



Technische Hochschule  
Ingolstadt

**Study on Potential of Energy Optimization in  
German Dairy Industry**

Faculty of Mechanical Engineering

Renewable Energy Systems

Submitted By

**Aditya Bhalchandra Dhavale**



Technische Hochschule  
Ingolstadt

# Technische Hochschule Ingolstadt

Faculty of Mechanical Engineering

Renewable Energy Systems

## Master's Thesis

### Study on Potential of Energy Optimization in German Dairy Industry

Submitted By

**Aditya Bhalchandra Dhavale**

<b>Issued on:</b>	27.07.2023
<b>Submitted on:</b>	24.01.2024
<b>First Examiner:</b>	Prof. Dr. Markus Goldbrunner
<b>Second Examiner:</b>	Prof. Dr.-Ing. Tobias Schrag

# Declaration

I hereby declare that this thesis is my own work, that I have not presented it elsewhere for examination purposes and that I have not used any sources or aids other than those stated. I have marked verbatim and indirect quotations as such.

Ingolstadt, 24.01.2024



**Aditya Bhalchandra Dhavale**

# Acknowledgement

I would like to thank all the people who helped and supported me in realizing this thesis. Your support is appreciated and helped me solve any problems that arose during the course of this work.

Here, I want to thank Prof. Dr. Markus Goldbrunner for guiding me through this work. I would also like to thank Prof. Dr.-Ing. Tobias Schrag for supporting me as the second examiner.

I would like to specially thank Mr. Julian Braun who guided and mentored me by providing valuable feedback and support during the course of the thesis. I am also thankful to Mr. Akhilesh Yadav for his feedback and support and helping right till the end of my work.

I want to fondly recall my late mother, who served as my greatest source of motivation during the periods when she was there to support me throughout my academic journey.

I want to thank my friends for supporting and guiding me during this time. Last but not least, I would like to show my gratitude to my family, especially my sister and father who supported me in difficult times and instilled belief in me in the course of my studies.

# Abstract

The dairy farms form a vital part of German agriculture and consume significant energy for their operation. Germany is working towards energy transition to transform the existing fossil fuel-nuclear system to a sustainable energy system that relies on renewable sources due to various societal and political demands. As the energy demand is increasing due to the rise in population, there is also a growing push in Germany to adopt energy efficient technologies and measures to reduce energy waste. There is a scope for improving the energy efficiency in dairy farms. Using energy optimization techniques can help reduce the load on energy suppliers as well as increase cost savings for farms.

German farmers are adopting newer digital technologies to achieve optimization of energy in their farms. One of the key tools in realizing energy optimization is the Energy Management System (EMS). The use of EMS in the case of dairy farms has been reviewed and presented in this work. The objective of the study is to investigate the potential of energy optimization in dairy farms. Efficiency measures like replacing inefficient farm equipment are necessary to achieve energy efficiency. These measures are discussed in detail and their potential to save energy in dairy farms is presented. A comparison of all these measures is studied and how much energy savings can be obtained is reviewed.

The use case scenario of EMS in different applications is presented as an indication of possibilities for energy savings using EMS. Furthermore, how the AI technology in combination with EMS can be used in farms and its benefits in dairy farming is reviewed. The types of farms on which the energy optimization measures can be implemented in an ideal case scenario are reviewed. The result of the study shows that there is vast potential for energy optimization in German dairy farms. Thus, the presented work can be further studied to identify further optimization possibilities with the advancement of AI and newer technologies.

# Table of Contents

<b>Declaration.....</b>	<b>I</b>
<b>Acknowledgement.....</b>	<b>II</b>
<b>Abstract.....</b>	<b>III</b>
<b>List of Figures .....</b>	<b>VII</b>
<b>List of Tables .....</b>	<b>VIII</b>
<b>List of Abbreviations.....</b>	<b>IX</b>
<b>Chapter 1 .....</b>	<b>1</b>
<b>Introduction .....</b>	<b>1</b>
1.1 Research questions: .....	3
<b>Chapter 2 .....</b>	<b>4</b>
<b>Means of Energy Optimization.....</b>	<b>4</b>
2.1 Milk collection .....	4
2.1.1 Conventional Milking System (CMS).....	4
2.1.2 Automatic Milking System (AMS) .....	6
2.2 Milk Cooling.....	8
2.2.1 Methods of Milk Cooling.....	9
2.2.2 Precooler .....	10
Types of Precoolers .....	11
2.2.3 Refrigeration Heat Recovery RHR units .....	13
2.2.4 Compressors .....	15
2.3 Pumps .....	15
2.3.1 Size of vacuum pumps.....	17
2.3.2 Application and Limitations of VSDs.....	17
2.4 Lighting .....	18

2.5 Cleaning .....	19
2.5.1 Water heating .....	21
2.6 Feed system .....	22
2.7 Load Management .....	25
2.7.1 Load Shifting .....	25
2.8 Energy Management System .....	27
2.8.1 EMS in Logistics and Transportation:.....	28
2.8.2 EMS in Manufacturing Industries:.....	29
2.8.3 Regulations for Energy Management in Germany: .....	30
2.8.4 ISO 50001 standard: .....	30
2.8.5 DIN EN 16247-1 standard:.....	31
2.8.6 Tax Reductions and Exemptions:.....	31
2.8.7 Artificial Intelligence in EMS:.....	32
2.8.8 Artificial Intelligence in Dairy Farms:.....	33
<b>Chapter 3 .....</b>	<b>35</b>
<b>Comparison and methodology of measures for Energy Optimization .....</b>	<b>35</b>
3.1 Comparison of Conventional Milking System and AMS .....	35
3.2 Comparison of cooling methods. ....	36
3.3 Comparison of farms with Precooling and RHR Units:.....	37
3.4 Comparison of Conventional and Vacuum pumps.....	38
3.5 Comparison of cleaning systems .....	39
3.6 Energy Management System in context of Dairy farms .....	40
3.6.1 Implementation cases of EMS in dairy farms .....	41
3.6.2 Challenges in Implementation of EMS.....	42
<b>Chapter 4 .....</b>	<b>44</b>
<b>Discussion .....</b>	<b>44</b>
<b>Chapter 5 .....</b>	<b>46</b>
<b>Conclusion and future scope .....</b>	<b>46</b>
<b>References .....</b>	<b>48</b>





# List of Figures

Fig 1.1: Electrical Energy consumption by different processes in Dairy [3].....	2
Fig 2.1 Milking Machine [25] .....	5
Fig 2.2: Herringbone Milking parlor [27][28].....	6
Fig 2.3: Parallel Milking Parlor [27][29] .....	6
Fig 2.4: Rotary Milking Parlor [30][31] .....	6
Fig 2.5: Robotic Milking system (AMS) [33][34] .....	7
Fig 2.6: Illustration of germ counts in raw milk at different temperatures and time [39].....	8
Fig 2.7: Bulk Milk Cooler [41] .....	9
Fig 2.8: Energy Flows in Cooling System with Precooler [45] .....	11
Fig 2.9: Concentric tube heat exchanger [45] .....	12
Fig 2.10: Shell and tube heat exchanger [45] .....	12
Fig 2.11: Plate heat exchanger [45] .....	13
Fig 2.12: Cross Sectional View of RHR unit [47] .....	13
Fig 2.13: Energy Flows in Cooling unit with RHR installed [47].....	14
Fig 2.14: Pump with VSD and Pressure Sensor [54] .....	16
Fig 2.15: Techniques in the process chain in realizing stages of automation in feeding system [64].....	23
Fig 2.16: A rail mounted AFS in dairy farm [65] .....	23
Fig 2.17: Daily load profile of a farm in Germany with direct cooling in winter [69].....	26
Fig 2.18: Daily load profile of a farm in Germany with ice bank cooling in winter [69].....	26
Fig 2.19: Hourly Sport Market Price for Winter Day in Germany [70] .....	27
Fig 2.20: EMS PDCA cycle [13] .....	31
Fig 3.1: Schematic of EMS in dairy farm setup .....	40
Fig A 1: Energy consumption data from KTBL calculator with 100 cows and 8240 kg/cow/a with CMS, direct cooling, precooling only. [71].....	56
Fig A 2: Energy consumption data from KTBL calculator with 100 cows and 8240 kg/cow/a with CMS, direct cooling, RHR unit only. [71].....	57
Fig A 3: Energy consumption data from KTBL calculator with 100 cows and 8240 kg/cow/a with AMS, direct cooling, precooling and heat recovery. [71] .....	58

## List of Tables

Table 2.1: Energy comparison between different lamps [56] .....	18
Table 2.2: Cost comparison between different lamps [56].....	19
Table 3.1: Comparison of Electricity consumption of Milking systems [71].....	35
Table 3.2: Comparison of Electricity consumption and Costs of different cooling methods [3].....	36
Table 3.3: Comparison of precooling and RHR units [71].....	37
Table 3.4: Cost and Energy comparison for Vacuum pumps [72].....	38
Table 3.5: Comparison of Cleaning Methods [3] .....	39
Table 4. 1: Ideal case scenario for Energy optimization measures .....	44

# List of Abbreviations

EMS Energy Management System

PV Photovoltaics

RHR Refrigeration Heat Recovery

Hex Heat Exchanger

LED Light Emitting Diode

CMS Conventional Milking System

AMS Automatic Milking System

BMC Bulk Milk Cooler

VSD Variable Speed Drive

CIP Cleaning in Place

CFS Conventional Feeding System

AFS Automatic Feeding System

BMC Bulk Milk Cooler

AI Artificial Intelligence

# Chapter 1

## Introduction

Germany is the largest milk producer in the EU, amounting to one-fifth of the total EU milk output in the year 2022 [1]. Every fifth farm in Germany houses dairy cows. In the year 2022, there were 52,895 farms, which generated 22 percent of the total agricultural production value through their milk production. This data highlights the role that milk production plays as an important branch of German agriculture in economic terms.

Germany is working towards energy transition to transform the existing fossil fuel-nuclear system to a sustainable energy system that relies on renewable sources due to various societal and political demands [2]. As the energy demand is increasing due to the rise in population, there is also a growing push in Germany to adopt energy efficient technologies and measures to reduce energy waste. This also holds true for the milk and dairy industry. To scale up milk production but at the same time reduce the impact on ecology and environment, there is a need to address the problems related to energy, by implementing energy saving mechanisms wherever possible. Using energy optimization techniques can help reduce the load on energy suppliers as well as increase cost savings for farms.

German dairy farmers are relying on technologies to achieve energy savings with the help of automation and digitalization [3]. One of the key technological tools is the Energy Management System (EMS) of dairy farms.

To implement the EMS on a farm, firstly the energy consumption in the farm must be identified and segregated based on each process and equipment. In recent years, there has been a significant adoption of technological equipment in farms in Germany in recent years. In Bavaria, for example, 14.6% of all dairy farms currently milk with an automatic milking system [2]. Not only the milking system but many of these farms also use automatic feeding and cleaning systems. These systems consume a lot of energy, mostly electrical energy. The typical electrical energy consumption matrix in dairy farms in Germany is represented in the pie chart below ([Fig 1.1](#)).

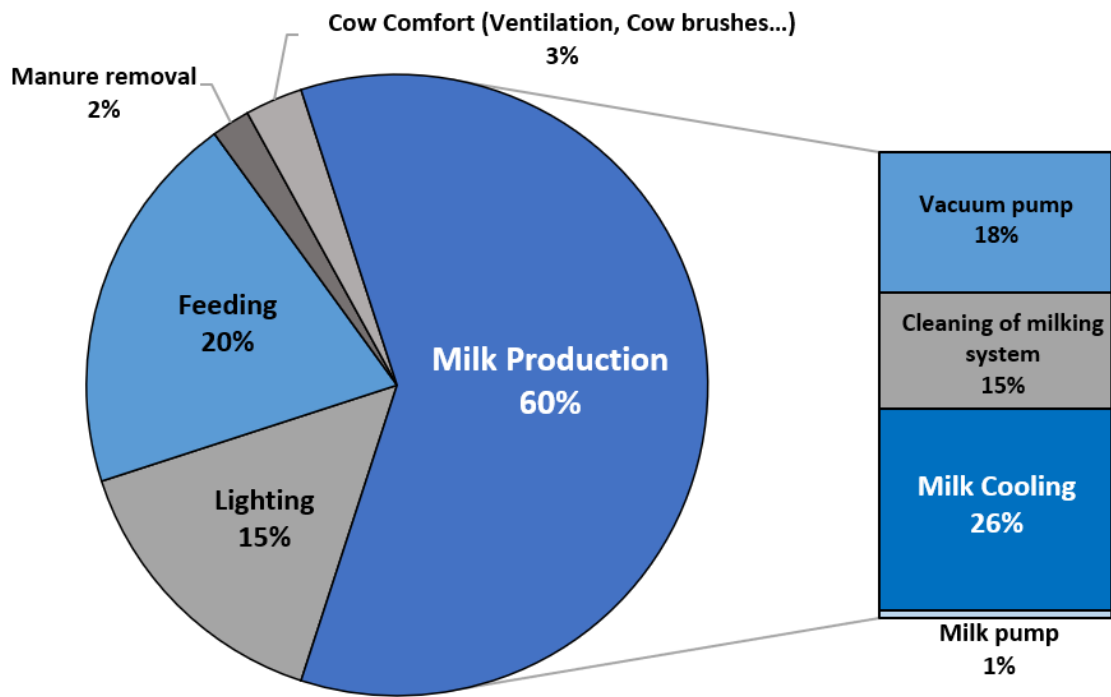


Fig 1.1: Electrical Energy consumption by different processes in Dairy [4]

As evident from [Fig 1.1](#), milk cooling stands out as the most energy-intensive process, demanding a substantial amount of energy to cool large quantities of milk. There is scope for improving energy efficiency in the milk cooling process by using energy optimization techniques like the use of modern energy-efficient cooling equipment and other areas of farms like milk collection by using efficient pumps and the use of EMS in the farms. Also, the use of electric vehicles like electric tractors, wherever possible, can be used to improve energy efficiency and also reduce emissions from the use of diesel tractors.

The energy optimization measures in dairy farms can be divided into three categories. These categories are based on costs incurred. The first category includes near cost-neutral measures such as behavioral changes of energy consumers or changing the schedule to use the equipment during low-cost energy supplied from self-generated renewable energy sources like Photovoltaics (PV), and Biomass. The second measure can be considered low investment measures, such as using motion detection for lighting or time control for automated processes like milking and cleaning. Also, this measure can include gradual replacement of light sources with modern energy-efficient lamps and conducting regular maintenance. The final category of measures is the most Cost-intensive as it involves replacing old equipment with modern energy-efficient ones. [5]

#### Scope of Energy Optimization in Milking:

- Use of Speed Controlled/ Variable Vacuum Pumps
- Installing Pre-cooler

- Refrigeration Heat Recovery (RHR) – using waste heat from refrigerant with the help of Heat exchangers.

#### **Scope of Energy Optimization in Milk Cooling:**

- Heat Exchangers (Hex) – using waste heat from milk cooling with them help of Hex and use it to heat water used for cleaning purposes.
- Use of Scroll Compressors, which are more efficient than generally used reciprocating compressors.

#### **Scope of Energy Optimization in Lighting:**

- Use of motion sensors
- Modern lamps-LEDs

### **1.1 Research questions:**

1. How can the Energy in dairy farms be optimized?
2. What are the different possibilities of Energy management systems?
3. What are the benefits of Energy Optimization for farmers?
4. What are the benefits in terms of environmental sustainability?

## Chapter 2

This chapter presents the means of implementing measures to optimize energy efficiency, like EMS, the areas of farms where energy can be optimized using different methods and equipment, which are essential to understanding the methods of optimization presented in this thesis research.

### Means of Energy Optimization

In this section, different measures through which energy optimization can be achieved are presented.

#### 2.1 Milk collection

Milk collection or harvesting is one of the primary consumers of electrical energy in dairy farms. The milk collection usually takes place two or more times per day on farms. This is generally done based on schedules i.e., in the morning and afternoon or evening. On average, milking utilizes 18 percent of the electrical energy used on a dairy farm [6]. Milk collection is done in different ways such as using portable milking machines, milking parlors, or milking robots. The milking machines or milking parlors are hereby referred to as CMS, and robotic milking is referred to as AMS. The details and comparison of these methods is done in this section.

##### 2.1.1 Conventional Milking System (CMS)

In conventional milking systems, cows are milked either individually using milking machines generally done in small farms or in a parlor system where multiple cows are milked using multiple milking machines in larger farms. Milking machines are used to harvest milk from cows and are made up of four teat cups attached to a claw, which is connected to a long milk tube and a pulsator [7]. The principle of machine milking is to extract milk from the cow by vacuum. The machines are designed to apply a constant vacuum to the end of the teat to suck the milk out and convey it to a suitable container [7]. In small farms, the milking machine is attached to a single bucket or container, as depicted in [Fig 2.1](#), enough to store the milk from a single cow and moved from cow to cow, manually. The vacuum is supplied by vacuum pumps, which require electrical energy to generate and maintain the vacuum in the system. In most cases, electrical energy is used to run these machines, but in remote areas, fuel-operated pumps are used if the electricity is

unavailable. The system is mechanically simple with relatively low investment, running and maintenance costs compared with milking machines in parlors [7]. The energy optimization opportunities of vacuum pumps in small farms are low as the milking units are not many and the gains are not significant to install new equipment like variable speed drives on vacuum pumps.



Fig 2.1: Milking Machine [8]

In large farms, milking is carried out in milking parlors such as herringbone milking parlors ([Fig 2.2](#)), parallel milking parlors ([Fig 2.3](#)) or rotary milking parlors ([Fig 2.4](#)), where multiple cows are milked simultaneously. These milking parlors vary by the size and the position of cows, but the milking machines remain the same. Except for the rotary parlor (carousel), where the platform on which cows stand rotates while milking, the rest of the parlors are stationary parlors. The rotation is driven by a motor. The milking machines are attached to cow teats manually and, after milking, washed and sanitized before attaching to another cow or for the next milking, manually by an operator. [7]

In parlor systems, there is scope for energy optimization by employing VSDs on vacuum pumps as the milking units are high in numbers and employing VSDs helps save considerable amount of electricity, which is discussed in [section 2.3](#). Also, in the parlor systems, the energy is consumed for washing and cleaning using hot water, which can be optimized by using heat recovery systems, which is discussed in [section 2.2.3](#).



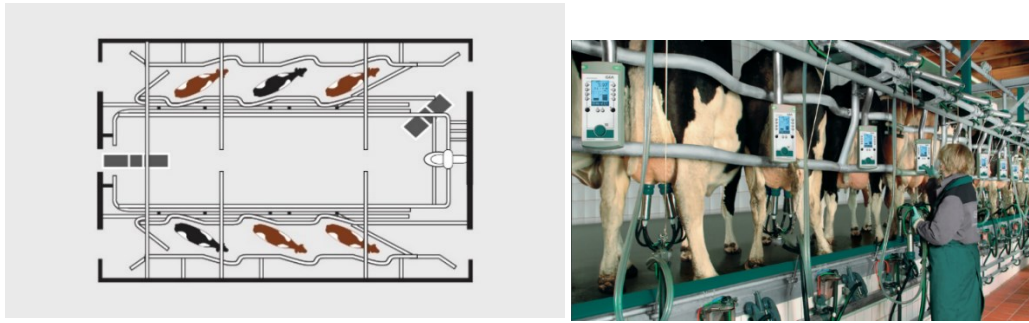


Fig 2.2: Herringbone Milking Parlor [9][10]

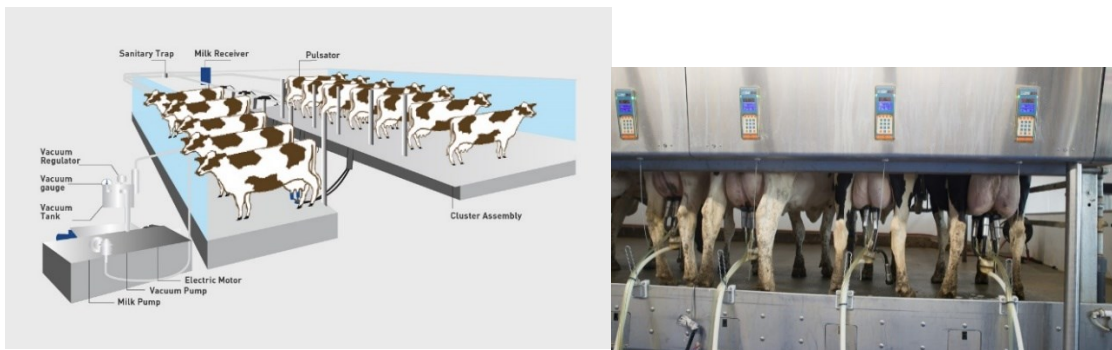


Fig 2.3: Parallel Milking Parlor [9][11]

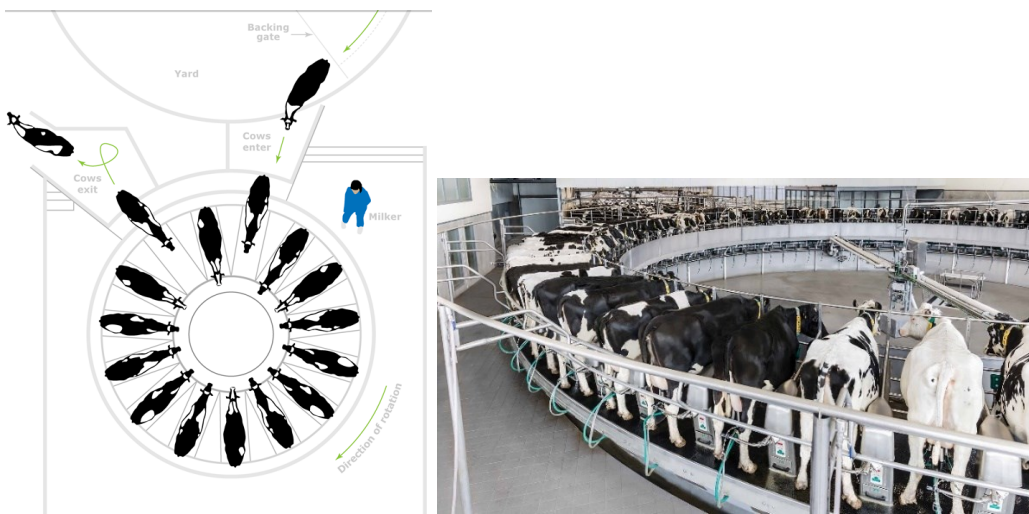


Fig 2.4: Rotary Milking Parlor [12][13]

### 2.1.2 Automatic Milking System (AMS)

AMS, also called robotic milking system, is a fully automated milking system. The milking unit of AMS consists of a milking machine, a teat position sensor, a robotic arm for automatic teat-cup application and removal, and a gate system for controlling cow traffic. The cows are allowed to decide their own milking time voluntarily rather than milked in groups at set times like in parlors. When the cow that wants to be milked enters the milking unit, the AMS checks if cow can be milked and if yes then it performs automatic teat cleaning, applies the teat cups, and starts the milking. After milking, the AMS performs

teat spraying and cleans the milking unit automatically as per the preset instructions on control unit. Since the whole system is automated, the AMS requires considerable energy to operate and function. [14]



Fig 2.5: Robotic Milking system (AMS) [15][16]

AMS includes single-stall systems where robotic and milking functions are integrated, as well as multi-stall systems with transportable robot devices combined with milking and detachment devices at each stall. However, most AMSs are single-stall units where an isolated milking experience for the cow differs drastically from most conventional parlor systems. The primary consumers of energy of the AMS milking unit includes the robot, vacuum pump, air compressor and heating of water for cleaning. Due to automation of operations, AMS consumes more electricity than conventional milking systems. [17]

Höhendinger conducted a study of AMS to examine the impact of different drive systems, like pneumatic drive and electric drive, within the attachment arm of AMS in practical conditions. A detailed quantification of energy consumption was carried out on two consecutive single-stall AMS of a dairy farm in southern Bavaria, Germany. The study concluded that the electrical drive of the attachment arm was more efficient than the pneumatic one, which was possible due to lower energy consumption and higher milking and production performance. The replacement of the pneumatic drive with electrical drives leads to higher energy consumption of the milking robot but reduces the energy consumption of the air compressor. Considering the increased performance of more milking events and reduced energy consumption of the total AMS, the energy efficiency of the electric attachment arm showed substantial advantages in the energy efficiency of the whole milking process. [17]

In dairy farms with AMS, an electrical drive can be implemented to optimize the energy and reduce the overall energy consumption of AMS. However, there needs to be more studies on different technologies used with the AMS to optimize energy consumption compared to conventional milking systems.

The comparison of energy consumption between conventional and automatic milking systems is presented in [section 3.1](#).

## 2.2 Milk Cooling

Milk cooling is the largest consumer of energy, accounting for approximately 26% of the farm's energy consumption as depicted in [Fig 1.1](#). Milk is collected from cows at 35-37°C and has to be cooled below 4°C within 3 hours to prevent any bacterial growth, which causes the quality of milk to deteriorate [18][19]. This is very critical as the milk at temperatures above 7°C is a favorable temperature for bacterial growth [18]. Hence, the microbial load can multiply rapidly if the milk is kept at that temperature. Cooling milk rapidly (below 6°C) is necessary to avoid the multiplication of microorganisms, especially psychrotrophs, which can grow at refrigeration temperatures but have optimal and maximal growth temperatures at >15 and 20°C, respectively as illustrated in [Fig 2.6](#) [20]. Refrigeration systems for milk cooling consist of a bulk tank, a motor-driven compressor unit, an evaporator, and a condenser unit [6]. The system functions by circulating a refrigeration coolant through a cycle in which it releases heat during the condensation process.

The location of the refrigeration unit has a significant influence on the energy requirement. For instance, raising the ambient temperature from 25 to 32°C results in an approximately 25% increase in energy consumption. Installing the refrigeration unit in a cool area with ample air circulation, along with structurally separating the milk storage room and compressor location, yields positive effects. Regular maintenance, in particular maintaining the optimum refrigerant level and cleaning the air heat exchanger, increases the energy efficiency of the system. [4]

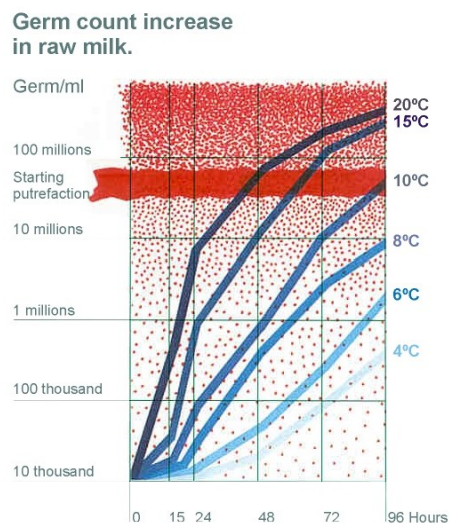


Fig 2.6: Illustration of germ counts in raw milk at different temperatures and time [21]

### 2.2.1 Methods of Milk Cooling

For milk cooling, BMCs are used both to cool the milk and store the cooled milk before the milk is collected by refrigerated trucks to the processing destination or plant. The BMCs operate on a vapor compression refrigerant cycle, where the refrigerant gas is compressed and then condensed to lower temperatures. Dairy farms utilize two different types of milk cooling systems, which are the Direct cooling and the indirect cooling type (ice bank cooling). [19]

Direct cooling or direct expansion uses evaporator plates that are used in the lower portion of the storage tank and have direct contact with milk, as illustrated in [Fig 2.7](#). The evaporator boils liquid refrigerant at a low pressure and temperature. This allows the heat from the surrounding surface, i.e., milk which is in direct contact with plates, to be absorbed and makes the refrigerant hotter and milk cooler. The agitators stir the milk for temperature distribution during the cooling process which keeps the milk moving and avoid freezing of milk. Excessive agitation can harm the milk inside the tank. [22]

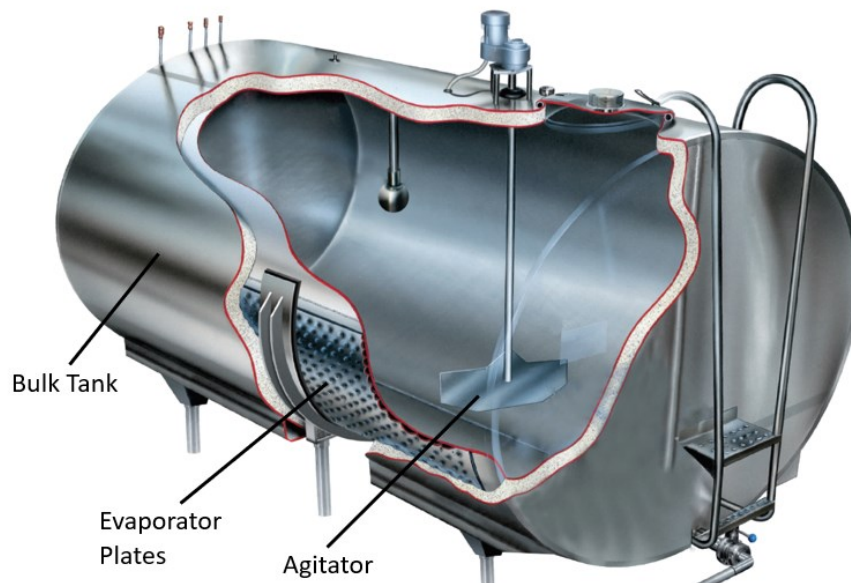


Fig 2.7: Bulk Milk Cooler [23]

Indirect cooling, or instant cooling, involves cooling milk in an external storage tank. Indirect cooling systems use Hex's to cool the milk. The cooling fluid (water or glycol water mix) from a chiller or cooling tower is used in the Hex to lower the temperature of the milk. The cooling takes place inside the Hex instead of the bulk tank, as is the case in direct cooling. The size of the Hex can be made as per the specific requirements of milk production in the farms. [22]

The ice bank cooling systems are beneficial for farms as refrigeration plant capacity can be minimized, as in this system ice bank meets the peak cooling demand of the milk, rather than the compressor. The ice bank can be created at any time which allows in maximizing the use of cheaper night-rate electricity or electricity generated from renewable sources. However, this system is less energy efficient than direct cooling as ice is built at one time, and the milk is cooled later. Due to this dual nature of the process and the unavoidable minor energy losses through the insulation during storage. [24]

Comparison between direct and indirect cooling: [4]

- Direct cooling systems have a lower energy requirement than indirect cooling systems. However, the power consumption is linked to the milking times, and the electrical connected load is approx. 20 percent higher.
- The power consumption of indirect cooling is higher. However, peak loads can be avoided through the possible time separation of ice production and cooling. In addition, relocating ice water production to off-peak times enables lower energy costs than using a comparable direct cooling system.

Among these two types of cooling methods, the direct cooling system saves 15–20% of electricity consumption in comparison to indirect cooling systems [25]. Therefore, the use of direct cooling is a better one for use in farms for optimized use of energy. A comparison of these two methods is presented in [section 3.2](#).

### **2.2.2 Precooler**

Precooling is the cooling of milk that is being transferred to a bulk tank for rapid cooling after it is collected from the cows. This helps in reducing the temperature of milk from 37°C to around 20°C or even lower depending on the precooling technology employed. Plate Hex is used in the precooling of milk in most cases. This device uses heat-conducting plates to run water and milk on either side, allowing the water to partially cool the milk. In theory, it is possible to achieve a milk temperature as it exits the plate cooler that is equal to the water temperature entering it, which is typically around 10°C. However, this would necessitate a very large plate cooler and a substantial water flow. [26]

The precooling of milk could also reduce the bacterial growth rate, which helps preserve the milk quality. Using a pre-cooler can significantly reduce the cooling demand and enhance milk quality for a dairy farm. Also, the heat is transferred from milk to water, which can be used for cleaning the milk equipment like BMC and other equipment and can be used as drinking water for cows. A properly sized precooling heat exchanger can lower milk temperatures to as low as 6°C, resulting in refrigeration energy reductions of about

60 percent [6]. The potential energy savings from the pre-cooler has been ascertained to be in the range of 40 to 60% [6][19]. The cost savings from cooling have been estimated to be about 50% [26]. Thus, this demonstrates the advantages of precooling the milk, helping reduce energy as well as costs and thus in sustainable farming.

When using a pre-cooler, it is important to note that while electricity costs for milk cooling are halved, there is an associated increase in costs for water and wastewater. Therefore, utilizing a pre-cooler is a practical choice, especially if the cooling water required for the pre-cooler is to be reused within the farm, e.g., as cleaning and drinking water. [4]

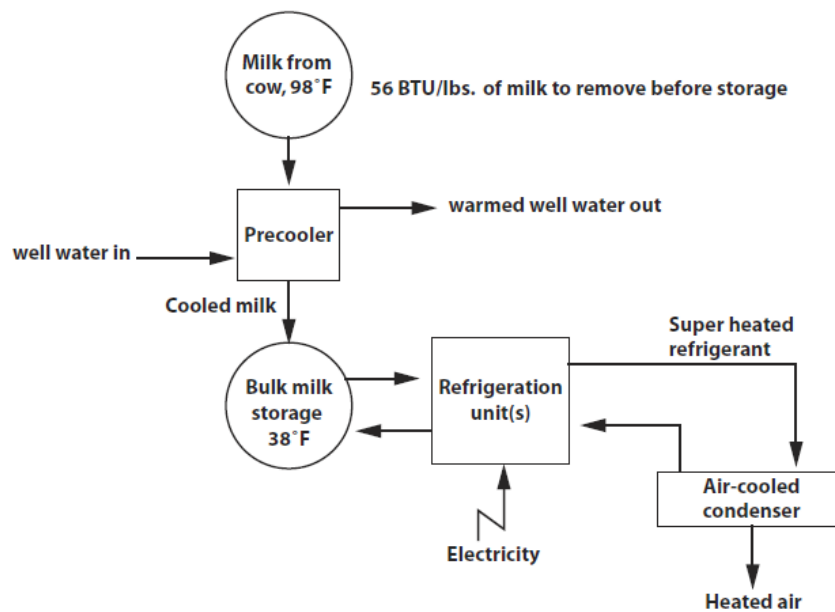


Fig 2.8: Energy Flows in Cooling System with Precooler [27]

### Types of Precoolers:

There are different types of precoolers based on heat exchangers used in the pre-cooler. These are the shell and tube type Hex and plate type Hex.

In Shell and tube type Hex, the milk flows through the smaller tube(s) while the well water flows through the shell. The simplest shell and tube Hex is a concentric tube heat exchanger where a single small tube is housed inside of a larger tube, as illustrated in [Fig 2.9](#). To achieve greater surface area for heat transfer, multiple small tubes can be housed inside of a larger tube or shell, as shown in [Fig 2.10](#). Other variations include configurations where a coil of tubing is enclosed within a chamber to increase the heat transfer area. Irrespective of the configurations, the milk passes through the smaller tube(s) while the well water flows through the shell. The shell and tube Hex come in fixed units or lengths that limit their flexibility to expand in capacity. [27]

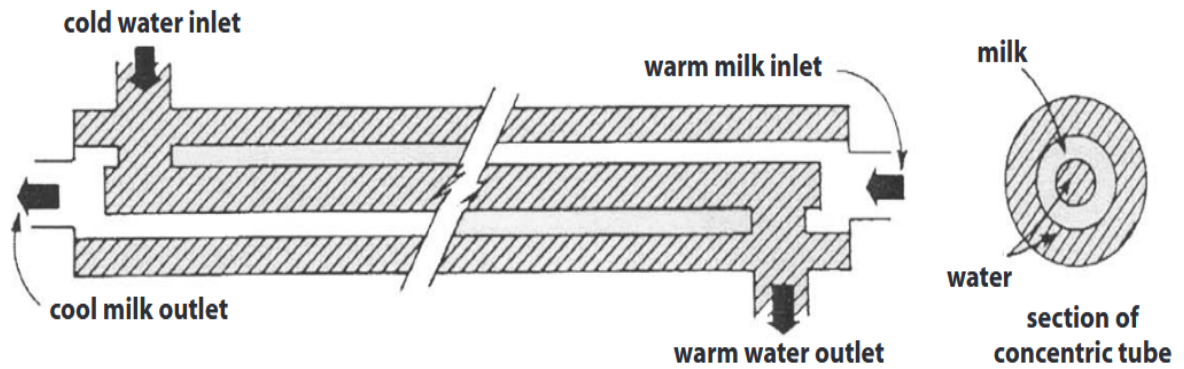


Fig 2.9: Concentric tube heat exchanger [27]

Figure 4. Shell & tube heat exchanger

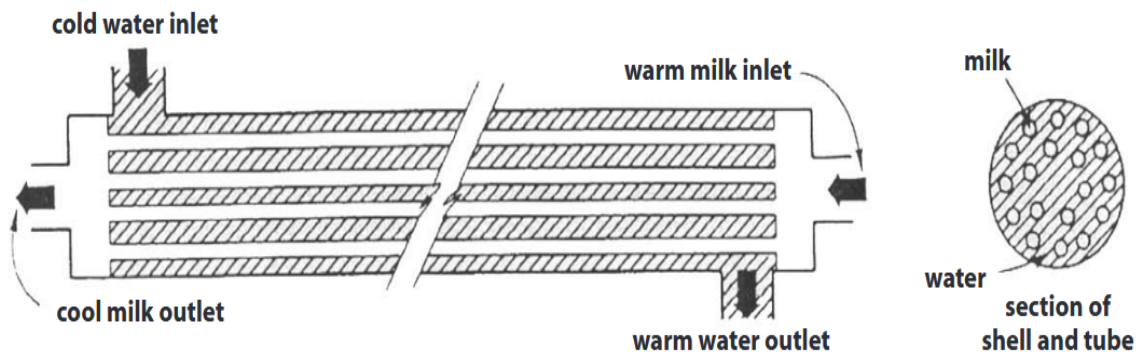


Fig 2.10: Shell and tube heat exchanger [27]

Plate type Hex consists of a series of ribbed plates placed side by side in a pack, as illustrated in [Fig 2.11](#). Plate coolers are made up of plate packs containing several stainless steel plates adapted to the milk flow rate. Rubber gaskets function as seals for the plates such that there are two separate circuits. The milk flows between every other plate while the well water flows through the circuit on the opposite side of the plate from the milk. Milk and cooling liquid pass each other in counterflow. The plates are ribbed to promote turbulent flow to increase the heat transfer rate. [27]

Among these two types of heat exchangers used for precooling, plate Hex's have the advantage of being compact as well as the ability to expand easily by adding additional plates to increase capacity as required. Shell and tube heat exchangers come in fixed units or lengths, so expansion is not as flexible. [27]

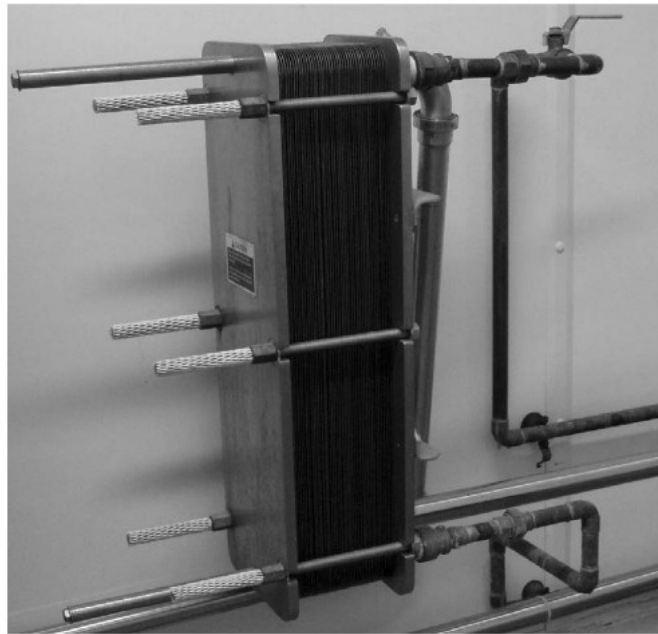


Fig 2.11: Plate heat exchanger [27]

### 2.2.3 Refrigeration Heat Recovery RHR units

The heat transferred from milk to refrigerant gas while cooling milk is generally not recovered or used for any purpose of heating. Installing a refrigerator heat recovery (RHR) unit could save substantial energy as the waste heat from milk is used to heat the water used for cleaning farm equipment. By harnessing heat recovery, it is possible to attain water temperatures reaching up to 60°C, resulting in a cost savings of 30% to 70% on water heating, depending on the amount of available heat [28]. The sizing of the RHR storage tank should be determined based on the number of cows being milked, ensuring it can supply sufficient hot water for a single milking session [6]. A cross-sectional view of an RHR unit is illustrated in [Fig 2.12](#).

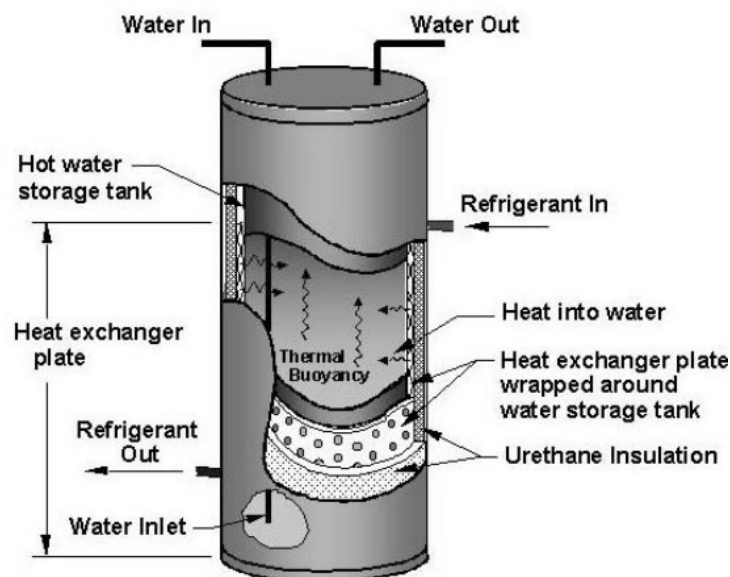


Fig 2.12: Cross-sectional View of RHR unit [29]



The RHR unit consists of a water storage tank and a heat exchanger. The heat exchanger may be either independent of the water tank or integrated into the tank's jacket, covered with insulation and a protective shell. The refrigerant gas can attain temperatures exceeding 93°C when entering the RHR heat exchanger based on ambient conditions. It exits the tank 24–30°C lower after transferring the refrigerant heat to the water. An air-cooled (occasionally water-cooled) condenser unit is connected in series with the RHR heat exchanger to eliminate any remaining heat from the refrigerant before it cycles through the evaporator to begin a new cycle. [29]

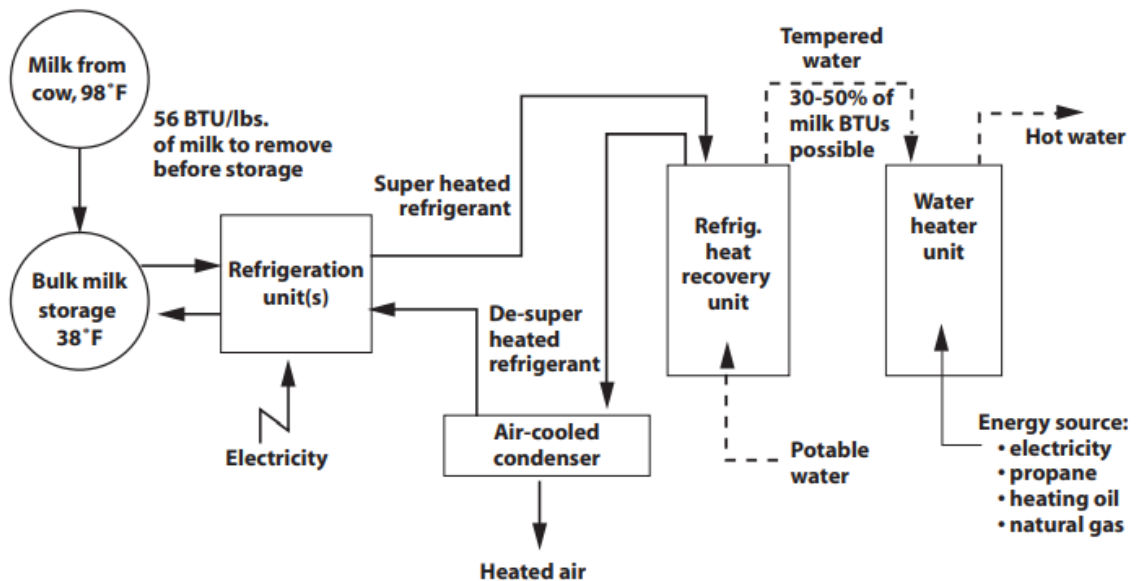


Fig 2.13: Energy Flows in Cooling unit with RHR installed [29]

There are two basic types of heat recovery systems, known as desuperheating and fully condensing units. As per a factsheet from Farm Energy Nova Scotia, desuperheaters consist of a small heat exchanger with refrigerant on one side and water from the water storage tank on the other. Desuperheaters are located outside of the hot water storage tank [30]. A desuperheater unit heats water to a temperature of around 35°C to 47°C and runs only when the refrigeration system is operating [6]. These units can be inexpensive to add but can recover and transfer only a portion of the available heat to the water.

Condensing units are made of a heat exchanger jacket inside a water storage tank. These units can pre-heat water to about 55°C, which may need to be heated to the required wash temperature [30]. The condensing units recover nearly all of the available refrigeration, with temperatures reaching 48°C to 60°C. A fully condensing RHR unit eliminates the need for a regular condenser used in the refrigeration system. If nearly all of the energy captured by the RHR unit is used for pre-heating water, then a pre-cooler is not needed to remove heat from the milk and may, in fact, increase overall energy costs. [6]

The RHR unit should be sized properly to reap benefits from its installation. The RHR storage tank should be sufficiently large to fulfill all the hot water requirements for a single milking session to optimize waste heat recovery. For larger farms, incorporating two or more RHR storage tanks can be beneficial. Alternatively, farms needing additional storage volume can install an insulated storage tank alongside the RHR unit, connecting the tank drains and plumbing the outlets at the top together. [29]

#### **2.2.4 Compressors**

Compressors are an essential component of cooling systems used to compress the cold, low-pressure refrigerant gas supplied from the evaporator to a high-pressure, high-temperature state for condensing. The types of refrigeration compressors used for milk cooling on most dairy farms are reciprocating and scroll compressors. Among these, the reciprocating compressor is most commonly used in dairy farms. [6]

A reciprocating compressor is a positive displacement machine operating with one or more single-action pistons. These pistons, driven by a piston rod connected to a crankshaft, reciprocate within cylinders. A scroll compressor is a rotary positive displacement machine that operates with two scrolls. One scroll remains fixed, while the other is positioned 180° from the first, moving around a fixed point on the stationary scroll. As the scroll compressor operates in a rotary motion with few moving parts and no intake or discharge valves, it has lower vibration and noise level than a reciprocating compressor. The scroll compressors are newer and more efficient than reciprocating compressors. Replacing the reciprocating compressors with scroll compressors can reduce milk cooling electricity demand by 20%. Efficiency, compactness, lightweight design, and low sound and vibration levels are all qualities that make them a practical option to be used in dairy farms when compared to reciprocating compressors. [31]

While scroll compressors are costlier than reciprocating to invest in, the energy efficiency of these compressors makes them a practical choice for energy optimization measures to be implemented in dairy farms.

### **2.3 Pumps**

The vacuum pump is one of the largest energy users on a dairy farm. Vacuum pumps are used to draw milk and power washing equipment on dairy farms. It is estimated that vacuum pumps are responsible for up to 25% of all the electricity used to operate a dairy farm. [32]

Vacuum pumps create the negative pressure that helps draw the milk from cows and then transport the milk from the milk receiver to either the receiver bowl or the bulk tank [32]. The airflow created by vacuum pumps also transports water and cleaning solution through the milking system when it is being cleaned. Traditionally, milking systems have achieved stable control of vacuum levels by bleeding air into the vacuum lines whenever vacuum levels exceeded the setpoint [33]. This resulted in the vacuum pumps operating at a full load of 100%, regardless of the actual vacuum used by the milking equipment. This rudimentary but effective method does a fine job of controlling vacuum levels but is not very energy efficient [34]. Additionally, it is common that the vacuum pump in milking systems is considerably oversized, particularly as modern milking equipment generally demands a reduced vacuum capacity to operate [33].

A solution to the problem of vacuum and energy waste is to vary the vacuum being created by the pump such that it matches the demand of vacuum on the pump. This can be achieved by installing a VSD or variable frequency drive, to the motor of the vacuum pump which adapts its speed according to the vacuum demand, generating more or less vacuum as necessary. A sensor (pressure transducer) is installed in the vacuum line to enable the variable speed drive to align with the vacuum demand, as depicted in [Fig 2.14](#). This demand fluctuates significantly across standby, milking, and cleaning loads, with cleaning cycles often presenting the periods of highest demand and shortest duration. [35]

The vacuum regulation on pumps with VSDs is equal to or better than conventionally regulated vacuum systems. Many styles of vacuum pumps can be found on dairy farms; VSDs work best if using a blower- or lobe- type vacuum pump. Other types of vacuum pumps (oil ring or vane pumps) may be less effective owing to the limits of speed at which they can operate effectively. Although it is possible to retrofit a VSD to a vane pump, the practical limit on their capacity is such that less energy savings will be made. If a farm is milking 3 times per day or more than 6 hours per day, the investment in the variable speed controller will typically pay for itself in less than 5 years. [33][35]



Fig 2.14: Pump with VSD and Pressure Sensor [36]

Conventional vacuum pumps run only at maximum speed and depend on a vacuum regulator to remove the excess air from the system that is not being used during milking or washing operations [6]. Installing a VSD on a vacuum pump eliminates the need for a vacuum regulator as less energy is delivered to the motor, and its operating speeds are reduced. Potential savings on electrical usage by installing VSDs can be on average of 50% but ranges from 30% to 80% can be achieved [33].

### **2.3.1 Size of vacuum pumps**

The size of the vacuum pump matters, as oversized pumps use more energy and are a waste of investment. Matching the pump size to the needs of the milking and washing system is essential. This can not only cut down the initial equipment investment but also decrease operational and maintenance costs over the pump's life cycle, ensuring maximum performance. [32]

The vacuum pump's size is dependent on all the components in the system that admit air during operation. Pumps are typically sized by considering the volume of air admitted into the milking system during the milk collection, along with a 50 percent reserve to account for the wear and tear of parts and accidental overload. In the past, industry standards incorrectly advocated for larger pumps under the mistaken belief that they were necessary to account for washing. However, an excessively large pump can lead to overheating toward the end of its cycle. [6][32]

Therefore, it is important to install a properly sized pump in the dairy farm after an evaluation of pumping requirements, which would save energy costs as well as investment costs.

The energy savings and other advantages that can be obtained from installation of VSDs are significant. However, there are a few of the disadvantages associated with VSDs. The applications and limitations of VSDs are presented in [section 2.3.2](#).

### **2.3.2 Application and Limitations of VSDs**

For installing VSDs on farms, certain factors, such as farm size, type of vacuum pump, milking time, and unit, must be considered. If the farm size is small or milking units are fewer in number, the investment will take many years to pay back. These factors determine whether VSDs can be used and their limitations.

The application and limitations of VSDs are: [37]

- Installing a VSD vacuum pump may be a suitable option only on farms with long enough milking times or if the installed vacuum pump is oversized.

- Blower or lobe type of vacuum pumps are the only suitable pumps for installing a VSD (they can be installed on rotary vane pumps only if a minimum rpm is programmed in to prevent overheating).
- Using three-phase current is suitable for VSDs. If the existing motor on the pump is single-phase, switching to a three-phase motor can increase the cost and payback, limiting the application of VSD for smaller farms.
- The VSD is sensitive to dusty and damp conditions, which can be damaged by lightning strikes. It should be installed in an area which is dry, dust-free, and warm in winter with proper grounding.

It is essential to consider these factors before installing the VSDs in the dairy farm to ensure optimum savings and optimum use of the equipment.

## 2.4 Lighting

Appropriate and energy-efficient lighting plays a prominent role in dairy performance. It can increase milk productivity and improve working conditions, making it a safer and more productive workplace for employees [37]. Factors that contribute to increased milk production include the type of light, the amount of light provided per watt, the temperature of the work area, the height of the ceilings, and the length of the lighting period. [6]

Lighting on dairy farms, on average, consumes about 15-17% of the farm's electricity consumption. This can be reduced by using modern energy-efficient lamps and motion detectors in lighting systems. In [Tables 2.1](#) and [2.2](#), a comparison of different types of lights in a dairy stable is presented. For comparison, the fundamental parameters considered are 120 cow places, approx. 1,360m<sup>2</sup> barn area, 120 lux, 1,825 operating hours, 5 hours/day.

Table 2.1: Energy comparison between different lamps [38]

	Unit	Fluorescent Lamp	Metal halide lamps	LED Spotlight
El. Connected load	[W]	58	250	100
Light output	[lm/W]	85	140	100
Quantity	n	72	12	14
Total Power	[W]	4176	3,000	1,400

	Unit	Fluorescent Lamp	Metal halide lamps	LED Spotlight
Power/area	[W/m <sup>2</sup> ]	3.1	2.2	1
Acquisition costs/ lamp	[€]	40	340	700
Total acquisition costs	[€]	2,880	4,080	9,800

Table 2.2: Cost comparison between different lamps [38]

	Unit	Fluorescent Lamp	Metal halide lamps	LED Spotlight
Average Life span	[h]	20,000	30,000	60,000
Replacement time	[a]	11	16	33
Cost	[€/a]	342	360	568
Energy consumption	[kWh/a]	7,621	5,475	2,555
Electricity price	[€/kWh]	0.22	0.22	0.22
Energy costs	[€/a]	1.677	1.205	562
Total Cost	[€/a]	2,019	1,565	1,130

From the data in Tables [2.1](#) and [2.2](#), it can be clearly observed that both operation costs and energy savings can be made by installing LED lamps in the barns. The initial investment is high for LED lamps, but this can be recovered within a few years as the operating costs per year are very low. Therefore, installing LED lamps is ideal measure for optimizing the energy usage in dairy farms.

## 2.5 Cleaning

Cleaning, washing and disinfection of milking systems are vital processes in dairy farms to help maintain the quality of the milk produced. Cleaning and washing of the milking equipment and cooling tanks are carried out after each milking operation [31]. Cleaning and washing of milking systems and barns are significant energy consumers on dairy farms. Energy consumption varies from farm to farm as it depends on the type of cleaning system used on farms. On average, it consumes about 15% of energy used on farms [4]. Hot water is an essential part of the cleaning process used on farms. A large portion of hot water is used for cleaning and sanitizing the milking system since washing typically consists of three or four cycles. The standard cleaning procedure includes a pre-rinse with

warm water (35-45°C), an application of a combined alkaline detergent and disinfectant (lasting 8-10 minutes), followed by a post-rinse with cold water [39]. A similar procedure is used with an acid solution, either once or twice a week or once a day, depending on the water hardness. For fat not to redeposit on milk contact surfaces, a water temperature of 43°C should be maintained at the end of the cycle [31].

In some farms, most of the cleaning process is generally done without dismantling the equipment, known as CIP. There are different types of CIP cleaning processes employed on farms, which are circulation cleaning, boiling water cleaning and batch cleaning [40]. The most widely used among these is the circulation cleaning system [41].

In circulation cleaning, the cleaning solution (water + cleaning and disinfectant) flows through the system several times [40]. Circulation cleaning is a three-stage process that involves a pre-rinse with water to remove any milk residue, main rinse at approx. 55 °C with alternating alkaline and acidic cleaning agents and disinfectants, and a concluding cold-water rinse to remove cleaning and disinfectant residues [41].

Batch cleaning involves a circulation cleaning process, with the distinct feature that the rinse water is collected and utilized for the subsequent pre-rinse. [40]

Boiling water cleaning involves generating a supply of hot water, which is then pumped once through the milking lines for the cleaning process. The rinsing process eliminates milk residues, and the disinfection is accomplished by maintaining the cleaning water at a temperature of 77°C for a minimum of two minutes. If the water is particularly calcareous, it is necessary to prevent limescale deposits by temporarily adding acid. [41]

To effectively clean all components in the system that come into contact with milk, it is crucial for the water or cleaning solution to pass through the milk pipe system and connected elements (such as milking clusters) with sufficient turbulence. During the cleaning process, a flushing seal must be created in the milk pipe system, and factors such as the air flow rate of the vacuum pump play a role in determining this blockage. [40]

All the cleaning processes require significant energy to operate, such as vacuum supply for turbulence and hot water for cleaning. A properly sized wash system, which minimizes air admissions and uses a warm pre-rinse (37–43°C), can wash the milking system effectively without needing excessively high-water temperature. Excessive flow rates can be reduced, effectively minimizing water reserve needs and lowering energy and costs needed for pumping. Additionally, oversized milk lines contribute to an increased demand for hot water during washing. Every 1-inch increase in milk line size approximately doubles the

hot water needed for washing. Therefore, properly sizing a cleaning system is vital to optimize energy without wasting energy. [42]

Monitoring the temperature of wash water during parlor clean-up can effectively reduce hot water consumption. Using cold water is sufficient for the initial coarse washing of the parlor, and incorporating a high-pressure, low-volume power washer can contribute to further reductions in water usage and clean-up time and, thus, energy use. In cases where warm water is required, utilizing water directly from an RHR unit rather than the water heater proves to be an energy-saving measure. All these measures are opportunities for optimization of energy in water heating and cleaning operations of dairy farms. [42]

### **2.5.1 Water heating**

Hot water plays a crucial role in ensuring the production of high-quality milk on dairy farms. It is used for the purpose of cleaning milking systems, bulk tanks, and parlor equipment, and feeding cows, and washing towels [42]. The quantity of hot water needed varies across farms, depending upon factors such as the size of the milking herd and the type and scale of the milking system in use. Typically, hot water is generated by water heaters utilizing fuel oil, natural or propane gas, solar energy, or electricity [6][31]. On average, a minimum of 15 liters of water at 75°C is necessary for each milking unit [6]. Approximately 14 liters of hot water are needed per cow in tie stall operations, and this requirement increases to about 17 liters for free stall operations. The amount of energy used for water heating is impacted by both the quantity of water used and the temperature to which the water is heated [42]. In some instances, heating water can constitute approximately 25 percent of the total energy consumption on a dairy farm [42].

The optimum temperature for hot water is about 74°C; heating water above this temperature is usually not necessary and can waste energy [42]. By using warm or cold water instead of hot water, when possible, energy consumption can be optimized. A warm-water pre-rinse, about 35 to 43 degrees, does not cause the milk to stick to the equipment, which is a problem with cold water. Additionally, a warm water rinse prevents the occurrence of mineral and protein deposits in the pipeline, which is frequently encountered when using hot water. [6]

There are several methods to decrease the energy consumption involved in heating water. In a direct water heater, the water storage tank and heating element are integrated, while in an indirect water heater, the storage tank contains a heat exchanger connected to a separate boiler unit. Regardless of the type of water heater in use, be it direct or indirect, the overall efficiency is impacted by the combustion efficiency of the fuel source and the extent of heat loss from the storage tank, referred to as standby loss. [6]



Standby losses occur when the heat within the water is conducted out through the walls of the water heater or when thermo-siphoning causes water to move up the pipes above the water heater, leading to the conduction of heat into the surrounding environment [42]. There are various measures to minimize standby losses in a water heater. If the water heater has an R-value (resistance to heat conduction) of less than 16 and is located in a dry spot, it can be insulated with fiberglass insulation. Electric water heaters can be insulated on the top and sides, whereas gas and oil water heaters are typically insulated only on the sides. An estimated reduction of 4% to 9% in electricity demand for water heaters is possible by insulating water heater tanks [43]. Alternatively, tankless (on-demand or instant) water heaters, which require less electricity than conventional heaters, can be used [43]. Heat can be maintained in pipes leaving the water heater by installing foam insulation and a heat trap on the hot water pipe leaving the water heater [42]. This decreases thermosiphoning of hot water from the water heater, resulting in reduced losses and energy use for heating. Additionally, insulating water pipes extending from the water heater to the final usage point helps in preserving water temperature before reaching its intended use.

## 2.6 Feed system

Feeding cows on dairy farms is a significant energy-consuming process requiring about 15% of farms' electrical energy consumption. Feeding carried out with semi-automatic system is referred to as CFS, or fully automated system is referred to as AFS.

CFS uses a diesel driven tractor operated mixing ration wagon to feed the cows. In studies conducted on CFS, the feed system has a certain level of mechanization in feeding fodder to cows, like using a feed robot and wagon driven by a tractor diesel engine [44][45]. AFS uses an automatic system equipped with stationary feeding hoppers, a mixing unit, and a distribution wagon operating on the rail.

In AFS, several technical approaches have been devised for the automated feeding of cattle, and these can be categorized into three distinct stages of automation [Fig 2.15](#). The stages are: [45][46]

1. Mixing and distribution (semi-automated)
2. Filling mixer, mixing and distribution (semi-automated)
3. Unloading and transport, filling mixer, mixing and distribution (fully automated)

In stage 1, a stationary feed mixer must be filled by mobile equipment from bunker silos. The advantage of this variant is that cows can be fed automatically several times a day, but

filling the feed mixer still requires time, and filling silos is carried out with manual labor using a tractor and a bucket. [44][46]

In stage 2, the filling of the mixer is also automated, and farmers do not need to worry about fixed mixing and feeding times. Except for the transport and unloading of fodder, the system is automated for all other feeding system operations. [44][46]

Stage 3 is the complete automation of the feeding system from storage transport to feeding the cows. This technology is very costly to invest in and energy-intensive compared to the other two semi-automated systems. [44][46]

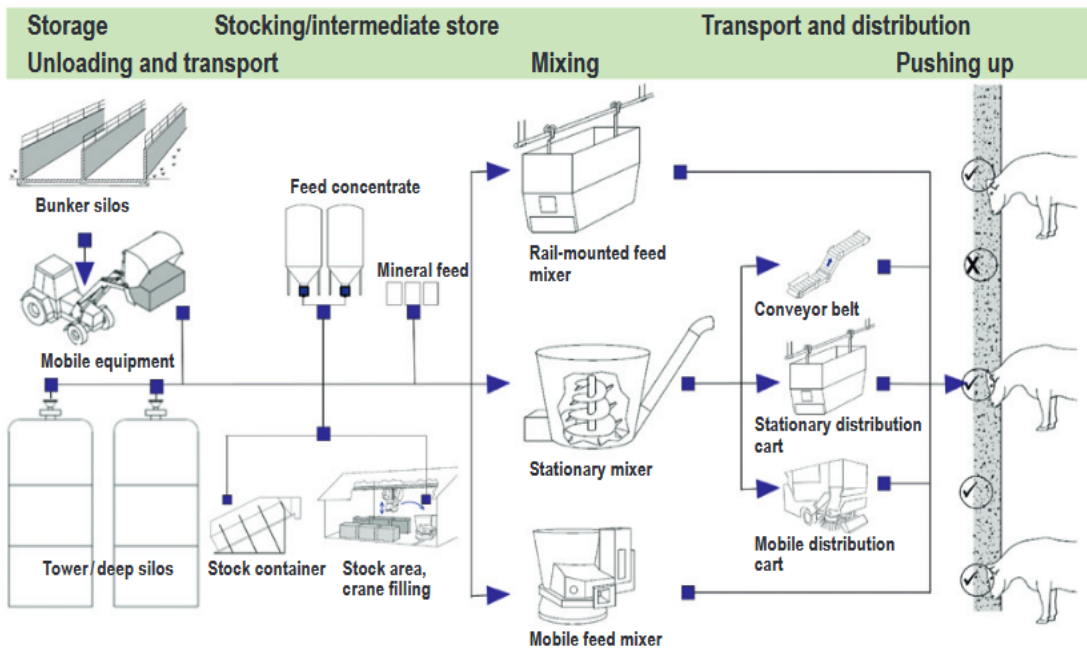


Fig 2.15: Techniques in realizing the stages of automation in feeding system [46]



Fig 2.16: A rail-mounted AFS in a Dairy farm [47]

As per the study conducted by Oberschätzl on farms with different stages of AFS installed in Bavaria, Germany, the transport of fodder from the stock container to the mixer process and mixing the rations are the most significant energy consumers of AFS in the dairy farms with a share of 77 % of the energy consumption of the whole feeding system. The transport of fodder from underground silos in dairy farm 3 reveals a high energy consumption of 34.5 kWh per day. They concluded that the texture of feed components influences the required energy consumption for transporting fodder to the mixer and mixing the rations. Their conclusion indicates that the texture of feed components plays a significant role in determining the energy consumption needed for transporting fodder to the mixer and mixing rations. Additionally, the results pertaining to the consumption of transport, distribution, and pushing of feed indicate that factors such as the number of animals to be fed, the quantity of the ration, the frequency of mixing rations, and the distance between the feeding hall and the barn significantly influence the required energy consumption. In their study of four dairy barns employing semi-automated and fully automated feed mixing and feeding systems, the daily electrical energy consumption was found to be 8.8 kWh with the semi-automated system, and up to 52.6 kWh for the fully automated system. [48]

Compared of CFS and AFS, according to Tangorra, AFS has the potential to result in lower energy costs for cattle feeding. According to a study outlined in their report, daily energy consumption, which takes into account installed power and operation times, is reduced by 70% for an AFS when compared to a CFS. Tangorra conducted their own study comparing the energy and labor utilization in CFS and AFS farms in Italy. The findings from their research indicated a significant reduction in both energy consumption and manual labor when transitioning to an AFS as opposed to a CFS. Transitioning from a CFS with a tractor and trailed TMR wagon to an AFS led to substantial reductions, including a 97% decrease in energy consumption and a 79% cut in labor requirements. [49]

From these findings, it becomes evident that the adoption of an Automated Feeding System presents an opportunity to optimize energy utilization in dairy farming. This is particularly significant in feeding systems where conventional methods tend to require substantial energy. However, it is also evident that using an AFS requires high investment as well as high energy consumption. Therefore, depending on the size and requirements of farms, adopting an AFS with stage 1 or stage 2 automation of feeding systems would be ideal for optimizing energy consumption in feeding systems.

## 2.7 Load Management

This section presents how load management and scheduling the different farm tasks can help manage the grid load and energy load, optimize energy generated on farms, and reduce energy costs.

The aim of load management is to coordinate the timing of electricity procurement and power consumption in such a way that the maximum power is as low as possible and the load curve runs as even as possible. Load management does not necessarily reduce electricity consumption, but it does reduce electricity costs. [50]

Given the constant rise in energy costs for farmers and the decreasing compensation rates (feed-in tariff) for solar power, prioritizing the self-consumption of electricity generated on the farm becomes sensible from an economic and ecological point of view. This trend of self-consumption is expected to continue growing in the future. Integrating self-generated electricity on farms requires precise planning, with detailed analysis of load profiles in specific consumption areas, both for new and existing systems. This approach enables the delay of power peaks, promoting a well-coordinated load management between energy production and demand. Using this approach, power peaks can be postponed in order to achieve load management that is coordinated between energy production and energy demand. [4]

### 2.7.1 Load Shifting

Managing schedules by shifting peak energy demand to optimize energy generation and consumption of energy during peak generation hours helps reduce load on the grid as well as on farm energy generators. This also helps in reducing energy costs greatly as more self-generated energy can be consumed and less from the grid. An electricity load profile of a farm during a winter day in Germany is illustrated in [Fig 2.17](#). The cooling process used in this case is direct cooling of milk and herringbone parlor for milking in a 2x8 configuration, with 2 times milking in the day and 120 milking cows.

From [Fig 2.17](#), it can be observed that the peak demand is during the morning time from 5:30 am to 9:00 am and late afternoon from 03:00 pm to 06:00 pm when milking is generally done at farms. These peaks are due to milking and subsequent cooling of the milk at those times, followed by cleaning. However, with this type of approach the energy costs would be significantly higher as the energy consumption is during peak demand time of the day, when the electricity costs in Germany are typically higher than during non-peak hours, as illustrated in [Fig 2.19](#). Tasks like milk cooling can be shifted to low demand and

low tariff times of the day if ice bank cooling system (as depicted in Fig 2.18) is used as ice can be prepared and stored, during night when tariff is low [4].

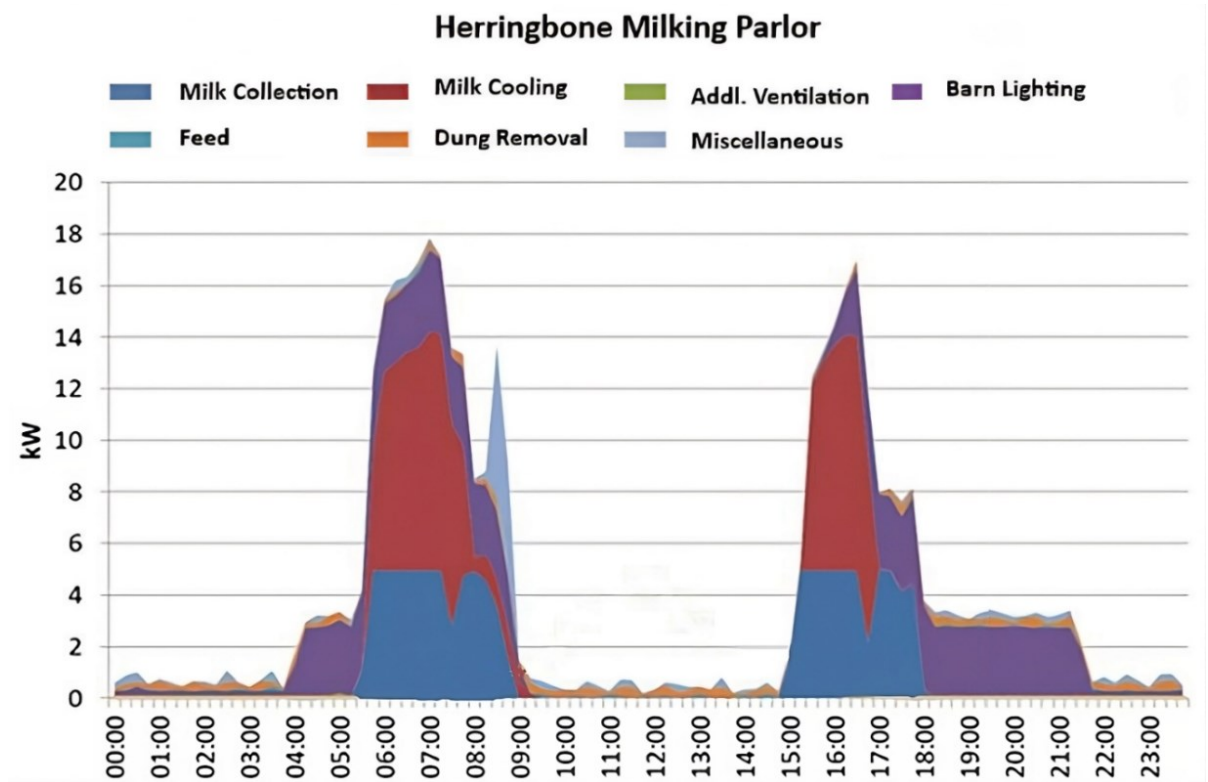


Fig 2.17: Daily load profile of a farm in Germany with direct cooling in winter [51]

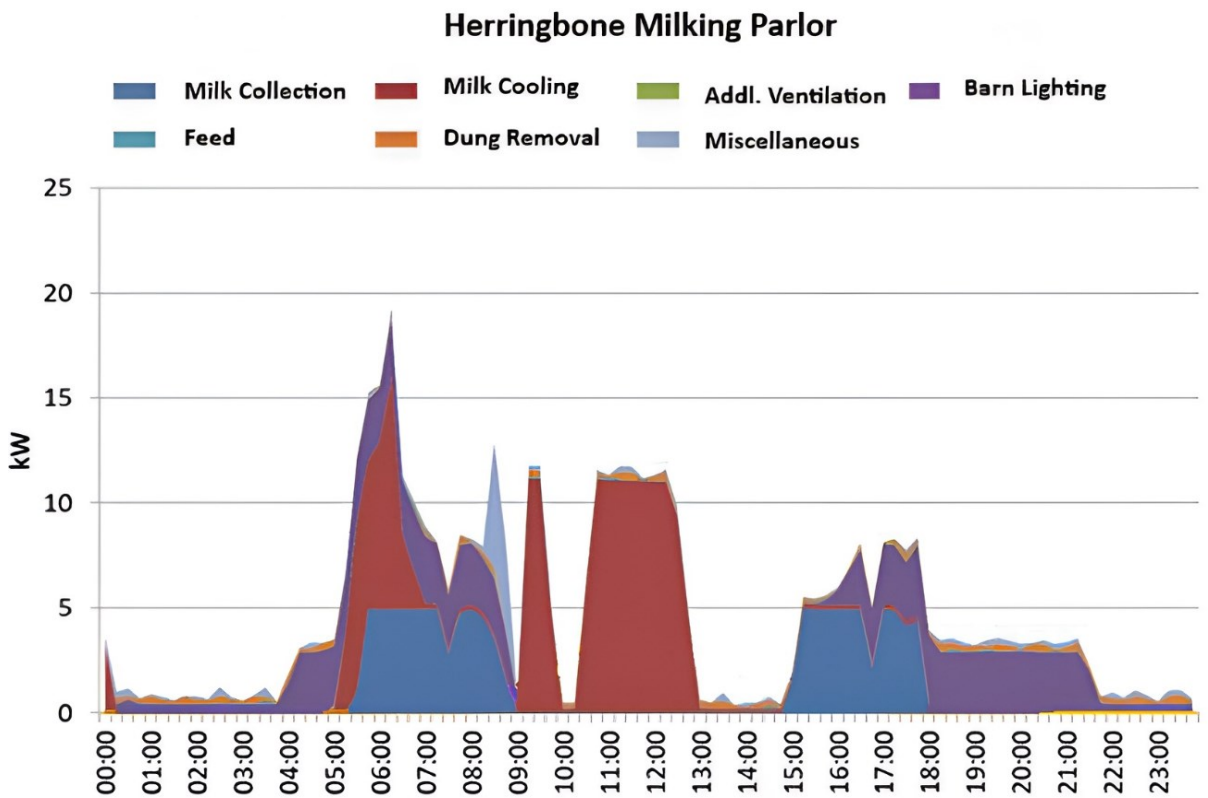


Fig 2.18: Daily load profile of a farm in Germany with ice bank cooling in winter [51]

As evident from [Fig 2.18](#), the energy demand is somewhat distributed, and lower peaks can be observed during peak demand hours. It is also evident that some of the cooling demand is shifted to daytime hours, which can be helpful if there is a self-energy generation plant like PV. However, the nighttime off peak tariff is not used in this case for the creation of ice bank. Shifting the cooling demand of ice bank formation to night time helps in utilizing the night time off-peak tariff to the maximum extent possible, save energy costs and prevent short term peaks and reduce load on the grid electricity.

Many electricity suppliers offer off-peak tariffs. Electricity consumption is charged at different prices depending on the time of day (HT - high tariff time and NT -low tariff time). Contracts for electricity consumption of significantly more than 100,000kWh/year usually already include a differentiation between HT and NT. Consistent electricity consumption throughout the year is better for the utilization of power plants and grids and consequently cheaper for the customer than a constantly fluctuating load profile with pronounced load peaks. [50]



Fig 2.19: Hourly Spot Market Price for Winter Day in Germany [52]

From observation of [Fig 2.19](#), it becomes apparent that energy prices tend to be higher during the morning and evening when there is increased demand during these periods. Therefore, by rearranging activities in the dairy operation, shifting them from peak-demand periods to times of lower demand, both energy costs and the stress on the grid can be reduced, and grid stability can be ensured.

## 2.8 Energy Management System

An energy management system (EMS) is a computer-aided tool used by power system operators to monitor, control, and carry out optimal energy management. EMS helps in the optimization of energy consumption to conserve use and decrease energy costs [53].

EMS in the context of dairy farms can be used to monitor, control and measure energy consumption and generation from renewable energy sources and help optimize the energy use and reduce energy related costs.

EMS offers various possibilities in dairy farms, helping to optimize energy use, reduce energy costs, and improve sustainability. Below are different possibilities for EMS in dairy farms:

1. **Monitoring and Control of Farm Equipment:** EMS can continuously monitor the performance of various energy-intensive equipment such as milking machines, cooling systems, and lighting systems. It can adjust settings to optimize energy usage based on real-time data obtained from sensors and weather conditions [54].
2. **Load Management:** EMS can manage the timing of energy-intensive processes like ice generation for milk cooling to avoid peak demand periods, which can lead to lower energy consumption from grid electricity and use solar PV energy during day time [55].
3. **Renewable Energy Integration:** For farms with renewable energy sources like PV, biogas, or wind turbines, EMS can control and optimize the use of this clean energy, ensuring it is used efficiently and stored when excess energy is generated [55].
4. **Lighting:** Efficient lighting systems can be managed by EMS to ensure that lights are only on when necessary, using occupancy sensors or time-based schedules.
5. **Energy Storage Management:** If the farm uses energy storage systems like batteries, EMS can manage the charging and discharging of batteries to optimize energy use and reduce grid dependency [2].
6. **Predictive Maintenance:** EMS can predict when equipment requires maintenance based on usage patterns and sensor data. This helps prevent unexpected breakdowns, reducing downtime and energy waste [3].
7. **Data Analysis:** EMS can collect and analyze large amounts of data, providing insights into energy consumption patterns. This data can be used for making long-term energy management strategies and investment decisions [3].
8. **Regulatory Compliance and Reporting:** EMS can assist in meeting regulatory requirements by tracking and reporting energy consumption data for compliance with energy efficiency standards like ISO 50001.

EMS in dairy farms is a versatile tool that can be customized to meet the specific needs of each farm, helping to improve efficiency, reduce costs, enhance environmental sustainability, and ensure regulatory compliance with energy regulations.

### **2.8.1 EMS in Logistics and Transportation:**

EMS in logistics can help in the selection of the proper transportation methods and routes, carry out load optimizations, the use of fuel-efficient vehicles, and the adoption of clean

fuels [56]. Emissions from road transportation activities result in around 15% of global CO<sub>2</sub> emissions. Implementing EMS can help in reduction of transportation cost as well as reduce emissions by proper capacity utilization and fuel-efficient vehicles, and thus help in addressing global warming. Logistics operations are energy-intensive and have a negative influence on the environment [57]. Implementing energy efficiency measures in logistics is crucial for reducing emissions to achieve environmental sustainability, and one of the approaches to realize energy efficiency in logistics operations is to maximize capacity utilization.

To improve energy efficiency in warehousing operations of logistics, installing energy-efficient electrical lighting system, control devices, and monitoring energy consumption for heating, cooling, ventilation, and freezing can result in energy consumption reductions of up to 20%. Importantly, the associated investments are relatively low and can be recovered in a short time frame. [58]

### **2.8.2 EMS in Manufacturing Industries:**

Manufacturing Industries overall have been reluctant to adopt energy management systems due to misconceptions like high investment costs, low production rates, long payback period for investment in energy efficiency [59]. Also, the lack of government regulations, and tax reductions and incentives aggravate these perceptions. However, in recent years the adoption of EMS is steadily increasing owing to tax rebates, higher benefits, sustainability, and government norms and introduction of EMS standards like ISO 50001.

There are several benefits that manufacturers in recent years have benefited from implementing EMS standards. Experience in various industries has demonstrated that companies can achieve savings of roughly 10-30% in their annual energy consumption and cost reduction by implementing improved energy management practices, often through simple operational changes. Through the implementation of an EMS to enhance energy performance, companies can simultaneously optimize their industrial systems and enhance the monitoring of system efficiencies. The resulting productivity gains for companies utilizing an EMS may encompass improved production and capacity utilization, reduced resource consumption and environmental impact, and decreased operational and maintenance (O&M) expenses. These advantages collectively lead to increased value generation, bolstering the company's competitiveness. [60]

A case study of iron and steel industry of ArcelorMittal Saldanha Works by Mac Nulty, illustrates that by adopting an EMS, ArcelorMittal saved around USD 13.5 million in 2011 with a capital investment of just USD 70,500. This translated to a 5.3% decrease in the



average energy demand when compared to the 2010 baseline figures. The company recovered its investment in less than four production days. Furthermore, even without additional energy efficiency enhancements and assuming all plant conditions remain constant, the savings achieved in 2011 would amount to approximately USD 51 million by 2016, five years after the initial investment. The 12 measures undertaken to achieve these savings included simple operational changes, such as switching off post-combustion cooling radial fans when not in use, increasing the temperature of the cooling water system in the melt shop, and switching off burners at ladle stations when not required, amongst other similar measures. [60]

The case study illustrates that simple operational changes and behavioral changes can amount to significant energy and cost savings, and environmental impact. Thus, industries are adopting the EMS more and more as they understand the enormous cost benefits and reduction in carbon footprint.

### **2.8.3 Regulations for Energy Management in Germany:**

There are several steps announced as well as rules implemented in Germany for energy consumption and efficiency measures for small commercial and industrial enterprises.

As per the new draft Energy Efficiency Law (EnEfG), final energy consumption is to be reduced by at least 26.5 % by 2030 compared to 2008. Also, companies whose annual average total final energy consumption of >15 GWh are obligated to set up energy or environmental management systems. Additionally, there is an obligation to record and implement the potential for use of waste heat and other energy saving measures. [61]

According to the German Energy Services Act (EDL-G), energy audits in accordance with DIN EN 16247-1, must be conducted by non-SMEs (Small and Medium Scale Enterprises) at intervals of every four years. This is exempted if the enterprise has already implemented EMS and has been certified with DIN EN ISO 50001. [62]

### **2.8.4 ISO 50001 standard:**

The ISO 50001 is an international standard for energy management system was created in 2011 by the International Standards Organization. This standard is not restricted to any specific industry or field and can be used by a wide variety of organizations, authorities, and companies or establishments of all sizes, including SMEs. [63]

The basic approach of an ISO 50001 standard is a Plan-Do-Check-Act (PDCA) continual improvement framework cycle, as illustrated in [Fig 2.20](#).



Fig 2.20: EMS PDCA cycle [60]

- **Plan:** Conduct an energy review and establish the baseline, benchmark against similar sites, set objectives and targets, develop resources and action plans necessary to deliver results in accordance with the organization's energy policy. [60]
- **Do:** Implement the action plans. [60]
- **Check:** Monitor and measure processes, review the level of target achievement and the effectiveness of the EMS against the objective of the energy policy. [60]
- **Act:** Recognize achievements, take action to continually improve energy performance and the EMS, derive new objectives. [60]

#### 2.8.5 DIN EN 16247-1 standard:

This European standard provides a consistent and standardized framework for conducting energy audits in various industries. It defines specific criteria, operational procedures, and outcomes. Utilizing DIN EN 16247-1:2012 enables the assessment of the company's current energy situation, including energy input, usage, and flow. With this information, tailored recommendations can be generated to enhance energy efficiency and decrease energy consumption within the organization. [62]

#### 2.8.6 Tax Reductions and Exemptions:

The German government has over the years introduced various tax reductions and exemptions to encourage enterprises to implement energy savings and management systems. One of the measures is electricity tax peak equalization (SpaEfV), is provided to enterprises if they have ISO 50001 implemented, or they conduct energy audit as per DIN EN 16247-1 [62].

### **2.8.7 Artificial Intelligence in EMS:**

With the growth of digital technology, new technologies and opportunities have emerged which can be used to monitor and control energy consumption and generation. AI is one such technology which is being increasingly used in the management of energy systems.

AI is a set of computerized systems that performs tasks mainly revolving around human beings (perception, reasoning, interacting, and learning). Generally, AI focuses on developing intelligent machines and software. It has countless applications in complicated problems of all fields, particularly energy management. By using Artificial Intelligence, energy management can be achieved more automatically and intelligently without human intervention, whereas most energy systems are yet operated manually or at a basic level of automation. [64]

An EMS has a large amount of data, which can be analyzed using several techniques of Machine Learning (ML), a subfield of AI [65]. ML uses complex algorithms to solve challenging problems that are difficult to solve with traditional approaches [66]. Those techniques can generate a mathematical model of the underlying phenomenon using historical data, that can be used to predict the energy consumption, identify consumption patterns, automatically operate lighting, ventilation, heating and cooling systems, Short-Term Load Forecast [65].

Applying these techniques to historical energy consumption data contributes to the effective implementation of an EMS by allowing feedback related to energy consumption, and thus encouraging continuous improvement. Thus, it is possible to assist users in decision making and improve users' understanding of the factors that influence the expenditure on energy, such as the excessive use of air conditioners on hot days, heaters on cold winter days, or energy consumption from renewable sources helping in reducing energy costs [65].

AI models using various algorithms can help in forecasting and other energy management areas, but AI models need training and immense volume of data has to be gathered. For this purpose, big data systems and data mining can be used which enable the discovery of new functions and relationships, which determine the performance of artificial intelligence. Data mining also refines the information. Thus, AI is trained iteratively with more accurate data. Energy management can be further enhanced through advanced digital technologies like Internet of Things (IOT) and blockchain. IOT can help in storage of data and in connecting AI to other hardware and software devices and systems using the cloud technology and, the data can be accessed from anywhere using cloud technology. [67]

While AI has a lot of potential in enhancing the EMS it also has certain challenges such as ensuring data security, understanding the principles of AI technology, ensuring cybersecurity, refitting existing systems, and quantifying the relationship between AI integration and economic benefits [67]. Some other challenges include initial implementation costs, specialized training and skill development, interoperability, and compatibility with equipment and different AI systems [68].

### **2.8.8 Artificial Intelligence in Dairy Farms:**

AI used in dairy farming enables real-time insights into individual cow health and behavior, optimizing feed management and reproductive performance. Robotic milking systems driven by AI provide stress-free and voluntary milking experiences, leading to increased milk yields and overall herd health [68]. AI encompasses several technologies, including machine learning, deep learning, natural language processing, and data analytics, which can be applied in the dairy sector to improve farming practices significantly [68].

Use of ML methods enable applications such as real-time analysis of video images to identify cattle, measure body condition and temperature, and detect changes in feed topography to measure feed availability and intake. Changes in behavior can be detected as early warning alerts for diseases such as lameness or as an indication of oestrus. Such AI applications can mimic human reasoning and enhance human tasks. These predictive alerts on herd health can help farmers in advance about the decrease in milk yield and make decisions based on such data alerts [69].

Listed below are several vital roles AI can undertake in the context of dairy farming.

- **Precision Dairy Farming:** In dairy farming, one of the most significant applications of AI is precision dairy farming, which involves the individualized monitoring and management of cows. AI-driven sensors and smart devices are utilized to track various aspects of each cow's health and well-being. These sensors can continuously monitor vital signs such as heart rate, rumination activity, body temperature, and overall behavior. By analyzing this real-time data, AI algorithms can identify any deviations from normal patterns, alerting farmers to potential health issues at an early stage. Early detection of health problems enables prompt intervention, which decreases the risk of severe illnesses and minimizes veterinary expenditures. [68]
- **Fertility Management:** Maintaining a productive and sustainable herd is vital for dairy farmers, and reproductive efficiency plays a key role in achieving this goal. AI technologies play a pivotal role in optimizing fertility management by closely

monitoring each cow's reproductive cycle. AI-driven systems can analyze cow behavior and physiological data to pinpoint the most fertile period, thus optimizing breeding and insemination schedules. This precision in fertility management leads to improved conception rates and reduced calving intervals, ultimately resulting in higher reproductive success rates and increased milk production. [68]

- **Data-Driven Nutrition:** Nutrition plays a crucial role in dairy farming, exerting a substantial impact on the health of cows and their milk production. AI-powered data analytics enable the formulation of personalized and balanced diets for individual cows. The system considers factors such as the cow's age, breed, weight, milk yield, and overall health status. By fine-tuning the feeding strategies based on real-time data, AI ensures that each cow receives the precise amount of nutrients required, leading to optimized milk production and overall cow health. This data driven approach also minimizes feed wastage, promoting sustainable farming practices. [68]
- **Robotic Milking Systems:** AI-driven robotic milking systems have revolutionized the milking process on dairy farms. These automated milking machines are equipped with AI technologies to identify individual cows based on unique identifiers, such as RFID tags. The system adjusts milking settings according to each cow's preferences and physiological conditions, ensuring a stress-free and comfortable milking experience. Robotic milking systems allow cows to be milked at their preferred times, respecting their natural behavior and rhythms. This personalized approach to milking not only enhances cow welfare but also leads to increased milk yields, as cows produce more milk when they are at ease and comfortable during milking. [68]

Thus, with the help of AI the farmers can have huge benefits in terms of increased milk production, reduced costs for feed, milking, and veterinary expenses.

The AI technology can be implemented in dairy farms to enhance the overall dairy farm by ensuring optimization in various fields of farms as mentioned in above sections. In the field of AI in EMS of dairy farms it can enhance energy efficiency, help in greatly reducing the energy costs, improve the energy production and reduce energy wastage. This also has a multiplier effect on the overall finances of the farm and in reducing pollution and ensure sustainability.

# Chapter 3

This chapter includes the calculations regarding energy use and how with the use of different energy efficient equipment and measures like load management energy consumption can be reduced while not affecting the farm output i.e., milk production.

## Comparison and methodology of measures for Energy Optimization

### 3.1 Comparison of Conventional Milking System and AMS

Considering 100 cows on a farm, the energy consumption in a typical farm is calculated using an online calculator from KTBL based on sample data. The comparison of energy consumption in farms with conventional milking, automatic milking, and other modern equipment is presented in this section.

For comparison, using an online calculator from KTBL, annual electricity consumption of both milking systems with 100 cows and milk quantity of 8240kg/cow/year is presented in [Table 3.1](#).

Table 3.1: Comparison of Electricity consumption of Milking systems [70]

	Conventional Milking system	Automatic Milking System
Electricity Consumption [kWh/a]	7577	12000
Electricity Consumption [kWh/cow/a]	76	120

The energy consumption in AMS is considerably higher than the conventional milking systems. This is due to most of the process being automated, which requires significant energy to operate. With an average of 0.42 kWh/milking, the power consumption of the AMS is significantly higher than in conventional systems which require 0.28 kWh on average. According to study reported by Höhendinger, AMS consumes 42% higher energy consumption compared to a conventional milking system [17]. The data from [Table 3.1](#) also indicates that Automated Milking Systems (AMS) consume 37% more energy than conventional milking systems. Hence, it is optimum to use conventional milking systems

from the point of view of energy consumption if there is no problem of labor force at the dairy farms.

### 3.2 Comparison of cooling methods.

In the comparison of energy consumption of cooling processes, pre-cooling with direct cooling method is the most energy efficient. The ice bank cooling is the most energy intensive of the cooling methods as it is an indirect cooling method and there are losses through insulation during storage of ice.

Comparison of cooling methods is presented in this section and [Table 3.2](#). The comparison is based on energy consumption and the energy costs for the process of cooling per liter of milk.

Table 3.2: Comparison of Electricity consumption and Costs of different cooling methods [4]

	Electricity Consumption per kg of milk [Wh/kg]	Milk quantity per year [kg/a]	Electricity consumption per year [kWh/a]	Electricity costs per year [€/a]
Direct Cooling	20	1,000,000	20,000[a]	4,000
Ice water cooling	24	500,000	12,000[a]	2,400
	24	500,000	12,000[b]	1,560
				3960
Pre-cooling with direct cooling	10	1,000,000	10,000[a]	2,000
	2[c]		2,000[d]	100
				2,100

[a] Electricity price HT: 20 ct/kWh

[b] Electricity price NT: 13 ct/kWh

[c] Water Consumption in liter/kg milk

[d] Water consumption in m<sup>3</sup>/year

From the data presented in [Table 3.2](#), it is evident that precooling with direct cooling method saves up to 48% of energy in comparison with cooling only with direct and ice bank cooling method. Therefore, employing a direct cooling method, along with precooling and heat recovery, offers an opportunity to optimize the energy usage in milk cooling on dairy farms.

### 3.3 Comparison of farms with Precooling and RHR Units:

Precooling and RHR units are competing technologies of heat transfer process [29]. Depending on the size of the farm, it is practical to install either of the two technologies or both technologies to benefit in energy efficiency and costs [6]. In this section, a comparative overview is illustrated to understand which technology is beneficial in different farm sizes.

To compare the two technologies, an energy consumption analysis is carried out using the same set of variables for farm energy consumption. The energy consumption data is derived from the online calculator from KTBL. For calculations, cow milk yield of 8240kg/cow/year and energy consumption of heating water for milk tank is considered.

Table 3.3: Comparison of precooling and RHR units [70]

	Precooler only		RHR unit only		Precooler and RHR	
	100	300	100	150	100	300
Herd Size [n]	100	300	100	150	100	300
Annual Energy consumption for cooling [kWh/a]	6,302	12,604	12,999	25,997	7,253	14,506
Annual Energy Consumption for heating [kWh/a]	1,572	3,144	684	1,368	684	1,368
Combined Annual Energy consumption [kWh/a]	7874	15,748	13,683	27,365	7,937	15,874

The comparison of the cooling methods, installing the precooler only is a better option as is evident from [Table 3.3](#). The energy consumption from cooling load when only precooler is installed is 51.5% lower in comparison to no precooler installed. The combined energy consumption when only precooler is installed is little less when compared to when both precooler and RHR are installed. When RHR only is installed the combined energy consumption for either size of farms is significantly higher as the energy used for cooling of milk without a precooler is about 50% higher. That means that installing precooler is a better energy optimization option as well as cost savings on investments. However, the data considered for heating from this calculator is only for bulk tank cooling, which is not the whole water heating energy requirement.

According to Sanford, if all of the energy recovered by the RHR can be used for preheating water, then the installation of a precooler will increase overall energy costs because some



of the heat in the milk will be transferred to well water as opposed to being used for preheating water. In case of RHR unit not being used, then using a precooler must be considered by maximizing the cooling of the milk close to well water temperature. If both RHR and precooler are installed, then cooling of milk by the precooler only fraction of potential reduction of up to 6°C must be used as reducing to the potential would lead to increasing energy usage. [27]

As per study outlined in report by Pradhanang, installing an RHR unit is best suited to farms with milk production volume of less than 400,000 liters per day and installing both precooler and RHR unit is suitable for farms with milk production of above 400,000 liters per day. Another study presented in their report concluded that for small farms with 60 milking cows or lower, RHR unit was the practical choice for energy optimization and for large farms with cow size of 200 and 400, installing both precooler and RHR units is the best option for energy optimization. [31]

Therefore, depending on the farm size, the cooling and water heating requirements, the ambient temperature at farm locations are the variables that influence the energy consumption of these two technologies. Both these technologies are very suitable options for implementing energy optimization measures. Energy audit has to be carried out to decide which technology is suited for the dairy farm.

### 3.4 Comparison of Conventional and Vacuum pumps

The cost savings and energy savings of conventional vacuum pumps in comparison with speed controlled vacuum pumps is presented in [Table 3.4](#) below.

Table 3.4: Cost and Energy comparison for Vacuum pumps [71]

Metric	Unit	Conventional vacuum pump		Speed-controlled vacuum pump	
		2000 l/min, 5.5 kW		2000 l/min, 5.5 kW	
Price	[€]	4500		7300	
Milking duration/day	[h]	3	6	3	6
Fixed costs, maintenance, repair <sup>[a]</sup>	[€]	720	900	1168	1460
Electricity consumption/year <sup>[b]</sup>	[kWh]	6000	12000	3600	7200
Electricity costs/year <sup>[c]</sup>	[€]	1200	2400	720	1440
<b>Total costs/year</b>	<b>[€]</b>	<b>1920</b>	<b>3300</b>	<b>1888</b>	<b>2900</b>

*[a] 10% depreciation, 4% interest, 2% maintenance for conventional pumps and 12% depreciation, 4% interest, 4% maintenance for speed-controlled pumps.*

*[b] 40% savings through speed control*

*[c] Electricity price € 0.2/kWh*

From the comparison presented in [Table 3.4](#), it can be observed that the electrical energy savings are about 40% by using speed control in operation of vacuum pumps. That is a substantial savings in energy consumption. Even though the speed-controlled pump has purchase and maintenance costs around 60 percent higher, it achieves a total cost saving of approximately 2 percent with a daily running time of 3 hours. Extending the running time to 6 hours increases the savings to over 12 percent in the given calculation example. In the scenario of an electricity price increase from 2 to 22 cents per kWh, the total cost savings would be around 4 or 14 percent. [71]

### 3.5 Comparison of cleaning systems

The different cooling methods presented in [section 2.5](#) are compared in this section. The comparison focuses on assessing the effectiveness of cleaning methods in terms of energy, water, and chemical usage.

Table 3.5: Comparison of Cleaning Methods [4]

	Consumption of			Functional safety/ Ease of maintenance
	Electricity	Water	Chemicals	
Circulation Cleaning	Average	High	High	Good
Boiling water Cleaning	High	High	Very low	Very good
Tank rinsing	Very Low	Average	Average	Medium
Batch Cleaning	Low	Low	Low <sup>a</sup>	--

a: Very expensive cleaning agents to use.

Based on the energy consumption data presented in [Table 3.5](#), it can be observed that in the circulation cleaning method the energy consumption is not too high but water and chemical consumption is high. The boiling water cleaning method is the most energy intensive process among the compared methods. In comparison to other methods, as the energy consumption is not high, it is an optimum method to be considered for energy optimization measures.

To optimize the energy consumption in farms, the length of piping from the milk room to the parlor should be kept to a minimum to reduce cleaning water volume, heat loss during cleaning [31]. This reduces the need for heating more amount of water, which would otherwise lead to higher energy consumption. Among the cleaning methods, which variant of milking system cleaning is optimum for energy and cost savings can only be assessed if the size of the system, cable length and cross-sections and electricity tariffs are known [41].

### 3.6 Energy Management System in context of Dairy farms

The EMS can be used in dairy farms in different ways to optimize energy used in the farms and to optimize the energy produced using renewable energy sources on the farm. The EMS methodology is illustrated in the [Fig 3.1](#) below.

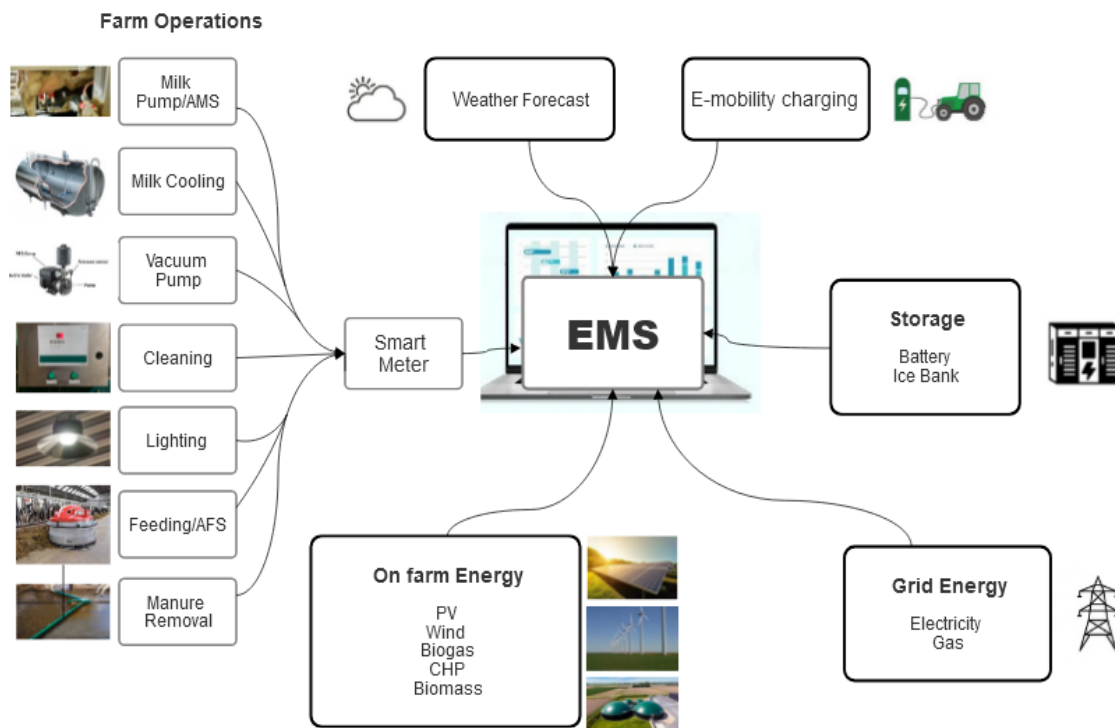


Fig 3.1: Schematic of EMS in dairy farm setup

As illustrated in [Fig 3.1](#), EMS has an autonomous central control unit which is connected to various equipment in the farm by the means of sensors and smart meters, which gather and process the data of energy consumed by the equipment. The EMS control unit is also connected to the grid and on farm energy generation equipment and energy storage systems like battery and ice bank storage if available. Weather forecast and historical data is fed into the EMS control unit, and it can predict the weather patterns and energy

generation possibilities and based on this it can communicate with the grid and decide when the energy from the grid is to be used and when the energy from the on-farm equipment or the energy storage systems to be used based on the availability.

The control unit is designed to decide the priority of each farm operation as to when an operation needs energy and if an operation can be postponed to a later time so that the higher priority operation can be fed energy. This is done by feeding the load profile data of each equipment and the flexibility of operations into the EMS, so as to achieve the highest possible energy efficiency and the load curve of the energy consumption is as flat as possible. The control unit tries to maximize the energy production and feed the energy to equipment on the farm to use on farm generated renewable energy as much as possible. EMS also communicates with the grid and uses the energy from the grid when energy from on farm energy generation and energy storage is not sufficient to meet the energy demand of the farm. Also, whenever there is excess energy generated which is not useful for the farm, it is fed into the grid using net metering. This communication with the grid also helps in stability of the grid.

The control unit can also communicate with the sensors that are installed on the equipment to detect any malfunction of devices and equipment and suggest corrective measures to users or can alert the users of the malfunction, thus helping in reducing the breakdown time.

### **3.6.1 Implementation cases of EMS in dairy farms**

There are many cases of EMS usage in different fields like industry, commercial buildings as Building EMS (BEMS), Facility EMS, or private households as Home EMS (HEMS) but use and study in the field of agriculture or livestock farming is not widespread. While the EMS use in farms has not been in large scale but some studies have been conducted and are being conducted to help know the technology as well as identify the problems to implement EMS in dairy farms. Some of these studies are discussed here.

In a study of EMS in dairy farms in Bavaria, Germany by Bernhardt, the study of EMS in automatic dairy farms was conducted which also included the Cow and her behavior as a part of the system and welfare of the cow was one of the central points of the study. The welfare of the cow was considered as the cows are the most important part of the farm which give milk and if the cows are well and feel good, the milk production is higher which is the ultimate purpose of the dairy farm. The study was conducted on automatic dairy barn with 125 dairy cows having two milking AMS, Robotic feeder to supply feed regularly to cows, automatic floor cleaner, and manure cleaning robot. Daily load profiles of all electrically operated machines were created by measurements on different dairy barns in

Bavaria. The data in time intervals of one minute was recorded, as some machines in the dairy barn work for only a few minutes. This was done to avoid missing any load peaks which otherwise would be missed if the time intervals of 15 minutes were used for recording. The farm had a PV system installed on the dairy farm. But this system was able to provide the energy only for electrically operated machines. Therefore, a biogas plant was planned for installation to provide energy during night or low sunny days. They observed that in case of short-term fluctuations it's even possible that EMS can provide more energy than only the surplus as single consumers can be timely shifted, and the excess energy can be sold with profit. The study found that energy from PV plant and biogas production was found to be sufficient for the farm needs. In this study, it was observed that the issue of communication of systems with each other is a significant problem faced in implementing the EMS as even the equipment from same manufacturer also are not able to communicate with each other. This study provides an insight into how to implement the EMS in dairy farms and the challenges and opportunities that exist. [54]

A study on implementation of ISO 50001 EMS in dairy farm was conducted in Ireland by Trubetskaya, which focuses on combining lean six sigma principles with EMS to achieve energy efficiency in the farms. The study focused on identifying the optimization possibilities in electrical as well as thermal energy needs of the farm. Their study estimated that using EMS can contribute to reduction in thermal energy use by 36% and CO<sub>2</sub> emissions by 46%. They also observed that the cost savings from this amounted to reduction in energy costs by 36%. From this study it can be concluded that implementing of EMS can contribute to significant energy demand, cost savings, and also contribute to the reduction in emissions, thus improving sustainability. [72]

From these studies, it can be observed that while there are significant challenges in implementing an EMS in dairy farms, the benefits can be high, encouraging the adoption of EMS. However, there needs to be more studies conducted to investigate the potential of EMS in optimization of energy consumption on dairy farms and cost savings for farmers.

### **3.6.2 Challenges in Implementation of EMS**

Implementing an EMS in dairy farms has several challenges like interoperability and compatibility of different systems on farms. These challenges are discussed below.

- **Communication with different equipment:** The communication of all technological systems involved is fundamental in EMS in order to be able to exchange current status data and necessary control variables with each other and the control unit [55]. The individual control systems are self-contained and often use proprietary systems. In some cases, even systems from the same manufacturer are unable to

communicate with each other. It is therefore often necessary to set up a parallel sensor and control system to enable communication with each other.

- **Specialized training:** EMS is a novel technology and has not been used widely, involves the use of computers and data sets, specialized training has to be provided to farmers and farm users to understand the components and functions of EMS.
- **Data integration and measurement:** EMS requires load demand, weather data, sensor data and other equipment data that needs to be measured or collected and fed into the system [54]. This can pose a challenge initially to have necessary measurement equipment and technology.
- **Data security:** As the control unit and other systems are connected to internet networks the risk of data theft and manipulation is high and therefore, robust data security measures need to be integrated while installing the EMS units.
- **High implementation costs:** Since the EMS involves installing the computer unit with servers and sensors and different electrical and electronic units, initial investment is very high [3]. This can be a challenge on small farms and has to be considered while planning for installation of EMS.
- **System Errors:** EMS can have detrimental effects on the functioning of the farm infrastructure if the bugs or systemic errors creep into the system which can have severe consequences, which may lead to power disruption in worst case scenario [3]. This can pose a significant challenge and hence resilient EMS systems have to be designed to prevent errors.

The implementation of EMS has many challenges as listed above. Therefore, it is important to review these challenges and seek solutions while implementing an EMS in dairy farms.

EMS is an effective solution to optimize the energy consumption in farms. As discussed in this section, the EMS has many advantages as well as challenges. It is important to compare and review them before implementing them in dairy farms.

## Chapter 4

### Discussion

The opportunities for optimizing energy are manifold across different areas of farms. The comparisons presented in chapter 3 help in understanding the benefits of implementing energy optimizing measures and use of energy management system. Here, in this chapter, the results of the comparisons are discussed, and what measure is useful for various types of farms is presented.

From the comparisons of [Chapter 3](#), the ideal case for different types of farms is presented here in [Table 4.1](#) below.

Table 4. 1: Ideal case scenario for Energy optimization measures

Measures	Farm with 20 cows	Farm with 50 cows	Farm with 100 cows	Farm with 150 cows and above
Milking systems	CMS	CMS	AMS	AMS
Cooling Method	Direct Cooling only	Direct Cooling with RHR	Direct Cooling with RHR	Direct Cooling with PC and RHR
Pump	Conventional Vacuum Pumps	VSD Pumps	VSD pumps	VSD pumps
Cleaning	Manual Cleaning	Circulation Cleaning	Circulation Cleaning	Circulation Cleaning
Feed system	Manual feeding	Level 1 automation	Level 1 or level 2 automation	Level 2 or level 3 automation

The ideal measures of energy optimization for different sizes of farms are presented in [Table 4.1](#). The scenario is presented based on the data presented in [Chapter 2](#) and [Chapter 3](#). These are based on theoretical assumptions and some practical considerations. The type of measures to be implemented for energy optimization in farms can be determined based on the farm size, location, investment potential, and other variables by calculations.

These measures can be implemented individually or combined based on each farm's requirements. The measures can also be implemented in combination with EMS to further enhance the energy efficiency of the farms. The use of EMS also reduces the work burden on the farmers and thus helps in efficient working conditions.



# Chapter 5

## Conclusion and future scope

The focus of this thesis was to identify the opportunities for energy optimization in German dairy farms. This is imminent as there is growing energy demand due to increased automation and depletion of energy resources and concerns on emissions due to energy use. To overcome these, the energy optimization in different areas of farm operations was studied. Even though there is wider adoption energy-efficient technologies in German dairy sector, there is still areas of improvement as presented in this work. As German dairy farms are increasingly adopting digital technologies to improve overall energy use, EMS as a tool of energy optimization is suggested.

There are various measures that can be implemented to optimize the energy use in dairy farms in Germany. Efficiency measures in milk cooling is identified as the biggest possible energy efficient measure that can be implemented on farms to reduce energy consumption. Vacuum pumps in the area of milk extraction and transport to milk tanks are also significant consumers of energy on farms, and the use of VSD on vacuum pumps can help reduce significant energy consumption. In the case of milking systems, the use of conventional milking parlors is the optimum method to extract the milk from cows they consume relatively lower energy in comparison to AMS. However, in large farms and in farms with labor shortage, the AMS can be implemented by using electrical drive-in place of pneumatic drives which reduces the energy consumption of air compressor.

In areas like cleaning, using optimum water temperatures and using cold water wherever possible can reduce the energy consumption for water heating. Also, properly sizing the milk lines can reduce hot water requirements thus reducing energy use. Using energy-efficient lighting like LEDs can reduce energy requirements by more than 50%. Feeding operations of the farm can be automated or semi-automated depending on farm sizes, which are energy efficient. Transitioning from CFS to an AFS system can save up to 97% of the energy used in the feeding system of farms. Also, the use of electric tractors in semi-automated farms can contribute to significant energy as well as emission reduction.

Along with the suggested measures, implementing an EMS was studied, which can help in significant reduction of energy use. EMS can also help in reducing the workload on the farm as most of the operations are automated. With features like weather prediction, real time monitoring of data, automated energy trading, and load management, EMS as a tool of

energy optimization can help farmers in reducing energy use and emissions and also contribute to the welfare of farm animals,

In this work, the potential for energy optimization in German dairy farms was studied and presented. It can be concluded that there is huge potential for energy optimization in German dairy farms.

Various case studies of EMS in farms have been conducted by different authors, which have been presented in this work. However, with the growing digital technologies and automation of farms, more studies need to be conducted to identify the true potential of EMS and its benefits for farmers and the overall agricultural economy. The emerging technologies like AI can be further integrated into EMS. The use of AI technologies like machine learning can help in optimizing the EMS technology by use of algorithms. Algorithms like NILM(non-intrusive load monitoring) can be integrated into the EMS system to identify and segregate various energy loads in the farm. Further research in these fields needs to be carried out to identify further optimization opportunities.

## References

- [1] Bundesinformationszentrums Landwirtschaft (BZL). "Die Milcherzeugung ist der ökonomisch wichtigste Zweig unserer Landwirtschaft: BZL." Accessed: Oct. 15, 2023. [Online]. Available: <https://www.landwirtschaft.de/landwirtschaft-verstehen/haetten-sies-gewusst/landwirtschaft-in-zahlen/die-milcherzeugung-ist-der-oekonomisch-wichtigste-zweig-unserer-landwirtschaft>
- [2] H. Bernhardt, M. Höhendinger, and J. Stumpenhausen, "Development of the Technical Structure of the "Cow Energy" Concept," *Agronomy*, vol. 11, no. 10, p. 1915, 2021, doi: 10.3390/agronomy11101915.
- [3] T. Theunissen, J. Keller, and H. Bernhardt, "Mind the Market Opportunity: Digital Energy Management Services for German Dairy Farmers," *Agriculture*, vol. 13, no. 4, p. 861, 2023, doi: 10.3390/agriculture13040861.
- [4] S. Nesor, J. Neiber, and K. Bonkoß. "Stromverbrauch und Energieeffizienz in der Tierhaltung." Accessed: Sep. 25, 2023. [Online]. Available: [https://energieeffizienz.landwirtschaft-bw.de/pb/site/pbs-bw-new/get/documents/MLR.Energieberatung/Unterlagen/03\\_Wissensbasis/Archiv%20Fachartikel/Schweinehaltung/Stromverbrauch%20und%20Energieeffizienz%20in%20der%20Tierhaltung\\_sub\\_1112\\_2012.pdf?attachment=true](https://energieeffizienz.landwirtschaft-bw.de/pb/site/pbs-bw-new/get/documents/MLR.Energieberatung/Unterlagen/03_Wissensbasis/Archiv%20Fachartikel/Schweinehaltung/Stromverbrauch%20und%20Energieeffizienz%20in%20der%20Tierhaltung_sub_1112_2012.pdf?attachment=true)
- [5] R. Pommer, H. Eckel, W. Hartmann, and H. Kämper. "Energiebedarf in der Milchviehhaltung." KTBL-Heft. Accessed: Sep. 3, 2023. [Online]. Available: <https://www.ktbl.de/fileadmin/produkte/leseprobe/40104excerpt.pdf>
- [6] A. Pressman. "Dairy Farm Energy Efficiency." Accessed: Sep. 15, 2023. [Online]. Available: [https://parasitology.cvm.ncsu.edu/vmp991/dairy/supplement/dairy\\_energy.pdf](https://parasitology.cvm.ncsu.edu/vmp991/dairy/supplement/dairy_energy.pdf)
- [7] D. N. Akam, F. H. Dodd, and A. J. Quick, *Milking, milk production hygiene and udder health* (FAO animal production and health paper 78). Rome: Food and Agriculture Organization of the United Nations, 1989. Accessed: Oct. 20, 2023. [Online]. Available: <https://www.fao.org/3/t0218e/T0218E00.htm#TOC>
- [8] Roys Farm. "How to Milk a Cow by Machine (Beginner's Guide)." Accessed: Nov. 15, 2023. [Online]. Available: <https://www.roysfarm.com/how-to-milk-a-cow-by-machine/>

- [9] Whitegold Technologies LLP. "Milking Machines / Parlors." Accessed: Nov. 15, 2023. [Online]. Available: <https://www.whitegoldtech.com/product-category/dairy-equipment/milking-machines-parlors/>
- [10] NK Dairy Equipments. "Milking Parlor – Herringbone by GEA." Accessed: Nov. 15, 2023. [Online]. Available: <https://nk dairy equipments.com/gea-milking-parlors/herringbone-parlours/>
- [11] Boumatic. "Simply Superior Parallel Stall With Best-in-Class Cow Comfort and Cow Flow." Accessed: Nov. 15, 2023. [Online]. Available: <https://boumatic.com/products/xcalibur-90lx-us/>
- [12] Robert Peden. "Farm buildings - Milking sheds How a rotary dairy shed works." Te Ara - the Encyclopedia of New Zealand. Accessed: Nov. 15, 2023. [Online]. Available: <https://teara.govt.nz/en/diagram/18505/how-a-rotary-dairy-shed-works>
- [13] GEA. "External rotary milking parlor Dairy Rotor T8900." Accessed: Nov. 28, 2023. [Online]. Available: [https://www.gea.com/en/binaries/gea-dairyrotor-T8900-rotary-milking-parlor-carousel-autorotor-cow-milking\\_tcm11-48271.jpgx](https://www.gea.com/en/binaries/gea-dairyrotor-T8900-rotary-milking-parlor-carousel-autorotor-cow-milking_tcm11-48271.jpgx)
- [14] DairyNZ. "Automatic milking system." Accessed: Dec. 13, 2023. [Online]. Available: <https://www.dairynz.co.nz/milking/new-dairy-technology/automatic-milking-systems/>
- [15] G. Dawson. "This Robot's Got Milk." Accessed: Nov. 15, 2023. [Online]. Available: <https://modernfarmer.com/2013/08/this-robots-got-milk/>
- [16] D. Cutress. "Robotic milking and cattle welfare." Accessed: Nov. 15, 2023. [Online]. Available: <https://businesswales.gov.wales/farmingconnect/news-and-events/technical-articles/robotic-milking-and-cattle-welfare>
- [17] M. Höhendinger, H.-J. Krieg, R. Dietrich, S. Rauscher, J. Stumpfenhausen, and H. Bernhardt, "Impacts of Divergent Moving Drives on Energy Efficiency and Performance of Various AMS in Operative Conditions," *Agriculture*, vol. 11, no. 9, p. 806, 2021, doi: 10.3390/agriculture11090806.
- [18] O. F. Segers, "Modeling Milk Cooling Within A Dairy Farm To Minimize Electricity Costs," Bachelor of Science Thesis, University of Twente, Enschede, Netherlands, 2022. [Online]. Available: [http://essay.utwente.nl/92249/1/Segers\\_BA\\_EEMCS.pdf](http://essay.utwente.nl/92249/1/Segers_BA_EEMCS.pdf)
- [19] R. Mhundwa, M. Simon, and S. Tangwe, "Energy Management Opportunities in Raw Milk Cooling in A Dairy Farm: The Potential Of Using A Raw Milk Pre-Cooler," 2017. [Online]. Available: [https://www.researchgate.net/publication/324686232\\_energy\\_management\\_opportunities\\_in\\_raw\\_milk\\_cooling\\_in\\_a\\_dairy\\_farm\\_the\\_potential\\_of\\_using\\_a\\_raw\\_milk\\_pre-cooler](https://www.researchgate.net/publication/324686232_energy_management_opportunities_in_raw_milk_cooling_in_a_dairy_farm_the_potential_of_using_a_raw_milk_pre-cooler)
- [20] L. F. Paludetti, A. L. Kelly, B. O'Brien, K. Jordan, and D. Gleeson, "The effect of different precooling rates and cold storage on milk microbiological quality and composition,"

- Journal of dairy science*, vol. 101, no. 3, pp. 1921–1929, 2018, doi: 10.3168/jds.2017-13668.
- [21] Agriculture and Horticulture Development Board. "How to ensure energy efficient milk cooling | AHDB." Accessed: Nov. 15, 2023. [Online]. Available: <https://ahdb.org.uk/knowledge-library/how-to-ensure-energy-efficient-milk-cooling>
- [22] "Explanation of Dairy Cooling and the Process it Used – Food Process Cooling." Accessed: Oct. 28, 2023. [Online]. Available: <http://foodprocesscooling.com/dairy-cooling/>
- [23] Abts Equipment. "Bulk Tanks - Abts Equipment." Accessed: Nov. 6, 2023. [Online]. Available: <https://abtsequipment.com/products/bulk-tanks/>
- [24] Agriculture and Horticulture Development Board. "Ice bank tanks | AHDB." Accessed: Nov. 20, 2023. [Online]. Available: <https://ahdb.org.uk/knowledge-library/ice-bank-tanks>
- [25] S. Kraatz, "Energy intensity in livestock operations – Modeling of dairy farming systems in Germany," *Agricultural Systems*, vol. 110, pp. 90–106, 2012, doi: 10.1016/j.agsy.2012.03.007.
- [26] Agriculture and Horticulture Development Board. "Milk pre-cooling: Plate heat exchangers | AHDB." Accessed: Oct. 15, 2023. [Online]. Available: <https://ahdb.org.uk/knowledge-library/milk-pre-cooling-plate-heat-exchangers>
- [27] S. Sanford, "Energy Conservation on the Farm: Well Water Precoolers," A3784-3, 2003. [Online]. Available: <https://cdn.shopify.com/s/files/1/0145/8808/4272/files/A3784-03.pdf>
- [28] Agriculture and Horticulture Development Board. "Recover heat from the refrigeration system." Accessed: Nov. 25, 2023. [Online]. Available: <https://ahdb.org.uk/knowledge-library/recover-heat-from-the-refrigeration-system>
- [29] S. Sanford, "Energy Conservation on the Farm: Refrigeration Systems," A3784-4, 2004. [Online]. Available: <https://cdn.shopify.com/s/files/1/0145/8808/4272/files/A3784-04.pdf>
- [30] Farm Energy Nova Scotia, "Refrigeration Heat Recovery," p. 2, 2017. [Online]. Available: [https://nsefp.ca/wp-content/uploads/2017/03/FENS\\_factsheet\\_refrigeration\\_heat\\_recovery.pdf](https://nsefp.ca/wp-content/uploads/2017/03/FENS_factsheet_refrigeration_heat_recovery.pdf)
- [31] M. P. Pradhanang, "Modelling and Benchmark Development for Electrical Energy Use and Energy Efficiency on Nova Scotia Dairy Farms," Master of Science Thesis, Dalhousie University Canada, Nova Scotia Canada, 2015. [Online]. Available: <https://dalspace.library.dal.ca/xmlui/bitstream/handle/10222/56308/Pradhanang-Mumu-MSc-AGRI-Feb-2015.pdf?sequence=1&isAllowed=y>

- [32] M. Hurlbatt, "Vacuum Pumps and Energy Efficiency for Dairy Farms," *Pump Solutions Australasia*, 02 Mar., 2017. Accessed: Nov. 18, 2023. [Online]. Available: <https://pumpsolutions.com.au/vacuum-pumps-energy-efficiency-dairy-farms/>
- [33] S. Sanford and A. Go, *Energy for Dairy Farms: in Regional Perspectives on Farm Energy Edited by Daniel Ciolkosz*, 1st ed. Springer, 2022. Accessed: Oct. 15, 2023. [Online]. Available: <https://link.springer.com/book/10.1007/978-3-030-90831-7>
- [34] D. Ciolkosz. "Dairy Milking Pump Energy." Accessed: Nov. 18, 2023. [Online]. Available: <https://extension.psu.edu/dairy-milking-pump-energy>
- [35] Agriculture and Horticulture Development Board. "Efficient use of vacuum pumps | AHDB." Accessed: Nov. 18, 2023. [Online]. Available: <https://ahdb.org.uk/knowledge-library/efficient-use-of-vacuum-pumps>
- [36] Severson Tim. "Variable Speed Pumps. What Are They and How Do They Work?" Accessed: Nov. 22, 2023. [Online]. Available: <https://southernwater.com.au/variable-speed-pumps/>
- [37] A. Laurent, J. Brinker, E. Wilichowski, M. Siska, K. St. Clair, and B. Jessen. "Farm Energy: Best Management Practices for Dairy Farm." Accessed: Nov. 15, 2023. [Online]. Available: <https://www.mass.gov/doc/energybmpdairypdf/download>
- [38] S. Nesper, J. Neiber, J. Niedermeier, M. Götz, L. Kraus, and K.-H. Pettinger. "Energieverbrauch im Milchviehstall Effizienz und Einsparpotential." Accessed: Aug. 25, 2023. [Online]. Available: [https://www.lfl.bayern.de/mam/cms07/publikationen/daten/informationen/energieverbrauch\\_im\\_milchviehstall\\_065687.pdf](https://www.lfl.bayern.de/mam/cms07/publikationen/daten/informationen/energieverbrauch_im_milchviehstall_065687.pdf)
- [39] D. J. Reinemann, G. M. Wolters, P. Billon, O. Lind, and M. D. Rasmussen, "Review Of Practices for Cleaning And Sanitation Of Milking Machines," [Online]. Available: <https://www.oxidationtech.com/downloads/Tech/Milk%20machine%20disinfection%20practices%20non-O3.pdf>
- [40] J. Oelgeschläger. "Reinigung und Desinfektion der Melkanlage-Nicht alles Gold was glänzt!" Accessed: Dec. 5, 2023. [Online]. Available: [https://www.lwk-niedersachsen.de/lwk/news/22408\\_Reinigung\\_und\\_Desinfektion\\_der\\_Melkanlage-Nicht\\_alles\\_Gold\\_was\\_glaenzt](https://www.lwk-niedersachsen.de/lwk/news/22408_Reinigung_und_Desinfektion_der_Melkanlage-Nicht_alles_Gold_was_glaenzt)
- [41] U. Averberg *et al.* "Energieeffizienzverbesserung in der Landwirtschaft." Accessed: Oct. 12, 2023. [Online]. Available: <https://www.landwirtschaftskammer.de/landwirtschaft/technik/pdf/energieeffizienzverbesserung.pdf>
- [42] S. Sanford, "Energy Conservation in Agriculture: Heating Water for Dairy Farms," A3784-2, 2003. [Online]. Available: <https://cdn.shopify.com/s/files/1/0145/8808/4272/files/A3784-02.pdf>
- [43] A. Mohsenimanesh *et al.*, "Review: Dairy Farm Electricity Use, Conservation, and Renewable Production—A Global Perspective," *Applied Engineering in Agriculture*,

- vol. 37, no. 5, pp. 977–990, 2021. doi: 10.13031/aea.14621. [Online]. Available: <https://elibrary.asabe.org/pdfviewer.asp?param1=s:/8y9u8/q8qu/tq9q/5tv/J/quqzIGIH/JN/L/UiHKMIH.5tv&param2=HI/HJ/IGIJ&param3=IIG.HLO.HLP.ILI&param4=52779>
- [44] W. J. Wardal, K. E. Mazur, K. Roman, M. Roman, and M. Majchrzak, "Assessment of Cumulative Energy Needs for Chosen Technologies of Cattle Feeding in Barns with Conventional (CFS) and Automated Feeding Systems (AFS)," *Energies*, vol. 14, no. 24, p. 8584, 2021. doi: 10.3390/en14248584. [Online]. Available: <https://www.mdpi.com/1996-1073/14/24/8584>
- [45] F. Da Borso, A. Chiumenti, M. Sigura, and A. Pezzuolo, "Influence of automatic feeding systems on design and management of dairy farms," *J Agric Eng*, vol. 48, s1, pp. 48–52, 2017. doi: 10.4081/jae.2017.642. [Online]. Available: <https://www.agroengineering.org/index.php/jae/article/view/642>
- [46] B. Haidn and R. Oberschätzl. "Automatic Feeding Systems for Cattle Technology: Performance - Notes on Planning." Accessed: Dec. 6, 2023. [Online]. Available: [https://www.dlg.org/fileadmin/downloads/landwirtschaft/themen/publikationen/merkblaetter/dlg-merkblatt\\_398\\_e.pdf](https://www.dlg.org/fileadmin/downloads/landwirtschaft/themen/publikationen/merkblaetter/dlg-merkblatt_398_e.pdf)
- [47] Farming.plus. "Athos-Fütterungsroboter." Accessed: Dec. 6, 2023. [Online]. Available: <https://www.farming.plus/de/c/athos-fuetterungsroboter.4327>
- [48] R. Oberschätzl, B. Haidn, and S. Naser, "Automatic feeding systems for cattle – A study of the energy consumption of the techniques," p. 5, 2015. [Online]. Available: [https://www.researchgate.net/publication/285592337\\_Automatic\\_feeding\\_systems\\_for\\_cattle\\_-\\_A\\_study\\_of\\_the\\_energy\\_consumption\\_of\\_the\\_techniques](https://www.researchgate.net/publication/285592337_Automatic_feeding_systems_for_cattle_-_A_study_of_the_energy_consumption_of_the_techniques)
- [49] F. M. Tangorra and A. Calcante, "Energy consumption and technical-economic analysis of an automatic feeding system for dairy farms: Results from a field test," *Journal of Agricultural Engineering*, vol. 49, 2018, Art. no. 4. doi: 10.4081/jae.2018.869. [Online]. Available: <https://www.agroengineering.org/index.php/jae/article/view/869/730>
- [50] P. Cremer, "Lastmanagement beim Strombezug in landwirtschaftlichen Betrieben," 2009. [Online]. Available: [https://lel.landwirtschaft-bw.de/pb/site/pbs-bw-mlr/get/documents\\_E1354968541/MLR.Energieberatung/Unterlagen/03\\_Wissensbasis/Archiv%20Fachartikel/Landwirtschaftlicher%20Betrieb/Lastmanagement%20beim%20Strombezug%20in%20landwirtschaftlichen%20Betriebeben\\_Baubrief47.pdf](https://lel.landwirtschaft-bw.de/pb/site/pbs-bw-mlr/get/documents_E1354968541/MLR.Energieberatung/Unterlagen/03_Wissensbasis/Archiv%20Fachartikel/Landwirtschaftlicher%20Betrieb/Lastmanagement%20beim%20Strombezug%20in%20landwirtschaftlichen%20Betriebeben_Baubrief47.pdf)
- [51] J. Neiber. "Strombedarf, Einsparpotenzial und Eigenstromversorgung in der landwirtschaftlichen Nutztierhaltung." Accessed: Nov. 20, 2023. [Online]. Available:

- <https://www.alb-bayern.de/media/files/0004/pr-sentation-energie-seminar-neiber.pdf>
- [52] Netztransparenz, *Spotmarktpreis nach § 3 Nr. 42a EEG*. Accessed: Nov. 28, 2023. [Online]. Available: <https://www.netztransparenz.de/de-de/Erneuerbare-Energien-und-Umlagen/EEG/Transparenzanforderungen/Marktpr%C3%A4mie/Spotmarktpreis-nach-3-Nr-42a-EEG>
- [53] M. Z. Shamseldin and A. Y. Abdelaziz, "Energy Management for Medium-Voltage Direct Current Networks," *Medium-Voltage Direct Current Grids Edited by Moustafa Mohammed Eissa*, p. 43, 2019. doi: 10.1016/B978-0-12-814560-9.00002-1. [Online]. Available: <https://www.sciencedirect.com/science/article/pii/B9780128145609000021>
- [54] H. Bernhardt, A. Graeff, S. Woerz, M. Hoehendinger, M. Hoeld, and J. Stumpfenhausen, "Energy management of automatic dairy farms with integration in regional grids," no. 1700262, p. 1, 2017. doi: 10.13031/aim.201700262. [Online]. Available: [https://www.researchgate.net/publication/320788873\\_Energy\\_management\\_of\\_automatic\\_dairy\\_farms\\_with\\_integration\\_in\\_regional\\_grids](https://www.researchgate.net/publication/320788873_Energy_management_of_automatic_dairy_farms_with_integration_in_regional_grids)
- [55] H. Bernhardt, "Digitales Energiemanagement im Milchviehbereich," *Informatik Spektrum*, vol. 46, no. 1, pp. 3–7, 2023. doi: 10.1007/s00287-023-01525-z. [Online]. Available: <https://link.springer.com/article/10.1007/s00287-023-01525-z>
- [56] Nasir. "Energy Management and Its Importance." Accessed: Oct. 12, 2023. [Online]. Available: <https://www.thesustainabilitycloud.com/energy-management/>
- [57] J. Wehner, "Energy Efficiency in Logistics: An Interactive Approach to Capacity Utilisation," *Sustainability*, vol. 10, no. 6, p. 1727, 2018. doi: 10.3390/su10061727. [Online]. Available: <https://www.mdpi.com/2071-1050/10/6/1727>
- [58] M. Stet, "Energy Management in Logistics Activities," *Valahian Journal of Economic Studies*, vol. 4, no. 13, pp. 83–90, 2013. [Online]. Available: <https://www.proquest.com/scholarly-journals/energy-management-logistics-activities/docview/1540957601/se-2>
- [59] M. Fahad, S. A. A. Naqvi, M. Atir, M. Zubair, and M. M. Shehzad, "Energy Management in a Manufacturing Industry through Layout Design," *Procedia Manufacturing*, vol. 8, pp. 168–174, 2017. doi: 10.1016/j.promfg.2017.02.020. [Online]. Available: <https://www.sciencedirect.com/science/article/pii/S2351978917300240>
- [60] H. Mac Nulty. "An Introduction to Energy Management Systems: Energy Savings and Increased Industrial productivity for the Iron and Steel Sector." Accessed: Sep. 15, 2023. [Online]. Available: [https://www.oecd.org/sti/ind/DSTI-SU-SC\(2014\)14-FINAL-ENG.pdf](https://www.oecd.org/sti/ind/DSTI-SU-SC(2014)14-FINAL-ENG.pdf)



- [61] L. Reubekeul and C. Ollech. "Part 1: Energy Efficiency Act (EnEfG) - New legal requirements for companies | DLA Piper." Accessed: Sep. 19, 2023. [Online]. Available: <https://www.dlapiper.com/en-jp/insights/publications/2023/05/energieeffizienzgesetz-enefg-neue-gesetzliche-anforderungen-fur-unternehmen>
- [62] Quacert. "DIN EN 16247-1." Accessed: Sep. 20, 2023. [Online]. Available: <https://quacert.de/index.php/en/certifications/energy-management/din-en-16247-1>
- [63] T. Adu-Baffour. "Energy management system according to ISO 50001 I DQS." Accessed: Sep. 18, 2023. [Online]. Available: <https://www.dqsglobal.com/intl/learn/blog/energy-management-system-according-to-iso-50001#Was-ist-ein-energiemanagementsystem-nach-iso-chapter02>
- [64] B. Mohammadi-Ivatloo, H. Yousefi, and G. Amini. "Artificial intelligence in Energy Management." Accessed: Oct. 1, 2023. [Online]. Available: <https://link.springer.com/collections/jdfhjgjebg>
- [65] L. S. B. Pereira, R. N. Rodrigues, and E. A. C. A. Neto, "Modeling of Energy Management Systems using Artificial Intelligence," *IEEE International Systems Conference (SysCon)*, pp. 1–6, 2020. doi: 10.1109/SysCon47679.2020.9275831. [Online]. Available: <https://ieeexplore.ieee.org/document/9275831>
- [66] N. Slob, C. Catal, and A. Kassahun, "Application of machine learning to improve dairy farm management: A systematic literature review," *Preventive veterinary medicine*, vol. 187, 2021, Art. no. 105237. doi: 10.1016/j.prevetmed.2020.105237. [Online]. Available: <https://pubmed.ncbi.nlm.nih.gov/33418514/>
- [67] J. Li, M. S. Herdem, J. Nathwani, and J. Z. Wen, "Methods and applications for Artificial Intelligence, Big Data, Internet of Things, and Blockchain in smart energy management," *Energy and AI*, vol. 11, 2023, Art. no. 100208. doi: 10.1016/j.egyai.2022.100208. [Online]. Available: <https://www.sciencedirect.com/science/article/pii/S2666546822000544>
- [68] A. Pathak and A. Rathore, "Dairy and Artificial Intelligence- Enhancing Efficiency and Productivity," vol. 3, no. 12, pp. 90–104. [Online]. Available: <https://justagriculture.in/files/newsletter/2023/august/17.%20Dairy%20and%20Artificial%20Intelligence-%20Enhancing%20Efficiency%20and%20Productivity.pdf>
- [69] A. de Vries, N. Bliznyuk, and P. Pinedo, "Invited Review: Examples and opportunities for artificial intelligence (AI) in dairy farms\*," vol. 39, no. 1, pp. 14–22, 2023. doi: 10.15232/aas.2022-02345. [Online]. Available: <https://www.appliedanimalscience.org/action/showPdf?pii=S2590-2865%2823%2900002-2>
- [70] Ktbl. "Energiebedarfsrechner Tierhaltung." Accessed: Dec. 12, 2023. [Online]. Available: <https://www.ktbl.de/webanwendungen/energiebedarfsrechner>

- [71] K. Bonkoß, J. Neiber, and S. Naser. "Energieeinsparung in der Milchviehhaltung: Milchgewinnung: Vakuumversorgung, Kühlung, Reinigung." Accessed: Nov. 10, 2023. [Online]. Available: [https://www.lfl.bayern.de/mam/cms07/publikationen/daten/informationen/energieeinsparung\\_milchviehhaltung-milchgewinnung\\_lfl-information.pdf](https://www.lfl.bayern.de/mam/cms07/publikationen/daten/informationen/energieeinsparung_milchviehhaltung-milchgewinnung_lfl-information.pdf)
- [72] A. Trubetskaya, O. McDermott, and S. McGovern, "Implementation of an ISO 50001 energy management system using Lean Six Sigma in an Irish dairy: a case study," *TQM*, vol. 35, no. 9, pp. 1-24, 2023. doi: 10.1108/TQM-08-2022-0252. [Online]. Available: <https://www.emerald.com/insight/content/doi/10.1108/TQM-08-2022-0252/full/html#abstract>

# Appendix

Energiebedarf für die von Ihnen ausgewählten Anlagen

Produktionsrichtung	Jährlicher Energiebedarf je Tierplatz			Jährlicher Energiebedarf		
	Standardwert	Minimal kWh/(TP · a)	Maximal	Standardwert	Minimal kWh/a	Maximal
<b>▼ Milchkuhhaltung 01</b>						
<b>Strom</b>						
Milchgewinnung	76	68	83	7.577	6.819	8.335
Reinigung Melkanlage	78	70	86	7.830	7.047	8.613
Milchkühlung	63	50	76	6.302	5.042	7.562
Kühltankreinigung	16	16	16	1.572	1.572	1.572
Lüftung	1,6	1,6	1,6	160	160	160
Futterbereitstellung	7,1	6,4	7,9	715	643	786
Entmistung	32	32	32	3.220	3.220	3.220
Beleuchtung	196	157	261	19.587	15.670	26.051
<b>Strom gesamt</b>	<b>470</b>	<b>402</b>	<b>563</b>	<b>46.963</b>	<b>40.173</b>	<b>56.299</b>
<b>Brennstoff</b>						
<b>Brennstoff gesamt</b>	<b>0,00</b>	<b>0,00</b>	<b>0,00</b>	<b>0,00</b>	<b>0,00</b>	<b>0,00</b>
<b>Energiebedarf gesamt</b>	<b>470</b>	<b>402</b>	<b>563</b>	<b>46.963</b>	<b>40.173</b>	<b>56.299</b>

Fig A 1: Energy consumption data from KTBL calculator with 100 cows and 8240 kg/cow/a with CMS, direct cooling, precooling only. [70]

Energiebedarf für die von Ihnen ausgewählten Anlagen

Produktionsrichtung	Jährlicher Energiebedarf je Tierplatz			Jährlicher Energiebedarf		
	Standardwert	Minimal kWh/(TP · a)	Maximal	Standardwert	Minimal kWh/a	Maximal
<b>▼ Milchkuhhaltung 01</b>						
<b>Strom</b>						
Milchgewinnung	76	68	83	7.577	6.819	8.335
Reinigung Melkanlage	78	70	86	7.830	7.047	8.613
Milchkühlung	130	104	156	12.999	10.399	15.598
Kühltankreinigung	6,8	6,8	6,8	684	684	684
Lüftung	1,6	1,6	1,6	160	160	160
Futterbereitstellung	7,1	6,4	7,9	715	643	786
Entmistung	32	32	32	3.220	3.220	3.220
Beleuchtung	196	157	261	19.587	15.670	26.051
<b>Strom gesamt</b>	<b>528</b>	<b>446</b>	<b>634</b>	<b>52.771</b>	<b>44.642</b>	<b>63.447</b>
<b>Brennstoff</b>						
<b>Brennstoff gesamt</b>	<b>0,00</b>	<b>0,00</b>	<b>0,00</b>	<b>0,00</b>	<b>0,00</b>	<b>0,00</b>
<b>Energiebedarf gesamt</b>	<b>528</b>	<b>446</b>	<b>634</b>	<b>52.771</b>	<b>44.642</b>	<b>63.447</b>

Fig A 2: Energy consumption data from KTBL calculator with 100 cows and 8240 kg/cow/a with CMS, direct cooling, RHR unit only. [70]

Energiebedarf für die von Ihnen ausgewählten Anlagen

Produktionsrichtung	Jährlicher Energiebedarf je Tierplatz			Jährlicher Energiebedarf		
	Standardwert	Minimal kWh/(TP · a)	Maximal	Standardwert	Minimal kWh/a	Maximal
<b>▼ Milchkühhaltung 01</b>						
<b>Strom</b>						
Milchgewinnung	120	108	132	12.000	10.800	13.200
Reinigung Melkanlage	78	70	86	7.830	7.047	8.613
Milchkühlung	73	58	87	7.253	5.802	8.703
Kühltankreinigung	6,8	6,8	6,8	684	684	684
Lüftung	1,6	1,6	1,6	160	160	160
Futterbereitstellung	7,1	6,4	7,9	715	643	786
Entmistung	32	32	32	3.220	3.220	3.220
Beleuchtung	196	157	261	19.587	15.670	26.051
<b>Strom gesamt</b>	<b>514</b>	<b>440</b>	<b>614</b>	<b>51.448</b>	<b>44.026</b>	<b>61.417</b>
<b>Brennstoff</b>						
<b>Brennstoff gesamt</b>	<b>0,00</b>	<b>0,00</b>	<b>0,00</b>	<b>0,00</b>	<b>0,00</b>	<b>0,00</b>
<b>Energiebedarf gesamt</b>	<b>514</b>	<b>440</b>	<b>614</b>	<b>51.448</b>	<b>44.026</b>	<b>61.417</b>

Fig A 3: Energy consumption data from KTBL calculator with 100 cows and 8240 kg/cow/a with AMS, direct cooling, precooling and heat recovery. [70]