of these fans and could reduce running hours by more than half, with significant savings (around $8000/year).

The boiler efficiency recommendations that were made in the energy assessment report included adding insulation to piping and valves, adding an automatic blow down control system, and adding continuous oxygen trim system. These measures had good energy savings and short payback periods. Other boiler specific measures that were investigated included blow down heat recovery and adding stack economizers. The blow down heat recovery system would be used to capture the heat energy of water that leaves the boiler as blow down and use it to pre-heat feed water. This measure may be financially viable, but actual measurements were not available, and in light of the recommendation to automate the blow down system, this measure could not be quantified. The same is the case with adding boiler stack economizers. The addition of continuous oxygen trim controls will lower the stack temperature and reduce the amount of available heat, making this measure difficult to quantify. Once the recommended measures are installed, these projects could be evaluated for cost effectiveness.

In addition to the boiler efficiency measures, the team also investigated the complete change out of the steam system in favor of a hot water system. The steam generated at this facility is used exclusively to generate hot water, either in the scalders at 130 F, or for sanitation water at up to 140 F. In this temperature range, generating hot water directly could be significantly more efficient than generating and transporting steam, which is later used to generate hot water. The overall efficiency of the steam system is likely on the order of 80%, while hot water systems typically have efficiencies in the range of 97%. The difference would result in a savings of around $150,000 annually in natural gas costs. However, since the overall system efficiency is likely very poor due to un-insulated piping and other deficiencies, it was difficult to recommend this very costly system change in lieu of the low cost, short payback measures that were available. In the long term, a hot water system should be considered, especially when a boiler change-out is required. The expected payback of this project is 5 or more years, but as an incremental cost versus boiler replacement, the payback may be very favorable.

Energy efficiency recommendations for the refrigeration system fall under the future work category. It was found that each major refrigeration load was serviced by dedicated compressors. To identify energy savings opportunities, a detailed process temperature and load study is recommended to compare with each compressor’s operation.
<table>
<thead>
<tr>
<th>DESCRIPTION</th>
<th>kWh/yr</th>
<th>kW-mo</th>
<th>MMBtu/yr</th>
<th>Total MMBtu/yr</th>
<th>DOLLAR $/yr</th>
<th>PROJECT COST $/yr</th>
<th>SIMPLE PAYBACK (years)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Replace T12 Office Lighting w/ T8</td>
<td>21,500</td>
<td>36</td>
<td>-</td>
<td>73</td>
<td>1,600</td>
<td>4,755</td>
<td>3.0 Calculated</td>
</tr>
<tr>
<td>Replace T12 Fixtures w/ T5</td>
<td>24,380</td>
<td>48</td>
<td>-</td>
<td>83</td>
<td>2,000</td>
<td>6,500</td>
<td>3.3 Calculated</td>
</tr>
<tr>
<td>Replace MH Lamps in Cooler with LED</td>
<td>38,845</td>
<td>72</td>
<td>-</td>
<td>133</td>
<td>3,000</td>
<td>6,875</td>
<td>2.3 Calculated</td>
</tr>
<tr>
<td>Upgrade Metal Halide Lamps</td>
<td>28,900</td>
<td>48</td>
<td>-</td>
<td>99</td>
<td>2,200</td>
<td>5,800</td>
<td>2.6 Calculated</td>
</tr>
<tr>
<td>Insulate Steam Pipes</td>
<td>-</td>
<td>-</td>
<td>6,700</td>
<td>6,700</td>
<td>30,500</td>
<td>24,400</td>
<td>0.8 Calculated</td>
</tr>
<tr>
<td>Insulate Steam Valves</td>
<td>-</td>
<td>-</td>
<td>240</td>
<td>240</td>
<td>1,100</td>
<td>1,850</td>
<td>1.7 Calculated</td>
</tr>
<tr>
<td>Install Automatic Blowdown System</td>
<td>-</td>
<td>-</td>
<td>2,078</td>
<td>2,078</td>
<td>18,700</td>
<td>25,700</td>
<td>1.4 Calculated</td>
</tr>
<tr>
<td>Install VSD</td>
<td>149,000</td>
<td>120</td>
<td>-</td>
<td>508</td>
<td>9,400</td>
<td>18,800</td>
<td>2.0 Calculated</td>
</tr>
<tr>
<td>Compressed air</td>
<td>461,200</td>
<td>463</td>
<td>-</td>
<td>1,574</td>
<td>26,900</td>
<td>53,800</td>
<td>2.0 Calculated</td>
</tr>
<tr>
<td>Boiler controls</td>
<td>-</td>
<td>-</td>
<td>6,000</td>
<td>6,000</td>
<td>27,300</td>
<td>18,000</td>
<td>0.7 Calculated</td>
</tr>
<tr>
<td>Sanitary compressed air</td>
<td>(244,000)</td>
<td>(780)</td>
<td>-</td>
<td>(833)</td>
<td>82,000</td>
<td>240,000</td>
<td>2.9 Estimated</td>
</tr>
<tr>
<td>Occupancy sensors at cooling shed</td>
<td>108,000</td>
<td>-</td>
<td>-</td>
<td>(833)</td>
<td>8,000</td>
<td>10,000</td>
<td>1.3 Estimated</td>
</tr>
<tr>
<td>Boiler blowdown heat recovery</td>
<td>-</td>
<td>-</td>
<td>1,100</td>
<td>1,100</td>
<td>5,200</td>
<td>35,000</td>
<td>6.7 Estimated</td>
</tr>
<tr>
<td>Boiler stack economizers</td>
<td>-</td>
<td>-</td>
<td>2,300</td>
<td>2,300</td>
<td>11,000</td>
<td>40,000</td>
<td>3.6 Estimated</td>
</tr>
<tr>
<td>Hot water system</td>
<td>-</td>
<td>-</td>
<td>20,484</td>
<td>20,484</td>
<td>150,000</td>
<td>800,000</td>
<td>5.3 Estimated</td>
</tr>
<tr>
<td>totals</td>
<td>587,825</td>
<td>7</td>
<td>38,902</td>
<td>40,539</td>
<td>378,900</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
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, and to offer suggestions to improve energy efficiency. This process 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. For the purpose of this study, the unit operations were defined as:

1. RKP – Receiving, Killing, and Picking
2. Evis – Evisceration
3. Offal – Collection and removal of non-edible parts
4. 2nd Process – Sizing, Cutting, and deboning
5. Pack and Ship – Packing and shipping
6. Utilities – Chilled ammonia, compressed air, waste water
7. Boiler – Steam production

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 with some novel data collection methods during April 2013. The data were presented in its raw form, as well as 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 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 other studies in the literature, this plant was found to have lower than average electricity and fuel energy intensities.

In addition, an energy assessment was performed at the facility, and this identified several measures that could be implemented to reduce the energy usage at the facility. These included 10 measures with calculated savings and 5 additional measures with estimated savings. If fully implemented, these measures could save over $378,000 annually on utility bills, with an average simple payback of 3 years or less.
References


