final report

Project code: P.PIP.0430

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Date published: 01 July 2018

PUBLISHED BY
Meat and Livestock Australia Limited
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NORTH SYDNEY NSW 2059

Energy Assessment of a Mixed Species Abattoir's Existing and Proposed Operations

This is an MLA Donor Company funded project.

Meat & Livestock Australia acknowledges the matching funds provided by the Australian Government and contributions from the Australian Meat Processor Corporation to support the research and development detailed in this publication.

Abstract

This project involved a review of energy usage at a mixed species abattoir in Victoria including evaluating the option of co-locating the rendering facility and abattoir in order to reduce energy usage between the two presently disaggregated operations. Currently the abattoir and rendering facilities are in two separate locations. Initially, the company conducted an energy assessment that looked into upgrading an existing system to be made more efficient. However, preliminary findings from the assessment found that co-locating the rendering facility and the existing abattoir would result in considerable energy savings. The evaluation of the key data has allowed us to present the mass balances for the existing process and assess the benefits of co-locating the facilities.

The distribution system for power and hot water was constructed in some areas as loops and ring mains causing allocation of energy usage to cross over departments. The mass balance calculations enabled calculations to narrow this down based on removing the separately recorded data from the totals. To develop a power consumption baseline for energy performance monitoring, an accurate predictive model with relevant variables was required. Overall power consumption follows the trend of production. As tonnes produced increased so did the energy required. The baseline equations for the model was believed to have a 92% accuracy when comparing actual power consumption with the model's prediction of the training data set. Gas usage was able to be successfully traced in all processes at the facility. 94% of gas usage is powering the two boilers for the production of hot water. All this energy produced is used to heat water to 92°C. From there 69% of the hot water is used to produce 85°C water for production, 22% is blended with 35°C RO water to produce 65°C water and 9% of the energy produced heats 15°C town water to 45°C via heat transfer. Total volumes consumed for 85°C, 65°C, 45°C water as well as water required for the cooling tower operations and miscellaneous (non-production) operations were fully understood. Current metering and layout meant that 8% of water use was unidentifiable.

During this study we have several areas where simple procedures, monitoring devices or controls could be put in place which would significantly reduce the amount of energy and water consumed on plant. Refrigeration is the major power consumer on site. It has been shown to use 44% of all power consumed. Improving power factor to ensure all motors are operating at optimum efficiency is recommended. The installation of VSD's will also help to ease the pressure of increasing power prices. The use of variable speed AC drives (VSD) to control motor speed therefore has the advantage of improving the power factor which will reduce losses in the supply cables and transformers. It can also help in avoiding the cost of power factor improvement. The hot water system was reviewed. A recommendation to incorporate metering on the plant to have a better understanding of what water is being used where and control valves to be implemented to reduce wasted water where ever possible was put forward. This energy review showed that there is potential for the infrastructure to be built to allow a hot water ring main around the entire site. This could connect the main boiler house with the proposed protein recovery plant (PRP) and include the ability to pass through the Cogen plant. The facility will assess and prioritise the energy saving initiatives. This will include areas for improvement and will consider if any or part of the initiatives may be included in existing upgrade plans or be segregated and reviewed individually.

Executive summary

The increased importance of energy efficiency has been highlighted by the Intergovernmental Panel on Climate Change in its last report when stating that "almost all greenhouse mitigation and concentration stabilisation scenarios are characterised by the introduction of energy efficient technologies for both energy use and supply" (Ramirez C.A. *et al* 2004). The National Energy Regulator in its May 2017 market update described the previous 12-18 months as 'some of the most challenging Australia's energy sector as experienced since the National Electricity Market was established in 1998'.

The Midfield Group (Midfield) own and operate an abattoir at the corner of Scott Street and McMeekin Road in Warrnambool. The Co-Products Facility at 165 Swinton Street commenced operations in 1965 and operates under an existing EPA Licence. Midfield Co Products have a current approval to develop a digester waste treatment plant at the Co products site. There is significant capital expenditure in construction of the digester and with the cost of energy in the form of gas and electricity doubling the business has paused to explore if there are other options. Midfield approached the MLA to seek assistance to review its energy usage and evaluate the option of developing on site protein recovery at the abattoirs to capture waste heat. Currently the abattoir and rendering facilities are in two separate locations. Initially, the company conducted an energy assessment that looked into upgrading an existing system to be made more efficient. However, preliminary findings from the assessment found that co-locating the rendering facility and the existing abattoir would result in considerable energy savings. Relocation has therefore been identified as the preferred option rather than upgrading older systems. The planned protein recovery facility will be built a best in class and efficient protein recovery facility within the main factory so the maximum impact of energy capture and therefore environmental improvement is achieved. The assessment also identified that building a new Protein Recovery Plant (PRP) will result in considerable energy savings.

Completing this energy assessment will enable industry to follow recommended steps to reduce energy and water consumption as well as incorporate renewable energy production at similar processing facilities.

An initial onsite consultation was conducted in order for the auditor to gain an overall understanding of the facilities various processes and sub-systems. Familiarisations with environmental and operational conditions were carried out as well as with key energy end use equipment. The electrical, water and gas distribution systems mapped and discussions around locations for metering, sub-metering and data logging were concluded to ensure the relevant energy intensive processes were reviewed accurately.

The facility uses three types of energy sources;

- Natural Gas which is used to run the boiler for the hot water system
- Electricity is used for refrigeration, lighting, processing equipment, machinery and other electrical appliances
- Diesel, to power trucks transporting product from abattoir to render

The evaluation of the key data has allowed us to present the mass balances for the existing process and assess the benefits of co-locating the facilities. The distribution system for power and hot water was constructed in some areas as loops and ring mains causing allocation of energy usage to cross over departments. The mass balance calculations enabled calculations to narrow this down based on removing the separately recorded data from the totals.

Electrical Analysis

After investigation it was discovered that the energy distribution was not very well documented or was out dated. The decision was made to draw and update a high level built in diagram of all major energy systems.

The plant is powered through four electrical substations, TX1, TX2, TX3 and TX4. Through these the power is then distributed through 39, first level, sub-distribution boards. The sub-distribution boards power nearly 200 tertiary level electrical boards from where individual load is powered.

Historical load data for each electrical circuit was not available, therefore due to time constraints, it was decided that each first level sub distribution boards would be logged for 10 minutes in the aim to calculate energy mass balance.

Looking at the graphed 10 minute snap shot data little to no changes in the various compressors power consumption was observed. This did not tie in with the theoretical basics of operation for this process and therefore a full operational day's data was required and logged. From the full operational days data it can been see that from midnight to 4am the compressor was not running. At approximately 5am the compressor turns on and remains operating until 4pm with a small break at around 1pm. From 4pm to 8pm it runs with less of a cooling load and after 8pm the compressor again stops running until 4am. During the shutdown period sudden small duration running spikes can be seen. This is due to necessity of maintaining required temperature. Refrigeration power usage is significantly higher than any other process or system requiring 44% of total power consumption. Processing comes in second.

Daily energy use was graphed for each month and analysed. Significantly less power was consumed on weekends which can be explained due to non-production days. Every week, within the month, Monday consumes less energy than all other weekdays. Tuesday through to Friday's power use appears to be fairly even and consistent. Investigation into why Monday's energy use is significantly less than other weekdays was investigated. Production was believed to be the contributing factor but after comparing production data it was found that Monday's production, whilst at times was less than other weekdays, was not consistent or significant enough to account for the difference in power consumption. This leads to questions around whether energy is being utilised or wasted during weekdays. Similarly, Sunday's power use is approximately one third that of Saturday's, yet neither day is a production period. One factor that may answer the above questions is cleaning. Each weekday night there is a cleaning shift. There is also a cleaning shift Saturday morning however, there is not Sunday night/Monday morning. This could account for the extra power consumed Tuesday through to midday Saturday.

Hourly power consumption was observed on weekdays and weekends. Power consumption trend is directly related to production shifts. It is believed that the majority of power consumed over the weekends would be refrigeration, however, this does not explain why Saturday's consumption is higher.

As previously stated, processing equipment and refrigeration are the two major power consuming activities in plant. Of those two, refrigeration works 24/7 all year. Process equipment runs during weekdays 5am to 4pm. Figure 4 also depicts another point that 15% of the power used could not be identified. This is significant because when calculating power utilisation, 15% of the energy consumption cannot be accounted for.

To develop a power consumption baseline for energy performance monitoring, an accurate predictive model with relevant variables was required. Overall power consumption follows the trend of production. As tonnes produced increased so did the energy required. However, there were three months which did not follow this trend. Further exploration occurred to find out suitable dependency of power consumption along with production as indicated earlier in exploratory analysis of power historical data. The baseline equations for the model was believed to have a 92% accuracy when comparing actual power consumption with the models prediction of the training data set. The predictive model can now be used with confidence of 92% accuracy when predicting power consumption against production output.

Gas and Hot Water

Gas usage was able to be successfully traced in all processes at the facility. 94% of gas usage is powering the two boilers for the production of hot water. The remaining 6% went to services. 68% of all gas used on plant powers boiler 3MW. All energy produced is used to heat water to 92°C. From there 69% of the hot water is used to produce 85°C water for production, 22% is blended with 35°C RO water to produce 65°C water and 9% of the energy produced heats 15°C town water to 45°C via heat transfer. 26% of the plants gas is consumed by Boiler 2.5MW. This boilers distribution of energy required to produce varying degrees of water temperatures is the same as the 3MW boiler.

During the investigation into water distribution, a map was found to exist which contributed to the understanding of water distribution and flow, however, understanding the volumes of water being used in specific areas was not easily measured. Total volumes consumed for 85°C, 65°C, 45°C water as well as water required for the cooling tower operations and miscellaneous (non-production) operations were fully understood. Current metering and layout meant that 8% of water use was unidentifiable. This 8% equates to approximately 250-300kL per day of waste water that cannot be explained. Although it is believed the general wash down and lairages may be a big contributor. Significantly less water and gas is consumed on weekends. This is due to non-production days.

Power Factor Improvement

Power Factor (PF) is a measure of how effectively incoming power is used in your electrical system. There are numerous benefits to improving PF efficiency. The benefits include reduced demand charges, increased load carrying capabilities in your existing circuits and overall reduced power system loses. There are also huge environmental benefits associated with PF improvement such as reducing the facilities carbon footprint. An electric motor with VSD installed would get reactive current from VSD DC bus. The VSD would draw sinusoidal current from supply, hence it improves the power factor. Individual substation PF needs to be validated before PF improvement initiative is implemented. Although overall PF is 0.898, individual PF vary from 0.84 (TX4) to 0.94 (TX2). Varying PF values means that each substation has a unique pay pack period. TX4 has the shortest payback period of 7 months. Due to this short timeframe it is concluded that, if desired, a VSD should be installed here first to ensure capital savings are realised at the earliest time possible.

	Existing	Corrected	
PF	0.898	0.97	
KVA	4415	4087	
KW	3964	3964	
Demand Charge	$ 35,600	$ 32,958	
Savings		$ 2,642	Monthly
		$ 31,710	Annually

Correction Required	1757	KVAR	
Estimated Cost	$ 166,958		
Simple Payback Period	5.27	Years	

VSD installation in Motor loads (Pumps, Refrigeration and Air compressors)

Induction motors are essential for industries and utilities operations. Compared to other types of loading, the induction motor has a relatively poor power factor which results in higher line currents causing additional heat in line cables and transformers. Induction motors takes both active and reactive current to produce the required torque and speed. As a more efficient means of capacity control, large motors with variable loads operating for long periods can benefit from VSD. VSDs are cost effective for motors that operate equipment with variable demands such as throttle valve-controlled water pumps, evaporator fans with variable flow requirements or air compressors. The use of variable speed AC drives (VSD) to control motor speed therefore has the advantage of improving the power factor which will reduce losses in the supply cables and transformers. It can also help avoiding the cost of power factor improvement.

	without VSD	with VSD
Annual Energy use (kWh)	5,775,000	4,620,000
Annual Energy Cost	$ 866,250	$693,200
Annual Saving	$173,152	
VSD Cost	$359,152	
Payback	25	Months

Refrigeration system

Refrigeration system is the largest user of electricity in the plant. Refrigeration energy consumption data can be broken down into a base demand and a production demand. Base demand is the energy required to maintain the chiller at the desired temperature with the doors closed. Product demand is the additional energy needed to reduce the temperature of the meat. The infiltration of warm air through the open doors during loading further adds to the product load on the refrigeration plant. The base demand depends on the average ambient air temperature, the level of insulation, the fan power and the control system used. From the energy consumption data of the refrigeration system we see that there is noticeable energy use even during non-production hours particularly on nonproduction weekends.

This indicates that there could be any or all of the following;

- cooling loss (insulation, open door)
- unnecessary heat gain
- other system losses

Detail system design parameter and further process specific investigation is required to pin point specific problem and suggest a suitable savings initiative for this system. Overall 10-20% improvement of refrigeration system would be expected.

Compressed Air system upgrading, leak detection and repair

The energy consumption curve shows that approximately 40% of power demand is outside the production hours. This indicates there could be some wastage (leaks or misuse) of compressed air. Leaks are a significant source of wasted energy in an industrial compressed air system. Leaks can also contribute to other operating losses such as;

- Drops in system pressure which can decrease the efficiency of the air tools and adversely affect production
- Forcing the equipment to cycle more frequently, shortening the life of almost all system equipment (including the compressor package itself)
- Increasing the running time that can lead to additional maintenance requirements and increased unscheduled downtime or,
- Adding unnecessary compressor capacity

To do adequate power cost calculations some accurate and consistent information is needed so that true costs can be calculated.

Plant Power Consumption p.a		18,000,000	kWh
Compressor Consumption p.a.(7-11%)	→ 10%	1,800,000	kWh
Compressed air system loss (20-50% Leaks, misuse)	→ 35%	630,000	kWh
At an average rate of 15cents/kWh	0.15	$ 94,500	$ p.a
Fixing cost (Estimated)		$185,000	$ p.a
Payback		23	Months

High-efficiency Motors

The use of high-efficiency electric motors (HEMs) can lead to significant drops in energy use as well as significant savings in cost. Although replacement of an existing motor with an energy efficient motor may not be justified financially in some instances, it is important to ensure energy efficient motors are considered when motors with long operating hours are due for replacement. The high efficiency motors are more cost effective when a new motor is purchased, or a failed motor requires replacement. HEM ranging from 4.5kW to 55kW has a payback period of 1-1.5 years in most of the cases.

Hot-water system operational improvement

Gas is predominantly used for the production of hot water. Reducing hot water wastage will improve gas consumption. Several areas were identified where simple measures could be taken to reduce hot water consumption. It was found that a possible 17% of overall hot water used could be saved through metering, consumption awareness and control valves which would ensure hot water was only being consumed during production time and not wasted during breaks, downtime or end of shift.

Equipment	Area	Water savings (kL)	Total Water used	% saving
Hand wash	MMI	41.26	1492.00	3%
	MMP	172.90	1888.62	9%

Tripe cooker	MMI	325	892	36%
	MMP	262	1012	26%
Sterilisers		1650.22	17090.38	10%
Gut Tables initial rinse	MMI - SS	275	275	100%
	MMI - BF	687	687	100%
	MMP - SS	275	275	100%
	MMP - BF	387	387	100%
	Total	4075.38	23999.00	17%

Whilst the above table shows the potential savings to be significant, the hot water system needs to be reviewed and evaluated to decide where control points should be implemented in order to achieve the desired savings. The valves would be programmed to divert or stop flows when water is not required. Currently there is not such control measure in place. An area where a shut off valve would have a significant effect of hot water consumption is sterilisers. A conservative estimate of water savings calculations said that a potential 10% water savings could be achieved with the application of a control valve on each production floor enabling the supervisor to shut off water flow to sterilisers during downtime, breaks and shifts end. This 10% savings equates to approximately 20ML of 82°C water per annum. This would have a flow on effect of not just the energy savings in gas but the expense of water supply and disposal charges.

Turning off hot water circulation systems during non-production times will save energy by not running pumps and also heat loss through uninsulated plumbing.

Discussion/Recommendations

The increasing energy demand by the meat sector can be explained by two major factors, consumer preferences and ever-increasing food safety/customer requirements (Ramirez C.A. *et al* 2004). Producing frozen or deboned product is energy intensive and therefore, increased demand in this product raises the energy consumption of a facility.

The purpose of this study was to analyse energy use and determine energy efficient developments to be taken to decrease the demand on energy making the process more economically viable and decreasing the detrimental effects the meat industry has on the environment.
During this study we have several areas where simple procedures, monitoring devices or controls could be put in place which would significantly reduce the amount of energy and water consumed on plant.
Refrigeration is the major power consumer on site. It has been shown to use 44% of all power consumed. Improving power factor to ensure all motors are operating at optimum efficiency is recommended. The installation of VSD's will also help to ease the pressure of increasing power prices. The use of variable speed AC drives (VSD) to control motor speed therefore has the advantage of improving the power factor which will reduce losses in the supply cables and transformers. It can also help avoiding the cost of power factor improvement.

The hot water system was reviewed. It was found that the water and gas consumption generally followed to the production trend. However, the amount of hot water used fluctuated throughout the production period and several days that produced the same tonnage of product consumed varying amounts of water. This was believed to be due to areas not turning of taps, hoses or sterilisers when not being used such as breaks or end of shifts. A recommendation to incorporate metering on the plant to have a better understanding of what water is being used where and control valves to be implemented to reduce wasted water where ever possible was put forward.

This energy review showed that there is potential for the infrastructure to be built to allow a hot water ring main around the entire site. This could connect the main boiler house with the proposed protein recovery plant (PRP) and include the ability to pass through the Cogen plant. Currently in place is a one-way flow from Cogen to which does not utilize the full potential of heat transfer. A ring main would allow the water to recirculated, utilizing all heat waste from Cogen and PRP and in turn reduce the boiler inputs.

Energy Saving Measures	**Savings**	**Cost**	**Payback**	
Power Factor Improvement	$ 31,710	$166,958	63	Months
Compressed air Leak repair	$ 81,000	$ 135,000	20	Months
VSD Installation	$ 173,250	$ 359,152	25	Months
Hot-water usage metering and control valves	$ 98,923	$217,000	2.2	Years
Solar PV	$394,200	$438,505	3.85	Years

The facility will assess and prioritise the energy saving initiatives. This will include areas for improvement and will consider if any or part of the initiatives may be included in existing upgrade plans or be segregated and reviewed individually. The facility will seek support from potential grants where possible to assist with shortening payback period and decrease financial stress on the business.

All costing's are estimated figures. Formal figures for upgrades to key areas and infrastructure will be submitted to confirm feasibility of payback periods.

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1 Background

1.1 Introduction

The increased importance of energy efficiency has been highlighted by the Intergovernmental Panel on Climate Change in its last report when stating that “almost all greenhouse mitigation and concentration stabilisation scenarios are characterised by the introduction of energy efficient technologies for both energy use and supply” (Ramirez C.A. *et al* 2004). As well as mitigating greenhouse gas (GHG) emissions, energy efficient technologies will help to reduce the financial strain on businesses caused by the ever increasing cost of energy supply.

Gas prices in Australia have transformed in the past 4 years. According to Oakley Greenwood’s 2017 Gas price trends review, in 2017, Victoria experienced the highest wholesale gas price. Whilst the East Coast is showing a slight downward trend in natural gas pricing, it still remains over $10.00/GJ. The National Energy Regulator in its May 2017 market update described the previous 12-18 months as ‘some of the most challenging Australia’s energy sector as experienced since the National Electricity Market was established in 1998’. The escalating price of gas has driven power prices higher (Cavanough E., Rajadurai E. 2018) and Australian consumers are suffering because of it. Electricity is a major cost for abattoirs, estimated to be $1-2 million per year for each of the top 25 processors, which is equivalent to over $8 per head for beef and $0.80 per head for lamb/sheep (Brooks R. B. 2012).

The Midfield Group (Midfield) own and operate an abattoir at the corner of Scott Street and McMeekin Road in Warrnambool. The Midfield Group has been operating this abattoir on the site since the 1980’s and the business now employs approximately 1500 people, mostly in the region. The Co-Products Facility at 165 Swinton Street commenced operations in 1965 and operates under an existing EPA Licence.

Midfield Co Products have a current approval to develop a digester waste treatment plant at the Co products site. There is significant capital expenditure in construction of the digester and with the cost of energy in the form of gas and electricity doubling the business has paused to explore if there are other options. Midfield approached MLA to seek assistance to review its energy usage and evaluate the option of developing on site protein recovery at the abattoirs to capture waste heat.

Currently the abattoir and rendering facilities are in two separate locations. Co-products raw material needs to be transported from the abattoir to the rendering facility. This involves over two hundred round trips of commercial trucks per week. Furthermore, because the rendering facility is at a separate location, the heat created in the rendering process cannot be reused at the abattoir facility. Due to the abattoir and rendering facilities being in separate locations, the company not only incurs huge operational costs, but there is potential to capture and utilise wasted energy and have a positive improvement on environmental impacts. The company has a very strong commitment towards the environment and the community.

To mitigate the impact of rising energy costs, a review of the energy consumption at a mixed species processing plant was undertaken with the support of MLA funding to determine opportunities for energy efficiency and cost reduction. Initially, the company conducted an energy assessment that looked into upgrading an existing system to be made more efficient. However, preliminary findings from the assessment found that co-locating the rendering facility and the existing abattoir would result in considerable energy savings as seen in previous milestone report. The development of the protein recovery facility at the main site has therefore been identified as the preferred option rather than upgrading older systems. The planned protein recovery facility will be built a best in class, and efficient protein recovery facility within the main factory so the maximum impact of energy capture and therefore environmental improvement is achieved. The assessment also identified that building a new Protein Recovery Plant (PRP) will result in considerable energy savings. Since then substantial work has been carried out researching technology suppliers and preparing necessary information to ensure the proposed work will result not only in energy cost reduction but will help mitigate a significant portion of the company’s GHG emissions and effects on the surrounding environment as was shown in the GHG Impact Assessment Report.

2 Project objectives

The paper will review and evaluate the results of the energy assessment work from individual metering and audit of Power, Gas and water across the main abattoirs and coproducts facilities including the infrastructure required to capture energy from the primary energy plant and NPP plant at the abattoir. It will produce a mass balance assessment and ex-ante cost benefit analysis (CBA) on developing protein recovery at the abattoir. The assessment will provide a baseline for current and future energy and water use benchmarks. This study is supported by the Mass Balance Assessment report previously submitted.

Completing this energy assessment will enable industry to follow recommended steps to reduce energy and water consumption as well as incorporate renewable energy production at similar processing facilities.

3 Methodology

3.1 Site Description

The abattoir is located in a regional area. It is a mixed species processing facility that generally operates 24 hours a day 5 days a week. The facilities operations include, but are not limited to the below

- 4x Kill floors
- 2x boning rooms
- Chillers
- Freezers
- Administration
- Maintenance
- Transport
- Laboratory operations
- Cattle yards
- Waste water treatment plant (WWTP)
- Reverse Osmosis Plant

3.2 Data Collection

3.2.1 Site visit

An initial onsite consultation was conducted in order for the auditor to gain an overall understanding of the facilities various processes and sub-systems. Familiarisations with environmental and operational conditions were carried out as well as with key energy end use equipment. Lists of equipment type, capacity operating principle and pattern of operation were put together. The electrical, water and gas distribution systems mapped and discussions around locations for metering, sub-metering and data logging were concluded to ensure the relevant energy intensive processes were reviewed accurately.

The facility uses three types of energy sources;

- Natural Gas which is used to run the boiler for the hot water system
- Electricity is used for refrigeration, lighting, processing equipment, machinery and other electrical appliances
- Diesel, to power trucks transporting product from abattoir to render

3.2.2 Historical Data

Historical data was collected for the previous year's energy consumption and production to form operational patterns and trends.

Information collected was;

- Power, water and gas bills
- Production data
- Weather data
- Facility specifications and drawings

3.2.3 SCADA Data

Refrigeration, main electrical, water and gas metering systems were linked to SCADA operating systems and therefore data in situ was used to validate historical data.

Where metering could not be seen through SCADA or where further sub-metering was needed data loggers were used. Loggers were used to meter main and first level electrical and water systems in order to record daily performance. Electrical data loggers used were CHKPower Quality and Metrel Powerview.

3.3 Data Analysis

3.3.1 Data Cleaning

The accuracy of the data analysis is dependent on the quality of the Data. Data Cleaning is considered one of the most important and crucial steps in data analysis. This process helps in Identifying and handling missing and outlier data, as well as, formatting data as per the requirement of analysis. When collecting information from various sources, such as SCADA, data loggers or historical records, data may be presented in different formats.

In this data cleaning/validation step, outliers and missing data point were identified (figure 1). The timestamps when the outliers or gaps appeared were identified and further investigation was carried out to rectify the anomalies or select another suitable data set for the same operation/activities. These actions were carried out in all data sources.

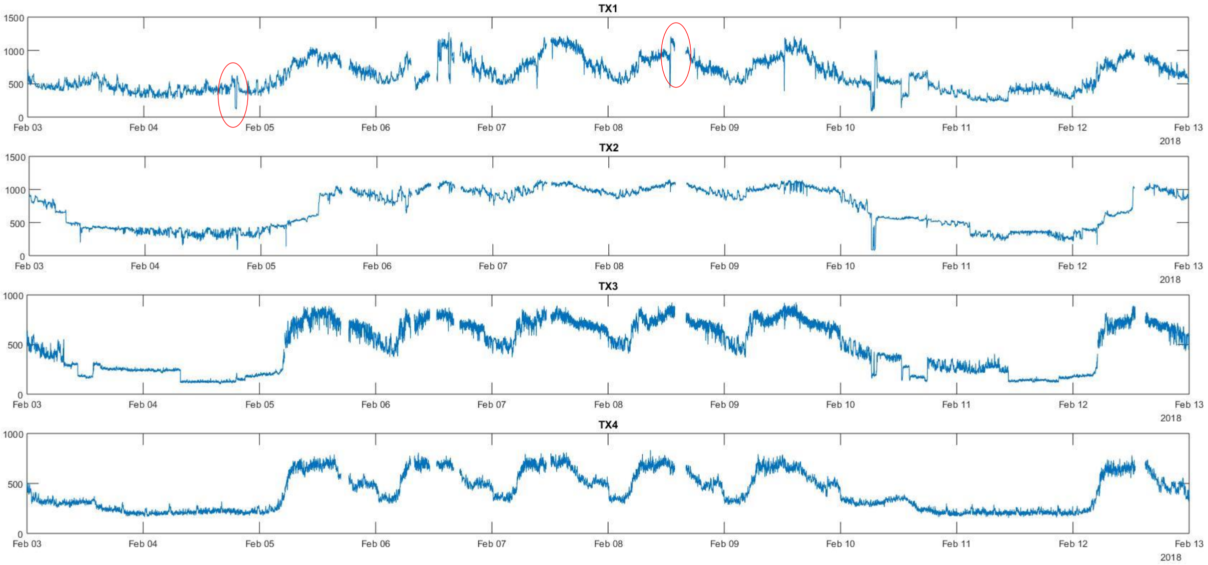


Figure 1. Power profile of all four substations (TX1-4) from 03 Feb-18 to 13 Feb-18 Showing outliers and missing data

3.3.2 Exploratory Analysis

In this step data collected from all sources were inspected using graphical (Scatter, box and histogram plots) and quantities analysis (Mean, media, mode and standard deviation) techniques. The objective of this step is to understand the main patterns and trends of operation from energy, water and gas consumption. This analysis was done using visualizing tools of R. Performing an Exploratory analysis helps us:

- to identify the key features in the data needed for the analysis
- to understand causes of an observed event
- to understand the nature of the data we are dealing with, and,
- assess assumptions on which our analysis will be based

In order to understand power consumption trending data was plotted yearly, monthly, weekdays and weekend daily and then hourly for both weekday and weekends. Power consumption appeared to fairly consistent and only rose slightly in the warmer months. This indicated that power consumption figures needed to be graphed with production values and temperature for each month of the year in order to determine any correlation.

In order to further investigate reasoning behind increased or decreased energy usage, data for power consumption, production and temperature was further broken down into days and then hours. This was then graphed, and comparisons and trends were able to be viewed clearly as well as potential reasoning behind trends.

The exploratory analysis then leads to observing the power consumption of various machines, equipment and processes along with their schedule of operation. The major areas/processes that contributed to the majority of power consumption were determined to be refrigeration and processing equipment, therefore, further investigation in to when and why these areas were consuming so much energy was undertaken.

Similar analysis was carried out for water and gas consumption.

3.3.3 Prediction Model Generation and Validation

Prediction modelling involved extracting features from the data and feeding them into learned algorithms in order to build a model to determine any correlations between energy consumption and production. This step involves Model Selection, Model Training and Model Evaluation.

3.3.3.1 Model Selection

Model selection builds a model to predict energy consumption v business operation, where, energy consumption is the function of all business operation variables such as production, ambient temperature, gas, water usage and production period in terms of time and space. Regression models were built involving several combinations of the aforementioned variables. These models were then trained and tested for evaluation.

To develop a power consumption baseline for energy performance monitoring, an accurate predictive model with relevant variable was required. Through this technique it was discovered that several months did not follow the expected trend of increase power consumption with increased production, therefore, further investigation was conducted in order to determine dependency of power consumption on production. Historical data was used to trend the power v. production dependency.

3.3.3.2 Model Training

After selection the model for analysis, the entire data set is then divided into two parts; Training Data and Test Data. Three-quarters of the data was fed as input to the model algorithms.

3.3.3.3 Model evaluation

Once the model is built it is then tested and validated. The data used to test the model was the remaining one-third of the data set referred to in 3.3.3.2. Once validated the model was used to then calculate the dependency of power consumption on production. The model was then compared to actual power consumption to determine accuracy.

3.3.4 Energy Baseline

Predictive mathematical equations are presented from statistical analysis which act as a baseline tool for monitoring future energy performance.

The base line equation used for the model was –

$$\text{Power consumption} = 2.49^{4} + 9.45^{-2} \text{ x Production}$$

With the accuracy of the model built validated, correlation of other variables were able to be explored.

Similar analysis was carried out for water and gas consumption.

3.3.5 Energy Mass Balance

The evaluation of the key data has allowed us to present the mass balances for the existing process and assess the benefits of co-locating the facilities. The distribution system for power and hot water was constructed in some areas as loops and ring mains causing allocation of energy usage to cross over departments. The mass balance calculations enabled calculations to narrow this down based on removing the separately recorded data from the totals.

Energy-mass-balance (EMB) is of utmost important for effective energy management system. EMB is an effective tool to determine the flows of mass, energy and other factors influencing energy utilization. This helps to determine the effectiveness of processes and equipment by identifying how much energy is being used, wasted or lost or whether systems and equipment are operating according to design. It can also show energy use variability in space and time. An EMB requires a company to look at their operation as a whole system. In the process, an EMB can identify ways of operating whilst using a substantially lower amount of energy and resources.

After collection and compilation of data, an energy mass balance report was prepared.

3.3.6 Identify suitable energy efficient measures

Energy efficient measures where identified using exploratory analysis. Various trend patterns were selected looking at gas, water and electricity overuse and wasted energy. For example, high energy and water use during non-production periods.

During the audit it became clear that the energy and water distribution mapping was outdated therefore, a high level built-in diagram of electrical, gas and water systems was composed as part of this work.

Through individual energy consumption data and mass balance trending, areas where efficiency lagged where able to be determined and recommendations put to the facility.

4 Results

4.1 Electrical Analysis

After investigation it was discovered that the energy distribution was not very well documented or was out dated. The decision was made to draw and update a high level built in diagram of all major energy systems. As part, an electrical single lined diagram was drawn (Figure 2) and mapped showing various zones of the facility in order to isolate energy consumption to a particular area.

The plant is powered through four electrical substations, TX1, TX2, TX3 and TX4. Through these the power is then distributed through 39, first level, sub-distribution boards. The sub-distribution boards power nearly 200 tertiary level electrical boards from where individual load is powered.

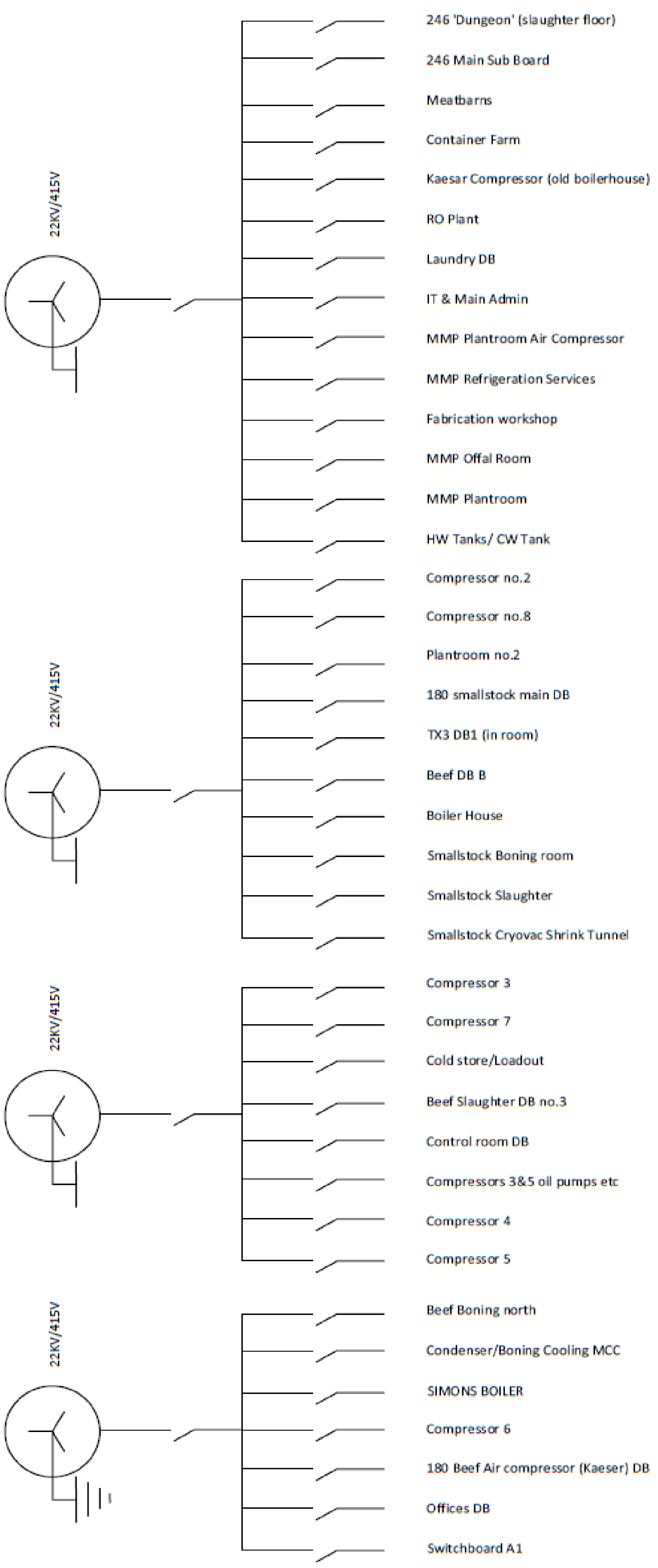

22KV/415V
246 'Dungeon' (slaughter floor)
246 Main Sub Board
Meatbarns
Container Farm
Kaesar Compressor (old boilerhouse)
RO Plant
Laundry DB
IT & Main Admin
MMP Plantroom Air Compressor
MMP Refrigeration Services
Fabrication workshop
MMP Offal Room
MMP Plantroom
HW Tanks/ CW Tank
22KV/415V
Compressor no.2
Compressor no.8
Plantroom no.2
180 smallstock main DB
TX3 DB1 (in room)
Beef DB B
Boiler House
Smallstock Boning room
Smallstock Slaughter
Smallstock Cryovac Shrink Tunnel
22KV/415V
Compressor 3
Compressor 7
Cold store/Loadout
Beef Slaughter DB no.3
Control room DB
Compressors 3&5 oil pumps etc
Compressor 4
Compressor 5
22KV/415V
Beef Boning north
Condenser/Boning Cooling MCC
SIMONS BOILER
Compressor 6
180 Beef Air compressor (Kaeser) DB
Offices DB
Switchboard A1

Figure 2: Single line diagram of Electrical systems of the facility

Substation TX1 distributed power to nine first level electrical boards powering;

- 2x Processing equipment
- 5x Refrigeration
- 1x Hot water
- 1x Air compressor
- 1x Office

Substation TX2 distributed power to seven first level electrical boards powering;

- 4x Refrigeration
- 3x Processing equipment

Substation TX3 distributed power to 10 first level electrical boards powering;

- 2x Refrigeration
- 6x Processing equipment
- 1x Hot water
- 1x Services

Substation distributed power to 14 first level electrical boards powering;

- 4x Processing equipment
- 6x Services
- 2x Air Compressors
- 1x Office
- 1x Refrigeration

Historical load data for each electrical circuit was not available, therefore due to time constraints, it was decided that each first level sub distribution boards would be logged for 10 minutes in the aim to calculate energy mass balance. After analysis however, it was concluded that a 10 minute snap shot did not sufficiently represent operational trend (figure 3 (A)).

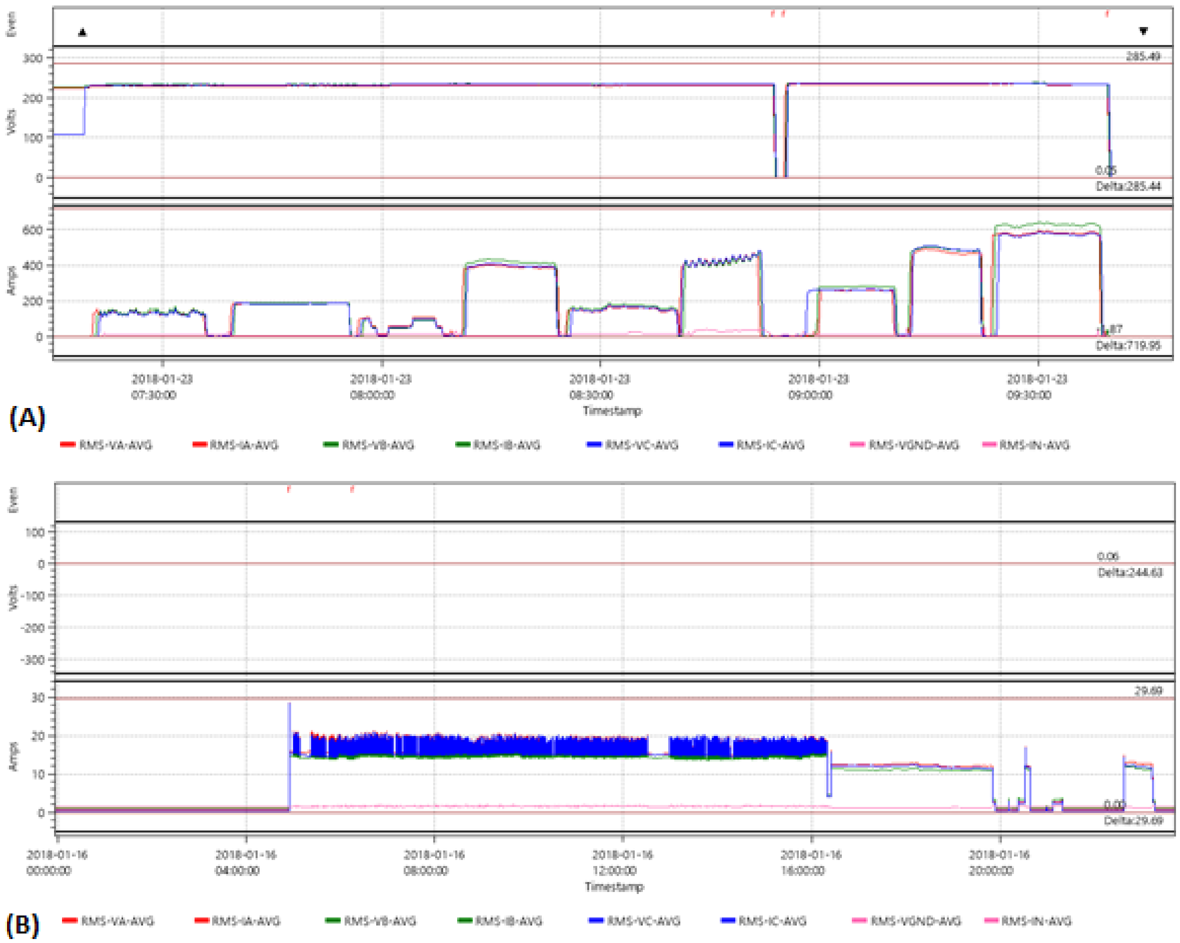


Figure 3. (A) 10 mins power logging of various circuits (compressors) (B) Full day power data for a compressor showing relationship of power consumption with production hours

Looking at the graphed 10 minute snap shot data little to no changes in the various compressors power consumption was observed. This did not tie in with the theoretical basics of operation for this process and therefore a full operational day's data was logged (figure 3 (B)) to provide accurate average estimation of total power consumption.

From the full operational days data it can been see that from midnight to 4am the compressor was not running. At approximately 5am the compressor turns on and remains operating until 4pm with a small break at around 1pm. From 4pm to 8pm it runs with less of a cooling load and after 8pm the compressor again stops running until 4am. During the shutdown period sudden small duration running spikes can be seen. This is due to necessity of maintaining required temperature.

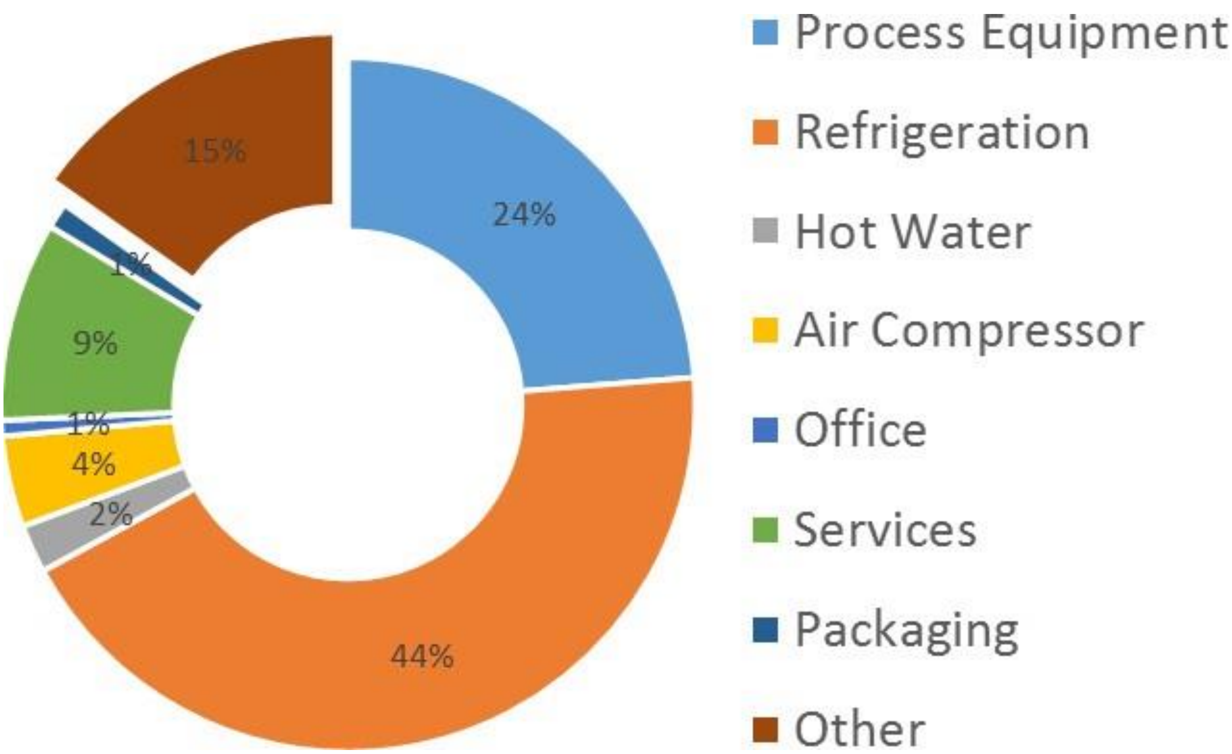


Figure 4. Percentage use of electricity by various processes and systems

Refrigeration power usage is significantly higher than any other process or system requiring 44% of total power consumption (Figure 4). Processing equipment uses 24%. Both process equipment and refrigeration are directly linked to production. 15% of electricity could not be accurately assigned to a process/system because the facilities electrical system was extremely complex and metering tertiary level substations was not feasible. On plant mapping of electrical distribution can be seen in figure 5. Various processes are being powered by several different electrical mains represented in figure 6 which also accounts for the unidentified portion.

Further repeated metering of substations allowed the facility to identify where a crossover of supply occurred to key areas of power consumption, such as refrigeration which was fed from two supply points. This realisation allowed unknown portion of the power consumption to be reduced from 15% to 8%.

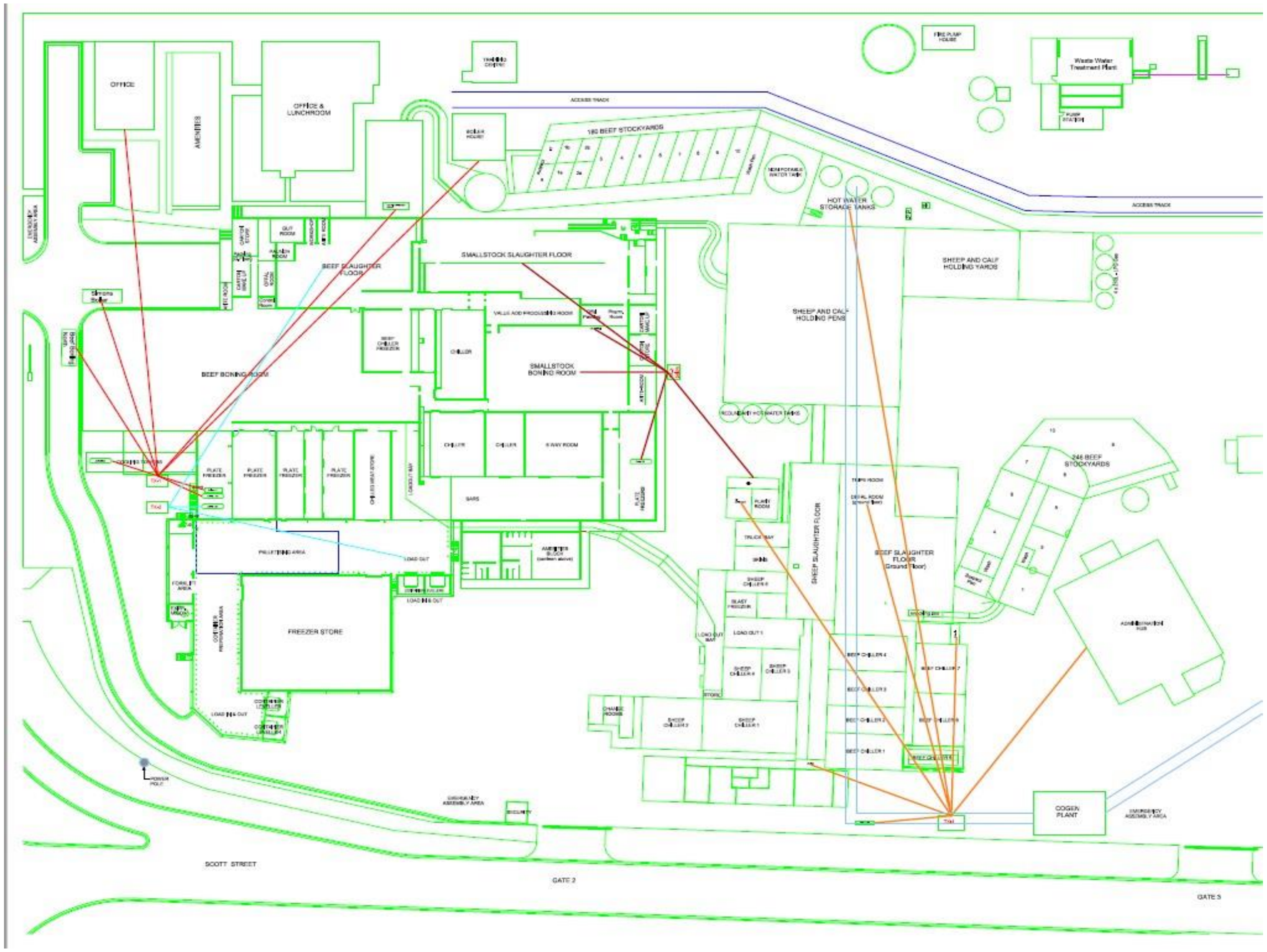


Figure 5. Electrical distribution mapped on plant layout

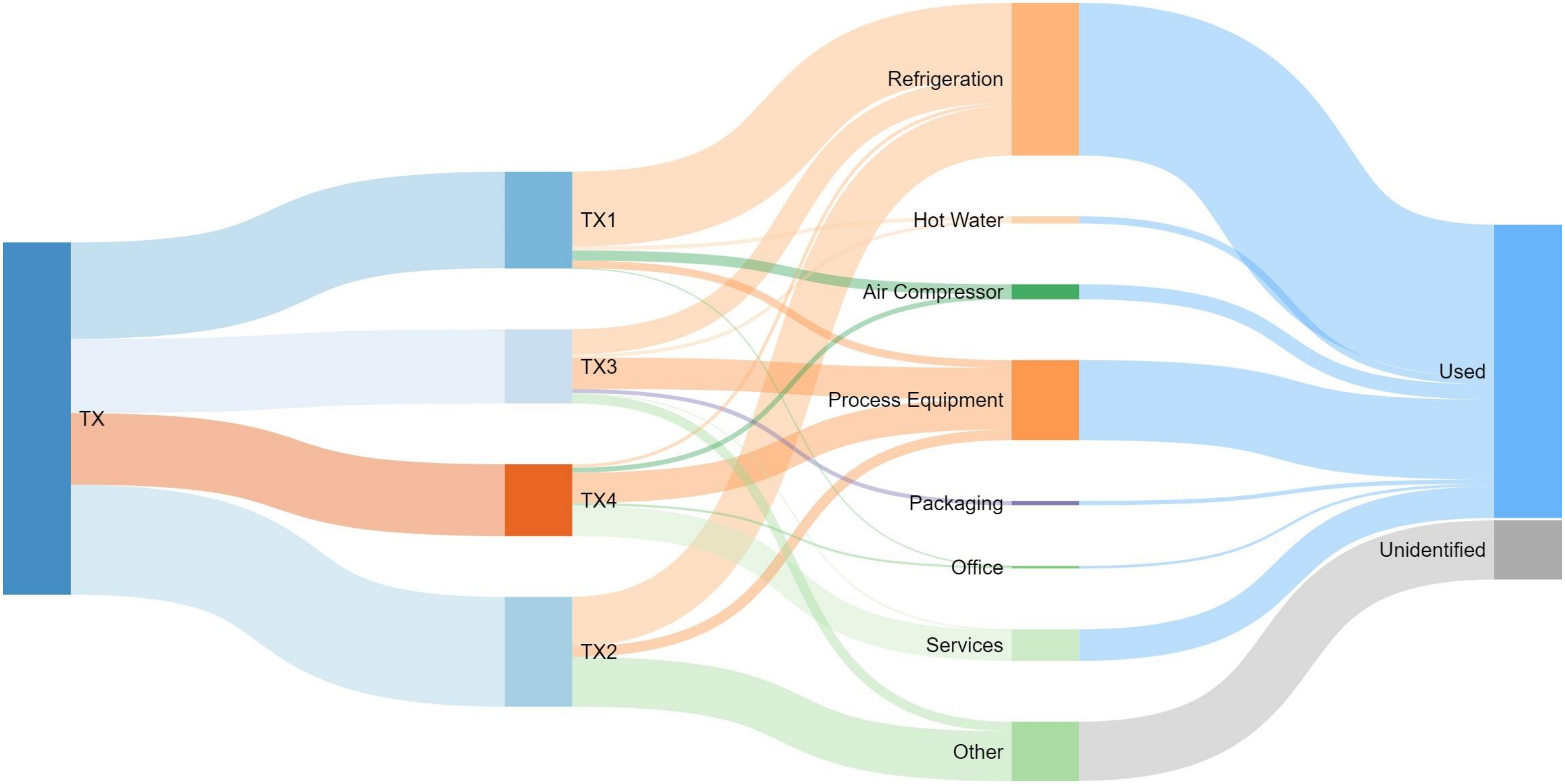


Figure 6. Power flow diagram of Midfield Meat International showing unidentified portion

In order to understand power consumption trend yearly, monthly, weekly, and days by hours were plotted.

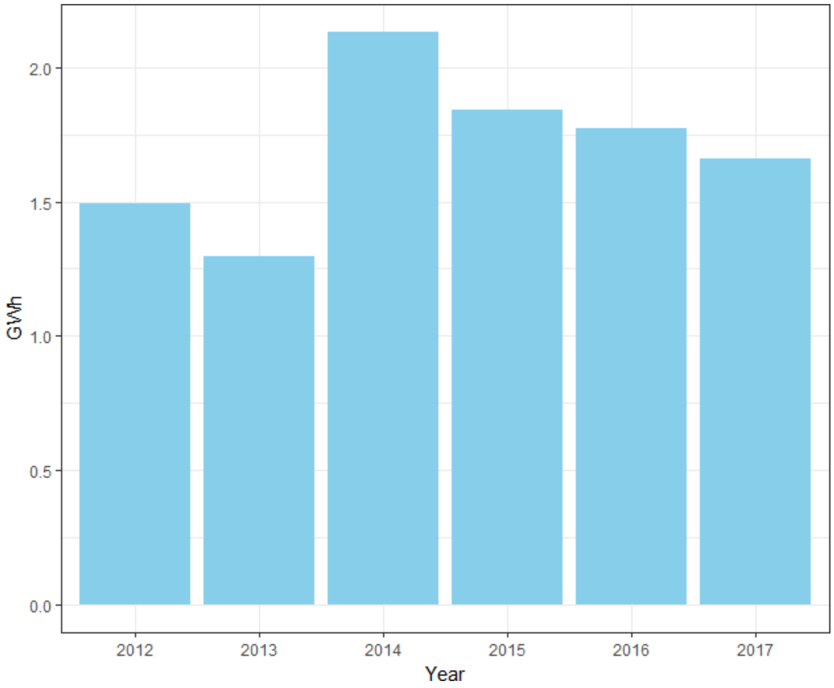


Figure 7: Yearly power consumption of main abattoir house

Figure 7 shows the power consumption to have significantly increased in 2014 from previous year. Power consumption gradually decreases from 2015 to 2017. However, after further investigation into the 2017 data, it was observed that December 2017 data set was not complete and therefore may contribute to the downward trend.

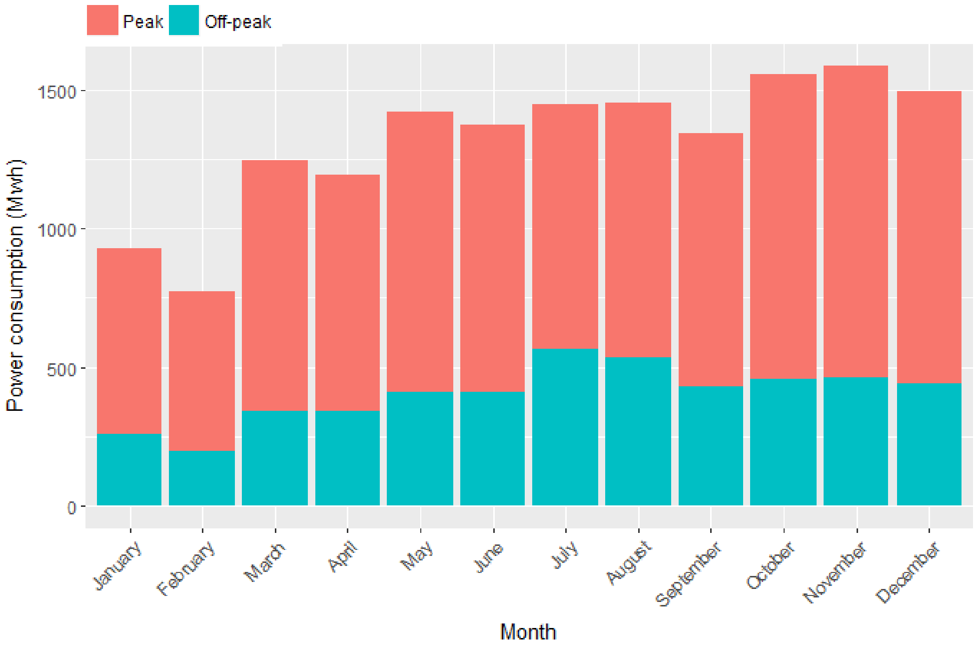


Figure 8: Monthly power consumption of 2017

Monthly trend of power consumption shows a gradual increase in demand. As months turn warmer and ambient temperatures rise, power demand may increase, however, January and March recorded the hottest temperature for the year of 2017 (figure 8), yet, the power consumption for those months were less than the winter, cooler months. This gives rise to an indication that power consumption may be dependent on other variables such as production.

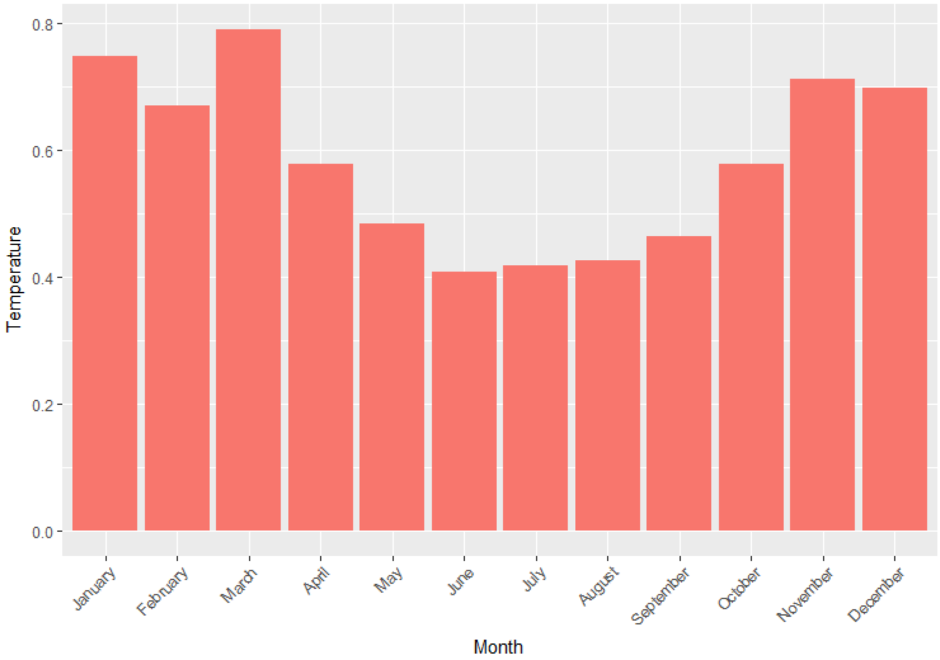


Figure 9. Monthly average ambient temperature for 2017

When comparing monthly power consumption (figure 9) and production in tonnes (figure 10) a strong correlation was observed. With the exception of February and April, the pattern of production follows the pattern of power use.

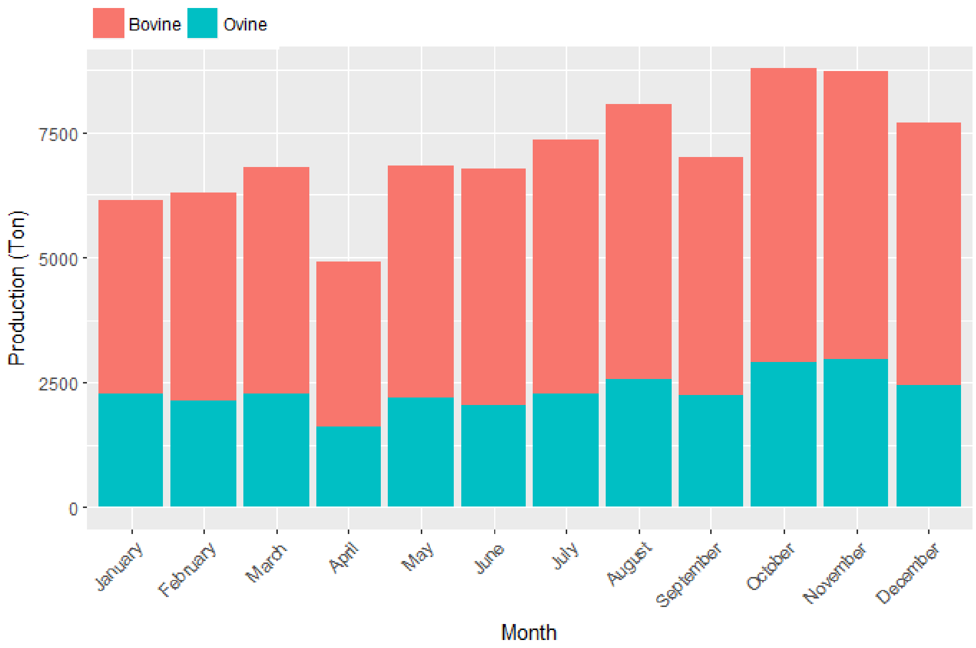
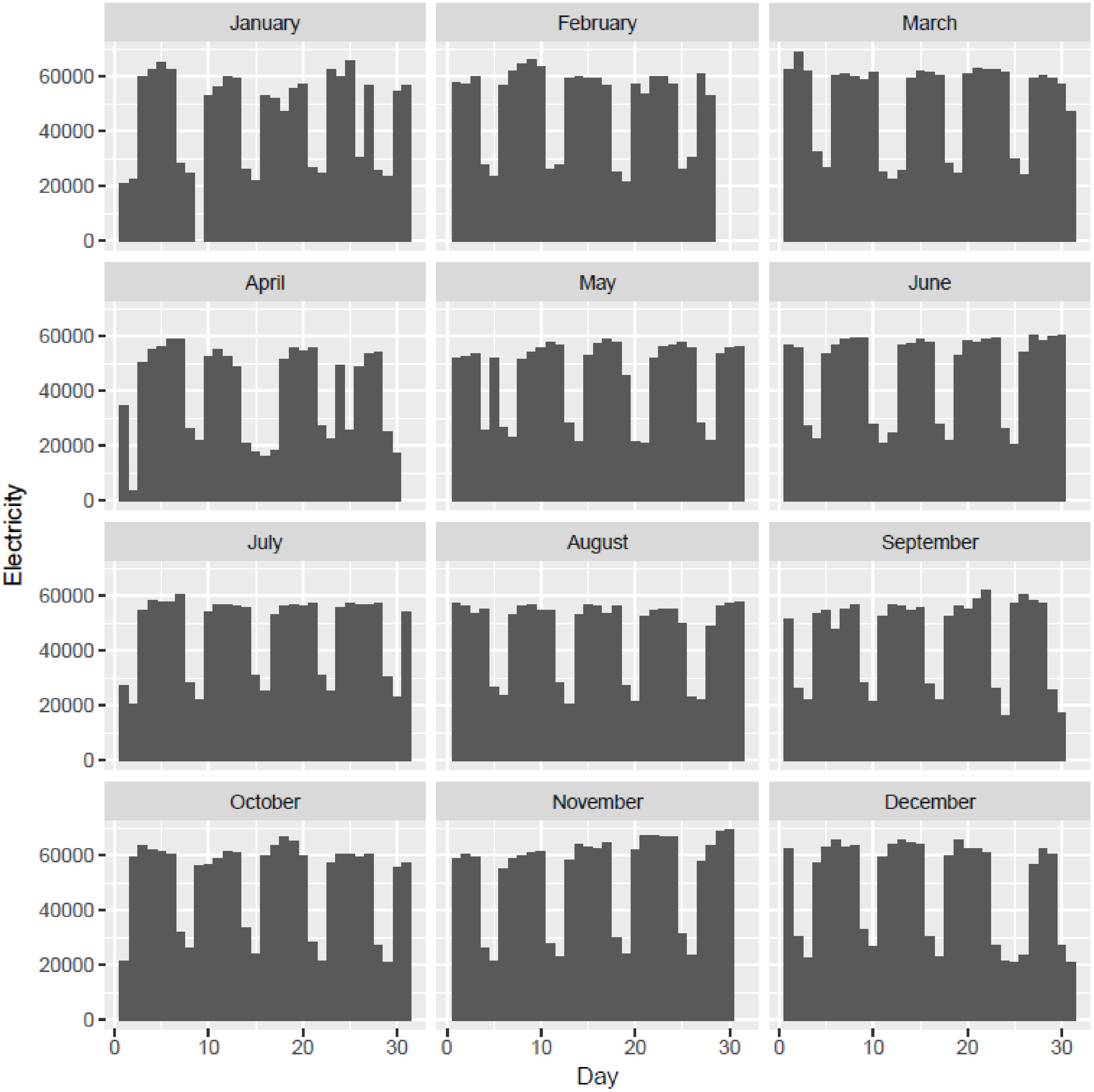


Figure 10. Monthly production of Bovine and Ovine

Daily energy use was graphed for each month and analysed (figure 11). Significantly less power was consumed on weekends which can be explained due to non-production days. Every week, within the month, Monday consumes less energy than all other weekdays. Tuesday through to Friday's power use appears to be fairly even and consistent. Investigation into why Monday's energy use is significantly less than other weekdays was investigated. Production was believed to be the contributing factor but after comparing production data it was found that Monday's production, whilst at times was less than other weekdays, was not consistent or significant enough to account for the difference in power consumption. This leads to questions around whether energy is being utilised or wasted during weekdays. Similarly, Sunday's power use is approximately one third that of Saturday's, yet neither day is a production period. One factor that may answer the above questions is cleaning. Each weekday night there is a cleaning shift. There is also a cleaning shift Saturday morning however, there is not Sunday night/Monday morning. This could account for the extra power consumed Tuesday through to midday Saturday.

Figure 11. Daily power consumption



Hourly power consumption was observed on weekdays and weekends. On a weekday energy consumption begins to increase from 5am, peaks around midday and begins to decline from 4pm (figure 12 (A)). This is trend is directly related to production shifts. From Midnight Friday the power demand continues to fall until 4pm Saturday (figure 12 (B)) where it levels out and is consistent until early Monday morning (figure 12 (C)). It is believed that the majority of power consumed over the weekends would be refrigeration, however, this does not explain why Saturday's consumption is higher.

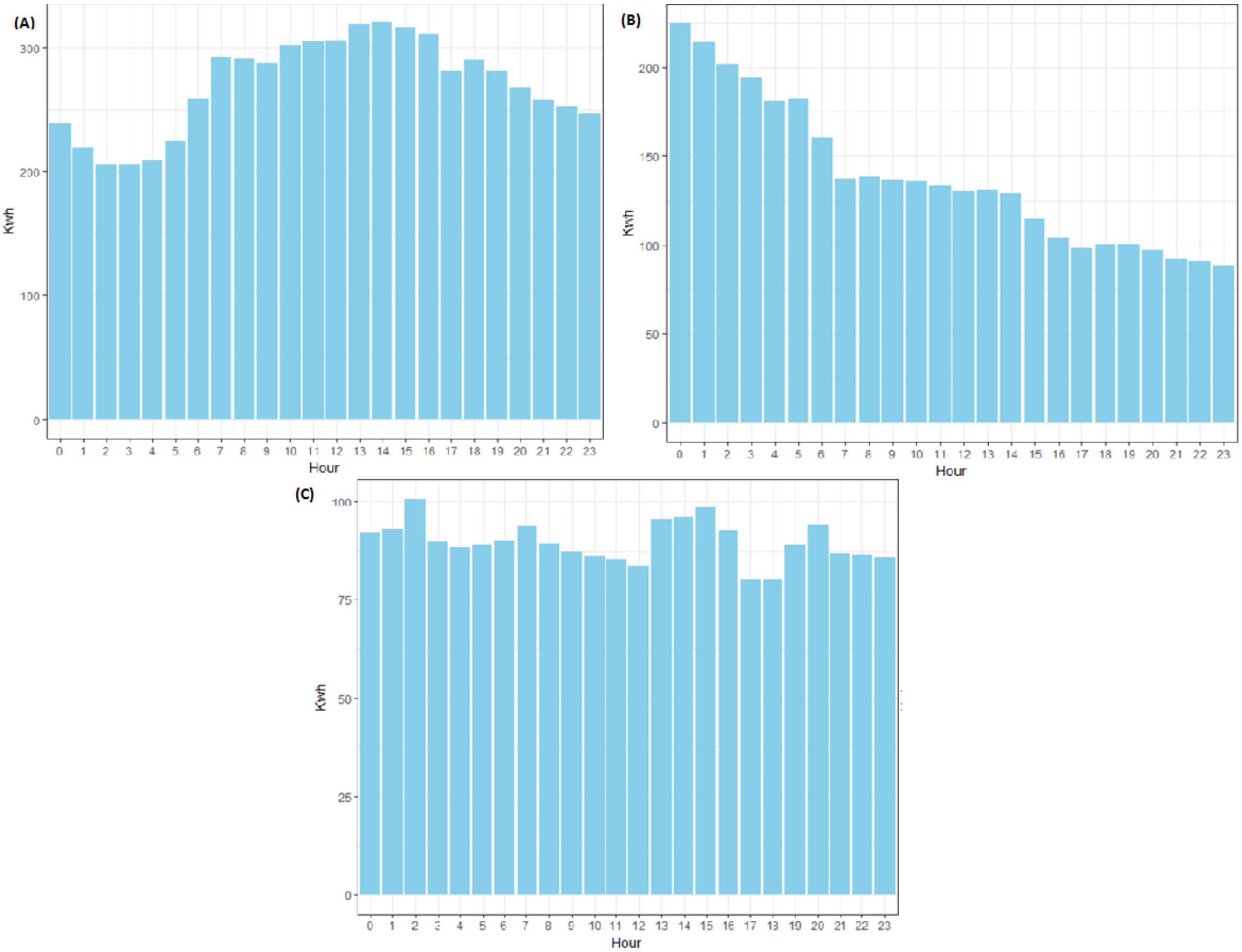


Figure 12. A) Hourly power consumption for an average weekdays B) Hourly power consumption for an average Saturday C) Hourly power consumption for an average Sunday

Power consumption pattern varies daily, however, this daily variation is carried throughout the month as seen in figure 13. All Monday's follow the same pattern, as do Tuesday, Wednesday's etc.

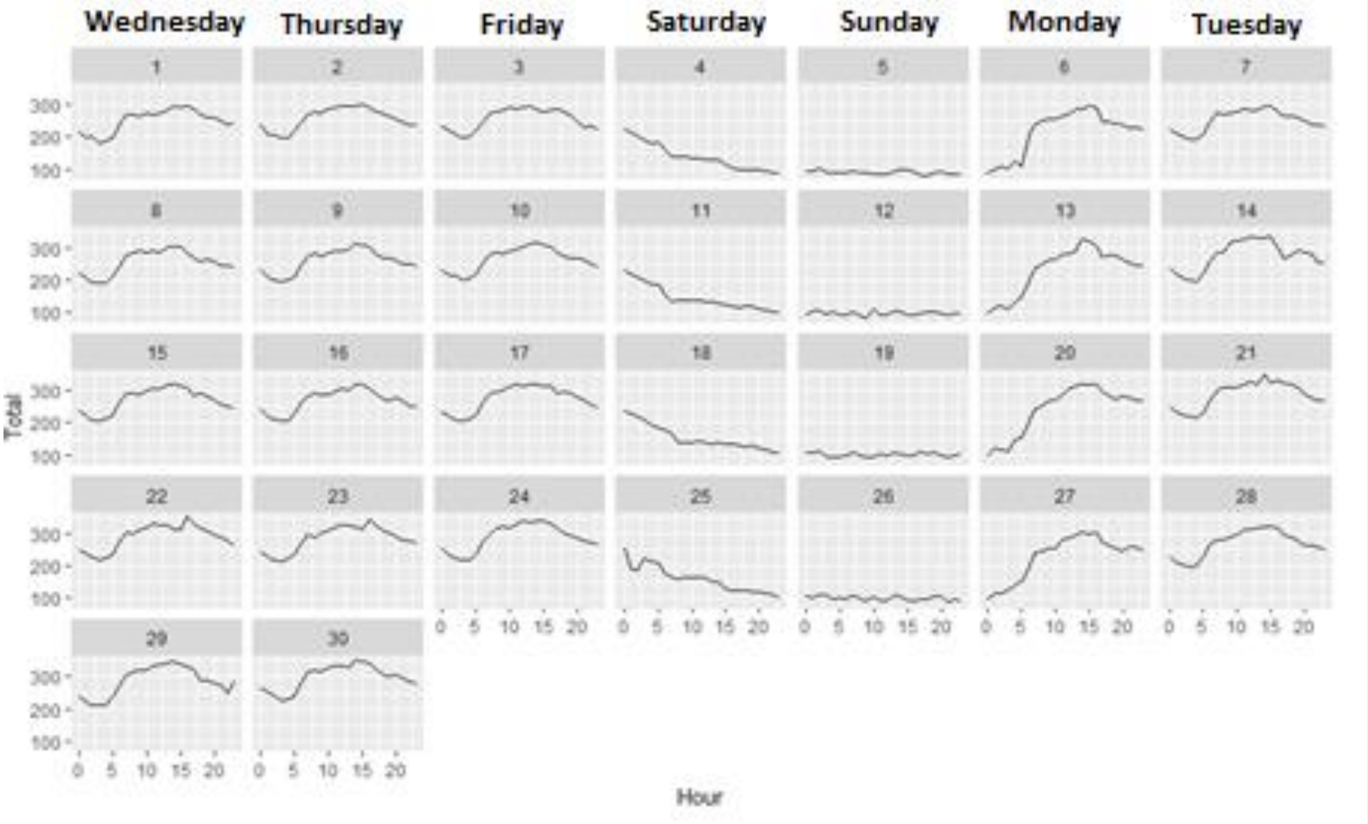


Figure 13. Hourly power consumption of a month showing hourly, daily, weekly pattern of power consumption.

As shown previously in Figure 4, processing equipment and refrigeration are the two major power consuming activities in plant. Of those two, refrigeration works 24/7 all year. Process equipment runs during weekdays 5am to 4pm. Figure 4 also depicts another point that 15% of the power used could not be identified. This is significant because when calculation power utilisation, 15% of the energy consumption cannot be accounted for.

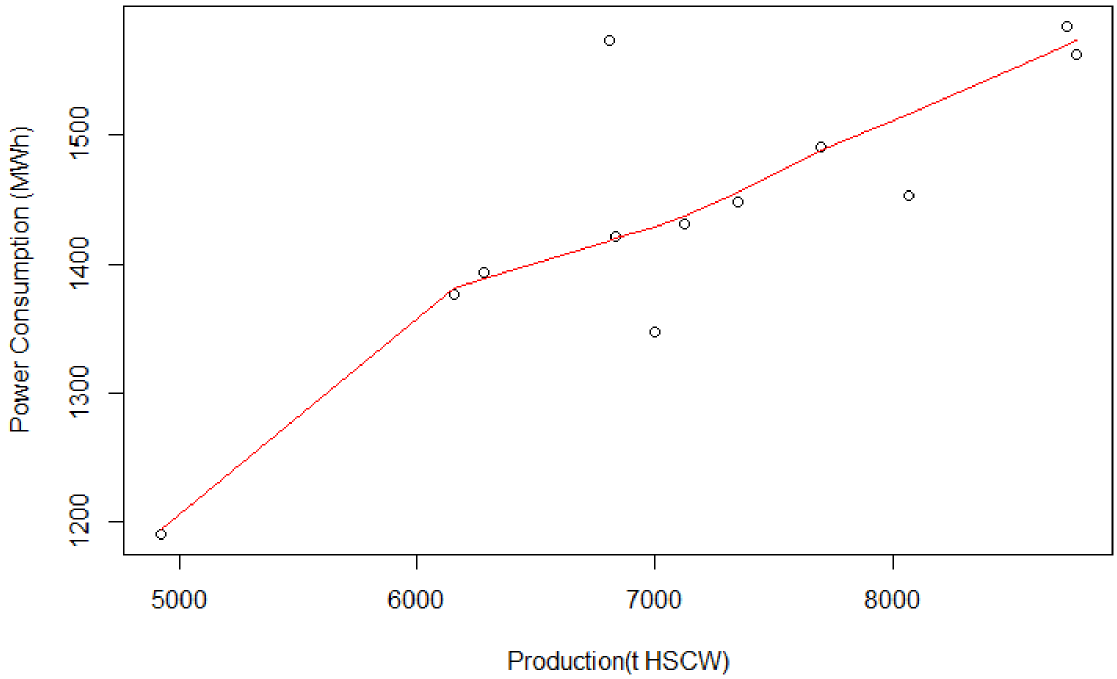
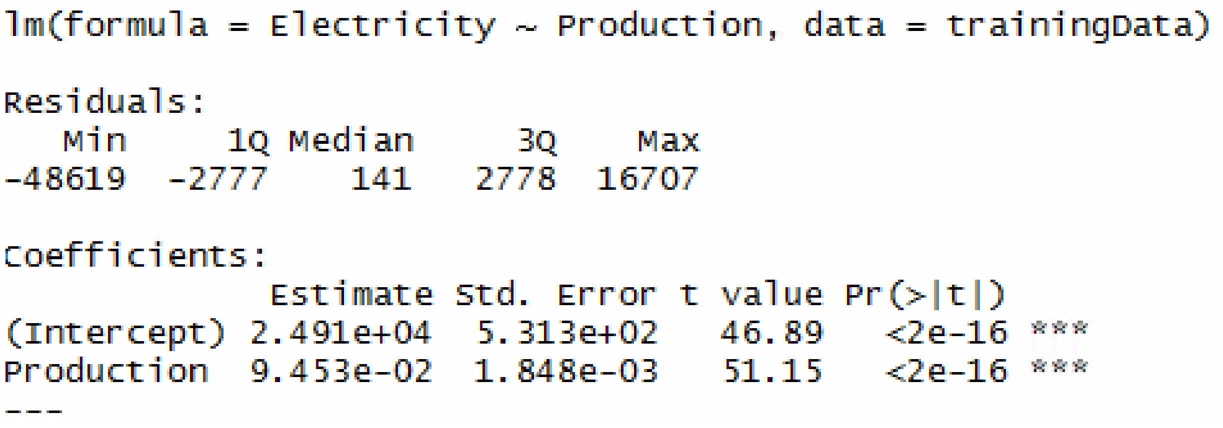


Fig 14: Correlation between production and power consumption

To develop a power consumption baseline for energy performance monitoring, an accurate predictive model with relevant variables was required. Figure 14 showed that overall power consumption follows the trend of production. As tonnes produced increased so did the energy required. However, there were three months which did not follow this trend. Further exploration occurred to find out suitable dependency of power consumption along with production as indicated earlier in exploratory analysis of power historical data.



```
lm(formula = Electricity ~ Production, data = trainingData)

Residuals:
   Min     1Q Median     3Q    Max 
-48619  -2777    141   2778  16707 

Coefficients:
             Estimate Std. Error t value Pr(>|t|)    
(Intercept) 2.491e+04  5.313e+02   46.89   <2e-16 ***
Production  9.453e-02  1.848e-03   51.15   <2e-16 ***
---
```

Figure 15. Typical output coefficient of the model

Figure 15 shows the coefficient model when working out the dependency of power on production. The baseline equations for the model was believed to have a 92% accuracy when comparing actual power consumption with the models prediction of the training data set (figure 16(B)).

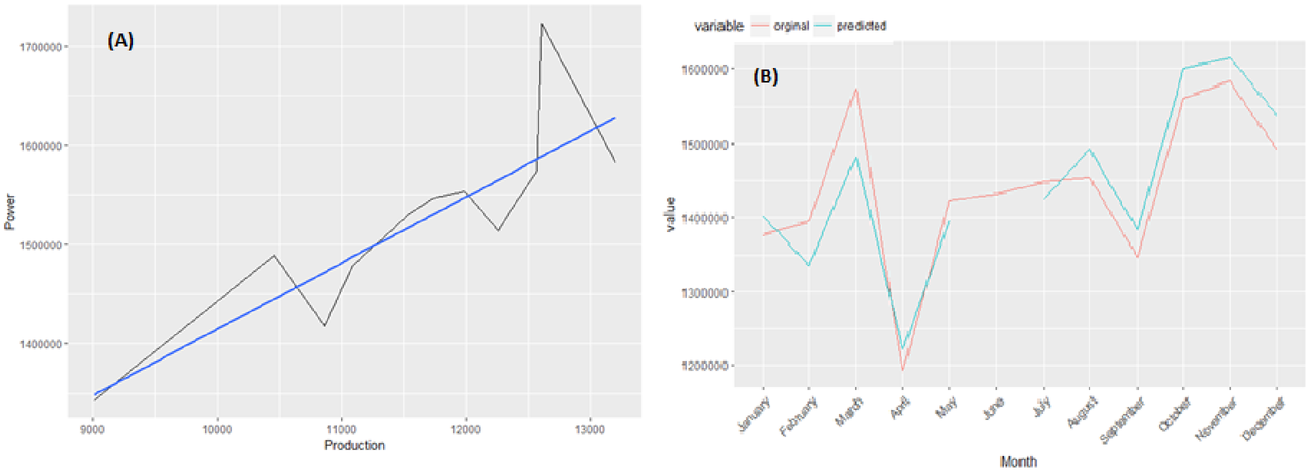


Figure 16. (A) Average model of baseline (B) Comparatively accurate model of baseline

The predictive model can now be used with confidence of 92% accuracy when predicting power consumption against production output.

4.2 Gas and Hot Water

Gas usage was able to be successfully traced in all processes at the facility. 94% of gas usage is powering the two boilers for the production of hot water (Figure 17). The remaining 6% went to services. 68% of all gas used on plant powers boiler 3MW. All energy produced is used to heat water to 92°C. From there 69% of the hot water is used to produce 85°C water for production, 22% is blended with 35°C RO water to produce 65°C water and 9% of the energy produced heats 15°C town water to 45°C via heat transfer (Figure 18). 26% of the plants gas is consumed by Boiler 2.5MW. This boilers distribution of energy required to produce varying degrees of water temperatures is the same as the 3MW boiler.

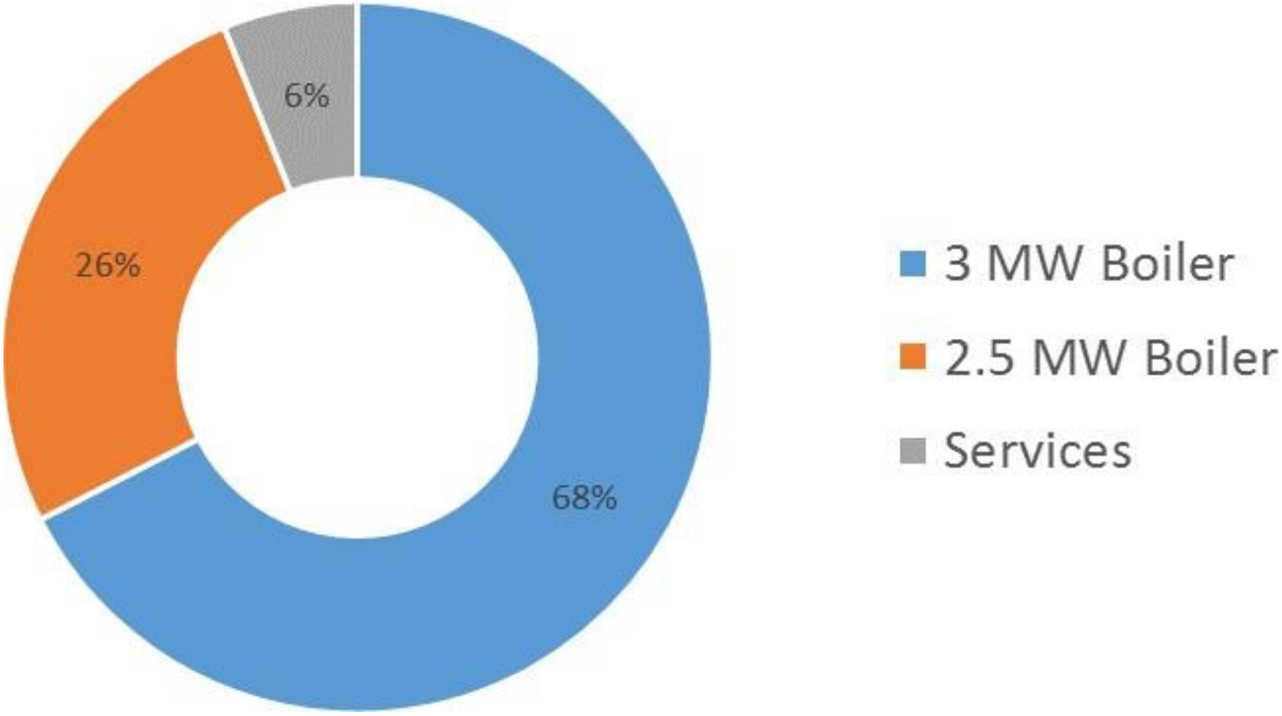


Figure 17. Mass balance Natural Gas consumption

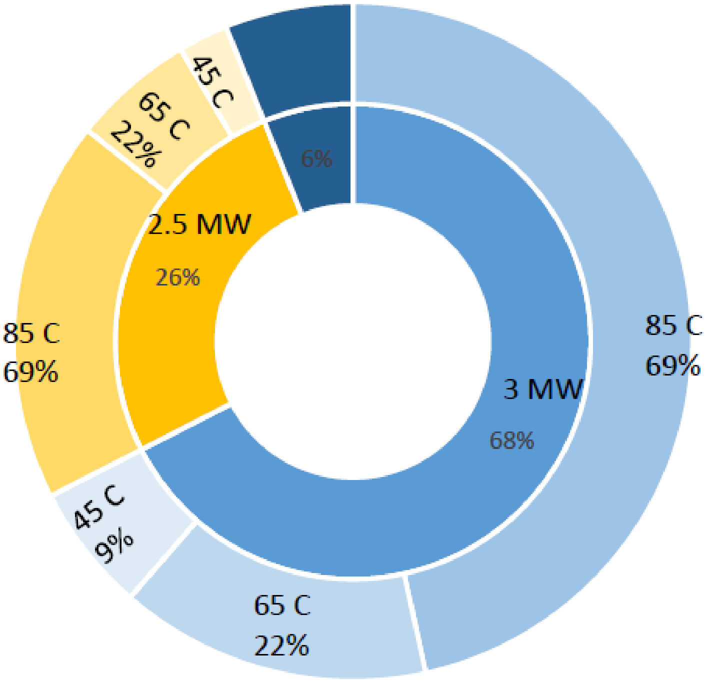


Figure 18. Gas distribution according to hot water usage per boiler

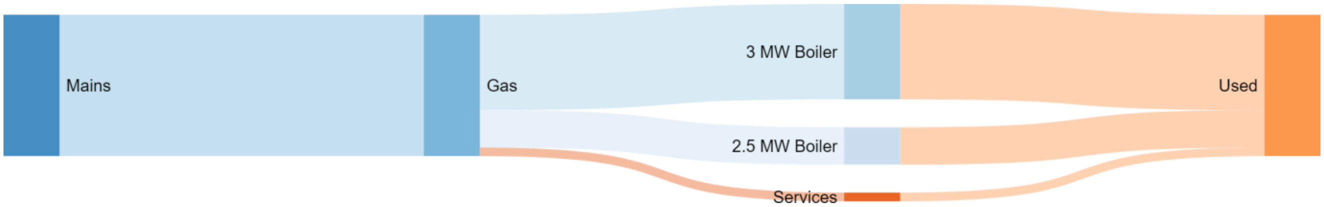


Figure 19. Gas consumption and usage flow diagram

Gas distribution is fully metered and understood.

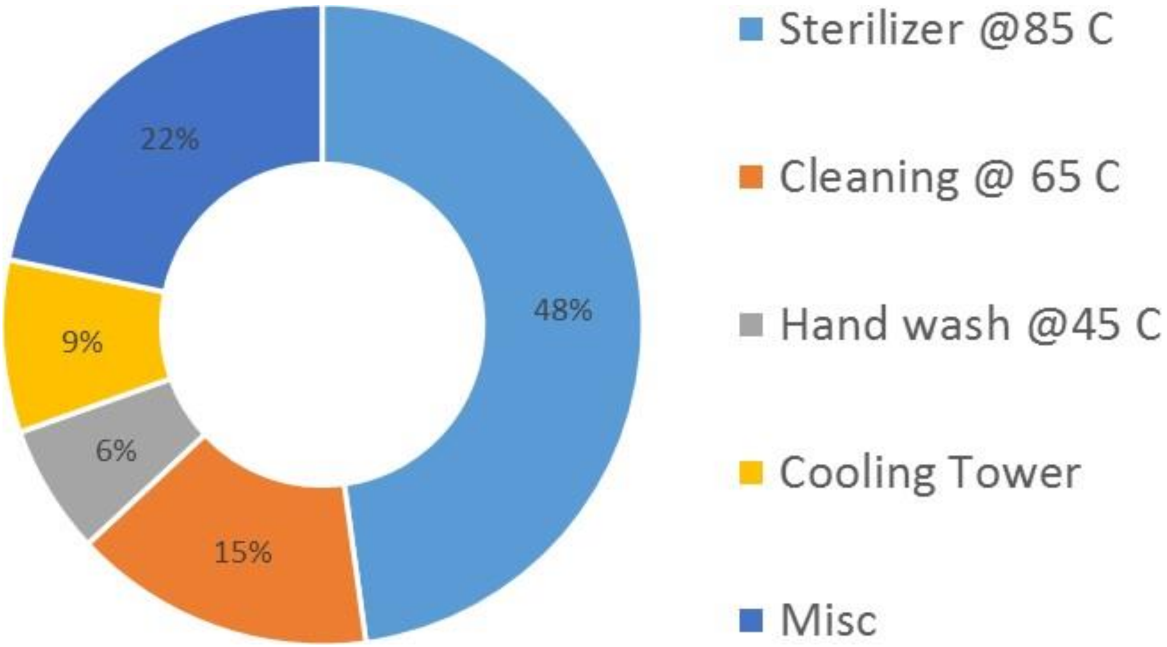


Figure 20. Hot water usages in various process and purpose, showing portion of unidentified water usage

During the investigation into water distribution, a map was found to exist which contributed to the understanding of water distribution and flow, however, understanding the volumes of water being used in specific areas was not easily measured. Total volumes consumed for 85°C, 65°C, 45°C water as well as water required for the cooling tower operations and miscellaneous (non-production) operations were fully understood (figure 15). Current metering and layout meant that 8% of water use was unidentifiable. This 8% equates to approximately 250-300kL per day of waste water that cannot be explained (figure 20). It is thought that general washdown water at lairages which use a portion of recycled water may contribute to the unidentifiable given the timing of collection, storage and use not aligning with outflow data.

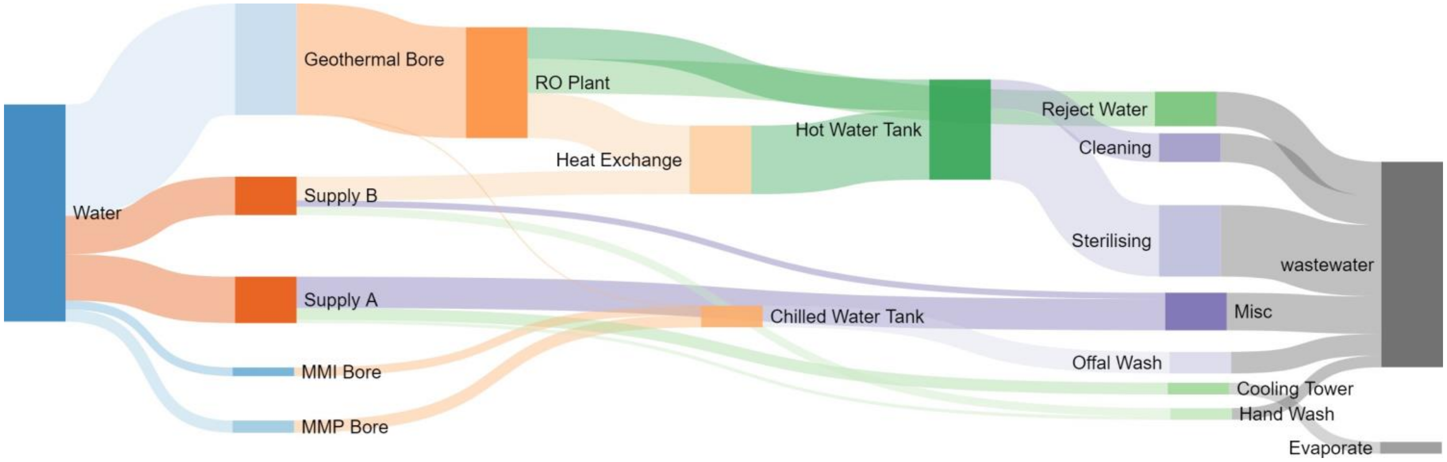


Figure 21. Water flow diagram showing supply and heat gain in various process and steps. It also shows unknown usage

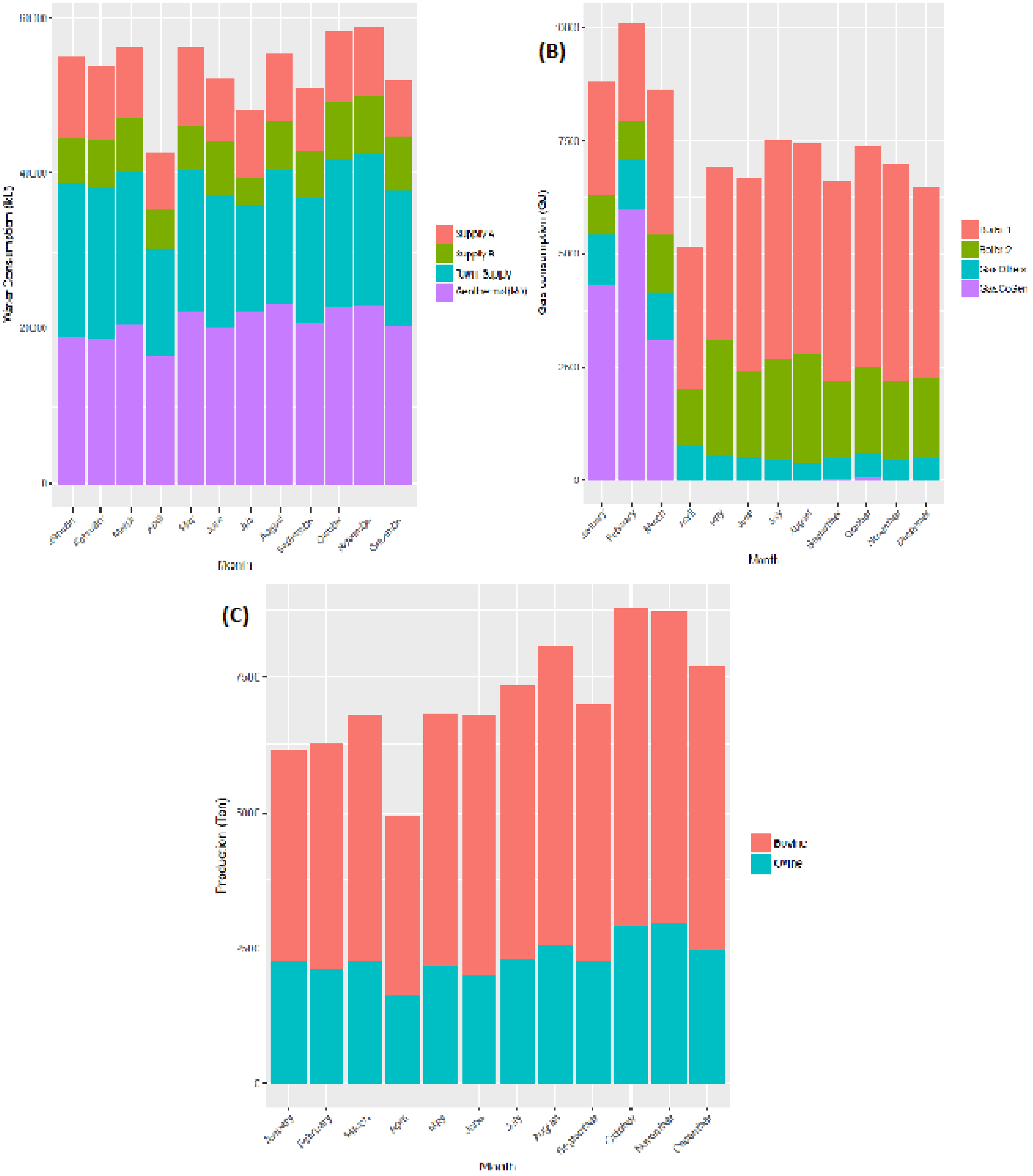


Figure 22. A) Water consumption over a 12 month period B) Gas consumption over a 12 month period C) Production tonnes over a 12 month period

There appears to be very little corellation between water use and gas consumption (figure 22 (A&B)).

Figure 23. Daily Water (A) and Gas (B) consumption. Daily production tonnes (C)

Daily water and gas consumption was graphed for each month and analysed (figure 23 (A) and (B)). Significantly less water and gas was consumed on weekends which is due to non-production days. Mid-March 2017 gas consumption dropped significantly. This was due to the reduction in use of the Cogen plant. From there gas usage remained fairly consistent throughout the year.

5 Energy Efficiency Measures

5.1 Power Factor Improvement

Power Factor (PF) is a measure of how effectively incoming power is used in your electrical system and is defined as the ratio of Real (working) power to Apparent (total) power. PF plays an important role in the efficiency of the electrical power system.

Real Power (kW) is the power that actually powers the equipment and performs useful, productive work. As seen in figure 24, if KVAR can be reduced, same amount of kW can be achieve from reduced amount of KVA.

PF at Midfield varies from 0.85 to 0.88. Below calculation shows savings if PF can be improved to 0.97.

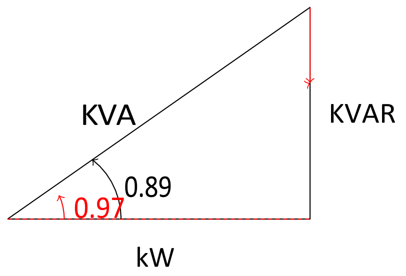


Figure 24: Power triangle showing KVAR reduction

Table 3: Overall all Power Factor Improvement cost benefit analysis

	Existing	Corrected	
PF	0.898	0.97	
KVA	4415	4087	
KW	3964	3964	
Demand Charge	$ 35,600	$ 32,958	
Savings		$ 2,642	Monthly
		$ 31,710	Annually
Correction Required	1757	KVAR	
Estimated Cost	$ 166,958		
Simple Payback Period	5.27	Years	

There are numerous benefits to improving PF efficiency. The benefits include reduced demand charges, increased load carrying capabilities in your existing circuits and overall reduced power system loses. There are also huge environmental benefits associated with PF improvement such as reducing the facilities carbon footprint. An electric motor with VSD installed would get reactive current from VSD DC bus. The VSD would draw sinusoidal current from supply, hence it improves the power factor. Section 5.2 presents energy efficiency improvement by VSD installation. If the VSD initiative was to be implemented, then the PF improvement on the electric motor would be significant.

Individual substation PF needs to be validated before PF improvement initiative is implemented.

Table 4: Substation 1 (TX1) Power Factor Improvement cost benefit analysis

	Existing	Corrected	
PF TX1	0.887	0.97	
KVA	927	848	
KW	822	822	
Demand Charge	$ 7,476	$ 6,836	
Savings		$ 640	Monthly
		$ 7,676	Annually
Correction Required	337	KVAR	
Estimated Cost	$ 32,033		
Simple Payback Period	4.17	Years	

Table 5: Substation 2 (TX2) Power Factor Improvement cost benefit analysis

	Existing	Corrected	
PF TX2	0.94	0.97	
KVA	883	856	
KW	830	830	
Demand Charge	$ 7,120	$ 6,900	
Savings		$ 220	Monthly
		$ 2,642	Annually
Correction Required	540	KVAR	
Estimated Cost	$ 51,336		
Simple Payback Period	19	Years	

Table 6: Substation 3 (TX3) Power Factor Improvement cost benefit analysis

	Existing	Corrected	
PF TX3	0.93	0.97	
KVA	1280	1227	
KW	1191	1191	
Demand Charge	$ 10,324	$ 9,898	
Savings		$ 426	Monthly
		$ 5,109	Annually
Correction Required	696	KVAR	
Estimated Cost	$ 66,131		
Simple Payback Period	13	Years	

Table 7: Substation 4 (TX4) Power Factor Improvement cost benefit analysis

	Existing	Corrected	
PF TX4	0.84	0.97	
KVA	1324	1147	
KW	1113	1113	
Demand Charge	$ 10,680	$ 9,249	
Savings		$ 1,431	Monthly
		$ 17,176	Annually
Correction Required	348	KVAR	
Estimated Cost	$ 33,065		
Simple Payback Period	23.1	Months	

Table 8: Power Factor Improvement cost benefit analysis summary of all substations

Substation	Power Factor	Payback	
TX1	0.88	4.17	Years
TX2	0.94	19	Years
TX3	0.93	13	Years
TX4	0.84	23.1	Months

Although overall PF is 0.898, individual PF vary from 0.84 (TX4) to 0.94 (TX2). Varying PF values means that each substation has a unique pay pack periods, as seen in Table 8.

TX4 has the shortest payback period of 23.1 months. Due to this short timeframe it is concluded that, if desired, a VSD should be installed here first to ensure capital savings are realised at the earliest time possible.

5.2 VSD installation in Motor loads (Pumps, Refrigeration and Air compressors)

Induction motors are essential for industries and utilities operations. Induction motors constitute more than 50% of the energy used in industry (M. Rabbani 2018). Compared to other types of loading, the induction motor has a relatively poor power factor which results in higher line currents causing additional heat in line cables and transformers. Induction motors takes both active and reactive current to produce the required torque and speed. The rotating torque is the result of interaction between the active current component and the magnetic field. The magnetic field is created by the reactive component. Although light loading requires less active current, the magnetic field remains the same therefore, a motor running lightly loaded has low power factor. As a more efficient means of capacity control, large motors with variable loads operating for long periods can benefit from VSD. VSDs are cost effective for motors that operate equipment with variable demands such as throttle valve-controlled water pumps, evaporator fans with variable flow requirements or air compressors. The use of variable speed AC drives (VSD) to control motor speed therefore has the advantage of improving the power factor which will reduce losses in the supply cables and transformers. It can also help avoiding the cost of power factor improvement.

Table 9: Cost Benefit analysis of VSD installation on motors considering 25% of total load are motors and those runs 3750

hours per year

	without VSD	with VSD
Annual Energy use (kWh)	5,775,000	4,620,000
Annual Energy Cost	$ 866250	$ 693,000
Annual Saving	$ 173,250	
VSD Cost	$ 359,152	
Payback	25	Months

5.3 Refrigeration system

Refrigeration system is the largest user of electricity in the plant. Refrigeration energy consumption data can be broken down into a base demand and a production demand. Base demand is the energy required to maintain the chiller at the desired temperature with the doors closed. Product demand is the additional energy needed to reduce the temperature of the meat. The infiltration of warm air through the open doors during loading further adds to the product load on the refrigeration plant. The base demand depends on the average ambient air temperature, the level of insulation, the fan power and the control system used. From the energy consumption data of the refrigeration system we see that there is noticeable energy use even during non-production hours particularly on nonproduction weekends.

This indicates that there could be any or all of the following;

- cooling loss (insulation, open door)
- unnecessary heat gain
- other system losses

The energy efficiency of a refrigeration system can be expressed as the Coefficient of Performance (COP) for that plant.

$$COP = \frac{Refrigeration\ Load\ in\ kW\ Refrigeration\ (kW\ r)}{Electrical\ Load\ in\ kW}$$

A higher COP for a refrigeration system indicates a higher efficiency of the electricity used in that system. Detail system design parameter and further process specific investigation is required to pin point specific problem and suggest a suitable savings initiative for this system. Overall 10-20% improvement of refrigeration system would be expected.

5.4 Compressed Air system upgrading, leak detection and repair

The energy consumption curve shows that approximately 40% of power demand is outside the production hours. This indicates there could be some wastage (leaks or misuse) of compressed air. Leaks are a significant source of wasted energy in an industrial compressed air system. Leaks can be responsible for between 20-50% of a compressor output making them the largest single waste of energy. Leakage can come from any part of the air compressor system and the sources can be numerous. Leaks can also contribute to other operating losses such as;

- Drops in system pressure which can decrease the efficiency of the air tools and adversely affect production
- Forcing the equipment to cycle more frequently, shortening the life of almost all system equipment (including the compressor package itself)
- Increasing the running time that can lead to additional maintenance requirements and increased unscheduled downtime or,
- Adding unnecessary compressor capacity

To do adequate power cost calculations some accurate and consistent information is needed so that true costs can be calculated. Calculations shown in Table 10 considers the compressed air system constitutes 7% of total plant energy consumption and runs at an overall efficiency of 65%.

Table 10: Cost Benefit analysis of Compressed air leak detection and repair considering 10% loss

Plant Power Consumption p.a		18,000,000	kWh
Compressor Consumption p.a.(7-11%)	→ 10%	1,800,000	kWh
Compressed air system loss (20-50% Leaks, misuse)	→ 35%	630,000	kWh
At an average rate of 11cents/kWh	0.15	$ 94,500	$ p.a
Fixing cost (Estimated)		$ 185,000	$ p.a
Payback		23	Months

Table 11: Cost Benefit analysis of Compressed air leak detection and repair considering 20% loss

Plant Power Consumption p.a		18,000,000	kWh
Compressor Consumption p.a.(7-11%)	20%	3,600,000	kWh
Compressed air system loss (20-50% Leaks, misuse)	35%	540,000	kWh
At an average rate of 15cents/kWh	0.15	$ 81,000	$ p.a
Repair cost (Estimated)		$ 135,000	$ p.a
Payback		20	Months

5.5 High-efficiency Motors

The use of high-efficiency electric motors (HEMs) can lead to significant drops in energy use as well as significant savings in cost. Although replacement of an existing motor with an energy efficient motor may not be justified financially in some instances, it is important to ensure energy efficient motors are considered when motors with long operating hours are due for replacement. Purchasing of HEMs could also be included in the purchasing policy of the company so the entire motor fleet could be replaced with HEMs over a number of years. HEMs are usually manufactured from materials which incur lower energy losses. The high efficiency motors are more cost effective when a new motor is purchased or a failed motor requires replacement. HEM ranging from 4.5kW to 55kW has a payback period of 1-1.5 years in most of the cases.

5.6 Hot-water system operational improvement

Gas is predominantly used for the production of hot water. Reducing hot water wastage will improve gas consumption. Table 12 shows the amount of gas required to produce varying degrees of hot water.

Table 12: Annual Gas consumption for various hot-water system

	Sterilizing	Cleaning	Handwash
Input Water Temperature ('C)	30	30	12
Target Temperature ('C)	92	65	45
Daily usage (kL)	1125	625	375
Annual Gas used for Heating (GJ)	130,450	43,733	24,740

Several areas were identified where simple measures could be taken to reduce hot water consumption. It was found that a possible 17% of over all hot water used could be saved through metering, consumption awareness and control valves which would ensure hot water was only being consumed during production time and not wasted during breaks, downtime or end of shift.

Table 13. Potential areas where water can be saved or reused

Equipment	Area	Water savings (kL)	Total Water used	% saving
Hand wash	MMI	41.26	1492.00	3%
	MMP	172.90	1888.62	9%
Tripe cooker	MMI	325	892	36%
	MMP	262	1012	26%
Sterilisers		1650.22	17090.38	10%
Gut Tables initial rinse	MMI - SS	275	275	100%
	MMI - BF	687	687	100%
	MMP - SS	275	275	100%
	MMP - BF	387	387	100%
	Total	4075.38	23999.00	17%

Table 14 shows gas savings due when 5-15% hot water savings is achieved.

Table 14: Gas savings due to water savings

	Sterilizing	Cleaning	Handwash	Total Savings (GJ)	Total
Savings (5%)	6522	2187	1237	9946	$ 99,462
Savings (10%)	13045	4373	2474	19892	$ 198,923
Savings (15%)	19567	6560	3711	29838	$ 298,385

Whilst the above table shows the potential savings to be significant, the hot water system needs to be reviewed and evaluated to decide where control points should be implemented in order to achieve the desired savings. A site schematic plan was drawn to identify potential locations to for installing metering and control valves (Appendix – 3. Site map with desired metering and control valves). The valves would be programmed to divert or stop flows when water is not required. Currently there is not such control measure in place. An area where a shut off valve would have a significant effect of hot water consumption is sterilisers. Currently each steriliser flowrate and shut off is controlled by the operator. A conservative estimate of water savings calculations said that a potential 10% water savings could be achieved with the application of a control valve on each production floor enabling the supervisor to shut off water flow to sterilisers during downtime, breaks and shifts end. This 10% savings equates to approximately 20ML of 82°C water per annum. This would have a flow on effect of not just the energy savings in gas but the expense of water supply and disposal charges.

Management tools have been developed in order to track water usage and waste. Waste water volumes have dropped significantly since January 2018 (Appendix – 4. Waste water tracking management tool). This is a direct result of implementing monitoring systems and management/operator awareness of water use.

5.7 Heat loss uninsulated ring main pipe

Turning off hot water circulation systems during non-production times will save energy by not running pumps and also heat loss through uninsulated plumbing.

Calculations of heat loss in a 100mm diameter, 500m uninsulated pipe for an eight hour period is shown in table 14.

Table 14: Heat loss calculation

Pipe Length	500	M
Pipe dia	100	Mm
Heat transfer coefficient	6	$W\ m^2K$
Temperature Difference	80	C
Heat loss	75.408	kW
For 8 hours daily	603	kWh
Annual Heat loss	660,574	kWh
Annual Heat loss	2,378	GJ
Savings	$ 23,779	

5.8 Solar PV

The power consumption pattern shows that the plant has a considerable amount of base load. Therefore during operation hours power consumption surges higher peaks which results in higher network charge. Solar PV has the potential to reduce and smooth down those peaks. Considering solar irradiation and power demand a 1500 kW system has been studied. Table 17 shows power generation, savings and payback of proposed solar. Although solar payback and savings appears to be economically sound, due to space limitation at the facility, implementing solar infrastructure at this stage is not viable.

Table 17: Solar PV system cost benefit analysis

PV system Proposed	1500	kW
Panel Required	6977	
space required	10,465	s^2m
Generation from 1.5MW system	7200	kWh daily
	2,628,000	kWh yearly
Price of Power Generated pa	$ 394,200	
Installation cost/kW	$ 1,000	
Installation cost	$ 1,500,000	
Payback	3.81	years

6 Conclusions/recommendations

The increasing energy demand by the meat sector can be explained by two major factors, consumer preferences and ever-increasing food safety/customer requirements (Ramirez C.A. et al 2004). Producing frozen or deboned product is energy intensive and therefore, increased demand in this product raises the energy consumption of a facility. Food safety and customer requirements also has an impact on the energy consumption of the facility by changing the processing conditions. In recent years food scandals have shaken the industry and generated a strong focus on food safety. Temperature has been a fundamental factor in increasing food safety. A Dutch study has shown that the introduction of the Hazard Analysis Critical Control Points method for food health, safety and quality has led to an increase in energy consumption in the meat industry (The Hague: MINEZ 1999). The higher energy consumption stems from higher demand of hot water for sterilization of tools and the bacterial decontamination of carcasses. Refrigeration, noted as being the biggest consumer of electricity, loading as increased also with the introduction of legislation requiring meat to be chilled to under 7°C in 24 hours.

The purpose of this study was to analyse energy use and determine energy efficient developments to be taken to decrease the demand on energy making the process more economically viable and decreasing the effects the meat industry has on the environment.
During this study we have several areas where simple procedures, monitoring devices or controls could be put in place which would significantly reduce the amount of energy and water consumed on plant.

Refrigeration is the major power consumer on site. It has been shown to use 44% of all power consumed. Improving power factor to ensure all motors are operating at optimum efficiency is recommended. The installation of VSD's will also help to ease the pressure of increasing power prices. VSDs are cost effective for motors that operate equipment with variable demands. The use of variable speed AC drives (VSD) to control motor speed therefore has the advantage of improving the power factor which will reduce losses in the supply cables and transformers. It can also help avoiding the cost of power factor improvement.

Air leaks were determined to be a potential issue on plant. A recommendation to install master controls to isolate areas when not being used were made, however, it was found that the current system has equipment which needs to operate continually connected with equipment that could be turned off. Therefore, ongoing measures must be determined to assess the ability to separate the different types of equipment to utilize the potential that a master control can offer.

The hot water system was reviewed. It was found that the water and gas consumption generally followed to the production trend. The majority or gas and water is consumed during production hours. However, the amount of hot water used fluctuated throughout the production period and several days that produced the same tonnage of product consumed varying amounts of water. This was believed to be due to areas not turning of taps, hoses or sterilisers when not being used such as breaks or end of shifts. The hot water consumption could not be broken down in to floors because of the labyrinth of pipes lining the facility. It was recommended therefore to look to incorporate metering on the plant to have a better understanding of what water is being used where and control valves to be implemented to reduce wasted water where ever possible. The recommended positions for metering and control valves can be seen in Appendix – 3. Site map with desired metering and control valves.

This energy review showed that there is potential for the infrastructure to be built to allow a hot water ring main around the entire site. This could connect the main boiler house with the proposed protein recovery plant (PRP) and include the ability to pass back through the Cogen plant. Currently in place is a one-way flow from Cogen to which does not utilize the full potential of heat transfer. A ring main would allow the water to recirculated, utilizing all heat waste from Cogen and PRP and in turn reduce the boiler inputs.

Table 18 shows a summary payback of all recommended energy efficient initiatives previously stated.

Table 18: Summary of Energy Saving Initiatives

Energy Saving Measures	Savings	Cost	Payback	
Power Factor Improvement	$ 41,000	$49,447	9	Months
Compressed air Leak repair	$ 94,500	$ 50,000	6	Months
VSD Installation	$ 358,050	$ 239,434	8	Months
Hot-water usage metering and control valves	$ 98,923	$217,000	2.2	Years
Solar PV	$394,200	$438,505	3.85	Years

The facility will assess and prioritise the energy saving initiatives. This will include areas for improvement and will consider if any or part of the initiatives may be included in existing upgrade plans or be segregated and reviewed individually. The facility will see support from potential grants where possible to assist with shortening payback period and decrease financial stress on the business.

All costing are estimated figures. Formal figures for upgrades to key areas and infrastructure will be submitted to confirm feasibility of payback periods.

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8 Appendix

Site map with desired metering and control valves