MODELLING AND BENCHMARK DEVELOPMENT FOR ELECTRICAL ENERGY USE AND ENERGY EFFICIENCY ON NOVA SCOTIA DAIRY FARMS

by

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Submitted in partial fulfilment of the

Requirements for the degree of Master of Science

at

Dalhousie University

Halifax, Nova Scotia

February 2015

Table of Contents

List of Tables iv

List of Figures v

Abstract vii

List of Abbreviations Used viii

Acknowledgements ix

Chapter 1: Introduction: 1

Chapter 2: Literature review 5

2.1 Milk Cooling 6

2.2 Water Heating 13

2.3 Milk Collection 17

2.4 Lighting 21

2.4.1 Effect of photoperiod 21

2.4.2 Lamp efficiency and lamp life 23

2.4.3 Color Rendering Index 23

2.4.4 Types of light: 24

2.5 Manure handling 28

2.5.1 Collections: 30

2.5.2 Waste transfer to storage: 32

2.6 Ventilation 33

2.7 Feed 39

Chapter 3: Objective and Methodology 47

Chapter 4: Energy Audit 53

4.1. Summary of NS Dairy Farm Audit Data 54

4.2. Sample t test: 56

4.3 Free stall: 57

4.4 Tiestall: 58

4.5. Small, Medium and Large Farm 59

4.6 Energy Utilization Index 62

4.7 Regression Analysis: 64

Conclusion 65

Chapter 5: Model and Benchmark Development 67

5.1. Milk Cooling 67

5.2. Water Heating 73

5.3 Milking 78

5.4. Lighting 80

5.5. Manure handling 84

5.6. Ventilation 88

5.6.1. Natural ventilation with cooling fans 89

5.6.2. Mechanical ventilation: 91

5.7. Feed 93

Chapter 6: Validation and Case Study 97

6.1. Water heating: 98

6.1.1. Heat recovery unit (HRU) and Precooler Case Study 99

6.2 Cooling: 105

6.3. Vacuum pump 108

Chapter 7: Conclusions and Recommendation 112

References: 120

Appendix A: Energy Audit 126

Appendix B: Milk Cooling 147

Appendix C: Water Heating: 149

Appendix D: Milking 151

List of Tables

Table 1 : The illumination level required in dairy facility for various task or in different work areas 22
Table 2: Characteristics of dairy facilities light sources used for indoor lighting 23
Table 3: The amount of manure typically produced from dairy cows of different weights..................29
Table 4: Recommended minimum efficiencies for energy efficient agricultural ventilation fans (30, 60, and 90 cm sizes)..................37
Table 5: Different ventilation rates for various ambient temperature (retrieved from Gooch et. al. 2008) 92
Table 6: Summary of model, benchmark parameter and EF technologies for each operations.....95
Table 7: Seven farms water heating energy use audited data using model and measured for different technology installed..................102
Table 8: Water heating EUI range for sink and bulk tank size 104
Table 9: Ten farm milk cooling energy use with model and measured data. 106
Table 10: 5 farms vacuum pump model and measured energy use with and without variable speed drive 108
Table 11: Vacuum pump EUI values..................111
Table 12: Results for model for each component and benchmark parameters and its savings....115

List of Figures

Figure 1: Milk cooling system with the presence of precooler, heat recovery unit and water heater....7
Figure 2: A precooler installed in one of the audited dairy farm to cool milk from the cow....9
Figure 3: A scroll compressor and fans installed in an audited dairy farm....11
Figure 4: A heat recovery unit installed in one of the audited dairy farms....14
Figure 5: Vacuum pump and motor....18
Figure 6: Milk receiving jar and transfer pump....19
Figure 7: T8 lights installed in milking parlour....25
Figure 8: HID light in cow barn....27
Figure 9: Alley scraper in a freestall barn....30
Figure 10: A barn cleaner....31
Figure 11: Natural ventilation with cooling fans in one of the audited dairy farm....35
Figure 12: Tower silo and Bins....41
Figure 13: A stationary Total mixed ration mixer....43
Figure 14. Feed mixing station....44
Figure 15: Total average energy use for 19 dairy farm....55
Figure 16: Boxplot of freestall and tiestall utility energy use....57
Figure 17: Breakdown of energy used by function in Nova Scotia Free stalls farms....58
Figure 18: Breakdown of energy used by function in Nova Scotia Tie stall farms....59
Figure 19: Percentage of various energy use components of small farm size....60
Figure 20: Percentage of various energy use components of medium farm size....61
Figure 21: Percentage of various energy use components of large farm size....62
Figure 22: Sink installed in an audited dairy farm to clean bulk tank, pipelines and milking units....74
Figure 23: Lighting energy consumption for various lighting systems for 19 audited dairy farms compared to number of milking cows....82
Figure 24: Manure handling energy use for 13 different farms including different types of manure handling equipments used and number of milking cows....88
Figure 25: Relation between energy use for milk cooling (kWh/yr) vs milk production per day (hl/day)....107

Figure 26: Relation between energy use for vacuum pump (kWh) vs vacuum pump size and time of use (hp*hr) 110

Abstract

The analysis of energy use on dairy farms faces a number of challenges, based partly on benchmark parameter currently used as a means to quantify energy consumption. This research addresses this issue, using energy audit data obtained from 19 dairy farms in Nova Scotia to produce benchmark parameters that relate energy use to each operational component of the dairy farm. Models were produced on the basis of energy audit data and theoretical performance of each operational component. These models for major energy component were validated using two statistical tools; Coefficient of Efficiency and Index of Agreement. Model approach was used to determine the benchmark parameters. EUI values were computed based on the model developed, audit data and benchmark parameter, resulting in more pragmatic benchmark values. This research also identifies the potential savings from installation of energy efficient technologies suitable for each major energy components.

List of Abbreviations Used

ASAE	American Society of Agriculture Engineer
ASABE	American Society of Agriculture and Biological Engineer
COP	Coefficient of Performance
cwt	Hundred Pounds of Milk
CFL	Compact Florescent Lamp
CFM	Cubic Feet per Minute
CRI	Color Rendition Index
EF	Energy Efficient
EUI	Energy Utilization Indices
FC	Footcandles
HPS	High Pressure Sodium
HRU	Heat Recovery Unit
HVLS	High Volume Low Speed
kWh	Kilowatt-hour
LED	Light Emitting Diode
LDPP	Long Day Photoperiod
LVLS	Low Volume Low Speed
Lux	Measure of Light Intensity (SI units)
MH	Metal Halide
MV	Mercury Vapor
NS	Nova Scotia
SDPP	Short Day Photoperiod
TMR	Total Mixed Ration
VSD	Variable Speed Drive

Acknowledgements

I would like to thank my supervisor Dr. Kenny Corscadden for his consistent support and leadership in carrying out this research, as well as my committee member Dr. Peter Havard and Dr. Sophia He for their valuable suggestions.

I would also like to thank Dr. Tess Astatkie for his statistical support in analysing data and Gerry Macdonald for his valuable help and advice during energy audits. I would also like to extend my thanks to Growing Forward Provincial and Federal Agriculture for providing financial support for carrying out this research.

Chapter 1: Introduction:

Nova Scotia's electrical energy cost per kWh is one of the highest in Canada (Manitoba hydro 2014). This has a direct impact on the agricultural industry, as electricity is the most common and highly used form of energy on Nova Scotia (NS) farms (Bailey 2007). Based on a survey conducted by Bailey 2007, the cost to operate with respect to electrical energy usage on farm was one of the major concerns for NS farmers. According to Statistics Canada, the total operating expense of Nova Scotia farms in 2011 was 188% higher than 1993 (Statistic Canada, Table 002-0044). This increase in operating expenditure has a negative impact on farm profitability and ultimately, sustainability. Although fuel and electricity comprises just 6.6% of total farm operating expense, since energy prices have an increasing trend, improving farm energy efficiency can help to stabilize one aspect of increasing farm operating costs. This will further help to maintain agriculture production costs and benefit both farmer and consumer (Bailey 2007).

Bailey et al., 2008, claimed that approximately 83% of farmers showed an interest in implementing energy efficiency and renewable energy options on their farms. The interest in the implementation of energy efficiency was found to be highest with dairy farmers (Bailey et al., 2008), which is not surprising since dairy farms are one of the highest energy consuming agriculture sectors (Canadian Farm Financial Database, 2010). Bailey 2007 reports NS dairy farms to have one of the highest energy bills of all farm types, twice as high as the average NS farm energy bills. The same study reports electricity to be the most common and highest proportion of NS dairy farm energy bill. Energy is required on a dairy farm for a number of operations, which include milking, cooling, lighting, ventilation, water heating, manure handling and a variety of tasks, which make it more energy intensive in comparison to other agricultural sectors (Ludington et al 2003) (Brown et al, 2005). In 2008 and 2009, the electricity costs in NS increased by 16% (Canadian Farm Financial Database, 2010). If this trend continues, even if the annual increase is not sustained at 16%, it will have a significant impact on energy costs (NS power 2014, International monetary fund 2013). Therefore, reducing energy through the implementation of energy efficiency is essential to stabilizing at least one aspect of total farm operating costs.

Initial studies conducted by Energy Conservation Research Program (ECRP) suggest that the recommendation of appropriate energy efficient equipment and to evaluate present energy use benchmarking values plays a vital role. Benchmarking is a method which allows comparison of energy use between similar entities. It allows the comparison of energy use on one farm with the average of other farms or most efficient farms which helps to identify efficient and inefficient farms (Halberg et al, 2005). Studies have investigated dairy farm electrical energy use around the world with researchers attempting to benchmark or equivalently, set a standard for the amount of energy a farm should use in its daily operations with varying degrees of success (Farmer et al. 1990) (Farmer et al. 1988) (Eden et al., 2003) (Ludington et al., 2003) (Murgia et al., 2008) (Kammel and Patoch 1993). These studies use a standard of energy usage based upon kWh/cow-year or kWh/hl or kWh/cwt of milk produced annually (Farmer et al. 1990) (Farmer et al. 1988) (Eden et al., 2003) (Ludington et al., 2003) (Murgia et al., 2008) (Kammel and Patoch 1993). Variations in electrical energy use on dairy farms of similar size (number of cows) and/or production (amount of milk) have been identified, suggesting that the number of cows or quantity of milk produced are not the only indicators which should be considered when attempting to quantify energy use (Eden et al., 2003). This leads toward the need of identifying factors influencing the energy use of each operational component and subsequently the need to develop a model as a function of each operational component, and based on this model, to provide a more practical approach of benchmarking the energy use on a dairy farm.

Efficiency Nova Scotia have targeted dairy farms to reduce electricity use. The adoption of energy efficiency practices can reduce significantly energy use (Sanford 2003) and thereby reduce farm energy costs. People need information to implement energy efficiency technology. Bailey 2007 reported cost saving to be a likely factor which can influence the implementation of energy efficient technologies. Showing people where and how energy is used i.e. giving people feedback on energy use and saving potential can help reduce energy consumption (Shipworth 2000). To determine cost saving, first it is important to know how much energy is consumed before energy efficient equipment can be installed. The research presented in this thesis provides information to the agricultural dairy industry in Nova Scotia about how to estimate electrical energy use (model development) for each operational component and based on these models provide better benchmark parameter. It also provides information about different energy efficient technologies suitable for dairy farms and the subsequent potential savings. The research uses primary data collected from 19 dairy farm energy audits and farm utility bills to establish representative baseline energy consumption for the sector.

The overall objective of this project is to determine benchmark parameters which relate energy use for seven key operational components of the dairy farm. The seven key operational components are of light, milk cooling, water heating, milking, ventilation and air circulation, manure handling, and feed. The outcome will result in a more practical method for determining how and where electrical energy is used on dairy farms. The specific objective of this project is to develop a pragmatic mathematical model or an alternative way of representing energy consumption and benchmark parameters for each of the components of a dairy farm, to facilitate the computation Energy Utilization Indices (EUI) and to offer potential energy saving suggestions for major operational components.

Chapter 2: Literature review

Dairy farming in Nova Scotia is one of the largest industry sectors (in terms of cash receipts) of the province. Bailey et. al 2008 reported that the largest proportion of the energy expenditure on Nova Scotia dairy farms can be attributed to electricity and diesel. Farmer et al. 1990 reports water heating, vacuum pump, milk cooling, lighting and ventilation to be the five largest electrical using components of a dairy farm. The electrical consumption between these components differs based on farm characteristics; for example, whether it is tiestall / freestall or what type of energy efficient equipment, if any, is used. Tie stall barns have been found to have a higher ventilation requirement than free stall barns (Farmer et al. 1990). Research conducted by Farmer et al. 1990, proposed that the demand for electrical energy on dairy farms is driven by the milking times, size of the herd and also by whether the farm has heat recovery, precooling, electrical water heating or ventilation fans. Demands for the various end uses in a dairy farm are more seasonal, with the highest electrical peak demand typically found in winter. A number of differences can be accounted for by seasonal variations; for example, water heating and lighting demands are higher in winter, whereas milk cooling and ventilation are higher in summer. The smallest proportion of total energy use is attributed to the waste pump and feeding; these two components are also less variable (Farmer et al. 1990). Milking and cooling are the components that are driven by electricity on all dairy farms. As the energy used by these components is higher, the type of equipment used and managed for milk harvest and cooling can have a significant impact on the amount of electrical energy used (Wells 1991). More detail descriptions of each seven electrical components of dairy farm is described below:

2.1 Milk Cooling

Milk collected from the cow is at 39°C and must be cooled to 10°C or less within one hour and between 4°C and 0°C within two hours of milking (Canadian quality milk 2010) to maintain high quality levels that meet the health and safety standards for human consumption. Milk cooling is a large electrical energy expense on the dairy farms (Farmer et al. 1990).

According to the Ontario Ministry of Agriculture, Food, and Rural Affairs, 21% of the energy used on the dairy farm goes towards milk cooling (Clarke and House 2010). In another study conducted by Ludington et al. 2004, 27% of total energy requirements were attributed to the milk cooling process. Milk cooling is related more to the quantity of milk cooled and thus it can be expressed in kWh/cwt (hundred pounds of milk) rather than kWh/cow/yr (number of cows) (Farmer et al. 1990). The energy utilization indices for milk cooling presented by Farmer et al. (1990) ranged between 0.8 to 1.1 kWh/cwt, which is lower than in comparison to the research conducted by Eden et al. (2003) which is reported as 1.02 kWh/cwt. Milk cooling energy use varies with ambient temperatures (Farmer et al., 1988). Load profiles clearly show that milk cooling electrical energy demand on dairy farms varies seasonally; it is highest during the summer (Farmer et al. 1990).

Milk cooling is achieved using a refrigeration system that comprises of a bulk tank, evaporator, condenser unit and a compressor unit (Sanford 2003c, Pressman 2010), see Figure 1.

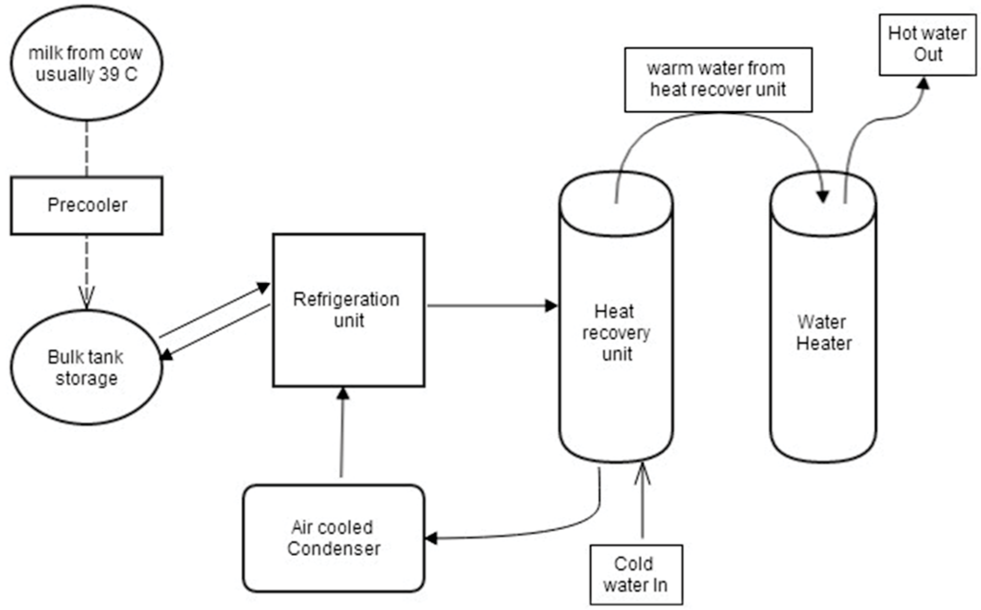


Figure 1: Milk cooling system with the presence of precooler, heat recovery unit and water heater

Energy efficiency technologies associated with the milk cooling include well water precooler, refrigeration, heat recovery unit and scroll compressor (Sanford 2003c, Pressman 2010). One proven technology for reducing energy use for milk cooling is a precooler (Abarikwu et al 1982), a heat exchanger that partially cools milk before it enters the bulk tank (Ludington et al. 2004). It is placed between the receiver group and the bulk tank after the milk filter (Sanford 2003b). A well water precooler is used to pre-cool milk before it enters the bulk tank through a heat exchanger where the intermediate cooling fluid is typically well water (Ludington et al. 2004). The well water absorbs heat from the warm milk, and this warm water can then be used as a drinking water for the cattle or some washing tasks on the farm (Sanford 2003b). It has been implemented in the precooling system of dairy farms for more than 20 years and is effective in reducing cooling energy cost by 0.2 to 0.3 kWh/cwt (hundred pound of milk) (Ludington et al. 2004). For the greatest reduction in milk temperature, the water and milk flow should be in opposite directions (counter flow) (Sanford 2003b). Also, for maximum amount of cooling, the water to milk flow ratio needs to be at least 1:1 along with sufficient residence time and heat transfer area (Sanford 2003b). However, for a plate coolers to perform efficiently a water to milk flow ratio of 3:1 is regarded as best (National milk harvesting center 2013). The extent of precooling is directly proportional to the heat exchange coefficient and the flow rate of milk through the precooler. The decrease in milk temperature in the precooler is a function of milk flow rate in the precooler, for a given design, size of a precooler and constant water flow rate. The milk flow rate, however, will depend on the number of cows milked (Abarikwu et al 1982). The precooler, shown in Figure 2, has various benefits in addition to energy savings, it allows the option of

Figure 2: A precooler installed in one of the audited dairy farm to cool milk from the cow

selecting a smaller refrigeration system to replace the same cooling requirement as the basic system. It saves from the expense of upgrading the refrigeration system in cases where additional refrigeration capacity would be required (Peebles et al. 1993). A study conducted by Farmer et al. 1988 in New York for three farms, two without precooler and one with precooler, found that precooling milk reduced electricity consumption for milk cooling by 30% on one farm and 50% in another farm. Other research conducted by Peebles et al 1993 concluded that precooling of milk reduced energy for milk cooling by 44%.These precooler studies had lower savings than found by Sanford 2003b, where he concluded that a precooling heat exchanger can lower refrigeration energy requirements by around 60 %.

The amount of milk heat removed by the precooler determines the quantity of heat available for the heat recovery unit (Peebles et al. 1993). A Heat Recovery unit (HRU) reduces the energy requirement of refrigeration system by absorbing the heat of the refrigerant coming from the refrigeration system which would usually be rejected by the condenser and using that heat energy to preheat the water that will be used for washing the milking system (Peebles et al. 1993, Ludington et al 2004). Therefore, it can be concluded that HRU and precooler are competing technologies as, the presence of a precooler reduces the heat availability for HRU. Corscadden et al. 2014 conducted a study to determine technology suitability based on volume of milk and equipment options for milk cooling and water heating energy consumption. It concluded that refrigeration heat recovery unit is best for volume of milk less than 4000hl per year and combination precooler and refrigeration heat recovery is best for large volume of milk higher than 4000hl per year. However for cases when only one technology is to be installed, RHR is best option for milk volume between 4000 and 14000hl per year, and precooler best option for milk volume higher than 14000hl per year.

The compressor is an important part of refrigeration system and major electrical user. The function of a compressor is to increase the pressure of vapour refrigerant gas coming from the evaporator from high level to low level evaporator from low to high level. The types of compressors used in dairy farms are reciprocating compressor and scroll compressor. A reciprocating compressor is a positive

Figure 3: A scroll compressor and fans installed in an audited dairy farm

displacement machine that works by one or more single-action pistons, driven by a piston rod from a crankshaft, reciprocating within cylinders. A scroll compressor is a rotary positive displacement machine that works by two scrolls. One of the scrolls is fixed and the other is phased at 180° from the first, which moves around a fixed point on the fixed scroll. Since a scroll compressor operates in a circular motion with few moving parts and no intake or discharge valves, it has low vibration and noise level compared to a reciprocating compressor. Scroll compressors are also more efficient and can reduce energy for refrigeration by up to 20% compared to reciprocating compressors (Ludington et al. 2004).The efficiency, compactness, lightweight, low sound and vibration level are all qualities that make them very popular compared to reciprocating compressor (Grace et al. 2002).

Kammel and Patoch 1993 conducted research on 74 Wisconsin dairy farm. They reported no correlation between herd size and milk cooling energy use. Further research will be conducted to see if milk cooling energy use does vary based on herd size or quantity of milk with the help of audit data which will be discussed in Chapter 4 (Energy Audit). Eden et al 2003 reported quantity of milk produced and monthly high temperature combined, explained 74% of variation in milk cooling energy use, and predicts that temperature drop of milk and final temperature may be possible factors in explaining the monthly milk cooling energy use. Kammel and Patoch 1993 concludes that the amount of milk produced, the presence or lack of ventilation, compressor cooling capacity and time of the year are possible factors affecting the milk cooling energy use. Therefore, further study will be conducted to find the possible factors affecting the milk cooling energy use, and based on these factors a model and benchmark value will be developed in Chapter 5 (Model and benchmark development).

The various studies mentioned above state different percentage for energy reduction in milk cooling by precooler and heat recovery units. Therefore, there is a need to know the exact energy savings attributed by precooler and heat recovery for milk cooling energy use, for this a case study will be conducted which will be discussed in Chapter 6 (Validation and case study) of this thesis.

2.2 Water Heating

Electricity, propane or oil are commonly used in the dairy farm for heating the large quanties of water required for washing equipment. The equipment used to extract milk from the cow, transfer and deliver milk to the storage tank requires cleaning after each use; these include milking unit, pipeline and bulk tank (Ludington et al. 2004), with the bulk tank cleaned after milk pickup. For cleaning and sanitizing the milking system, a large portion of hot water is used since washing typically consists of three or four cycles. These include a warm pre-rinse (half hot and half cold water), detergent or caustic wash (hot water), an acid rinse (temperature based on manufacture's recommendation) and a sanitizer rinse (warm water) (Canadian Quality Milk 2010) with each cycle using one full sink of water. Washing of the milk lines and equipment starts with a warm pre-rinse since a hot pre-rinse can cause milk to bake on to the milk line rather than rinsing out excess solids. The minimum start temperature for pre rinse should be 35°C to 60°C and end temperature is 35ºC. After the pre-rinse, washing the milk line with chlorinated alkaline detergent takes place to remove fat and protein in the equipment. The minimum start temperature and end temperature for detergent wash is 71°C and 43°C respectively. For fat not to redeposit on milk contact surfaces, a water temperature of 43°C should be maintained at the end of cycle (Canadian Quality Milk 2010).

The optimum temperature for hot water is 74°C, heating water above this temperature is usually not necessary and can waste energy (Sanford 2003a). Optimizing the wash cycle can improve the effectiveness as well as reduce the energy use for the cleaning process (Ludington 2004). Cuthbertson (2006) estimated that 14L and 17 L of hot water is

Figure 4: A heat recovery unit installed in one of the audited dairy farms

required per cow for tie stall and free stall operations respectively. The amount of water used and the temperature up to which the water is heated both influences the amount of energy used for water heating (Sanford 2003a). The wash cycle temperatures and sink volume vary greatly from one farm to the next (Canadian quality milk 2010), this is one of the reasons why the amount of energy used for hot water heating varies between farms. Water heating energy use also varies based on ambient temperature (Farmer et al. 1988), load profiles show that electrical energy demand on dairy farms varies seasonally, it is higher during winters (Farmer et al. 1990). Another factor for variation in water heating energy use between farm is the presence of energy efficient technology (Corscadden et al. 2014). Heat recovery systems, as shown in Figure 4 which is also known as bulk tank heat exchanger and heat reclaimer (Peebles and Reinemann 1994, Kammel and Patoch1993) are heat exchangers that use heat generated from the bulk tank refrigeration compressor that would normally be rejected by the condenser, to preheat water before it enters the water heater for washing the milking system (Kammel and Patoch 1993, Ludington et al. 2004). It also helps to reduce load on the refrigeration system as it removes heat from the refrigerant (Peebles et al. 1993) by providing higher heat transfer rate at the condenser (Ludington and Sanford 1985). Heat recovery systems are considered to be one of the most effective energy savers in dairy operation (Okezie et al. 1982). Kammel and Patoch 1993 report that it can increase the temperature of water from 10 ºC to about 37.8 to 54.4 ºC. Kammel and Patoch 1993 conducted a study to monitor energy savings for milk cooling and water heating from installation of heat recovery system in 74 dairy farms in Wisconsin. When metered individually, an average of 48% of energy saving was found for water heating alone and 6.6% reduction in energy use was found for milk cooling after the installation of heat recovery system. However, a combined energy saving (for both milk cooling and water heating) was monitored to be 33% (91% of the total energy savings attributed to reduced water heating and 9% attributed to reduced refrigeration unit energy use). Peebles et al. 1993 found that a heat recovery unit can save 40 to 50% of the energy required for water heating.

The precooler is a heat exchanger that cools milk partially before it enters the bulk tank (Ludington et al. 2004). Peebles et al 1993 report that a precooler helps to reduce milk cooling energy use by 44%, while Ludington et al. 2004 reports that precooler reduces cooling energy cost by 0.2 to 0.3 kWh/cwt (hundred pound of milk). It is another efficient technology used in dairy farms to reduce the temperature of milk coming from the bulk tank. Hence, it leads to reduction in heat availability for heat recovery unit (Peebles et al. 1993). Therefore, this leads a question about which technology to use, either the precooler or heat recovery since using a combination of both tends to reduce energy savings compared to individual use. Corscadden et al. 2014, conducted research to determine which technologies to choose between two. Based on his research finding, heat recovery was best for volume of milk less than 4000 hl per year, and combination of both for volume of milk above 4000 hl per year. His research findings were similar to a study conducted by Peebles et al. 1993 who studied the relationship between farm size and different equipment options at four different modeled scenarios 60 (48mm pipeline), 60 (73mm pipeline), 200 (double 6 milking parlor) and 400 (double 6 milking parlor) cow farm size. His research conclusion was that for small farms of 60 milking cow size, heat recovery was the best option for saving energy; however, for large farms of 200 and 400 cow size, combined heat recovery and precooler was the best option.

Scott Sanford 2003a reports that water heating accounts for approximately 25% of the total energy requirements of the average dairy farm; another study presented by the Ontario Ministry of Agriculture, Food and Rural Affairs (OMAFRA) suggests that 15% of the energy used on Ontario dairy farms for the task of heating water (Clark 2010). There is a need to know water heating energy use for Nova Scotia farms audited, which will be discussed in chapter 4 (Energy Audit). Kammel and Patoch 1993 reported that energy used for water heating does not vary based on number of cows, and predicts different hot water use practices might have impacted its variation, which was not recorded in his research. Similarly, another study conducted by Eden et al. 2003 concluded that the number of cows or quantity of milk does not explain the variation in water heating energy use, and predicts volume of hot water used, temperature of hot water might be possible factors affecting the monthly water heating electrical consumption. Further analysis will be conducted with the help of audit data to see if number of cows or quantity of milk production is a good indicator for benchmarking energy use for water heating, which will be discussed in Chapter 4 (audit data).

According to Sanford 2003a, adequate washing of a milking system can be accomplished successfully with a warm pre-rinse, a hot wash and a cold acid rinse. Based on Sanford's proposed wash temperatures, the wash system hot water requirement will be 1.5 times the quantity of water used per cycle. Similarly, wash cycles for different water temperature used in practice for heating water in Nova Scotia dairy farms will be determined based on measured audit temperature data. Also, factors affecting the water heating energy required for Nova Scotia dairy farm will be determined. Based on these parameters a model will be developed and a benchmark value will be developed in Chapter 5 (Model and Benchmark development).

2.3 Milk Collection

Milk harvesting is the most important operation on a dairy farm (Ludington 2004). It takes place two or three times a day in most dairy farms throughout the year (Pressman 2010). The center piece of the milking system is the vacuum pump, shown in Figure 5 which operates whenever milking or washing of the milking equipment occurs. Milking consist of harvesting milk from the dairy cow to a receiver jar through a vacuum pump and transporting milk from the receiver jar to a bulk tank storage through a transfer pump, see Figure 6 (Pressman 2010). According to Eden et al. 2003 energy utilization indices for vacuum pump operation range from 0.9 to 1.14 kWh/cwt (100 pounds of milk) which varies in comparison to an extensive review by Farmer et al. (1990) that report EUI's ranges from 0.4 to 1.19 kWh/cwt. This variation in energy use for milking varies from farm to farm due to differences in farm size, equipment type, management and operating

Figure 5: Vacuum pump and motor

practices, maintenance and proper equipment sizing (Peebles et al. 1993). Milking energy use has one of the highest proportions of total dairy farm electric use; therefore, they offer significant potential for electric energy savings and cost reductions (Peebles et al. 1993).

Conventional vacuum systems use a vacuum pump which operates at a fixed speed, and use a vacuum regulator and a load. The load comprises the components that make up the

Figure 6: Milk receiving jar and transfer pump

milking system including milking units, pulsators, claws other devices that admit air during operation and air leaks. To maintain a desired vacuum level, the vacuum pump must remove air from the milking system at the same rate as air is being admitted through the loads. In a conventional vacuum system, the vacuum regulator admits air and helps to match the air inflow rate with the pump output rate (Ludington 2004). This leads to more energy consumption when compared with variable speed drives (Farmer et al., 1990; Ludington et al., 1990). A variable speed drive regulates the speed of the vacuum pump to maintain the set vacuum level instead of admitting air when a vacuum regulator is used (Ludington 2004). According to ASAE Standard S518.2, Milking Machine

Installations Construction and Performance, vacuum pumps are sized, based on the number of milking units; however, they are generally oversized to accommodate higher vacuum capacity for washing purposes. This over sizing of a vacuum pump wastes energy, since the energy required for milking is below the pump's capacity. A solution for conservation of this energy is the replacement of one large vacuum pump with two smaller vacuum pumps; one pump is used for milking and both pumps are used for washing. Another solution for reducing energy caused due to over sizing of a vacuum pump is through the use of a variable speed drive (Farmer et al., 1990; Ludington et al., 1990). With the use of a variable speed drive, the vacuum pump energy use can be reduced by 50% or more, without any loss of milking system performance (Ludington 2004).

According to Ludington 2004 the vacuum pump consumes 26% of all electrical energy used on California dairy farm. The same study shows that milking constitute up to 12% of the total energy use on the dairy farm. Another study by the Ontario Ministry of Agriculture, Food and Rural Affairs (OMAFRA) suggests that 23% of the energy used on Ontario dairy farms goes towards the task of milking. There is a need to know the percentage of milking energy use for NS dairy farms, which will be discussed in audit data Chapter 4. Also, there is a need to determine if milking energy use varies based on number of cows or quantity of milk produced.

Okezie et al. 1982 reports that average milking time, the milk rate of flow in the system, and its relation to the milking parlor size are factors that can be used to predict the energy use for milking. Eden concludes milk production only represented 44% of variability in vacuum pump energy use and more than 50% vacuum pump energy use was not explained. Therefore, this shows that there is a need to know factors that actually influence energy use for milking. These factors will be discussed in Chapter 5 (benchmark and model development) and based on these factors a model will be developed.

2.4 Lighting

Lighting plays a significant role in creating a high quality working environment to improve worker efficiency, safety and comfort and animal well-being (ASAE 1996). It is an important environmental characteristic for physiological growth of the animal. Light level, quality and photo period length are three characteristics required for lighting (ASAE 1996). Light quality involves uniformity, glare, and color rendition index. High uniformity and low glare is important for offices, animal treatment, and milking areas (ASAE 1996).

2.4.1 Effect of photoperiod

Milking cows exposed to 16 to 18 hours of light with a brightness of 15 to 20 foot candles followed by 6 to 8 hours of uninterrupted darkness per day had milk production increases ranging from 5 to 16% compared to cows exposed to 13.5 hours or less of light per day (Peter 1994). This lighting pattern of exposing milking cows to 16 to 18 hours of light per day with a brightness of 15 to 20 foot candles is referred to as long-day photoperiod (Peters, 1994). This subsequent increase in milk production can provide a payback in less than one year including initial installation, operating, and replacement costs of lights and also the feed intake (Chastain and Hiatt, 1988). According to research conducted by Dahl et al. 1998, twenty-four hours of continuous light each day does not provide additional milk yield response compared to sixteen to eighteen hours of light. Whereas the dry cows require short day photoperiod i.e. a dark period of at least 12 hours per day. Unnecessary lighting periods and excessive light levels are uneconomical and waste energy. The illumination level required in diary facilities for different work areas is listed in Table 1. Energy efficient lighting system along with energy management practices on a dairy farm conserve light energy consumption as well as help to increase milk production (Clarke 2006) .

Table 1 : The illumination level required in dairy facility for various task or in different work areas

Work Area or Task	Minimum Light Intensity [Lux]
Parlour, pit and near udder	538
Parlour, stalls & return lanes	215
Parlour, holding area	108
Milk room, general	215
Milk room, washing	753-108
Stall barn, manger alley	108
Stall barn, milking alley	269-323
Drive through feed alley	215
Housing area	54-108
Office general	538
Equipment and utility rooms	161- 215
General storage	54

(Source: ASAE, 1996)

2.4.2 Lamp efficiency and lamp life

Lamp efficiency and its life are two operating characteristics of light. Lamp efficiency is defined as the amount of light provided per unit of input energy, which is expressed as lumens per watt (Chastain 2000). The number of hours that pass when reaching the point at which half of the lamps are burning and half gets burned out is known as lamp life (Chastain 2000). From Table 2, it can be seen that the most energy efficient lamps are also found to have longest useful life

2.4.3 Color Rendering Index

Color is another important quality of light required in a dairy barn. Color rendering index (CRI) is defined as the whiteness or color of light source which is presented in a scale of 0 to 100. Dairy facilities, office areas, animal treatment centers, washing equipment and milking operations requires light source with a CRI value of 80 or more (Chastain 2000). The CRI of different light source is listed in Table 2.

Table 2: Characteristics of dairy facilities light sources used for indoor lighting

Lamp types	**Lamp size (W)**	**CRI**	**Efficiency (lumens/W)**	**Average lamp life (hr)**
Fluorescent	32-110	70-95	75-98	15000-20000
High pressure sodium	35-400	20-80	63-125	15000-24000
Metal halide	70-400	60-80	60-94	7500-10000
Compact fluorescent	5-50	80-90	50-80	10000
Halogen	50-150	100	18-25	2000-3000
Incandescent	34-200	100	11-20	750-2000

(Source: Chastain 2000)

The lighting sources available for dairy farms include natural light, LED, incandescent, fluorescent, high intensity discharge (HID), mercury vapour, metal halide (MH), high pressure sodium (HPS) fixtures (ASAE 1996). However the most commonly used lighting in milking center are incandescent and fluorescent (Chastain 1997).

2.4.4 Types of light:

a. Natural light: In the case of a totally enclosed dairy barn such as mechanically ventilated barns, the required light is provided solely through artificial sources for 16-18 hours per day for milking cows and 12 hours for dry cows. However in the case of naturally ventilated curtain side dairy barns, natural light plays a major role. Natural light level measured during the winter in curtain side dairy facilities ranges from 215 lux on cloudy day to as much as 53000 lux on a clear day (Chastain 1997). In these types of barns artificial lights are used to supplement the natural day length.

b. Incandescent lamps: They are the least efficient lighting system. They convert only about 5% energy to light and the rest is wasted as heat energy. In addition, flies and other insects are attracted by incandescent lights, so they are quickly coated with dirt that further reduces the amount of light available. They also have a relatively short-rated life compared to other lighting types (Clarke 2006). Positive features of incandescent lights is that they perform well at cold temperatures i.e. at -6.7°C (20F) or colder and they have high brightness, hence should be used in appropriate luminates to minimize glare (ASAE 1996).

Figure 7: T8 lights installed in milking parlour

c. Fluorescent light: They are very energy efficient compared to incandescent. They have has long life cycles compared to other lighting types. They are also available in different sizes such as T5, T6, T8 (Figure 7), T9, T10, T12 and T1, different shapes such as straight or linear, U-shaped or circular, from 0.15 to 2.44 meter (6” to 96”) long with color temperatures from 2750˚K to 7500˚K (ASAE 1996) (Sanford 2003d). Hence, these qualities makes fluorescent lights the most suitable source of light for dairy farms. In comparison, fluorescent are more expensive than incandescent, but the energy savings combined with longer lamp life can offset the higher initial cost for such energy efficient lighting systems, generally in two years or less in dairy applications (Chastain,1992). They are also temperature sensitive; therefore light output drops when used in either very high or extremely low ambient temperatures. Fluorescent lamps have a minimum starting temperature of 10°C, hence a specially designed ballast with an enclosure should be used for low temperatures (ASAE 1996).

Compared to T12 and T8, T5 lamps are more energy efficient. Whereas compared to T12, T8 lamps are more energy efficient (Chastain 2000). Based on a study conducted by Chastain et al. (1998) for comparison between T8 and T12 florescent lighting in three dairy facilities, T8 lighting technology reduced annual lighting energy cost by up to 29% to 35% and peak demand by 32 to 35% when compared to T12 lighting system.

d. Compact fluorescent lamps: They are equipped with the same medium screw base as a standard incandescent lamp, hence CFL can be used as a replacement for incandescent bulbs. They are more energy efficient, using approximately 75% less energy with 6 to 10 time longer average life compared to incandescent lights. But in the case of color rendering index and correlating color temperature, both are found to be similar to that of incandescent bulbs (Sanford 2003d).

Figure 8: HID light in cow barn

e. High-intensity discharge lamps (HID lamps) (Figure 8) are used in places which have minimum of 4m (13ft) mounting height (ASAE 1996). Metal halide (MH), high pressure sodium lamp (HPS) and mercury vapor (MV) are different types of HID lamps used in dairy farm. HPS, MH and MV emits approximately about 95 lumens/watt, 60 lumens/watt and 32 lumen/watt respectively. Mercury vapor is the least efficient of HID lamps, in addition it also poses environmental risk compared to other HID lamps (Sanford 2003d). The warm up time required for HID sources is 3 to 7 minutes, hence this characteristic of HID lamps makes it unsuitable for applications where lights should be switched on or off quickly. Another demerit of HID lamps is that they differ in color rendering ability in general being lower than fluorescent or incandescent (ASAE 1996). However, they are easy to install and requires fewer fixtures to provide the same light level

(Clarke 2006).

f. Light emitting diode (LED) are latest technology highly efficient solid state lamps having a lamp life of about 100,000 hours (Clark 2006). LED lamps are reported to be about 10 times more efficient than incandescent lamp (Sterenka et al. 2002). LED technology are fully dimmable, environment friendly (Clark 2006) and comes in a variety of forms such as regular lamps, strip lamps, modular bars and strip rolls (Chang 2012). They are available at different ranges of temperatures such as -20 to +85 °C (Sterenka et al. 2002).

Light level, quality and photoperiod length are important characteristics to be considered for installing light in dairy farm. Lamp efficiency and lamp life are two important operating characteristic of lamps. The most efficient lights that are suitable for dairy farm are LED, florescent (T5 and T8), HID (high pressure sodium and metal halide) since they provide high lumens per watt. However florescent and incandescent are the most common lamp types used in milking center and livestock farms. Peterson in 2008 reported that lighting represented an average of 17 % of total dairy farm electrical energy use. Other research conducted by Ludington 2004 reports that lighting represents 16% of energy use in dairy farm. There is a need to know percentage of lighting energy use in NS dairy farm; for this purpose, audit data will be used in Chapter 4. Also, there is a need to know the exact parameters affecting the lighting energy use. Based on these parameters a model and benchmark parameter will be developed, which will be discussed in Chapter 5.

2.5 Manure handling

Manure is produced on dairy farms as a product of waste from the dairy cow. The manure weight produced varies from one cow to another due to its weight and milk production. The manure produced from lactating cows is approximately twice that from a dry cow (ASAE D384.2 MAR2005).

Table 3: The amount of manure typically produced from dairy cows of different weights

Dairy cattle (size, kg)	Manure produced (kg/day)
68	6
113	10
227	20
454	39
635	54

(Source: American society of agricultural engineers, data adapted from 1992 standard D384.1)

A specialised technique is required for collection and transferring manure in the dairy farm to the storage tank, which is defined as manure handling. Manure in a dairy farm can be handled as solid, semi- solid or liquid. The amount or type of bedding or dilution water added influences the manure form i.e. solid, semi- solid or liquid. Manure is converted to solid waste by draining liquid and drying waste or by adding beddings such as straw or wood chips, whereas liquid manure is produced from dilution of waste water with manure. The form of manure, i.e. solid or liquid, influences the selection of equipment for collection and the choice of storage type. Solid manure, due to the addition of bedding, does not flow and stays in a pile, therefore, is typically collected with tractor scrapers or front end loaders. Liquid manure in the other hand is collected with scrapers, flushing systems, gravity flow gutters or slotted floors. Different types of equipment are used for collection of manure from the dairy barn and transport from the barn to storage.

2.5.1 Collections:

Various types of equipment such as shovels or pushers, manure scrape gutter, front end loaders, skid steers, alley scrapers (Figure 9), barn cleaners (Figure 10), underslat

Figure 9: Alley scraper in a freestall barn

scrapersare used for collection of manure from the freestall and tiestall barns. These technologies use either manual labor, electric, propane or diesel energy to function. A shovel or pusher is used to scrape manure manually from the gutter to the sump or deep narrow collection gutter at the end. The skid steer is a four wheel vehicle that runs with gasoline or propane. It has a mounted blade that moves manure to the end of the barn where it falls onto a storage or transportation unit.

The advantage of a skid steer over the mechanical scraper is that they work better on frozen manure compared to mechanical scrapers. The barn cleaner is a chain linked system of paddles that operates in a narrow gutter via electric power. It is designed to

Figure 10: A barn cleaner

transfer high solid content manure from the gutter into a pit for storage. Barn cleaners are typically used in tie stall barns. The alley scraper is a "V" shaped mechanical electric powered blade designed to scrape manure from an alley and pull manure to a collection channel at the end of alley. The alley scrapper is dragged back and forth over an alley by chain or cable at a speed of 0.02 to 0.04 m/s (4 to 7 ft/min) (Midwest plan service, 1985), and it is designed not to interfere with the cow in the scraped alley. Alley scrapers are most often used in freestall barns. Some freestall barns have slotted floors instead of solid floors. Slotted floors are wide slats of 0.038 to 0.044 meter (1 ½ ″ – 1 ¾ ″) (Midwest plan service, 1985) where dairy cows are rapidly separated from the manure and urine. The manure and urine is collected in a shallow pit where it is scraped by underslat scrapers. The speed of underslat scrapers is much higher than alley scrapers since dairy cows safety is not a concern.

2.5.2 Waste transfer to storage:

The manure collected is deposited directly into a storage tank or pit under the end of the building, or into a cross conveyor or pump hopper for conveying to storage outside the building. Waste is transferred from pit to the storage via a pneumatic pump, piston pump, centrifugal pump or gravity. Transfer of manure from pit to storage is possible through gravity when no bedding or little bedding is added to manure. But in the presence of manure with bedding, water is added to the pit to ensure there is sufficient moisture when emptying the pit. The manure solid and liquid is mixed through agitation to break up the crust before pumping the manure out to the storage.

Manure handling system selection depends on the individual farms waste characteristics, housing system, waste storage system, bedding practices and labor availability. Due to different types of systems, energy use from one farm differs a lot from another. Number of cows or quantity of milk produced is used as benchmark value to quantify the energy use in dairy farms. However, as manure produced from one cow varies from another based on milk produced and weight of cow, two farms with the same number of milking cows would have different quantity of manure for collection. Also due to the addition of water for dilution in the pit and bedding addition, farms with the same number of milking cows would have different quantity of manure for transfer to the storage. Farmer et. al 1988 and Farmer et al. 1990 reported that manure handling energy use was 3 kWh/yr/cow and 10 kWh/yr/cow respectively. Another research conducted by Murgia et al. 2008 benchmarked manure handling energy use as 23 kWh/yr/cow, which was quite contrasting compared to 10kWh/yr/cow and 3 kWh/yr cow benchmarked by Farmer et. al 1990 and Farmer et al 1988 respectively. Due to these wide variations in energy utilization indices there is a need to know if manure energy use actually varies based on number of cows or quantity of milk produced or if there are other better options for benchmarking. For this purpose Nova Scotia farm audit data will be used to verify which will be discussed in chapter 4. Also, based on this audit data, a model for manure handling energy use and benchmark value will be developed in Chapter 5 for Nova Scotia dairy farms.

2.6 Ventilation

Ventilation is the process of replacing air inside a barn with fresh outside air to remove unwanted gases, odours, dust, disease organisms from the barn and maintain adequate oxygen level (Mrema, 2011). A dairy farm contains stale air, the product of respiration, evaporated moisture and carbon dioxide from cows, and unwanted gases and pathogens from manure (Midwest plan service, 1993). This stale air adversely affects the health and well being of cows in the dairy farm (Gooch 2001); therefore, to provide a good environment for cows it is necessary to replace stale air with fresh outside air (Federation of animal science society 1998). Ventilation is also needed to maintain temperature and moisture within the barn to avoid heat stress (Mrema, 2011). Dairy cows prefer colder temperatures and can withstand exposure to temperatures as low as -17.8 ºC for a long period of time with little loss either in production or in the efficiency of food utilization (Gooch 2008) (Gooch 2001) (Mrema 2011). Regan et al.1938 conducted research in an experiment station where temperature, humidity and air movement was controlled to determine the relationship between temperature and milk produced from dairy cows at constant air velocity of 0.254 m/s (50 feet per minute) and 60% humidity. They found a decrease of 0.907kg (2lb) in milk production per cow per day when temperature rises from 21.1°C to 26.6°C (70ºF to 80ºF), followed by further 0.907 kg (2lb) drop at every additional 2.8ºC (5 °F) increment from 26.6ºC to 35ºC (80 °F to 95 °F), a factor that may have significant economic impact on the dairy farm. Heat stress also causes increased respiration rate, increased water intake, increased sweating, decreased dry matter intake, and decreased blood flow to internal organs and poor reproductive performance. Different ways of mitigating the effects of heat stress on dairy cows consist of providing shade from direct solar radiation, increasing barn ventilation rate and providing air circulation directly over cows . Ventilation in a dairy barn is provided either by natural or mechanical means. With either type of ventilation, a properly ventilated barn should result in barn air that has low concentration of manure gases, dust, and pathogens and same level of relative humidity as the outside air throughout the year (Gooch 2012). Natural ventilation takes place with the principle of thermal buoyancy and wind pressure whereas mechanical ventilation exchange air through fans (Palmer and Homes 2005). In the case of natural ventilation, fresh air moves into the barn through inlet (openings) and replaces warm air. This warm air rises and moves out of the barn via a roof ridge. Naturally ventilated barns need adequate sidewall, endwall and ridge openings for sufficient air to enter and exit. Also they should be properly orientated such that prevailing summer winds should be perpendicular to the sidewall, and enough spacing provided between barn and wind obstructions so naturally moving air can pass through the barn properly (Gooch 2011)**.** Barns that are incorrectly oriented, sited or have inadequate openings are subjected to insufficient air exchange (Gooch 2011) and ultimately will require mechanical ventilation, where air is pushed out of the barn through negative pressure fans. The advantage of natural ventilation over mechanical is zero operating cost and low initial cost i.e. it does not require fans and electricity to provide ventilation. The disadvantage, however, is that there is little air circulation or cooling effect within the barn (Ludington et al. 2004), presence of non uniform ventilation rate, and a need for some management to set the inlet openings that control the range of ventilation rates over the barn. Mechanical ventilation does, however, provide uniform ventilation rate throughout the barn along with additional cooling effects. The disadvantage of mechanical ventilation is the possibility fear of power outages, especially during summer months when cows may suffer from heat stress. Mechanical ventilation requires both high initial costs and operating costs due to constant fan operation (Mrema 2011). The use of natural ventilation during the summer does helps to remove stale and warm air;

Figure 11: Natural ventilation with cooling fans in one of the audited dairy farm

however, in the hot summer days with low wind speed, high temperature and humidity this ventilation rate is usually inadequate to provide sufficient airflow across the cow resulting in additional need for cooling especially when the inside barn temperature rises above 21ºC (70 °F) at 60% humidity (at higher humidity above 60%, temperature should be maintained below 70F) (Regan et al. 1938). When there is adequate air exchange, heat stress can be minimised by providing air circulation over the cows body at a velocity of between 2.02 to 3.05 m/s (400 to 600 ft/min) (Shearer et al. 1991). Air circulating fans, Figure 11, need to be located both in the feed alley, holding area and parlor of freestall barn and in the feed alley of tiestall barn to cool the cows (Palmer and Holmes 2005). Placement of these fans is dependent on the type and size of fan used (Ludington et al. 2004), however box and panel type fans need to be placed above the feed alley and freestall area at a height of ten feet for each foot of fan blade diameter (Bray 1994). Several types of fans are available for air circulation and include basket, box, panel, low volume low speed (LVLS) and high volume low speed fans (HVLS) (Ludington et al. 2004). High volume low speed (HVLS) fans are large diameter paddle fans with up to 10 blades that range from 1.2-3.7 meter (4-12') long and operate at lower speeds in the range of 117 and 50 rpm. HVLS fans consume less energy and require lower maintenance compared to high speed fans. HVLS are one of the most efficient fan type, with low energy intake. Fan efficiency can significantly impact the amount of energy needed for air circulation.

For both ventilation and air circulation systems overall energy efficiency and energy cost depends on the selection of the fan type. Inefficient fans result in low performance and high energy consumption compared to more efficient fans (Loudon, 1993). Fan efficiency is defined as the ratio of air circulated to the electrical energy input (m^3 /s /W).

Numerous factors affect the fan efficiency and performance; speed of the fan, clearance between blade tip and fan housing , design of fan housing and orifice panel, efficiency of the fan motor, any obstruction to air flow such as fan screens, shutters and guards (Mrema 2011) (Ludington et al. 2004). Ventilation fan efficiency of similar sizes operating against equivalent static pressures can vary significantly. The American Society of Agriculture Engineer has benchmarked the minimum ventilation efficiency of fans operating against equivalent static pressures for different sizes of fans. These values are listed in Table 4, fans should be selected exceeding these minimum efficiencies (Energy and Utilization Committee, June 2012).

Table 4: Recommended minimum efficiencies for energy efficient agricultural ventilation fans (30, 60, and 90 cm sizes)

Static pressure, Pa	Fan efficiency, L/s /W		
	0.60 m fans	0.90 m fans	1.20 m fans
0	6.6	9.6	10.3
10	6.2	8.8	9.5
20	5.8	8	8.7
30	5.4	7.2	7.9
40	5	6.4	7
50	4.6	5.4	5.9
60	4	4.3	4.9

(Source: Energy and Utilization Committee, June 2012)

However, when test data or air flow rate and fan efficiency information are not available, a few tips for selecting the most efficient fans are (1) choose large diameter fans since larger diameter blades will move more air per unit of input power compared to smaller diameter fans, (2) choose a few larger fans rather than a large number of smaller fans, (3) when two fans has the same diameter, motor horsepower, voltage and same air flow rate, choose the fan with lower full load ampere rating (Energy and utilization committee, June 2012).

Maintenance of ventilation fans is as important as choosing the most efficient model. Fan efficiency can be reduced up to 50% or more due to poor maintenance. Cleaning fan blades, motors and shutters helps remove any accumulated debris or dust and prevents the fan to reduce airflow (Energy and utilization committee, June 2012).

Results of California dairies provide EUI’s for freestall barns in the range of 100 to 175 kWh/cow-year (Ludington et al. 2004). However for parlor and holding areas the energy use for air circulation was in the range of 10- 20 kWh/cow year. Farmer et. al 1990 present EUI’s for ventilation fans as 225 kWh/cow yr, however energy efficient fans reduced the EUI to 170 kWh/cow yr with total ventilation representing 20% of total energy use on New York dairy farms (Farmer et al.1990). Various studies have shown different EUI range for ventilation and benchmarked either based on number of milking cows or milk produced. Hence in chapter 4 ventilation energy use for Nova Scotia dairy farms audit data collected will be discussed and identified if the benchmarking based on milk production and number of milking cows is appropriate. Ventilation energy use varies greatly based on type of ventilation, natural or mechanical. However, there is no published information that benchmarks dairy farm ventilation energy use based on ventilation types. Hence there is a need to determine the exact parameters affecting the energy use for both types of ventilation. Barn configuration, climate zone and total animal population are some of the factors affecting ventilation energy use. A model and benchmark parameter for both natural and mechanical ventilation system will be developed to determining the energy use in Chapter 5 (Model and Benchmark development).

2.7 Feed

The dairy cow is a ruminant that requires nutrition in the form of protein, energy, fiber, mineral and vitamins in their diet. This nutrition fed to dairy cows is referred to as feed. Feed intake is the key factor in maintaining high milk production (Natural resources and environment, 2002). After calving, a cow achieves its lactation stage which is usually 305 days followed by 60 days of dry period. The cows has three stages of lactation i.e. early, mid and late lactation, which has been categorized based on milk production. Based on research conducted by Nutrient Requirements of Dairy Cows (published by the National Research Council 1989 and 2001) dairy cows producing 40, 30 and 20 kg/day of milk during early, mid and late lactation respectively should be fed an average dry matter of between 24-26, 21-23 and 11-12 kg/day for early, mid and late lactation respectively**.** Another study conducted by Roseler et al., 1997b concluded that milk yield, feed management, body weight, climate and body condition score are the factors that determine the level of dry matter intake in lactating dairy cows with the amount of variance of 45%, 22%, 17%, 10% and 6% respectively (Roseler et al., 1997). This therefore shows that milk yield has the highest relative importance to the feed intake. Nutrition in the form of energy varies based on amount of milk production, stage of pregnancy, cow size and activity, whereas protein requirement varies with stage of lactation and whether milking or dry cow (Natural resources and environment, 2002). A dairy cow requires a certain amount of nutrition in the form of feed, varies based on milk yield and body weight. However, if the provided feed material is of lower quality i.e. lower energy density, the cow needs to eat a greater amount of feed to substitute that required nutrition (Natural resources and environment, 2002). Due to all these various factors influencing the feed intake, the best way to benchmark feed cost is through per kilogram of dry matter rather than per cow per day, feed cost/ day/cow does not reflect feed requirement based on milk production, various stages of lactation or nutrient requirement (Hutjens, 2010).

Feed storage system:

Feed material or forage harvested is in the form of hay, corn, bailey, soy, alfalfa etc. These harvested crops containing adequate moisture are stored in horizontal or vertical silo for two to three weeks. It is during storage that the feed turns into silage through an anaerobic process called ensiling (Bodman et al. 1997). The advantage of the horizontal silo is that it has low capital cost, can have longer forage material cut length and can be filled and unloaded more quickly compared to the vertical silo. The disadvantage of the horizontal silo is higher storage losses (between12% to 25%), problem with rodents, wind, snow, rain, birds and exposure to all kinds of weather during unloading of silage. Horizontal silo consist of bunker, trench and bag silo. Bunker silo is built above ground with supportive walls made of concrete panels whereas trench silos are built into the ground with side walls made of either concrete or soil (Bodman et al. 1997). Both bunker and trench silos are mostly unloaded with a bucket loader which can be part of a tractor front end, skid steer or industrial loader. Another method of unloading is with mechanical face cutters, which provide a smoother face than bucket loaders but are expensive and slow at removing silage. Bag silo is the most famous and fastest growing horizontal silo in North America. They vary in length from 30.48 to 91.44 m (100 to 300 feet) depending on manufacture. They have a fast unloading rate and the lowest capital cost compared to tower silos (Muck et al. 2006).

A vertical or tower silo, Figure 12 works with a mechanized feeding system, provides protection from weather hazards during storage, has low dry matter loss ranging between 4 to 12%

Figure 12: Tower silo and Bins

and can be unloaded in any weather condition. The main disadvantage is safety issues with silo gas and incompatibility of slow unloading with Total Mixed Ration mixer (Ministry of agriculture, food and rural affairs, 2011). A vertical silo consists of oxygen limiting silo and top unloading silo. The oxygen limiting silo is made up of both poured concrete and glass-lined steel structures where feed material is blown into the top and silage is unloaded from the bottom. Glass lined steel silo have breather bags that minimize oxygen access to the silage from the daily heating and cooling of the silo. The advantage of the oxygen limiting silo is low dry matter losses about 4-8%; disadvantages consist of high capital costs, unloads more slowly than bunker, trench or bag silo, not well suited for corn silage as crops need to be drier to work well, not suited for long chop length if desired. Top unloading tower silos are made up of concrete staves and have characteristics similar to the oxygen-limiting towers. The main difference between top unloading tower silos and oxygen limiting silo is that the top of the silo is open to the atmosphere allowing spoilage of the top surface and removal of silage is by top unloading i.e. first in is the last out, whereas in the case of oxygen limiting silo, silage unloading is first in first out. Standard ensiling recommendation for top unloading silo is 45% to 60% higher than oxygen limiting silo which is 40% to 50% moisture, wet basis. Top unloading tower silo has the advantage that it can be used for high moisture corn. Capital cost of top unloading silo is one third less compared to oxygen limiting silo. Dry matter loss is a little higher than oxygen limiting silo i.e. 6%-12% (Muck et al. 2006). Dairy cows are also fed grains which is stored in bins which run by electric.

Figure 13: A stationary Total mixed ration mixer

Total Mixed Ration mixer:

A balanced ration consists of all feed ingredients required for proper growth, development and maximum performance of a dairy cow. Cows have their own preference for feedstuffs, thus, if cows are separately fed ingredients then cows will consume feedstuff based on their own preference. This may cause a feed deficiency in their diet. Total mixed ration (TMR) is one way to avoid such situation and assure that the each cow has consumed a balance ration. TMR consist of all the feed ingredients such as forages, grain, and supplements mixed together into a homogeneous mixture so that each

Figure 14. Feed mixing station

mouthful of feed consumed contains the adequate amount of nutrition for a balanced ration. It provides flexibility to formulate accurate feed requirement for separate groups such as dry, early, mid and late-lactation cows. In TMR mixer the feed ingredients are weighed accurately selecting the right amount of each feed ingredient and then mixed in the mixer (Kammel, 1998).

TMR is either prepared with a stationary or mobile mixer. The stationary TMR, Figure 13 remains in a specific site and all feed ingredients must be conveyed to the it where all the mixing takes place. After mixing, the ration is delivered to the cows via conveyors or feed carts. The stationary system is most common for herds of 90 cows or fewer that depend on upright silos and mechanical conveyors for moving feed. Unlike stationary TMR, mobile TMR are more flexible since they use a trailer or truck mounted mixer for mixing the feed ingredients and delivering the TMR to the feed bunk. Mobile TMR are cost and time efficient for herds of 100 cows or more (Midwest plan service, 2000). One of the factors of highest importance for feed intake is milk yield. Feed intake of one cow varies from that another cow if the milk production is different, also dry matter intake varies between different stages of lactation. Due to these reasons, feed cost is more related to weight of feed rather than number of cows. Numerous technology/equipment are available to handle feed for dairy farms. Feed after harvest is stored either in horizontal or vertical silos. Horizontal silos consist of bunker, trench and bag silo, which are unloaded via a bucket loader or mechanical face cutter. A vertical silo is loaded either by electricity or tractor run by diesel and unloaded by electric consist of an oxygen limiting tower and top unloading tower silo, which is completely mechanized. Grains are stored in bins that are loaded and unloaded by electricity. Feed material is unloaded from vertical or horizontal silo and grains from bins based on daily requirement of the farm and then mixed either in stationary or mobile total mixed ration mixer. In the case of a stationary mixer, the TMR is distributed through a mobile tractor or carter which runs by diesel. The preference for vertical silo, horizontal silo, stationary TMR or mobile TMR or individual feeding system, all are based on farm type, size and personal preference. Therefore, it is difficult to decide on a model for feed preparation on a dairy farm. However, in this thesis only electric components are studied and a model and benchmark value focusing only on electrical feed energy has been formulated, which will be discussed in Chapter 5.

Energy Utilization Indices:

Energy utilization indices (EUI) are developed to establish a benchmark for evaluation of how efficiently electrical energy is being used on the farm. It also helps to know the efficiency of individual pieces of equipment, identify areas of excessive energy use and finally provide an indication of effectiveness from implementing energy conservation measures (Ludington 2004). EUI's, which have been commonly used on dairy farms are expressed based on energy used as a function of the number of cows milked (kWh/cow) and quantity of milk produced (kWh/cwt) (Eden 2003). According to a dairy farm energy audit conducted by Ludington 2004, the energy used by 14 tiestall barns consisting of 42 to 140 cows ranged from 542 to 1561 kWh/cow-yr and 18 free stall barn consisting of 65 to 860 cows ranged from 424 to 1736 kWh/cow-yr. Whereas the electricity consumption based on a study conducted by Murgia et al. 2008 on 14 dairy farms ranging from 40 to 300 cows were 314 to 630 kWh/cow-yr. Other researchers (Wells et al. 1991) (Kammel and Patoch 1993) noted similar variations in electrical energy use on dairy farms of similar size and production. These large variation based on EUI's of kWh/cow or kWh/cwt suggests that the number of cows or quantity of milk produced are not the only indicators that determine energy use and there are other parameters which may have impact in explaining the energy use, which requires further research (Eden et al. 2003). Further analysis will be presented in Chapter 4 (Energy audit) with statistical tools used to determine if NS dairy farm energy use varies based on number of cows or quantity of milk produced. Also, parameters that actually influence energy use of each component will be researched in Chapter 5 (Model and Benchmark development).

Chapter 3: Objective and Methodology

The overall goal of this project is to determine benchmark parameters which relate energy use to an operational component for Nova Scotia dairy farms. The outcome will be a more practical method for determining how and where electrical energy is used on dairy farms.

The specific objective of this project are:

- develop a pragmatic mathematical model or an alternative way of representing energy consumption for:

1. Milking
2. Cooling
3. Water heating
4. Lighting
5. Ventilation
6. Manure handling
7. Feed

- determine benchmark parameters for each of the components listed above
- compute Energy Utilization Indices [EUI] for major operational components
- identify energy efficiency options and offer potential energy saving suggestions for major operational component of Nova Scotia dairy farms

The methodology here aims to address the objectives presented in the previous section. An audit of Nova Scotia dairy farms was conducted to determine or understand how and where electrical energy was consumed and to identify the range of different equipment used by the sector. This is an essential component of this research and the first step in establishing energy use in the sector and in determine how much energy could be saved after energy efficient equipment is installed. Farms selected for the research were based upon willingness to participate and agreement to have an energy audit conducted. Of the two hundred and fifty dairy (250) farms registered in Nova Scotia, nineteen (19) dairy farms agreed to participate in the research and provided utility bills for a two year period. An energy audit was conducted on these 19 farms between September 2010 and March 2012. These 19 dairy farms were a good representative of the sector, since they included all farm types (tiestall and freestall) and farm sizes i.e. small, medium and large. Energy audits followed the American Society for Agricultural and Biological Engineers standard for On-farm Energy Auditing (ASABE 2009). There are three classes of audit identified in the standard. This research used class 1, 2 and 3 where class 1 comprises a comparison of utility bills, class 2 comprise an inventory of electrical energy using equipment and time of use, and class 3 is based on measured data. Class 2 audit data have been used in part for benchmark and model development and class 3 for model validation and verification. The detail is listed below:

An energy audit Level 1 was conducted to determine the total electricity energy consumption of the whole farm. This information is gathered from farm utility bills from 19 farms for a two year period.

An energy audit level 2 was conducted, which is an itemized farm approach. This involves breaking down the total energy usage on the farm into energy used for each operational component such as milking, water heating, cooling, ventilation, lighting, feed and manure handling. This involves interviews with farmers to quantify the operational time of use and detail analysis, numbers and wattage, of each piece of equipment. Based on this information the energy use for each component is calculated. For milking, the horse power of vacuum pump motors and time of use is used to determine the energy required for milking. For example, a 10 hp motor running for 3 hours per day is estimated to use 22.38 kWh per day (10hp*0.746 kW/hp*3hrs). For lighting, energy use is based on the number of light fixtures, wattage of each fixture and (time of use) estimated with interview with farmers. For cooling the energy use is based on horse power of refrigeration unit (compressor) and time of use. Similarly for water heating, by wattage of electric water heater/ size of electric water heater and time of use. Ventilation by the number of fans, horsepower (hp) of each fan motor and time of use. Manure handling and feed through the horsepower of motor and time of use. These audited energy use data were compared with utility bills of corresponding farms to know the energy use proportion for each operational component. And based on these energy use were grouped as primary and secondary energy use. These audit data derived will be discussed in Chapter 4.

Based on information collected from audit data (energy audit level 2), inventory of dairy farm equipment and theoretical calculation of energy requirements, a model has been developed to better represent the energy consumed for each component of the farm. This model is a more pragmatic way for evaluating energy use than the audit value alone. The model approach is used in conjunction with operational process information, obtained from farm visits, to provide a benchmark parameter for each component. Model and benchmark development will be discussed in Chapter 5. This addresses the first and second objective of this thesis i.e. model development and to determine benchmark parameter for each operational components which is presented in Chapter 5 (Model and benchmark development).

An energy audit level 3 is conducted to determine actual energy usage, validation and verification. This is achieved by measuring actual energy consumption. To undertake the field measurements various equipment was used including fluke power analyser, clamp meter, hobo (Model no – U12-00064- Channel onset company) and sensors for measuring temperature. The instruments were installed on farm motors and electricity panels for a minimum of 2 days. Then the data were collected, downloaded to a computer and analyzed using an excel spread sheet. This measured energy use data collected is further compared with model energy use through a statistical method. The statistical method used for model validation with actual measured data is the Coefficient of performance and the Index of agreement. These methods are used to evaluate how good the prediction model are predicting actual energy usage. This model validation is presented in chapter 6.

Coefficient of efficiency (E) ranges from -∞ (minus infinity) to 1 with higher values indicating better performance. It was proposed by Nash and Sutcliffe in 1970 which is given as:

$$E = 1 - \frac{\sum_{t=1}^{n}(O_t - P_t)^2}{\sum_{t=1}^{n}(O_t - \tilde{O})^2}$$

Here Õ is the mean of the observed values and P is the predicted values. If E > 0, the model gives better forecasts than forecasting all values by the mean (Õ); E = 0 means the model forecasts are as good as the mean, and E< 0 means that the model is worse than forecasting the values by the mean.

The index of agreement is a relative measure that ranges from 0 to 1, where higher value indicating better performance. This index of agreement was developed by Willmott in 1981.

$$d = 1 - \frac{\sum_{t=1}^{n}(\mathrm{O_t} - \mathrm{P_t})^2}{\sum_{t=1}^{n}(|(\mathrm{P_t} - \tilde{\mathrm{O}})| + |(\mathrm{O_t} - \tilde{\mathrm{O}})|)^2}$$

Where Õ the mean of the observed values, P is is the predicted values and O is the observed values. Coefficient of efficiency and Index of agreement were used to compare the model energy use with the measured energy use. Energy use was only measured for primary component which constitute of milking, water heating, cooling and light. However, light energy use was not validated as published model from Chastain 1994 was used. The validation was not performed for secondary energy use, which comprises manure handling, feed and ventilation and air circulation.

Energy utilization indices were calculated for primary/major operational components with the help of the model developed, benchmark parameters (for example number of cows, quantity of milk or milking units) and audit data. This addresses the third objective of this research, i.e. facilitate the computation of Energy Utilization Indices [EUI], more detail of this will be discussed in Chapter 6 (Validation).

The potential savings from energy efficient technologies suitable for major electrical energy components such as water heating, milk cooling, milking and lights have been presented from case studies and various published resources. For heat recovery and precoolers, a case study has been conducted by measuring energy use on farm with precooler and heat recovery switched on and off to determine the actual energy use. For variable speed drive published information from Ensave is used. This finally addresses the fourth objective of this research which will be discussed in Chapter 6 (Validation and case study).

Chapter 4: Energy Audit

Further research is needed to fully identify and accurately quantify how and where energy is used on dairy farm and in the development of benchmarks that provide a pragmatic indication of operational electrical efficiency as a function of task that allow comparison between farms. The energy audit is a fundamental step in an energy conservation program that consists of a systematic study to document and know how and where current energy is consumed to offer a means to identify opportunities to reduce energy consumption (Bhattarcharya 1992). Energy audits also help to gather benchmark data. Benchmarking is a method used to compare energy use between one farm with the average of other farms or most efficient farms, which helps to identify efficient and inefficient farms (Halberg et al, 2005). The process of identifying efficient and inefficient farms helps to select where changes need to be made. To develop benchmark values for electrical energy consumption for Nova Scotia dairy farms, energy data has been obtained by conducting energy audits on 19 Nova Scotia dairy farms using their utility energy bills. The audit data is then used to (1) identify where and how energy was used, (2) identify the real energy use of each operational task (3) develop a means to estimate energy usage (model) for each operational component (4) produce benchmarks from the model for each operational component, which will help to compare one farm's energy use with another. Audits have been conducted using the American Society for Agricultural and Biological Engineers standard for On-farm Energy Auditing (ASABE 2009). The standard and methodology provide consistency and the creation of sector based benchmarks. Three classes of audit are identified in the standard described in

Chapter 3. This chapter uses energy audit class 1 and 2, which comprise the inventory of electrical energy using equipment, time of use and comparison to utility bills

This chapter provides an overview of NS dairy farms energy use to identify where and how electrical energy is used on dairy farm, this includes a crossection of NS dairy farm energy use, i.e. a detailed study of audit data for all operational components. This data is used to determine if the number of cows or the amount of milk produced is a suitable way of benchmarking; a method which has been used up to date by the industry and many researchers.

4.1.Summary of NS Dairy Farm Audit Data

The following analysis is based on primary data obtained from 19 dairy farm utility energy bills and energy audits conducted in Nova Scotia between September 2010 and March 2012. This chapter starts with a summary of the audits results. The 19 farm energy audit data have been further subdivided according to the type of animal housing used on the farm i.e. tiestall or freestall. The audits revealed that 12 farms use free stall housing and 7 tiestall housing. In tiestall barns, animals are housed, milked, fed and watered in individual stalls. In this type of farm, a milk pipeline is used around the barn and the milker moves from cow to cow. Whereas in a freestall barn animals are housed, fed and watered in a separate barn, and brought in groups to be milked at a milking parlor.

Based on the audit data, lighting represents the highest energy use in Nova Scotia dairy farm about 25%, followed by refrigeration, water heating and vacuum pump representing 17%, 16% and 15% respectively. Feed energy use, manure handling and ventilation and air circulation consumed the least energy representing 4%, 4% and 6% respectively, Figure

15. These results were comparable to research conducted by Bailey in 2004 (Bailey 2007), who confirmed that lighting was one of the greatest electrical energy requiring operation on Nova Scotia dairy farms.

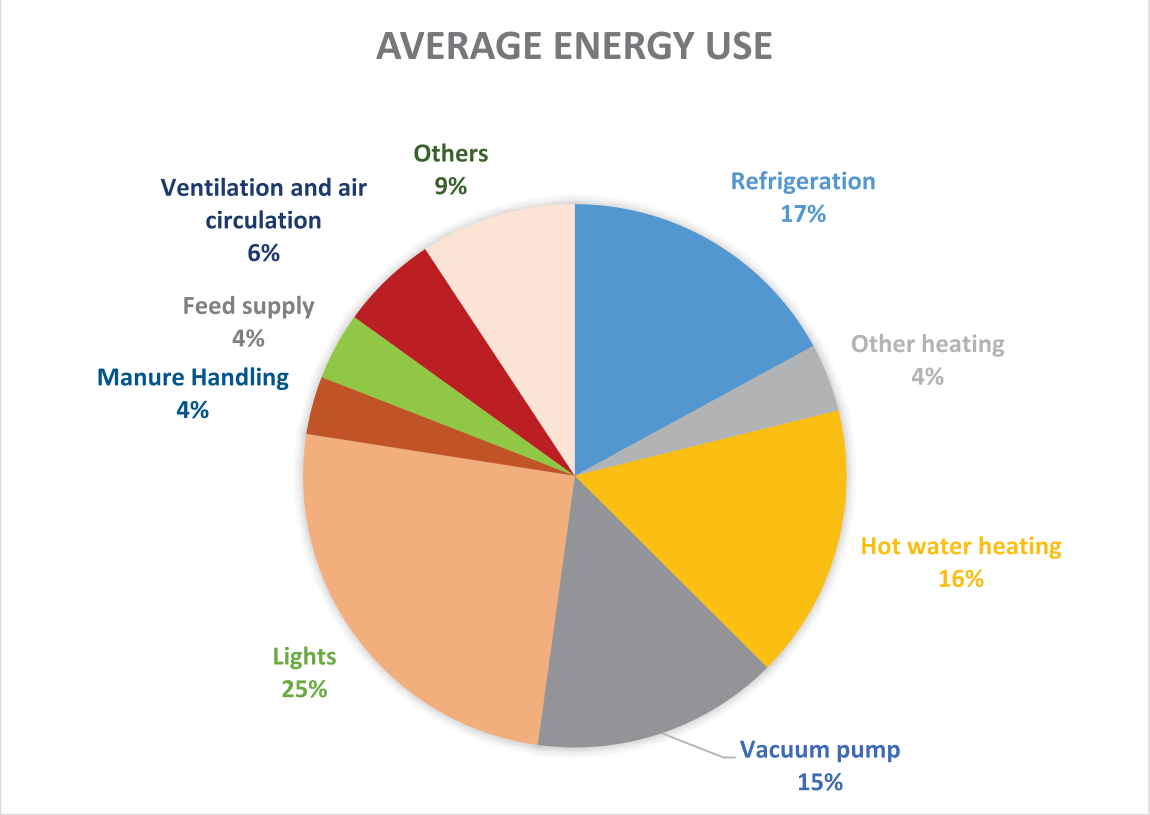


Figure 15: Total average energy use for 19 dairy farm

The average milk production for tiestall and freestall barn is 97 hl/cow/yr and 100 hl/cow/yr respectively. A broad range in farm size (in terms of number of cows) was found for both tiestall and freestall barn. The average energy use for these 19 NS dairy farms is 55,661 kWh. This is 20% lower compared to a survey conducted by Bailey 2007 which states that NS dairy farm average electrical energy expense in 2004 was 69,567 kWh ($8348, 0.12c price per kWh).

4.2. Sample t test:

The graph between utility energy use for tiestall and freestall vs number of cows is shown in Graph A (Appendix A).

To determine if the tiestall and freestall utility energy use are statistically different or the same, a 2 sample t test is used: tiestall and freestall had varying size of farm based on number of cows.

Method: two independent variables t distribution test (2 samples t-test carried out by Minitab software).

Solution: A Normality test was conducted for tiestall and freestall utility energy use. The conclusion of the two sample t test between the freestall and tiestall barns was that there is no statistical difference between tiestall and freestall utility energy use, based on the audit data obtained for the 19 dairy farms.

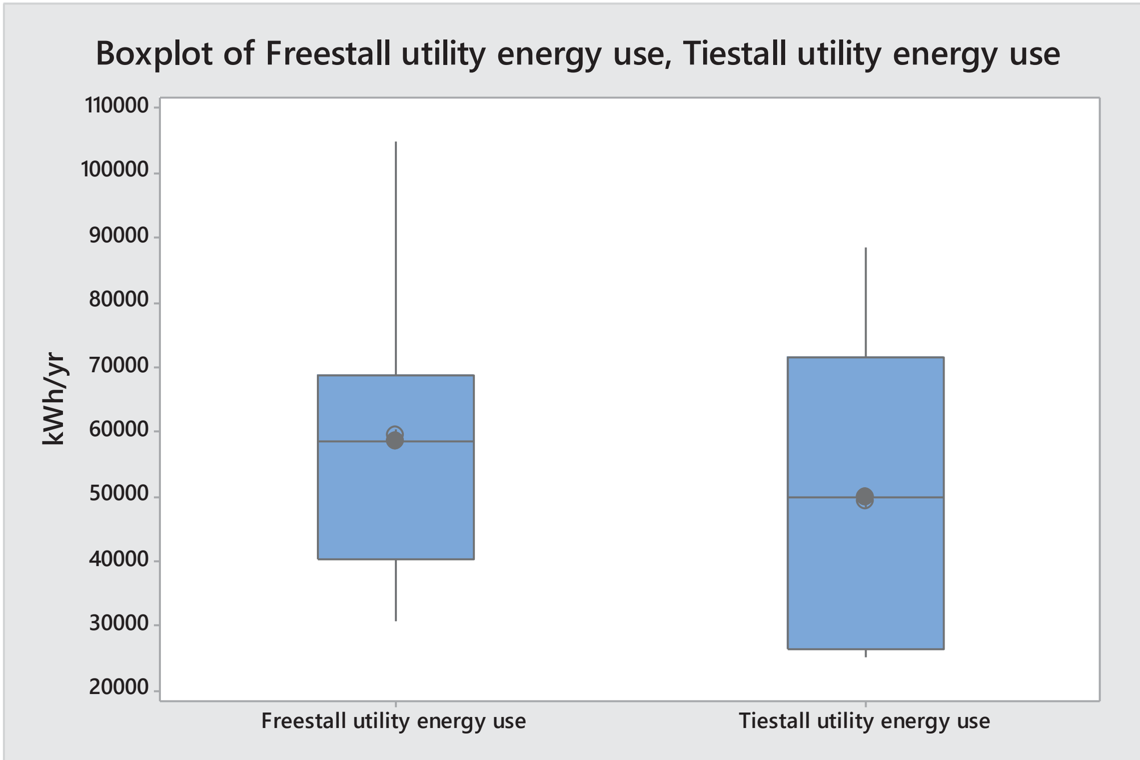


Figure 16: Boxplot of freestall and tiestall utility energy use

4.3 Free stall:

The average electrical energy per freestall farm was 59469 kWh which ranged from 30720 to 104813 kWh annually. These 12 freestall farms produced yearly 87,582 hecto litres of milk from 863 cows. The number of milking cows per farm ranged from 35 to 125, with an average of 116 cows. The highest energy user among the freestall dairy farms was found to be lighting followed by refrigeration, vacuum pump, hot water heating, ventilation and air circulation, feed supply and manure handling Figure 17 below,

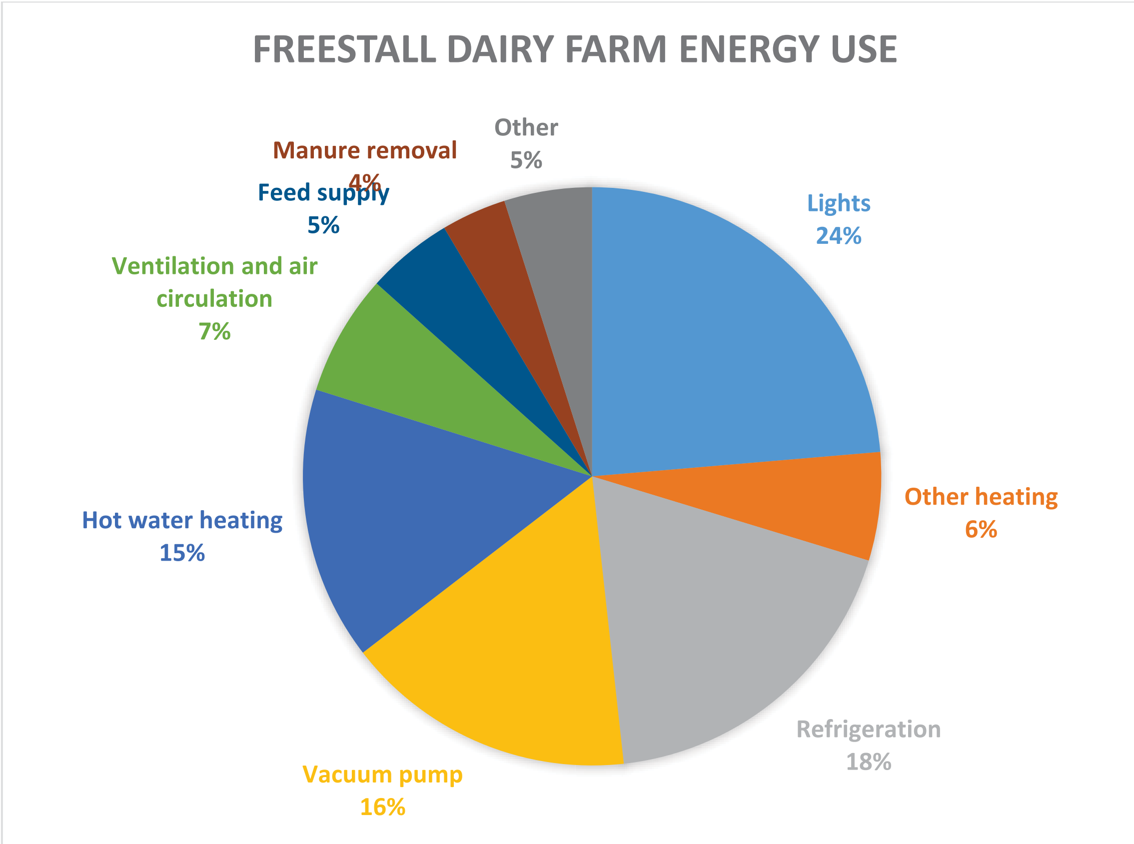


Figure 17: Breakdown of energy used by function in Nova Scotia Free stalls farms

4.4 Tiestall:

The average electrical energy per tiestall farm was 49133 kWh which ranged from 25184 to 88,343 kWh annually. These 7 freestall farms produced 30,934 hectoliters of milk from 318 cows. The number of milking cows per farm ranged from 17 to 80, with an average of 45 cows. The highest energy user among the tiestall dairy farms audited was also found to be lighting which comprises 29% of total tiestall energy use, Figure 18.

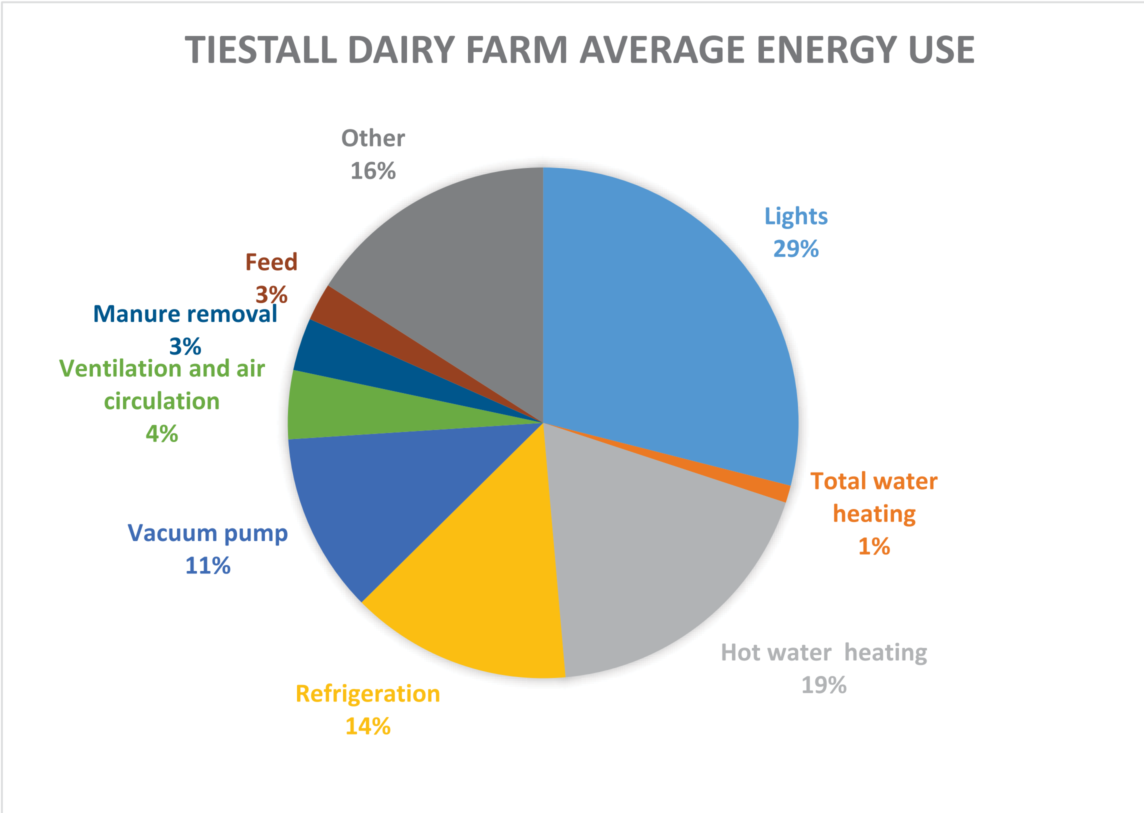


Figure 18: Breakdown of energy used by function in Nova Scotia Tie stall farms

4.5. Small, Medium and Large Farm

The audit data from 19 dairy farms is representative of different sizes of dairy farms in Nova Scotia. These 19 dairy farms have been further grouped into three sizes based on the economy of scale determined from audit and utility data. The three categorized scales have been selected using the following metric; farms with less than 50 milking cows categorized as small, farms between 50 to 80 milking cows as medium and farms with more than 80 as large dairy farms. From the data collected for the 19 audits, small farms range between 17 to 50 cows, medium between 55 to 80 farms and large between 84 to 125 cows. The list of annual utility energy used for small, medium and large is listed in Table A (Appendix A)

The average annual energy used for small, medium and large farms is 44,069 kWh, 60,225 kWh, and 74,897 kWh respectively. Lighting is the highest energy use for small and large dairy farms in Nova Scotia, representing 33% and 28% of total energy use. In the case of medium farms however refrigeration accounts for the highest energy component representing 18%. This data therefore shows that the percentage of energy use for each individual component may be dependent to some degree on the size of the farm. Figures 19, 20 and 21 display the various energy component percentages for the three different farm sizes.

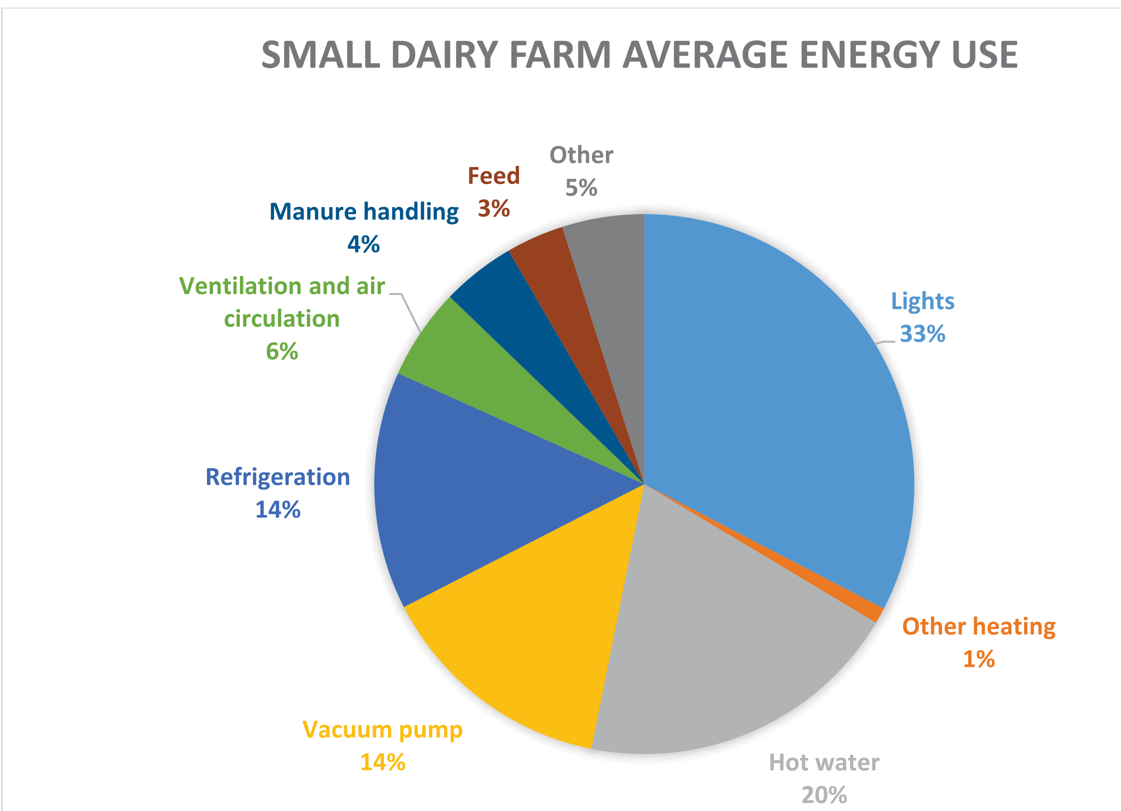


Figure 19: Percentage of various energy use components of small farm size

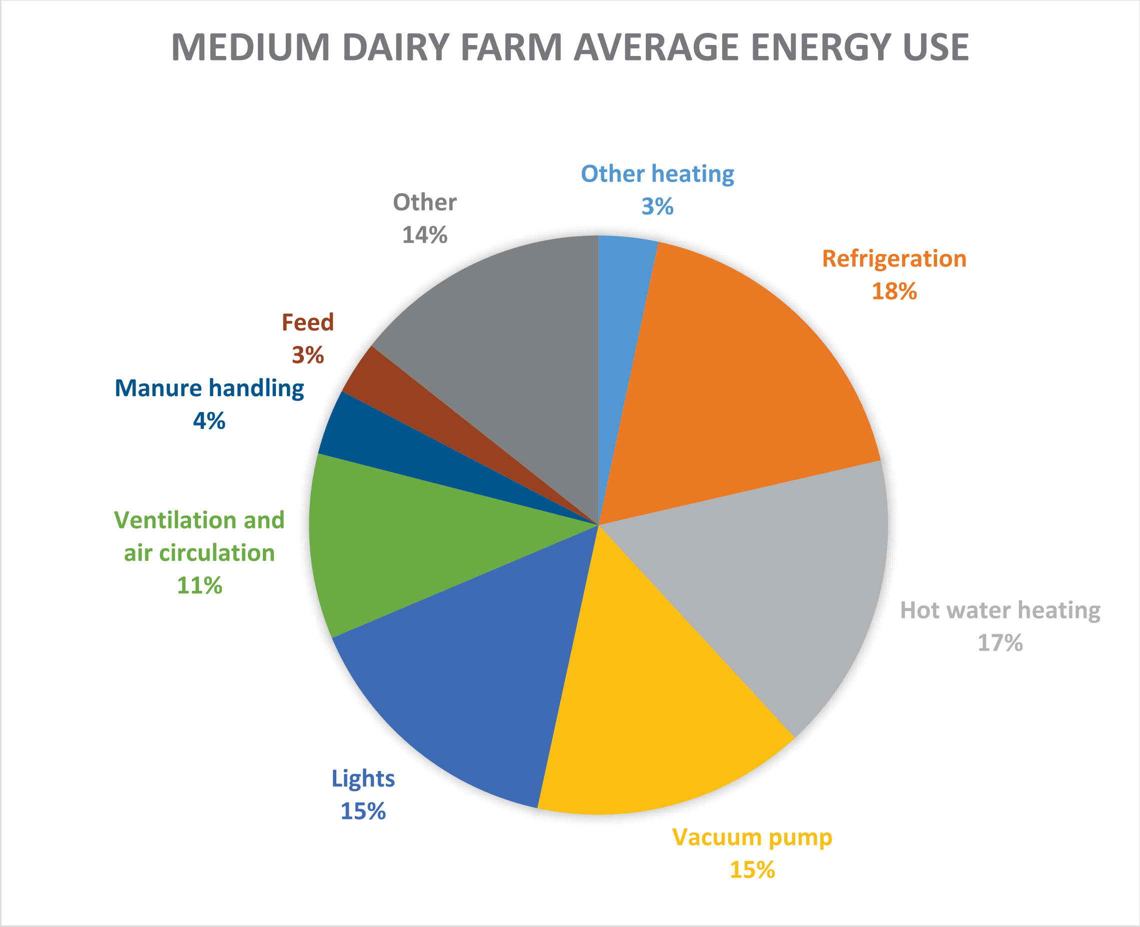


Figure 20: Percentage of various energy use components of medium farm size

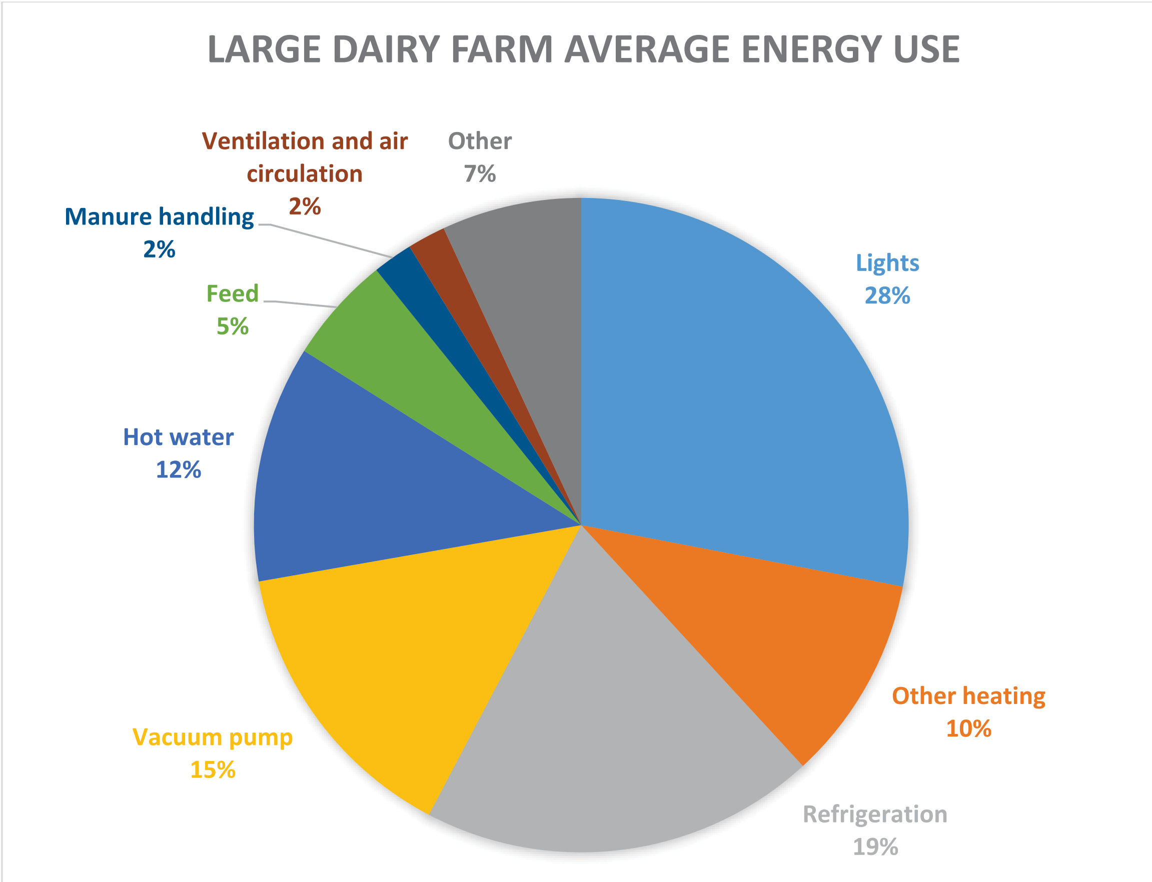


Figure 21: Percentage of various energy use components of large farm size

Fig 19, 20 and 21 shows that lighting energy use becomes a small portion of total energy use. This research was quite comparable to the survey conducted by Bailey 2007, lighting was considered as one of the highest percentage of energy use by small farmers; however, as size increased, the number of farmers with lighting as principal energy use decreased.

4.6 Energy Utilization Index

The Energy Utilization Index (EUI) is a quantitative method for understanding or describing electrical energy use. It provides a common basis which relates the amount of energy used by a piece of equipment (energy input) with some output. In the dairy industry kWh/cow/yr and kWh/cwt (hundred weight of milk) are the two EUIs which have been commonly used for benchmarking electrical energy use. Applying these two EUI's to the data obtained from the 19 dairy farms audits, results in average annual energy use per cow is 971 kWh/cow and per quantity of milk is 9.96 kWh/hl. Likewise the EUIs for other components of the dairy farm is listed in Table B (Appendix A).

NS dairy farms use 971 kWh per cow per year, this result was 9.2% lower than the research conducted by Bailey 2007 thesis (NS dairy farm spend 1069 kWh/cow/yr) and 24.3% higher than New York state (781 kWh/cow/y) (Ludington, et al, 2003). Various research (Eden et al 2003) (Farmer et al. 1990) states that energy use on dairy farms is influenced less by the number of cows compared to the quantity of milk. Therefore indexing dairy farm energy use based on milk produced has a better indicator of energy used. On the basis of this, NS dairy farms uses 4.52 kWh/cwt (9.96 kWh/yr/hl) which is 11 % higher than research conducted by Bailey for NS dairy farm in 2004 (4.07 kWh/cwt) and 28% higher than Ontario dairy farm in 2006 (3.53 kWh/cwt) (Agviro Inc, 2007).

The nineteen Nova Scotia dairy farm EUIs have further been divided based on small, medium and large farms (less than 50 number of cows as small farm, 50 to 80 as medium and above 80 as large). The resultant EUI's range from 560 to 1767 kWh/cow/yr and 4 to 16 kWh/hl/yr. The lower values are found on large dairy farms and the higher values on small dairy farms. The average EUIs for small, medium and large dairy farms are 1154 kWh/yr/cow, 844 kWh/yr/cow and 747 kWh/yr/cow respectively. Similarly 12 kWh/yr/hl, 9 kWh/yr/hl and 7 kWh/yr/hl are EUIs for milk production on small, medium and large farm respectively. Table C (Appendix A) shows EUIs of all energy consuming components of a dairy farm. This table shows that economy of scale plays a significant role in benchmarking energy use on a farm.

Similarly, tiestall and freestall energy use was also subdivided based on milk production and number of cows to see how it varies Table D (Appendix A). An average 878 kWh/yr/cow and 1130 kWh/yr/cow are the EUIs based on number of cows for freestall and tiestall utility energy use respectively, with 8.89 kWh/yr/hl and 11.56 kWh/yr/hl based on milk production for freestall and tiestall respectively.

4.7 Regression Analysis:

MiniTab software was used for regression to assess the relationship between response (in this case utility energy use/ energy use components) and predictor (number of cows/quantity of milk production). For the 19 dairy farms utility energy use, the regression model for number of cows has linear equation with R-Sq value of 45.7% (scatter plot in Graph 1.1, Appendix A). And for milk production a linear equation was found with R square value of 47.18 % (scatter plot in Graph 1.2, Appendix A). This shows that the total energy use for dairy farm is more related to milk production compared to the number of cows. This analysis was similar to the research conducted by Eden et al. 2003 which states milk production best explained the total energy consumption of dairy farms.

Regression analysis was also conducted for dairy farm operational energy use, for this analysis energy audit data were used. In the case of vacuum pumps, the regression model had a linear equation with R-square value of 38.79% for number of cows (scatter plot in Graph 1.3, Appendix A) and a linear equation with R-square value of 35.43% for milk production (scatter plot in Graph 1.4, Appendix A). For refrigeration energy use, linear equation with R-square value of 49.14% and 31.38% for milk produced and number of cows respectively (scatter plot in Graph 1.5 and 1.6, Appendix A). In the case of lighting energy use, the regression model for number of cows had a linear equation with R-sq value of 12.5% (scatter plot in Graph 1.7, Appendix A), and for milk production it also has linear equation with R-sq value of 15.3% (scatter plot in Graph 1.8, Appendix A). Similarly for manure handling a quadratic equation with R square value was 9.4% for number of cows and a cubic equation of 11.6% was observed for milk production (scatter plot in Graph 1.9 and 1.10, Appendix A). For feed energy use, a cubic equation with R-square value of 20.7% and 27% was found for number of cows and milk produced respectively (scatter plot in Graph 1.11 and 1.12, Appendix A). Likewise for ventilation energy use, a quadratic equation showing variability of 4.1% for number of cows and cubic equation of 16.9% for milk produced (scatter plot in Graph 1.13 and 1.14, Appendix A). For water heating a linear equation with R square value of 23% was observed for both number of cows and milk produced (scatter plot in Graph 1.15 and 1.16, Appendix A).

Conclusion

EUI for the 19 audited dairy farm ranges from 560 to 1767 kWh/yr/cow and has an average energy use of 971 kWh/yr/cow. EUI based on milk production ranges from 4 to 16 kWh/yr/hl and has an average EUI of 9.96 kWh/yr/hl. This therefore shows a large variation in benchmark values. Also, results from regression analysis, which have been discussed above, 19 dairy farm utility energy data shows that number of cows shows R square value of 45.7%, more than 50% of the utility energy consumption was not explained by number of cows alone. However, milk production is related more to energy use compared to number of cows showing 47.18% of variability. But still the regression analysis indicates there might be other predictors that may have influenced greater impact in energy use rather than number of cows or quantity of milk alone. It was found that there is least correlation between the number of cows and quantity of milk for any of the operational components of a dairy farm with maximum R square value of 49.14% for refrigeration energy use.

The energy audit data and utitlity energy data suggest that EUI's based on the number of cows and quantity of milk are not the only parameters that impact energy use since there is large variation in benchmark values. It was seen that there is no statistical difference between tiestall and freestall energy use, farms with the same number of milking cows for freestall and tiestall farms, in some cases tiestall had higher energy use and in some case freestall was higher. Therefore, there must be other parameters such as energy efficient technologies, size of the farm, environmental variations etc too, which might have influenced the energy use which needs to be further researched. For this purpose the total energy use is further categorized based on each operational components which will be discussed in detail in Chapter 5 (Model and benchmark development).

Chapter 5: Model and Benchmark Development

In the previous Chapter 4 (Energy audit), it has been discussed that energy use for dairy farm does not vary based on number of cows or milk production alone. Therefore, to determine better benchmark parameters for dairy farm electrical energy use, in this Chapter the total energy use is further broken down to each operational component such as milk cooling, milking, water heating, light, manure handling, feed and ventilation and air circulation. A model is developed for all of these operational component with the help of audit data, farm inventory and theoretical energy calculation for each component. These models will better represent the energy use for each operational component. With the help of the model developed and operational process information a benchmark parameter will be identified for each operational component that will better represent the energy use.

5.1. Milk Cooling

Cooling milk is an essential step in ensuring the safety and quality of milk produced on the dairy farm. Fresh milk is normally collected from the cow at 39°C and must be cooled to 10°C or less within one hour and down to between 4°C and 0°C within two hours of milking (Canadian Quality Milk 2010) to meet the health and safety standards for human consumption. The equipment used for refrigeration systems on Nova Scotia dairy farms consist of a bulk tank, evaporator, condenser and a compressor unit. In most of the dairy farms visited as a part of the audit, milk cooling takes place in a stainless steel milk tank equipped with one or two compressors. Typical energy conservation technologies found in the milk cooling process are precoolers and scroll compressors.

A number of studies have determined that the energy used in the milk cooling process is related more to the quantity of milk cooled i.e. kWh/hl (Eden et al. 2003)(Farmer et al. 1990). The amount of heat to be removed from the milk can be estimated using the specific heat capacity (0.003891 MJ/L °C) of the milk, if the mass of milk and the temperature differential are known, when there are no energy efficient technologies used. Therefore this is one operational component of the dairy farm that is directly related to milk production, differential temperature and compressor efficiency. Technologies such as precoolers, high efficiency compressors and heat recovery units serve to reduce energy requirement. The amount of milk produced daily varies greatly on Nova Scotia dairy farms. The dairy farm audits identified that the average dairy farm size of 71 (17-125) cows in Nova Scotia collects an average of 1962.5 (425-3500) liters of milk each day. The temperature differential is 35° C (temperature of the milk from cow is usually 39°C and milk to be cooled is 4°C) and the amount of heat to be removed from the milk considering coefficient of performance (COP) of the refrigeration system as 1 is 267.26 MJ per day. Based on this data the milk cooling energy requirement for average Nova Scotia dairy farms is 27119 kWh per year obtained from equation below.

***Equations used:**

heat removed (MJ/day) = mass of milk (kg/day)x specific heat of milk (MJ/kg/°C) x temperature reduced (°C)

= 1962.5 kg x 0.003891 MJ/kg °C x 35°C

= 267.26MJ/day

kW-h = 269.5 MJ/day x 1 kW-h / 3.5971 MJ

= 74.29 kWh/day

Per year = 27,119kWh/yr

However, other factors can affect the amount of energy required to remove a given amount of heat from the milk. The efficiency of the refrigeration system is expressed as coefficient of performance (COP). C.O.P is the amount of energy removed from the milk for each unit of electrical energy input to the system. It is also a mean of comparing the efficiency of similar equipment (Energy research institute). C.O.P is inversely proportional to the temperature difference between a heat sink and heat source (Energy research institute). The heat source, in the case of the milk cooling refrigeration system, is the milk from the cow, which is almost constant i.e. 39ºC. So the only variable is the temperature of the heat sink, which varies based on temperature of the season. This is one of the reasons why milk cooling energy use is higher in the summer than the winter. Ten farms were monitored to determine COP of refrigeration system. COP was determined by measuring actual energy used for milk cooling, volume of milk, temperature of milk from the cow or precooler (in cases where precooler was present) and temperature of milk from the refrigetation unit.

To calculate COP, following formula is used:

COP = Theoretical energy requirement for refrigeration / Actual energy requirement for refrigeration

Theoretical energy requirement for refrigeration = $m \times \Delta T \times C_m \times 0.278$

Where,

m = mass of milk production per year (kg)

ΔT = difference in temperature between milk from cow and the temperature of milk to be cooled (°C)

C_m = specific heat of milk (0.003891 MJ/kg °C)

0.278 is a conversion factor to convert MJ to kWh (1kWh = 3.6 MJ)

The COP determined as a part of energy audit process was found to range between 1.62 to 2.61 (average 2.12) for refrigeration unit with and without precooler (See Appendix B, Milk cooling).

The electrical efficiency of the compressor(s) and fans directly affect the performance of the cooling system; the electrical requirement can be reduced by up to 20% using a modern scroll compressor compared to traditional reciprocating compressors (Ludington et al. 2004).

Two other factors that affect the amount of energy required are the volume of milk produced and presence of a pre-cooler. Pre-cooler performance varies based on the temperature of well water and efficiency of the pre-cooler. The dairy audits identified Nova Scotia dairy farm had average ground water temperatures of 11.5°C (10-13°C) so the only variable is the efficiency of the pre-cooler which is impacted by the flow rate. The audit data shows that 54.1% of audited Nova Scotia farms studied already had pre-coolers installed. One of the reasons for the popularity of this technology is due to its capacity for reducing the amount of heat that has to be removed by refrigeration system. The ratio of milk and water flow rate, type of precooler (size and number of plates in precooler) which is determined by maximum flow rate of milk expected from milk pump, water temperature, direction of milk and water flow, plate compressions and cleanliness, are the factors that affect the effectiveness of precooler (National milk harvesting center, 2006). According to research conducted by National milk harvesting center 2006, an efficiently working precooler can reduce the milk temperature to within 2°C of the cooling fluid temperature. Considering this case and Nova Scotia ground water average temperature as 11.5°C, milk temperature outflow from an effective precooler should be

13.5°C, which would lead to milk cooling energy reduction of 65% using equation 1 (below). This saving percentage for milk cooling energy use is close to the results obtained by Sanford 2003b, which claims that a precooler can reduce milk cooling energy use up to 60%. However, in this research, an average of 32% precooler saving, resulting from a case study which was conducted on Farm X has been used to determine the milk cooling energy reduction from precooler (detail of this case study will be discussed in Chapter 6).

A Refrigeration heat recovery unit (HRU) unit can reduce the energy requirement of refrigeration system by more efficiently removing heat away from the refrigerant (Sanford 2003c). Based on a case study conducted on Farm X, HRU reduces the energy requirement for cooling by about 6.4% (detail of this case study will be discussed in Chapter 6). This saving percentage is quite comparable to the research conducted in 74 Wisconsin dairy farms by Kammel and Patoch 1993, a saving of 7% milk cooling energy use was identified after the installation of heat recovery system. To calculate the savings from heat recovery unit, heat recovery case study saving for milk cooling (saving of 6.4%) is used here.

One factor which makes determination of refrigeration system performance unreliable is the reliance on ambient temperature; however, to develop a model for energy use for milk cooling energy following formula is used:

Energy used for milk cooling (MJ/yr) = (m* Cm* ΔT)*365 / COP

$$\text{Energy used for milk cooling (kWh/yr)} = ((m^* \; Cm^* \; \Delta T)^*365)/3.6 \; / \; COP \qquad \text{Eq.1}$$

Where,

m= mass of daily milk production (kg /day)

Cm= specific heat of milk (0.003891 MJ/kg °C)

ΔT = temperature of milk from the cow (°C) – bulk tank set point (°C) = Temperature difference without the presence of precooler is usually 35°C

kW-h/yr = 1 MJ/yr x 1 kW-h / 3.5971 MJ

COP here used is an average of 2.12 (ranges between 1.62 to 2.61)

Based on the model presented above and looking at theoretical performance of milk cooling process, the benchmark parameter for the milk cooling energy use is amount of milk produced (hl) which is presented as below:

Benchmark parameter used for milk cooling = milk production

This model for milk cooling energy use presented above is for a farm that does not have any energy efficient technology installed. Various authors present different savings for the heat recovery and precooler, which have been discussed in literature review in previous Chapter 2. Ludington et al. 2004 reports scroll compressor reduces energy use for milk cooling by about 20%. This saving for scroll compressor is used for farm with scroll compressor installed; however, for heat recovery and precooler, a case study has been conducted to present exact savings for milk cooling. The detailed case study will be discussed in chapter 6 (validation and case study), but the results of the case study are as follows:

Presence of a precooler - 32% reduction in milk cooling energy use

Presence of heat recovery unit - 6.4% saving in milk cooling energy use

This model for milk cooling (equation 1) which has been developed will further be validated with measured data which will be discussed in Chapter 6.

5.2.Water Heating

Large volumes of hot water are used for cleaning the pipelines, bulk tank, utensils and towels. The amount of energy used for water heating varies tremendously from one farm to another. One of the main reasons for this variation is economy of scale and the volume of water required to perform the cleaning task for basic infrastructure. Smaller farms tend to use proportionately more water because of the scale factor in pipeline washing. The amount of water used and the temperature to which the water is heated both influence the amount of energy used for water heating . The audit data indicates that the average electric water heater on a Nova Scotia dairy farm is typically required to raise the water temperature from 11.5°C (10-13°C) to 74.5°C (64-85°C) i.e. an average increase of 63°C. The average wash sink holds 140 L (60-220L) of water and average bulk tank capacity is 3500 L (1000- 6000L) for an average milking herd of 71 (17-125) cows. Of the farms studied the average farm in Nova Scotia milks 2-3 times per day with the majority milking twice daily, milking equipment and pipelines are washed after each milking operation and bulk tanks are washed every second day. The bulk tanks and milking equipment are cleaned, typically using four cycles: rinse (usually warm water, which is half hot and half cold), wash (hot water), acid rinse (determined based on manufacture recommendation) and sanitize (warm). Based on Canadian Quality Milk (2010) standards which required certain temperatures be maintained until the end of the wash cycle, these temperatures are 35(end), 71(start), and 43(end) °C for the rinse, wash, and sanitize cycles respectively; the acid cycle temperature is to be determined by the manufacturer or supplier of the acid solution. The formula used for calculation of cycles of hot water required based on temperatures is:

Figure 22: Sink installed in an audited dairy farm to clean bulk tank, pipelines and milking units

$$\mathbf{Cycles} = \frac{\sum_{n}(n^{th}\ \text{Cycle Temperature}(°\text{C})) - n * \text{Cold Temperature}\ (°\text{C})}{\text{Hot Temperature}(°\text{C}) - \text{Cold Temperature}(°\text{C})}$$

Using this formula for calculation of cycles (sinks of hot water) required for Canadian quality milk standard temperatures, the number of cycles is 2. Based on this the amount of water required for washing the pipelines is 2 (cycles calculated) times the size of the sink and number of milking per day.

As a rule of thumb the amount of hot water equal to 2% of bulk tank volume is required for tank cleaning after the milk is collected which occurs every second day. Therefore, the amount of hot water required for washing the bulk tank per day is 2*2%*0.5* size of the bulk tank, 0.5 is used because bulk tanks are washed every second day.

During the audits, it was observed that cycle temperatures and sink volume vary greatly from one farm to the next, one of the reasons why the amount of energy use for hot water heating and hence benchmarking varies between farms of similar size. Since the majority of farms milk twice per day, this will be used for subsequent analysis and benchmark development for water heating. Based on actual measured temperatures on 5 dairy farms, the average wash cycle is 2.51 (2.30 to 2.79). This would result in the wash requiring 789 L per day, for twice milking and 1141 L per day for three times milking, the equivalent of 21,101 kWh per year for twice milking and 30,520 kWh per year for thrice a day milking for the average Nova Scotia dairy farm while still assuming 100% water heater efficiency (detail calculation listed below).

Sink wash = Cycles * Number of milking per day * wash sink capacity

=2.51* 2 *140 = 702 L (twice a day milking)

=2.51 *3* 140 = 1054 L (thrice a day milking)

Bulk tank wash = Cycles * 0.5* 0.02 * bulk tank capacity

=2.51 *.5*.02 *3500= 87 L

Yearly water required = (Sink wash + bulk tank wash)*365

= (702 +87) *365 = 789*365 L = 287,985 L (twice a day milking)

= (1054 +87)*365= 1141*365 = 416,538 L (thrice a day milking)

Required temperature increase = Hot water set point – Supply temperature

=(74.5 -11.5)ºC = 63ºC

Energy required for water heating = yearly water required * required temperature increase* (4.187/3600) kWh

= 287,985 *63*(4.187/3600) =21,101 kWh/yr (twice a day milking)

= 416,538 *63 *(4.187/3600) =30,520 kWh/yr (thrice a day milking)

Efficiencies for water heater used in dairy operations however are not 100% due to standby losses and although the efficiencies do vary considerably between various models Scott Sanford (2003a) suggests the average water heater has an energy factor of 0.7-0.85 and high efficiency heaters have energy factors of 0.91 or greater. This means that for a high efficiency water heater, the average energy usage could be as high as 23,187 kWh/yr (twice a day milking) and 33,539 kWh/yr (three times a day milking).

Energy required for water heating = 21,101 /0.91 = 23,187 kWh/yr

= 30,520 /0.91 = 33,539 kWh/yr

Energy required for water heating (kJ/yr) = (mass of water (kg/yr) * required temperature increase (°C) * specific heat of water (KJ/kg °C)) / WHe

1 kWh = 3600 kJ

Model for water heating energy use is:

Energy required for water heating (kWh/yr) = (yearly water required * required temperature increase* (4.187/3600)) / WHe

Where,

WHe = water heater efficiency

Yearly water required = (Sink wash + bulk tank wash)*365 (L)

Sink wash = Cycles * Number of milking per day * wash sink capacity (L)

Bulk tank wash = Cycles * 0.5* 0.02 * bulk tank capacity (L)

$$\textbf{Cycles} = \frac{\sum_n(\text{nth Cycle Temperature}(°\text{C})) - n * \text{Cold Temperature }(°\text{C})}{\text{Hot Temperature}(°\text{C}) - \text{Cold Temperature}(°\text{C})}$$

Required temperature increase = Hot water set point – Supply temperature (°C)

Presence of heat recovery system –56% water heating energy saving due to heat recovery system has been used from case study detail of this is presented in chapter 6 (Validation chapter, case study section)

Presence of precooler alone - presence of a precooler alone does not contribute to the energy saving for water heating unless the warm water from precooler is used for preheating the well water.

Presence of a precooler and heat recovery both - precooler lessens the energy saving contributed by heat recovery. A 55% reduction in water heating energy is found in case study where combination i.e. both technologies are used. Detail of this is presented in chapter 6 (Validation chapter, case study section)

Even though the actual percentage of saving from heat recovery is difficult to measure, it was found that 70% of Nova Scotia dairy farms studied were currently using both energy saving technologies. However, one question raised by many farmers visited as part of the audit process was how they know which technology to install, based on their farm size and production scale. The initial studies conducted by Peebles et al (1994) showed that for small farms of 60 milking cow size, heat recovery was best option for saving energy, however for large farms of 200 and 400 cow size combined heat recovery was best option.

Based on the model presented in equation 2 and looking at theoretical performance for water heating operation at dairy farm. The benchmark parameter choose for water heating is size of the sink and bulk tank (L).

Benchmark parameter for water heating = size of sink and bulk tank (litre)

This model for water heating which has been developed in equation 2 will further be validated with measured data which will be discussed in Chapter 6. Also there is a need to know the percentage of saving attributed by heat recovery unit. Peebles et al. 1993 reports that heat recovery reduces water heating energy by 40 to 50% on all farms. Another research conducted by Kammel reports an average of 48%. How much saving does a heat recovery actually produce, and what is the effect of combined heat recovery and precooler? For this a case study will be conducted which will be discussed in chapter 6 (validation and case study).

5.3 Milking

The equipment used for milking in Nova Scotia dairy farms comprises a vacuum pump and transfer pump. The vacuum pump extracts milk through the pipeline from the milking cows to the receiver jar, the transfer pump then transfers the milk from receiver jar to the bulk tank. The transfer pump represents a very small portion of the milk collecting energy use i.e. 1%. The vacuum pump is used for milking and washing the pipelines and is typically sized based on the number of milking units; however, they are generally oversized to accommodate higher vacuum capacity for washing purposes. This over sizing of vacuum pump wastes energy, since the energy required for milking is typically lower than the pump's capacity. A variable speed drive is an energy efficient technology for reducing vacuum pump energy use without any loss of milking system performance.

Five farms (listed in Appendix D, Milking) were analyzed for vacuum pump energy use, the predictor for energy use for a dairy farm was found to be time of use, horsepower of vacuum pump and number of milking days. Based on data from five dairy farms, time of operation has found to be the best predictor for milking energy use. Different analysis was performed to find whether milking energy use differs based on size of the farm (small, medium or large) or type of farm (tiestall or freestall). The research data shows that the energy use for operating a vacuum pump did not vary based on size or type of farm alone but was greatly influenced by the time of use. The energy use for running the vacuum pump is dependent on the time of operation of the vacuum pump, which varies greatly based on the management practices and volume of milk production. Data from two different farms, one small and one medium sized dairy farm was analyzed. The small dairy farm had lower milk production but the same motor size and same number of milking days as the medium size dairy farm. However, the time of use of the vacuum pump on the small dairy farm was higher than the medium dairy farm due to different management practices. This therefore led to higher milking energy use for the small size farm in comparison to the medium size farm. A similar approach was applied to determine energy use in tiestall and freestall barns with the same vacuum pump motor size and the same number of milking days. The research showed that there is no difference. The difference in milking energy use is due to differences in time of use, management and operating practices, proper equipment sizing, use of energy efficient equipment and number of milking days. Based on these conclusions for factors influencing energy use for vacuum pump, a model has been developed as follow:

Energy used for Milking (kWh) = hp of vacuum pump* 0.746* (average hrs of milking+ 0.5) * number of milking days * 365

_____Eq.3

(Washing time usually lasts for 25 mins to 30 mins, so an average of 30 mins (0.5) is estimated)

Saving by adding variable speed drive is 67%. Ensave conducted a variable speed drive energy savings case study in 10 dairy farms and found the actual saving varies from 46% to 80%, and concluded an average 67% is good approximation to be used for saving due to variable speed drive.

Energy used for Milking with variable speed drive (kWh) = hp of vacuum pump* 0.746* average hrs of milking * number of milking days * 365 – saving from variable speed drive + hp of vacuum pump* 0.746* 0.5* number of milking days * 365

Based on the model for vacuum pump presented in equation 3, and looking at theoretical performance for vacuum pump operation, the benchmark parameter chosen for vacuum pump energy use is the number of milking units and amount of milk produced. Vacuum pump are sized based on number of milking units; however, they are oversized generally to accommodate higher vacuum capacity for washing purposes. Milking units gives a tentative indication about size of vacuum pump and milk production gives running time of vacuum pump.

Benchmark parameter for vacuum pump = milking units* milk produced

This model for vacuum pump energy use presented above in equation 3 is further validated with measured data which will be discussed in Chapter 6 (Validation). And a series of EUI values will be presented for vacuum pump.

5.4. Lighting

The types of light seen in 19 dairy farm audit were T8, T5, T12 florescent lights, incandescent and HID light fixtures. The energy use for lighting varies from one farm to another based on the number of light fixtures, type of light used and time of use (which differs based on whether it is milking or dry cows). Figure 23 below shows lighting energy use obtained from audit data for the 19 dairy farms with various different lighting systems used such as T8, T12, CFL, Incandescent etc. This graph also shows the relationship between annual lighting energy of milking cows and provides a measure of energy used for lighting and indicates that it generally does not vary based on number of cows. However as shown from Figure 23, type of light, number of lights and hours of operation are key factors that can be used to predict the lighting energy use of a dairy farm with more efficient lights offering the potential of significant reduction in energy consumption depending on operational procedures. The number of lights differs based on the barn size. Milking cows, dry cows both play an important role as this dictates the time of use. Milking cows exposed to long day photoperiods require 16 to 18 hours of light with a brightness of 15 to 20 foot candles followed by 6 to 8 hours of uninterrupted darkness per day (Peter 1994), whereas dry cows require short day photoperiod (SDPP) i.e. a dark period of at least 12 hours per day (House 2006). Therefore, dry cows require less energy for lighting than milking cows.

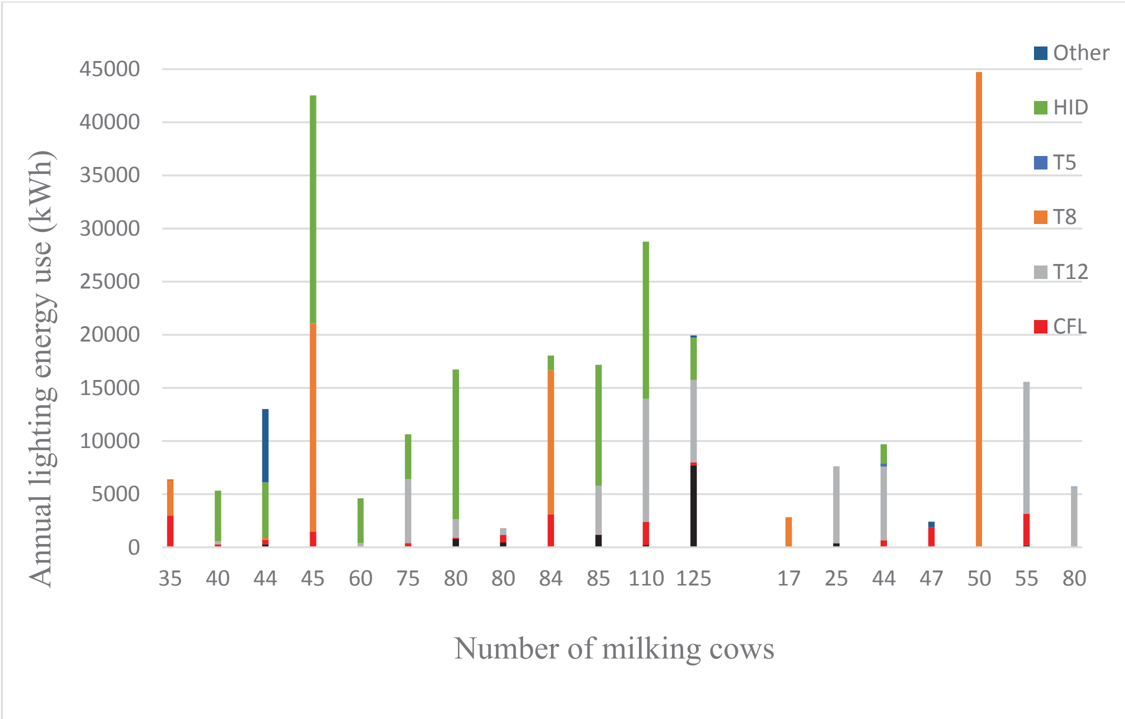


Figure 23: Lighting energy consumption for various lighting systems for 19 audited dairy farms compared to number of milking cows.

From left hand side, farms with number of milking cows between 35 to 125 are freestall barn and from 17 to 80 number of cows are tiestall barn.

From the above figure, which has been plotted from audit data, it can be concluded that light energy use does not vary based on number of cows, neither type of housing i.e. tiestall or freestall. The energy use for lighting however varies based on type of energy efficient lights installed, and hours of operation. Higher the number of energy efficient lights installed lower is the energy use, and similarly lower the hours of operation lower is the energy use. Another major factor that determines the number of fixture required for the barn is area of the barn itself. From this it can be concluded that the energy required for light for a dairy barn can be determined by area of the barn, hours of operation and type of light installed.

The illumination level required in dairy facility for various task or in different work areas is listed in Table 1 (Source: ASAE, 1993).

Similar work has been done by Chastain 1994 for determining dairy facility light energy use. To establish a recommendation for energy use applied to lighting, a design equation developed by Chastain 1994 is used in this thesis which is presented below:

$$\boldsymbol{WAf} = \frac{\text{TTLf. LDF}}{DI}$$

Where,

WA_f = work area illuminated per fixture (m^2/fixture)
TTL_f = total lamp lumens per fixture
DI = design illumination (lux or lumen/m^2)
Design illumination level is determined from table 1
LDF = overall light depreciation factor

Light depreciation factor: The overall light depreciation factor is defined as the fraction of the light emitted from the lamp which can be utilized at the work plane. It is a function of reduction in light output resulting from:

- collection of dirt deposited in light
- and when lamp reaches the end of its useful life

Also LDF is a function of luminaire design, reflectivity of the floor surfaces wall and ceiling.

Light depreciation factor is given as (LDF) = 0.539 /Hp

Where Hp is the mounting height (height of the lamp above the work plane)

Once the work area per fixture is determined from eq. 1, the total number of fixtures needed is determined by dividing the total area to be illuminated by the allowable work area per fixture (WA_f).

No of fixtures required = Total area to be illuminated (m^2) / WA_f ……………..(Eq.4)

Lighting for LDPP (kWh/yr) = Number of fixtures required (eq. 4) * hours of operation (LDPP) /day * kW (wattage of each fixture) *365…………………………….....(Eq.5)

Lighting for SDPP (kWh/yr) = Number of fixtures required (eq. 4) * hours of operation (SDPP) /day * kW (wattage of each fixture) *365………………………………(Eq.6)

Hours of operation LDPP (milking cows) = 16- 18 hrs

Hours of operation SDPP (dry cows) = 12 hrs

Model for Light energy use:

Lighting Energy use (kWh/yr) = Lighting for LDPP + Lighting for SDPP

…...(Eq.7)

Based on the model for light energy use (equation 5) and looking at theoretical performance of light energy use, the benchmark parameter for light energy use is area of the barn.

Benchmark parameter for lighting = Area of the barn (m^2)

5.5.Manure handling

In Chapter 4, regression analysis showed that manure handling energy use does not vary based on number of cows or milk produced. Therefore, there is a need to know the exact parameters that actually influence the energy use for manure handling. For this audit, data of 13 farms were carefully studied (remaining 6 farms out of 19 farms did not use electricity for manure handling). The farm audit data revealed that 13 farms used various different types of equipment such as plunger, cross scraper, alley scraper, gutter cleaner, agitator, compressor, barn cleaner, skid steer and front end loader. The detail discussion of each farm is listed below:

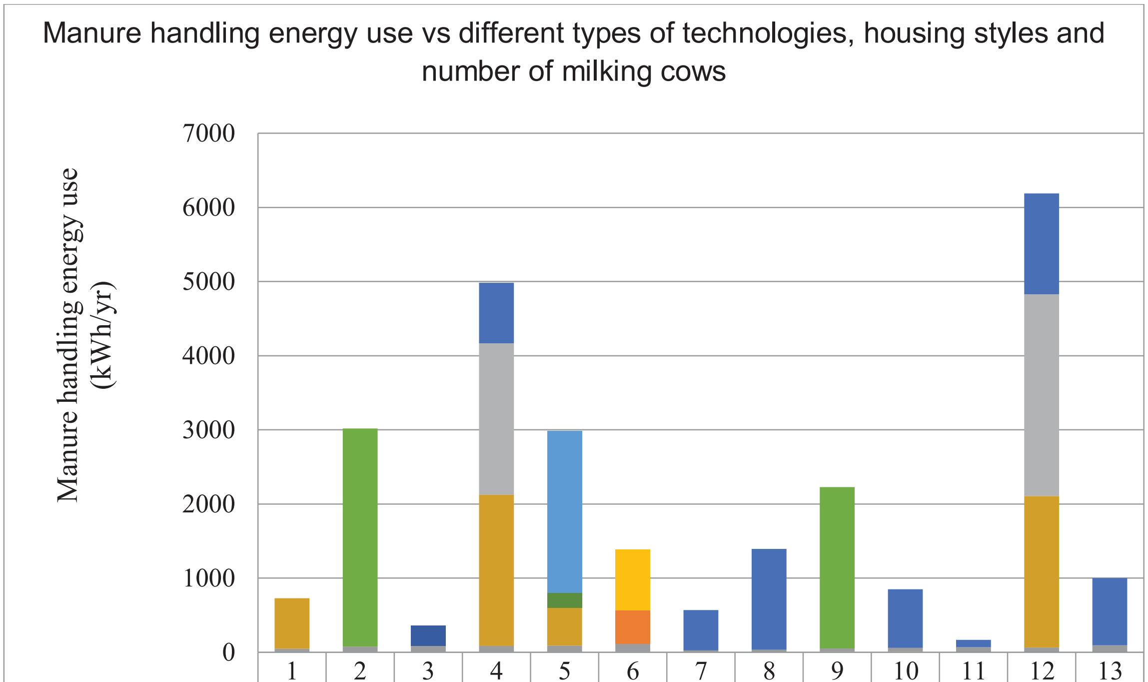
1. Farm 1: A freestall dairy farm. The manure is collected through skid steer into the pit. Plunger pump is used which pushes the manure from the pit through the conduit to the storage area.
2. Farm 2 and 9: Farm 2 is a freestall and Farm 9 is a tiestall. A gutter cleaner is used in both farms. A gutter cleaner is a rugged dependable barn cleaner. All the manure moves from the barn to outside, where manure is then transferred by a tractor
3. Farm 3: A freestall dairy barn. A mechanical scraper is used for collection of manure, the manure is piled in at the end of barn and transferred via a skid steer.
4. Farm 4, 12: Farm 4 is a freestall dairy barn and Farm 12 is a tiestall. Both farms use a barn cleaner for collection of manure to the pit, an agitator to stir the manure and water, which is added for dilution, and a plunger pump for forcing to transfer the manure to storage.
5. Farm 5: A freestall barn where manure is collected via two different types of scrapers alley and cross scraper. The manure is collected at the low end of the barn and transferred via a plunger pump
6. Farm 6: A freestall dairy farm, with slotted holes for collection of manure in the gutter. A gutter scraper is used for scraping manure from the gutter and then it gets collected in a steel tank pit, where it is pumped by compressor.
7. Farm 7, 8 , 10, 11 and 13 : These dairy barns are tiestall, which uses barn cleaner for collection of manure, which is later transferred via a skid steer or a front end loader.

The tie stall farms usually have a gutter cleaner or front end loaders for the collection of manure, a conveyor or pump is used to transfer the manure outside the barn to the storage area. In the case of a free stall barn, manure is usually collected under slatted floors or with the use of a scrapper. The scrapper is either a cable, hydraulic or tractor. Manure is held in a pit under the floor or is transferred to long-term storage utilizing conveyors, gravity flow pits or pumps. While liquid manure is transferred by gravity or pumps, solid manure is usually transferred by conveyors, augers, piston pumps or front end loaders. It can therefore be concluded that the electrical energy used for manure handling is independent of type of housing (can be predicted from Figure 24 below). Energy use for manure handling varies based on the type of equipment used for handling manure. The type of equipment used in a farm for manure handling completely depends on farm needs, which is based on farmer's preference and existing equipment. The farm that uses a skid steer for the collection of manure, does not have any impact on the electrical load. Similarly, the farm that uses manual labor for cleaning the floor also uses less energy for manure handling compared to farm which uses mechanical scrapers. The farm that uses gravity flow for transfer of manure from housing to the storage uses the hydraulic head exerted by the relatively liquid waste to force the wastes to flow which has zero load on electricity bill. Because of these factors, it is difficult to predict a model for energy used for manure handling in a farm; it completely depends on the existing manure handling equipment used in the dairy farm. However, to develop a benchmark for energy use, a benchmark is proposed in this thesis for those farms that use electrical devices. The main components then are the hp of motors used for manure handling and running time.

The annual electrical energy used for manure handling systems (farms using only electrical devices) = hp of motor used * 0.746* time of operation per day *365……………………..(Eq.8)

Based on the model for manure handling energy use (equation 8) and looking at theoretical performance, the benchmark parameter for manure handling is weight of manure produced from the total population of cows in the barn and bedding added in the barn. The total weight of manure and bedding added gives an indication of how long the motor should be operated. The weight of manure produced can be calculated from Table 3 (amount of manure typically produced from dairy cows of different weight).

Benchmark for parameter for manure handling = weight of manure + weight of bedding added



	1	2	3	4	5	6	7	8	9	10	11	12	13
gutter cleaner		2939							2178				
barn cleaner				817			545	1361		794	102	1361	908
compressor						822							
agitator				2042								2723	
gutter scraper						449							
alley scraper					2178								
cross scraper					204								
scraper			272										
Plunger	681			2042	511							2042	
Average cows milking	45	75	85	80	84	110	17	25	40	47	55	50	80
Housing style	1	1	1	1	1	1	2	2	2	2	2	2	2
Farm	1	2	3	4	5	6	7	8	9	10	11	12	13

Figure 24: Manure handling energy use for 13 different farms including different types of manure handling equipments used and number of milking cows.

Farm 1 to 6 includes freestall farms and farm 7 to 13 includes tiestall farms.

5.6. Ventilation

In chapter 4, regression analysis showed that ventilation energy use does not vary based on milking cows or milk production. Nova Scotia has a moderate climate, i.e. cool winters, mild spring and hot summers, one reason why Nova Scotia dairy farms mostly use natural ventilation with fans for additional cooling during summer and early fall, and curtains during the winter. Mechanical ventilation or hybrid ventilation is also used in some dairy farms. Hybrid ventilation is using both ventilation system, the use of natural ventilation during winter and mechanical during summer. The advantage of mechanical ventilation is a uniform ventilation rate throughout the barn; however, due to moderate temperatures in Nova Scotia except for summer, natural ventilation with summer cooling is suitable if the barn design is correct (i.e. correct orientation and no obstruction) and large windows for air to flow. The time of use for air circulation varies from one farm to another because some farms prefer grazing cows outside in the pasture on cloudy days during summer and early spring. In this case, air circulation fans are not in use for a long time.

The majority of the dairy farms audited in Nova Scotia had only natural ventilation with additional cooling fan. As energy use for ventilation depends on the type of ventilation, i.e. either mechanical or natural, here is a method to estimate the energy use for mechanical ventilation and natural ventilation with cooling fans.

5.6.1. Natural ventilation with cooling fans

Natural ventilation required no energy. In summer cows are exposed to heat stress when the temperature of the barn increases above 21 ºC (70 degree Farenheit). During this period air circulation is required to decrease heat stress. Based on research conducted by Shearer et. al., 1991, to minimize or alleviate heat stress, airflow should pass above the cow's bodies between 2.03 to 3.05 meter per second (400 to 600 feet per minute)

(Shearer et al.1991). The model uses an estimate of air flow required to cool dairy cows in a barn, based on the desired speed requirement (i.e. 2.03 to 3.05 meter per second). Multiplied by the area of the barn produces total air volume required for air circulation in cubic meter per second (cubic feet per minute (cfm)). For example in the case of 1858 sq meter (20, 000 sq ft) barn, the air circulation required will be 1858*2.54 = 4719 m^3/s) (20,000* 500 ft^3 /min = 100,000 ft^3 /min). Dividing the total air volume required for air circulation by the capacity of each fan gives the number of fans required for sufficient air circulation. These fans should be spaced at 10 times the diameter to achieve air speeds in the recommend range.

The energy required for air circulation depends on fan efficiency and time of use. In Nova Scotia air circulation is only required during summer and early spring (6 months approximately) because during this time the temperature of the barn rises above 21ºC (70 degree Farenheit). Fans are usually rated either by air volume, output in cubic meter per second (or cubic feet per minute (cfm)) at a specified static pressure (in inches), or wattage of electrical consumption (watt). However combining these two components provides a comprehensive rating for fan efficiency i.e. m^3s^{-1} /watt "X" static pressure. This rating helps to compare the efficiency of one fan with another. For example, a high efficiency fan may have a rating of 20 m^3s^{-1} /watt at 0.05" static pressure and a low efficiency fan have 15 m^3s^{-1} /watt at 0.05" static pressure.

Therefore the energy requirement for air circulation depends on the size of barn, time of use and efficiency of the fans used.

Total air volume required (m^3/s) = area of the barn (m^2) * velocity of air over cow body (m/s)…………………Eq. 9

Number of fans required =Total air volume required (m^3s^{-1}) (Eq. 9) / rating of fan (m^3s^{-1}) ………………….……..Eq.10

The model for air circulation energy use is:

Energy used for air circulation (kWh/yr) = No of fans (Eq. 10) * wattage of each fan (kW) *time of use	_(Eq.11)

Time of use - six months time period is considered as air circulation fans are used just for 6 months i.e. summer and early springs in Nova Scotia

The benchmark parameter chosen for air circulation is barn area which has been decided based on the model and theoretical performance of air circulation energy use.

Benchmark parameter for air circulation: **barn size** (m^2)

5.6.2. Mechanical ventilation:

Unlike natural ventilation, mechanical ventilation requires energy, which depends on the required ventilation rate and type of fan. The ventilation rate required to maintain air quality inside the barn depends on a number of variables, including the conditions of the outside air (temperature and moisture level), number of cows, size of the barn, building material of the barn (for knowing insulation of the barn). Different ventilation rates are required for different seasons since ventilation is required to control heat in summer and moisture in winter. The ventilation rate required depends on heat generated inside the building, area of the barn and material of barn (for knowing the insulation value), inside and outside temperatures. Gooch et al. 2008 has conducted a research for different air exchange rates for a dairy farm for different seasons. Research product (Table 1. Different air exchange rates for all the seasons) will be used in this chapter for development of model and benchmark for mechanical ventilation energy use. The different seasonal air exchange rates for dairy cattle shown in Table 5 are used to design mechanical ventilation systems for dairy cow barns.

Table 5: Different ventilation rates for various ambient temperature (retrieved from Gooch et. al. 2008)

	Weight (kg)	Ventilation rates (m^3/s / number of cows)			
		cold	mild	Warm	summer
cows	567 - 816	0.05	0.14	0.24	0.47

Example: For a farm having 400 cows, the summer ventilation rate will be 400* 0.47 m^3/s = 188 m^3/s. But for winter the ventilation rate will be 400*0.05 cfm = 20 m^3/s only. Air exchange is required in a dairy farm to reduce heat in the summer and control moisture in the winter. Therefore, the ventilation rate varies based on the season of the year.

Energy used for mechanical ventilation is based on type of season and total number of cows in the farm, and fan efficiency

Number of fans required = (type of season (ventilation rate m^3/s)) * total population of cow) / rating of each fan (cfm/watt)……………………………………………Eq. 12

The model for mechanical ventilation energy use is:

Energy used (kWh/yr) = Number of fans used * wattage of each fan (kW)* time of use per year

…Eq.13

The benchmark parameter chosen for mechanical ventilation is total population of cows in the barn, which has been decided based on the model and theoretical performance of air circulation energy use.

Benchmark parameter for air circulation: Total population of cows

Efficiency of fan can hugely impact the energy use for ventilation. For example a farm using five 1 hp fans with a rating of 10 m^3/s /watt would only need three 1 hp fans with a rating of 18 m^3/s /watt to exchange the same amount of air. This would result in a saving and demand reduction of 40 percent.

5.7.Feed

In Nova Scotia feed for dairy cow is either harvested once a year and stored for the whole year or purchased anytime. Feed in the form of fodder is stored in two types of storage, horizontal and vertical silo. Horizontal silo is loaded and unloaded via a bucket loader that runs on diesel, whereas vertical silo uses electric energy for unloading and for loading either electric or diesel which is run by tractor. Grains are stored in bins that are filled and emptied by electrically powered augers. The feed from horizontal or vertical silo and bins are unloaded based on daily requirement of the farm. This unloaded feed is mixed either in stationary TMR (runs by electric) or mobile TMR (runs by diesel). Stationary TMR requires separate carter or feeder (which runs with diesel) for transporting feed material to cows, unlike mobile TMR, which are equipt with this facility. Mobile TMR equipment is run by diesel, whereas stationary is run by electric. Therefore electric load on dairy farm for feed is completely based on selection of type of storage system and equipments. If a farm has horizontal silo for storage, and mobile TMR then there is no electric load on this dairy farm. However if a farm has vertical silo and stationary TMR, then electrical load on the dairy farm would be high. Feed energy use is dependent on horsepower of motor and operation time. Horsepower and operation time is directly related to quantity of feed loaded and unloaded in case of vertical silo and bins, and quantity of feed mixed in case of TMR mixer. Feed intake quantity, however, differs based on factors such as feed quality and level of milk production. If low quality, i.e. low energy density, feed material is fed, then a greater amount of feed needs to be fed for the same level of milk production. Feed intake varies from one cow to another based on milk yield. Also, if dairy cows are dependent on pasture grazing during certain time of the year, forage intake load on dairy farm is low during this time. Hence, due to all these factors, it can be concluded that feed electrical energy use is more related to per kg of dry matter than per cow.

Model for feed energy use is:

Feed energy use (kWh/yr) = (hp of (vertical silo motor + bin+ stationary TMR) motor * 0.746 * hrs of operation per day) * 365

____Eq.14

Based on this model for feed energy use and looking at the theoretical performance of feed energy use. The benchmark parameter for feed energy use is weight of feed.

Benchmark parameter for feed energy use = weight of feed (kg)

In this Chapter 5 (Model and benchmark development) model, benchmark parameter and energy efficient technology for each operation has been identified. The summary of these models, benchmark parameter and energy efficient technologies are summarised in the Table below:

Table 6: Summary of model, benchmark parameter and EF technologies for each operations

Energy use	Model for energy use (kWh)	Benchmark parameter	Energy efficient technologies
Light	Total area barn / WAf, WAf =(TTLf. LDF)/DI	Area of barn (m^2)	LED, T5, T8, HPS, CFL
Refrigeration	(m* Cm* ΔT)*365 / COP	Milk production (hl)	Precooler (32%),HRU (6.4%), Scroll compressor (20%)
Hot water heating	(Amount of water* ΔT* Cw)*365/ Whe	Sink size, bulk tank size (L)	HRU (56%) HRU+Precooler (55%)
Vacuum pump	hp * 0.746* (average hrs of milking+ 0.5) * number of milking days * 365	Milking unit*milk production	VSD (67%)
Mechanical ventilation	((type of season (ventilation rate) * total population of cow)) / rating of each fan (cfm/watt)	Cows (total population)	
Energy use	**Model for energy use (kWh)**	**Benchmark parameter**	**Energy efficient technologies**
Air circulatio	(Velocity *barn area)/ rating of fans	Area of barn (m^2)	

n (No of fans)			
Manure handling	hp of motor used * 0.746* time of operation *365	Weight of manure and bedding added (kg)	
Feed	(hp of vertical silo motor * hrs of operation per day + hp of bin motor * hrs of operation per day + stationary TMR motor * hrs of operation per day) * 0.746* 365	Weight of feed (kg)	

Chapter 6: Validation and Case Study

The benchmarks parameters in Chapter 5, which have been outlined in Table 6 have been chosen using mathematical models that reflect the operational components of a dairy farm. These benchmark parameters provide a practical mechanism for accurately determining energy use as a function of operational requirements. This chapter presents the methodology used and the results to provide model validation as a function of operational components. Water heating, milk cooling and milking model validation has been achieved using measured data from 7, 10 and 5 farms respectively and coefficient of efficiency and index of agreement which is discussed later in this Chapter. Model validation was only done for primary energy components, water heating, milking, light and milk cooling. The model validation was not done for secondary energy components such as manure handling, ventilation air circulation and feed because these component were the least energy consuming operation representing 4, 6 and 4% of the total energy use respectively. In the case of lighting, a published resource has been used, which has been discussed in Chapter 5 (Benchmark and model development), thus lighting energy use is not validated. LED lights, T5 and T8 florescent lights, HPS and MH lights are the recommended energy efficient lights suitable for dairy farm.

Model validation is further complicated by the fact that many farms have some form of energy efficient technology installed, and there is no common application based on farm size. In order to provide accurate validation, the potential range of savings that may be obtained from technology such a precooler and heat recovery systems must be determined. An additional case study is used that provides data for four scenarios from one farm, (i) without precooler or heat recovery system, (ii) precooler only, (iii) heat recovery system only and (iv) both precooler and heat recovery system. The case study provides actual savings, allowing a comparison with published data. Upon completion of the model validation, benchmark values are calculated from the mathematical model for different operational components (lighting, water heating, cooling and milking) for a range of farm sizes. This benchmarking will further help to indicate the amount of energy that should be used for a range of farm sizes, and provides a tool for estimating the energy use for each operation.

6.1.Water heating:

The model used in Chapter 5 was:

Energy required for water heating = yearly water required * required temperature increase* (4.187/3600)

$$\textbf{No. of cycles} = \frac{\sum_{n}(\ n^{th}\text{Cycle Temperature}(^\circ C)) - n * \text{Cold Temperature } (^\circ C)}{\text{Hot Temperature}(^\circ C) - \text{ Cold Temperature}(^\circ C)}$$

Required temperature increase = Hot water set point – Supply temperature

Yearly water required = (Sink wash + bulk tank wash)*365

Sink wash = Cycles * Number of milking per day * wash sink capacity

Bulk tank wash = Cycles * 0.5* 0.02 * bulk tank capacity

The model for water heating energy use, which has been developed in Chapter 5, has been validated using water energy use measurements obtained from 7 farms. Measurements were taken with a Fluke power analyser and hobo data loggers. These devices were installed on the farm for 2-3 days, and the data analysed using excel. The energy use was recorded at a sample rate of once per minute for a period of up to 48 hours. The daily energy use was calculated and then prorated to estimate annual energy consumption. Farms 3, and 4 are the same farm with heat recovery system switched on and off. Farm 1, 7 and 8 had both a precooler and heat recovery system installed, Farms 2,3 and 6 had a heat recovery system only and Farm 5 had a precooler only.

In order to validate the model developed for water heating energy use, Coefficient of efficiency and Index of agreement were used, which will be discussed in detail later. The presence of energy efficient technology creates a challenge when attempting to produce a generic benchmark since the efficiency improvement varies as a function of the technology and farm size. There is therefore a need to know the exact savings from precooler and heat recovery technologies, in both conditions i.e. precooler and heat recovery used alone and combined. A number of authors (Kammel and Patoch 1993) (Peebles et al. 1993) (Farmer et al. 1988) (Scott Sanford 2003b) present different savings for heat recovery and precooler. Hence a case study is used, based on a farm that has both precooler and heat recovery units installed. The farm agreed to participate in the study by (a) running the farm without either the precooler or heat recovery unit (b) with only the heat recovery unit, (c) with only the precooler and (d) with both precooler and heat recovery units. These case studies help to verify the potential range of savings proposed in published literature.

6.1.1. Heat recovery unit (HRU) and Precooler Case Study

The case study was conducted on a dairy farm with 80 milking cows using 15,920 kWh of electricity for water heating. After installing a heat recovery unit, the water heating energy was reduced to 6920 kWh, a saving of about 56 %. The installation of a heat recovery unit also helped to reduce the energy requirement for cooling. The cooling energy reduced from 34,940 kWh to 32,720 kWh, a saving of about 6.4%. Hence it can be concluded from this case study that heat recovery reduces the energy requirement of both water heating and cooling. The drawback of HRU is that they rely on the heat being removed from the condenser (refrigeration unit) and therefore their effectiveness is greatly reduced by the presence of a pre-cooler. It was found on the same case study that the heat recovery unit alone saved 56 % energy required for water heating. However, after the installation of a precooler i.e. combination of both technologies (precooler and heat recovery) the water heating energy was reduced to 7030 kWh a saving of 55%. This concludes that the effectiveness of heat recovery is reduced due to the presence of a precooler as the amount of heat removed by the precooler, reduces the quantity of heat available for heat recovery.

Similarly, for the precooler, a case study was conducted on same dairy farm with 80 milking cows. The annual energy used for cooling was 34,940 kWh. Precooler effectively reduced the energy required for cooling up to 23,640 kWh, a saving of 32.3%. Hence, saving of 56 % was achieved due to heat recovery unit for water heating and 32 % due to precooler for refrigeration alone. However, the range of saving differs from one farm to another based on production, ambient temperature, technology size and overall system efficiency. Hence for validation of model energy use data with the measured farms, a 56% reduction due to heat recovery for water heating, 6.4% reduction in milk cooling energy use due to the presence of heat recovery unit, 32% reduction due to precooler, and 55% reduction is used where combination both technologies (precooler and heat recovery) is used. This heat recovery case study savings were found to be close to the study conducted by Kammel and Patoch 1993, he reported a refrigeration heat recovery unit reduces the energy requirement for water heating by an average of 48%, and cooling energy requirement by an average of 6.6%. Likewise, for the precooler, Farmer et al. 1988 measured milk cooling energy use in New York for three farms, two without precooler and one with precooler. They reported that precooling of milk has been found to reduce electricity consumption for milk cooling by 30% in one farm and 50% in another farm. Another research conducted by Peebles et al. 1993 concluded precooling of milk helps to reduce energy use for milk cooling by 44%.

To evaluate how good the prediction model in predicting actual energy usage, Coefficient of efficiency and Index of agreement is used:

1. **Coefficient of efficiency:**

Coefficient of efficiency (E) ranges from minus infinity to 1 where higher values indicating better performance. It was proposed by Nash and Sutcliffe in 1970 which is given as:

$$E = 1 - \frac{\sum_{t=1}^{n}(O_t - P_t)^2}{\sum_{t=1}^{n}(O_t - \tilde{O})^2} \quad \text{.......Eq. 15}$$

Here Õ is the mean of the observed values and P is the predicted values. If $E > 0$, the model gives better forecasts than forecasting all values by the mean (Õ); $E = 0$ means the model forecasts are as good as the mean, and $E < 0$ means that the model is worse than forecasting the values by the mean.

2. **Index of agreement:**

The index of agreement is a relative measure that ranges from 0 to 1, where higher value indicating better performance. This index of agreement was developed by Willmott in 1981.

$$d = 1 - \frac{\sum_{t=1}^{n}(\mathrm{O_t} - \mathrm{P_t})^2}{\sum_{t=1}^{n}(/(\mathrm{P_t} - \tilde{\mathrm{O}})/+/\mathrm{O_t} - \tilde{\mathrm{O}}/)^2} \quad \text{Eq. 16}$$

Where Õ the mean of the observed values, P is is the predicted values and O is the observed values.

Validation for water heating model:

The water heating energy use for seven farms are listed in Table 7 for both measured and model energy use data using the different technology options. Based on the case study described above, the saving for water heating alone from heat recovery alone was taken as 56 %, for precooler no savings and saving from presence of precooler and heat recovery system both was 55%.

Table 7: Seven farms water heating energy use audited data using model and measured for different technology installed.

Farm.No	**Measured Energy Use (0)**	**Model Energy Use (P)**	**Technology Installed**
1.	8886	7479	Precooler & HRS
2.	20138	13116	HRS
3.	6924	5129	HRS
4.	15920	12372	No
5.	26547	23817	Precooler
6.	4032	4669	HRS
7.	16189	14174	Precooler & HRS
8.	18848	11381	Precooler & HRS

Inserting the value of observed (measured energy use) and predicted (predicted energy use) from Table 7 for determining the value of Coefficient of efficiency and Index of agreement, we have **E = 0.69 and d = 0.92.** Since both the values are higher and close to 1, it can be concluded that the predicted model is good in predicting the actual energy use. And this model for water heating can be used for predicting the water heating energy use.

Benchmark parameter:

Benchmark parameter for water heating = size of sink and bulk tank (litre)

Conclusion for water heating energy use:

Water heating energy use is a function of sink size, bulk tank size, cycle temperatures, hot water set point, and number of milking per day. For different farms having the same cycle temperature, hot water set point and number of milking per day, the farm water heating energy use is dictated by, or is a function of sink size and bulk tank. For concluding a range of benchmark values, EUI for water heating considering a constant cycle of 2 (The Canadian Quality Milk (2010) standards require certain temperatures to be maintained until the end of the wash cycle, these temperatures are 35 to 60 °C at the start of the cycle and minimum 35 °C at the end of the rinse cycle, 71°C (start) for the wash, and 43(end) °C for sanitize cycles respectively, the acid cycle temperature is to be determined by the manufacturer or supplier of the acid solution), and a hot water set point of 74° C (The optimum temperature for hot water is 74°C, heating water above this is usually not necessary and can waste energy), and number of milking per day as 2 (in most of the farms milking is done twice a day). The EUI for different farm sink and bulk tank size using farm audit data for bulk tank and sink size is listed in Appendix E: Table A. Based on Table A

(Appendix E), EUI, benchmark value with and without HRU and precooler for a range of sink and bulk tank size is listed in Table 8.

Table 8: Water heating EUI range for sink and bulk tank size

	Wash sink (l)	**Bulk tank size**	**EUI range (kWh/l)**	**Benchmark value (kWh/l)**	**Benchmark value after HRU**	**Benchmark HRU+ precooler**
1	60-65	1000-4000	123-149	136	60	61
2	90-95	3850-5000	137-145	141	62	63
3	100	3838-6000	136-148	142	62	64
4	120-160	5300-6000	135-142	138.5	61	62
5	190-220	4700-6000	128-129	128.5	57	58

For a farm having a wash sink capacity of between 60- 65litres, one would expect EUI range for water heating between 123 -149 kWh/ lt per year. A greater EUI value is expected if the bulk tank size is larger or lower if the bulk tank size is smaller. A tentative 56% reduction is used for EUI with HRU and 55% reduction for both HRU and precooler installed. This benchmarking helps to indicate the amount of energy that should be used for a farm having different sink and bulk tank sizes, and can be used as a tool for determining the potential of energy efficiency measures that could be included on that farm.

6.2 Cooling:

The model for milk cooling energy use is:

Energy used for milk cooling (MJ/yr) = (m* Cp* ΔT)*365 / COP

Where,

M = mass of milk (kg/day)

Cm = specific heat of milk (0.003891 MJ/kg/°C)

ΔT = temperature of milk from the cow – bulk tank set point = temperature reduced (°C)

To convert heat removed (MJ/yr) to kWh

kW-h/yr = heat removed (MJ/yr) x 1 kW-h / 3.5971 MJ

Measured data obtained from 10 farms is used to validate the model produced in Chapter 5 for milk cooling energy use. An average COP value of 2.12 is used for calculation of model milk cooling energy requirement for these 10 farms (listed in Appendix B). The validation was achieved by comparing measured data with the model data for each farm using a Coefficient of efficiency and Index of agreement. The energy used for milk cooling was measured with a fluke power analyser and hobo data loggers at one minute sample interval for up to 48 hrs. Of the 10 farms, only 1 Farm had a precooler installed. Based on the case study above a saving of 32% was considered for energy use for milk cooling for a farm with precooler installed.

Table 9: Ten farm milk cooling energy use with model and measured data.

Farm.No	Measured Energy Used (kWh/yr) (0)	Model Energy Used (kWh/yr) (P)	Precooler
1	7070	7496	no
2	17520	15285	no
3	10862	9817	no
4	6607	5052	no
5	4865	4563	no
6	20221	22814	no
7	5676	6518	no
8	7081	8716	yes
9	6059	5866	no
10	12943	13037	no

Inserting the value of observed (measured energy use) and predicted (predicted energy use) from Table 10 for determining the value of Coefficient of efficiency and Index of agreement, we have **E = 0.93 and d = 0.98.** Since both the values are higher and very close to 1, it can be concluded that the predicted model is good in predicting the actual energy use. And this model for milk cooling can be used for predicting milk cooling energy use for other farms.

Conclusion for milk cooling:

Milk cooling energy use is a function of quantity of milk produced and temperature difference between bulk tank set point and temperature of milk entering the bulk tank. The benchmark parameter for milk cooling is milk produced per day (hl).

Benchmark used for milk cooling = milk production (hl)

Considering the temperature drop of milk as 35 ºC (milk from cow is usually 39ºC and bulk tank set point is 4ºC), an average value of COP as 2.12 (which lies in the range of 1.62 to 2.61, measured from 10 farms) and milk production data achieved from 19 farm audit data. Energy used has been calculated using milk cooling energy use model for 19 audited farms which are listed in Appendix E: Table B. Based on Appendix E Table B, a Graph has been plotted between energy used for milk cooling and milk production Figure 25.

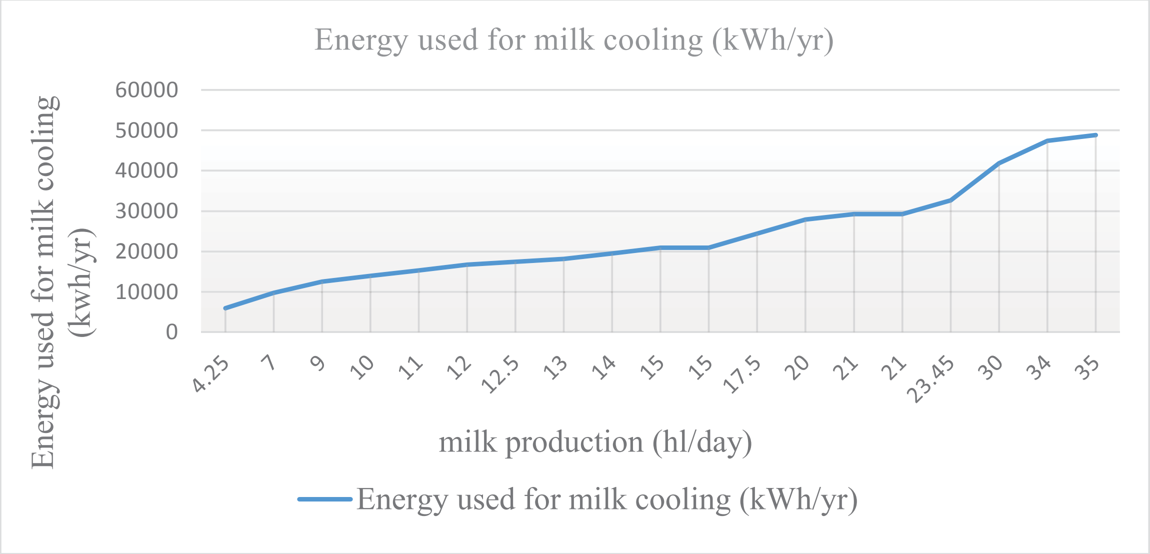


Figure 25: Relation between energy use for milk cooling (kWh/yr) vs milk production per day (hl/day)

This graph can be used to predict energy use for milk cooling for a given daily milk production for a farm. For example, a farm having daily milk production of 15 hl will have yearly milk cooling energy use of 20000 kWh with no technologies installed. In case of precooler, heat recovery, scroll compressor installed then milk cooling energy reduction could be considered as 32%, 6.4% and 20% respectively.

For computation of EUI, the 9 measured milk cooling energy use data has been used without precooler. EUI values lies in the range of 1.58 to 2.34 kWh/hl –yr for milk production of 2829 to 12775 hl/yr. A 32% saving is used for calculating EUI for milk cooling with precooler which lies in the range of 1.07 to 1.59 kWh/hl-yr. Similarly for scroll compressor 20% reduction is used and EUI has found be in the range of 1.26 to

1.87 kWh/hl-yr. And for HRU, EUI ranges between 1.51 to 2.19 kWh/hl-yr considering 6.4% reduction due to presence of HRU.

6.3.Vacuum pump

Measured energy for vacuum pump was obtained from five farms and is used to validate the model produced in Chapter 5 for milking energy use.

> Formula used for vacuum pump energy use = hp of vacuum pump* 0.746* (average hrs of milking+ 0.5) * number of milking per day * 365
>
> (Washing time usually lasts for 25 mins to 30 mins, so an average of 30 mins (0.5) is estimated.)

The validation was achieved by comparing measured data with the model data for each farm using Coefficient of efficiency and Index of agreement. Of the five farms, only two had variable speed drives installed. For savings due to variable speed drive, published results from Ensave are used. Ensave conducted a variable speed drive energy savings case study on 10 dairy farms and found the actual saving varies from 46% to 80%, and concluded an average of 67% is good approximation to be used for saving due to variable speed drive.

Model vacuum pump energy use with variable speed drive = hp of vacuum pump* 0.746* average hrs of milking * number of milking per day * 365 – reduction due to presence of variable speed drive + hp of vacuum pump* 0.746* 0.5* number of milking per day

Table 10: 5 farms vacuum pump model and measured energy use with and without variable speed drive

Farm. No	Measured vacuum pump energy use	Model vacuum pump energy use	Variable Speed drive
1.	14123	12253	No
2.	13404	12253	No
3.	5582	6127	No
4.	4359	4520	Yes
5.	3610	4520	Yes

Inserting the value of observed (measured energy use) and predicted (predicted energy use) from Table 11, the value of Coefficient of efficiency and Index of agreement are **E = 0.98 and d = 0.98** respectively**.** Since both the values are higher and very close to 1, it can be concluded that the predicted model is very good in predicting the actual energy use. And this model for milking can be used for predicting the milking energy use for other farms.

Conclusion:

Milking energy use is a function of size of vacuum pump and total running time. The size of vacuum pump motor in a dairy farm is usually 5, 7.5, 10, 15 or 20 hp.

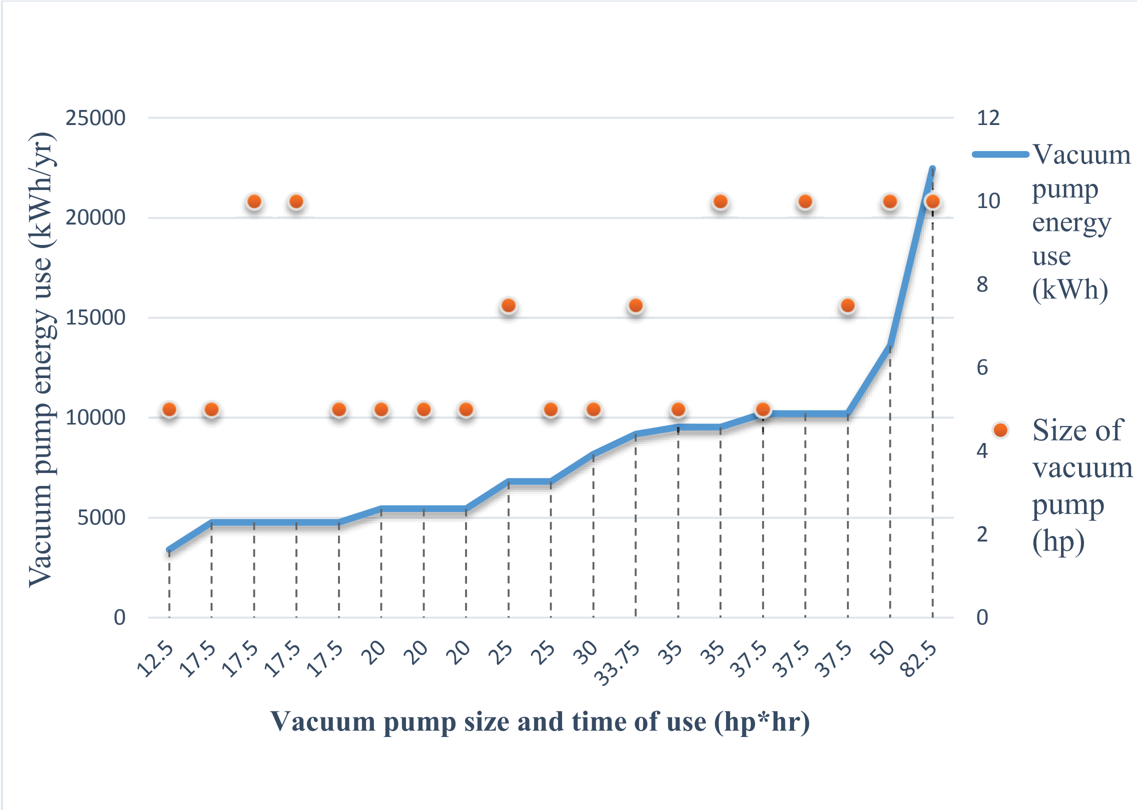


Figure 26: Relation between energy use for vacuum pump (kWh) vs vacuum pump size and time of use (hp*hr)

X axis: Vacuum pump size (hp)* (average hour of milking + washing time) * Number of milking per day

Figure 26 can be used to predict energy use for the vacuum pump. For example, a farm having a vacuum pump size of 5hp operating 1.25 hour and milking 2 times a day, would have x axis value = 5 *(1.25+0.5)*2 =17.5 and vacuum pump energy use 4765 kWh/yr from Figure 26.

After validation of milking energy use, the benchmark parameter for vacuum pump energy use is the number of milking units and the amount of milk produced. The milking units gives an indication of size of vacuum pump and amount of milk produced gives an indication of running time (**Benchmark for milk collection is = kWh/milking unit*amount of milk produced(hl/day))**. The detail of 19 audit data milking units and benchmark value is presented in Appendix E, Table C. Based on these 19 audit data, the

EUI, benchmark value with and without variable speed drive for vacuum pump energy use has further been grouped based on milking units and is presented in Table 11.

Table 11: Vacuum pump EUI values

Milking units	**EUI = (audit vacuum pump energy use/(milking units*amount of milk (hl/day))**	**Benchmark value (kWh/(milking units*hl)**	**Benchmark value after VSD**
20	17	17	5.61
18	22	22	7.26
16	18	18	5.94
8	32 - 134	83	27.39
6	61-102	81.5	26.9
5	97	97	32
4	136-280	208	68.64

Chapter 7: Conclusions and Recommendation

This research project has met its overall goal, which is to determine benchmark parameters for each operational component. Out of 19 audited dairy farms lights had the highest energy consumption about 25% followed by refrigeration, hot water heating and vacuum pump representing 17%, 16% and 15% respectively. Feed energy use, manure handling and ventilation and air circulation were the least energy consumption representing 4%, 4% and 6% respectively. The parameters used for benchmarking dairy farm energy use up to now is based on milk production or number of cows. Based on these benchmark parameters energy utilization indices for 19 audited dairy farm range from 560 to 1767 kWh/yr/cow for cow size between 17 to 125 cows. EUI based on milk production ranges from 4 to 16 kWh/yr/hl for milk production between 1551 to 12775 hl/yr. This shows a large variation in EUI values, which also has been encountered by other authors such as Ludington 2004 and Murgia et al. 2008. Regression analysis shows that the utility energy use of the 19 dairy farms was related more with milk production having a maximum R square value of 47%. However more than 50% of variability was not explained by milk production alone. A similar result was concluded by Eden et al. 2004 and Farmer et al. 1990 that dairy farm energy use was more related to milk production compared to number of cows. Regression analysis results for vacuum pump, refrigeration, water heating, light, manure handling, feed, ventilation energy use are 38.79%,31.38%, 23%, 12.5%, 9.4%, 20.7%, and 4.1% respectively for number of cows and for milk production was 35.43%, 49.14%, 23% 15.3%,11.6%, 27% and16.9% respectively. These regression results shows that energy use for each operational component was not related, based on either milk production or number of cows. This result was quite comparable to study conducted by Kammel and Patoch 1993, which concluded that water heating and milk cooling energy use was not related to number of cows. Eden et al. 2004 concluded in their study that water heating energy use was not related to number of cows or milk production, and milk cooling and vacuum pump was not related to number of cows. Therefore, to determine the factors that actually influence the energy use and develop better way of benchmarking, the total energy use is divided based on percentage of energy usage defined in this thesis as primary and secondary. The primary energy use consists of vacuum pump, lights, refrigeration and water heating and secondary energy use consist of feed component, manure handling and ventilation and air circulation. Model were developed for these components on the basis of an inventory of NS dairy farm, through audit data and based on theoretical energy calculation of each operation. Benchmark parameters were determined for these components based on these models and operational process information. As primary energy use comprises of highest energy use (about 57% of total energy consumption), main focus of this research has been provided to primary energy use. Hence the validation of the models were only conducted for primary energy components, however model of light energy use was not validated as published resource from Chastain 2004 has been adapted for model development for light energy use.

Type of lights installed, area of the barn, and time of operation are factors influencing energy use for lights. The benchmark parameter for lighting energy use is barn area. Light emitting diode (LED), florescent (T5 and T8), compact florescent (CFL), high pressure sodium (HPS), metal halide are the most energy efficient lights. For the vacuum pump, size of motor, number of times of milking per day and hours of operation are the factors influencing energy use. The benchmark parameter is milking unit and milk production. Energy efficient technology for the vacuum pump is a variable speed drive, which saves on average about 67% in energy use. In the case of refrigeration, the factors influencing energy use are volume of milk produced, temperature difference (temperature of milk to be cooled and temperature of milk from cow) and coefficient of performance of refrigeration system. Precooler, heat recovery and scroll compressors are energy efficient technologies, saving on an average about 32%, 6.4% and 20% respectively for milk cooling. The benchmark parameter for refrigeration energy use is amount of milk to be cooled. For water heating, the predictors for energy use are size of sink and bulk tank, number of cycles and temperature difference (temperature up to which the water is heated and temperature of well water). The energy efficient technology for water heating is heat recovery which saves on an average 56% of energy use for heating water. The benchmark parameter for hot water heating is sink and bulk tank size (litres). For feed energy use, the electrical energy load on a dairy farm differs based on the farmer preference of vertical silo or horizontal silo for storage of silo and stationary total mixed ration mixer (TMR) or mobile TMR for mixing of total mixed ration, and conveyors or feed carts, or mobile TMR for transporting the feed material. For manure handling, the electrical energy use depends on farmer preference for selection of equipment type, which run either by electricity, gasoline, propane or manual labor. Shovel or pusher, front end loader, skid steer, barn cleaner, alley scraper and underslat scraper are different types of manure collection equipment used in dairy farm. Pump and gravity flow are different types of systems used for transferring the manure from the barn to the storage. For manure handling and feed component the predictors are the size of the motors installed and hours of operation. The benchmark parameter for manure handling and feed component are weight of manure (kg) and weight of feed (kg) respectively. In the case of ventilation and air circulation, barn size, hour of operation, efficiency and size of fan installed determines the energy required for air circulation, whereas for mechanical ventilation, total population of cows in the barn, hour of operation, efficiency of ventilation fan installed determines the ventilation energy requirement. These results for a model for each component and benchmark parameters, and their consecutive savings are presented in Table 12:

Table 12: Results for model for each component and benchmark parameters and its savings

Energy use	**Model for energy use (kWh)**	**Benchmark parameter**	**Energy efficient technologies**
Light	Total area barn / WAf, WAf =(TTLf. LDF)/DI	*Area of barn	LED, T5, T8, HPS, CFL
Refrigeration	(m* Cm* ΔT)*365 / COP	Milk production	Precooler (32%),HRU (6.4%), Scroll compressor (20%)
Hot water heating	(Amount of water* ΔT* Cw)*365/ Whe	Sink size, bulk tank size	HRU (56%) HRU+Precooler (55%)
Vacuum pump (15%)	hp * 0.746* (average hrs of milking+ 0.5) * number of milking days * 365	Milking unit*milk production	VSD (67%)
Mechanical ventilation	((type of season (ventilation rate) * total	*Cows (total population)	

Energy use	Model for energy use (kWh)	Benchmark parameter	Energy efficient technologies
	population of cow)) / rating of each fan (cfm/watt)		
Air circulation (No of fans) (6%)	(Velocity *barn area)/ rating of fans	*Area of barn	
Manure handling(4%)	hp of motor used * 0.746* time of operation *365	*Weight of manure and bedding added	
Feed (4%)	(hp of vertical silo motor * hrs of operation per day + hp of bin motor * hrs of operation per day + stationary TMR motor * hrs of operation per day) * 0.746* 365	*Weight of feed	

Based on the model developed, audit values collected during audit process and benchmark parameter, EUI were computed for milking, milk cooling and water heating.

The EUI and benchmark value for milking energy use, which have been grouped based on milking units, are as follow:

Milking units	EUI = (audit vacuum pump energy use/(milking units*amount of milk (hl/day))	Benchmark value (kWh/(milking units*hl)	Benchmark value after VSD
20	17	17	5.61
18	22	22	7.26
16	18	18	5.94
8	32 - 134	83	27.39
6	61-102	81.5	26.9
5	97	97	32
4	136-280	208	68.64

The EUI value and benchmark value for water heating energy use which has been grouped on the basis of sink and bulk tank size are as follow:

	Wash sink (l)	Bulk tank size	EUI range (kWh/l)	Benchmark value(kWh/l)	Benchmark value after HRU	Benchmark HRU+ precooler
1	60-65	1000-4000	123-149	136	60	61
2	90-95	3850-5000	137-145	141	62	63
3	100	3838-6000	136-148	142	62	64
4	120-160	5300-6000	135-142	138.5	61	62

	Wash sink (l)	Bulk tank size	EUI range (kWh/l)	Benchmark value(kWh/l)	Benchmark value after HRU	Benchmark HRU+ precooler
5	190-220	4700-6000	128-129	128.5	57	58

The EUI value for milk cooling energy use without any energy efficient technologies varies between 1.58 to 2.34 kWh/hl per year for milk production between 2829 to 12775 hl/yr. The EUI value for milk cooling energy use with precooler, heat recovery unit and scroll compressor varies between 1.07 to 1.59 kWh/hl per year, 1.51 to 2.19 kWh/hl-yr and 1.26 to 1.87 kWh/hl per year respectively.

The EUI value presented in the thesis could not be computed for light, ventilation and air circulation, feed and manure because barn area, total population of cows, feed weight and manure weight was not collected during auditing process.

Energy use varies from one farm to another due to individual preference for equipment type and difference in farm management. Also, the major role of amount of energy use was found to be determined by whether energy efficient technologies were installed or not. Based on the 19 NS dairy farm audited, only vacuum pump, light and milk cooling were found to be major electricity consumers contributing in total, to about 57% of average electrical energy use, whereas water heating was either electric, propane, biomass or oil. Feed and manure was either diesel, propane or electric or combination of both. In the case of ventilation and air circulation, some farms had only natural ventilation, some only natural ventilation with cooling fans and some had mechanical ventilation. In this research the total energy use for dairy farm has been further broken down into each operational components to develop a pragmatic benchmark parameter for each operational component. These benchmark parameters for each operational components better represents the energy use in comparison to number of cows or quantity of milk produced that has been used for benchmarking total dairy farm energy use. The main contribution of this research is therefore the development of benchmark parameters for each operational component that better represents the energy use compared to the conventional benchmark parameters such as number of cows or milk produced which has been used till date in dairy industry to benchmark dairy farm energy use.

Based on previous literature review, lighting and water heating energy use is higher in winter, and milk cooling and ventilation and air circulation higher in summer. However, in this research seasonal variation were not included which may have an impact in overall energy consumption. Therefore, further work needs to be done in this area. Barn area, total population of cows, manure weight and feed weight data need to be collected during the audit process. These values are required for proper benchmarking for light, ventilation and air circulation, manure and feed energy consumption. Hence, it is recommended to add these values during future dairy farm auditing process.

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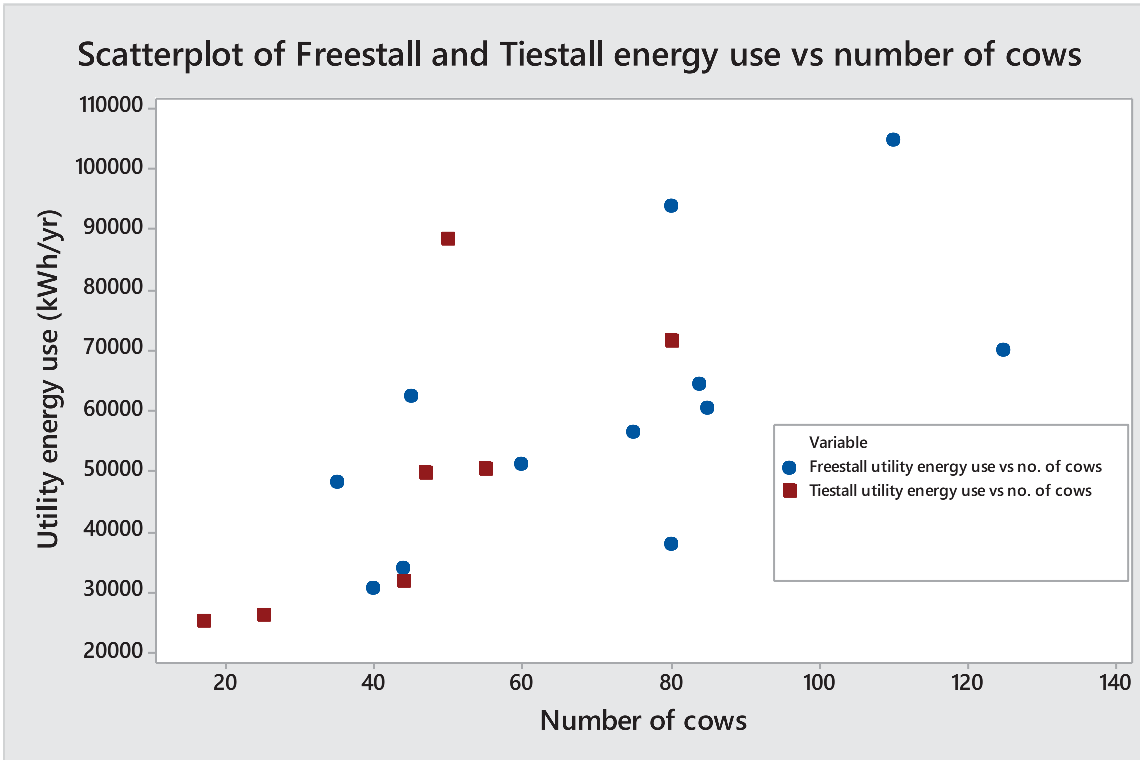
Appendix A: Energy Audit



Graph A: Graph between utility energy use of tiestall and freestall vs number of cows.

Table A: List of small, medium and large farms total energy use

	Small Farms		Medium farms		Large farms	
	Number of cows	Annual energy use (kWh)	Number of cows	Annual energy use (kWh)	Number of cows	Annual energy use (kWh)
1.	17	25184	55	50593	84	64422
2.	25	26440	60	51240	85	60393
3.	35	47996	75	56400	110	104813
4.	40	30720	80	71574	125	69959
5.	44	32044	80	93754		
6.	44	33882	80	37790		
7.	45	62262				
8.	47	49750				
9.	50	88343				

Table B. Energy use mean and EUI of all dairy farms

	Mean (kWh/yr)	kWh/cow/ yr	kWh/cow/y r (range)	kWh/hl/y r	kWh/hl/yr (range)	range for number of cows	range for production of milk (hl/yr)
Energy used utility	55661	971	560 to 1767	9.96	4 to 16	17 to 125	1551 to 12775
Lighting	14074	247	23 to 945	2.4	0.21 to 8.32	17 to 125	1551 to 12775
Vacuum pump	8187	144	68 to 281	1.48	0.71 to 3.07	17 to 125	1551 to 12775
Refrigeration	9496	153	54 to 253	1.6	0.41 to 2.60	17 to 125	1551 to 12775
Hot water heating	9100	190	30 to 483	1.96	.26 to 5.29	17 to 125	1551 to 12775
Manure handling	1921	35	1.9 to 61	0.34	.02 to .64	17 to 110	1551 to 12410
Feed supply	2237	39	.8 to 160	0.11	0.002 to 0.482	17 to 125	1551 to 12775
Ventilation and air circulation	3219	56	1.1 to 164	0.17	0.002 to .715	17 to 125	1551 to 12775

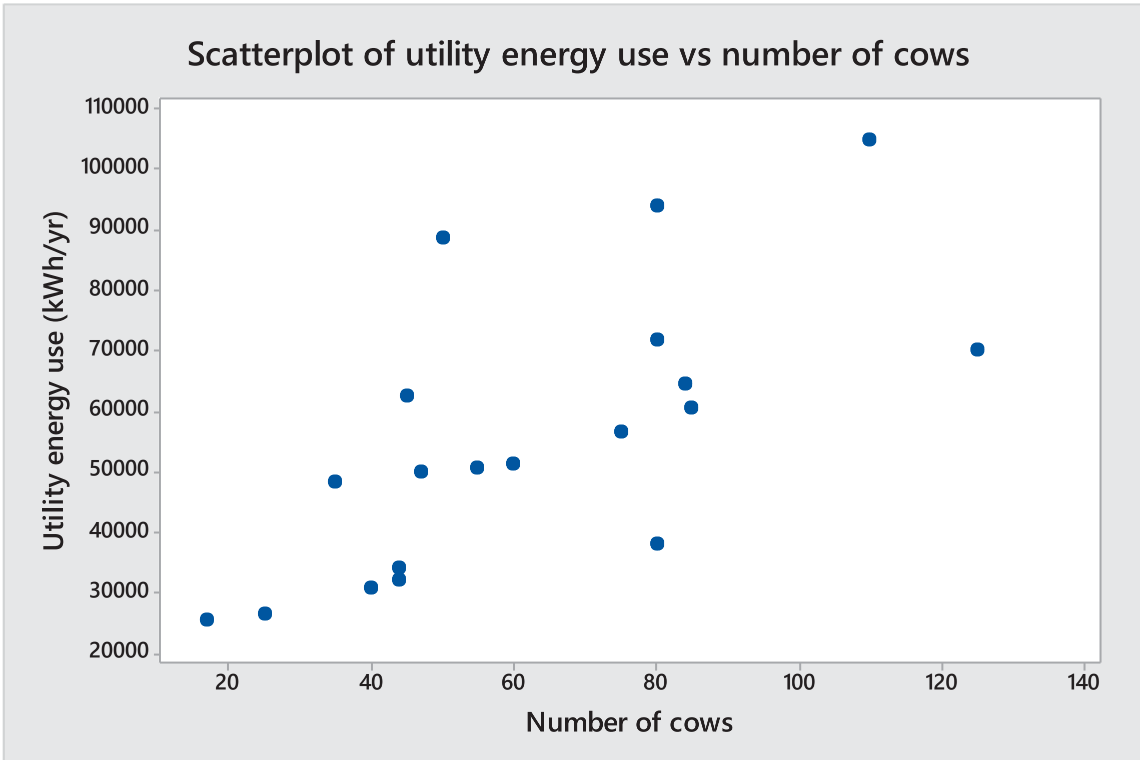
Table C. Energy Utilization Indices (EUIs) for small, medium and large farms.

	Energy per cow (kWh/cow/yr)			**Energy per production (kWh/hl/yr)**		
	Small	Medium	Large	Small	Medium	Large
Total Energy Use	1154	844	747	12	9	7
Lighting	342	134	209	3.28	1.48	1.97
Milking	173	125	109	1.77	1.34	1.04
Refrigeration	162	150	138	1.67	1.62	1.40
Heating all	267	177	151	3	1.92	1.48
Hot water	254	152	82	2	1.62	0.85
Manure handling	49	28	16	0.5	0.31	0.13
Ventilation and air circulation	64	84	15	0.66	0.96	0.16
Feed	53	26	38	0.55	0.27	0.33

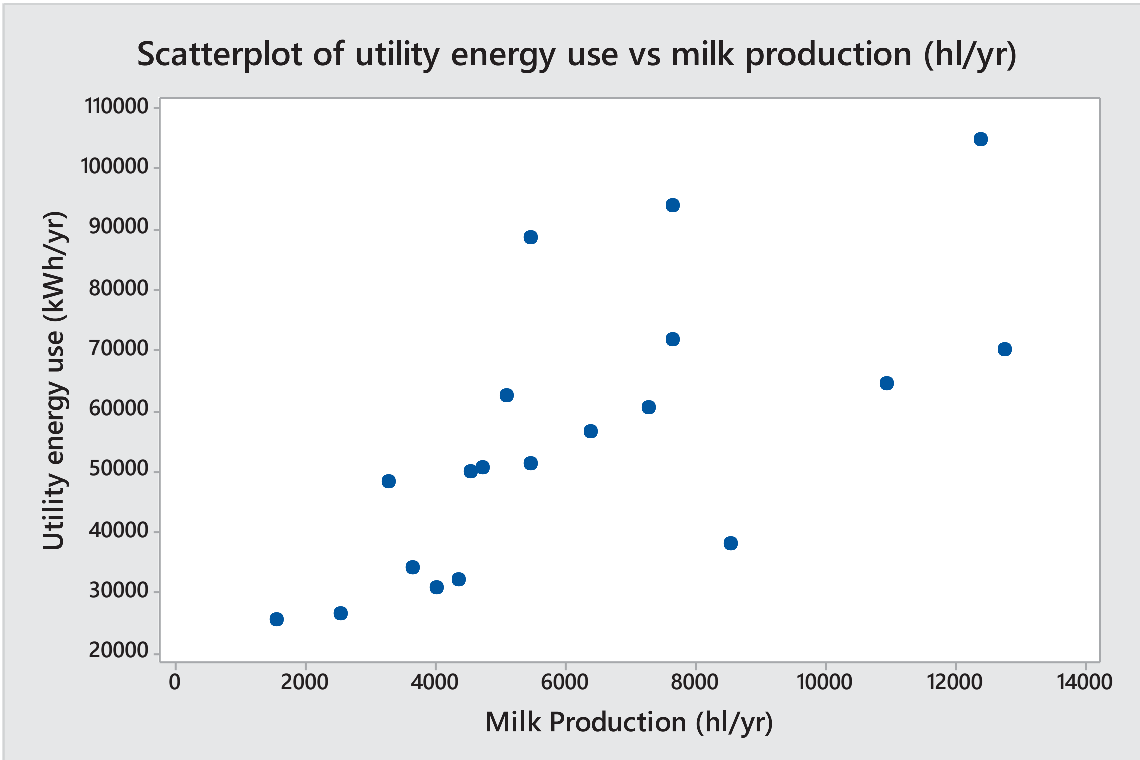
Table D: Energy utilization indices of freestall and tiestall farms.

	Freestall		Tiestall	
	kWh/cow/yr	kWh/hl/yr	kWh/cow/yr	kWh/hl/yr
Energy used utility	878	8.89	1130	11.56
Lightning	214	2.06	304	3.03
Vacuum pump	145	1.48	144	1.48
Refrigeration	153	1.61	153	1.57
Manure handling	39	0.35	32	0.34
Ventilation and air circulation	57	0.17	54	0.16
Total heating energy use	195	1.96	246	2.58
heating hot water	154	1.56	236	2.48
Feed supply	39	0.10	40	0.12

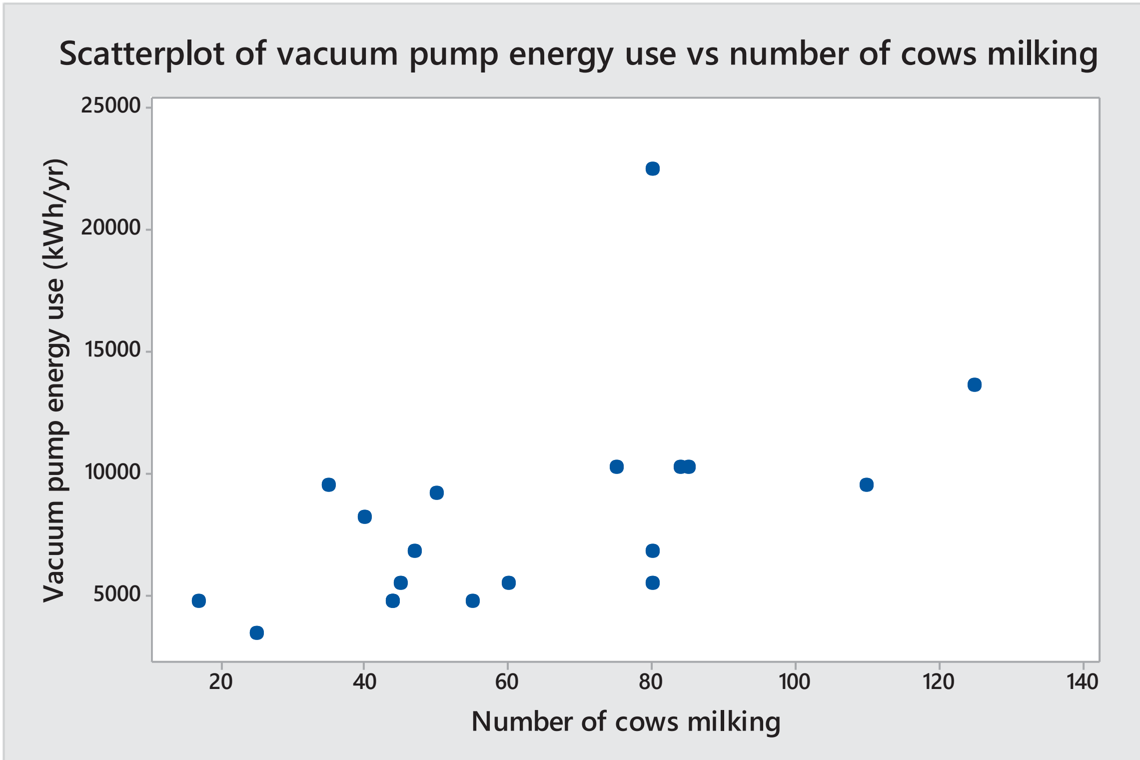
Graph



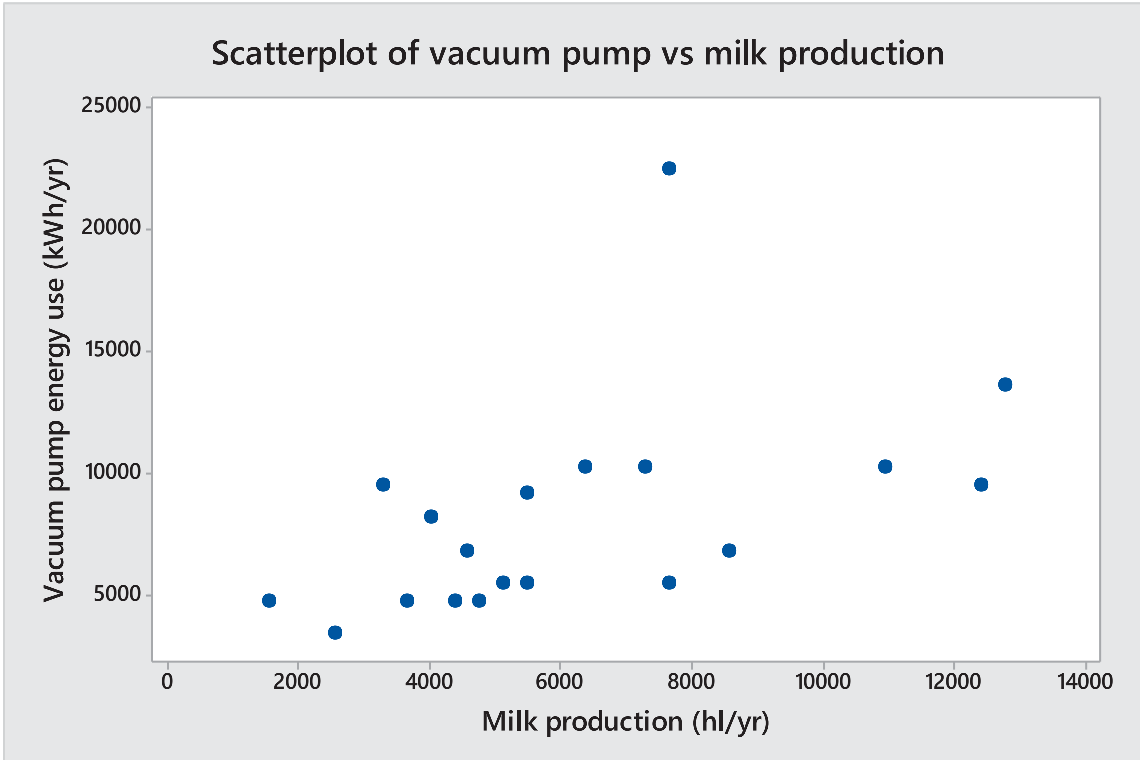
Graph 1.1. Scatter plot of 19 dairy farm utility energy use vs number of cows



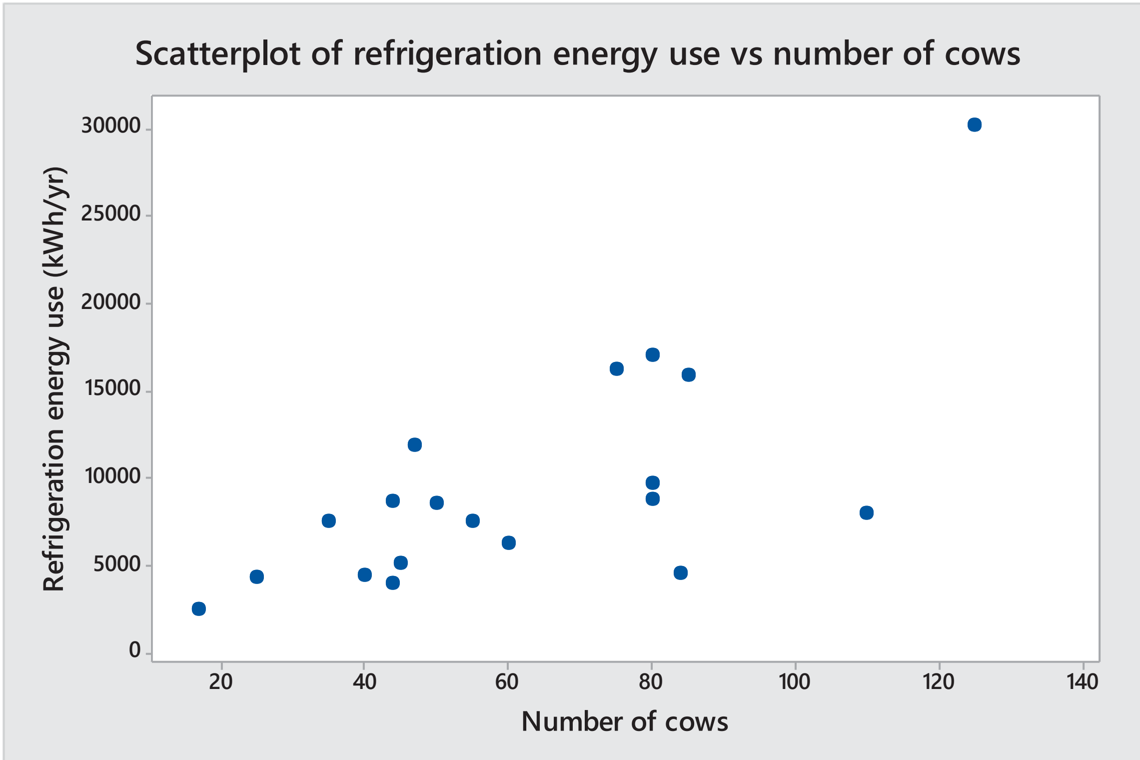
Graph 1.2. Scatter plot of 19 dairy farm utility energy use vs number of cows



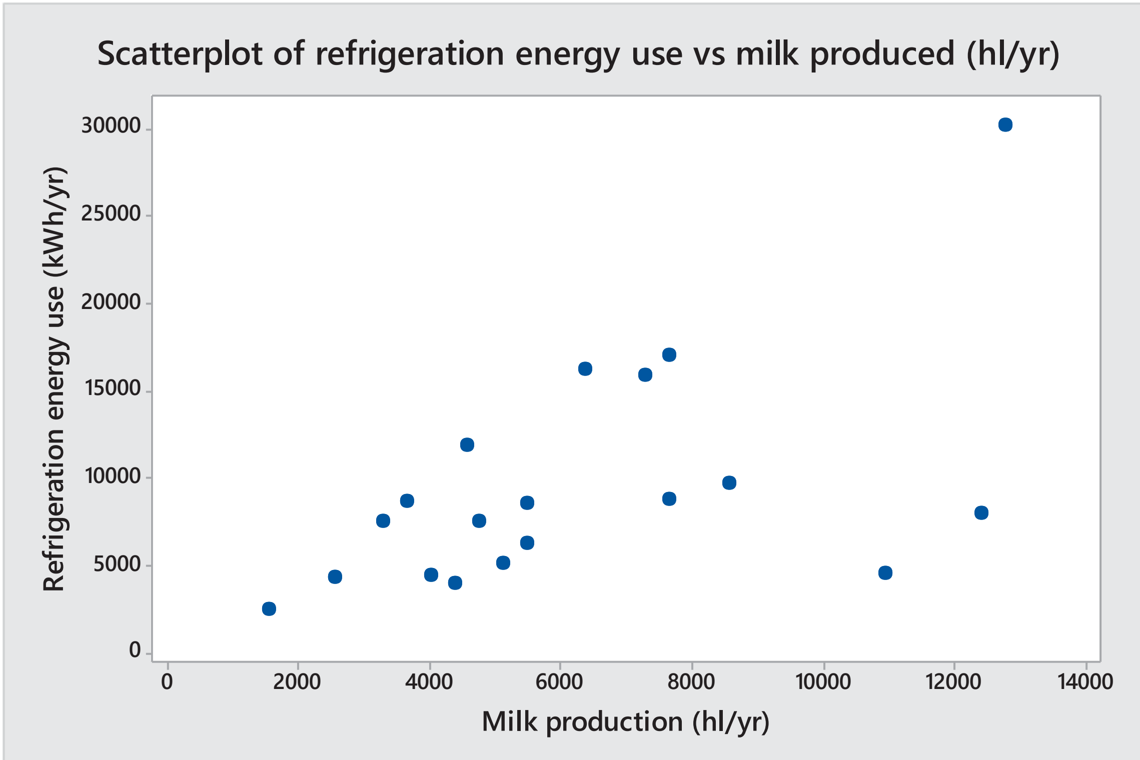
Graph 1.3: Scatter plot of 19 dairy farm vacuum pump energy use vs number of cows milking



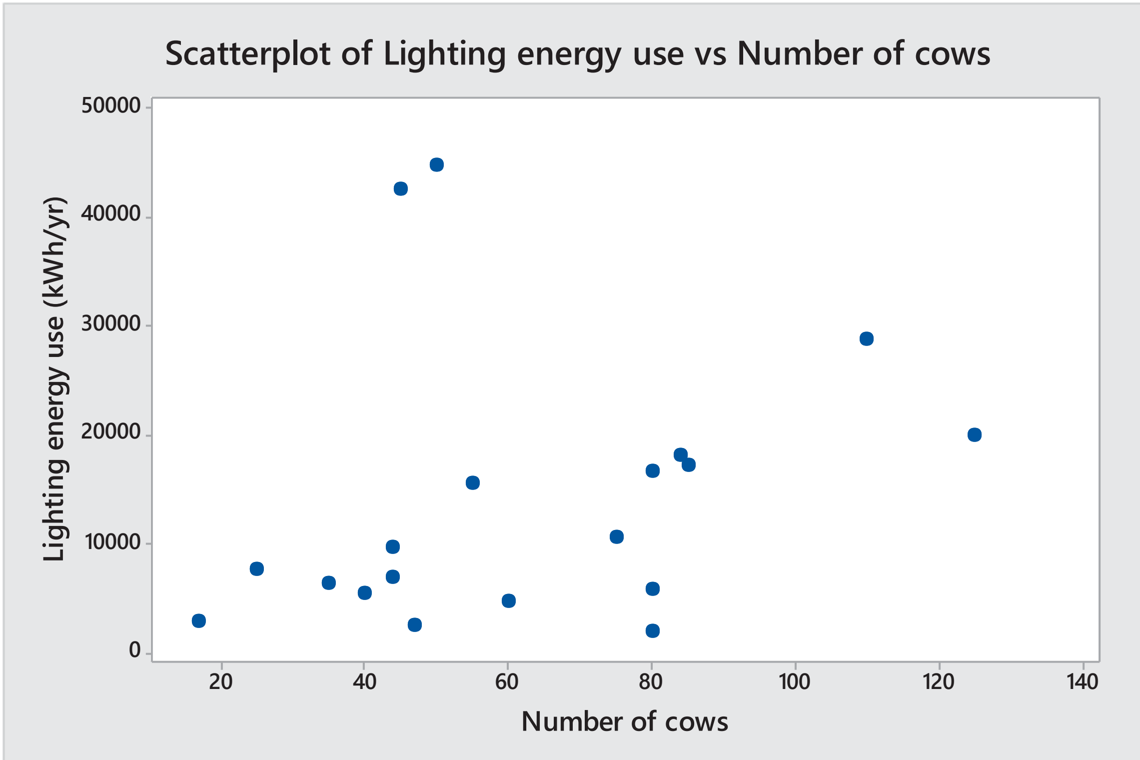
Graph 1.4: Scatter plot of 19 dairy farm vacuum pump energy use vs average daily milk production



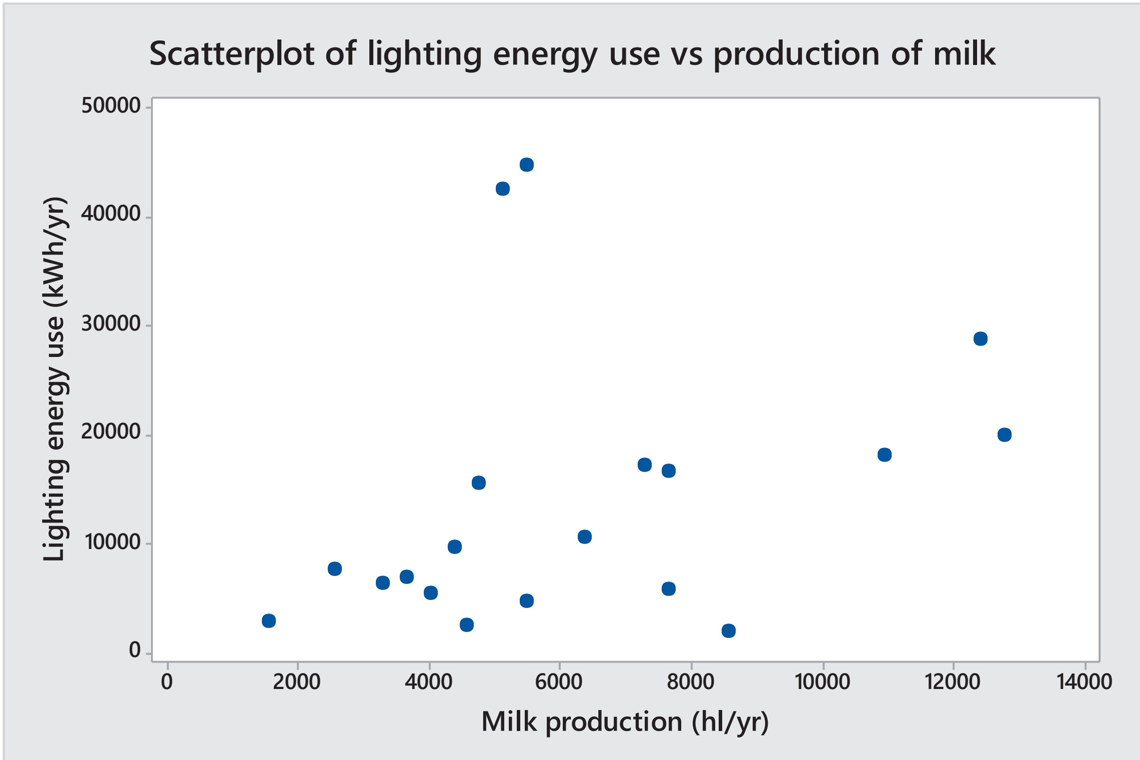
Graph 1.5 : Scatter plot of 19 dairy farm refrigeration audit data vs number of cows milking



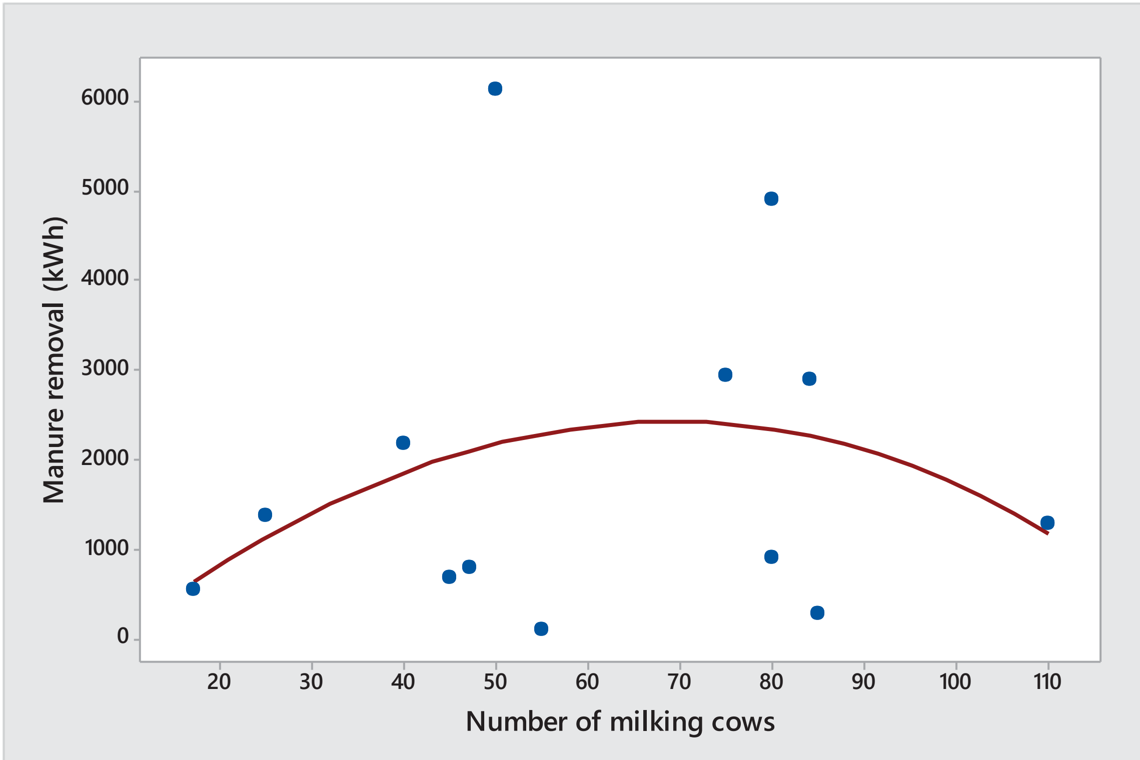
Graph 1.6: Scatter plot of 19 dairy farm refrigeration audit data vs average daily milk production



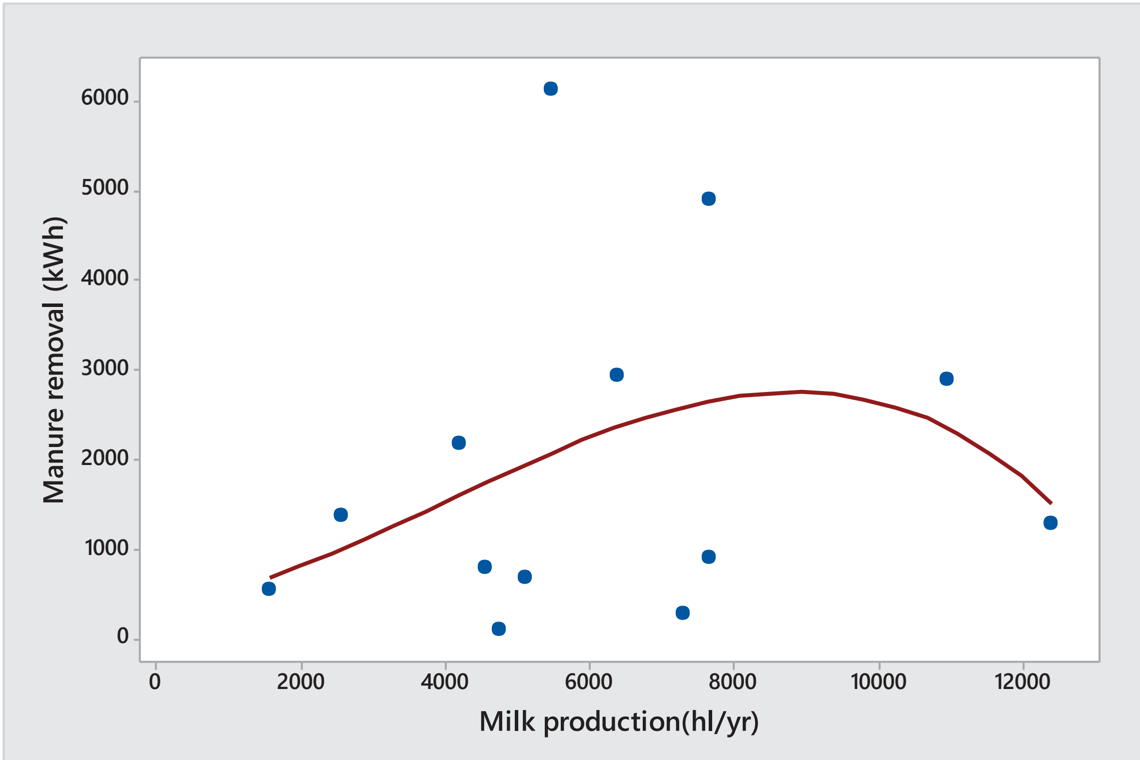
Graph 1.7: scatterplot of 19 dairy farm lighting energy use vs number of cows milking



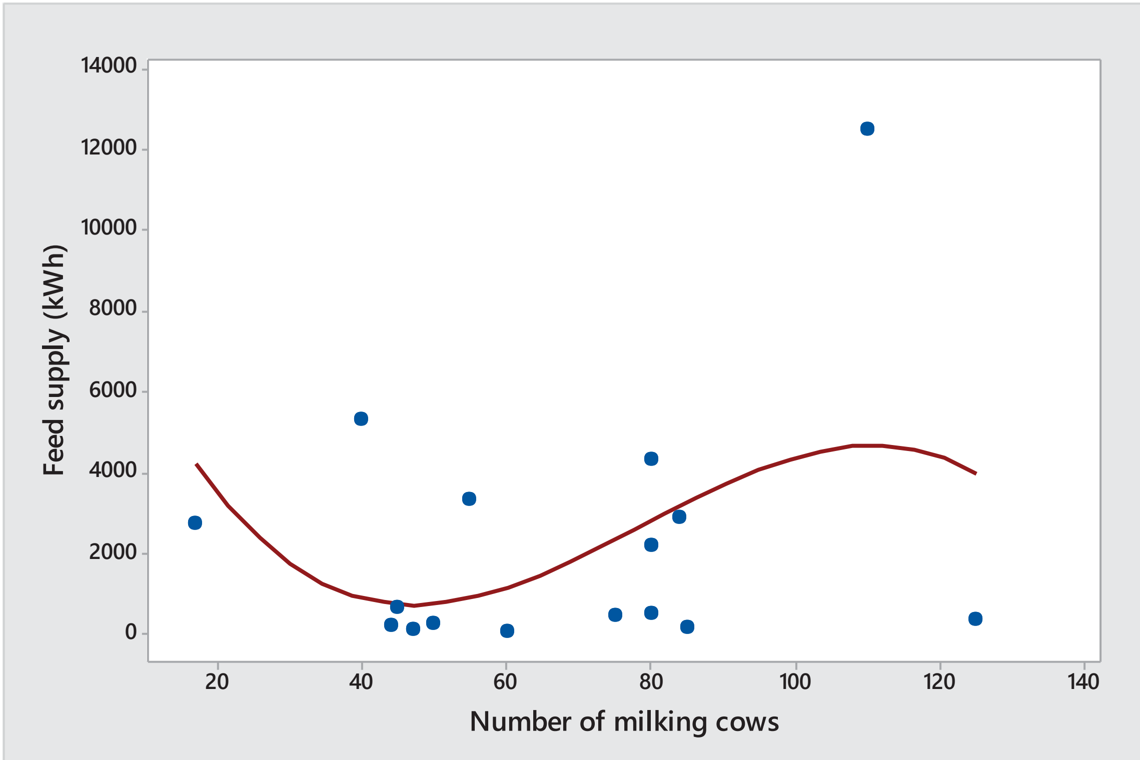
Graph 1.8: scatterplot of 19 dairy farm lighting energy use vs average daily milk production



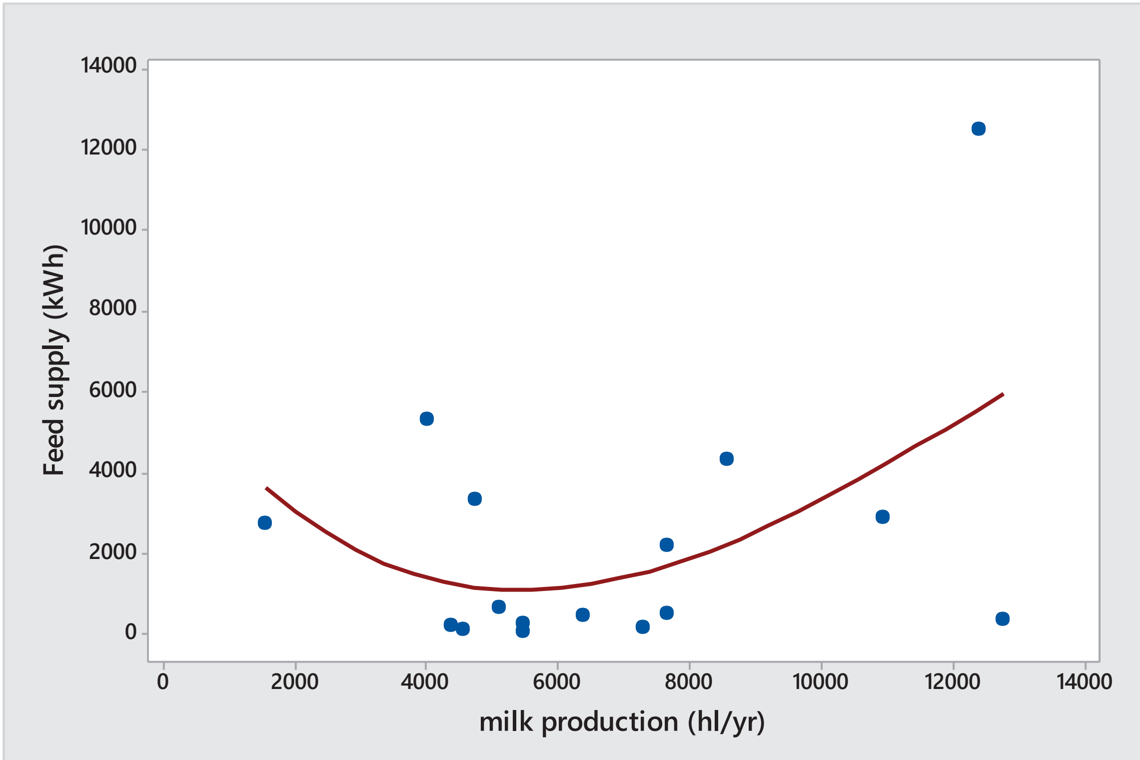
Graph 1.9: scatterplot of 13 dairy farm manure energy use vs number of cows milking



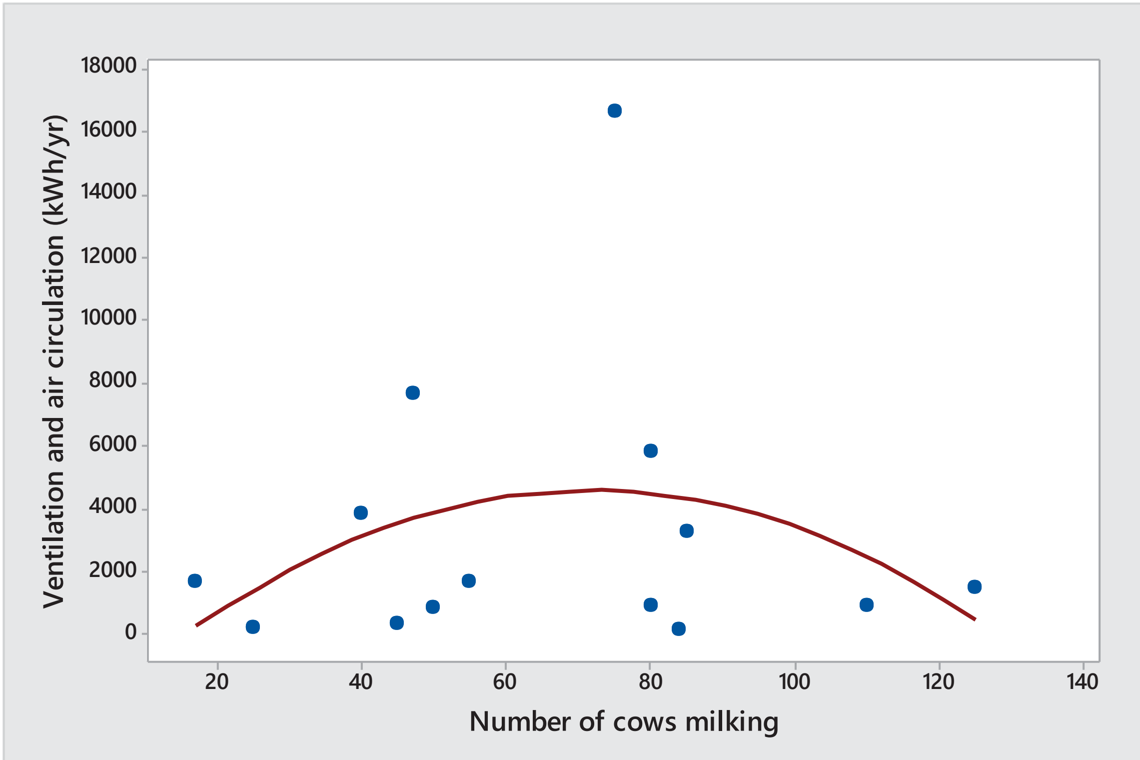
Graph 1.10: scatterplot of 13 dairy farm manure energy use vs average daily production



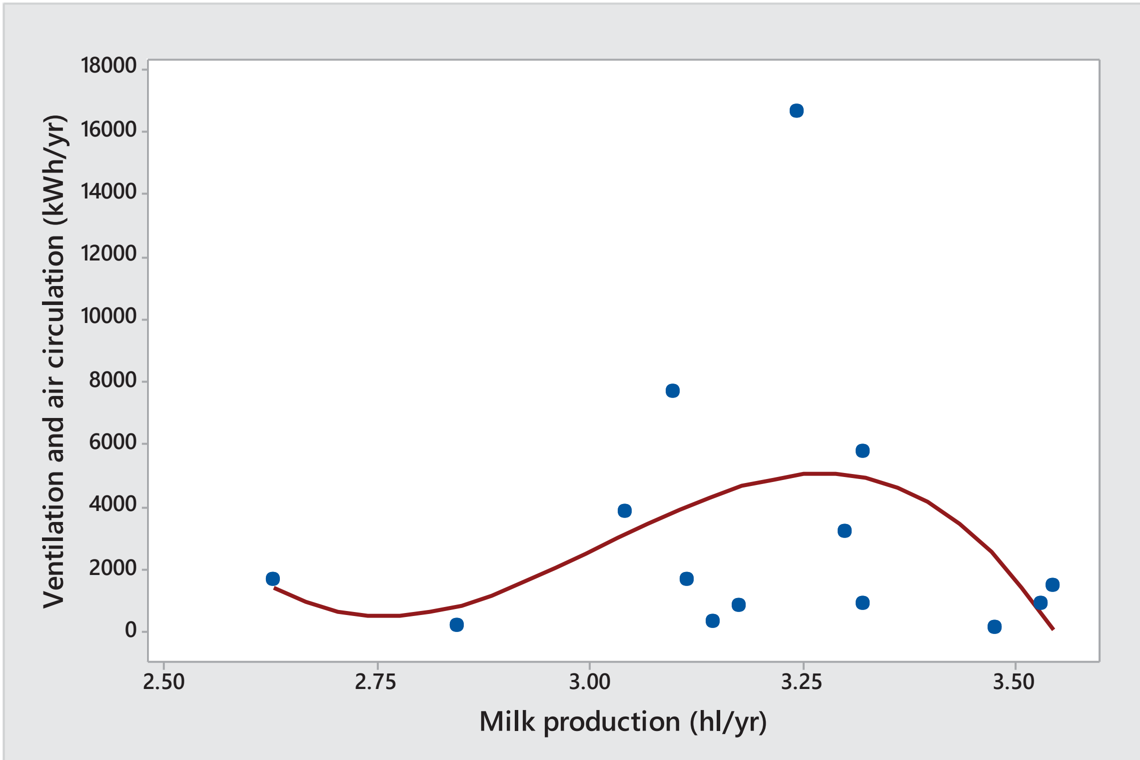
Graph 1.11: Scatter plot of 16 dairy farm feed energy use vs average cows milking



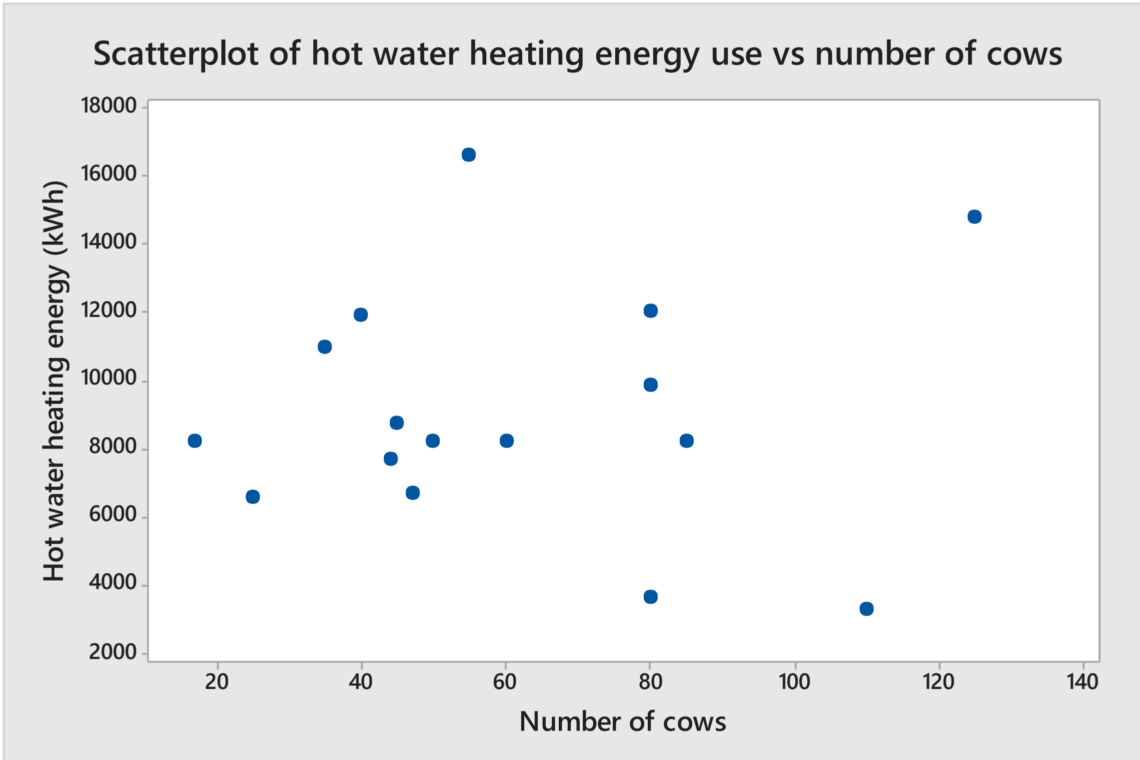
Graph 1.12: Scatter plot of 16 dairy farm feed energy use vs average daily milk production



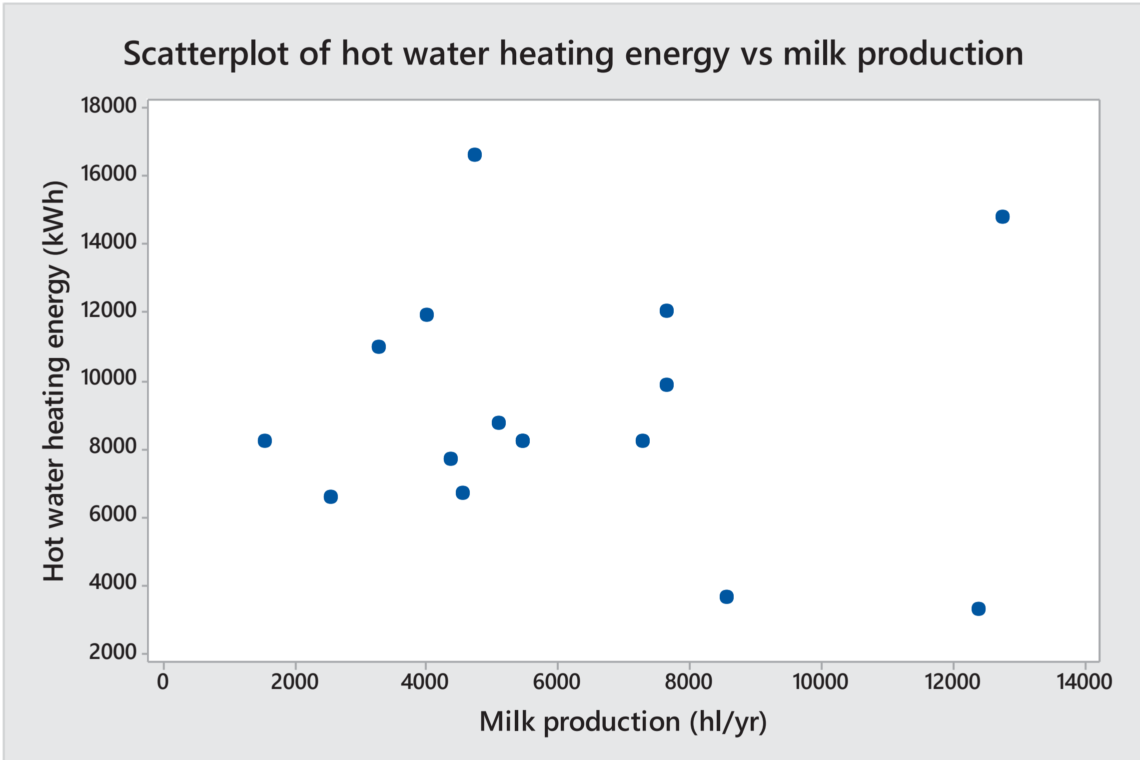
Graph 1.13: scatter plot of 14 dairy farm ventilation and air circulation energy use vs number of cows milking



Graph 1.14: scatter plot of 14 dairy farm ventilation and air circulation energy use vs average milk production



Graph 1.15: scatter plot of 16 dairy farm water heating energy use vs number of cows milking



Graph 1.16: scatter plot of 16 dairy farm water heating energy use vs average milk production

Appendix B: Milk Cooling

	Bulk Tank set Point (°C) A	Temperature of Milk entering the bulk tank B	Average daily production (L)	Yearly production (L) C	Change In temp (°C) D	Energy used for refrigeration (MJ) E	Energy used for refrigeration (kWh/yr) F	Measured energy used for refrigeration (kWh/yr) G	COP = (F/G)
1.	4	39	1150	419750	35	57164	15892	7070	2.25
2.	4	39	2345	855925	35	116564	32405	17520	1.85
3.	4	39	1506	549690	35	74860	20811	10862	1.92
4.	4	39	775	282875	35	38523	10710	6607	1.62

	Bulk Tank set Point (°C)	Temperature of Milk entering the bulk tank	Average daily production (L)	Yearly production (L) C	Change in temp(°C) D	Energy used for refrigeration(MJ) E	Energy used for refrigeration (kWh/yr) F	Measured energy used for refrigeration (kWh/yr) G	COP = (F/G)
5.	4	39	700	255500	35	34795	9673	4865	1.99
6.	4	39	3500	1277500	35	173976	48366	20221	2.39
7.	4	39	1000	365000	35	49708	13819	5676	2.43
8.	4	22	2600	949000	18	66466	18478	7081	2.61
9.	4	39	900	328500	35	44737	12437	6059	2.05
10.	4	39	2000	730000	35	99415	27638	12943	2.14

Farm 8 has a precooler installed

Appendix C: Water Heating:

Farm	Number of milking cows	Supply temp (^{0}C)	Hot water set point (^{0}C)	Number of milking / day	Pre-Cooler (Plate Cooler)	Refrigeration Heat Recovery	Wash sink capacity (L)	Bulk tank (L)
1	85	13	64	2	Yes	Yes	100	5000
2	80	10	85	3	No	Yes	100	6000
3	80	12	76	2	off	Yes	65	4000
4	50	10	77	2	Yes	No	125	5300
5	25	10	75	2	No	Yes	60	1500
6	35	11	74	2	yes	yes	190	4700
7	125	10	82	2	yes	yes	120	6000

Farm	Required temperature increase	Sink wash	Bulk tank wash	Yearly water required	Energy required (no HRS and precooler)	Measured energy use	55% off due to combine (HRS and Precooler	56% due to HRS
	Hot water set point - Supply temperature	Cycle*sink size* number of milking /day	Cycles*2%*0.5* bulk tank size	(sink wash + bulk tank wash)* 365	(Yearly water required *temperature increase*(4.187/3600)) / WHe WHe = 0.91			
1.	51	559	140	254963	16619	8886	7479	
2.	75	710	142	310980	29809	20138		13116
3.	64	299	92	142521	11658	6924		5129
4.	67	629	133	278138	23817	26547		
5.	65	311	39	127736	10612	4032		4669
6	63	954	118	391196	31499	16189	14174	
7	72	602	151	274845	25292	18848	11381	

Appendix D: Milking

Farm #	**Average cows milking**	**Average Annual Produciton (hl)**	**No. of milking units**	**Number of milking / day**	**Average hours / milking**	**Measured total (vacuum pump)**	**Vacuum pump hp**	**Variable Speed Vacuum Pump**	**Theoretical vacuum pump energy use**	**Which has variable speed drive**
1	85	7300	8	2	2.5	14123	7.5	No	12253	
2	35	3285	8	2	1.75	13404	10	No	12253	
3	50	5475	4	2	1	5582	7.5	No	6127	
4	40	1150	6	2	1	4359	10	yes	8169	4520
5	35	1000	6	2	1	3610	10	yes	8169	4520

Vacuum pump energy use without variable speed drive = hp of vacuum pump* 0.746* (average hrs of milking+ 0.5) * number of milking days * 365

Vacuum pump energy use with variable speed drive (kWh) = hp of vacuum pump* 0.746* average hrs of milking * number of milking days * 365 – saving from variable speed drive + hp of vacuum pump* 0.746* 0.5* number of milking days * 365

Appendix E: Validation and Case study

Table A: Water heating EUI for different sink and bulk size

	Number of milking cows	**Wash sink capacity (L)**	**Bulk tank (L)**	**Energy used for water heating (kWh/yr)**	**EUI (kWh/lt)**
1	25	60	1500	7683	128
2	17	65	1000	7968	123
3	44	65	4000	9675	149
4	80	65	4000	9675	149
5	60	90	5000	13090	145
6	47	95	3800	12976	137
7	40	95	3850	13005	137
8	55	100	3838	13567	136
9	80	100	5000	14228	142
10	85	100	5000	14228	142
11	80	100	6000	14797	148
12	125	120	6000	17074	142
13	50	125	5300	17245	138

	Number of milking cows	Wash sink capacity (L)	Bulk tank (L)	Energy used for water heating (kWh/yr)	EUI (kWh/lt)
14	45	160	6000	21627	135
15	35	190	4700	24302	128
16	110	220	6000	28457	129

Table B: Dairy farm milk cooling energy audit data calculated based on model

Farm	Average cows milking	Bulk Tank set Point (°C)	Temperature of Milk entering the bulk tank	Average daily production (hl)	Change in temp(°C)	Energy used for milk cooling (kWh/yr)
1.	17	4	39	4.25	35	5927
2.	25	4	39	7	35	9762
3	35	4	39	9	35	12551
4	44	4	39	10	35	13946
5	40	4	39	11	35	15341

Farm	Average cows milking	Bulk Tank set Point (°C)	Temperature of Milk entering the bulk tank	Average daily production (hl)	Change in temp(°C)	Energy used for milk cooling (kWh/yr)
6	44	4	39	12	35	16735
7	47	4	39	12.5	35	17433
8	55	4	39	13	35	18130
9	45	4	39	14	35	19524
10	50	4	39	15	35	20919
11	60	4	39	15	35	20919
12	75	4	39	17.5	35	24406
13	85	4	39	20	35	27892
14	80	4	39	21	35	29287
15	80	4	39	21	35	29287
16	80	4	39	23.45	35	32703
17	84	4	39	30	35	41838
18	110	4	39	34	35	47417
19	125	4	39	35	35	48811

Table C: Dairy farm Vacuum pump EUI calculated based on vacuum pump energy use model data, milking units and milk production

S.No	Milking units	Milk production (hl/day)	Vacuum pump (hp)	Vacuum pump energy use (KWh)	EUI (Audited vacuum pump energy use/(#milking units*hl/day)
1	4	4.25	5.0	4765	280
2	4	12.5	5.0	6807	136
3	5	7	5.0	3404	97
4	6	12	5.0	4765	66
5	6	13	5.0	4765	61
6	6	15	5.0	5446	61
7	6	15	7.5	9190	102
8	8	9	10.0	9530	132
9	8	10	5.0	4765	60

S.No	Milking units	Milk production (hl/day)	Vacuum pump (hp)	Vacuum pump energy use (KWh)	EUI (Audited vacuum pump energy use/(#milking units*hl/day)
10	8	14	5.0	5446	49
11	8	20	7.5	10211	64
12	8	21	5.0	5446	32
13	8	21	10.0	22464	134
14	8	23.45	5.0	6807	36
15	12	11	10.0	8169	62
16	12	17.5	7.5	10211	49
17	16	34	10.0	9530	18
18	18	35	10.0	13615	22
19	20	30	10.0	10211	17