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Improving Dairy Shed Energy Efficiency

Technical Report

October 2007

CAENZ

Venture Southland
Enterprise, Tourism & Community Development

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Ministry of Agriculture and Forestry
Te Manatū Ahuwhenua, Ngāherehere

Dairy InSight

Improving Dairy Shed Energy Efficiency

Technical Report

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PREFACE

Since February 2006 the New Zealand Centre for Advanced Engineering (CAENZ) has carried out real-time monitoring of five Southland farms to examine the practical realities of implementing energy efficiency measures into the dairy shed, and also to analyse how the economics of dairy shed operations can be improved through optimising on-site power and energy use. This $500,000 project was funded by the Sustainable Farming Fund and Dairy InSight and facilitated by Venture Southland.

A novel approach to the project has been the development and use of a cost-effective Internet- based monitoring system whereby operational data relevant to the performance of selected pieces of equipment in the dairy shed could be communicated to Christchurch where it was further analysed, graphically presented and made available to the general public through the project website, www.cowshed.org.nz. A number of reports prepared for the project are published on the website and are freely available for download.

The project has involved a considerable commitment of vendor, supplier and farmer time plus significant investment from the project team in time and capital to:

- Identify, analyse and install the various technologies and approaches trialed in the project;
- Develop and implement the monitoring system and web-based information system;
- Work with suppliers to improve system designs using their technologies; and
- Capture the learning from the trials and consolidates these findings into a decision tool suitable for every day farmer needs.

To date it has been possible to demonstrate energy efficiency gains of the order of 30% utilising different technology types and improved practises. More can yet be done, however, especially at the level of the dairy shed system design and in incorporating alternative energy sources when planning for new investments in dairying activity. These are issues for further investigation and action.

An understanding of the ways in which we use energy within our farming sector is vitally important if we are to improve environmental outcomes and meet the challenges of sustainability of our farming practices. This report offers a comprehensive coverage of energy efficiency opportunities within the dairy shed and provides an important contribution to improving the economics of dairying by improving energy efficiency and energy use.

In particular, the report brings together the technical information and monitoring data gathered during the project to assist dairy farm owners and mangers to make more informed decisions on their use of energy within the dairy shed. The findings and results also provide equipment designers and suppliers with an objective assessment of the performance of existing technologies and, it is hoped, help inform product development and system design for the future.

If this report succeeds in encouraging individual farmers and vendors to re-examine their energy management practises, then it has achieved its purpose.

R J (George) Hooper
Executive Director

AUTHORS & ACKNOWLEDGEMENTS

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The main authors of *Energy Efficiency in Dairy Sheds* were Ken Morison, Warren Gregory and Rowan Hooper.

Contributions to the text were also made by Scott Caldwell (CAENZ Project Co-ordinator) and Robin McNeill (Venture Southland Project Manager). Editing and pre-press production was done by Charles Hendtlass (CAENZ).

Acknowledgements

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Funders

Dairy InSight

Ministry of Agriculture Sustainable Farming Fund

Farm owners and managers

FarmRight for assistance in co-ordinating the farm sites

Owners, managers and staff of:

- Coldstream Downs Ltd
- Graejo Trust
- Glencairn Land Company Ltd
- Tussock Creek Dairies Ltd
- Moorabool Farm Ltd

Suppliers

Woosh Wireless

Scott Technical Instruments Ltd

Corkill Systems Ltd

Dairy Technology Services Ltd (DTS)

Azzuro Solar

Solar South Ltd

Attitude Switchboards Ltd

Multi Machinery (Superheat) Ltd

Installation contractors

Progressive Engineering Southland Ltd

Munro Electrical 2001 Ltd

Karl Boniface Plumbing Ltd

Bill Sheddan Plumbing Ltd

Consultants

Emeritus Professor Arthur Williamson

1 INTRODUCTION

Electricity is a significant cost for the dairy sector and a major factor in rural energy demand growth. Technologies have been developed to improve energy efficiency in New Zealand dairy sheds, but a lack of independent assessment and easily accessible information has meant that farmers have largely remained unaware of potential efficiency gains available to them, or have been unwilling to commit time and investment into this area.

This project - *"Energy Efficiency in Dairy Sheds"* – was initiated to provide farmers with a robust and objective view on ways that, with good practice, individual farmers can achieve improvements in energy efficiency and energy use for all types of dairy farms. One of the main focuses of this project has been to identify equipment and practice that can be used to improve dairy shed operations and to carry out practical demonstrations of these technologies.

Commissioned by Venture Southland, and managed by the New Zealand Centre for Advanced Engineering (CAENZ), this independent study has undertaken field trials for a range of applications and technology options over two seasons. From the results of these the performance of the energy saving equipment tested was assessed and farmers provided with a decision-making tool which can help them to select the best energy saving device for a particular situation.

In addition, an important component of the study was earlier work undertaken by Venture Southland, which identified that access to cost-effective broadband (or high speed communications systems) is critical for the development of economic and social opportunities in the regions, and that such access is vital for regional economies to remain competitive. Demand for broadband services in rural areas is presently suppressed by low availability of information rich content, which in turn is perpetuated by low data rates denying such information to users. With the completion of the Venture Southland broadband project in Southland, nearly all rural properties are now able to get affordable access to the Internet through the Woosh Wireless network; thereby providing opportunities for the Project to demonstrate the efficiency gains that might be achieved through wider implementation of rural broadband services.

A secondary purpose of the study has thus been the development and use of a cost-effective Internet-based monitoring system suitable for remote monitoring of the trial sites. Instrumentation was installed on the equipment under trial at each of the selected farm sites and logging and telemetry equipment integrated to enable direct communication with the CAENZ project office in Christchurch where the data was further analysed, graphically presented and made available in real time through the project website.

Dairy InSight and the Sustainable Farming Fund were the major funders of the project. Because of the limitations as to the number of technologies that could reasonably be covered in the timeframe and resources available to the project team, it was necessary to limit the number of technologies or alternatives evaluated. An open tender process was used for supply of equipment and related services. Suppliers were selected after careful evaluation against the project needs. It is acknowledged that other technology options are possible depending on individual farmer requirements. This report takes into account information provided by the suppliers of equipment and services used in the trials, but all conclusions and opinions are those of the study team alone.

Further information on the background to the project can be obtained from the project website on www.cowshed.org.nz.

Project Scope

The objectives of this project were to identify potentially cost effective measures that will improve dairy shed efficiency and trial these on a number of Southland farms so as to provide dairy farmers with dependable data as well as objective, readily understandable recommendations from which to base investment decisions for their own dairy sheds with respect to energy efficiency, power loading, water usage, effluent disposal (where it can be used) and milk quality.

Unlike previous studies, which have focussed on these factors in isolation, this study set out to take an integrated approach with an emphasis on making the findings widely accessible. Equipment trials were carried out on five farms during the 2006/07 dairy season on a range of technologies options selected as offering practical solutions across the range of possibilities available.

Manufacturers of dairy shed equipment were invited to submit their proposals for equipment that could be retrofitted to existing dairy sheds to improve energy efficiency and reduce operating costs based upon specifications developed by the study team. A desktop study and base line data gathered from two "model" farms were used to inform this selection process.

When considering energy-saving options that require plant alterations or investment in new plant, ownership of equipment is an important factor. For this project, it was assumed that the farm owner owns all the dairy shed equipment - with the exception of the milk storage vats, which are owned by Fonterra. Following the technology selection, agreement was reached with the farmers and suppliers for installation and use of the equipment. Detailed engineering was then carried out for each site and the installation undertaken under the supervision of the study team. Ownership of the equipment resides with Venture Southland.

As stated earlier, it has not been possible to carry out practical trials of all the energy-saving ideas identified. The reasons for this were many including:

- a commercially available product could not be found;
- preliminary economic analysis showed the investment would be unattractive to farm owners; and
- there was too much risk to farm operations to do a practical trial.

A detailed description of the technologies and methods employed during the course of the study is provided in Chapter 2 of this report. A particular innovation was open sourcing the data in real time via the Internet. Use of the Internet is seen as particularly relevant to Southland farmers, most of whom have broadband access by virtue of the Venture Southland broadband project initiative.

It was expected that because the results of all farms were available in real time through the cowshed website, other farmers would be able to compare their own farming operations with the test farms and so "benchmark" themselves. Whilst this was not specifically measured during the study, anecdotal evidence suggest a broad farmer and vendor interest in the study results with the website experiencing up to 1,000 hits a day.

Finally, it was recognised that in order to bring about performance improvements in the dairy shed it was necessary to progress further than just reporting on the trials and the improvements noted. To this end, a seminar was held in Invercargill on completion of the trial phase to report back to farmers and vendors on the key findings. By bringing farmers' attention to the areas of study it was hoped that individual farmers might want to invest in some of the technology being tested if results were sufficiently promising.

To support this objective a decision tool has been developed that calculates the energy savings and investment return possible from the applications considered. This is described in more detail in Chapter 9 of this report.

Understanding the context

This study has highlighted the overall importance of, firstly, understanding the ways in which energy is used in the dairy shed and, secondly, the opportunities for reducing usage. Whilst our key focus has been to identify ways in which energy use can be reduced and to measure the energy saving possible under practical conditions, recognition also needs to be given to the overall cost effectiveness of taking action.

Dairy farmers face increasing costs for electricity and (in many cases) water. Tighter requirements for effluent disposal can be expected. These can all be anticipated to detract from farm profitability. Conversely, improvement to milk quality is rewarded by better payouts and may yet be forced onto farmers by end markets. The dairy shed is where all these drivers come together through energy and power interdependencies. Farmers thus need to confidently know how to reduce the overall embedded and operational energy requirements of their dairy shed operations in a straightforward, cost-effective manner.

Cost effectiveness has been evaluated using standard decision making tools and most often the "simple payback" method – how many years of savings it takes to equal initial cost. In this report we have taken a five-year payback periods as the standard hurdle required for investment.

There are a range of other factors that also must be taken into account when assessing investment in new technology or operating procedures. Some of the important lessons learnt from this study relate to installation and farm management issues. Suppliers and installation contractors too often were not set up to meet the demands for planning and coordination of the work to ensure successful installation.

Often, and especially for retrofit of existing sheds, engineered solutions were required that fell outside normal trade or farm management practice. After sales service and the capability of farm staff to adjust to new operating regimes is an important component of this, especially when dealing with one-off installations. It was found during the course of this project that often significant intervention was required to correct faulty installation work and to ensure that farm staff were "up with the play".

A benefit arising from the project is that it has been able to provide suppliers and manufacturers of the equipment used in this trail with authentic data with which to further develop their technology designs and implementations. A number of manufacturers have commented elsewhere of the difficulty they have in getting reliable and useful performance data. This project has done much to overcome this shortcoming.

It should be noted that as well as farm equipment suppliers who stand to develop from the research, power supply companies should also be able to benefit from likely de-stressing of the electricity reticulation network due to power demand spreading, reduced energy demand and/or power factor correction.

Farm owners and managers will learn useful information about the efficiency of their shed by reading the electricity meter at regular intervals (monthly, weekly or even daily) and charting the total shed energy use. Those who chose to monitor individual equipment items will get even more information. The study reinforced the importance of choosing the best purchasing plan for electricity as well as looking to align dairy shed practise with available tariff structures. This is discussed in more detail in Chapter 9

Overall our aim in this report is to bring together the analysis and findings of the trials and studies undertaken into a coherent information compendium. The trials undertaken during the project are described (Chapter 2), and the various operations with the dairy shed (vacuum pumping, hot water supply, milk cooling, effluent and water pumping, and lighting) examined in terms of the potential for improving the energy efficiency of the systems. For each of the systems examined, energy use statistics are benchmarked and cost benefit analyses provided on the opportunities identified for improvement (Chapters 3 though to 9). The final issues and conclusions chapters set out the study team's views of the way forward and the "how" this might be achieved.

2 MEASURING DAIRY SHED EFFICIENCY

2.1 Dairy Shed Operations

Dairy shed energy usage is affected by many factors including herd size, design and capacity of the milking equipment and management practices. This report is based on research carried out on Southland farms where the following were found to be typical:

- herd sizes are 700 cows
- cows are milked twice a day
- the milking season begins in early August and ends in late May (270 to 290 days long)
- the milking lines are washed after each milking but hot water is used only once per day
- the milk is collected daily and the milk vat washed with hot water prior to the start of the next milking following collection
- water is heated with electricity.

The Milking Shed

Modern dairy sheds may be 'herringbone' or 'rotary' design.

In the 'herringbone' design, the operators stand in a pit below floor level and the cows stand in two rows – one on either side of the pit. Milking is a batch process and the cows enter and leave the milking area in batches. The shed size is designated by the number of sets of milking cups. In a '40 a side' shed, there are 40 sets of cups and space for 80 cows to stand in two rows. When cows in the first row have finished milking, the cups are swung over to the cows in the second row and the cows from the first row walk out of the shed. This process continues until all the herd has been milked.

In the rotary design, milking is a continuous process in which each cow steps onto a circular platform that is continuously rotating. The milking cups are attached and after one rotation of the platform, the cups are removed and the cow backs off the platform. The platforms are typically designed to hold 50 to 60 cows although larger designs (80 to 100 cows) are in operation. The platform size is commonly referred to by the number of 'bails' – the stalls that hold the cow while it is being milked. The rotary design is the most efficient for large dairy herds. It is typically operated by two people although with increasing automation (e.g. automatic cup removers), single person operation is becoming possible.

The 50 bail rotary dairy shed is a very common size and design in Southland and where this report refers to a 'typical' dairy shed, it can be assumed that this means a 50 bail rotary design.

The milking equipment used in both the herringbone and rotary designs is very similar and the following description of dairy shed operations is applicable to both designs.

Milking

Milk is extracted from the cow's udder using pulsating cups that simulate the action of a suckling calf. At the peak of the season, a cow produces about 10 litres of milk at each milking and the milking time for each cow is about 7 to 10 minutes.

Power for the pulsation is provided by the vacuum pump and the vacuum also aids the transport of the milk to a central collecting vessel known as the 'milk receiving can'. From the can, the milk is pumped to the milk storage vat via filters and the plate cooler.

The vacuum pump is normally driven by an electric motor and is one of the most important pieces of equipment in the milking shed. Some sheds use two pumps operating in tandem.

It is normal for the vacuum pump to operate at a pressure of -45 kPa gauge i.e. a 'vacuum' of 45 kPa. A herringbone design requires a greater vacuum than a rotary design because the milk lines run overhead and the milk must be lifted up into the overhead line. An air bleed valve is commonly used to regulate the vacuum by automatically admitting extra air into the vacuum line when required.

The air pumped by the vacuum pump is discharged to the atmosphere and this exhaust air is warm and moist. The commonly-used water ring vacuum pump also discharges a continuous flow of water and this water normally runs to waste.

Milk cooling and storage

The plate cooler is a heat exchanger that uses water to cool the milk. The water is continuously pumped through the cooler during the milking period and discharged into a storage tank for later use. It is normal for the milk to be cooled from about 35 °C to about 20 °C in this way.

A common size of cooler used in 50 bail sheds is designed for a milk flow rate of 6,000 litres per hour and a water flow rate of 12,000 litres per hour.

The remainder of the cooling takes place in the milk storage vat. The vat is fabricated from stainless steel and has capacity for at least one full day's milk production. The size of the vat is determined by the size of the herd with typical sizes for large farms being 14,000 to 26,000 litres.

The vat is fitted with a cooling pad that uses refrigerant supplied by an electrically driven refrigeration unit. Electric motor driven stirrers in the vat keep the milk at a uniform temperature as it is cooled. The refrigeration unit (often known as a condensing unit) is usually a package comprising a hermetically sealed compressor, air cooled condenser and all ancillary equipment.

The milk is collected from the vat by a tanker truck which usually calls once a day during the main part of the season. When there is sufficient storage capacity, milk may be collected every second day. Normally, the milk vats are owned by the milk processing company.

Cleaning

Following milking, the inside surfaces of the milking equipment are rinsed with cold water and then cleaned by pumping a solution of hot (80 °C) water and detergent through them. This is commonly referred to as the 'plant wash' or the 'lines wash' A typical cleaning regime is:

After morning milking:

- Wash with acid detergent and hot water on five days per week.
- Wash with alkali detergent and hot water followed by a cold wash with acid detergent on the other two days.

After afternoon milking:

- Wash with acid detergent and cold water every day.

At calving time (August and September), cleaning becomes more difficult because of the colostrum milk and some farms use hot water twice a day during this period.

Milk vats are cleaned after the milk has been picked up and before the vat is re-filled. For most farms, this is a daily process. The cleaning regime is similar to that outlined for the morning cleaning of the milk lines. Typically, 500 litres of hot water are used each day for vat cleaning.

The water for cleaning is normally heated in an insulated, stainless steel or copper cylinder which is similar to (but larger than) a domestic water heater. A typical dairy shed has two water cylinders of 500 litres capacity and each is usually fitted with two or three 3 kW heating elements.

The used cleaning water is discharged to waste.

Effluent disposal

At the completion of milking, the shed and yards are hosed clean and the effluent from this operation is collected in a pit adjacent to the dairy shed. Normal practice is to pump this effluent to a spray irrigator positioned in a nearby field.

2.2 Dairy Shed Energy Use

This section provides an overview of the main areas of energy use in the dairy shed. The main uses for energy are:

- pumping water, milk and effluent

- generating the vacuum needed to operate the milking machine
- chilling the milk
- heating water for cleaning.

The usual source of energy for all these purposes is electricity and a typical farm uses about 100,000 kWh per year. Figure 2.1 shows the typical distribution of this energy amongst the main users.

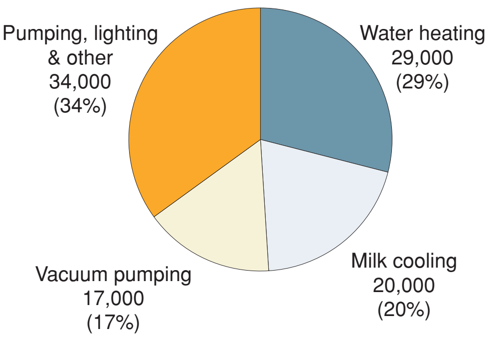


Figure 2.1: Distribution of 100,000 kWh annual energy use in a typical dairy shed

Figure 2.2 shows the energy flows and some water flows on a daily basis.

Electricity costs vary depending on the purchasing arrangements but in April 2007 were in the range 12 c/kWh to 16 c/kWh after discounts and excluding Goods and Services tax (GST). The annual electricity cost for a typical farm is therefore in the range $12,000 - $16,000.

Most Southland farms do not pump water to irrigate their pasture land. In other parts of New Zealand where spray irrigation of dairy farm pasture is common, total electricity costs will be much greater than in Southland. The energy efficiency of spray irrigation was not included in the scope of this project.

Pumping

Pumps are used to :

- transport bore water to the storage tanks
- transfer water from the tanks to the farm houses and stock troughs
- transfer milk to the storage vat
- supply washdown hoses
- circulate cleaning water through the milking lines and storage vats

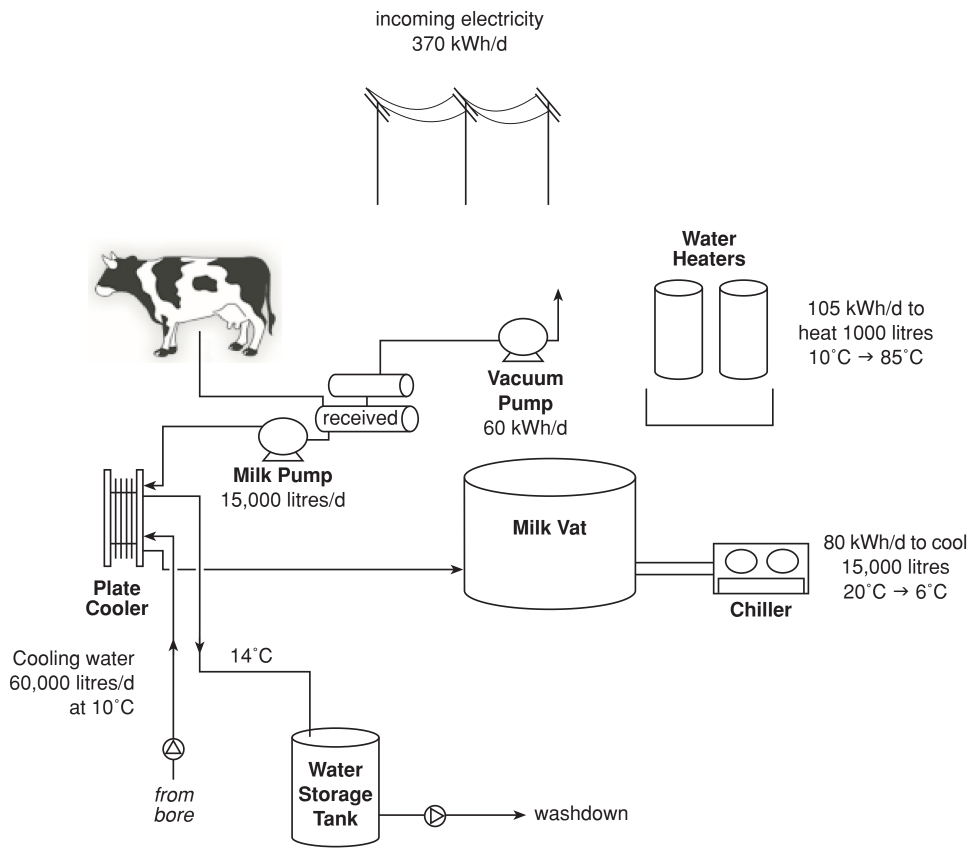


Figure 2.2: Energy flows and some water flows on a daily basis

- pump away effluent.

For these there are no realistic energy options apart from electricity.

Vacuum pump

A typical vacuum pump is of the water ring type (see photo) and driven by a 10 to 15 kW motor. The pump is used during milking and the following cleaning and typically runs for about 6 to 8 hours per day.

A vacuum pump drawing 10 kW and running for 1600 hours per year uses 16,000 kWh – about 16% of the total shed usage. At 15 c/kWh, the annual cost is $2,400.

Water heating

Hot water is required for cleaning the milking lines and the milk storage vat(s). A typical cleaning regime uses 1000 litres of hot water each day – 500 litres to wash the milk vat and 500 litres to wash the milk lines.

Cleaning procedures can vary from farm to farm. If hot washes are used after every milking, hot water consumption will increase to 1500 litres per day.

To heat 1000 litres of water from 10 °C to 85 °C each day for a season of 270 days theoretically requires 24,000 kWh but heat losses from storage cylinders and pipework might increase this to 29,000 kWh – about 29% of the total annual energy usage. If all of this energy is from electricity purchased at 15 c/kWh, water heating will cost about $4,400 per year.

Milk cooling

Milk needs to be cooled to below 7 °C within three hours of the completion of milking and there are suggestions that this temperature may be reduced to 4 °C in the future to meet the requirements of major export markets.

Nearly always the first part of the cooling (from 34 °C to 20 °C) is carried out in a plate heat exchanger using the farm water supply as the coolant.

The balance of the chilling is traditionally done in the milk storage vat using a direct expansion refrigeration unit with air cooled condenser. A typical dairy shed uses about 20% of its electricity (20,000 kWh) to run the refrigeration unit and at 15 c/kWh this electricity costs about $3,000 per year.

Other energy users

Other uses for electrical energy include lighting and smaller drive motors e.g. the drive motors for the rotary milking platform and the yard backing gate and maybe a small air compressor.

2.3 Instrumentation and Measurement

Data on energy use before and after the implementation of energy efficiency measures was obtained by measuring electricity use, temperatures and flows in five Southland dairy sheds. Brief details of the five sites are given in Table 2.1.

The data from the instruments was recorded by a datalogger installed at each site and then transmitted via the internet to a remote computer. The remote computer provided 'near real time' graphs for the website and also stored the data for later analysis. Details of the equipment used are set out in the following sections.

Two dairy sheds (Coldstream Downs and Graejo Trust) were instrumented in the 2005/06 season in order to establish the range of temperatures, flows and energy usage found in a 'typical' Southland dairy shed before starting improvements. In the 2006/07 season, this same instrumentation was used to measure the results of energy efficiency trials.

Three more dairy sheds (Moorabool, Glencairn and Tussock Creek) were instrumented in the 2006/07 season. The instrumentation installed

	Coldstream Downs Ltd	Glencairn Land Company	Graejo Trust	Moorabool Farm Ltd	Tussock Creek Dairies Ltd
Location	Riversdale	Dipton	Thornbury	Dipton	Winton
Milking system	60 bail rotary	50 bail rotary	38 a side herringbone	40 a side herringbone	50 bail rotary
Herd size	800	680	670	600	750

Table 2.1: Details of the trial farms

in these three sheds was less extensive as it was tailored to suit the equipment being trialed.

Instruments

The instruments used included:

- temperature sensors for measuring air, milk and water temperatures
- flow meters - turbine type for water flows and magnetic type for milk flow
- electricity meters to measure electrical energy use, power and power factor
- pressure sensors for vacuum line pressure

and were mainly sourced through Scott Technical Instruments Ltd.

The instruments were located generally as shown on the diagram in Figure 2.3.

The temperature sensors used were mainly of the thermistor type (Campbell Scientific 108). These were strapped to the outside of milk and water lines and inserted into existing wells in the milk vats. A fast response RTD sensor was used in the milk line leaving the plate cooler.

Simple turbine type flow meters with reed switches to give a pulse output were installed in the water lines. Two ABB brand stainless steel bodied electromagnetic flow meters were used in the milk lines at Graejo and Coldstream.

Watthour (Wh) and volt amp reactive hour (VArh) transducers were used for monitoring the main electricity cable and watthour meters were also installed on the vacuum pump and milk vat refrigeration unit. The water heater elements were monitored using HOBO brand current sensors.

In addition, weather stations supplied Scott Technical Instruments Ltd were installed at three sites (Graejo, Glencairn and Moorabool)

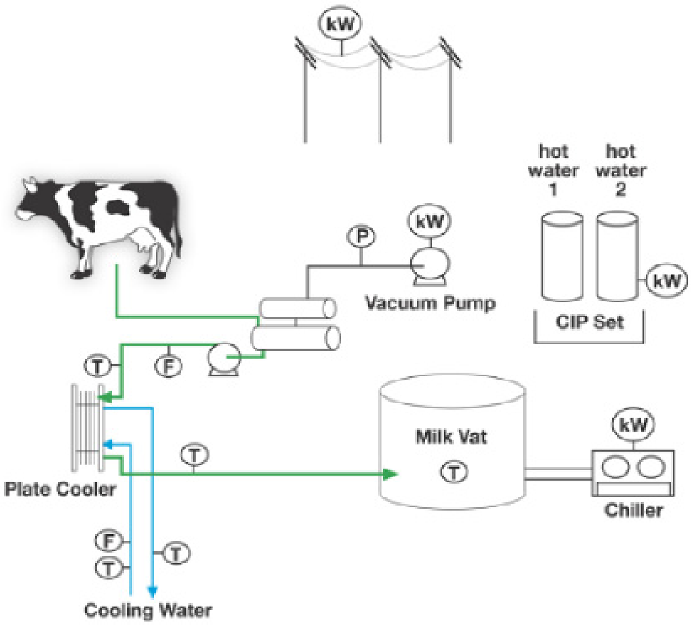


Figure 2.3: Dairy shed flow diagram showing location of instrumentation (T = temperature sensor; F = flow meter; P = pressure sensor; kW = kilowatt hour meter)

to measure air temperature and humidity, wind speed and direction, rainfall and solar radiation.

2.4 Monitoring and Web Display

An important feature of the instrumentation was to provide for all of the data to be made available in real time at a remote location. This was achieved by connecting the instruments to dataloggers located in each dairy shed and providing for the automatic downloading of the stored data by a remote computer using the internet. Most areas of Southland now have broadband internet access through the Woosh Wireless system and this was utilised for this project.

The system was engineered from a broad specification prepared by Venture Southland by Scott Technical Instruments, who provided the equipment and programmed the data loggers. Woosh Wireless provided the Internet service.

Telecommunications

The equipment line-up is shown in Figure 2.4. In order to allow for polling by the CAENZ database computer, the Woosh Wireless connection was provided with a static IP address. This was translated into a local IP address by an off-the-shelf SOHO (Small Office, Home Office) Internet router with Network Address Translation (NAT) ability. The NAT function allowed different devices in the local network to be addressed by the polling computer by translating the local IP addresses to (software) ports on the static address.

An unforeseen difficulty that arose as a consequence of polling the devices from outside of the local network is worth noting. SOHO Internet routers are designed for devices in the local network to initiate sessions rather than for devices outside of the network to initiate sessions. As a consequence, the router is unable to close (software) sockets opened by the polling computer in the Network Link Interface, or serial server, which in turn results in unpredictable polling once all the sockets have been opened. It was found that all the different types of SOHO routers available treated sessions in the same way. The easiest solution was to write a software patch for the Network Link Interface so that it reset itself – and all its registers – before all the sockets had been opened.

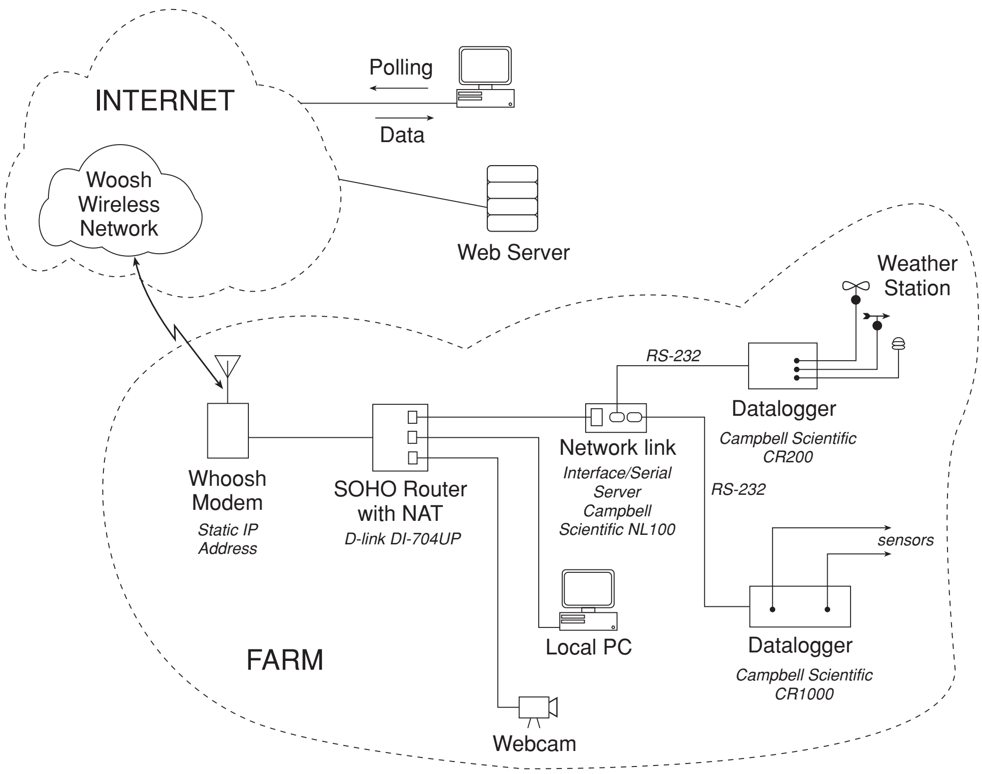


Figure 2.4 Telecommunications equipment line-up

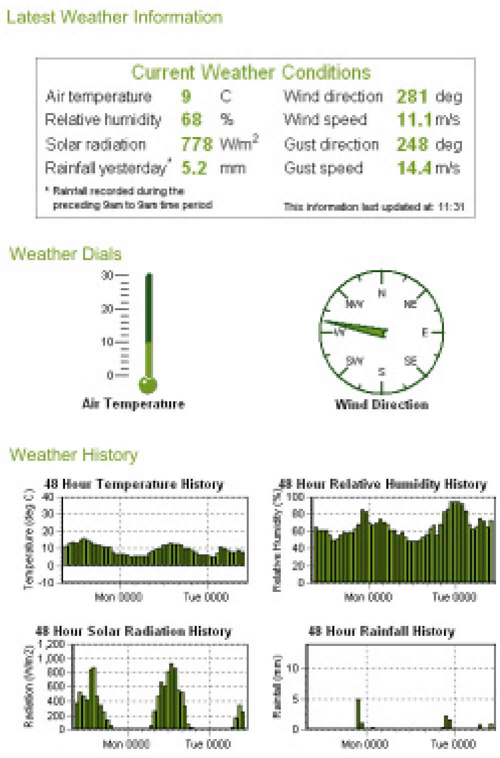


Figure 2.5: Website screenshot showing weather data for Coldstream

Datalogging

Each of the instruments was connected to one of two dataloggers. A Campbell Scientific CR1000 for the dairy shed instruments and a CR200 for the weather station. The dataloggers were programmed to record measurements at time intervals of 1, 5 or 30 minutes and also to process some of the readings and record the result such as maximum and minimum readings and accumulated totals.

The instrument readings and the calculated figures were stored in the memory of the datalogger until a request was received from a computer connected to the logger via the internet.

Data telemetry

At each site, the dataloggers were cabled to a serial server, router and modem located in a panel in the dairy shed. The modem was connected wirelessly to the internet using the Woosh Wireless network. A remote computer connected to the internet and running Campbell LoggerNet software was used to download the data at regular intervals and store the downloaded information as a series of comma delimited text files. This computer was located in Christchurch but could have been located anywhere that internet access was available.

The data files were used in two ways:

- imported into a standard spreadsheet (Microsoft Excel) for technical analysis; and
- used to generate graphs and similar images which were uploaded to the project web site.

Web display

An important aim of this project was to make as much information as possible available to any interested party. The project website http://www.cowshed.org.nz was the main means of doing this with data from the farm instruments being displayed there in 'near real time'.

This was done using Campbell RTDM software to generate graphical images. These images were saved in jpg format and uploaded to the web server using file transfer protocol (FTP) software operating across the internet.

The data for the graphs was downloaded from the dataloggers every hour. Updated images for the web pages were generated two minutes later and immediately sent to the web server via the internet. Examples of these graphs can be seen by visiting www.cowshed.org.nz.

2.5 Economic Analysis for Decision Making

While this report is mainly about improving energy efficiency, one of the main incentives for doing this is the resulting reduction in operating costs. In many cases however, capital expenditure is required to achieve these twin objectives and normal business practice is to carry out an economic analysis before making the decision to invest. There are a number of ways of doing this with the simplest being the calculation of the 'simple payback period' – the number of years of savings it takes to equal the initial cost.

While the simple payback period is a relatively crude method of making investment decisions, it is easily calculated, easily understood and commonly used by equipment suppliers to promote the sale of their products. For these reasons, it has been used in places throughout this report to assist with decision making. Calculations (refer to Appendix A) show that an investment with a simple payback period of 5 years will have a positive return over a 10 year period after including interest, depreciation and taxation. A simple payback period of 5 years is therefore likely to meet normal business investment criteria.

A calculator has also been developed as part of this project and this is available to assist with economic decision making. The calculator calculates both 'simple payback period' and 'net value over 10 years' and can be downloaded from the project website www.cowshed.org.nz.

Costs quoted throughout this report were correct at April 2007 and so may need to be adjusted when carrying out economic analysis at a later date.

Electricity costs

Electricity costs in this report are based on tariffs applicable in rural Southland at April 2007. At that date, electricity purchased on an 'anytime' plan had an average cost of 15 c/kWh after deducting the prompt payment discount and before adding Goods and Services tax (GST). This figure includes the fixed daily charge that a consumer must pay regardless of the energy usage.

When evaluating savings attributable to improved energy efficiency, the fixed daily charge has been excluded and a marginal electricity cost of 14 c/kWh used.

2.6 Experiences and Practical Advice

Some of the experiences and practical lessons learned from the project are summarised below.

Planning the Equipment Installation

- **Adequate Time:** Suppliers and installation contractors can provide better (and possibly cheaper) service if they are given adequate time to plan a job.
- **Reduce Travel Costs:** Travel costs can be a significant part of the total installation cost. Minimise travel costs by ensuring that the contractor can complete all required work at one visit.
- **Coordinating Trades:** In many cases, energy saving equipment for a dairy shed will require more than one type of tradesman to install it. In most cases, the organisation supplying the equipment is able to organise the necessary installation contractors and usually this is the best arrangement. Farmers wishing to use their 'normal' plumber or electrician may find that problems arise with coordinating the work.
- **Quotations:** Ideally, a fixed price should be obtained for any project being contemplated. For a straightforward project that the contractor is very familiar with, it may be possible to obtain a price without having the supplier visit the site. For a project involving less common technology, a site visit is essential. Wherever possible, the quotation should include the total cost of getting the equipment installed and running properly.

Correcting Defects

- **Correcting faulty installation work:** Some of the equipment installed may require one or more return visits from the supplier and/or installation contractor to correct faults. While most contractors will accept that this re-work is done at their expense it is probably worthwhile for a customer to make this point clear at the beginning of the job. The supply and installation of a piece of energy-saving equipment should include all the work necessary to commission it and get it operating as the supplier intended.
- **After sales service:** Some suppliers ensure that their equipment is installed and performing correctly and make a site visit to check this. If possible, a purchase contract should include at least one after-sales inspection visit by the equipment supplier. Some suppliers also offer good telephone support via a free phone number and this can be a valuable service.
- **Watching for defects:** Farmer managers and their staff should be on the lookout for any sign of problems around new equipment. This might include checking the vacuum gauge reading, temperatures, operating times and inspecting for signs of water and refrigerant leaks (A low refrigerant level is

indicated by bubbles in the sight glass on the refrigeration unit).

Staff Training

As dairy farm operations grow in size, farm owners often employ a farm manager and other staff to handle the day–to-day running of the farm. Although many dairy sheds are similar in design, there will often be important differences in equipment between sheds. Any efficiency measure that relies on a person for its success is at risk if that person is inadequately trained for the job.

Staff turnover can also have a negative effect on dairy shed efficiency. If a new manager or new shed staff are not well trained by former staff then energy efficiency may be a casualty.

For best energy efficiency, farm owners need to ensure that their manager is fully informed of all energy saving systems installed and how to use them to best effect. The manager in turn needs to ensure that the shed staff are also fully informed and motivated. This includes any relief or casual staff.

Information

Owners and managers can not manage energy use effectively without good information and most dairy sheds are not adequately equipped with instruments to provide this.

Farm owners and managers would learn useful information about the efficiency of their shed by reading the electricity meter at regular intervals (monthly, weekly or even daily) and charting the total shed energy use. Electricity meters are readily available at reasonable prices and there must now be a good case for dairy sheds to have check metering on the main loads (water heaters, vacuum pump and refrigeration unit).

The milk vat temperature gauge is useful for gauging the efficiency of the milk cooling system and on an energy efficient farm, additional temperature gauges should be considered (water cylinder temperatures, temperature of milk leaving the plate cooler).

3 VACUUM PUMPING

3.1 Introduction

The vacuum pump is the heart of the milking machine and is also a significant consumer of electricity. As an example, a water ring vacuum pump used to operate a 50 bail rotary milking machine might consume 20,000 kWh over a season – typically 17% the total electricity used in the dairy shed.

Three main types of vacuum pump are in common use:

- the water ring pump
- the positive displacement or rotary lobe blower commonly referred to as a 'blower'
- the rotary vane pump

None of the farms in the project had a rotary vane pump installed at the start of the project but one was later installed as a trial.

The water ring pump commonly in use has been manufactured in recent times by the Skellerup Group under the names Allflex and Flomax. It is commonly badged with the name of the milking machine supplier.

Rotary lobe blowers have been used in industry and to supercharge internal combustion engines for over 150 years and are often still referred to as Roots blowers after the American company that was prominent in developing their use. They have only recently been utilised for powering milking machines but are rapidly becoming the most-favoured type of vacuum pump, especially for larger dairy sheds.

Rotary vane pumps have been used for milking machines for many years but have been largely supplanted by the water ring and lobe blower pumps in recent years. They have good energy efficiency but also disadvantages that have reduced their popularity.

Vacuum pump selection

Most dairy shed operators have little input into the selection of the type and size of vacuum pump that is fitted to their milking machine. These decisions are normally left to the equipment suppliers, each of whom will have their own preference for type and capacity.

Each of the three main types of pump available has advantages and disadvantages and these

Water ring	**Rotary lobe blower**	**Rotary vane**
Advantages milk or wash water can pass through without damaging the pump quieter than other designs	Advantages no lubrication required well-suited to speed control higher energy efficiency than water ring pump no water required	Advantages highest energy efficiency no water required
Disadvantages least energy efficient least well-suited to speed control require a continuous supply of good quality water	Disadvantages noisy can be damaged if milk or wash water passes through	Disadvantages requires oil lubrication can be damaged if milk or wash water passes through limits on maximum and minimum speed

Table 3.1: Advantages and disadvantages of three different vacuum pump designs

must be weighed up when deciding which type to install. Factors to consider include

- initial cost
- maintenance requirements
- noise
- cleanliness (oil lubricated pumps can be messy)
- energy efficiency
- suitability for variable speed operation

Some of the advantages and disadvantages of the three pump types are shown in Table 3.1.

A vacuum pump has to be sized with some reserve capacity to allow for leaks and to ensure that the vacuum pressure is maintained within reasonable limits at all times. The basis for choosing the pump capacity has not been investigated in this project but it is assumed that machine suppliers base their selection on the guideline published by the New Zealand Milking and Pumping Trade Association (NZMPTA).

As an example, the NZMPTA guideline gives the air pumping capacity required for a 50 cluster milking machine as 3850 litres per minute. Note that this flow rate is measured at atmospheric pressure, not at the pump inlet pressure which is typically 45 kPa below atmospheric pressure. At the pump inlet, the air flow rate is almost double that at the pump discharge. Some United States literature quotes flow rates at the pump inlet pressure and this can be confusing.

Pressure control

During milking, the rate at which air must be removed from the milking lines will vary as both milk flow and air leakage into the system varies. Without some means of pressure control, the vacuum pressure at the milk receiving can will also vary with this varying flow rate.

Most vacuum pumps operate at a fixed speed although variable speed systems are becoming more common. To prevent the pressure at the milking cups from varying widely as the air flow varies, a system with a fixed speed pump has a pressure regulating valve fitted to the vacuum line. As the pressure sensed in the vacuum line falls below its setpoint (eg -45 kPa), the pressure regulating valve opens to bleed air into the pump suction line and so keep the vacuum pressure stable.

More recently, some vacuum pump motors have been fitted with electronic controls that allow the pump speed to be automatically varied in response to the vacuum line pressure. This is an energy-saving feature.

Noise

All vacuum pumps are noisy but sound level data doesn't appear to be readily available. Anecdotal evidence from suppliers is that water ring pumps are the quietest and lobe pumps the noisiest.

Much of the noise from a vacuum pump is emitted from the exhaust and this can be substantially reduced by fitting an absorptive silencer in the exhaust line.

Transfer of vacuum pump noise into the dairy shed can be minimised by:

- locating the pump in a separate room or acoustic enclosure
- fitting a silencer to the exhaust line
- positioning the pump exhaust so that it points away from any work area

Water Use

Water ring vacuum pumps require a continuous flow of water to make up for the water carried out of the pump with the exhaust air. The water supply arrangement typically seen in Southland is the 'once through' system where the water carried over is drained to waste. A water ring vacuum pump with a 'once through' water supply consumes about 5 litres per minute which compares with about 100 litres per minute for milk cooling.

Variable speed drive

Speed control of standard alternating current (AC) motors has become common in industry since the availability of the variable frequency controller at reasonable prices and, since 1996,

these controllers have been applied to the dairy shed vacuum pump. The main advantage of speed control is that as the pump speed reduces, the power required to drive it reduces also. Most dairy vacuum pumps have a considerable amount of spare capacity at their rated speed and controlling the motor speed results in significant energy savings. There is also the possibility of improving control of the vacuum pressure. However these do not necessarily both occur together.

If there is surplus capacity in the vacuum system and if a standard air-bleed vacuum control system is used there will be:

- a lot of air bleeding as the pump is pulling out much more air than necessary
- a lot of energy wasted through air bleeding
- a fast response to a large demand for vacuum.

If a variable speed drive was installed we might see:

- a large reduction in average power
- slower vacuum control as the motor cannot be accelerated or decelerated quickly.

In contrast if a vacuum system has little surplus capacity and if a standard air-bleed vacuum control system is used there will be:

- very little air bleeding into a standard vacuum control system
- very little energy wasted through air bleeding
- a slow response to a large demand for vacuum.

If a variable speed drive was installed we might see:

- a small reduction in the average power
- better vacuum control as the motor can be run at speeds faster than normal

When comparing these two cases it can be seen that changing to variable speed may result in better vacuum control or lower power use. It is unlikely to give large improvements in both areas.

As well as being installed in new dairy sheds, motor speed controllers can also be retro-fitted to the vacuum pumps in existing sheds. As part of this project, three speed controllers of the Varivac brand (manufactured by Corkill Systems Ltd) were trialled. The results of these trials are reported in Section 3.3 of this report.

3.2 Vacuum pump efficiency

As noted above, the water ring vacuum pump operates with a lower efficiency than the rotary vane or the lobe rotor blower. This means it uses more electricity to pump the same quantity of air.

Typical efficiencies are shown in Table 3.2. Column 1 shows flow performance in litres per minute per kilowatt calculated from catalogue data for pumps operating at a flow rate of 2700 litres per minute and an inlet pressure 50 kPa below atmospheric pressure. Note that the best possible performance with 100% efficiency (adiabatic compression) is about 770 L/min per kW.

Column 2 shows the typical power requirement for the size of pump that would be used in a 50 bail milking system (4000 litres per minute).

The larger the 'flow performance' figure the better; so a rotary vane pump is more efficient than a lobe rotor pump, which is more efficient

Vacuum pump type	Flow performance [L/min per kW]	Power for 4000 L/min [kW]
water ring	300	13.3
lobe rotor (Roots blower)	390	10.3
rotary vane	420	9.5

Table 3.2: Typical vacuum pump performance

than a water ring pump. Based on this table, changing from a water ring to a rotary vane vacuum pump will reduce the energy usage for vacuum pumping by 32%.

A vacuum pump cannot be selected on energy efficiency alone however - other factors such as noise and maintenance requirements have to be considered.

Rotary vane vacuum pump trial

A trial of a rotary vane vacuum pump was carried out at the Graejo Trust farm located near Thornbury.

Graejo has a herringbone milking shed with 38 sets of cups. Details of the existing vacuum pump are shown in Table 3.3.

For the trial, the electrical energy used to drive the pump was monitored by an Electrade LP-1KW3 watthour meter. During milking, the typical operating power (averaged over 30 minutes) was 9 kW.

In October 2006, a rotary vane vacuum pump was installed alongside the existing water ring pump with piping arranged so that either pump could be selected (Figure 3.1).

The rotary vane vacuum system was supplied by Corkill Systems Ltd (CSL) as a unit marketed by them under the name Supervac 7. Details of the rotary vane pump fitted to this unit are as follows

From 4 to 15 November 2006, the pump was run at the fixed speed of 970 rpm. During milking, the typical operating power (averaged over 30 minutes) was 6 kW – a 33% reduction on the power required by the water ring pump.

Daily energy usage for vacuum pumping before and during the trial is shown in Figure 3.2 and in Table 3.5.

Based on this data we estimate that changing from a water ring pump to a rotary vane pump

Figure 3.1: The installed rotary vane vacuum pump at Graejo farm

would reduce energy use by 6750 kWh per year (38%) at Graejo. At an electricity price of 14c/kWh, this saving is worth $945. This saving exceeded the 29% expected from Table 3.1.

Although a significant saving in electricity use is possible, it is unlikely that any farm would find it economic to replace an existing water ring pump simply to save energy. As supplied (and including the oil trap in the exhaust) the complete CSL Supervac 7 vacuum system sells for $16,000. Allowing $2,000 for installation, the total investment was $18,000. A lower cost retrofit could have been carried out by remov-ing the existing water ring pump and installing the new pump and motor on the existing baseplate.

In a new installation and combined with a variable speed drive, this energy-efficient pump would be a more attractive proposition.

The Graejo staff found the noise from the rotary vane pump to be more annoying than the noise from the water ring pump. This was particularly so when the pump was operated at variable speed and the pitch of the sound varied with the pump speed. The main problem was the noise emanating from the pump exhaust. In a permanent installation, it is likely that the noise could be significantly

Motor power and nominal speed	11 kW, 1450 rpm
Pump operating speed	1675 rpm
Air flow rate at 50 kPa vacuum	2675 litres per minute
Air flow rate at operating vacuum (46 kPa)	2975 litres per minute

Table 3.3: Alfa Laval Agri Vp240 vacuum pump at Graejo farm

Motor power and nominal speed	11 kW, 1450 rpm
Pump operating speed	1675 rpm
Air flow rate at 50 kPa vacuum	2675 litres per minute
Air flow rate at operating vacuum (46 kPa)	2975 litres per minute

Table 3.4: Description of the RVS M7000 rotary vane pump installed at Graejo farm

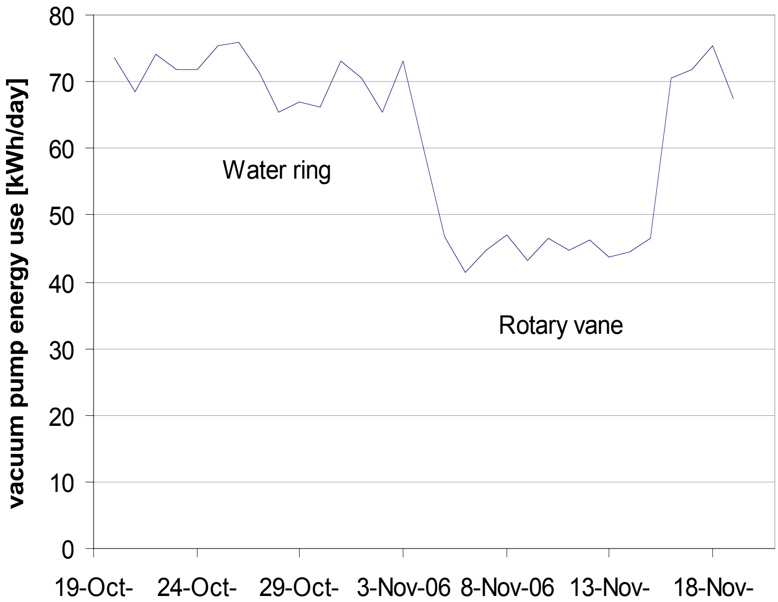


Figure 3.2: Daily energy use at Graejo using the water ring and rotary vane vacuum pumps

	water ring pump[1]	**rotary vane pump**[2]
average daily energy use (kWh)	72	45
estimated annual energy use (kWh)[3]	18,000	11,250

[1] Energy use analysed for the water ring pump from the 13th to the 31st of October, 2006
[2] Energy use analysed for the rotary vane pump from the 4th to the 14th of November, 2006
[3] Assumes that one year's operation of the vacuum pump is equivalent to 250 days at full production

Table 3.5: Comparison of energy use for the water ring and rotary vane vacuum pumps

reduced by the use of a silencer and by directing the exhaust opening away from areas where people are working.

A meter was used to measure the sound level 1 metre away from each pump and the following readings were obtained.

water ring pump:

90 dB(A)

rotary vane pump:

87 dB(A) when running at 1100 rpm
87 dB(A) when running at 920 rpm
91 dB(A) when running at 710 rpm

As a reference, 30 dB(A) is typical sound level for a bedroom at night while heavy traffic or power tools can produce sound at 90 dB(A).

These measurements show that the rotary vane pump was quieter than the water ring pump except when it was running at low speed. As noted above, Graejo staff found the noise from the rotary vane pump to be more annoying. This was possibly due more to the changing pitch as the pump speeded up and slowed down under variable speed control.

Another issue, besides noise, that arose during the trial was oil leakage. Oil leaks from the lubricators and associated pipework were an ongoing problem. Again, it is likely that this problem would have been fixed in time but it highlights the fact that rotary vane pumps require continuous lubrication and this requires dairy shed staff to regularly check lubricator oil levels and add oil when required.

Because of the relatively short length of the trial, no information was obtained on maintenance costs.

3.3 Vacuum pump variable speed control

Speed controllers were fitted to the water ring vacuum pumps at two farms and to the trial rotary vane pump at the Graejo Trust farm. Details of the existing vacuum pumps at those farms are shown in Table 3.6.

An appropriately-sized Varivac speed controller (manufactured by Corkill Systems Ltd) was fitted to each pump motor. In the case of the tandem pumps at Glencairn, a single 15 kW controller was used to control both motors.

In each case, the installation was quite straightforward and was carried out by electrical contractor Munro Electrical. A pressure transducer had to be fitted into the vacuum line but this work was simply done by the electrician and there was no need to have a milking machine fitter on site.

The electrician also commissioned each controller with telephone support from CSL.

Vacuum control

It is claimed that in some cases variable speed control can improve vacuum control. This was checked at the three farms using pressure measurements made in the vacuum line at a point as close as practicable to the milk receiving can. The pressure was measured every second and the average, maximum and minimum values were recorded for each one minute period.

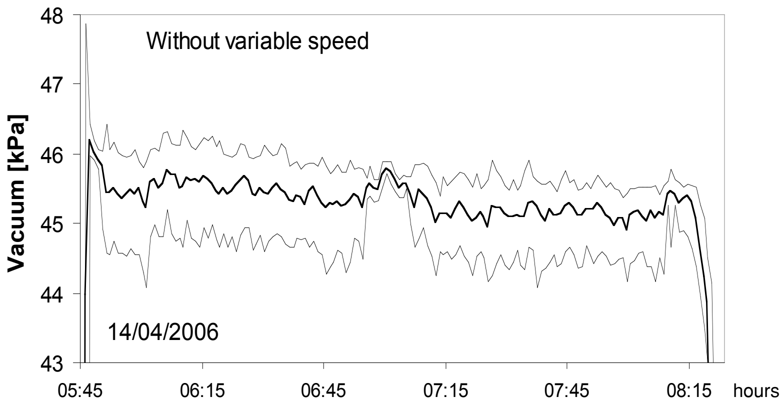
A comparison of vacuum control at Coldstream shows slightly better stability of the average vacuum when using speed control but the range from minimum to maximum is greater. There was no significant advantage for vacuum control in using variable speed.

At Graejo Trust farm, the vacuum control when using the rotary vane pump was typically as shown below in Figure 3.4. As expected there was no noticeable difference between control for the water ring pump and the rotary vane pump. A Varivac was installed on the rotary vane pump and the pressure control obtained was inferior as shown in Figure 3.4.

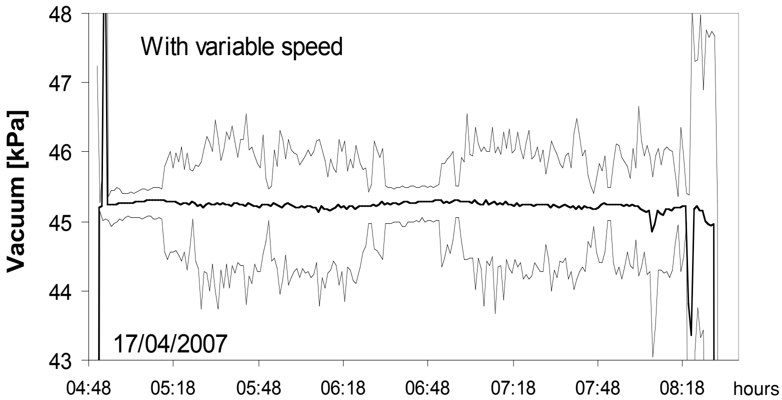
At Glencairn with the Varivac the average vacuum was more consistent but the range (over any one minute period) was greater than control without the Varivac (Figure 3.5). The difference in setpoint is due to local adjustments and is not a point of difference between the two systems.

	Coldstream Downs	**Glencairn**	**Graejo Trust**
milking machine type	60 bail rotary	50 bail rotary	38 a side herringbone
vacuum pump type	water ring	water ring	rotary vane
brand of milking machine	Nu Pulse	De Laval	Alfa Laval Agri
pump manufacturer	Flomax	Flomax	RVS
model	1 x WR1700 1 x WR2400 on a common shaft	2 x WR1700 operating in tandem	M7000
motor power	15 kW	2 x 7.5 kW	7.5 kW
pump speed	1455 rpm	1625 rpm	970 rpm
rated flow rate at 50 kPa vacuum	4000 litres/min	3600 litres/min	2600 litres/min

Table 3.6: Vacuum pumps currently in use



	Avg	Std
Upper line	45.79	0.241
Middle line	45.34	0.215
Lower line	44.68	0.337



	Avg	Std
Upper line	45.87	0.283
Middle line	45.22	0.054
Lower line	44.48	0.367

Figure 3.3: Vacuum pressure control at Coldstream without and with a Varivac showing maximum, average and minimum values recorded every minute

From these three farms there is no evidence that vacuum control is improved by the use of variable speed control of the vacuum pump. However, the control achieved was satisfactory.

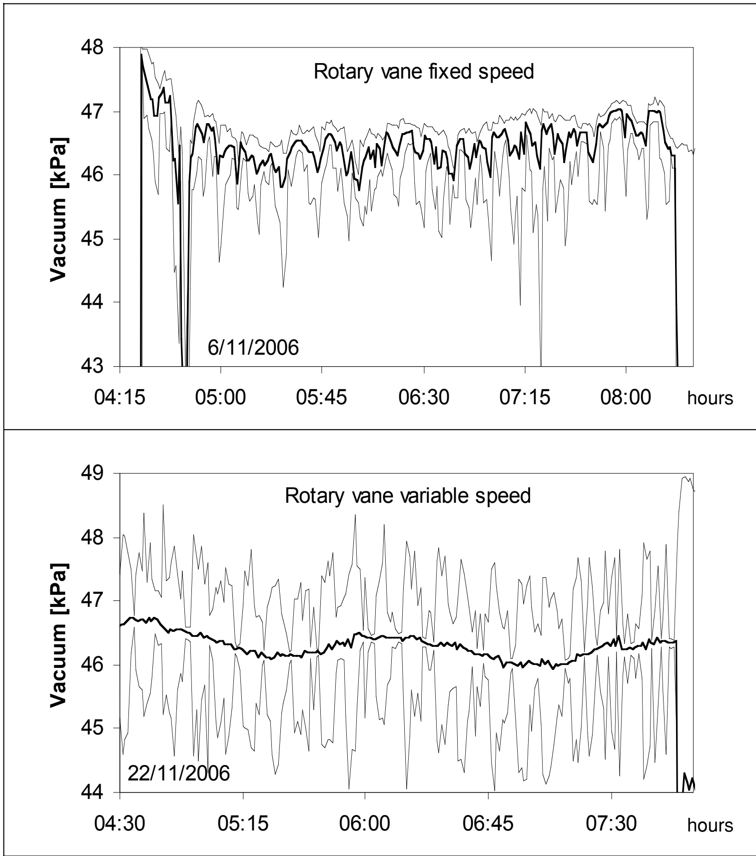
This trial was aimed mainly at determining the energy efficiency benefits of vacuum pump speed control and not at measuring reduction in milk letdown time or incidence of mastitis that are sometimes said to be benefits of variable speed control. Given the lack of improvement in vacuum control however, there seems no reason why vacuum control by variable speed drive would result in reduced milking time or lower somatic cell count that has been reported by others.

Figure 3.6 below shows the somatic cell count in the bulk milk collected from Glencairn over the 2005/06 and 2006/07 seasons. In 2005/06 there was no variable speed control of the vacuum pump. In the 2006/07 season, the Varivac was on and off at the times marked on the graph. The factors that influenced the somatic cell count were not investigated as this was beyond the expertise of the study team. It is possible that reduction in noise and vibration in the milking equipment contributed to the changes but this was not tested.

The vacuum line pressure data shows that the conventional air bleed system can work well. If a farm is having control problems the existing vacuum control system should be checked.

Power Saving

The Glencairn Varivac was commissioned on 20 September 2006. During commissioning, the electrical contractor set the minimum speed setting to 32.5 hertz – equivalent to a pump speed of approximately 1060 rpm. On a later visit by a CSL representative the minimum



	Avg	Std
Upper line	46.78	0.444
Middle line	46.44	0.584
Lower line	45.84	0.834

	Avg	Std
Upper line	47.06	0.523
Middle line	46.28	0.188
Lower line	45.34	0.651

Figure 3.4: Vacuum control without and with variable speed drive on a rotary vane pump

speed setting was lowered to 27 hertz – equivalent to a pump speed of approximately 880 rpm. With this setting, the pump has typically run with a power of 6 to 8 kW during the milking period and rising to full power (15 kW) for short periods during washing.

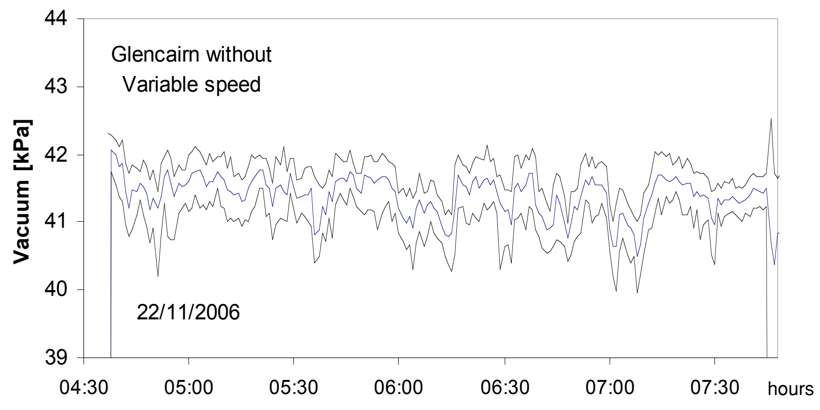
For two periods (3 November to 23 November 2006 and 2 March to 21 March 2007), the Varivac unit was switched to "test" mode which causes the pumps to run at fixed speed as if connected to a normal 50 Hz electricity supply. During these periods the average power consumption was 16.3 kW. This was surprising as the two motors were rated at 7.5 kW each. When the Varivac ran in variable speed mode, the average power consumption was 7.7 kW. Figure 3.7 shows that difference during two milkings on a single day. The pump speed (and hence power) are altered as required to match the demand.

The difference in electricity use between fixed speed running and variable speed running over many months is illustrated in Figure 3.8.

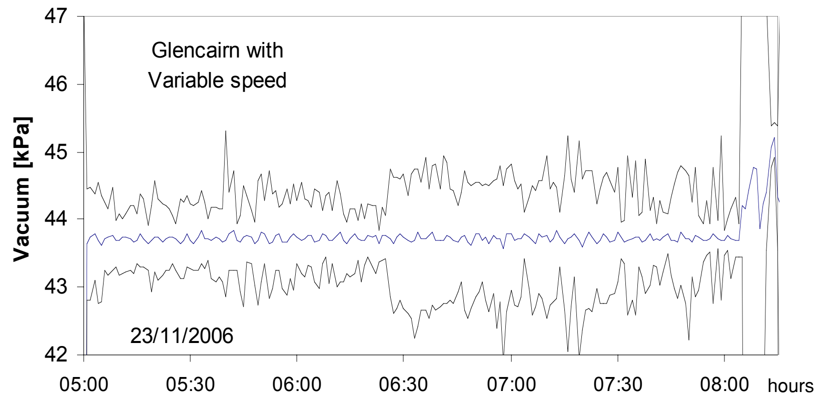
Daily energy use in late November was 44 kWh per day compared with 97 kWh per day in early November – a reduction of 55%. At the end of February daily energy use jumped from 36 kWh/day to 81 kWh/day when the Varivac was set to "test". This also indicated a 55% energy saving when using the Varivac.

For the period 17 October 2006 to 5 June 2007 the Glencairn vacuum pump ran for 1127 hours. Using data from Coldstream and Graejo, where the vacuum pumps ran for 1880 and 1970 hours respectively in the 2006/7 season, it was estimated that the Glencairn pump would operate for between 1440 and 1620 hours over a full season. The saving over an entire season from using the Varivac is estimated to be 12,300 to 13,800 kWh/yr worth $1720 to $1930 per year ($0.14/kWh).

At Coldstream for 27 days in the period 16 March to 14 May there was corresponding data for the same days in both 2006 and 2007 (Figure 3.9). For these 27 days the power consumption was 1480 kWh in 2006 without



	Avg	Std
Upper line	41.73	0.26
Middle line	41.39	0.27
Lower line	40.97	0.32



	Avg	Std
Upper line	44.39	0.29
Middle line	43.72	0.05
Lower line	43.01	0.32

Figure 3.5: Vacuum control at Glencairn with and without variable speed control

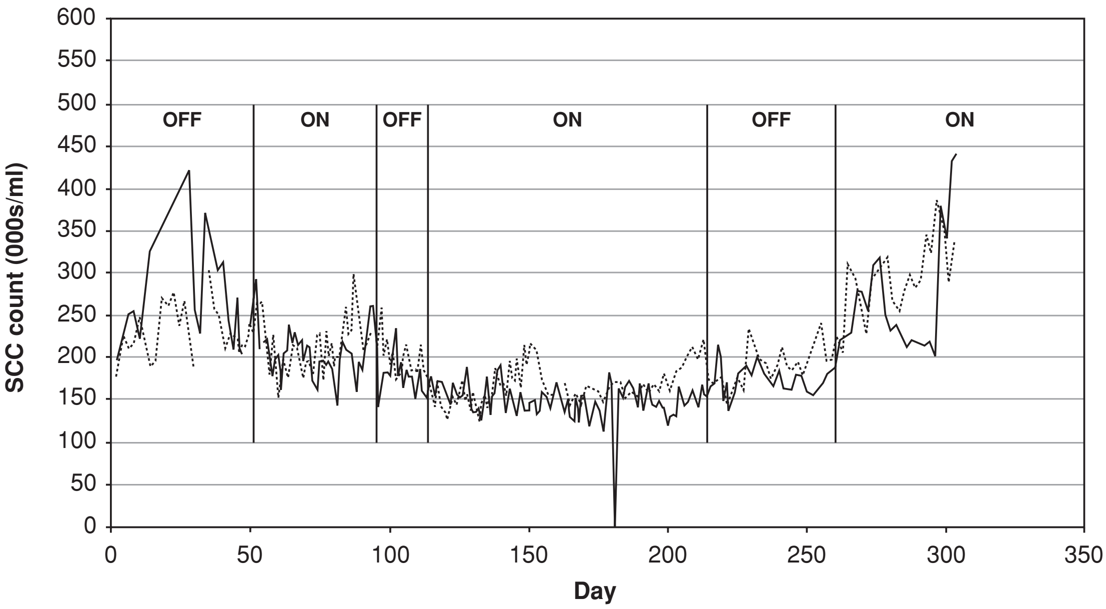


Figure 3.6: Somatic cell count (SCC) at Glencairn over two seasons, 2005/06 (line 1, dotted) and 2006/07 (line 2, solid)

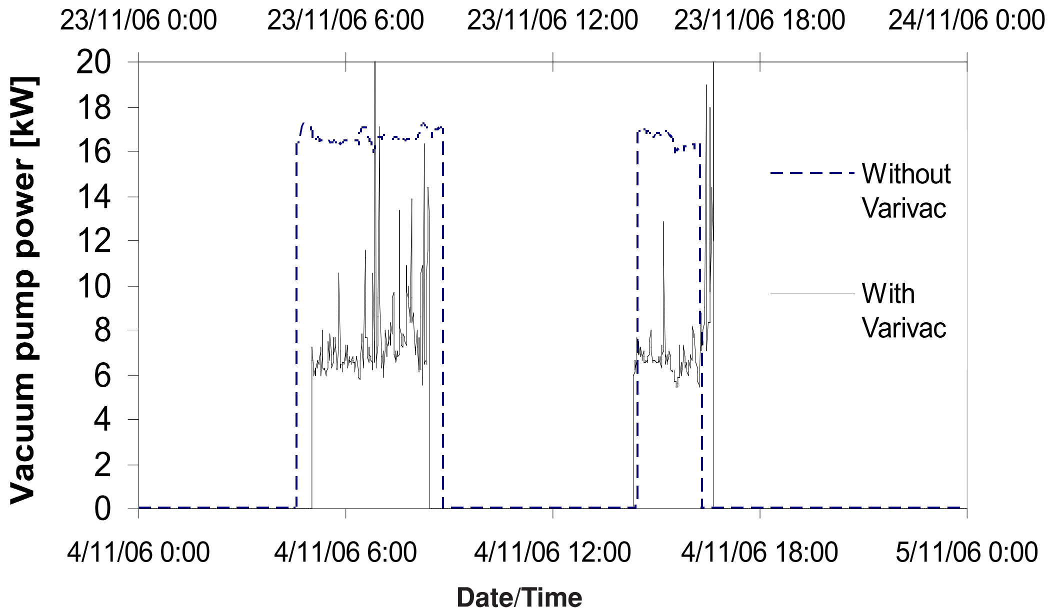


Figure 3.7: The effect of variable speed on power consumption on a typical day

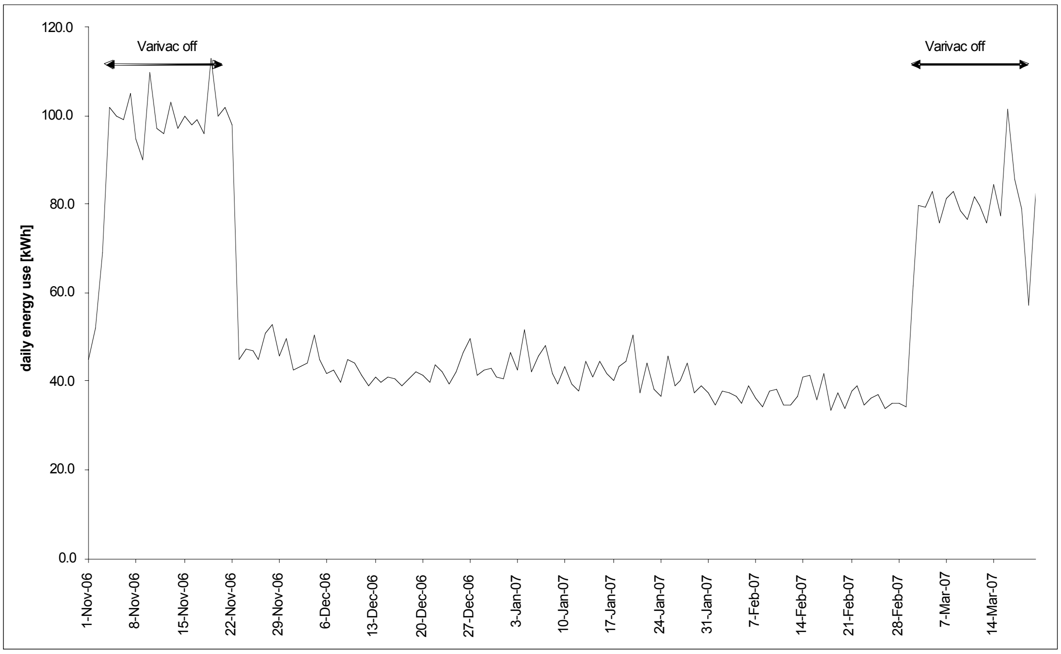


Figure 3.8: Daily energy use for vacuum pumping at Glencairn Land Company 50 bail shed

the Varivac and 980 kWh in 2007 with the Varivac. A saving of 500 kWh (34%) was made with the Varivac.

In the entire 2007 season the vacuum pump used 12,600 kWh all with the Varivac in use. It is therefore estimated that about 6400 kWh of electrical energy was saved. At a value of $0.14 per kWh the saving is $900 over one year.

The effect of variable speed control on the rotary vane pump at Graejo is clearly seen in Figure 3.10 below. When using variable speed

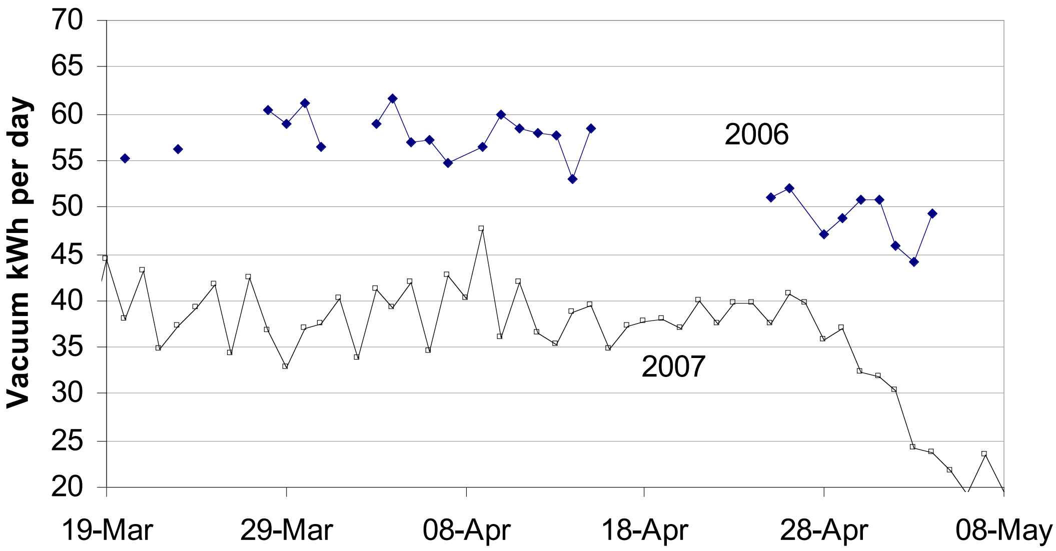


Figure 3.9: Comparison for Coldstream without (2006) and with (2007) variable speed control

control the rotary vane pump had a power consumption of just 56% of the same pump without variable speed. This equates to an energy saving of 5,400 kWh over a season.

Operating experience at Glencairn

While running in variable speed mode, the vacuum pumps were noticeably quieter than when running at fixed speed and the farm manager and dairy shed staff were pleased with this. Subjectively, the farm manager thought the cows were happier when the variable speed control was in operation. There was no measurable evidence that the milking time was reduced. Figure 3.11 shows the hours that the vacuum pump was on for each milking. The periods when the Varivac was on fixed speed (i.e., variable speed is "off") are shown.

There was also no obvious difference in the somatic cell count of the bulk milk sent to the Fonterra processing plant. There are many factors that affect mastitis and somatic cell count and it would be very difficult to prove that running the vacuum pump at variable speed has a beneficial effect.

The lack of any change in somatic cell count is consistent with previous studies. In a Danish study Rasmussen and Madsen (2000) found no

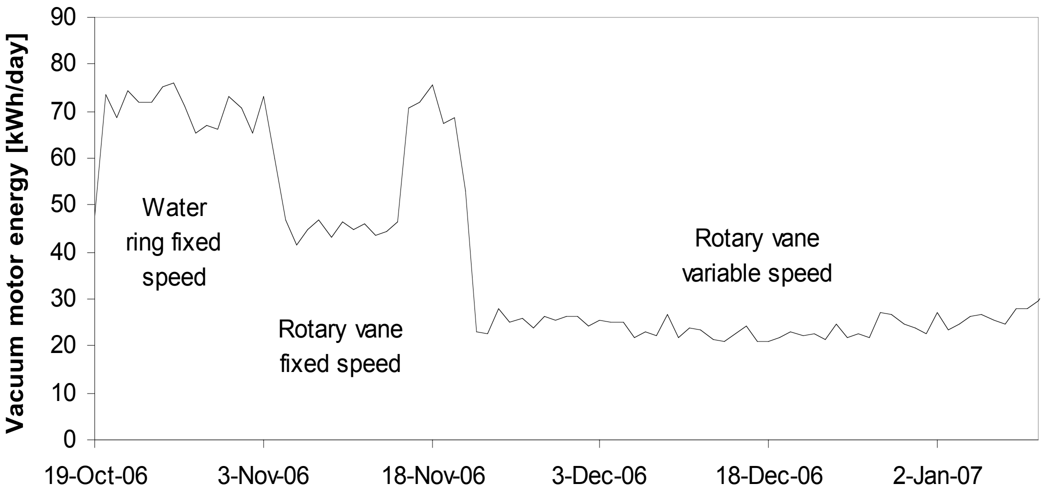


Figure 3.10: Daily energy use for vacuum pumping using a rotary vane vacuum pump with and without variable speed

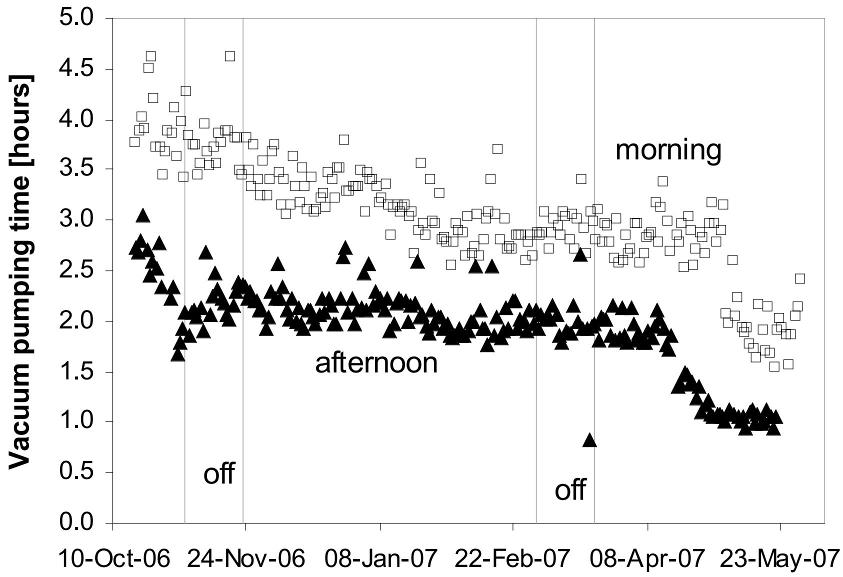


Figure 3.11: The running hours of the vacuum pump were not affected by the Varivac ('off' is where the Varivac was turned off)

effect of vacuum level or pulsator vacuum on the cell count. However a Swiss study by Gygax and Nosal (2006) found a strong correlation between vibration, but not noise, and cell count. It is possible that anecdotal reports of lower cell counts in sheds with the introduction of variable speed control are due to lower vibration levels.

3.4 Energy Savings

There is a significant range in the power requirement of vacuum pumps and energy savings can be made by using an energy-efficient design. Liquid ring pumps are the least efficient and, in this study, rotary vane pumps were the most efficient. The use of a rotary vane pump rather than a water ring pump (11 kW rated at 2675 L/min at 50 kPa vacuum) reduced energy use of the vacuum pump by 6750 kWh per year (38%) for a 38 a side herringbone shed. It is estimated that a lobe blower in the same application would reduce energy use by between 3,900 kWh and 5,300 kWh (22% - 30%).

A further reduction in pumping energy requirements can be achieved with the addition of a variable speed drive system such as a Varivac onto an existing pump. The annual energy savings achieved when a Varivac system was added at three farms are shown in Table 3.7

Combined savings can be achieved if a water ring pump is replaced with a rotary vane or lobe pump with variable speed drive. A saving of 64% is expected for the rotary vane and 61% for the lobe pump.

3.5 Cost Savings

The use of a rotary vane pump rather than a water ring pump saved an estimated $945 per

Farm	Pump	Annual energy saving when using Varivac
Coldstream	Water ring	6400 kWh (34%)
Glencairn	Water ring	13,000 kWh (55%)
Graejo Trust	Rotary vane	5,400 kWh (46%)
Graejo Trust	Lobe pump	6,000 kWh (50%)*

Table 3.7: Energy savings using a variable speed drive on an existing pump
**This is an estimate based on theoretical performance*

year (38%) for a 38 a side herringbone shed. It is estimated that a lobe blower in the same application would save $550 - $750 per year (22% – 30%). These estimates are based on an electricity cost of 14 c/kWh. The influence of electricity price on these figures is shown in Figure 3.12.

Table 3.8 shows the estimated annual cost saving when a variable speed drive such as the Varivac is fitted to an existing pump. These cost savings are based on performance data from Section 3.3 that have been extrapolated over a full milking season. An electricity price of 14 c/kWh is assumed.

The estimated cost savings will vary with electricity price as shown in Figure 3.13.

Further savings can be achieved by combining the above, i.e. replacing the old pump with a more efficient one that has a variable speed drive. Table 3.7 predicts the savings achievable when this is done. The calculation assumed 1900 hours of vacuum pumping per year (it was found that the annual hours were equivalent to 235 times the running hours on the peak day) and flow performance data from Table 3.9.

Figure 3.14 shows the influence of electricity prices on these predicted savings.

Tables 3.8 and 3.9 give estimates of the energy and cost savings, and payback time, from a new vacuum pump and/or variable speed control system.

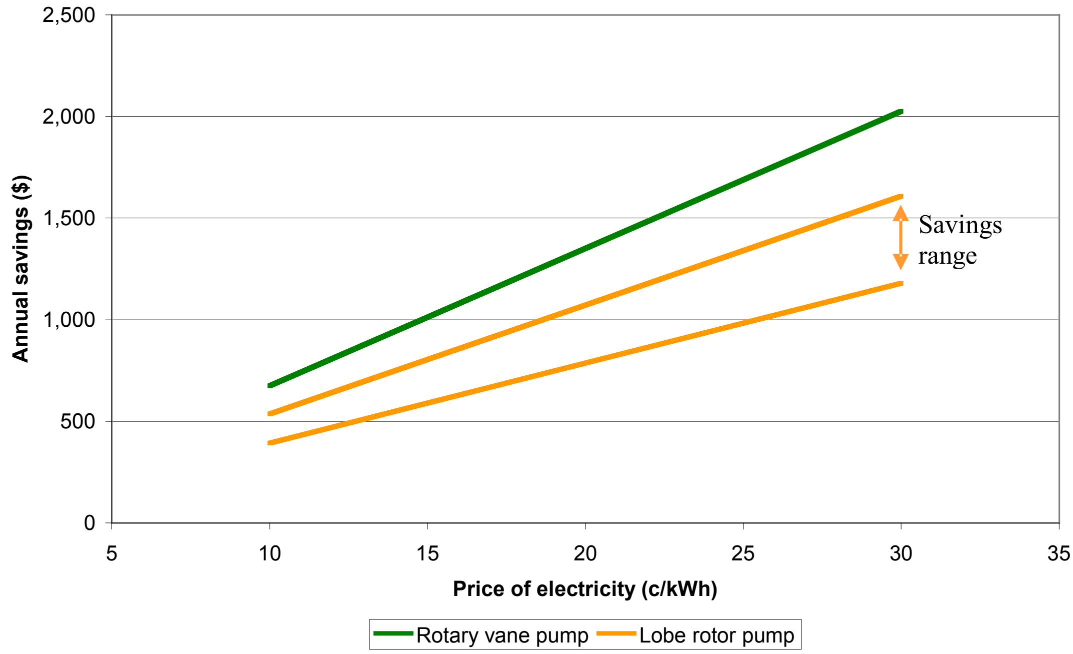


Figure 3.12: Estimated annual cost saving when replacing a water ring pump with an alternative pump type in a 38 cluster dairy shed

Farm	Pump	Annual savings when using Varivac
Coldstream	Water ring	$900
Glencairn	Water ring	$1800
Graejo Trust	Rotary vane	$750
Graejo Trust	Lobe pump	$850*

Table 3.8: Estimated annual cost savings by using a variable speed drive on an existing pump
** This is an estimate based on theoretical performance*

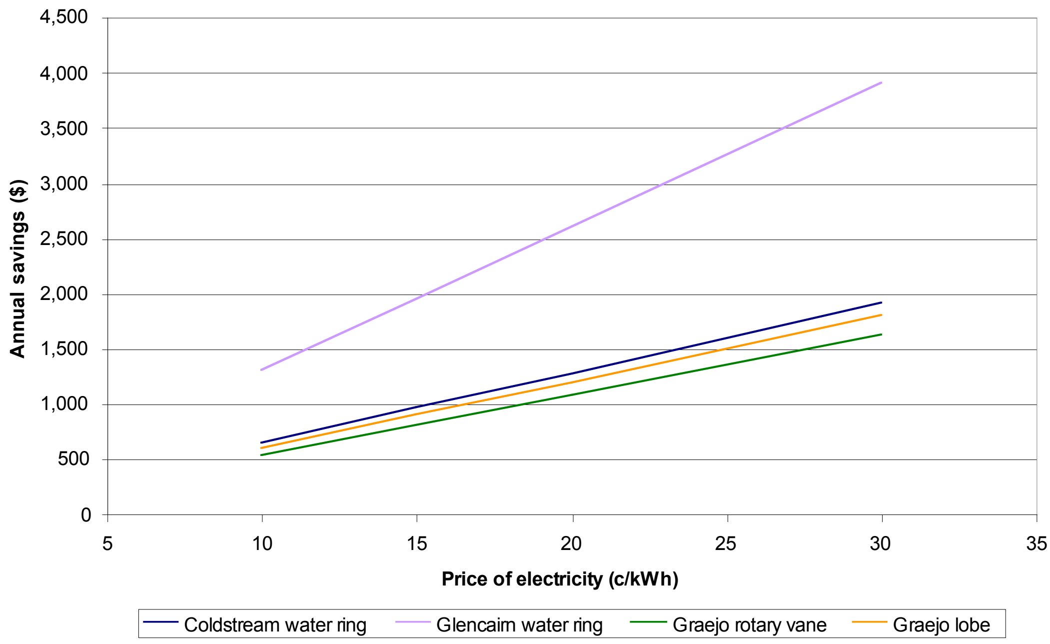


Figure 3.13: Influence of electricity price on the predicted savings from Table 3.6

3.6 Conclusions

Using a 5 year simple payback period as the criterion, changing from a water ring pump to a more efficient rotary vane pump at Graejo Trust farm is only justifiable if it can be done for $5000 or less.

The current Varivac prices are about $7800 for 15 kW and $6500 for 11 kW plus installation of $600. To achieve a 5 year payback period, annual savings of $1680 for a 15 kW system and $1420 for an 11 kW system would be required. The savings achieved at Glencairn were large enough to justify this investment but the savings achieved at Coldstream and Graejo were not.

Again using a 5 year pay back period, an additional investment of $13,000 - $14,000 for a rotary vane or lobe pump with variable speed control would be justified on a 60 bail farm.

It is understood that a lobe pump with variable speed costs about $4000 more than a water ring pump without a variable speed controller. For a new installation the extra investment is likely to be worthwhile for most farms.

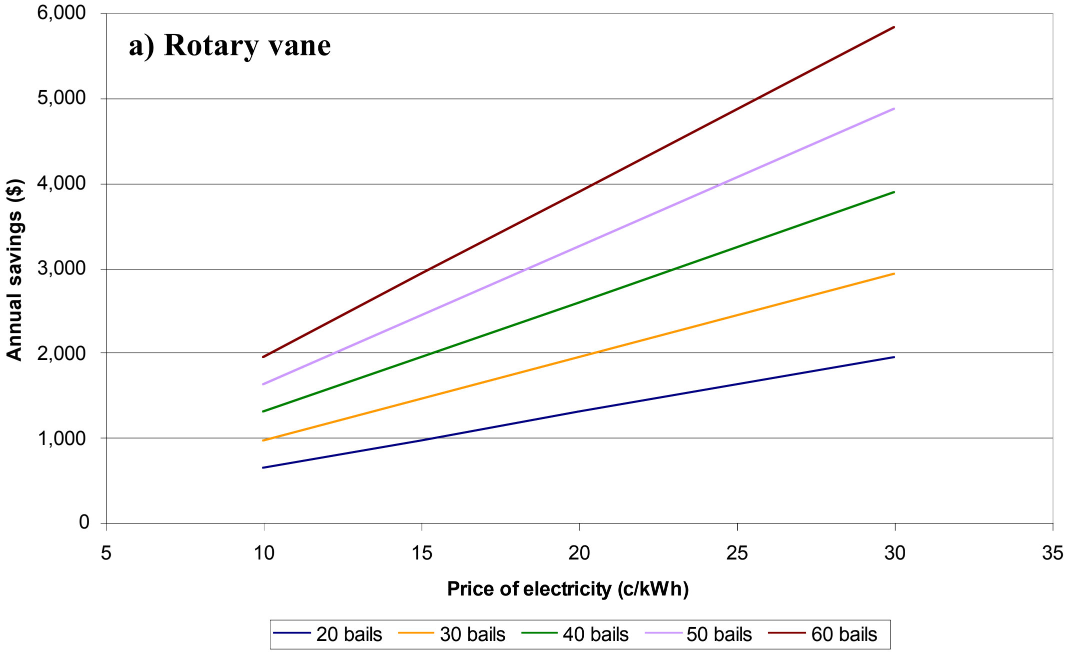
References

Gygax, L and Nosal, D, 2006. "Contribution of vibration and noise during milking to the somatic cell count of milk", *Journal of Dairy Science*, 89:2499–2502

Bails	Design flow rate [L/min]	Saving when using rotary vane with variable speed	Saving when using lobe pump with variable speed
20	1600	$910	$870
30	2400	$1370	$1300
40	3200	$1820	$1730
50	4000	$2270	$2170
60	4800	$2730	$2600

Table 3.9: Annual savings using a new rotary vane or lobe pump with variable speed drive in place of a liquid ring pump

Rasmussen, M D and Madsen, N P, 2000. “Effects of milkline vacuum, pulsator airline vacuum, and cluster weight on milk yield, teat condition, and udder health”, *Journal of Dairy Science*, 83:77–84.



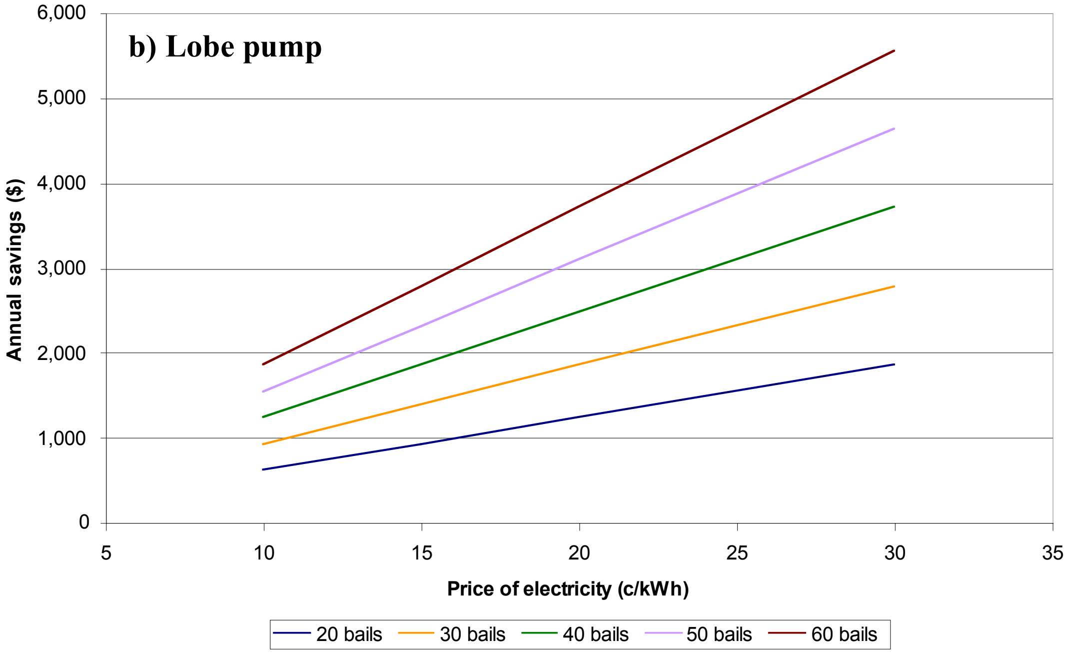


Figure 3.14: Influence of electricity price on the predicted savings from Table 3.7 for a rotary vane (a) and a lobe pump (b) with variable speed drives.

4 REDUCING HOT WATER USE & IMPROVING SYSTEM EFFICIENCY

4.1 Introduction

Cleaning the Milking Plant

After each use, the milking plant and the milk storage vat must be cleaned to remove the milk residues (soil) from the internal surfaces. Effective cleaning is normally considered to require adequate amounts of:

- mechanical force;
- cleaning chemical;
- heat; and
- contact time.

Commonly, cleaning procedures are recommended by the supplier of the washing chemicals and a typical recommendation for the milking plant is to wash with hot water after morning milking and with cold water after afternoon milking.

It is usually recommended to begin with a hot water temperature of at least 80°C and to circulate the wash water for at least 5 minutes to get adequate contact time. At the end of washing, the water should be still above 60°C to ensure that fat is not re-deposited on the cleaned surfaces.

The New Zealand Food Safety Authority (NZFSA) code of practice 'NZCP1: Code of Practice for the Design and Operation of Farm Dairies' provides practical guidance on most matters related to dairy shed hygiene including cleaning. It recommends the use of hot water for cleaning and in Section 15.4.1 says :

> *'The minimum quantity of hot water available shall be 10 litres per set of cups and 2% of the vat volume with a minimum volume for vats of 120 litres.'*

As an example, a farm with 50 sets of milking cups and a milk vat of 25,000 litres would require at least 1000 litres – 500 litres for the plant wash and 500 litres for the vat wash.

Energy used for water heating

The amount of energy used to heat water in a dairy shed depends on:

- how much hot water is used
- the temperature range through which the water is heated
- the efficiency of the heating and storage system.

A 50 bail dairy shed typically uses about 1,000 litres of hot water each day but this figure could rise to 1,500 litres if the cleaning procedure requires the milk lines to be washed twice with hot water.

On-farm monitoring has shown that the amount of energy (usually electricity) required to heat this water from 10°C to 85°C and to hold it at this temperature is about 0.1 kWh per litre in a conventional electric water heater. Considerably less energy is required by the water heater if there is some means of pre-heating the water e.g. a heat recovery unit on the refrigeration system.

Table 4.1 gives some examples taken from farms monitored in this project and before any energy saving equipment was installed

Most reports on New Zealand dairy sheds suggest that the proportion of total shed energy used for water heating is around 30%. In the five dairy sheds that have been monitored in this project, water heating accounted for between 22% and 36% at the beginning of the project. As energy-saving equipment was introduced however, the portion of the total used for water heating also changed. For example, at Glencairn in April 2007, only 15% of total energy usage went into water heating. This is because of the use of a heat pump at this site.

A 'typical' dairy shed that uses 1,000 litres of hot water per day during most of the season might expect to consume 250,000 to 300,000 litres of hot water in a full season. Based on

	Coldstream	Glencairn	Graejo	Moorabool	Tussock
number of cupsets	60	50	38	40	50
milk silo capacity (litres)	1 x 16,000 1 x 14,000	21,500	18,000	14,000	1 x 17,000 1 x 9,000
typical daily hot water use (litres)	1,500	830	815	700	1,120
typical electricity used for water heating each day (kWh)	150	85	87	75	110
electricity used for water heating each year (kWh)	36,000	23,500	24,500	20,000	32,000
total annual electricity use (kWh)	130,000	107,000	112,000	87,000	90,000
proportion of total electricity used for water heating	28%	22%	22%	23%	36%

Table 4.1: Water heating energy use at trial farms prior to implementing changes

0.1 kWh per litre, the 'typical' shed will therefore consume 25,000 to 30,000 kWh of electricity per year for water heating.

Cost of heating water

Most dairy sheds in Southland use electricity for water heating. The average price of this electricity in April 2007 was:

- 15 c/kWh where an 'anytime' pricing plan was used.
- 8 c/kWh where a 'night rate' supply was used.

A dairy shed using 25,000 kWh per year for water heating can therefore expect to pay between $2,000 and $3,800 for water heating depending on the cost of the electricity used.

4.2 Water Heating System Design

Features of Commonly Used Water Heating Systems

All dairy sheds (with one exception) visited in connection with this project had electric water heaters. The exception was a shed that had gas-fired water heaters that were supplied with LPG from 45 kg cylinders.

A typical electric system consists of water heaters (usually two) built to New Zealand Standard 4604 'Dairy-Type Thermal Storage Electric Water Heaters'. These heaters have a copper or stainless steel tank, polyurethane foam insulation and a metal or plastic protective outer casing. They are available in a range of capacities but the most common are 350 to 500 litres in capacity. Usually two electric heating elements each of 3 kW rating are fitted and each element has a separate thermostat.

Normally the two water heaters are positioned above a wash tub (typically of 500 litres capacity) and when hot water is required for washing the milking lines or the milk storage vat, it is drawn off from a valve near the base of one of the heaters and flows directly into the wash tub.

It is normal for the hot water piping to be uninsulated.

Filling of a dairy water heater is usually started by opening a valve in the cold water inlet line. Sometimes this line is directly connected to the dairy shed cold water supply and shed staff must monitor the filling and shut off the supply when the heater is full. More often the cold water comes from a small tank (typically a standard toilet cistern) mounted on the wall beside the water heaters. This tank is fitted with a float valve so that the water supply to the heater automatically shuts off when the heater is full. A 'non-return' or 'check' valve is usually fitted at the cold water inlet to prevent water from flowing between heaters that have a common feed system.

Reducing Hot Water System Heat Losses

While the amount of energy required to heat water from cold to 85°C is fixed according to the laws thermodynamics, there is an opportunity to improve the energy efficiency of the water heating system by reducing heat losses from the cylinder and pipework.

In this project the heat lost from a dairy hot water system was studied in two ways :

- by monitoring the energy use of actual water heating systems in five Southland dairy sheds; and
- by measuring hot water cylinder heat losses under controlled conditions.

On-farm measurements

The amount of electricity used for water heating was monitored at five farms. All farms used electric storage water heaters and details of the water heaters installed are as shown in Table 4.2.

The power demand of each water heater on the five farms was monitored using a current meter. The current was measured every second and the 5 minute average recorded in the datalogger. The rate of heat loss was assessed by looking at electricity usage during the period when the water had reached its required temperature (nominally 85°C) and the heating elements were switching on and off as required to maintain the water temperature.

Trial at Multi Machinery Superheat

During January and February 2007, trials were carried out in the Christchurch factory of water heater manufacturer Multi Machinery (Superheat) Ltd. A 300-litre Dairy Heat hot water cylinder with a 3 kW element was set up and fitted with pipework to simulate a typical dairy shed installation.

The setup used was as shown in Figure 4.1.

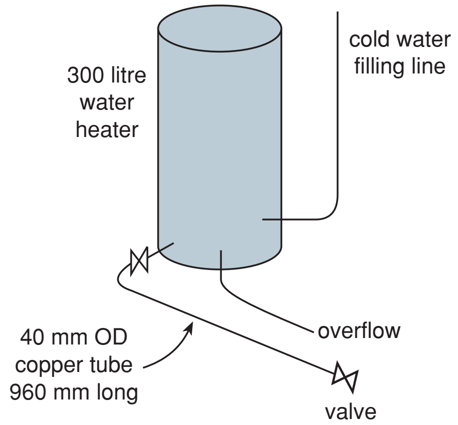


Figure 4.1: Water heater trial at Multi Machinery (Superheat) Ltd

A copper pipe 40 mm diameter and 960 mm long was attached to the 40 mm diameter hot water outlet on the cylinder. This pipe had a valve at each end and could be left empty or full.

Hobo brand current and temperature sensors were used to monitor:

- the heating element current;
- temperature of the water in the cylinder; and
- ambient temperature.

The data was recorded using a Hobo datalogger.

The water heating system was then used to carry out a series of trials to determine the potential for saving energy and cost by adding

	Coldstream	Glencairn	Graejo	Moorabool	Tussock
no. & capacity	2 x 600 litres	2 x 500 litres	2 x 400 litres	2 x 350 litres	2 x 500 litres
year of manufacture	unknown	2001	2001 & unknown	2000	2006 & 2001
insulation grade	unknown	A	A & unknown	A	A
elements in each	3 x 3 kW	2 x 3 kW	2 x 3 kW	2 x 3 kW	2 x 3 kW
electricity supply	anytime	anytime	night rate	day/night	anytime

Table 4.2: Water heaters installed on five monitored farms

insulation to the water heater and/or the pipework.

Results of On-Farm Measurements

Table 4.3 is a summary of the heat loss data from the monitored farms. This data is an average of measurements made on ten separate days during the months shown.

Table 4.3 shows that the Moorabool water heaters were held at temperature for a much shorter time than the heaters on the other four farms. This is because they are controlled by time switch to turn on at 12.30am. This 'just-in-time' heating approach minimises heat loss and the cost of electricity for keeping the cylinders at temperature.

The other four farms refill the hot water cylinders immediately after use. Once up to temperature, these cylinders lose heat at the rate of 320 to 500 W until the hot water is required, often not for at least 18 hours and sometimes much longer. Over a 24 hour period it is not unusual for a single water heater to consume 10 kWh of electricity simply to make up for these heat losses.

Over the five farms the average rate of heat loss was 440 W. This is equivalent to an energy loss of 3170 kWh over a 10 month season. At 14 c/kWh, this electricity is worth $440. The actual loss will be less than this, as this figure does not take into account the time the cylinder spends refilling and reheating after use. However, the value would be substantially higher if the water heating system was not in good repair e.g. it had a leaking tap.

Ways to reduce this heat loss include

- reducing the length of time a hot water cylinder remains at temperature, i.e implementing 'just-in-time' heating;
- adding thermal insulation; and
- eliminating leaks.

Results of Workshop Tests

Measures to reduce heat losses were tested by trial 2. In this trial, heat losses were measured from a 300 litre hot water cylinder at 90°C. The cylinder was set up in the workshop of Multi Machinery (Superheat) Ltd and this ensured that it was not exposed to wind or large variations in the ambient temperature (average ambient temperature for each run varied between 18°C and 20°C).

Four conditions were altered and the resulting effect on the rate of heat loss determined. The yearly cost of making up this loss (assuming that conditions remained constant) was calculated and compared.

The conditions altered between experimental runs were:

- In some runs hot water was left in the outlet pipe; in other runs this pipe was drained and left empty.

Farm	Water Heater	Month	Time at temperature [hr]	Energy used while at temperature [kWh]	Heat Loss rate [W]
Coldstream	1	February	11.4	5.8	500
	2	February	13.2	5.9	450
Glencairn	1	March	19.6	9.0	460
	2	March	20.0	8.2	430
Graejo	1	February	17.7	7.6	430
	2	February	17.6	5.7	320
Moorabool	1	March	2.8	1.7	600
	2	March	1.0	0.8	320
Tussock	1	February	12.6	5.9	480

Table 4.3: Measured heat losses from five dairy shed hot water systems

Note: Values shown are the average of ten readings obtained on separate days during the month listed

- In some runs the outlet, inlet and overflow piping was insulated with 30 mm thick fibreglass insulation.
- In half the runs a fan was located by the hot water cylinder, which pushed air across the front of the cylinder at an average speed of 2 m/s. The air was pushed across the front half and bottom two thirds of the cylinder. The front of the cylinder was the side that contained the three external pipes, i.e. the external piping was exposed to the airflow.
- For two runs, extra insulation was added to the cylinder.

The results of this trial are summarised in Table 4.4.

The minimum heat loss rate measured was 146 W (3.5 kWh per day) but this was with the outlet piping empty, cylinder and piping additionally insulated and in still air. Under conditions designed to more closely mimic those in a dairy shed (outlet piping full, no additional insulation, fan on) a heat loss rate of 338 W was measured. Note that this is still lower than the average 440 W measured on the farms.

This data shows that:

- air movement around the cylinder and piping had the largest influence on the rate of heat loss.
- the majority of the heat loss was from the external piping.
- a cylinder wrap gave a small reduction in heat loss rate.

Recommendations on Heat Losses

It is clear that reducing heat losses can give worthwhile savings. Two approaches can be taken to achieve this.

Firstly, adopt 'just-in-time' heating – refer to Section 4.4. Secondly, the hot water system should be designed and maintained to minimise heat losses. The main points to consider are:

- Location – cylinders and their piping that are exposed to air movement will have substantially greater heat loss than those in still air. Locate new cylinders indoors in a sheltered location. Existing cylinders and piping that are exposed to draughts will benefit from being enclosed or otherwise shielded from draughts.
- Pipe insulation – insulate all warm pipework
- Cylinder insulation. A modern cylinder in good condition will not benefit greatly from having a cylinder wrap added - insulating the pipework is a better investment. Older cylinders or those that are exposed to the

Experimental set-up			**Heat loss rate**	**Electricity use**	**Estimated annual cost [1]**	**Relative annual cost**
Outlet Piping	Pipes Insulated	Fan on	[W]	[kW/h per day]	[$]	[$]
Empty	No	No	196	4.7	165	42
Full	No	No	210	5.1	176	54
Empty	Yes	No	150	3.6	126	3
Full	Yes	No	157	3.8	132	9
Empty	No	Yes	303	7.3	255	132
Full	No	Yes	338	8.1	284	161
Empty	Yes	Yes	200	4.8	168	45
Full	Yes	Yes	189	4.5	159	36
Empty	Yes + wrap	No	146	3.5	123	0
Empty	Yes + wrap	Yes	174	4.2	146	24

Table 4.4: Results of heat loss trials on a 300 litre dairy water heater
[1] Estimated annual cost is based on 14c/kWh and a 10 month season with the cylinder at temperature for 17 hours per day.

wind will benefit more from a cylinder wrap.

The dairy shed hot water cylinders monitored had an average heat loss rate of 440 W. In comparison the best performance achieved in the workshop trial was 150 W. The cost saving that would be achieved by reducing the loss rate from 440 W to 150 W would be $195 per year per cylinder. This number is based on an electricity cost of 14 c/kWh and assumes the cylinders are at temperature for 16 hours a day, 300 days a year. The annual cost saving at other electricity prices is shown in Figure 4.2.

Based on a 5 year payback, expenditure of $800 per cylinder would be justified to achieve this saving.

4.3 Reducing Hot Water Use

An obvious way to reduce the energy used for water heating is to use less hot water but this must not be done at the risk of affecting shed hygiene and milk quality. An annual cost saving of $2,000 would be quickly wiped out by the cost of having a load of milk down-graded because of inadequate cleaning of the plant or vat.

Ways to minimise hot water use include:

- eliminating losses from dripping taps or overflowing cylinders.
- optimising the cleaning procedure so that the minimum amount of hot water is used for each wash.
- reducing the frequency with which the dairy shed equipment is washed with hot water.

Eliminating water losses

A dripping hot tap is an obvious source of energy loss but it is not always appreciated how big a loss can occur. During this project, it was noted that a water heater outlet valve was not sealing and hot water was dripping steadily into the wash tank below. The flow rate was measured and found to be the equivalent of 144 litres per day. Assuming this water to average 70°C, the system was losing 9 kWh of energy per day. If left unchecked for the whole 300 day season, this drip would have wasted 2,700 kWh of electricity worth $380.

Optimising the cleaning procedure

It was noted during the trials of heat recovery equipment that two similar 50 bail sheds (Tussock Creek and Glencairn) had significantly different hot water usage. Both sheds are fitted with the DeLaval Hygenius automatic cleaning system and both aimed to use 1000 litres of hot water each day - 500 litres for the plant wash and 500 litres for the vat wash.

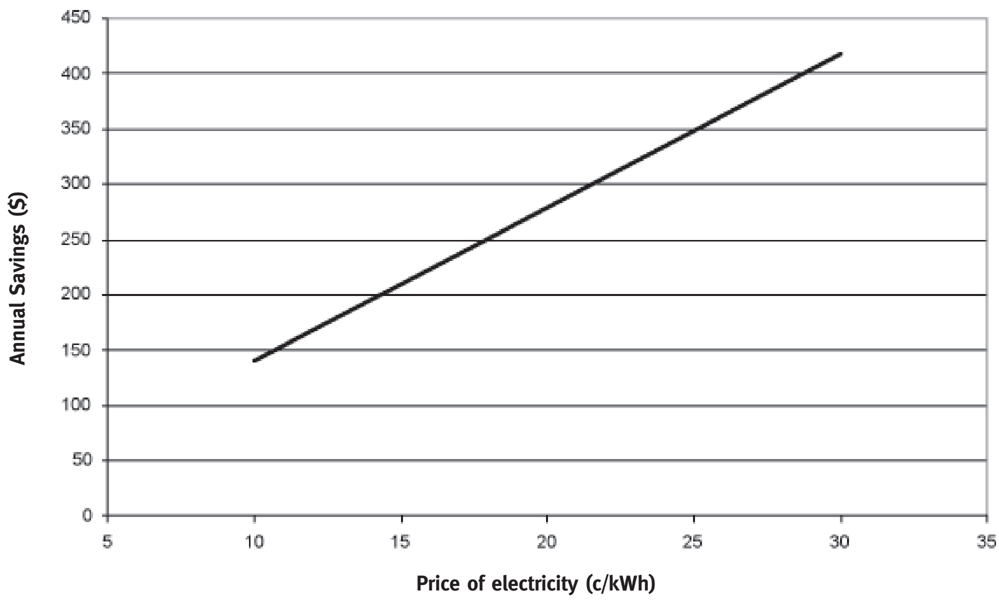


Figure 4.2: Annual savings that would be achieved if the rate of heat loss from water cylinders on the monitored farms was reduced to the level achieved in the workshop trial.

Metering of the cold water feed to the heaters at both sites showed that on an average day Tussock Creek was using 1200 litres of hot water and Glencairn was using 830 litres. The reason for this was not established with certainty but one possibility is that the water level sensor in the wash tub was set too high in the case of Tussock Creek and too low in the case of Glencairn. Glencairn had no trouble meeting milk quality tests and so the under-use of hot water was not detrimental to plant hygiene in that case.

This finding shows that actual hot water use can be significantly different from that planned. There is an opportunity for any shed to reduce hot water use to that required by the cleaning procedure and make a saving in heating costs.

DeLaval advertising for the Hygenius (C200) washing system claims that hot water and detergent use can be significantly reduced when changing from manual washing to their automated system. This claim was not investigated in this project.

Reducing the Frequency of Hot Water Washing

The cost of heating water for cleaning can be reduced by doing more cleaning with cold water. This energy and cost saving measure was not given a practical trial in this project but the cost saving for any particular dairy shed can be easily estimated given some basic data. The information and comments below are based on calculations and on information provided by detergent supplier Deosan Ltd.

The cost savings quoted are theoretical and actual savings may differ from those calculated.

Equipment cleaning

The washing procedure varies from farm to farm but typically one wash each day uses hot water and the other uses cold water. Two detergents are normally used –an alkali detergent on one or two days per week and an acid detergent on all other days. The alkali wash is always followed by a cold rinse containing acid detergent. It is normal to use the same acid detergent in both hot and cold washes.

Each milk vat is washed after it is emptied – usually once a day but sometimes once every two days. In the calculations, it has been assumed that hot water is used for all vat washes.

Electricity cost saving

Based on the recommended hot water quantities, a farm with 38 sets of milking cups and a milk vat of 18,000 litres would require at least 740 litres – 380 litres for the plant wash and 360 litres for the vat wash.

If such a farm reduced hot washing of the plant from once a day to once every two days (and retained a daily hot wash of the vat), the number of hot washes would reduce from 280 to 140 per season. Deosan recommend that hot washing frequency is not reduced during the first 8 or so weeks of the season while calving cows are producing colostrum. This is a precautionary measure due to the high fat content of colostrum milk. This increases the required number of hot washes to 168 so 112 hot washes might be saved over the remainder of the season.

Each hot wash requires about 120 MJ (33 kWh) of energy[1]. Over one milking season the possible saving in electricity for this shed is about 3700 kWh and at the current Southland electricity price of 14 c/kWh, this is worth $520. A smaller shed using 240 litres of hot water per wash would save 2400 kWh ($330) and a larger shed using 600 litres would save 5900 kWh ($820).

The value of these energy savings at different electricity prices is shown in Figure 4.3.

Detergent

Changing to a programme of reduced hot washing requires a change in detergent. Deosan Ltd supplies a suitable detergent ('Supernova') that is applied at a concentration of 1 millilitre per litre of water. Other detergents designed for a daily hot wash routine are usually applied at a concentration of 1.5 millilitre per litre of water.

A change to 'Supernova' may change the cost of detergent and therefore reduce (or increase) the cost saving achieved by reduced electricity use. No assessment or comparison of the price of detergents was made in this study due to the large variability in detergent prices

[1] (380 kg of water x 75°C increase in temperature x 4200 J/kg)

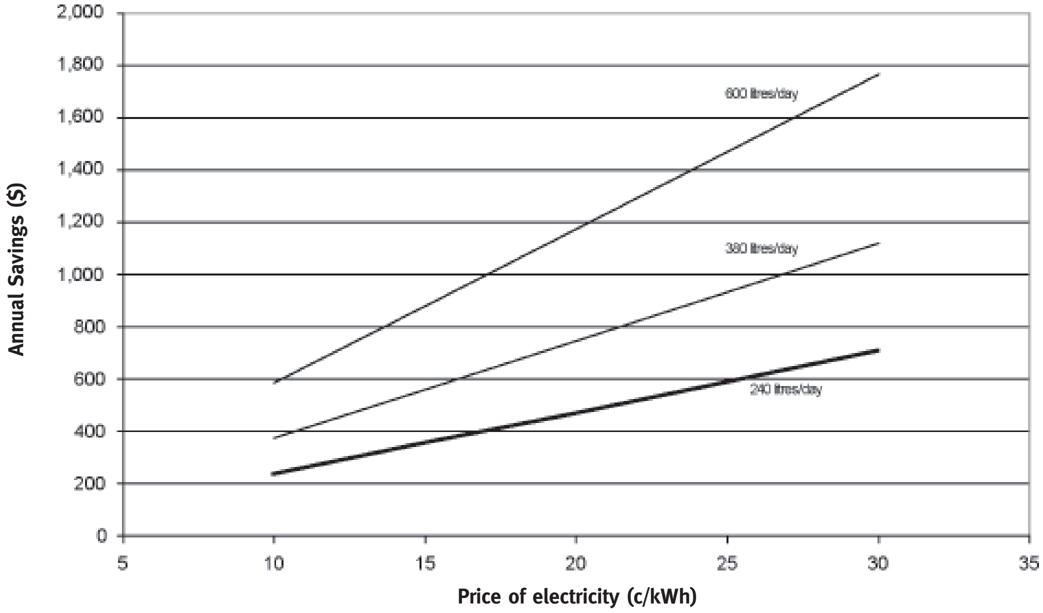


Figure 4.3: Estimated annual savings for reducing the number of hot washes on a farm from 280 to 168

depending on the type and supplier.

Approval for Use

No assessment of the effect of reduced frequency hot washing on plant hygiene and milk quality was made in this project. It is noted however that for compliance with the Animal Products (Dairy) Regulations 2005, washing chemicals for use in a farm dairy must be approved by the New Zealand Food Safety Authority (NZFSA). It is reasonable to assume that an approved product used in accordance with the manufacturer's instructions will not adversely affect milk quality.

Prior to seeking NZFSA approval, Deosan conducted trials on a number of dairy farms to investigate the efficiency of reduced frequency hot washing. The trials were overseen by an independent consultant with experience in dairy hygiene issues. The trial results were assessed by AgriQuality Ltd who certified the product as suitable for use in a reduced frequency hot washing programme subject to the farm meeting all requirements of the Deosan protocol and to the dairy shed hygiene being unaffected.

All farmers are required to carefully monitor their dairy cleaning systems to ensure that good hygiene is maintained and users of the Deosan reduced hot washing programme are no exception. Fonterra have a system in place to monitor shed hygiene and milk quality and will notify the supplier of any deficiencies. Some detergent suppliers also offer assistance with plant inspections and with identifying and resolving cleaning problems and some customers are happy to pay a higher detergent price to get this service.

Cost saving

In the example given above, the electricity cost saving is $520 per year before taking account of any difference in detergent cost. The 'Deosan' company website (http://www.deosan.co.nz/) provides an 'on-line' calculator that can be used to calculate the savings that would be achieved by adopting their wash programme in place of an existing wash programme. This calculation takes account of both electricity savings and the change in detergent cost. We have checked the results produced by this calculator and they appear correct to us.

The Table 4.5 shows how the net cost saving can be calculated for the typical 38 cluster dairy shed mentioned earlier. Because the cost of acid detergents varies widely, the table shows figures for a 'low cost' detergent (Example 1) and a 'premium' detergent (Example 2). All costs exclude GST.

In these examples, the net saving from using the Deosan reduced frequency hot washing system varies from $192 per year to $1018 per year depending on the cost of the detergent

	Example 1	Example 2	Deosan system
frequency of hot washing of milking lines	once per day	once per day	once every second day
number of hot washes per season	280	280	168
detergent type	'low cost' acid detergent	'premium' acid detergent	Deosan 'Supernova'
detergent cost	$2.25 per litre	$4 per litre	$4.42 per litre
detergent used per season	470 litres	470 litres	314 litres
annual cost of detergent	$1,058	$1,880	$1,388
annual electricity cost for water heating	$1,305	$1,305	$783
annual cost of water heating + detergent	$2,363	$3,185	$2,171

Table 4.5: Comparison of the annual costs for a 38 cluster dairy shed using different combinations of detergent and hot washing frequency

that was being used before changing to the Deosan system.

Conclusion

There is no capital investment required to change to reduced frequency hot washing and it is certain that there will be some saving in electricity use due to reduced usage of hot water. The annual cost of detergent will probably change and the effect of this needs to be taken into account when estimating the cost saving.

As with any washing procedure, there is always the possibility that hygiene can be affected and the procedures recommended by the detergent manufacturer must be closely followed to minimise this risk.

The $520 per year electricity cost saving quoted above was based on purchasing electricity at a cost of 14 c/kWh. The cost of water heating can be lower than this if using night rate electricity or an alternative heating system (e.g. a heat pump). In such cases, the electricity cost saving will be reduced and the economics of reduced hot washing should be carefully checked before proceeding.

4.4 Making Better Use of Electricity

Improved Control of Electric Water Heaters

The electricity supply to the heating elements of an electric water heater is usually controlled by isolating switches mounted close to the heater – one for each element. Many dairy shed managers leave the electricity supply turned on at all times and this means that heating starts as soon as the heater is filled with cold water.

This method of control is not usually best for energy efficiency. A water cylinder that is reheated immediately after morning milking will normally be up to temperature within 5 to 7 hours. If the hot water is not required until the following morning, a significant amount of electricity will be used to hold the water at 85°C over the intervening period.

Figure 4.4 is a graph of the power required by a 400 litre water heater over a 24 hour period. The heater was filled with cold water at 8am and immediately began re-heating. Over the 6 hours from 8am to 2pm it consumed 34 kWh. From 2pm until 8 am the following day, the elements switched on at regular intervals to make up heat losses and keep the water up to temperature. During this period, the heater consumed a further 7.8 kWh. If this was repeated every day of a 300 day season, the annual energy loss would be 2,300 kWh. In a shed with two water heaters, the annual energy loss could be twice this amount.

This energy loss can be greatly reduced if the heating is delayed until nearer the time the hot water is required. Most water heaters have a heating time from cold of between 5 and 8 hours – see Table 4.6.

To minimise heat losses, a time switch should be used to switch the heater on at the latest

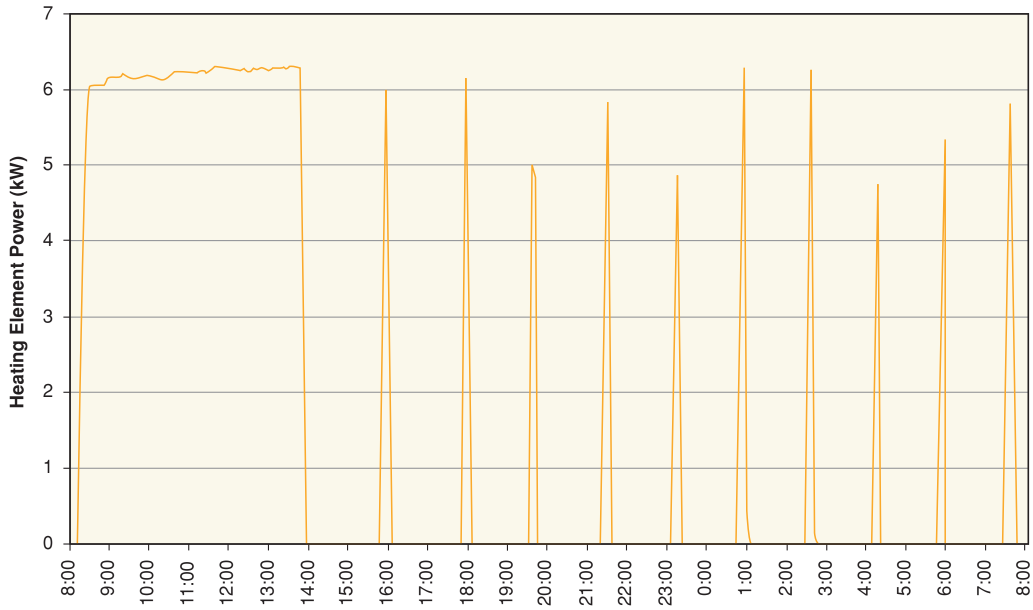


Figure 4.4: Power requirement of a typical 400 litre water heater that is refilled immediately after use for the morning 'lines' wash

possible time that will ensure hot water is available when needed. Delaying the start of heating in this way will reduce energy losses and, in the case where the water is needed after morning milking, delayed heating is also ideal for making use of cheaper night rate electricity.

If the hot water is needed at afternoon milking, the best time to heat the water depends on the electricity purchase plan. If the electricity price is the same both day and night then turning the heater on 5 to 8 hours before the water is needed will be best because losses will be minimised. If night rate electricity is available however, it will always be much cheaper to use this to heat the water at night and accept that there will be a significant heat loss from the hot cylinder throughout the day. In this case, it is likely to be worthwhile improving the insulation of the hot water system to minimise the losses.

Faulty water heater thermostats or thermostats set at too high a temperature are also a source of unnecessary electricity use. A thermostat that fails to open will cause the water to overheat and boil. Usually this will be obvious to the shed manager but not always. Any signs of steam discharging from the overflow pipe should be a signal to suspect a faulty thermostat. Having the thermostat set above 85°C also results in unnecessary heat loss from the water cylinder and pipework. The water temperature should be checked periodically (using an accurate thermometer) when the

Cylinder size	Number of heating elements	Heating time from cold	Switch-on time to ensure hot water at 7am (example)
(litres)		(hours)	
180	1	5.3	1.30am
225	1	6.6	12midnight
270	1	7.9	11pm
350	2	5.1	1.30am
500	2	7.3	11.30pm
600	3	5.8	1am
800	3	7.8	11pm
1000	3	9.7	9pm

Table 4.6: Heating times for some commonly used water cylinders

wash tub is being filled.

Night Rate Water Heating

If dairy shed cleaning operations can be organised so that most water heating is done between 11pm and 7am, 'night rate' electricity can be used. Not only will heat losses be reduced (as discussed above) but the electricity will be purchased at a much lower price.

This cost-saving option is discussed in more detail in Section 9 Electricity Generating and Purchasing Options.

Heating water at night only may not be suitable when the milk lines are washed with hot water twice a day (e.g. during the calving period). Solutions to this are to increase hot water storage or to use a day/night electricity tariff and allow daytime heating when necessary for plant hygiene reasons.

In some dairy sheds where cheaper electricity is available at night under a day/night purchasing plan, water is routinely heated during the day and owners and managers seem unaware of the cost penalty for doing this. In the usual arrangement, a time switch is programmed to turn the water heaters on at 11pm and off at 7am. Commonly, the 'auto/manual' switch has been set so that the time programme is bypassed thus allowing the water heater to heat during the day when electricity is at its most expensive.

Successful use of the 'day/night' pricing plan relies on all shed staff knowing how it works and why it is important to avoid using electricity during the day for a job that can be done at night.

There is also scope for developing a time switch that is better-suited to dairy shed water heating on a 'day/night' purchasing plan. Features of the 'ideal' time switch might be:

- simple to programme the water heater on and off times;
- automatic compensation for daylight saving time;
- indicator lamp to show when electricity is available to the heating elements;
- over-ride switch for heating water during the day; and
- automatic re-set of the over-ride switch so that it can't be left on by mistake.

The use of night rate electricity for water heating has an important bearing on the economics of alternative methods of water heating and also on energy conservation. If water heating electricity is being purchased at night rates, there is a smaller cost saving from installing energy-saving technologies such as heat recovery. There may also be a tendency for shed staff to be less careful with hot water use and to put off making simple efficiency improvements such as repairing leaks and insulating hot pipes.

4.5 Conclusions

There are several steps that can be taken to reduce hot water use and improve the efficiency of a water heating system.

Firstly, the current system should be checked to see if any simple changes can be made to improve efficiency. The obvious measures to be taken include adding insulation to any part of the hot water system that is warm to the touch, fixing water leaks and reviewing washing procedures to see if hot water use can be reduced.

Heat losses can also be reduced significantly by adopting a 'just in time' approach to water heating i.e. installing a time switch to turn the water heater at the latest possible time before the hot water is required (typically 5 to 7 hours before).

These low cost actions can reduce energy use in a typical 'two cylinder' water heating system by between 2000 and 4000 kWh per year and save $300 to $500 per year in electricity cost.

Table 4.7 (over page) shows some options for reducing hot water use and improving heating system efficiency with expected energy and cost savings for a typical 50 bail dairy shed using 1000 litres of hot water each day. These figures were calculated using the 'Dairy Shed Energy and Electricity Cost Calculator' developed as part of this project and available for download on the project website http://www.cowshed.org.nz.

Action	Capital cost [$]	Annual energy use [kWh]	Annual energy cost [$]	Energy saving [kWh]	Energy cost saving [$]
Base case	0	28,040	3,810	0	0
Reduce hot water use by hot washing milk lines every second day instead of daily	0	23,470	3,190	4,570	620
Reduce heat losses from the water heating system by 'just in time' heating	1000	23,950	3,260	4,090	560
Reduce heat losses from the water heating system by improved insulation	500	25,440	3,460	2,600	350
Heat water at night using night rate electricity	1,000	23,980	1,570	4,060	2,250

Table 4.7: Energy and cost savings from reducing hot water use and improving heating system efficiency. This table is based on a 'typical' 50 bail rotary platform dairy shed using 1000 litres of hot water each day. The savings shown are based on implementing one action only. Annual energy cost excludes the fixed costs (daily charge)

5 ALTERNATIVE WATER HEATING SYSTEMS

5.1 Overview of Alternative Water Heating Systems

Heating water to 85°C is a simple process and there are many sources of energy that can be used in place of, or to supplement, mains electricity for this task. These include:

- fuels such as wood, coal, oil and gas;
- biogas from an 'on-farm' digester;
- electricity from a wind or hydro-powered generator;
- 'waste' energy recovered from other dairy shed equipment; and
- solar energy.

Wood and fossil fuels

Farm dairy water heating systems using wood, coal, or oil are all possible but suitable equipment is not commonly available and is rarely seen in modern dairy sheds. In recent years, electricity has largely supplanted these alternatives because it is clean, convenient and for most farms it is readily available at reasonable cost.

Gas water heating systems are readily available but in Southland piped gas supplies are not. The most feasible option is to use liquefied petroleum gas (LPG) delivered in 45 kg cylinders (each will heat about 7000 litres of water).

In recent years New Zealand has increased its reliance on thermal generating stations and using electricity produced in this way to heat water is less efficient than using the same fuels to directly heat the water on the farm. Because dairy shed water heating requirements are not large (typically 25,000 kWh per year) and electricity is a very convenient and reasonably-priced energy source, the incentive to move away from electric water heating is not great.

A Dunedin company (McKenzie Heating Design) has developed a small coal-fired water heater and is targeting dairy sheds as a possible application. The price is given as $15,500 plus freight and installation so a total installed cost of about $20,000 seems likely. This system appears perfectly feasible but has not been evaluated in this project. It is noted however that at present electricity prices, it is difficult to make an economic justification for spending $20,000 in a typical dairy shed where electricity for water heating is costing $3,000 to $4,000 per year. Other alternatives such as waste heat recovery are likely to offer a better return on investment for most farms.

Diesel oil is currently cheaper than it has been in the recent past and the August 2007 price (approx $0.90 +GST per litre) is equivalent to 11 c/kWh when used in an oil-fired water heating system. This is cheaper than 'anytime' electricity (14 c/kWh) but not cheaper than 'night rate' electricity (7 c/kWh). Oil prices are also very volatile and there is no guarantee that this price advantage over 'anytime' electricity will exist in the future.

LPG can be delivered to a Southland farm in 45 kg cylinders for $1.68 + GST per kilogram. Assuming an appliance efficiency of 80%, this is equivalent to 16.4 c/kWh. Although this price appears to make LPG a more expensive heat source than electricity, a gas-fired water heating system has the advantage that there is no need to store hot water and pay for heat losses from the storage cylinder.

Any of these heating systems also has the benefit of reducing the dairy shed maximum electrical demand. This may permit the use of a lower capacity electricity supply to the dairy shed which could save money on the initial cabling cost and also in on-going daily charges.

Biogas

The production of biogas from dairy shed waste is discussed in Section 9.2 of this report. It is unlikely that a biomass digester would be installed simply to provide gas for dairy shed water heating as there are other cheaper and more convenient methods of heating water. The BioGenCool system currently being developed by Natural Systems Ltd near Christchurch utilises all of the biogas as fuel for electricity generation and the waste heat from the generator engine to maintain the digester temperature. Water heating is accomplished using heat recovered from the refrigeration system by a heat pump – see Section 5.3.

Electricity from renewable sources

The production of electricity from a renewable energy source (e.g. hydro, wind, solar) is also discussed in Section 9.2 of this report. As with biogas, it is unlikely that an electricity generator would be installed principally to heat water.

Recovered heat – direct heating

There are a number of heat sources available on the farm and some of these have a high enough temperature that they can be used to heat cold water directly. If not, a heat pump can be used to extract energy and generate hot water.

Direct heating is possible from:

- The condenser of the milk vat chiller unit where "superheat" at 90°C is available.
- Hot used wash water which is typically 60°C

The first of these sources is used by the DTS heat recovery unit that was trialled in this project and is discussed in Section 5.2.

This product was not tested in this project but a recent trial was sponsored by the Energy Efficiency and Conservation Authority (EECA) as part of the Energy Intensive Business programme. The trial was independently monitored and the report (www.eecabusiness.govt.nz/eib/case-studies/documents/awarua-07.pdf) says that the electricity used for heating water for lines washing was reduced by 30% during the one week trial period. The report estimates an annual saving of 2,245 kWh worth $279 at the trial farm's electricity price of 12.42 c/kWh. The installed cost of The Retriever was reported as $2,200. The report also notes that the economics would be greatly improved on a farm where the used wash water from the vat can also be captured.

The Retriever unit is self-contained and reasonably easy to install and is likely to appeal to a sharemilker who can take it with him when moving farms.

Recovered heat – heat pumping

To heat water for cleaning, a heat pump should be able to produce water at a temperature of at least 85°C. The energy source can be any one of the following:

- the condenser of the chiller unit (at least 40°C);
- hot used wash water;
- the local water supply (about 15°C-20°C);

The second source is used wash water. After use, wash water is likely to have a maximum temperature of 60˚C. This is available to heat cold water coming into the hot water cylinder and might provide up to 40% of the heating energy required. Equipment for such a system is available from Dairy Innovations of Hamilton who market their product under the name 'The Retriever'

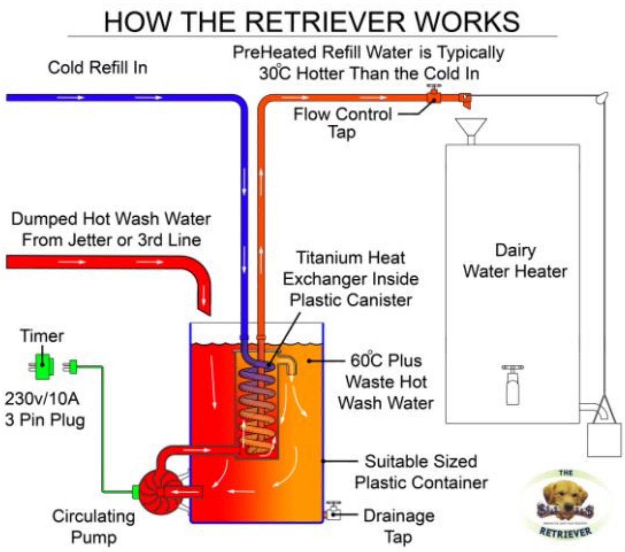


Figure 5.1: Diagram of 'The Retriever' heat recovery system

- the surrounding air (10°C-20°C);
- milk (6°C-20°C).

Of these the first is the most feasible. The efficiency of a heat pump is best when the temperature change is smallest. The amount of energy removed from the milk is normally more than enough to heat the amount of hot water required for cleaning. The Mahana Blue system (see Section 5.3) uses this energy source.

In comparison, none of the other options is likely to be more effective. The second option (hot used wash water) has only enough energy available to heat half of the required water and the expense of a heat pump system is unlikely to be worthwhile for this limited energy source. The last three options have a much larger temperature difference (at least 65°C) that would limit the efficiency of a heat pump. A single stage heat pump from 6°C milk to 85°C water would be quite inefficient. None of the other options offers lower capital costs.

The third option provides the possibility of heat pumping during the night using night rate electricity but at a lower efficiency.

Heat pumping from air will be the least effective because of the low density of air.

Option 1 is the most feasible and is discussed further in Section 5.3. Option 2 is unlikely to be cost effective, option 3 might be feasible and the last two options will be significantly less efficient.

Solar energy

Solar water heaters are discussed in detail in Section 5.4.

5.2 Heating water with refrigerant gas (de-superheater)

Most milk vat refrigeration systems reject the heat extracted from the milk through an air-cooled condenser. By adding a refrigerant-to-water heat exchanger between the compressor and the condenser, a portion of this heat (the superheat) can be removed without causing the gas to condense. This superheat can be used to pre-heat the water for the dairy shed hot water system. The heat exchanger in this system is sometimes referred to as a 'de-superheater' or more simply as a 'heat recovery unit'.

Dairy Technology Services (DTS) offers a system based on this technique. Invercargill-based companies Progressive Engineering Ltd and Refrigeration Supplies Ltd (RSL) also offer a heat recovery system under the name PE Heat Minda. This system has the added feature of storing the hot water and recirculating it to maximise the heat recovery.

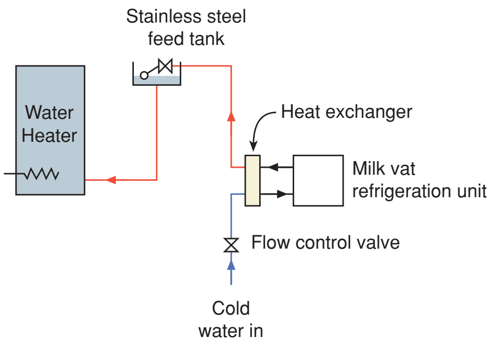


Figure 5.2: Diagram of the DTS de-superheater system

In the DTS system, a small brazed plate heat exchanger is fitted into the refrigerant circuit of the milk vat cooler. The cold feed to the water heater passes through this heat exchanger and into the water heater. A float valve in a stainless steel cistern stops the water flow when the water heater is full. This is a 'once through' system and so the water flow has to be kept low so that it reaches an adequate temperature.

The cost of incorporating the heat exchanger into a refrigeration unit at the time of manufacture is quite low (about $400) and DTS now do this on all new units sold. Once the new refrigeration unit is installed, the owner has the choice of piping a water supply to the heat exchanger to generate warm water or leaving it disconnected.

In the PE Heat Minda system a similar (but larger) heat exchanger is used in conjunction with a pump and an extra hot water storage tank. When the refrigeration unit is running, water from the tank (which typically has a 1000 litre capacity) is circulated through the heat exchanger and back to the tank. This pre-

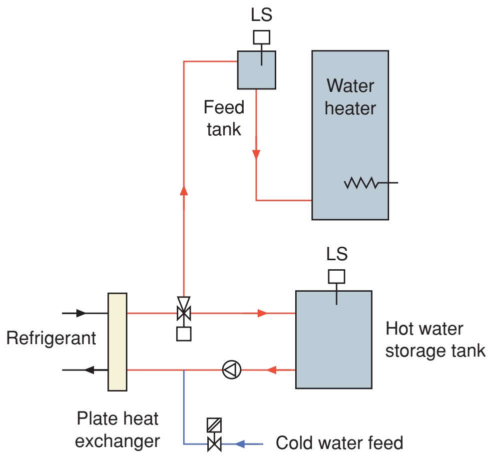


Figure 5.3: Diagram of the PE Heat Minda system

heated water is then used to automatically refill the water heaters through an insulated make-up tank.

The Heat Minda system was not trialled.

DTS heat recovery trial at Tussock Creek Dairies

The DTS heat recovery system can be used in both new and existing dairy sheds. To test the effectiveness of a retrofitted system, a trial was set up at the Tussock Creek Dairies Ltd farm. DTS suggested that their heat exchanger should be capable of pre-heating all of the hot water to a temperature of 50°C using equipment with an installed cost of $2,600. This looked to be a very attractive investment with a predicted payback within two years.

A drawback of the DTS system is that warm water is produced only when the milk vat refrigeration unit is running and if the water heaters are already full, the opportunity to make use of the surplus energy is lost. It was thought that there would be merit in adding an additional hot water storage tank to minimise this drawback. This is what the PE Heat Minda system does but the existence of this system did not become known until late in the project.

It was decided to carry out a trial of the simple, low cost system as promoted by DTS.

Existing equipment at Tussock Creek

The Tussock Creek Dairies Ltd farm at Tussock Creek (15km southeast of Winton) has a 50 bail rotary platform milking machine that was built in 2001. There are two milk vats, one of 17,000 litres and one of 9,000 litres. The 9,000 litre vat is normally used for only short periods when 'skip-a-day' collection takes place and two days' production can't be accommodated in the large vat.

The refrigeration unit fitted to the 17,000 litre vat is a Patton CCH1200.

There are two water heating cylinders. At the beginning of the trial, the cylinders were 500 litres and 350 litres. On 31 October 2006, the 350 litre cylinder was replaced with a 500 litre cylinder.

Water is heated to 85°C before use and the normal pattern of use is:

- after morning milking is complete (about 8.30am), 500 litres of hot water is used to wash the milking equipment.
- after the milk tanker has collected the milk (usually sometime between 10am and 2pm), the remainder of the hot water (500 litres) is used to wash the milk vat.
- usually, no further hot water is required until 8.30am on the following day.

This requirement remains approximately the same throughout the milking season which lasts for 9 1/2 months from early August to mid-May although there is a significant reduction in hot water use when 'skip-a-day' collection is in operation. There is little requirement for hot water during June and July.

Electricity is supplied to the Tussock Creek dairy shed on the Contact Energy 'anytime' pricing plan.

Installation and operation of the heat recovery unit

The DTS heat recovery unit was installed in late September 2006. Two separate tradesmen were required – a refrigeration fitter and a plumber. There was some delay in getting the plumbing completed and working satisfactorily and it was late October before the unit was running at full potential.

Figure 5.4 is a simplified diagram of the piping arrangement used by DTS at Tussock Creek.

The cold feed water for the cylinders was taken from the shed cold water supply which is

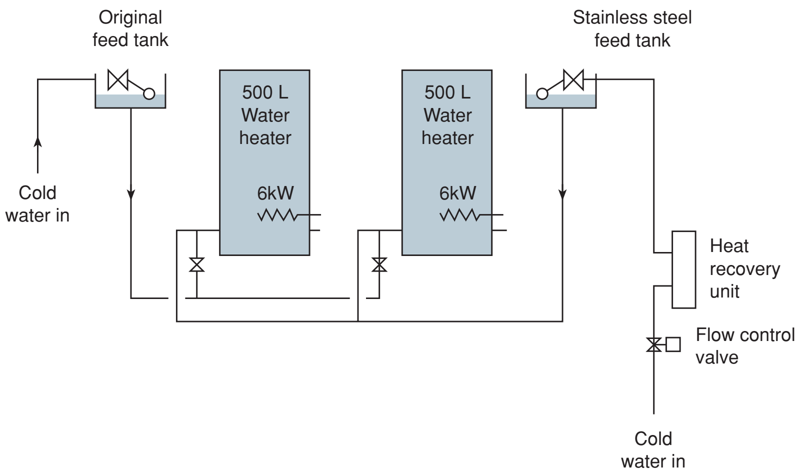


Figure 5.4: Diagram of DTS heat recovery unit piping at Tussock Creek

pumped from a bore on the property. When the water temperature was measured early in the season (September) it was 11°C.

In the original DTS design, the rate of water flow through the heat recovery unit was set using a manually operated flow control valve in the cold water line. With this design, the water flow rate remains fixed. At Tussock Creek, DTS decided to try a different idea and fitted an automatic control valve that allowed the water flow to vary depending on the gas pressure in the refrigerant pipework. The idea was to make better use of the available heat from the refrigeration system and the intention was to set this control valve up so that the unit delivered water at 50°C. In practice, the automatic flow control valve was unsatisfactory.

The outflow from the heat recovery unit was piped to a new stainless steel feed tank mounted beside the cylinders with a float valve to cut off the water supply when the cylinders were full.

The strategy used for refilling the cylinders was decided by the farm manager. Normally, he kept the two cylinders isolated from each other and controlled the refilling by opening and closing the appropriate filling valve. An alternative strategy is to cross connect the two cylinders and effectively operate them as one large cylinder of 1000 litres capacity.

Monitoring

The system was datalogged from 18 October 2006 through to June 2007 and the following measurements recorded:

- water flow rate through the heat recovery unit
- the temperature of water leaving the heat recovery unit (measured at the feed tank)
- cylinder 1 heating element amps
- cylinder 2 heating element amps

The water flow rate, leaving temperature and an assumed entering temperature (15°C) were used in the datalogger programme to calculate an estimate of the energy contributed by the heat recovery unit and this figure was logged with the other data.

The heat recovery unit was not in operation throughout all of the seven months. There were various reasons for this including

- a delay in getting the unit commissioned
- a problem with the farm water supply in November 2006
- a deliberate shutdown in February/March 2007 to enable the collection of baseline data
- the shed manager turning the unit off in mid-April because it wasn't producing enough water to fill the cylinders.

There was also a period in November/December 2006 when water flow data was not obtained because the flow meter failed.

Trial results

Figure 5.5 shows the daily energy use for water heating. The daily figures have been calcu-

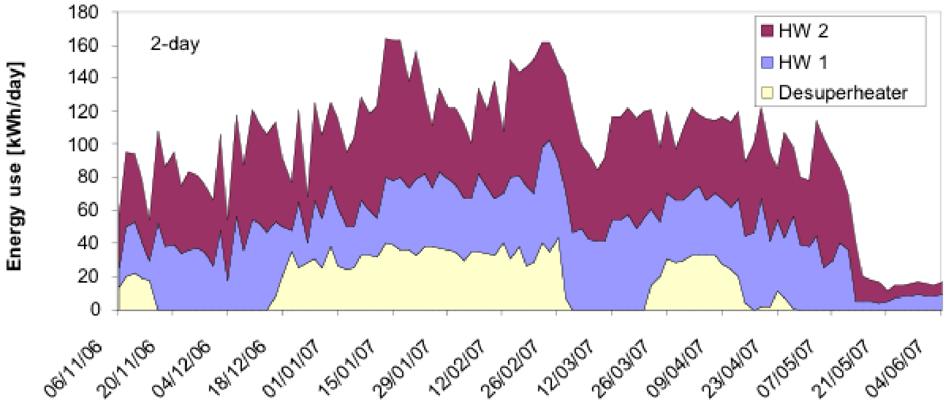


Figure 5.5: Daily energy use for water heating at Tussock Creek Dairies

lated as the average of two consecutive days to reduce variability due to the timing of cylinder refilling. Electricity used by each water heater is shown together with the estimated energy recovered from the refrigeration system by the heat recovery unit.

The best data came from the period 18 December 2006 to 12 April 2007. The heat recovery unit ran for all of this time except when it was deliberately shut off between 26 February and 21 March 2007 in order to collect baseline data on electricity used by the water heaters.

When the heat recovery unit was running, all of the feed water for the water heaters came through it and it typically produced water at a temperature between 30°C and 35°C.

The amount of water flowing through the heat recovery unit each day was surprising. Each hot water cylinder has a capacity of 500 litres but often 700 litres flowed into one or both of them. Figure 5.6 shows the water flow through the heat recovery unit for 10 days in February 2007.

Over the period 18 December 2006 to 12 April 2007, daily hot water use averaged 1220 litres. The period of highest use was in February when it averaged 1370 litres per day.

A reasonably consistent relationship between water flow rate and temperature was obtained as seen in Figure 5.7. Even at the lowest flow rate, the water cannot be heated above 80°C by the system.

When expressed in terms of power it shows clearly that there seems to be an optimum flow rate after which the improvements in power are small – see Figure 5.8. For this system it was about 0.1 L/s (360 L/h) but this would give

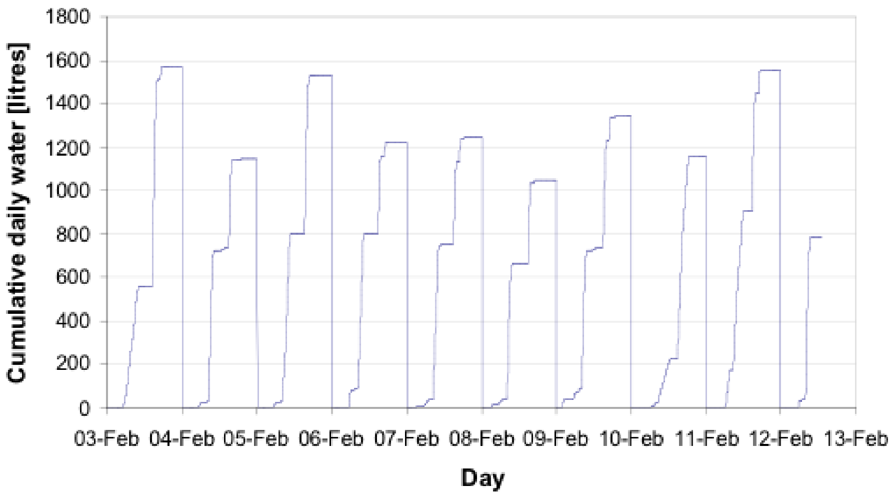


Figure 5.6: Typical daily water volume passing through the heat recovery unit

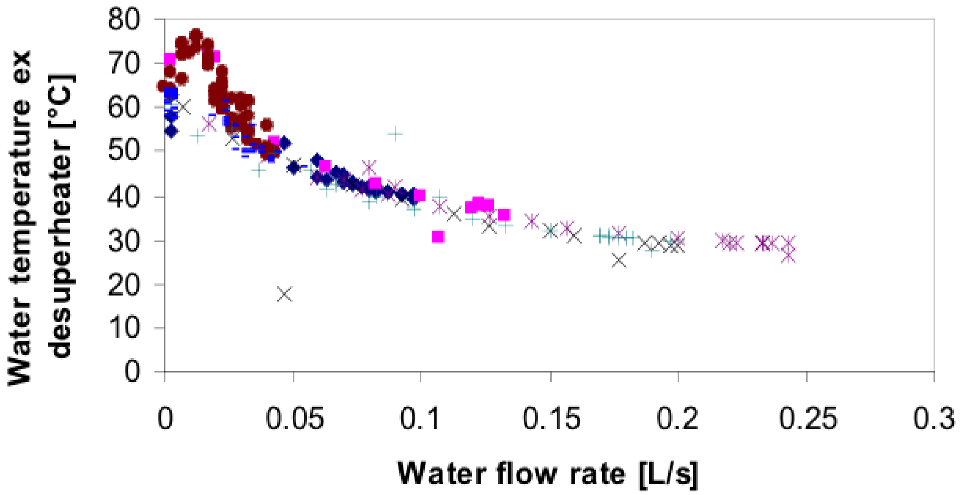


Figure 5.7: Temperature of water leaving DTS heat recovery unit at various flow rates

water at about 40°C only. Generally more time was available and water could flow at a lower rate, thus filling the hot water cylinder more slowly. A flow rate of 0.07 L/s is sufficient to fill a 500 L cylinder in 2 hours and at this flow rate the water temperature is estimated to be about 45°C. Lower flow rates, with higher temperatures, are possible if milk chilling continues for a number of hours after milking has finished.

Figure 5.9 below shows some typical flow rates during about 2 hours of filling. There is a large variation both within a single fill and on different days.

The high and erratic flow rates were caused by the use of the automatic flow control valve which ultimately proved unsatisfactory. A simple manual flow control valve has been installed for the 2007/2008 season. This will be set for a low and constant flow rate and is expected that water temperatures of at least 50°C will result.

Energy and cost savings

Based on the measurements made during the trial, it is estimated that over a full season the Tussock Creek dairy shed is using 32,000 kWh of electricity for water heating. This is higher than normally expected for a 50 bail shed and is due to higher than normal hot water usage.

When operating well, the heat recovery system has been giving savings equating to 8,500 kWh per year. At a marginal rate of 14 c/kWh, this saving has a value of about $1200. Figure 5.10 shows how this saving is affected by the price of electricity.

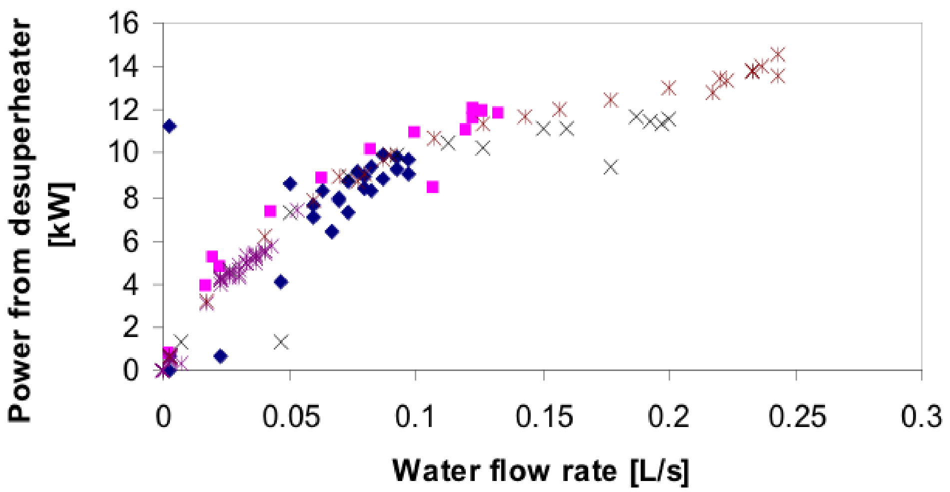


Figure 5.8: Relationship between heat recovery unit power output and flow rate

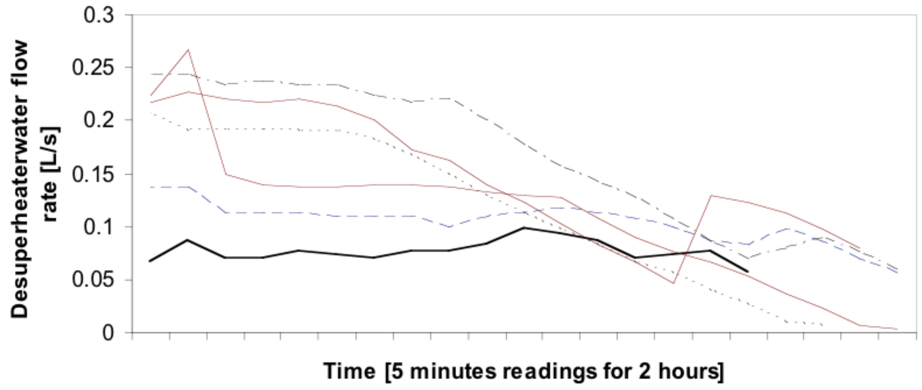


Figure 5.9: Typical water flow rates through the heat recovery unit during a 2 hour filling period

Based on a total installed cost of $2,600, the DTS heat recovery has a simple payback period of about 2 years at the 2007 electricity price.

Improvements

As noted above, the performance of this unit will be improved by replacing the automatic flow control valve with a manual valve and reducing the flow rate.

A further improvement would be to feed the water into a well-insulated hot water header tank that would later be used to refill the water heaters. This would enable water to be produced at up to 65°C and it would enhance the flexibility of the system. However a header tank might be exposed to the elements and suffer heat losses that negate the advantage gained. A tank inside the milking shed with a transfer pump might be more effective.

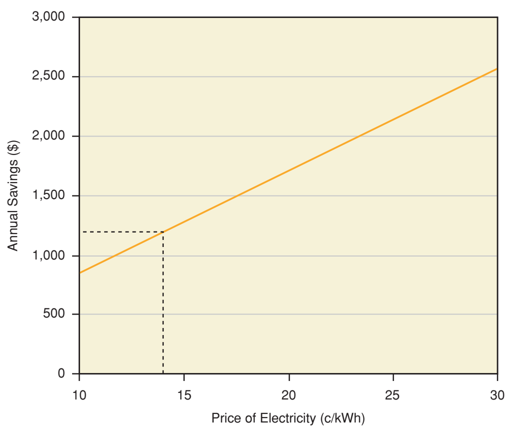


Figure 5.10: Estimated annual savings when installing a DTS heat recovery unit. Savings based on an annual reduction of electricity for water heating of 8,500 kWh.

5.3: Water Heating by Heat Pump

The Mahana Blue heat pump manufactured by Heatcraft Ltd connects to the refrigerant circuit of the milk vat cooling system. Whenever the refrigeration unit is running to cool the milk, the heat pump can be used to heat a small flow of water which can then be used to refill the dairy water heater.

An important difference between this device and the DTS heat recovery unit is that the heat pump can generate water at 85°C temperature. This means that the water needs very little additional heating before use.

Trial at Glencairn Land Company

A Mahana Blue heat pump was installed in the 50 bail dairy shed at the Glencairn Land Company farm at Dipton West. This shed has two 500 litre water heaters and the 26,000 litre milk vat has a Blue Star HGZ160 refrigeration unit.

Normally, the milking machine is washed with hot water once a day after morning milking and daily hot water usage for this plus the vat wash was expected to be 1000 litres. Heatcraft predicted that the unit would easily produce 1000 litres of hot water over the two milking periods each day.

Installation and commissioning

The heat pump was installed by a local refrigeration contractor. The installation required the services of three separate contractors – a refrigeration fitter, plumber and electrician. Initially the unit was not installed fully in accordance with Heatcraft's recommendations and the plumbing had to be altered later to correct this.

Figure 5.11 is a simplified diagram of the piping arrangement at Glencairn.

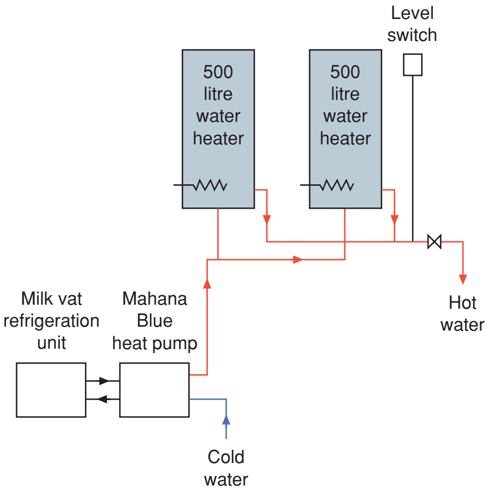


Figure 5.11: Diagram of Mahana Blue piping installation at Glencairn

In addition to the piping shown, the original cold water supply to the cylinders was retained so that the cylinders could be refilled with cold water in the normal way should it be necessary.

The unit was initially commissioned on 13 October 2006 but it was the end of October before it was working fully.

Operation

As suggested by Heatcraft, the valves on the hot water manifold are left open so that the two 500 litre water heaters effectively operate as one large cylinder. This means that after the morning wash water has been taken out, the water level in both cylinders is down to halfway. The remainder of the water is then available for the vat wash which at Glencairn usually takes place at about 9am. Because the milk is usually collected at about 8.30am, the refrigeration unit stops then and no more hot water is produced until afternoon milking starts. Shed staff had to learn not to top up the cylinders with cold water as they would have in the past – the cylinders are slowly refilled with hot water between about 2pm and 5 pm. The normal rate of hot water into the cylinder is 220 litres per hour.

At Glencairn, usually about 25% of the day's hot water is produced during morning milking. The heat pump could produce a lot more but until milking is finished, there is nowhere to store it. At 5am, when the refrigeration starts, the hot water cylinders are still full from the previous afternoon and little or no water can be added until about 7.45am when 500 litres is taken out for the plant wash. From then until the milk tanker arrives, the Mahana Blue unit produces hot water. On a typical day, 200 litres of hot water is produced at morning milking and the remainder during afternoon milking. Once the water heaters are full, a float switch stops the unit.

No change was made to the original electric heating system. The electricity supply is available to the heating elements 24 hours per day and they switch on and off under the control of their thermostats as normal. At Glencairn, the water from the heat pump was entering the cylinders at a temperature a few degrees below 85°C and so the elements were normally running at this stage to top up the temperature. The elements also run periodically through the day and night to make up for the heat losses from the cylinders. Monitoring of electricity use during these 'idle' periods showed typical heat losses of approximately 400 W from each of the two cylinders. Assuming this loss remained constant over a 24 hour period, the typical daily electricity use to make up these losses was 19 kWh.

There were no significant operational problems in the seven months during which operation was monitored.

Energy saving

The performance of the water heating system was monitored over the period mid-October 2006 to end May 2007. During this time there were two periods when the heat pump was deliberately shut down so that comparative measurements of electricity use could be made.

The flow rate and temperature of the water leaving the heat pump were measured and heat pump drive motor energy use recorded.

It turned out that on most days, hot water usage was less than the full 1000 litres available. In mid season when the plant and milk vat are washed daily, average daily usage was approximately 830 litres. Figure 5.12 shows daily hot water use for January 2007.

Figure 5.13 shows the corresponding daily electricity use for water heating in January 2007. The daily use is the sum of the electricity used by the heating elements and the electricity used by the Mahana Blue drive motor.

On days when the Mahana Blue did most of the heating, electricity use averaged 39.4 kWh – 22.5 kWh for the heating elements and 16.9 kWh for the heat pump motor. On the other days (1 - 3 January and 7 and 8 January), the cylinders were refilled with cold water, possibly by relief staff who were not aware of how the heat pump system worked. On these days, most of the heating was provided by the elements.

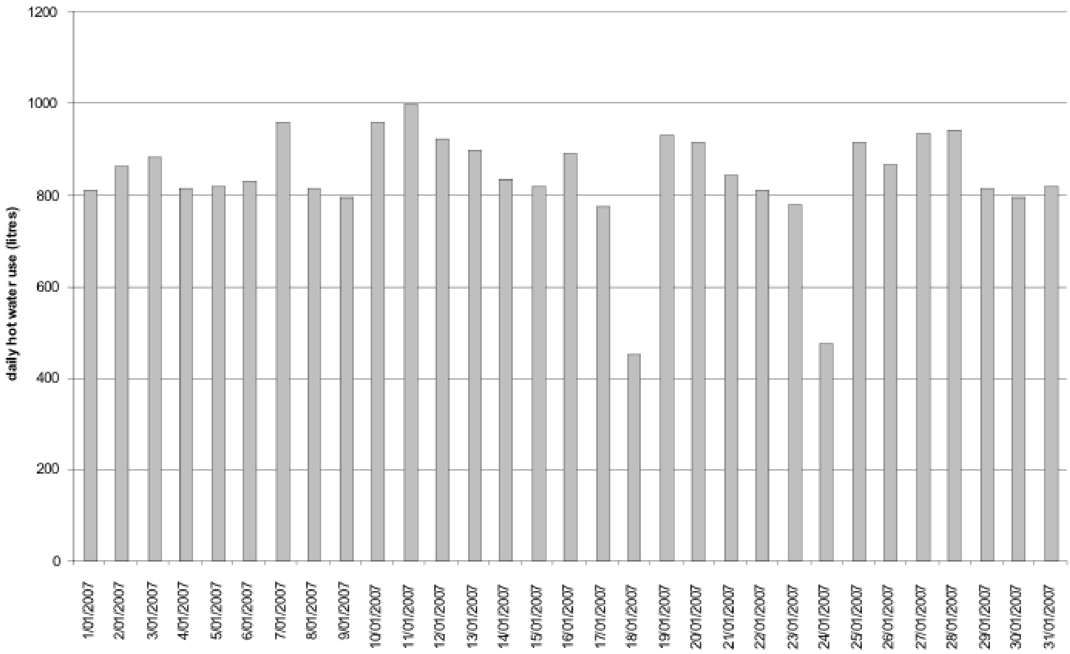


Figure 5.12: Glencairn daily hot water usage in January 2007

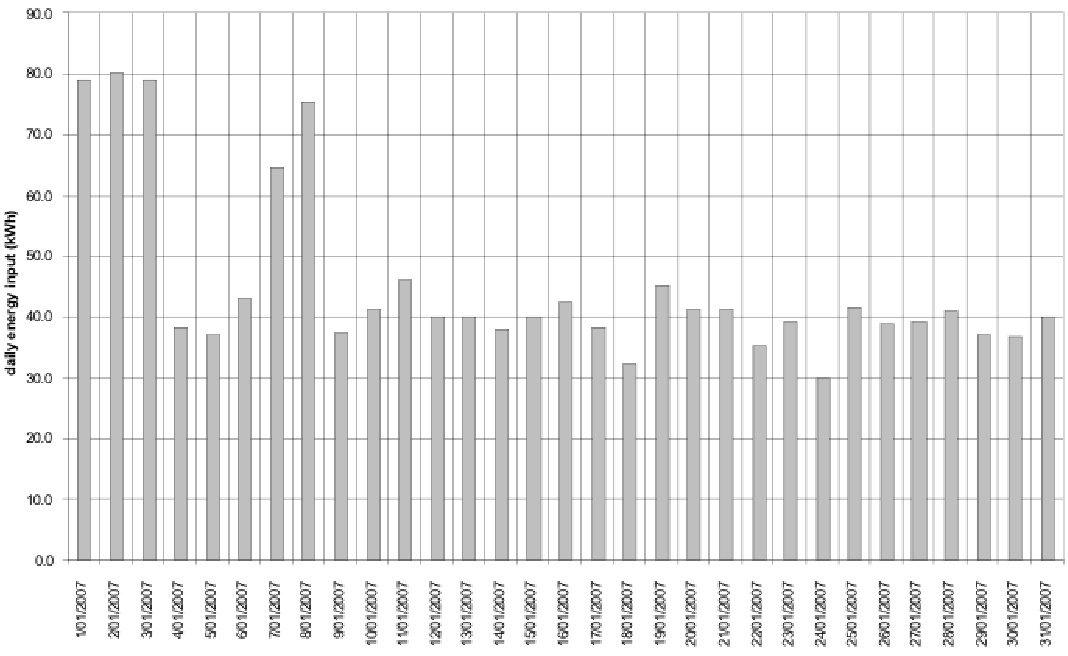


Figure 5.13: Glencairn daily electricity use for water heating, January 2007

Figure 5.14 shows electricity use for November 2006. During the period 3 to 27 November, the heat pump was turned off and an average 88 kWh of electricity was used each day to heat the water from cold.

Based on these figures for a typical mid-season day, use of the Mahana Blue reduced daily electricity use from 88 kWh to 39 kWh – a saving of 49 kWh (56%).

Near the end of each season, hot water use at Glencairn is reduced. This is mainly because the milk vat is only washed every seco nd day because of 'skip-a-day' milk collection. Data collected between 22 March and 29 May 2007 shows that hot water use averaged 627 litres per day in this period and electricity used for water heating averaged 33 kWh per day. The average daily saving in this period resulting from use of the heat pump is calculated to be 35 kWh per day (51%).

Annual electricity saving

Calculating the electricity use and cost for water heating over an entire year requires some estimation of the factors that change through the year. Table 5.1 gives annual estimates for Glencairn based on the data gathered from November 2006 to May 2007.

This calculation indicates that the Mahana Blue heat pump will reduce annual electricity use at Glencairn by approximately 13,700 kWh. At the

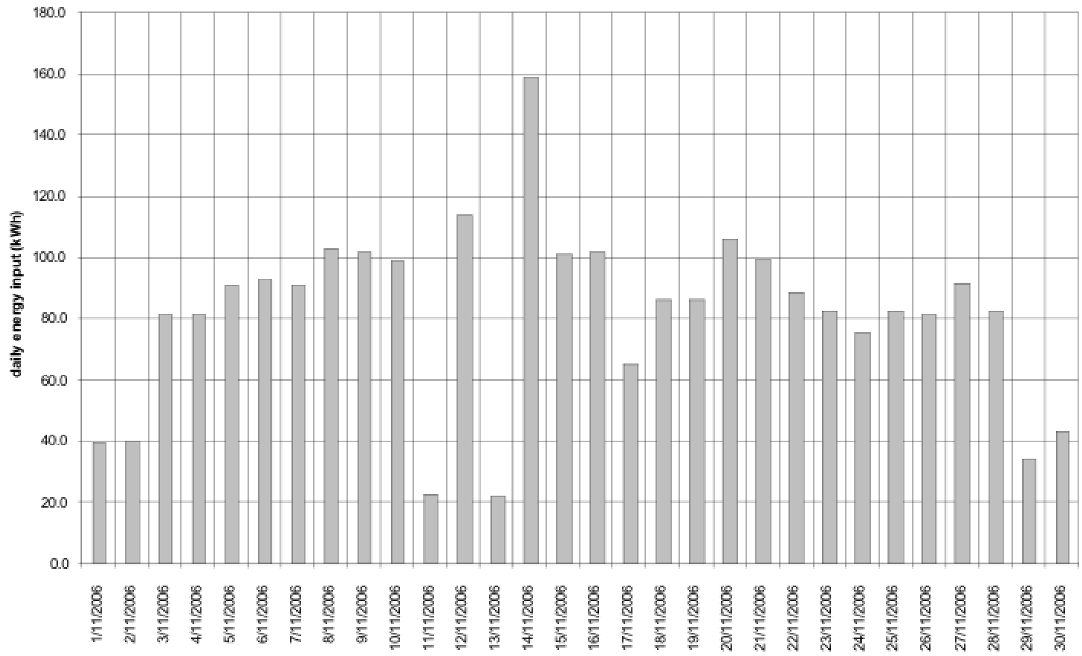


Figure 5.14: Glencairn daily electricity use for water heating November 2006

Start date	End date	Days	Daily electricity [kWh]	Electricity for the period [kWh]	Comments
Without Mahana Blue					
1 Aug-06	10-Mar-07	221	88	19,448	daily milk collection
11-Mar-07	31-May-07	81	68	5,508	skip-a-day milk collection
Totals		302		24,956	
With Mahana Blue					
1 Aug-06	10-Mar-07	221	39	8,619	daily milk collection
11-Mar-07	31-May-07	81	33	2,673	skip-a-day milk collection
Totals		302		11,292	

Table 5.1: Annual hot water electricity cost calculation for Glencairn

marginal rate for 'anytime' electricity of 14 c/kWh, this saving is worth $1,900 per year. Figure 5.15 shows how this saving is affected by the price of electricity.

Initial cost

The Mahana 50 unit installed at Glencairn cost $6,700 and the installation work (refrigeration, plumbing and electrical) cost $3,000 bringing the total cost to $9,700.

Discussion

The Mahana Blue heat pump was installed with minimum difficulty and has performed well for seven months. Monitoring data shows that it has reduced electricity use for water heating by up to 56% depending on the time of year. The calculated saving over a full year is 55%. To achieve this saving however, the unit must run every day and this requires all shed staff (including relief staff) to understand the operation of the system.

The estimated saving of 55% is a little lower than the 60% expected by Heatcraft. There is no doubt that under more carefully controlled conditions, a greater saving could be made but the purpose of this trial was to find out how the unit performed in a normal installation.

As noted above, the estimated cost saving at Glencairn is $1,900 per year. This gives a simple payback period of 5.1 years on an initial cost of $9,700.

If the alternative heating source was night rate electricity at 7 c/kWh, the cost saving would be halved and the payback period doubled to 10.2 years.

5.4 Solar Water Heating

Systems for heating water using solar energy collectors have been available for many years but are not commonly used on dairy farms. There is no doubt that installing solar panels to heat water for dairy shed washing will reduce the amount of electricity used but farmers need to know whether the savings are sufficient to justify the extra capital expenditure.

In an average year, Invercargill receives about 1400 kWh of solar energy on each square metre of land. While this is less than the solar energy received in more northerly parts of New Zealand (1700 kWh/m² in Auckland), it is still a significant resource. One of the simplest ways to utilise this energy is to use it to heat water.

At first glance, a dairy shed appears to be an ideal candidate for solar water heating. It requires a large amount of hot water every day of the dairy season and little or none during the winter months when solar water heaters are less effective.

General information on solar water heating is available from a number of sources. Useful

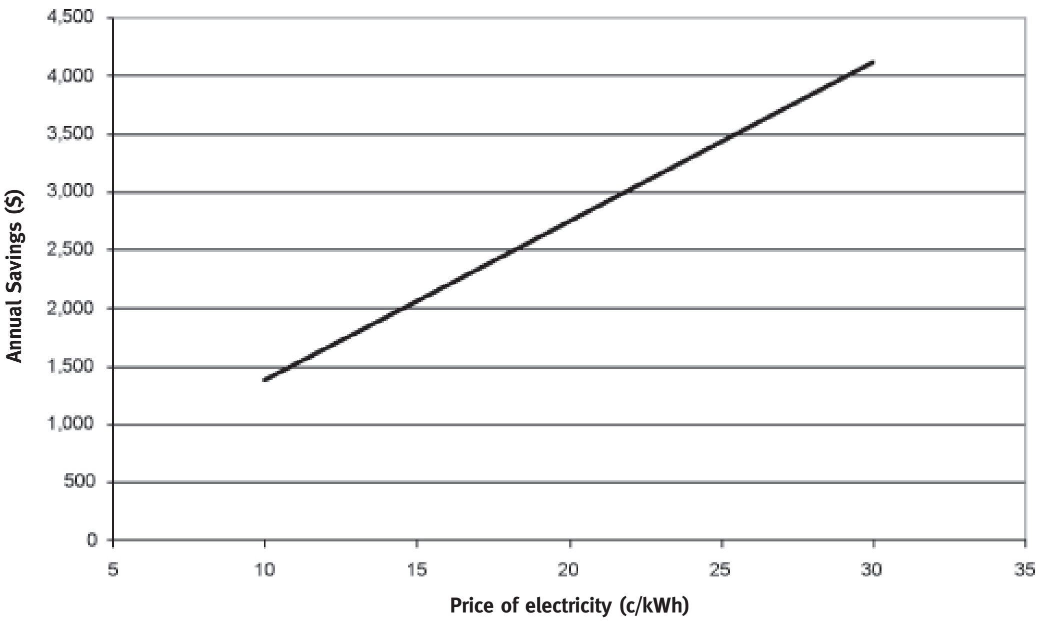


Figure 5.15: Estimated annual savings at Glencairn using a Mahana Blue heat pump.

websites include:

- Energy Efficiency and Conservation Authority (www.solarsmarter.org.nz)
- New Zealand Solar Industry Association (www.solarindustries.org.nz).

Dairy shed hot water requirement

The requirement for hot water in a dairy shed and the systems normally installed to supply this hot water have been described in Sections 4.1 and 4.2.

Solar water heating systems available

There are numerous suppliers of solar water heaters (SWHs) in New Zealand and the Solar Industry Association lists 17 that are accredited by them. Of these however, only five are listed as having installers based in Southland.

There is also a range of alternative designs available. Variations include

- closed loop and open loop
- flat panel collectors and evacuated tube collectors
- natural circulation (thermosiphon) and pumped circulation.

These technologies are well-explained in other places e.g. the EECA website (www.solarsmarter.org.nz).

General statements made by SWH manufacturers regarding performance and potential savings usually relate to domestic systems. The savings potential is sometimes expressed as *'kWh per year'* or *'kWh per year per square metre of collector area'* but more commonly by using statements such as *'Cuts hot water costs by 75%'* or *'Eliminates 80 to 95% of your water heating bill'* or *'FREE hot water'*.

Some manufacturers also make claims regarding payback time (the length of time it takes for savings to equal the initial purchase price) e.g.*'payback is often within 3 years'.*

An article published in 'Consumer' magazine in January/February 2001 included the following general findings for domestic systems:

- 'In a typical four-person house, solar energy will provide 50% to 75% of your annual hot water requirement'
- 'The payback time is typically between 8 and 12 years'.

There are significant differences between domestic and dairy shed hot water systems:

- domestic systems are usually required to heat water to 65°C whereas dairy wash water is usually heated to 85°C – a more difficult task for a solar heater.
- in a typical dairy shed, all of the stored water is used each day and so there is no opportunity to store extra heat on a sunny day in case the following day is overcast.
- sometimes shed managers need to wash the milk lines twice a day. Unless extra storage is installed, they have to rely on re-heating one of their cylinders in the 9 hours between milkings.
- bore water from a farm water supply may cause 'furring' problems in some systems.

Trials at Moorabool Farm Ltd

The Dipton West property belonging to Moorabool Farm Ltd was selected as the location for a trial solar water heating system. The shed lies well to the sun and the normal hot water usage pattern was favourable for solar heating.

The Moorabool dairy shed is a herringbone design with 40 sets of milking cups and a 14,000 litre milk vat. In the 2006/07 season, the milking herd was approximately 600.

Existing water heating equipment

The shed has two conventional 350 litre water heaters, each of which has two 3 kW electric heating elements.

Water is heated to 85°C before use and the normal pattern of usage at Moorabool is:

- after morning milking is complete (about 7.30am), 400 litres of hot water is used to wash the milking equipment.
- after the milk tanker has collected the milk (usually soon after 8am but can be any time up until 2pm), the remainder of the hot water (approx 300 litres) is used to wash the milk vat.
- usually, no further hot water is required until 7.30am on the following day.

This requirement remains approximately the same throughout the milking season which lasts for 9 1/2 months from early August to mid-May. There is no requirement for hot water during June and July.

At Moorabool, the electricity meter has two registers and electricity is purchased on a ‘day/night’ pricing plan under which electricity used between 11pm and 7am is considerably cheaper than electricity used during the day. In the original installation, the water heaters were wired so that they can be switched on and off by a time switch to take advantage of night prices. As seems common however, it was found that the time switch had been set to ‘manual’ and the more expensive daytime electricity was being used.

Solar systems offered

Three suppliers of solar water heating equipment were given information on the existing water heating system and invited to provide detailed proposals.

Various design options were suggested by the suppliers:

- circulating water from the heater through an external heat exchanger
- fitting a heat exchange coil into the existing water heating cylinder
- installing a separate solar storage tank on the roof above the collector panels and using this as a pre-heater for the water feeding the main heater.

In addition to these options, the project team proposed a fourth option that can be described as a ‘trickle feed’ design. In this design, the water heater is filled slowly throughout the day and the cold feed water is passed once through a solar collector that raises its temperature before it enters the cylinder. This design (which would not suit a domestic system) is not offered by any commercial supplier.

The options suggested by the three suppliers are summarised in Table 5.2.

Equipment selection

None of the suppliers or their installation contractors visited the site before making a proposal and none provided a fixed price inclusive of installation. This is a service that a prospective customer should expect to receive.

Choosing the most suitable system was difficult because the economics of solar heating are best if the capital cost of the equipment is minimised. A complicating factor affecting the Beasley option and two of the Solartech options was the need to mount a heavy water tank above the roof. Because the roof was almost flat and of lightweight construction, the cost implications of this were unknown. The third Solartech option carried with it some risk

	Azzuro Solar	Reid (Beasley)	Solartech (Solar Edwards) 1	Solartech (Solar Edwards) 2	Solartech (Solar Edwards) 3
system type	closed loop with external heat exchanger	Pre-heat system with storage tank on roof	closed loop with new heat exchange 'rod' inserted in existing cylinder	Pre-heat system with storage tank on roof	Pre-heat system with storage tank on roof
collector type	evacuated tube	flat panel	flat panel	flat panel	flat panel
heat transfer fluid	water	water	propylene glycol	propylene glycol	propylene glycol
pre-heater storage capacity		480 litres		350 litres	440 litres
number of collection panels	4	3	3	2	3
total collection area	12 m²*	6 m²	6 m²	4 m²	6 m²
supplier's est. annual energy collection	not stated	6480 kWh	5000 kWh	4000 kWh	6000 kWh

* Note that the collector area proposed by Azzuro was based on heating both 350 litre cylinders while the other proposals were based on heating one 350 litre cylinder only.

Table 5.2: Solar water heating proposals

of problems when modifying the existing water heater. In retrospect, both of these issues could have been dealt with but a decision was made to choose the apparently more straight-forward design offered by Azzuro Solar.

Azzuro Solar were also the only supplier to offer evacuated tube collectors that were expected to perform better in the Southland climate than flat plate collectors. Azzuro offer collectors made by Linuo Paradigma in China and several other suppliers offer similar designs. Each 3 m^2 collector consists of 18 glass tubes each containing a loop of copper tube through which the water passes. Some designs use a heat pipe in place of the loop of water pipe and in retrospect a heat pipe design would have made frost protection easier. The glass tubes have a double wall and a vacuum between the inner and outer walls provides thermal insulation. The surface of the inner tube is coated with a product to improve energy absorption. Figure 5.16 is a photograph of a typical collector.

Figure 5.16: Evacuated tube solar collection panel

West water heater

The system fitted to the west water heater is a 'closed loop' system with two 3 m^2 collectors, an external heat exchanger and two circulating pumps. Figure 5.17 is a diagram of the system as it was installed at Moorabool.

The system is designed so that whenever there is sufficient solar energy available, pump P2 draws cool water from the bottom of the water cylinder, circulates it through the heat exchanger and returns it to the cylinder. To avoid modifying the existing cylinder, the new pipework to and from the heat exchanger was connected into the existing drain and hot water outlet connections.

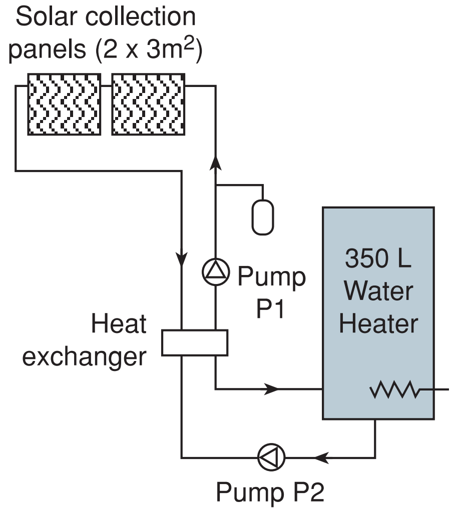


Figure 5.17: Diagram of west solar heating system at Moorabool

The primary heating circuit is a closed loop between the heat exchanger and the solar collectors and contains water at a nominal pressure of 400 kPa. A gas-filled expansion tank provides overflow capacity as the water expands on heating and a pressure relief valve set to 700 kPa protects the system against over-pressurisation.

Frost protection of the primary circuit is provided by running the circulating pumps for short periods whenever a temperature close to freezing is detected. Azzuro do not favour using a propylene glycol (ant-freeze) solution in the collector circuit.

The electric heating elements are controlled by time switch and are set to turn on at 12.30am. This provides adequate time to bring the water up to the required 85°C by 7am, even if starting from cold. The power to the elements is turned off at 7am which coincides with the time when the electricity price changes. An over-ride function on the time switch allows the shed manager to select electric heating at any time he needs to for operational reasons. After the over-ride function has been used, the time switch automatically reverts to its normal programme. This is a feature that is missing from the simple time switches typically used for water heater control in dairy sheds.

The system was commissioned in November 2006, but problems with water circulation through the heat exchanger prevented it from operating at full potential until mid-March 2007.

East water heater

Two additional Azzuro 3 m^2 collectors were purchased and set up to heat water for the east water heater by the 'trickle feed' method. In this system, the water cylinder is slowly filled over the day. The feed water is trickled through the solar collectors and on a summer day can reach a temperature of 70°C.

Figure 5.18 is a simplified diagram of the system. Initially, the flow regulator was set to 50 litres per hour with the aim of filling the 350 litre cylinder over the 7 hour period from 9am to 4pm. It was found that after a few days, the flow rate had dropped markedly and after a few more days it stopped altogether. Several different arrangements of pressure control and flow regulation were tried but stable operation was never achieved during the trial period.

The trickle feed system has the virtue of being simpler and cheaper than a pump circulated system and based on the limited information obtained during the trials, it seems capable of saving as much electricity. The present design needs further development to make it reliable in operation.

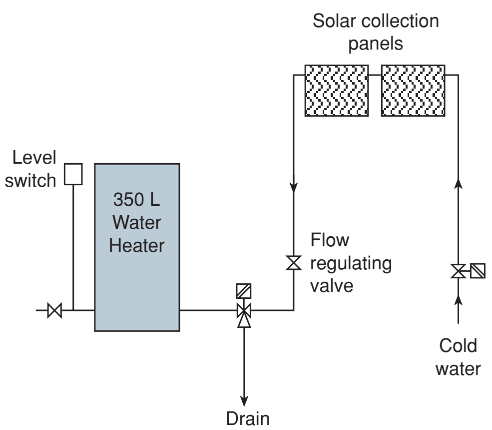


Figure 5.18: Diagram of east solar heating system at Moorabool

Performance monitoring

The performance of both the east and west solar heating systems was continuously monitored using instruments to measure water flows and temperatures and the amount of electricity used by the heating elements.

Solar radiation data was also collected from a weather station located on the site.

West water heater trial

Following commissioning in November 2006, problems were encountered with the design and installation of the system and these adversely affected operation until mid March 2007. The main problem was that water did not always circulate from the water cylinder through the heat exchanger even though the circulating pump was running. A consequence of water circulation stopping on a sunny summer day was overheating of the primary (solar collector) circuit. On at least two occasions, this led to hot water and steam being released through the relief valve.

The circulation problem was attributed by Azzuro to cavitation at the secondary circuit pump inlet and several changes were made to increase the system pressure at that point. The solar controller was also changed to a model with an 'anti-cavitation' programme. During one of these changes it was also found that the pipe leading from the cylinder to the pump had become partly blocked with debris from inside the water cylinder.

The last change made was to increase the operating head of the circulating pump by replacing the original single speed pump with a three speed pump.

From mid-March onwards, the system operated without incident but by this time in the season, the energy available from the solar system was much reduced.

Figure 5.19 is a graph of electricity used by the water heater elements during February 2007 when the solar system performance was erratic. The tallest bars represent the daily electricity usage (38 kWh) on days when there was no sun or when the circulating pump was not working. The shortest bars show the usage on days when the system was operating well and solar radiation was high. On the best day, 17 kWh of electricity was used at night to bring the water up to 85°C. This represents a saving

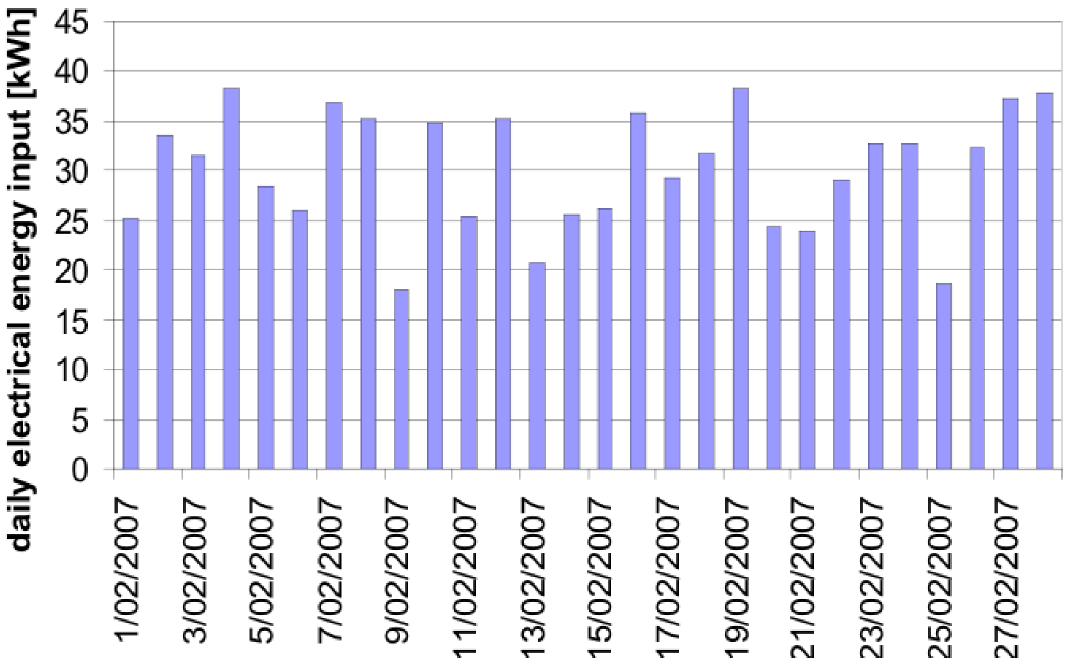


Figure 5.19: Daily electricity usage for west water heater at Moorabool in February 2007

of 55% on the 38 kWh that would normally have been required. Even if the circulating pump had operated correctly every day, the average saving in February would have been less than 55% because some days were cloudy.

Figure 5.20 is a similar graph for April 2007.

By April, the water circulation problems had been solved. Because milk production was reducing however, the full 350 litres of hot water was not used every day. The low electricity use on 21, 25 and 27 April was due mainly to reduced hot water use on those days and not to good solar performance.

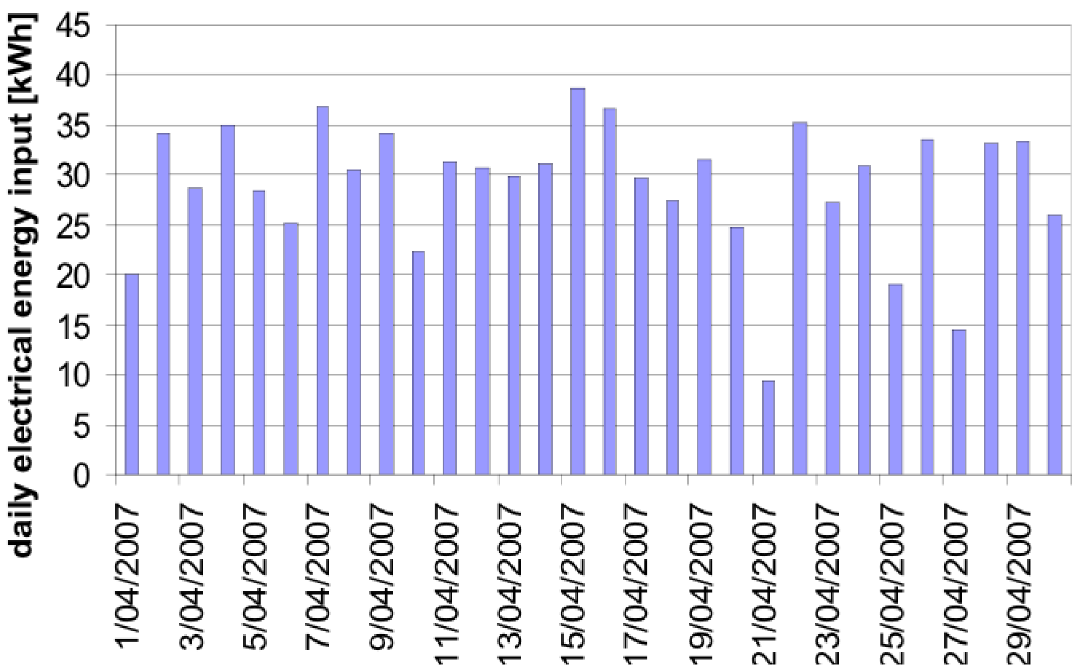


Figure 5.20: Daily electricity usage for west water heater at Moorabool in April 2007

Excluding 21, 25 and 27 April, electricity use for water heating ranged from 20 to 38 kWh per day with an average of 31 kWh. While the saving may have been as high as 47% on one day, the average saving was only 18%.

Figure 5.21 is a graph using data from the period 9 March 2007 to 8 May 2007 when the solar heating system ran without problems. It compares the temperature of the water in the cylinder at 5pm each day with the amount of available solar energy measured on that day.

The graph shows that on the sunniest days, the available solar energy was 5.2 kWh/m² and at 5pm on those days, the water temperature in the cylinder reached 57°C.

On days with less available solar energy, the 5pm water temperature was commensurately lower.

Calculations based on the data from this graph show that approximately 50% of the available solar energy was being usefully utilised to heat the water in the cylinder. This figure can be used to estimate the energy and cost saving over a full years operation.

Table 5.3 shows daily solar radiation in Southland for each month of the year. The data in the first column is taken from the Canadian Government RETScreen website (www.retscreen.net) and is for Invercargill. The data in the second column was recorded by the project weather station at Moorabool in 2007 and shows good agreement with the average data for Invercargill.

	Invercargill [kWh/m²/d]	Moorabool [kWh/m²/d]
January	5.50	
February	4.83	4.82
March	3.44	3.38
April	2.14	1.94
May	1.28	1.25
June	1.03	
July	1.19	
August	1.94	
September	3.08	
October	4.33	
November	5.50	
December	5.92	

Table 5.3: Monthly average daily radiation on horizontal surface

Based on the RETScreen data, a north facing solar collector in Invercargill receives an average 1380 kWh/m² of solar energy in a year. Over a 10 month dairy season, the figure is 1260 kWh/m².

Assuming the Moorabool system with 6 m² of collector area and an overall system efficiency of 50%, the annual saving in energy for water

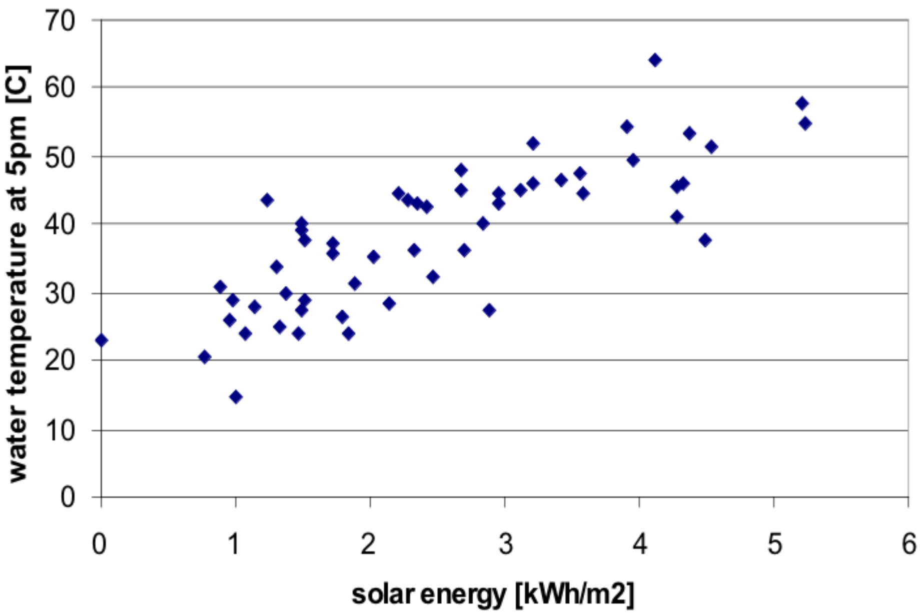


Figure 5.21: West water heater 5pm temperature vs. available solar energy

heating would be 3,800 kWh.

Azzuro Solar advised that they had insufficient experience with system performance in the Southland climate to predict the annual energy saving. They indicated that a theoretical expectation based on Invercargill sunshine hours was to gain approximately 4,500 kWh of useful heating energy over a full year from this system with two 3m² collectors. The calculation above indicates that this figure is probably too optimistic.

Economics

The value of the saving made by using solar water heating depends on the price paid for the energy that would otherwise have been used to heat the water. At Moorabool, most of the water heating is carried out at night using night rate electricity with a marginal cost of 6.5 c/kWh and so a saving of 3,800 kWh is worth $250. For a farm using an anytime pricing plan with electricity costing 14 c/kWh, the value of the saving would be $530.

The capital cost of the Moorabool system was approximately $9,900 made up as follows:

solar collection panels & mounts	$4,200
heat exchanger, pumps, controller	$2,500
installation materials and labour	
— plumber	$2,500
— electrician	$700

This cost excludes the work needed after commissioning to get the system running reliably. This was carried out at the supplier's expense.

With an estimated annual saving in electricity cost of between $250 and $530, clearly this was not an attractive investment. To repay the purchase price in five years, the electricity price would have to rise to 50 c/kWh.

Discussion

A typical large dairy farm such as Moorabool requiring 700 litres of 85°C water each day for cleaning purposes uses 20,000 kWh of energy each year to heat this water. If the energy is all provided by electricity at 14 c/kWh, the annual cost is $2,800.

In Southland, a solar water heating system with 12 m² of collector area can be expected to provide between 8,000 and 10,000 kWh of the total required energy. The Moorabool experience was that a system retrofitted to existing water heaters performs at the bottom of this range.

A system with more than 12 m² of collector area will contribute more energy but will also cost more. For the purpose of this discussion, 12 m² is considered to provide a reasonable balance between capital cost and electricity saving potential.

The electricity cost saving potential is $1,000 to $1,400 per year assuming the alternative heating source is electricity costing 14 c/kWh. The saving potential is only $500 to $700 if night rate electricity is the alternative.

Based on the experience at Moorabool, a solar heating system with 12 m² of collector area will cost approximately $19,000 to retrofit to an existing water heating system with two water cylinders. The simple payback period of 14 to 19 years makes this an unattractive investment for most businesses.

In the case of a new dairy shed, the extra cost of fitting a solar water heating system would be less than for a retrofit so the economics would be better. In the case of shed such as Moorabool, it is assumed that a system designed for solar heating would use a single water cylinder of 1000 litres capacity fitted with a heat exchange coil for the solar heater. The estimated cost of such an arrangement is $18,000 made up as follows:

1,000 litre water cylinder with solar coil	$4,000
solar collection panels (12 m²)	$8,300
pump and controller	$1,600
installation materials and labour	$4,000
subtotal	*$17,900*
less cost of standard water heating system	$4,000
net additional cost	*$13,900*

Even at this reduced cost however, an annual saving of $1,000 to $1,400 still gives a long payback period.

Conclusion

It is feasible to use solar water heating in a Southland dairy shed but the following points should be considered:

- solar water heater suppliers do not seem to be very experienced in designing systems for dairy sheds
- only a few solar water heater suppliers are established in Southland and they and their installation contractors are still building up experience
- suppliers don't seem prepared to make a site visit and provide an all-inclusive quotation
- the savings case for solar water heating in a dairy shed is not compelling. At current electricity prices, it is not possible to achieve the five year payback that most businesses would expect. For most dairy sheds there are more cost-effective ways of saving money on water heating – e.g. by using night rate electricity, a heat pump, or a heat recovery system.

5.5 Recommendations for Alternative Water Heating

There is a range of alternative methods for heating water in a dairy shed.

There is no evidence that any energy sources have a lower cost than electricity for most dairy farmers. However in special cases LPG or diesel might be an effective alternative.

There are a number of sources of heat on a farm that can be recovered for heating water. These include, in order of capital cost, "The Retriever", the DTS heat recovery unit and the Mahana Blue heat pump. It was found in practice that the high cost equipment had higher savings in the long term. The DTS heat recovery had the shortest payback time, but because of greater energy savings the Mahana Blue heat pump is likely to provide the greatest return over its lifetime.

None of the solar water heating systems were as effective as the heat pump. Their capital cost was higher and because of the changeable weather it is unlikely that their long run efficiency would ever be higher than the heat pump.

Table 5.4 shows some alternative water heating systems with expected energy and cost savings for a typical 50 bail dairy shed using 1000 litres of hot water each day. These figures were calculated using the 'Dairy Shed Energy and Electricity Cost Calculator' developed as part of this project and available for download on the project website www.cowshed.org.nz.

Action	Capital cost	Annual energy use	Annual energy cost	Energy saving	Energy cost saving
	[$]	[kWh]	[$]	[kWh]	[$]
Base case	0	28,040	3,810	0	0
Add a de-superheater heat recovery system	2,700	19,630	2,670	8,410	1,140
Add a heat pump heat recovery system	9,700	12,900	1,750	15,140	2,060
Add a solar heating system with 12 m^2 of collector area	14,600	20,990	2,850	7,050	960

Notes

This table is based on a 'typical' 50 bail rotary platform dairy shed using 1000 litres of hot water each day
The savings shown are based on implementing one action only.
Annual energy cost excludes the fixed costs (daily charge)

Table 5.4: A comparison of alternative water heating systems

6 MILK COOLING

6.1 Introduction

Milk inside a cow has a temperature of about 38°C but it usually drops to about 35°C once it passes through the collection can and some pipe work. This warm milk has to be cooled to ensure that bacteria don't affect its quality.

The current requirements for cooling (NZCP1) are:

"Unless used immediately for further processing, milk shall be:

- *primary cooled after filtering, refer to section 13.1 for further primary cooling requirements;*
- *cooled to 18°C or less at the completion of every milking;*
- *cooled to and maintained at 7°C or below within 3 hours of the completion of milking and kept at or below 7°C until it is collected or the next milking."*

It is understood that in some other milk-producing countries (e.g. Australia), storage at 4°C is the norm. It is possible that for marketing reasons, New Zealand dairy farms may have to reduce the maximum milk storage temperature from 7°C to 4°C at some time in the future.

Milk cooling equipment

On most Southland dairy farms, primary cooling is carried out by passing the milk through a plate heat exchanger and using the dairy shed water supply as the coolant. A typical plate heat exchanger for a 50 bail dairy shed is designed for a milk flow rate of 6,000 litres per hour (1.7 litres/s) and a water flow rate of 12,000 litres per hour (3.4 litres/s).

Desirably, the plate cooler will reduce the milk temperature from 35°C to 18°C although based on measurements made at two farms as part of this project, 18°C is not usually attained.

The further cooling of the milk from 18°C to below 7°C is commonly carried out inside the milk storage vat, usually using a direct expansion refrigeration system. Other secondary systems are possible but are not often seen in Southland. These include

- 'in-vat' cooling using chilled water sprayed onto the exterior of the storage vat (e.g. the Sphericool milk vat)
- 'instant' cooling in which the milk is cooled before it enters the vat by passing through a second plate heat exchanger that uses chilled water or glycol as the coolant.

The most common secondary milk cooling system uses a cooling pad attached to the floor of the milk vat and supplied with refrigerant from a refrigeration unit located nearby. The refrigerant evaporates inside the cooling pad and absorbs heat from the milk as it does so. To prevent the milk freezing, the vat has a motor-driven agitator that continuously moves the milk across the base of the vat. On very large vats, a second cooling pad is fitted to the lower wall of the vat and this is supplied from a second refrigeration unit.

The refrigeration units are nearly always of the type known as an 'air cooled condensing unit'. The condensing unit includes the refrigeration compressor together with its related components and also the refrigerant condenser – a finned coil similar to a car radiator.

In Southland, most dairy farms are suppliers to the milk processing company, Fonterra. The normal arrangement is that Fonterra supplies, at its cost, a milk storage vat (or vats) of the capacity best suited to its collection schedule. The dairy farm owner is responsible for cooling the milk and so has ownership of the refrigeration unit.

Energy use and cost

The refrigeration unit on a farm producing 15,000 litres of milk per day at peak season operates at a power of about 10 kW and typically runs for 10 hours per day at peak periods thus consuming about 100 kWh of electrical energy. Over a full season, energy use is likely to be 20,000 kWh – about 20% of total dairy shed electricity use.

Because the refrigeration system works as a heat pump, typically with a coefficient of performance of 2.7, the 20,000 kWh of electrical energy is actually used to provide about 54,000 kWh of cooling capacity.

At the typical August 2007 electricity price of 15 c/kWh, a milk vat refrigeration unit costs about $3,000 per year to run.

6.2 Primary Cooling

Existing system

The typical milk cooling system is shown in Figure 6.1.

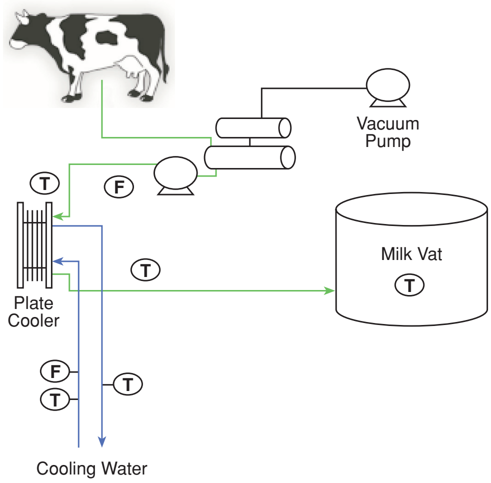


Figure 6.1: Milk pre-cooling

While there are financial benefits (discussed below) gained by using water rather than electricity to cool milk, the main driver for improved pre-cooler design is faster cooling of milk in the milk vat to achieve 7°C in less than three hours after milking.

Waikato Milking Systems state on their web site that their "coolers are designed to reduce the temperature of milk to within 3 degrees of the ground water temperature, providing the water ratio is no less than two and a half times that of the milk." (www.waikatomilking.co.nz/cooling.aspx). Delaval state "When the milk leaves the plate cooler its temperature has been reduced to 2 – 4°C above the water temperature" (www.delaval.co.nz/Dairy_Knowledge/EfficientCooling/Cooling_Technology.htm). This difference between the milk outlet and water inlet temperatures is normally referred to as the 'temperature approach' of the heat exchanger.

Trial at Graejo and Coldstream Downs

To monitor the effectiveness of the milk pre-cooler (plate heat exchanger), an electromagnetic flow meter with a fast response was inserted in the milk line and temperature probes were attached to the pre-cooler. To ensure a fast response the temperature of the milk from the pre-cooler was measured using a specially designed fast temperature probe with a response time of about 2 seconds.

Data was obtained during milking every 2 seconds but because of the large amount of data that would be produced only 10 minutes of milking was measured.

Results

Graejo Trust

The temperature and flow rate of the water were monitored at the Graejo Trust farm and

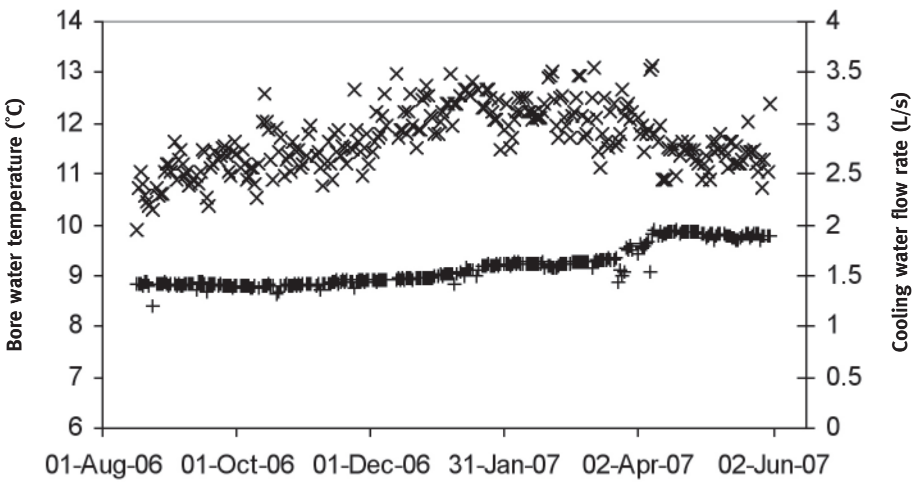


Figure 6.2: Cooling water temperature and flow rate at Graejo Trust farm

are shown in Figure 6.2. Here the water is pumped from a bore immediately before use in the cooler. The change in water temperature in April 2007 (seen in Figure x.2) was associated with a significant drop in average air temperature. The plate cooler was disassembled a number of during the season for cleaning but no significant build-up was observed.

During the 2005/6 season and for the start of the 2006/7 season the milk pump was controlled by an on/off level switch. As can be seen in Figure 6.3 below, the milk flow rate would be about 2.5 L/s but with flow for less than half the time. When the milk flow stopped the milk temperature within the cooler would reduce to about 15°C and as soon as the milk flow started there would be a small amount of milk (about 10 litres) coming out at this temperature. As flow continued the milk temperature reached about 27°C. The bore water temperature on 1 Oct 2006 was about 11.5°C so the "temperature approach" was about 15.5°C.

On 10 October 2006 a variable speed milk pump controller from Corkill Systems Ltd was installed and it was tuned over the next few weeks. The installed cost was about $3000. The new control reduced the maximum milk flow rate to about 1.2 L/s (about half of the previous value). The pump still stopped when it was running at minimum speed and the milk level in the can was too low. The temperature of the milk leaving the cooler was reduced to as low as 18°C. However the temperature approach was still high, being in the range 11°C (at higher milk flow rates) to 6°C at lower flow rates. The maximum milk flow rate was still higher than the estimated 0.9 L/s flow rate that was produced by the cows.

Later in the season (11 Jan 07), 10 additional plates were added to the cooler and later again, the water flow rate was increased. Early in the season, the water flow rate was 1.45 L/s but following maintenance work on the pump, it had increased to about 1.9 L/s by early April. The cooling water temperature at that stage was about 11.5°C. As seen in Figure 6.5 the maximum temperature of milk leaving the cooler was 19°C giving a 7.5°C temperature approach.

The Graejo Trust pre-cooler never achieved the expected temperature approach of 4°C. Even with a higher water flow rate it seems unlikely that it would.

An overview of changes made during the season is shown by Figure 6.6. The vat temperature and milk volume after 1 hour, and power data were used to predict the temperature of the milk entering the vat. This calculation was done whenever milking started with an empty vat, i.e., most mornings. Results are shown in Figure 6.6. The first vertical bar (11 Jan 07) shows when 10 extra plates were added to the existing 30. The second shows when the cooling water flow rate had been

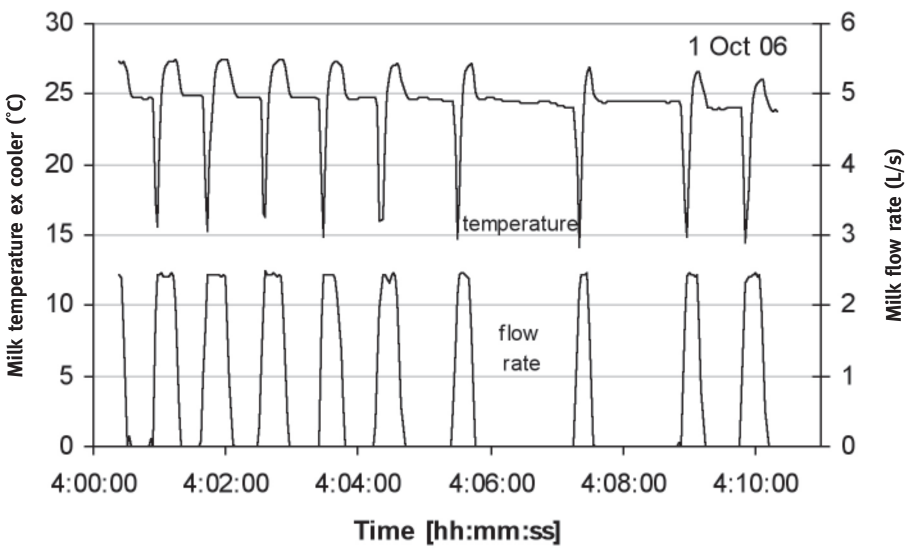


Figure 6.3: Typical milk temperature and flow rate with on/off control of milk pump

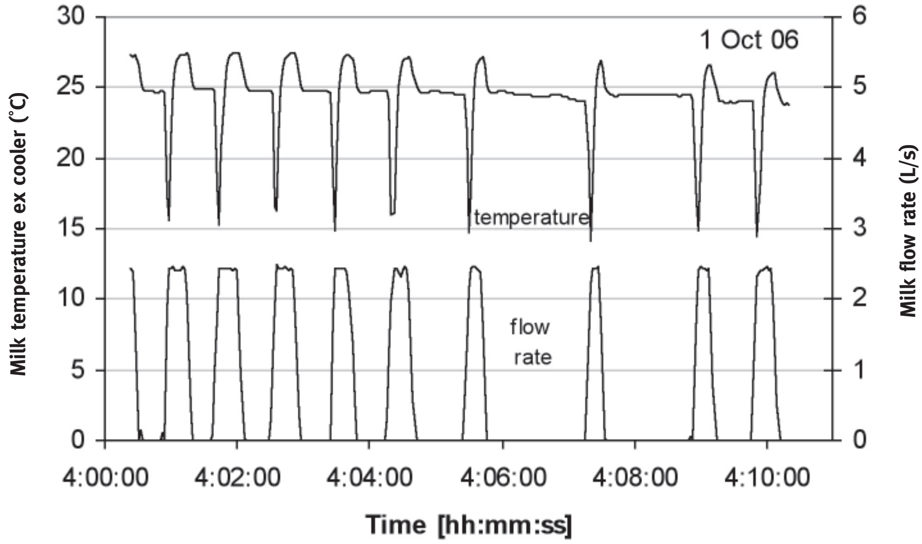


Figure 6.4: Typical milk temperature and flow rate with variable speed control of milk pump

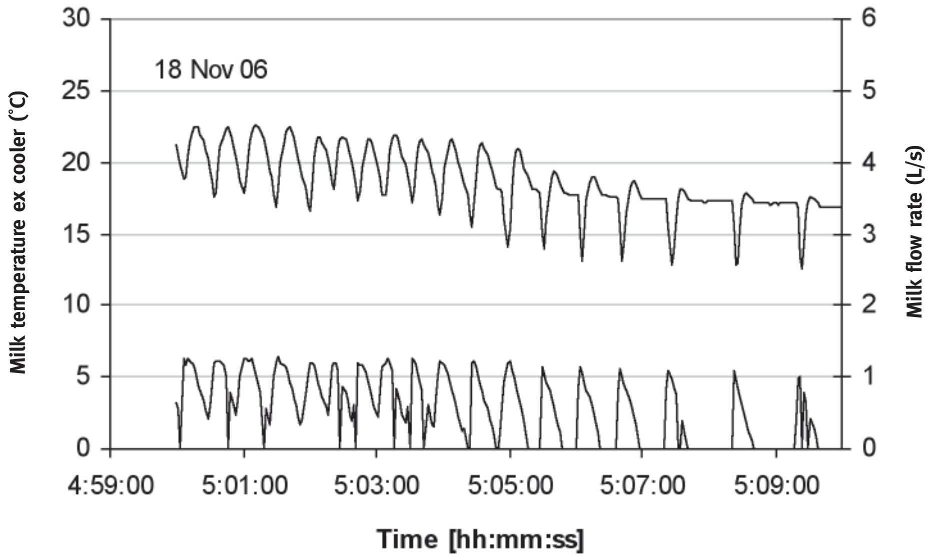


Figure 6.5: Milk temperature with increased heat exchanger area and cooling water flow rate of 1.9 L/s

increased to 1.9 L/s. A small improvement was seen on both occasions.

The performance of the Graejo cooler was disappointing and there were no obvious causes of this. The variable speed milk pump improved the cooling by lowering the maximum milk flow rate. Further process improvements for the plate cooler were beyond the scope of this project. It does however show the need for better understanding of the performance of plate coolers.

Coldstream Downs

The data from Coldstream Downs was quite different. The cooler had 35 plates, only 5 more than the initial number at Graejo, but cooling was much more effective. Cooling water is obtained from a dam so its temperature is strongly affected by ambient conditions. The cooling water temperature ranged from 8°C at the start and end of the season to 22°C on some days in January and February. The cooling water flow rate was normally about 3.3 L/s.

The milk pump produced a flow rate of about 2.9 L/s with an average flow rate for the data shown below of 0.65 L/s. The cooling water temperature on 25 August was about 8°C, so

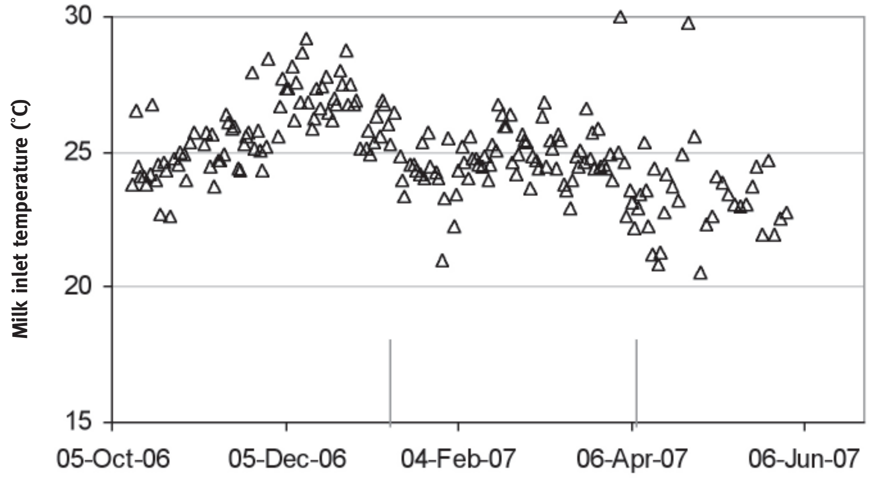


Figure 6.6: Calculated average milk temperature at vat inlet

the temperature approach was about 7°C.

Later in the season (Figure 6.9) when the cooling water was about 20°C, the milk was cooled to about 24°C. The temperature approach was about 4°C.

The differences between Coldstream and Graejo Trust on typical days in April 2007 are shown in Table 6.1. There is no clear cause for differences in performance. The ratio of the water flow rate to the maximum milk flow rate was better at Graejo Trust but the performance was worse. However the ratio of water flow rate to average milk flow rate was worse at Graejo Trust compared with Coldstream. We can conclude that the performance of plate heat exchangers with variable flow rates cannot be predicted by simple flow ratios alone.

Improvements

Neither of the two plate coolers studied consistently matched the typical performance expectation of cooling milk to within 2 to 4°C of the cooling water temperature. Further improvements seem possible.

The variable speed controller reduced the maximum milk flow rate at the Graejo Trust farm. However further improvements in flow control might be possible by using a modified level sensor to take advantage of some new features in variable speed drives.

The next stage in improvement of pre-coolers is to use a two-pass system rather than the current single pass. The single-pass system has the advantage that all the pipe work can be at one end, making maintenance easier.

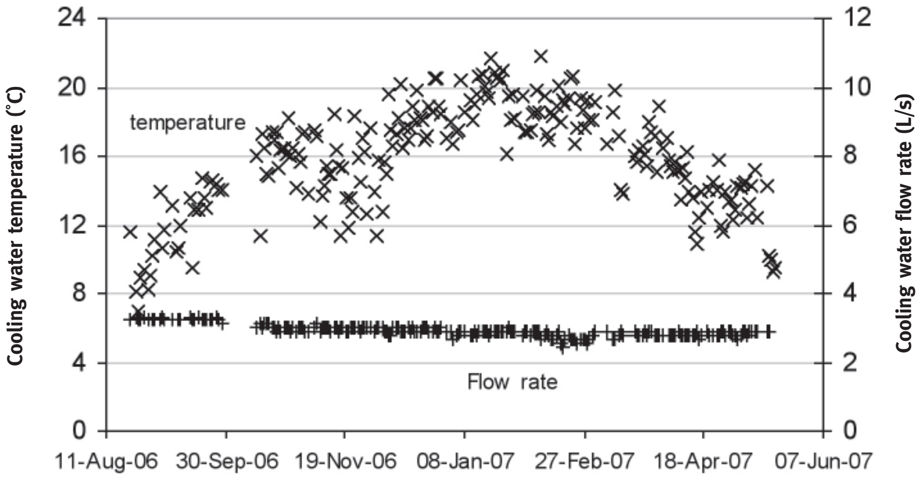


Figure 6.7: Cooling water temperature at Coldstream Downs

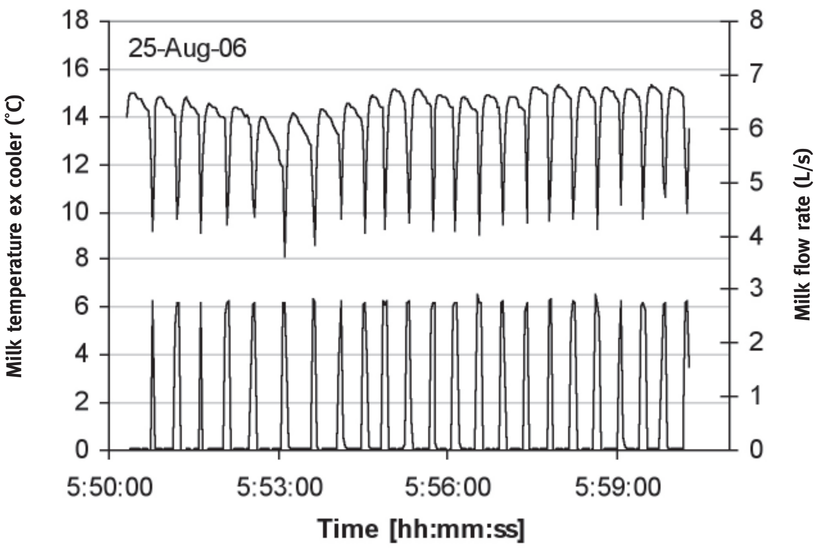


Figure 6.8: Ex-cooler milk temperature and flow rate at Coldstream in early spring

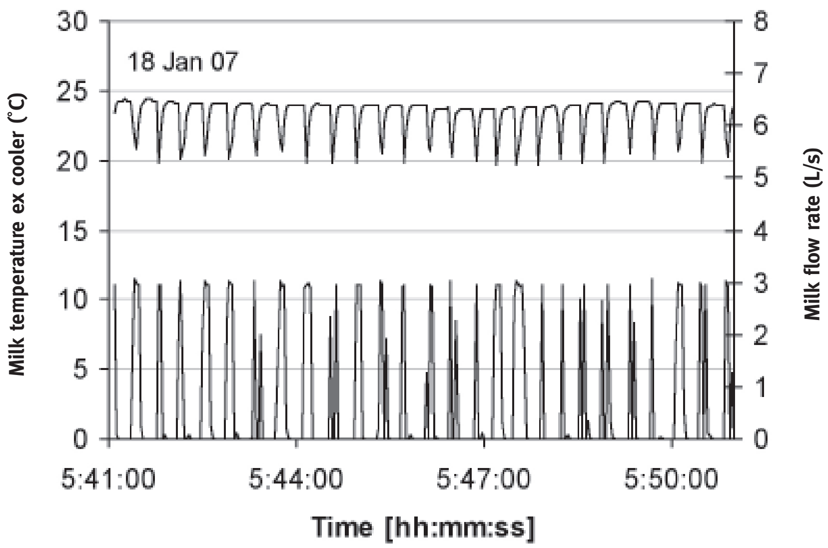


Figure 6.9: Ex-cooler milk temperature and flow rate at Coldstream in summer

Farm	Average milk flow rate [L/s]	Max milk flow rate [L/s]	Water flow rate [L/s]	Temperature approach [°C]
Graejo Trust	0.9	1.2	1.9	7.5
Coldstream	0.65	2.9	3.3	5

Table 6.1: Comparison of milk cooling performance later in 2007 season

With two passes there needs to be pipe connections at both ends of the plate stack. The piping needs to be designed so that it can easily be removed and reassembled, possibly with a different number of plates.

Such a system should achieve better cooling with the same or reduced flow of water.

Economics

It would be inefficient to cool all of the milk using the milk vat refrigeration system. On a farm producing 15,000 litres per day at the peak it might cost about $3500 per year to cool the milk with an efficient refrigeration system (COP = 3). If water at an average of say 18°C is used to cool the milk to an average temperature of about 23°C, the electricity cost reduces to about $2100. Every 1°C drop in milk temperature from the cooler is worth about $120 (860 kWh) per year.

The maximum economic investment justified to cool milk from 35°C to 23°C is about $11000. The maximum justified investment increases by about $600 for every extra degree of cooling achieved. Improvements in the cooler are unlikely to be economic by themselves.

It is estimated that the installation of the variable speed drive on the Graejo milk pump resulted in an improvement of 5°C in the cooled milk temperature which is sufficient to justify the investment made. The effect of the variable speed control on the milk pump power is insignificant.

Conclusions

NZCP1 recommends that primary cooling systems be able to cool the milk to 18°C or lower but neither the Graejo nor Coldstream coolers were able to achieve this. At Graejo the bore water temperature was low (10°C to 13°C) throughout the season and yet the temperature of milk leaving the cooler rarely fell below 20°C.

At Coldstream, the cooling water is supplied from a surface stream and so rises above 20°C in mid-summer. Despite this, the pre-cooling at Coldstream was more effective with the milk temperature getting to within 4°C of the cooling water temperature in mid-summer.

Pre-cooling at Graejo was improved following the implementation of milk pump speed control, increasing the surface area of the heat exchanger and increasing the water flow. As a result of all three actions, the pre-cooler approach temperature was reduced from 16°C to 8°C.

Spending about $3000 on a milk pump speed controller was a good investment as it was expected to save about $600-$700 per year. An alternative was investment to increase the cooling water flow rate up to the recommended 2.5 times the maximum milk flow rate. It is estimated that this would have required an additional 4000 m^3 of water per year as well as the capital and pumping costs involved.

In general, to decide if variable speed milk pump control is justified, a farmer needs to estimate the temperature approach of the plate cooler. This can be estimated from the external temperatures of the relevant pipes but not all farmers have equipment to do this. If the temperature approach is less than about 6°C it is very unlikely that cooling will be greatly improved by a pump speed controller. If the temperature approach is greater than about 12°C a controller might be economic for a farm processing at least 15,000 L/day. If the temperature approach is more than about 6°C and if the milk is not chilled quickly enough in the vat, then a milk pump controller is likely to assist in reducing the chilling time.

6.3 Milk vat refrigeration units

Introduction

On most dairy farms, a direct expansion refrigeration system provides the final cooling of the milk while it is in the storage vat.

It is a feature of the mechanical refrigeration cycle that the heat energy removed from the milk exceeds the electrical energy required to run the refrigeration unit. The ratio of the energy extracted from the system to the energy used to run the unit is known as the 'coefficient of performance'(COP). The higher the COP, the more energy-efficient the refrigeration system is. A typical COP value for a milk vat refrigeration unit is 3 and a milk cooling system operating at this COP will remove heat from the milk at three times the rate at which electrical energy is consumed.

In this project, milk vat refrigeration units at two farms (Coldstream Downs and Graejo Trust) were monitored and their energy efficiency calculated.

Equipment Installed

The Coldstream Downs farm has two milk storage vats designated 'east' and 'west' for the purposes of this project. Each vat is fitted with a direct expansion cooling pad in the base and each pad is connected to a Patton Refrigeration Ltd air cooled condensing unit model CCH1200.

The Graejo Trust farm has one milk vat which is also cooled by a Patton CCH1200 unit.

Catalogue performance data for the Patton CCH1200 using refrigerant 22 and operating in an ambient temperature of 32°C is given in Table 6.2 below. The evaporating temperature is the temperature in the refrigeration pad in the vat and is expected to be in the range -5°C to 5°C. This indicates a COP in the range 2.7 to 2.9.

Evaporating Temperature [°C]	Heat extracted [kW]	Power input [kW]	COP
-10	21.5	8.7	2.5
-5	26.3	9.8	2.7
0	31.3	11.0	2.8
5	36.4	12.4	2.9
10	42.6	13.8	3.1

Table 6.2: Expected performance of a Patton Refrigeration CCH1200 air-cooled condensing unit (Source: www.pattonrefrig.co.nz (June 2007))

Trials

During the 2006/7 season, the performance of the milk cooling systems at Coldstream and Graejo was continuously monitored. The following data was recorded

- rate of milk flow into the vat
- refrigeration unit electricity use
- temperature of milk in the vat

Ambient air temperature, wind speed and direction and solar radiation were measured at a weather station on each site.

Calculations

The COP for each unit was calculated as follows.

$$COP = \frac{\text{Heat removed from milk}}{\text{Electrical energy used by chiller}}$$

The heat removed from the milk was calculated from the known mass of milk (recorded by the milk flow meter), the temperature change and the period of time for that temperature change. In addition an estimate of the heat gained by the milk from the ambient air was included in the calculation.

$$\text{Heat removed from milk} = mC_p\Delta T + \text{external heat gain}$$

The external heat gain was determined by finding the rate of temperature rise of the milk when milking had finished and the refrigeration unit had switched off. It was found that for Graejo, the rate of heat gain in kW could be represented by:

$$\text{Rate of heat gain} = (0.197(T_{ambient} - T_{vat})v^{0.6} + 0.0043\,Radiation)V/16000 + 0.5$$

Here v is the wind speed in m/s, Radiation is the solar radiation in W/m^2 and V is the volume of milk in the vat in litres. The value of 16,000 is the approximate maximum capacity of the vat. The exponent of wind speed (0.6) was chosen independently using normal correlations for the effect of speed on heat transfer. The last constant (0.5) was added to give agreement of predicted and measured heat gains.

For Coldstream the rate of heat gain was similar being:

$$\text{Rate of heat gain} = (0.094(T_{ambient} - T_{vat})v^{0.6} + 0.0045\,Radiation)V/12000 + 0.47$$

At Coldstream it was found that atmospheric heat gains increased the cooling load by about 20% during the periods checked. For Graejo, the value was 13%.

Results

Table 6.3 is a summary of the COP results. For each refrigeration system about twenty COP values were calculated and only those covering a time period of more than one hour have been reported.

	Graejo	Coldstream west	Coldstream east
Number of tests	20	17	19
COP average	2.7	1.86	1.55
COP range	2.0-3.8	1.6 – 2.1	1.4 – 1.7
Standard. deviation	0.49	0.17	0.09
Data collection dates	3/11/06 – 17/11/06	28/9/06 – 19/11/06	2/12/06 – 5/1/07

Table 6.3: Typical performance of Graejo and Coldstream refrigeration systems

The Coldstream units both had COP values below 2. The Graejo unit was much closer to the expected range of 2.7 – 2.9.

The large range of COP values obtained for Graejo indicated that refrigeration unit performance was being influenced by factors such as weather conditions. It was found that on colder and windier days the COP tended to be higher at Graejo but no such relationship was found at Coldstream.

At Coldstream the east vat refrigeration unit often operated continuously between the first and second milkings indicating unsatisfactory performance. For this vat the rate of heat removal was much lower (by about 9 kW) than expected. Possible causes of the poor performance include a cooling pad that is too small, poor installation of refrigerant lines to the vat, or a faulty refrigeration unit. A full investigation into the performance was not carried out.

Using the COP data, the potential for saving electricity by improving refrigeration unit performance was calculated. At Coldstream there is a requirement to cool 2.7 million litres of milk from 18°C to 6°C each year and to cope with atmospheric heat gains equal to 20% of the milk cooling load. If the observed average COP of 1.7 was increased to 2.7 (as observed at Graejo), this would save 9000 kWh per year of electricity. This represents an annual cost saving at August 2007 prices of $1300.

Improvement of the Coldstream refrigeration system does not require new technology but just maintenance or improved installation of current technology.

Conclusions

The monitoring work done here has highlighted a problem and shown an opportunity for improvements in the design and/or implementation of vat cooling systems. The extent of under-performing cooling systems is unclear as they might not be easily detected by farmers. Detection of the causes for under-performance is likely to require a thorough practical and theoretical analysis of the systems.

6.4 Milk Vat Insulation

Background

The Coldstream farm has two milk vats, known as east and west, that are similar.. The west vat has a volume of 16000 litres and the east has a volume of 14000 litres. The diameter of both is about 2.88 m and the heights are about 3 m and 2.5 m respectively for the west and east vats.

Trials

On 14 December 2006 the west vat was fitted with a insulating wrap supplied by Dairy Technology Services (DTS) under the brand Polar Wrap. The normal cost of this was about $2800 installed; it was dependent on the vat size. During most of 2006 and some of 2007, sufficient data was gathered to estimate the heat gain of the vats. This was calculated when the milk volume has reached its lower temperature setpoint so the chiller unit was turned off. The rise in milk temperature was combined with the measured mass of milk to estimate the rate of heat gain in kilowatts. The weather conditions (air temperature, wind speed, solar radiation) during the period were also recorded and related to the heat gain.

Results

It was found that the rate of heat gain [kW] could be expressed as:

Rate of heat gain = $(0.094(T_{ambient} - T_{vat})v^{0.6} + 0.0045 Radiation)V/12000 + 0.47$

where T is the temperature of the air or milk in°C, v_{wind} is the wind velocity in m/s, *Radiation* is the solar radiation which ranged from 0 to 1000 W/m^2 and V is the volume of milk in the vat in litres. The exponent value (0.6) is based on typical textbook correlations. Heat gain from solar radiation and heat gain from warm air were both significant.

The volume of milk in the vat typically varied from 6000 to 12000 L. The correlation between heat gain and the mass of milk in the vat was not strong but it was included because of the expected relationship.

The chillers for these vats used about 7.1 kW of electrical power and typically extracted heat from the milk at a net rate of 8-12 kW. At times a significant proportion of the heat extracted was heat gain from the surroundings.

Once the insulation was applied to the vat, the maximum heat gain was found to be 0.6 kW compared with gains of up to 6 kW before. When a comparison was made for days with similar weather the heat gain was 80% less for the insulated vat.

The correlation obtained was used with the weather data to estimate the heat gain at any time for a full vat of milk without insulation. These values were averaged over each month to give Figure 6.11.

From this we can estimate the heat gain over a season. The average rate of heat gain for the months other than June, July and August are 2.1 kW continuous. At Coldstream milk is often collected every second day so at various times none, one or two of the vats contain milk. It is estimated that they contain milk 65% of the time with an average 80% capacity. Thus the annual reduction in heat gain is estimated to be about 2.1 x 65% x 80% x 80% saving x 270 days/year x 24 hours/day = 5700 kWh/year. A chiller with a CoP of 2.0 will require half this amount of electricity (2850 kWh/year). At a price of $0.14/kWh the annual saving is about $400.

For a 5 year payback an investment of about $2000 is worthwhile. This is less than the cost of $2800.

It was estimated, using the weather data, that if the air temperature was 7°C higher, the savings would increase to about $600 per year and justify and investment of $3000. A more efficient refrigeration system reduces the savings.

However a more important gain might be made in cooling time. Say 7000 L of milk is to be cooled from 14°C to 7°C (in the vat at the end of milking) with a refrigeration capacity of 12 kW. This will take 4.4 hours. But if on a hot

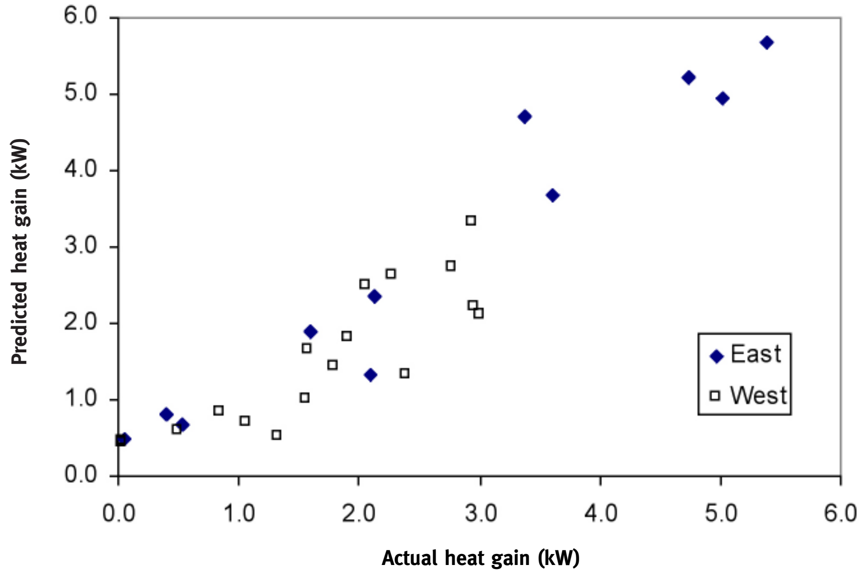


Figure 6.10: Heat gain in milk vats at Coldstream

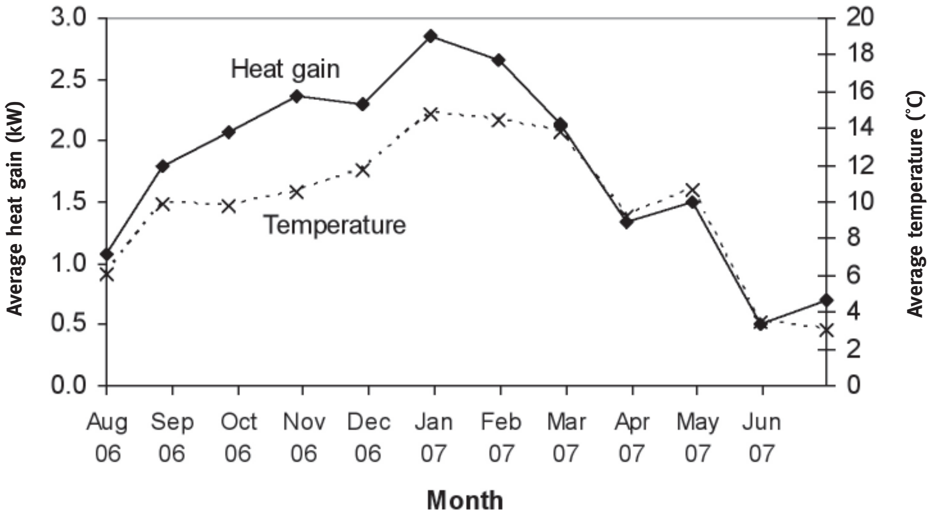


Figure 6.11: Average heat gain estimated from Coldstream weather data

sunny day there is a heat gain of 5 kW the net refrigeration is reduced to 7 kW and cooling will take 7.5 hours.

Conclusions

The heat gains from the sun and air into milk vats were measured to be up to 6 kW on warm, sunny, breezy days. Based on average conditions the heat gain into a vat was estimated to be about 2.1 kW at the Coldstream farm.

It was estimated that vat wrap reduced heat gains into the milk by about 80%.

On this farm the vat wrap was not economic for energy savings alone but the investment might enable a farm to meet the milk chilling requirements more easily. A vat wrap should be considered by any farm that is struggling to cool milk to 7°C within 3 hours of milking.

In much warmer areas of New Zealand, the vat wrap is likely to economic for energy savings alone.

6.5 Cooling milk with chilled water

Introduction

Water chillers or ice banks are sometimes installed in farm dairies to provide chilled water for milk cooling and there are various reasons for this.

In New Zealand today, probably the most common use for chilled water is to supplement the capacity of the pre-cooler which uses the farm water supply to do the initial cooling of the milk. Ideally, milk should leave the pre-cooler at 18°C but this target is often impossible to achieve where the farm water supply is restricted in quantity or is too high in temperature. If vat chilling is effective the requirement to cool the milk to 18°C by the end of milking might still be achieved anyway but using chilled water in an external heat exchanger is another method to overcome the problem. The chilled water is used in a second plate heat exchanger or a second stage added to the existing plate cooler.

Another use for chilled water is to provide 'instant' cooling of the milk so that it is down to 7°C or less before it reaches the storage vat. Some equipment manufacturers claim that this rapid cooling improves milk quality.

A third use for chilled water is to spray it onto the outside walls of the milk vat to cool the milk. This is an alternative to the more normal direct expansion refrigeration system that is most commonly used in New Zealand. Robert Stone Stainless Steel manufacture milk vats designed for this cooling method under the brand name Sphericool. The Sphericool vat has a spherical shape and the chilled water is sprayed over the outer wall of the lower half of the vat thus cooling the milk inside. The system is claimed to have a number of advantages including more rapid and efficient cooling than the traditional cylindrical vat fitted with direct expansion cooling pads. The Sphericool system was not trialled as part of this study and no data was found to enable the claim of increased efficiency to be checked.

Ice banks are sometimes used to provide the chilled water because they have the added advantage of providing a method of storing cooling energy for later use. They were sometimes used in the early days of mechanical refrigeration when low-powered refrigeration systems were unable to cool the milk quickly enough. By storing the cooling energy as ice, the refrigeration unit could operate at low power over a long period to provide the required cooling. It is understood that some of these ice banks are still in use in remote areas of New Zealand where electricity supply capacity is limited.

For a similar reason, the BioGenCool system currently under development in Canterbury uses an icebank to spread the refrigeration load across the whole day and so provide a steady base load for an on-farm generator partly powered by biogas.

The use of ice banks (or chilled water storage tanks) on dairy farms to shift electrical load from periods of high demand to periods of low demand has also been suggested by many and adopted by some. While this may be of advantage to the owners and operators of the electricity supply network, the incentive provided by current electricity pricing is not sufficient to make this a common practice. Some equipment suppliers and energy advisers promote the use of thermal storage systems as a means of reducing electricity costs and this part of the report looks at the economics of this.

Equipment available

Water chillers are readily available from refrigeration equipment suppliers such as DTS and Heatcraft. For a farm requiring a normal direct expansion cooling pad on the milk vat and also a chilled water supply for the pre-cooler, the necessary equipment can be purchased as a single unit.

A water chilling heat exchanger can also be added on to an existing milk vat refrigeration unit. This is sometimes referred to as a 'clip-on' system.

Ice banks are not so readily available but there are some refrigeration companies that can supply these or build them to order.

Trial at Coldstream Downs Ltd

System selection (ice bank v chilled water tank)

After considering the advantages and disadvantages of an ice bank and a chilled water tank as a means of thermal storage, it was concluded that although a chilled water tank requires a lot more space, it has a lower capital cost. Ice banks are known to be commonly used to provide thermal storage in applications where space is restricted (e.g. in the air conditioning plantroom of an office building) because they are able to store a large amount of cooling energy in a small volume.

On a typical dairy farm, availability of space is not usually a major issue and so a thermal storage system based on a large store of chilled water (or water/propylene glycol solution) is likely to be more cost-effective.

Description of system installed

Hamilton-based dairy refrigeration equipment supplier Dairy Technology Services (DTS) offers chilled water systems with thermal storage specifically designed for dairy farms. They also indicate in their advertising that an electricity cost saving can be made by using electricity at 'off-peak' rates to chill the water.

For the Coldstream trial, DTS supplied a 'clip on' water chiller, chilled water storage tank, plate heat exchanger and circulating pumps and installed and commissioned the system. The equipment was arranged as shown in Fig 6.12.

The chilled water storage tank was a plastic tank of 25,000 litres capacity and was uninsulated. The 'clip on' water chiller consisted of a brazed plate heat exchanger, thermostatic expansion valve and a water circulating pump (P1) capable of circulating 5,000 litres per hour through the heat exchanger. The refrigerant required to operate the chiller came from the existing Patton CCH1200 refrigeration unit on the east milk vat. This unit continued to operate the east vat

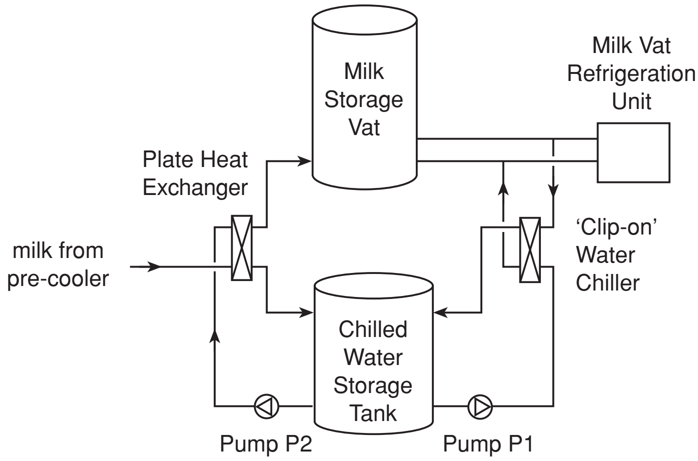


Figure 6.12: Diagram of the Coldstream chilled water system

cooling pad whenever required and during the night, was used to operate the water chiller.

A time switch was installed so that the water chilling equipment ran only between the hours of 11pm and 7am. The intention was to change the dairy shed electricity purchasing plan from 'anytime' to 'day/night' so that the water chiller running was all carried out using 'night rate' electricity but this change was not made.

A second plate cooler was added in to the existing milk line and during milking, chilled water was circulated through this heat exchanger at the rate of 12,000 litres per hour by pump P2.

Operating experience

The system was commissioned in early March 2007. After some initial problems, it ran without incident from about 24 March until the season finished on 18 May.

Performance monitoring

The electricity used to operate the water chiller was monitored using a kilowatthour meter. This measured the combined electricity usage for the east vat refrigeration unit and the two new water circulating pumps, P1 and P2.

Not all of the milk cooling was completed using chilled water and the direct expansion cooling pads in the milk vats also had to be available for final cooling and to maintain the milk temperature below 7°C until the tanker arrived. During the trial period from 24 March to 18 May, all milk was stored in the west milk vat so only the west refrigeration unit was operating during the day. Electricity used by this unit was measured with a separate kilowatthour meter.

Energy saving

Electricity used for milk cooling in a 28 day period before and after the installation of the chilled water system is shown in Table 6.4.

This shows an fall in daily electricity use after the chilled water system was installed but does not take account of the large change in milk production between the two periods.

Table 6.5 shows the milk production and a

	Electricity used for milk cooling	
	for the complete period [kWh]	*daily average* [kWh]
Before installation of chilled water system[1]	2651	94.7
After installation of chilled water system[2]	2591	92.5

Table 6.4 Electricity used for milk cooling before and after the installation of a chilled water cooling system [[1] 1 Feb 2007 to 28 Feb 2007 (28 days); [2] 24 Mar 2007 to 20 Apr 2007 (28 days)]

	Electricity used for milk cooling [kWh]	**Milk production** [litres]	**Specific electricity use** [kWh per litre]
Before installation of chilled water system[1]	2651	292,629	0.0091
After installation of chilled water system[2]	2591	186,851	0.0139

Table 6.5: Specific electricity use for milk cooling before and after the installation of a chilled water cooling system [[1] 1 Feb 2007 to 28 Feb 2007 (28 days); [2] 24 Mar 2007 to 20 Apr 2007 (28 days)]

calculation of specific electricity use for milk cooling in kWh per litre.

At 0.0139 kWh per litre, the specific electricity use for milk cooling in March/April was 53% greater than in February. While an increase might be expected as milk production reduces towards the end of the season, an increase of this magnitude indicates that the chilled water cooling system is less energy-efficient than the system it replaced.

The main reason for the increased electricity use is likely to be the two water circulating pumps plus some additional heat gains through the chilled water storage tank and piping. In the trial, the circulating pumps consumed an estimated 30 kWh each day. Because of the system design, pump P1 ran for 24 hours per day which was unnecessary. This pump only needs to run while the water chiller is running i.e 8 hours per day maximum. Deducting the energy use associated with this unnecessary pump running leaves the daily electricity use for pumping as 17 kWh.

Based on the above, it is estimated that daily electricity use for milk cooling would have been at least 111.7 kWh per day in February if the chilled water system had been in operation. This ignores all heat gains so is an underestimate.

Cost saving

An advantage of using a chilled water storage system to provide most of the milk cooling is the ability to re-charge the chilled water store at night when electricity prices are lowest.

In the Coldstream Downs trial, the electricity was actually being purchased under the Contact Energy 'anytime' plan but the potential for saving money under a 'day/night' purchase plan was calculated. The calculated cost saving by using chilled water cooling at Coldstream in February 2007 is $2.58 per day. This figure was calculated on the basis of the information shown in Table 6.6.

Assuming that the annual cost of electricity for milk cooling is equal to 250 days at the average daily cost in February, the annual cost saving will be approximately $645.

Note that changing to a day/night electricity purchase plan at Coldstream will also affect the cost of running the other electrical plant and the impact of this (which could be positive or negative) has not been assessed in this calculation.

Economics

The total cost of installing the chilled water system at Coldstream Downs was approximately $19,000 This was made up as follows.

	Average daily electricity use [kWh]	**Electricity price** [cents/kWh]	**Daily electricity cost** [$]
Direct expansion cooling	94.7	13.6	**$12.88**
Chilled water cooling			
day	33.8	15.5	5.24
night	77.9	6.5	5.06
total	111.7		**$10.30**

Table 6.6: Daily electricity cost for milk cooling by two alternative methods

'clip on' water chiller unit	$3968
chilled water storage tank (25,000 litres)	$3060
refrigeration and electrical installation	$1630
milk cooler, pump and chilled water piping incl installation	$9850
tank installation	$373
Total	$18,881

To achieve a 5 year simple payback on this investment would require annual cost savings of $3,800 whereas actual savings achieved were in the order of $600.

Discussion

Most articles on milk cooling note that indirect cooling using chilled water uses more energy than cooling the milk in the vat using direct expansion cooling pads.

The Australian Cowtime website (www.cowtime.com.au) carries this statement:

> *"Direct expansion is the simplest and most energy efficient way of cooling milk to the required storage temperature".*

Although comparing energy usage before and after the installation of the chilled water system was made difficult by the large change in milk production, it is estimated that energy usage for milk cooling increased by at least 17 kWh per day due to water pumping.

The question therefore is whether a worthwhile saving in electricity cost can be made by moving the majority of the milk cooling load into the night (11pm – 7am) when electricity companies offer cheaper tariffs. At August 2007 electricity prices it clearly can not.

It has been suggested that moving the cooling load into the night time will reduce the maximum electrical demand for the dairy shed and that possibly this will provide a cost saving. This was not the case at Coldstream because even with the chilled water cooling, it was still necessary to run a refrigeration unit during milking in order to achieve the final 6°C storage temperature.

Conclusion

Instant cooling of milk using chilled water is less energy-efficient than the normal in-vat direct expansion cooling system. Shifting the cooling load into the night hours and using night rate electricity can save money but not nearly enough to make it economic to invest in a chilled water plant (or ice bank) simply as a cost saving measure.

The main reason for installing a chilled water system should be to solve a milk cooling problem, not in an attempt to reduce electricity cost.

6.6 Recommendations for Efficient Milk Cooling

The opportunities for reducing energy use and electricity cost in the area of milk cooling are fewer than in the areas of vacuum pumping and water heating.

The main opportunities identified in this project were:

a) optimising the operation of the pre-cooling system by the installation of a milk pump speed controller to give a more even flow of milk through the cooler
b) insulating the milk vat

While these measures will improve energy efficiency, the amount of energy saved on most farms is likely to be relatively small and in many cases will not meet a 5 year payback criterion.

In general, to decide if variable speed milk pump control is justified, a farmer needs to estimate the temperature approach of the plate cooler. This can be estimated from the external temperatures of the relevant pipes but not all farmers have equipment to do this. If the temperature approach is less than about 6°C it is very unlikely that cooling will be greatly improved by a pump speed controller. If the temperature approach is greater than about 12°C a controller might be economic for a farm processing at least 15,000 L/day. If the temperature approach is more than about 6°C and if the milk is not chilled quickly enough in the vat, then a milk pump controller is likely to assist in reducing the chilling time.

Based on the results measured at Coldstream Downs, a vat wrap is unlikely to be economic for energy savings alone but the investment might enable a farm to meet the milk chilling requirements more easily.

In much warmer areas of New Zealand, the vat wrap is likely to be economic for energy savings alone.

7 WATER & EFFLUENT PUMPING

7.1 Introduction

A dairy shed has several pumps for moving fresh water and effluent. A 'typical' dairy shed is likely to have pumps for

- circulating water through the milk cooler (cooler pump)
- supplying water to the shed washdown hoses (washdown pump)
- pumping water to the drinking troughs on the farm (farm pump)
- pumping effluent from the holding pond to an irrigation system

Normally these pumps are fitted with electric motors of various sizes ranging from 1 to 18.5 kW. The effluent pump usually has the largest motor and is typically 15 kW or 18.5 kW.

Energy use usually gets little attention when pumping and piping systems are designed and installed.

7.2 Water consumption

NZCP1 gives a guideline requirement of 140 litres of water per cow per day in summer - 70 litres for drinking and 70 litres for cleaning the dairy shed.

Figure 7.1 shows water usage in the Graejo and Coldstream dairy sheds. The annual usage of 13 million to 18 million litres (of which 280,000 to 300,000 litres is subsequently heated for washing purposes) is likely to be typical of similar dairy sheds in Southland.

7.3 Sizing pipelines

The energy required to move water through a pipe is lowest when the pipe diameter is large but a large diameter pipe costs more to buy and install than a small diameter pipe. The optimum diameter is the one that provides the best balance between initial cost and ongoing running cost.

For farm installations, selecting a pipe diameter that gives a pipeline velocity in the range of 1 to 2 metres per second (m/s) is likely to be optimum. The cost of energy to operate the pump will not vary much if the water velocity is within this range but at higher velocities, there will be a significant increase in energy required.

	Graejo		Coldstream		
	Cold	**Hot**	**Cold**	**Hot**	
Season Total	13,174,000	282,000	17,934,000	370,000	litres
Months					
July	0	0	0	0	litres
August	643,000	29,000	461,000	20,000	litres
September	1,122,000	33,000	1,752,000	45,000	litres
October	1,410,000	24,000	1,945,000	48,000	litres
November	1,462,000	57,000	1,958,000	49,000	litres
December	1,406,000	27,000	2,006,000	53,000	litres
January	1,607,000	25,000	2,086,000	48,000	litres
February	1,633,000	24,000	2,064,000	29,000	litres
March	1,671,000	25,000	2,309,000	33,000	litres
April	1,730,000	22,000	1,929,000	26,000	litres
May	491,000	17,000	1,424,000	20,000	litres
June	0	0	0	0	litres

Figure 7.1; Water usage in the Coldstream and Graejo dairy sheds in the 2006/2007 dairy season

Example

A milk cooler is designed for a water flow rate of 12 m^3 per hour (0.0033 m^3/s). Calculate the pipeline diameter that gives a velocity in the range 1 to 2 m/s.

Try 38 mm diameter

cross sectional area of
a 38 mm diameter pipe = 0.0011 m^2

velocity in pipe = 0.0033/0.0011 m/s
= 3 m/s

This is a bit too high.

A 50 mm diameter pipe will have a velocity of 1.5 m/s; a 65 mm diameter pipe will have a velocity of 1 m/s.

Both of these sizes give velocities in the range 1 to 2 m/s so either is suitable.

Energy losses in pipelines also increase if there are other restrictions to the flow such as valves and reductions in pipe diameter. If the pipeline contains many such restrictions, this can be a major source of energy loss. The chosen pipe diameter should be used for the full length of the pipeline and all fittings should be matched to this diameter.

Pipelines operating with a water velocity greater than 3 m/s are likely to require too much pumping energy and should be replaced. Farm owners/managers should check this by measuring (or estimating) the flow rate in a pipeline and then comparing it with the values in Table 7.2.

If the flow rate is greater than those in the table, replace the pipeline to get lower pumping costs.

Water pumping

The energy used by an electrically driven water pump for a given pumping duty depends on the efficiency with which the pump converts the input mechanical energy into useful pumping energy. This is determined by the pump design and also by the condition of the pump – a worn pump will be less efficient than a pump in good condition.

Most pumps used in the dairy shed are centrifugal pumps with a pumping efficiency in the range of 50% to 70%. This means that 50 to 70% of the power put into the pump does useful pumping work. Most of the remaining 30 to 50% is converted to heat and lost.

To get an understanding of the amount of energy used by a typical pump, consider the following example

A dairy shed cooler pump pumps 10 m^3/h at a head of 15 m for 7 hours per day. How much energy does the pump consume?

A Grundfos CH12-20 will meet this duty with a power input of 943 watts.

Daily energy usage = 6.6 kWh

Annual energy usage
(assuming 270 milking days) = 1800 kWh

Annual energy cost at 15 c/kWh = $270

The efficiency of this pump is approximately 50%. If a pump operating at 70% efficiency could be found, this would reduce energy usage by 530 kWh per year – a saving of $80 in electricity. While this is a worthwhile saving, it may not be justification for replacing an existing pump that is otherwise performing satisfactorily.

Strictly speaking, the calculations above apply only to the energy absorbed by the pump itself. There will also be some inefficiency in the electric motor. Not all of the energy absorbed by an electric motor is converted into useful mechanical energy – some is lost as heat. Electric motors sold in New Zealand since 2002 have been required to comply with minimum energy performance standards (MEPS) and these standards were upgraded in 2006. As a result, most motors purchase after 2002 will be reasonably efficient. It is unlikely that there are significant savings to be made in a dairy shed by replacing pre-2002 motors with motors of higher efficiency. Whenever possible however, failed motors should not be repaired

pipeline inside diameter (mm)	38	50	65	80	100
flow rate equating to 3 m/s velocity (m^3/h)	12	21	36	54	85

Table 7.2: Flow rates, for various pipe diameters, that will have high pumping costs

but replaced with new motors that comply with the latest (2006) MEPS.

Effluent pumping

Many Southland farms dispose of dairy shed effluent by spreading it on pasture land using a travelling irrigator. This is considered to be an effective and environmentally acceptable disposal method provided the application rate is low enough to prevent contamination of waterways through surface runoff or via sub-surface drains.

The amount of energy used for effluent pumping is closely related to the quantity of effluent that is pumped. Minimising the use of washdown water and diverting stormwater away from the effluent system will help to reduce the cost of pumping.

Traditionally, centrifugal pumps such as the Reid and Harrison Yardmaster design have been used to pump the effluent from the holding pond through a reticulation network to the irrigator. While this type of pump works reliably, its energy efficiency can be low.

Each centrifugal pump operates most efficiently at a particular flow rate and head. The wide range in pumping distances on some farms will often result in the pump operating at a high head and low flow rate and consequent low efficiency.

Recently, a positive displacement pump of the progressive cavity design (Mono brand) has been used on some farms to replace the centrifugal pump. This pump typically has a much smaller motor fitted (4 kW compared with 11 kW, 15 kW or even 18.5 kW) and is also capable of generating a pressure of 600 kPa or more when necessary. Advantages of this type of pump are claimed to be:

- the lower powered motor means that the pump can be run at any time without fear of overloading the dairy shed electrical supply. It can therefore be used in automatic mode and will turn on and off according to the holding pond water level.
- the lower powered motor means the electrical cable to the pump can be smaller (and cheaper)
- the higher pump efficiency means reduced energy usage
- the high pressure may allow the irrigator to operate at a greater distance from the pump.

Typically the 4 kW Mono pump is installed as part of a new or substantially upgraded effluent handling system that may include

- a concrete-lined effluent sump or pond complete with stone trap
- pump
- pond stirrers / mixers
- float switches and controls for automatic operation

The cost to replace the pumping system in an existing pond is likely to be at least $17,000 and more elaborate upgrades may cost $25,000 or more. Expenditure of this magnitude cannot be justified by electricity savings alone and the decision to upgrade is usually based on achieving several benefits including improved environmental performance reduced maintenance and reduced energy use.

An estimate of the scale of likely electricity savings is shown in Table 7.3.

Based on the above, electricity saved by changing to a Mono pump is 5,700 kWh per year. Assuming a marginal price of 14 c/kWh, the electricity cost saving for pumping alone is $800.

Typically one or two stirrers are also used in conjunction with the Mono pump and adding the electricity used by these would reduce the annual cost saving to about $690 (one stirrer) or $530 (two stirrers).

Conclusion

There is no doubt that energy usage in the dairy shed can be reduced by designing pumping and piping systems to be as energy-efficient as possible. In the case of an existing dairy shed however, the saving in electricity costs is unlikely to be sufficient to encourage replacement of existing pumps or pipelines for that reason alone. In the case of a new shed however, it is well worthwhile considering the energy efficiency of each pump and piping system at the time of design and installation.

		Yardmaster centrifugal pump	Mono progressive cavity pump
effluent quantity pumped	m^3/day	45	45
pumping rate	m^3/h	15	15
pumping time	hours/day	3	3
pump head	m	50	50
pump model		RH7/1	PT061
motor size	kW	11	4
pump speed	rpm	2800	350
absorbed power	kW	10*	3
calculated pump efficiency	%	21	69
daily energy usage	kWh	30	9
annual energy usage	kWh	8,100	2,400

Table 7.3: Estimate of the scale of likely electricity savings
**estimate only*

The dairy shed effluent pump is likely to have the largest motor and to consume the most electricity and should be the starting point when looking at saving pumping energy.

Effluent pumps with significantly lower power requirement than the traditional centrifugal pump are in use on some farms already and are worthy of consideration for new installations.

8 EFFICIENT LIGHTING

8.1 Introduction

In a typical modern dairy shed, electricity used for lighting accounts for 1 to 2% of the total electricity use[1]. In some sheds however, this figure may rise to 5% if incandescent light fittings are still being used. Although lighting is not a major cost, it is one that can be reduced quite easily.

One of the ways to reduce the energy used for lighting is to design the dairy shed to make maximum use of natural light. This can be done by building orientation and by the inclusion of translucent sections in the roof and wall cladding.

The energy used by artificial lighting can be reduced in two main ways – minimising running hours and choosing energy efficient light fittings.

Running hours can be minimised by switching off lights when they are no longer required. Where lights are switched manually, it is very likely that they will be left on for longer than necessary and savings can be made at no cost simply by making a conscious effort to turn off un-needed lights. Light switches that sense light levels and movement can be used to automate the switching.

Energy use for lighting can also be minimised by choosing energy efficient light fittings. In existing dairy sheds this may require the replacement of inefficient light fittings and in new sheds, it may require extra investment to pay the higher first cost of energy efficient fittings.

Maintenance of light fittings is also important. Light output will deteriorate with time unless the fittings are regularly cleaned and lamps replaced.

Section 8.2 gives some general information on the selection of the most appropriate light fittings for dairy sheds and Section 8.3 is a case study showing the savings that can be made by applying these recommendations to a typical dairy shed.

[1] http://www.dairysavings.co.nz/; Genesis Energy

8.2 Lighting Options

Table 8.1 is based on information taken from the Australian CowTime Project website[2] and with some added comments. The third column gives an indication of the energy efficiency of each type of light source expressed as lumens of light output per watt of power input (lm/W). The higher the number, the better the energy efficiency.

Fluorescent light fittings are particularly suited to dairy sheds. The fittings are cheap and the triphosphor tubes commonly used in modern fittings are very energy efficient. They also have good colour rendering characteristics and instant re-start.

In dairy sheds still using incandescent lights, compact fluorescent lamps can be used as a direct replacement for the existing lamps. Compact fluorescent lamps are now available in high wattages and substituting a 45 watt lamp for a 200 watt incandescent lamp will cut energy use by almost 80% while still providing the same light output.

8.3: Case study – Graejo Farm

The following information is theoretical but is based on the lighting systems installed in the Graejo Trust 38 a side herringbone dairy shed.

The Graejo shed has:

- 22 ◊ 200 watt incandescent lamps over the milking area (i.e. 4.4 kW); and
- 3 ◊ 500 watt quartz halogen floodlights in the yards (i.e. 1.5 kW).

At the milking pit, replacing the 22 incandescent lights with 10 twin tube fluorescent fittings would give increased light output and cut the power from 4.4 kW to 1.3 kW – a saving of 70%.

In the yards, replacing the three 500 watt quartz halogen floodlights with three 150 W high pressure sodium (or metal halide) flood-

[2] CowTime Project; http://www.cowtime.com.au/

Light source	Typical use	lm/W
Incandescent (the traditional lightbulb)	Best used in areas where lighting is only required for brief periods. These lights are cheap, easy to replace, and produce light instantaneously, however they are energy inefficient and the lamps have a short life span.	15
Halogen	Designed to provide high intensity light in a specific direction. Inexpensive to purchase but expensive to operate because of low energy efficiency. These are often seen in dairy shed yards.	20
Fluorescent	The most cost-effective general lighting for a dairy shed. Tubes need to be cleaned annually and replaced every 4-5 years to maintain the light output.	45 - 80
Mercury vapour (high pressure)	A high output light suited for general lighting in larger areas with high roofs. They are fairly inexpensive and the lamps have a long life. Disadvantages are that they take several minutes to reach full brightness after being turned on and emit a slightly pinky-blue-white light. The energy efficiency of a mercury vapour lamp is lower than a metal halide lamp.	30 - 45
Metal halide	Metal halide lights have similar uses and operation to mercury vapour lights. They are more energy efficient than the mercury vapour light and emit white light	50 - 60
High pressure sodium	Pinkish orange light. Very energy efficient and with a long lamp life. Best suited to outdoor floodlighting.	60 - 70

Table 8.1: Lamp types used in dairy sheds

lights would give increased light output and cut the power from 1.5 kW to 0.5 kW – a saving of nearly 70%.

Table 8.2 shows the estimated annual energy use for milking pit and yard lighting before and after the change to energy-efficient light fittings.

The total saving in energy use is 4,620 kWh. At the marginal electricity cost of 14c/kWh, the annual cost saving is $650. The annual cost saving at other electricity prices is shown in Figure 8.1.

In addition to the saving in energy use, there will also be a reduction in the cost of replacement lamps. Although the fluorescent and high pressure sodium lamps are more expensive initially than the incandescent lamps they replace, they also have a much longer life. Over a period of 5 years, the total cost of lamp replacement will be lower.

8.4 Conclusions

Energy use for artificial lighting can be minimised by making maximum use of natural light to light the dairy shed and by turning off the artificial lighting as soon as it is no longer needed.

Fluorescent lighting provides cost-effective general lighting for most dairy sheds and is particularly suited to herringbone sheds where the low roof does not permit the use of metal halide fittings. Where incandescent lamps (the traditional light bulb) are still in use, they should be replaced with compact fluorescent lamps or new linear fluorescent light fittings installed. Changing from incandescent to fluorescent lighting will reduce lighting electricity usage by 70% and will also reduce the cost

	Milking Pit		Yard	
	before	*after*	*before*	*after*
lighting power (kW)	4.4	1.3	1.5	0.5
estimated running hours	1200	1200	900	900
annual energy use (kWh)	5280	1560	1350	450

Table 8.2: Lighting energy use before and after changing to energy-efficient lamps

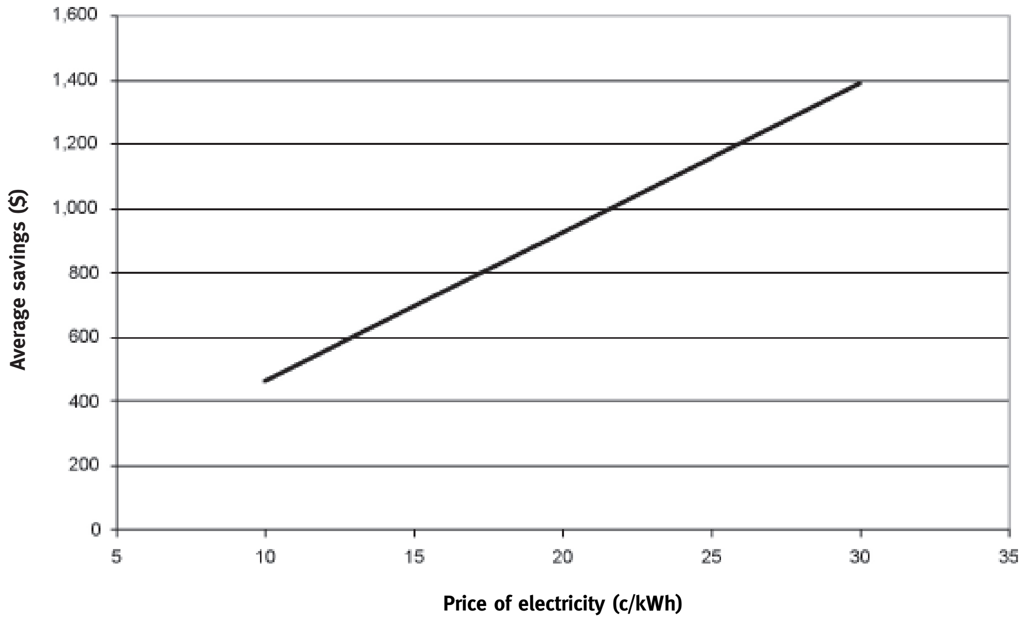


Figure 8.1: Electricity cost saving at Graejo after replacement of low efficiency light fittings

9 ELECTRICITY

9.1 Introduction

The primary source of energy in most dairy sheds is electricity supplied by a retailer (e.g. Meridian Energy or Contact Energy) via the distribution network that covers most of the country. In recent years, New Zealand has had a good supply of electricity available at a relatively low price. The country now seems to be entering a new period of energy supply and pricing. Wholesale prices for electricity have increased significantly and seem likely to remain at this higher level because of the high international price of petroleum products coupled with the depletion of New Zealand's gas reserves.

Section 9.2 looks at the various options for on-farm generation. For a dairy shed with easy access to electricity supply the economics are not favourable for these options.

Section 9.3 discusses the options for reducing electricity costs by making best use of the purchasing plans offered in Southland and Section 9.4 examines the issue of load control and power factor.

9.2 On-farm Generation

While there are many options currently available on the market, the utility of the various options are not optimal for combination with the dairy shed demand requirements as will be discussed below.

Methane from Biomass

The manure collected from cows in the dairy shed is a potential source of biomass from which methane can be produced by anaerobic digestion. There has been a large amount of interest in this especially in the USA where cows are farmed intensively in barns giving a large amount of manure with its problems and opportunities.

A report by Schwart et al. (2005) included detailed analysis of many cow manure digesters mostly in Texas (USA). They found that capital costs were in the range US$250-500 per cow and that in many cases the operation was not economical. They pointed out that the main driver for digesters was often odour control. In cases of intensive farming of animals in barns, digesters can form part of an effective effluent treatment system.

The USEPA (2002) stated that facilities best suited to biogas digesters typically have stable year round manure production with collection of at least 50% of the manure.

Biomass gasifiers were studied in the early 1980s being promoted by Jeanette Fitzsimons (1985) and others. Cost estimates ranged from $30000 to $90000. The lack of progress since 1985 suggests they might not be appropriate for farms in New Zealand.

Rural Energy (www.ruralenergy.co.nz/bioenergy/bioenergy+assessment.html) claims some expertise in this area but give few details on their website.

Ian Bywater (2004) made news with his proposed system integrating a number of features as reported in Energy Watch (2004) www.energywatch.org.nz/issues/EW34_9-2004.pdf

- An ice bank to reduce the peak refrigeration load, by spreading it over 6–12 hours instead of a 2 hour milking period. Ice banks have other benefits to the dairy industry, such as reserve cooling capacity if the network supply fails.
- A biodigester to treat the dairy shed effluent, providing a primary source of energy. Initial trials will have electrical backup, but LPG is another option if only occasional backup is needed.
- A Stirling engine to generate power from biogas.
- Solar thermal heating for shed hot water.
- Local groundwater for initial milk cooling, if available.
- Further integration, such as using biogas or waste heat from the Stirling engine to heat water for shed use, and hot water to maintain the biodigester at optimum temperature.

The first claim is incorrect as refrigeration typically runs for about 5 hours for each milking or 10 hours per day. It seems unlikely that such a system could be built with a payback of less than 10 years even if all the farms electricity need was replaced.

In New Zealand, with the use of pasture grazing, very much less of the cow manure is collected in the dairy shed than in the USA where cows are often kept in barns. The lower amount of manure would reduce the productivity of methane production making it even less economical than in the USA.

Even if methane was produced, a use needs to be found for it. Given that many other effective technologies are available for heating water, electricity production would seem to be the most likely option in New Zealand. In the 1980's biogas was compressed and used as a vehicle fuel (Fitzsimons, 1985) but this practice seems to have stopped perhaps because of the overall maintenance costs involved.

It can be concluded that it is not currently economic to convert cow manure to biogas on a typical New Zealand dairy farm. Given the style of farming used in New Zealand it is unlikely that methane production will be economic in the medium term unless there are significant pressures other than energy cost.

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Generation of Electricity from Wind

Small wind generation has been often mentioned as an opportunity for farmers in remote areas. A decision to generate electricity from wind is independent of dairy shed efficiency as there is no interaction with shed operations; it is simply an alternative source of electricity.

An exception to this would be wind electrical power generated specifically for hot water heating. It is conceivable that a system dedicated to hot water might have a lower cost as electrical 50 Hz synchronisation is not required. To heat a single 500 L tank of hot water each day would require an average of 1.5 kW over 24 hours. Wind turbines are available in this size (www.provenenergy.co.uk), but care in selection is advised, as the maximum rating stated for a wind turbine does not represent the realisable power output, which is dependent on the site conditions as shown below.

The NZ Wind Energy Association provides some information for smaller users (http://www.windenergy.org.nz/FAQ/diy.htm). Bergey Windpower Ltd (www.bergey.com) give a price of at least US$27,900 for a 10 kW unit, tower and electronics. The same site has a spreadsheet (www.bergey.com/technical/excels.xls) that can be used to calculate the likely energy output of their wind turbine.

Wind data was recorded at Coldstream and Graejo using an anemometer mounted 2.5 m about ground. It was used to estimate the wind speed 15 m above ground (Figure 9.1) and hence the energy produced by a Bergey 10 kW unit mounted at this height. The wind data is given in the table and graph below. For both sites the most energy produced would be about 6500 kWh (compared to 72,000 kWh if at continuous maximum output) with a value of $900 over a 10-month dairy season. The payback period for this would be many decades.

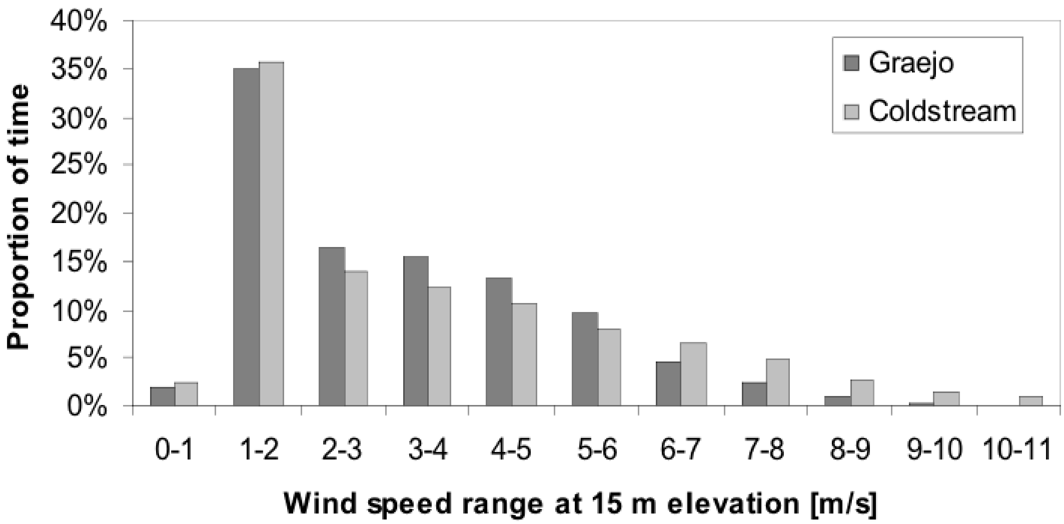

Figure 9.1: Windspeeds at Graejo and Coldstream

The maximum gust recorded at Coldstream in the period 12 May 2006 to 17 Feb 2007 was 24 m/s on 13 Oct 2006. The maximum at Graejo over the same time was 20 m/s on 8 Oct 2006. The wind run from 12 May 06 to 22 Feb 07 (285 days) was 52000 km at Graejo and 58000 km at Glencairn.

It seems unlikely that small-scale wind energy will be economic in the short or medium term unless special circumstances apply.

Small-Scale Hydro-generation of Electricity

Small scale hydroelectric generation is often given as a potential source of electricity for farms. Such generation requires a flow of water with a head and would be sized to match the resource available.

The following calculations are based on an average dairy shed power consumption of about 20 kW. The flow rate and/or head required can be calculated from:

Power [W] = 80% x Flow Rate [m^3/s or cumecs] x Pressure [Pa]

which could be expressed as:

Power [kW] = 8.0 x Flow Rate [m^3/s] x Water Head [m]

As an example 2.5 m^3/s (216,000 m^3/day) with a water head of 1 m or would generate 20 kW. This flow rate is just under half the flow rate of the Oreti River in Southland at the end of March 2007. At a lower flow rate of say 0.0012 m^3/s (100 m^3/day), which is similar to the usage rate of some dairy farms, a water head of 2100 m is required to generate 20 kW.

These two extreme examples show that very few farms are likely to have the flow rate and head required to produce a significant amount of electricity. It is therefore concluded that hydroelectric generation of greater than 10 kW is not an option available for many, if any, farmers. One exception is the integration of electricity generation with irrigation water supplies, but this would be limited to a few farms in the country.

An example of a commercially available Pelton-wheel design micro-hydro generator (www.ecoinnovation.co.nz) has the following characteristics:

Head required:	5 - 130 m
Flow required: (0.00025 – 0.008 m^3/s)	0.25 - 8 L/s
Power output:	1.8 kW maximum

This unit would be able to generate 13,000 kWh if operating continuously at maximum output for the 10 month milking season, with a value of $1,900. The cost of the basic pelton wheel unit is $2,200 plus there would potentially be an additional cost for piping and installation of the assembly, associated electrical equipment and resource consent costs.

The unit might achieve a good payback period (if the total installation and resource consent cost was less than $9,000 and the unit could operate 24/7 at maximum output), but the generation is spread over the entire day and not concentrated in the times the shed is in use. While this might be stored in batteries for use when required, this adds additional expense and requires a larger footprint in the form of an enclosed building. The other issue is the availability of water to run the unit and potential seasonal variability.

Due to the physical requirements for such installations, this project was unable to trial any micro-hydro installations. For further information, the Ecoinnovation website provides good case studies on installation of such systems.

9.3 Electricity Purchasing Options

Introduction

It is possible to minimise the cost of electricity used in the dairy shed by selecting the best option from the range electricity purchasing plans available.

Choosing the most cost-effective plan for a particular dairy shed is not an easy task however. Farm managers have the choice of five electricity retailers and from each retailer there is a wide choice of pricing plans.

The following sections provide information on some pricing plans commonly used on dairy farms in rural Southland and discuss the likely future trends in electricity pricing.

Energy Retailers in Southland

Dairy farmers in Southland have the option to purchase their electricity from any one of five retailers :

- Contact Energy
- Genesis Energy
- Mercury Energy
- Meridian Energy
- TrustPower

In addition, farmers can purchase from some of these retailers through farm supply companies such as RD1, PGG Wrightson and CRT.

Contact Energy has by far the largest share of the Southland market followed by Meridian Energy. The other three retailers have a relatively small share.

Pricing Plans

The electricity suppliers break their charges into two main parts :-

- a fixed daily fee to cover meter rental, meter reading and the fixed charge from the network operator. This is based on the capacity of the dairy shed electricity supply measured in kilovolt amps (kVA).
- a variable charge based on the quantity of energy used. The energy usage is measured in kilowatt-hours (kWh).

Most of the farms studied as part of this project use either the 'anytime' plan or the 'day/night' plan.

Anytime plan

This pricing plan has a fixed daily fee plus a charge for each kWh of electricity used. The kWh charge is the same at all times of the day and night.

To reflect the fee charged by the network operator, the fixed daily fee varies according to the capacity of the electricity connection provided.

Example of a typical 'anytime' pricing plan

supplier	Contact Energy
date of pricing plan	1 April 2007
capacity of supply to example farm	50 kVA
daily fee	$4.18
variable charge	13.6 c/kWh
Electricity Commission levy	0.142 c/kWh

(Prices exclude GST and assume the prompt payment discount of 10% is applied).

Based on an annual energy usage of 100,000 kWh, the average cost of electricity to this farm is approximately 15.2 c/kWh. The marginal cost is 13.7 c/kWh.

Day/night plan

A common alternative to the 'anytime' plan is the 'day/night' plan. Under this plan a lower price applies to energy used at night (11pm to 7am).

Example of a typical 'day/night' pricing plan

supplier	Contact Energy
date of pricing plan	1 April 2007
capacity of supply to example farm	50 kVA
daily fee	$4.40*
variable charge during the day	15.5 c/kWh
variable charge at night (11pm to 7am)	6.5 c/kWh
Electricity Commission levy	0.142 c/kWh

(Prices exclude GST and assume the prompt payment discount of 10% is applied.)

** Daily fee reduces to $3.32 if the load is classified by The Power Company as 'off peak'. Night energy use must be at least 25% of total use to qualify.*

Because the day price is higher than it is for the 'anytime' plan, a significant proportion of the electricity usage has to be at night before the 'day/night' plan becomes more economical than the 'anytime' plan. For the present Contact Energy plan, more than 23% of energy must be used at night before the total cost under the 'day/night' plan is lower than the cost under the 'anytime' plan.

Based on an annual energy usage of 100,000 kWh and assuming 23,000 kWh is used at night, the average cost of electricity is again 15.2 c/kWh. Increasing the night usage to 25,000 kWh lowers the average cost to 15.0 c/kWh or 14.6 c/kWh if the load is classified as 'off peak'.

Controlled supply pricing plans

A number of plans are available. These are usually based on having a portion of the load (usually one or both water heaters) connected in such a way that the electricity supply to it can be turned off and on by the network operator using the ripple control system.

Control options include:

- night only supply (supply is only available from 11pm to 7am)
- night plus day boost supply (supply is available at night and for a short period during the afternoon)
- controlled supply (supply may be interrupted for short periods).

These controlled supply plans appear to have little advantage over the day/night plans and seem to be less common in recently-built dairy sheds. This may be due to farm managers preferring to be able to heat water at any time rather than at the specific times required under these 'controlled' pricing plans.

Time-of-use pricing plan

Another option made possible by modern metering systems is to use a 'time-of-use' purchasing plan. A 'time-of-use' meter records electricity use for each half hour period and the electricity is charged at different rates depending on the time of day and whether it is a normal business day. This option is not widely promoted for dairy farms but may be worth investigating for very large dairy sheds where the high fixed charges associated with the more sophisticated metering equipment can be more easily absorbed.

Reducing cost by using electricity at night

As noted above, many of the pricing plans provide lower cost electricity at night (11pm to 7am). Retailers are able to do this because the network operator (The Power Company) has structured its pricing so that its variable charge of approximately 5 c/kWh applies only to electricity consumed during the day. The intent of this is to encourage the transfer of usage from the daytime into the night hours so as to utilise the distribution network assets more efficiently. It also enables more efficient use of the country's electricity generation and transmission infrastructure.

The availability of lower-priced electricity at night is advantageous for dairy farms for two reasons.

- For farms milking twice a day, much of the morning milking can be completed before 7am when the price rises.

- Water heating can be shifted from day to night hours to take advantage of the lower prices.

Water heating typically consumes 20% to 30% of the total electricity used in a dairy shed. Provided there is sufficient storage capacity, the water can be heated between 11pm and 7am and then held in storage until required. Ideally the water should be heated as late as possible in the night so a heater that requires 5 hours to heat the water from cold should be switched on by time switch at about 2am.

Another electrical load that can be partly shifted into the night hours is milk cooling but the trial carried out at Coldstream Downs (refer to Section 6.5) showed that this is not an economic proposition.

Potential exists for up to 40% of the dairy shed daily energy requirement to be supplied at night. Figure 9.2 (based on the 1 April 2007 Contact Energy 'anytime' and 'day/night' plans) shows how the average electricity price on the 'day/night' plan compares with the 'anytime' price as the percentage of energy used at night increases.

At about 23% of energy used at night, the average cost of electricity under the two plans is the same – 15.2 c/kWh.

By shifting the water heating into the night hours, it would be possible to raise the night energy usage to 40% of the total. At 40% of energy used at night, the average cost using the day/night plan is 13.6c/kWh – a saving of 10.5% over the anytime plan. For a farm using 100,000 kWh of electricity each year, this change would reduce the total cost from $15,200 to $13,600 - a saving of $1,600.

Once night energy use exceeds 25%, the site can also be classified as 'off peak' load and an additional $316 per year saved because of the reduced daily charge. This gives a total saving of almost $2,000 per year.

Reducing cost by lowering the daily fee

As noted above, all pricing plans include a fixed daily fee to cover the use of assets that are required irrespective of the amount of electricity consumed. The main part of this fixed fee reflects the fixed part of the charge made by the network operator to the electricity retailer for the use of the distribution network – the lines, cables, transformers, and switchgear that are required to transport electricity to the farm gate.

In the rural areas of Southland, this distribution network is owned by The Power Company Ltd and managed for them by PowerNet Ltd.

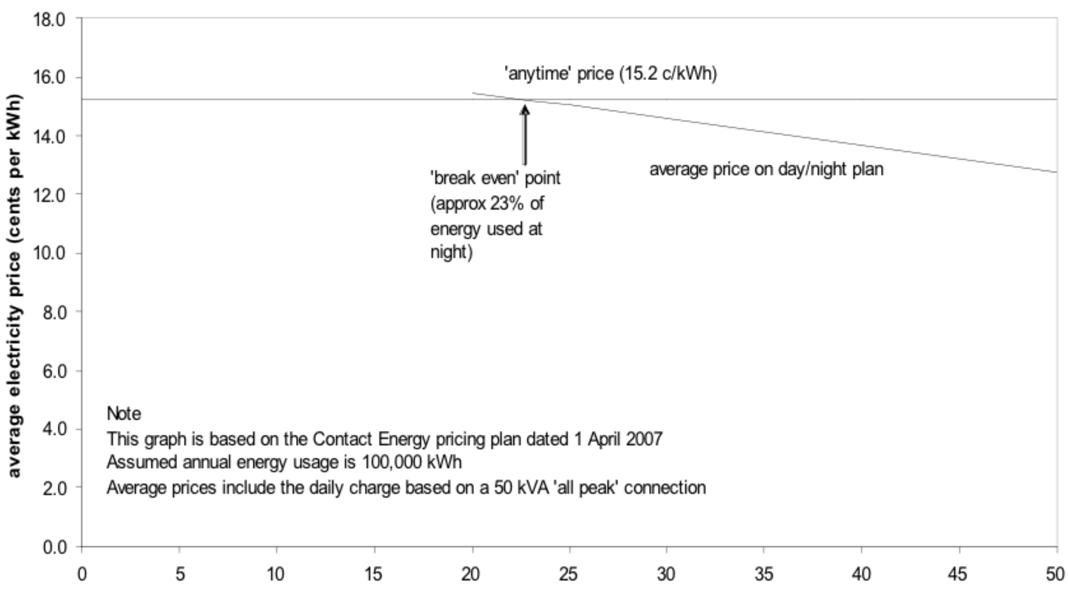

Figure 9.2: Comparison of 'anytime' and 'day/night' prices (Contact Energy)

Although The Power Company does not charge consumers directly, their charges are incorporated in the pricing plans of the electricity retailers.

Dairy sheds with 40 to 50 sets of milking cups typically require an electricity supply of 50 kVA capacity and for this capacity, the fixed daily fee is about $4 ($1,500 per year). Larger sheds may require 75 kVA or even 100 kVA capacity and the daily fees for these higher capacity supplies are substantially higher. The daily charge for a 100 kVA connection is typically $17 (about $6,000 per year).

The most efficient way to utilise an electricity network is to provide consumers with only sufficient capacity to meet their normal maximum demand. It is a poor use of resources for The Power Company to provide a dairy shed with a capacity of 100 kVA when the maximum demand is only 40 kVA. The network pricing is therefore designed to encourage the consumer to nominate the lowest capacity that will meet his needs.

Dairy farm electricity costs can therefore be minimised by ensuring that the capacity of the electricity supply is kept to a minimum.

On a typical diary farm, the maximum electrical demand occurs during milking when most of the electrical equipment is running. Ensuring that non-essential equipment such as the water heaters and the effluent pump don't run during milking is one way to keep the maximum demand down. In some cases, managing the maximum demand in this way may permit the nominated capacity of the connection to be reduced. This is likely to be most effective on a larger dairy shed with a 75 kVA or 100 kVA supply. A reduction in nominated capacity from 100 kVA to 75 kVA would save approximately $2,700 per year in fixed charges. This capacity reduction can be done simply by changing the rating of the main fuses at the power supply connection point.

Reducing cost by being classified as 'off peak' load

The Power Company fixed charges are structured to encourage consumers to transfer load to the night hours. A consumer that uses at least 25% of his energy between the hours of 11pm and 7am is classified by The Power Company as having an 'off peak' load and will benefit from a lower fixed charge from the energy retailer.

Any farm owner who is currently paying a daily fee that includes the words 'peak' or 'all peak' and who is using at least 25 % of his electricity at night should apply to PowerNet Ltd to have his connection re-classified as 'off peak'.

Reducing cost by switching to a different supplier

Switching to a different supplier is not difficult - the difficulty is in working out which supplier is offering the best price. In the current environment it is not likely that there will be substantial differences in price amongst the five retailers currently operating in Southland.

Table 9.1 shows the annual cost of electricity purchased from each of the five retailers. It is based on the following farm profile:

connection capacity	50 kVA
total annual energy usage	100,000 kWh
fraction of energy used at night (11pm to 7am)	25%
fraction of energy used in 'summer' (1 October to 30 April)	70%

Based on current pricing plans, the difference in annual electricity cost between the dearest and cheapest supplier is about $1,200. Note however that Contact has only just raised its price (1 April 2007) whereas the other suppliers are using prices dating from 2006 or 2005.

	Contact	Genesis	Mercury & RD1	Meridian	Trustpower
date of last price change	1 Apr 07	4 Sep 05	Nov 06	1 Dec 06	27 Jul 06
anytime plan	15,226	15,287	14,724	14,070	15,147
day/night plan	14,621	14,218	14,793	13,695	14,556

Table 9.1: Comparison of the annual cost of electricity from five retailers

One significant difference between the retailers is that Meridian Energy uses different prices in summer (1 October to 30 April) and winter (1 May to 30 September). This suits a dairy farm well as the majority of electricity use is in the summer period when prices are lower.

Reducing cost by changing to a 'Time-of-Use' Purchasing Plan

The dairy industry uses most of its electricity in the spring, summer and autumn. This is in contrast to the country as a whole where electricity use is greatest in the winter.

This is illustrated in Figure 9.3 provided by Contact Energy.

The price of electricity supplied under a 'time-of-use' contract will vary according to the season and this should work in favour of the dairy industry where the greatest demand is in summer when electricity prices are at their lowest.

This assumption was tested by obtaining a quotation for electricity supply to one of the project farms for which the half-hourly electricity usage was known. The farm dairy shed had an annual electricity usage of approximately 125,000 kWh. The annual cost of electricity was calculated using the quoted prices and compared with the cost of purchasing under the more common 'anytime' and 'day/night' plans.

The results are shown in Table 9.2.

In this example, the total annual cost under the 'time-of-use' plan was greater than under the other more common plans and if the usage pattern remained unchanged, it offered no saving. This result was contrary to the positive price signals for use of night rate electricity and may well change as this part of the market develops.

An issue for a farmer considering changing to a 'time-of-use' plan is that the annual cost can only be predicted accurately if half hourly usage data is available which normally it is not. A change in electricity purchasing arrangements made without an accurate prediction of

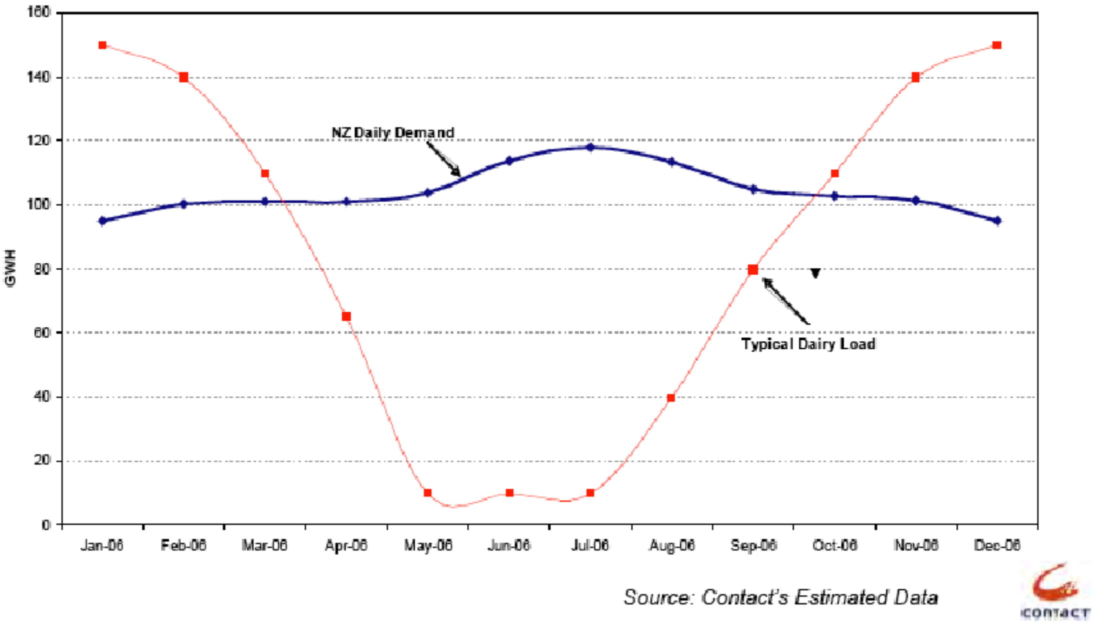

Figure 9.3: NZ electricity demand (GWh/month) and relative dairy load

Plan	Variable cost*	Fixed cost	Total cost
Time-of-use	$15,421	$4,572	$19,993
Anytime	$17,105	$1,526	$18,631
Day/Night	$17,911	$1,526	$19,437

Table 9.2: Annual cost of electricity supplied to a typical dairy shed under a 'time-of-use' plan

the annual cost may end up increasing costs instead of reducing them.

Future trends in electricity pricing

Recent history

The cost of generating energy in New Zealand has risen steadily over recent years as new hydro generating resources have become increasingly scarce and the cost of gas for thermal generating stations has increased. Figure 9.4 shows typical prices paid by Southland dairy farmers over the past six years.

The prices shown are for the variable components of two common pricing plans – the 'anytime' plan and the 'day/night' plan. The fixed daily fee is not included in these costs and typically adds another 1 to 2 c/kWh to the average price.

Points to note are:

- Since 2001, the 'day' rate has almost doubled from 8 c/kWh to almost 16 c/kWh while the 'anytime' rate has risen by a lesser amount from 8 to 13.6 c/kWh.
- The 'night' rate is currently about 42% of the 'day' rate and has retained this relativity throughout the period.
- In 2007, the 'anytime' rate is more attractive than it was in 2001. Because the 'day' rate has risen above the 'anytime' rate, the 'day/night' plan is only cheaper than the 'anytime' plan if more than 23% of the electricity is consumed at night (11pm to 7am).

Future Prices

The trend of steadily rising prices is expected to continue in the foreseeable future and this will provide a greater incentive for dairy farmers to reduce costs by using electricity in the most efficient way. Increased prices will also improve the economics of investing in energy-saving equipment.

In a report titled 'New Zealand's Energy Outlook to 2030' published by the Ministry of Economic Development (MED) in September 2006, Table 9.3 appears.

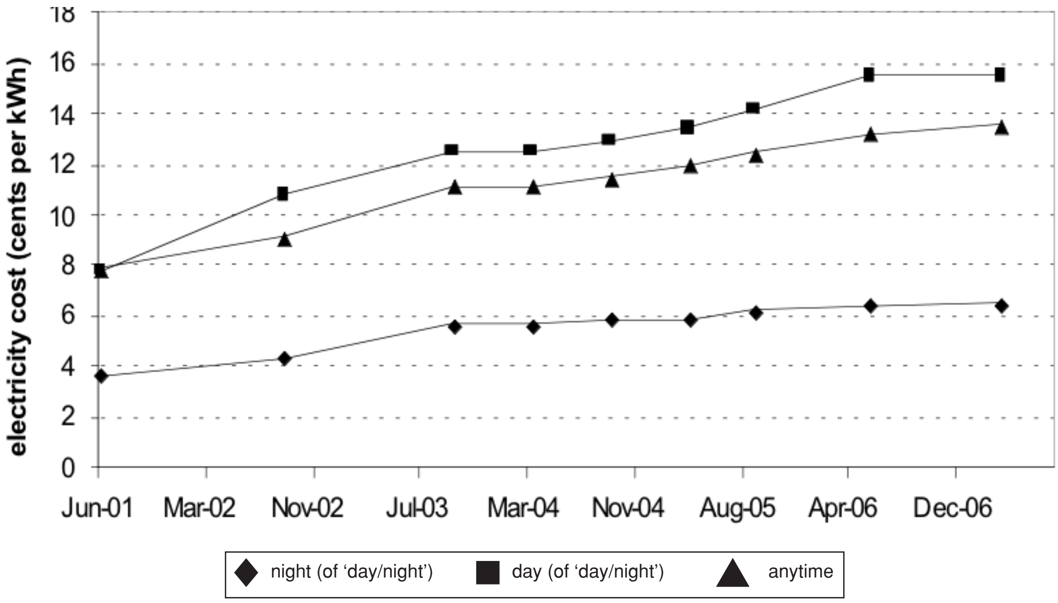

Figure 9.4: Variable cost of electricity in rural Southland (The graph is based on prices from Contact Energy. Prices exclude GST and a prompt payment discount has been applied)

Electricity Prices (c/kWh)	Base Case					
	2005	*2010*	*2015*	*2020*	*2025*	*2030*
Electricity (Residential)*	16.5	16.8	17.9	19.5	19.9	19.9
Electricity (Wholesale)	7.4	7.4	8.2	9.4	9.8	9.8

Table 9.3: Predicted electricity prices (MED, 2006)

This is a prediction of residential and wholesale electricity prices through to 2030 on the assumption that no changes take place in the New Zealand economy and that we continue to do ‘business as usual’. The MED call this the ‘base case’.

The report also explores other scenarios for the future such as:

- a move to reduce reliance on coal and gas-fired generating stations and to increase the use of renewable sources (hydro, wind, geothermal). This is predicted to cause prices to be higher than in the base case.
- faster uptake of energy efficiency measures. This is predicted to lower demand and cause prices to be lower than in the base case.

There is no certainty in predicting future electricity prices and the authors of this report do not claim special knowledge in this area. The most likely scenario, at least in the near future seems to be for electricity prices to continue to increase in real terms i.e. at a rate greater than the rate of general price inflation. If the MED ‘base case’ scenario proves a realistic guide, these real price increases will result in the wholesale price increasing by 30% in the next 25 years. Despite this, price increases within a five year investment period are unlikely to influence investment decisions.

Price of Night Rate Electricity

In past years, electricity used during the night hours (usually 11pm to 7am) has been about half the price of ‘anytime’ electricity. This cheaper pricing has been mainly the result of network owners such as The Power Company encouraging the shifting of load into the night hours to make better utilisation of their network assets.

In addition, electricity retailers can usually buy energy at lower prices at night, especially in the summer when loads are light.

Recently the average cost of electricity purchased under a ‘day/night’ plan has increased relative to the cost of electricity purchased at ‘anytime’ rates because the ‘day’ price has increased at a faster rate than the ‘anytime’ price. Despite this, the ‘day/night’ plan is still attractive for some dairy farms but only if night usage is greater than 23% of the total usage.

It is becoming increasingly common for large industrial consumers to purchase some or all of their energy at spot market prices. They are able respond to the hour by hour changes in the market price by scheduling the running of equipment items to avoid periods when the price is too high. While this level of control is unlikely to apply in dairy sheds, systems for more accurately signalling the true price of

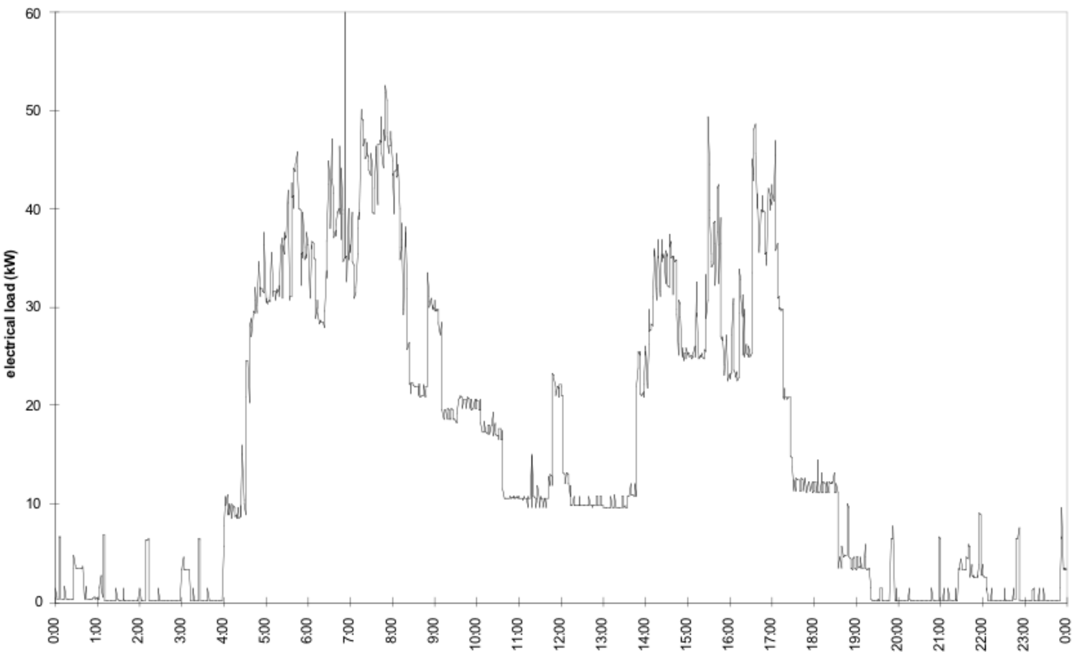

Figure 9.5: Electrical load at Graejo Trust on 28 March 2006

generating and distributing electricity will become increasingly common in the next few years and may bring changes to this area of dairy shed operations.

In the meantime, the day/night pricing plan will continue to provide a way to minimise dairy shed electricity costs by shifting water heating and other load into the 'off peak' hours.

9.4 Electrical Load and Power Factor

The electrical load in a dairy shed varies greatly throughout the day. Figure 9.5 shows these load variations over a typical day for the Graejo Trust dairy shed.

Provided the maximum load doesn't exceed the installed capacity of the electricity supply transformer (typically 50 kilovolt amps), these variations in load do not usually concern the farmer.

They are, however, of great interest to the operator of the local electricity distribution network (in this case PowerNet) and ultimately to the operator of the national transmission system (Transpower). These businesses have to ensure that there is adequate capacity in their distribution systems to meet the maximum demand in each part of the system. In rural areas of Southland, demand peaks are likely to occur near the end of both morning and afternoon milking when all dairy sheds are in full operation and households are also contributing to demand for electricity.

Load control and load shifting

There are opportunities for reducing the dairy shed maximum electrical load by means such as:

- heating water at night
- reducing vacuum pump power by fitting a variable speed drive
- making sure that the effluent pump doesn't run during milking
- adding power factor correction capacitors to the main motors.

Some of these actions may not benefit the individual farmer immediately but will help to ensure that the electricity distribution network is used more efficiently thus deferring the need for investment in system upgrades and the consequent increase in network charges.

There are also a number of ways in which a dairy farm can benefit directly and immediately from reducing the maximum electrical load:

- for a new shed, the capacity of the electricity supply can be reduced saving money on the mains cable and associated equipment.
- reducing the nominated capacity of the electricity supply will result in a lower daily fee. For example, a dairy shed that is able to reduce the maximum capacity of its supply from 50 kVA to 30 kVA will save approximately $600 per year in daily charges.
- shifting electrical load into the night hours (11pm to 7am) allows cheaper night rate electricity to be used.

Power Factor Correction

Power factor also has an effect on the maximum demand that the distribution system has to meet. This is because a higher current is required when the power factor is low.

The consequence of operating a dairy shed with low power factor is that the maximum demand (as measured in kilovolt amps) will be higher than it would be if the power factor was high. As discussed above, minimising maximum demand is not of direct consequence to an individual farmer but is of importance in ensuring that the electricity distribution network is being used efficiently.

In industry, it is common for a significant part of the price of electricity to be based on the maximum demand and hence there is a direct financial incentive for consumers to control their maximum demand. Some industrial and commercial electricity purchasing plans also include a specific charge for low power factor. Charges based on maximum demand and power factor are not currently applied to dairy farms in Southland but the network operator (PowerNet) does require its customers to maintain a good power factor (0.95 minimum) as a condition of supply. Compliance with this requirement may not have been routinely checked in the past but as the rural load continues to grow at a fast rate, this condition is likely to be given more attention.

The power factor was monitored at the Coldstream Downs and Graejo Trust farms and Figures 9.6 and 9.7 show the electrical load and power factor for a typical day.

At Coldstream, the power factor is satisfactory being above 0.95 at all times except when the load is very low.

At Graejo, the power factor during the main part of the day varied between 1.00 and 0.82. Ideally the power factor should not fall below 0.95. Note that from 7.30pm through to 4am the power factor fluctuated between 0.50 and 1.00. At the times of low power factor, the load was negligible and so the low power factor was of no consequence.

Achieving a satisfactory power factor is a simple matter of connecting capacitors to the larger electric motors – typically the vacuum pump, effluent pump and refrigeration unit. Most new dairy sheds will be fitted with these correction capacitors during construction but in older sheds, it is possible that they have not been fitted or that they have failed in service and not been replaced.

Dairy farm owners or managers should ask their electrician to check that power factor correction capacitors are fitted and that they are operative.

9.5: Recommendations

The generation of electricity on farm is unlikely to effective for most dairy farms but might be considered by enthusiasts or those with special resources.

There is a strong price signal for farms to change their load pattern to use more electricity at night. This would make more effective use of national and local infrastructure for the generation and distribution of electricity.

By heating water at night and having a 'day/night' tariff, electricity charges can be reduced by about $2000 per year. To make use of night rate electricity it is necessary to install a night switch that will match the management structure of the farm. Such a switch should be automatic but allow override for a short period. Cancellation of the override must also be automatic.

Time-of-use metering is not recommended based on current prices but this might change in the future.

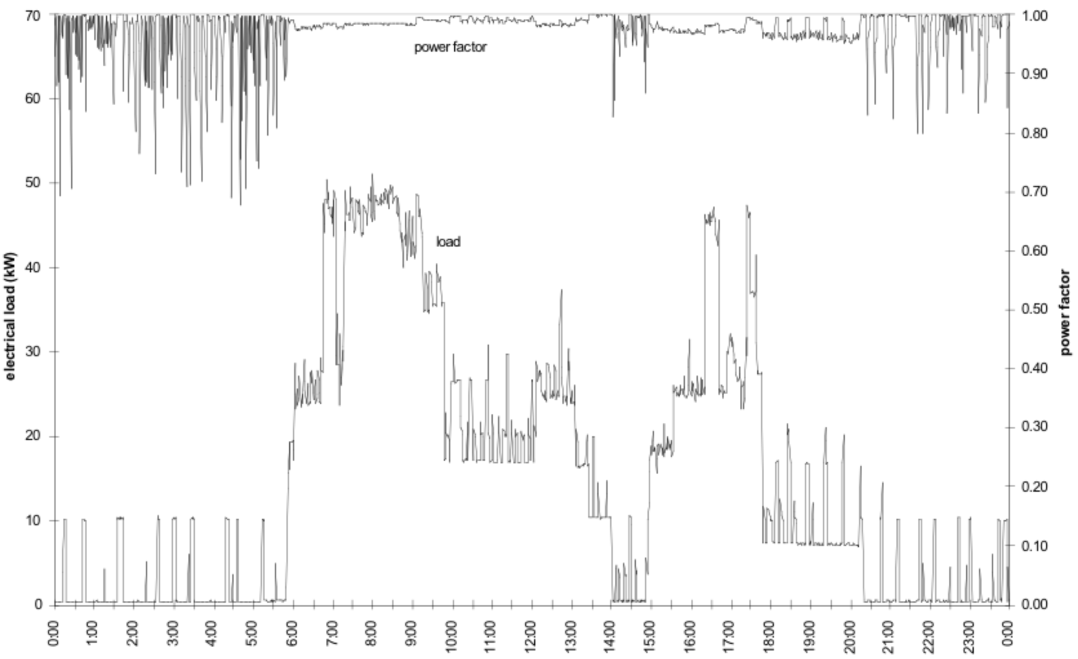

Figure 9.6: Electrical load and power factor at Coldstream Downs on 28 March 2006

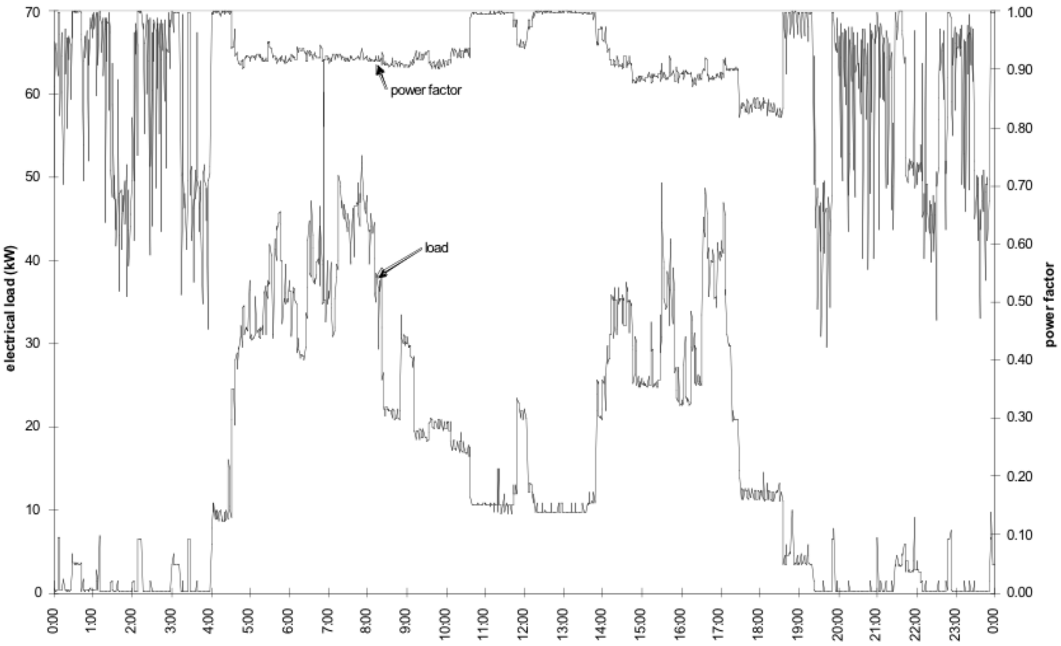

Figure 9.7: Electrical load and power factor at Graejo Trust on 28 March 2006

10 ISSUES FOR FURTHER INVESTIGATION

10.1 Overview

This study has been important in bringing together independent evaluation and study of a range of technology options and energy efficiency interventions aimed at improving energy use in the dairy shed. The data collected and experience developed, as reported in earlier chapters, offers for the first time a coherent information source to allow comparative assessments of the different energy efficiency measures employed as well as the potential for improved energy use throughout the dairy shed operation.

A novel approach to the project has been the development and use of a cost-effective Internet based monitoring system whereby operational data relevant to the performance of selected equipment were transmitted to the CAENZ office in Christchurch where it was further analysed, graphically presented and made publicly available through the project website, www.cowshed.org.nz. This capability allowed CAENZ to bring publicly “on-line” processes and equipment and to monitor externally the performance of individual equipment items as well as overall shed performance.

There is no doubt that energy usage in the dairy shed can be reduced by better design and operating practices. In the case of existing dairy sheds options are more limited, but in new installations significant benefits can be realised from integrated design and the deployment of higher efficiency equipment.

An important factor highlighted by the study is that investment in energy efficiency on its own, whilst important, cannot be looked at in isolation of other farm management issues. In particular the study identified that considerable improvements were possible in water use and effluent treatments. The same conclusion is likely to be valid for those farms that rely on irrigation for pasture management and maintenance of stocking rates.

The current two-year study represents a significant investment in time and resources to develop and implement the trial approaches and measurement techniques employed, the monitoring system that is now in place and the web based information system created. It was limited, however, to just six farms and a narrow range of commercially available products. Because of the nature of the trials and the overarching requirement that farm operations should not be placed at risk during the course of any testing of the trial equipment it was not possible to carry out practical tests of all the energy-saving ideas identified. Moreover, the trials, of course, were limited to the Southland region and do not purport to represent the range of circumstances occurring within other major dairying regions of New Zealand.

Thus the Dairy Shed project should be seen as a catalyst for action and precursor to a broader dairy-wide industry sustainability initiative. The intellectual capital and research platform that has been established by this study offers much, and provides a considerable assurance that ongoing targeted study will deliver participants integrated energy solutions and operational efficiencies to improve farm economics and dairy shed performance. Significant benefits will also accrue from improved resource utilisation, enhanced farm practice and the optimisation of power and energy budgets.

There is also the potential to capture Intellectual Property from the integrated solutions that may subsequently be developed in any further extension of the current project.

10.2 Continuation of the Dairy Shed Project

As stated above, the current study in effect only covered one Southland milking season. A key finding from this study is that faulty installation, sub-optimal sizing and operating defects constitute one of the most important factors in overall energy performance. It is the view of the study team that there would be significant value in extending the monitoring for at least another season so as to:

- Gain more consistent data from which to create energy efficiency benchmarks (or Key Performance Indicators) for farmers to do easy comparisons and to more closely examine their own operations.
- Work with suppliers to improve the system designs using their technologies. We believe there are significant gains that could be made by modifying and improving the system design of the hot water heating technologies, in particular.
- Develop a good practice guide for energy efficient dairy shed design and construction, covering the technical and engineering aspects of selection of component equipment. This should enable farmers/owners to ask informed questions of dairy shed integrated system suppliers and ensure new sheds are as energy efficient as practicable.

The identification of what defines 'good practice' (rather than 'best practice') from a farm management perspective should be the major focus of this next stage. To this end we see more widespread uses for the monitoring methodology that has been developed in this initial study. In particular there are opportunities to further develop the communication protocols and website functionality to allow a wider range of value-added services to the farmer.

Having sites on-line enables constant feedback on equipment performance allowing for a more intensive approach to process optimisation. By observing the operational characteristics of equipment it is possible to identify areas where improvements to operational efficiency can be made. In such cases a model system can be built and studied in a controlled environment in parallel. This enables feedback from the model system to be applied to the more complicated real-life situation.

An example from the current project is the optimisation of dairy water heaters. During the study high heat losses were recorded from the dairy shed water heaters being monitored. The reasons for this were further explored by direct measurement and corrective measures taken so as to reduce farm-heating requirements. This work was carried out by CAENZ in Christchurch at Multi Machinery (Superheat) Ltd. There is no reason to suppose that other equipment vendors would not be similarly interested in improving equipment design and technical support.

Finally it was also observed during the course of the study that sensor equipment in remote regions provides a useful source of information to local communities. Anecdotal evidence suggests that, at least for one site, the on-line weather station installed on a trial site farm was being used by local farmers (via the web) to obtain accurate local weather data – see figure below.

The cowshed website is thus a very valuable resource that has only just begun to realise its true potential. The following improvements should be considered to maximise the investment in this capability:

- Improve the web interface
- Provide a benchmarking tool
- Provide more information and guidance
- More links to other relevant sites
- Provide a diagnostic tool

Further enhancement of the technology and the information published could assist the dairy industry by improving energy efficiency for the sector as a whole by providing ongoing monitoring and energy auditing; and by creating a system of energy benchmarks for easy evaluation.

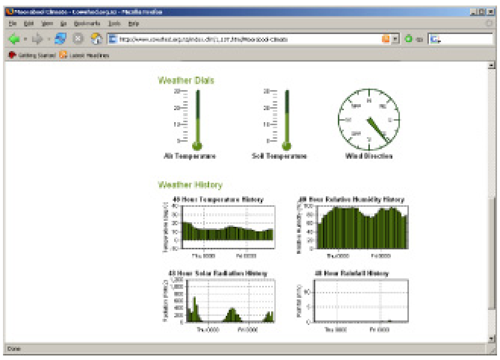

Figure 10.1: Weather images uploaded to the project website. This shows how weather data recorded at the Moorabool farm, Southland, can be processed so as to provide the general public a visual description of the weather at the farm

Beyond the above scope there is opportunity for a broader approach involving a wider stakeholder group and with an overriding industry focus on sustainable farming practice. In particular consideration should be given to extending the scope beyond Southland to other regions with different environmental conditions so as to provide comparison and a better understanding of the different requirements. Also there is opportunity to extend on-farm demonstration to include other technologies not covered by this study. Care will need to be taken in examining this aspect because, too often, the economics of these emergent technologies have not been proven and when combined with the technical risk from a less-than-hoped-for performance may present an unacceptable risk to normal farming operations. This is an important consideration that should not be overlooked.

10.3 Technology Demonstration

On the basis of the work completed to date the following technical issues have been identified as areas for future deliberation:

- **Solar Heating** – gains can be made in optimising the system design. The project team with consultation with industry experts developed the current design, but there is limited experience for its use in the dairy industry. It should also be noted that the desktop study undertaken as part of this study showed that solar hot water was unlikely to be economic for the stated service without subsidies. Further work would help to define the tipping point for investment decisions.
- **Chilled Water Cooling** – due to the late start setting this technology up, and the subsequent delays involved in bring the technology into operation, there would be benefit from a further full seasons monitoring. Unless significant improvements and cost efficiencies are able to be realised economics are unlikely to be favourable.
- **Water Heating Systems** – several of the heat recovery technologies monitored may benefit from a redesign of current industry standard system designs. This will require vendor support and preparedness to contemplate system improvements. Additional work can also be undertaken to reduce the water heater energy losses.
- **Natural Systems Integrated Energy System** – This concept dairy shed integrated energy solution is currently being commissioned. Monitoring and displaying of the alternative technologies incorporated into the design of this facility would have a wide public interest. Agreement of the technology and farm owners would be needed.

Additionally there were various distributed generation technologies that were too difficult and expensive to be included in the project. There may be an opportunity to pursue the monitoring of such technologies in new installations or existing installations outside Southland. These include:

- **Micro-hydro** – this is a new emergent technology based on improved turbine designs promoted by a number of individuals or technology companies. Whilst the economics appear unfavourable there maybe an opportunity to look at the feasibility of using micro-hydro on farms external to the current study.
- **Wind/Battery** – there were several ideas explored as part of the development of the project, but limited by a lack of suppliers. More suppliers are coming on to the market and with the current renewable emphasis from government this may become more feasible.

10.4 Best Practice Guideline

An important step forward would be to ensure that there is in the public domain a trusted information source to aid farmers and suppliers alike in the specification of engineering design requirements for the construction of a new dairy shed, or for the upgrading of current facilities. There is a design standard at present maintained by the Milk and Pumping Trade Association of NZ, but there is no easily accessible information for the user to assist them to make informed decisions. A Best Practice Guide is proposed to provide:

- **Design Checklist** – a summary checklist to ensure that important factors are identified and the right questions asked before a purchase decision is contemplated.

- **Detailed Explanations of Design Principles** – this will cover a lay guide to the engineering fundamentals and will establish the key performance criteria for individual equipment items and overall energy use.
- **Component Level Specifications** – most dairy shed set-ups are sold as integrated systems, this guide will help the farmer ensure the component parts are suitable for their needs. This should be in sufficient depth to establish service requirements and sizing
- **Energy Efficiency Tips** – provide guidance on using the equipment in its most energy efficient operation and how to compare against industry standards.

It is anticipated that the guidelines will make reference to the decision flow chart presented in the main body of the report and will be complemented by the economic decision tool also produced as an output from the current study. Further development of these tools is envisaged to complete the overall design guide.

Further extension of the guideline approach to include benchmarking against key performance indicators as proposed in the additional monitoring and farm evaluations (Section 10.2) would offer a consistent and easy-to-use benchmark database for developing the required comparison analysis. A key requirement will be specification (with vendor agreement) of appropriate measurement protocols for in-service equipment, combined with a cost effective monitoring/logging service.

There are also significant energy uses outside the dairy shed that warrant investigation, such as:

- **Irrigation** - by far the greatest load during summer and a significant factor for the national demand profile. This is a significant concern for many regions in New Zealand with regards water allocation and efficient usage of water as well as electricity.
- **Effluent disposal** – is an important concern with regards environmental impact, electricity usages and water usage and quality.

The current study has not covered these aspects in any degree but, again, there are many opportunities to optimise resource use and investment in a properly designed engineered system. Consideration might be given to including these aspects in future investigations.

10.5 Conclusion

This study has identified several areas of further investigation that warrants active consideration and action. Specifically it is recommended that the current web-based monitoring and information tool developed by CAENZ be extended to increase its functionality as well as to include the benchmarking of on-farm performance for a range of different farm sites.

Other potential future action focusing on technology demonstration is also suggested. The key principles of any future programme in this area should seek to:

- incentivise good farming practice;
- improve resource efficiency;
- standardise dairy shed operations;
- strengthen farm economics; and
- improve sustainability outcomes.

The development of a good practice guideline is an essential component to achieving this objective.

11 CONCLUSIONS

This study provided a quantitative view of energy and electricity use in six farms with very detailed information from two of these. A monitoring system was successfully implemented using a range of temperature, pressure, flow and power measurements that were recorded in a local datalogger, and transmitted via the internet to enable analysis and display on the project web site. The system provided a large amount of data for subsequent analysis.

When each energy or cost saving technology was proposed or tested, it was possible to provide a quantitative assessment of the effectiveness of that technology. Thus few assumptions were necessary to make conclusions about the effectiveness of a particular technology.

One of the aims of the project was to identify the key information required to make decisions about investment in new technology. It was found that by applying typical economic conditions and tax information, the acceptable economic payback time was no more than six years. A period of five years was used here as it offered a small margin for improvements being less than expected.

It was clear that decisions relating to vacuum pumping, hot water systems, and milk cooling were effectively independent of each other. However the choice of electricity tariff has a strong effect on the choice of hot water system.

Many of the decisions were simply economic and in general there is no reason to expect dairy farmers to contribute to energy efficiency when the economics are not favourable.

11.1 Technology Conclusions

Vacuum Pumping

The savings that could be made by changing the vacuum pumping system were very dependent on the capacity of the pump currently in place and the vacuum demand. Where the vacuum pump has little spare capacity and a well maintained vacuum control system, the potential savings from any changes are relatively low.

It was found on the farms examined that it was not economic to replace a water ring vacuum pump with a more efficient rotary vane or lobe rotor pump. For example at the 38-bail Graejo Trust farm changing from a water ring pump to a more efficient rotary vane pump at Graejo Trust farm was only justifiable if it can be done for $5000 or less. Given the high capital cost of vacuum pumps it seems unlikely that such a replacement would be economic on any farm. However for new farms, or when an upgrade is required, either a rotary vane or lobe rotor pump should be seriously considered.

A variable speed vacuum pump control system (the Varivac) was found to reduce energy consumption for vacuum pumping by up to 55%. Higher savings were not ruled out. At Glencairn the existing water ring pump had ample capacity and the savings achieved at were large enough to justify this investment but the savings achieved at Coldstream and Graejo were not. In cases where a vacuum pump have plenty of spare capacity, a variable speed control system such as a Varivac might be economic. Estimates for calculating the likely savings and payback time are given in Table 3.9.

Based on recommended vacuum pump capacity for new installations, an additional investment of $13,000 - $14,000 for a rotary vane or lobe pump with variable speed control would be justified for a 5-year payback period on a 60 bail farm.

For a new installation the extra investment required for a variable speed controller is less than for a retrofit and is likely to be worthwhile for most farms.

Reducing Hot Water Use & Improving System Efficiency

There are several steps that can be taken to reduce hot water use and improve the efficiency of a water heating system.

Firstly, the current system should be checked to see if any simple changes can be made to improve efficiency. The obvious measures to be taken include adding insulation to any part of the hot water system that is warm to the touch, fixing water leaks and reviewing washing procedures to see if hot water use can be reduced.

Heat losses can also be reduced significantly by adopting a 'just in time' approach to water heating i.e. installing a time switch to turn the water heater at the latest possible time before the hot water is required (typically 5 to 7 hours before).

These low cost actions can reduce energy use in a typical 'two cylinder' water heating system by between 2000 and 4000 kWh per year and save $300 to $500 per year in electricity cost.

Table 4.7 shows some options for reducing hot water use and improving heating system efficiency with expected energy and cost savings for a typical 50 bail dairy shed using 1000 litres of hot water each day. These figures were calculated using the 'Dairy Shed Energy and Electricity Cost Calculator' developed as part of this project and available for download on the project website http://www.cowshed.org.nz.

Alternative Water Heating Systems

When evaluating technologies for hot water generation or recovery, it was clear that amount of hot water was the most significant variable. Other variables such as the number of cows were only indirectly related.

There is a range of alternative methods for heating water in a dairy shed.

There is no evidence that any energy sources have a lower cost than electricity for most dairy farmers. However in special cases LPG or diesel might be an effective alternative.

There are a number of sources of heat on a farm that can be recovered for heating water. These include, in order of capital cost, "The Retriever", the DTS heat recovery unit and the Mahana Blue heat pump. It was found in practice that the high cost equipment had higher energy savings and hence higher cost savings in the long term. The DTS heat recovery had a shorter payback time, but because of greater energy savings the Mahana Blue heat pump was likely to provide the greater return over its lifetime.

None of the solar water heating systems were as effective as the heat pump. Their capital cost was higher and because of the changeable weather it is unlikely that their long run efficiency would ever be higher than the heat pump.

Table 5.4 in Section 5 shows some alternative water heating systems with expected energy and cost savings for a typical 50 bail dairy shed using 1000 litres of hot water each day. These figures were calculated using the 'Dairy Shed Energy and Electricity Cost Calculator' developed as part of this project and available for download on the project website www.cowshed.org.nz.

Milk cooling

The opportunities for reducing energy use and electricity cost in the area of milk cooling are fewer than in the areas of vacuum pumping and water heating. If a chiller system is running efficiently the cost of running the system is not easily reduced.

The main driver for improving the milk cooling system was to achieve the required temperature of less than 7°C with 3 hours of milking. Failure to achieve this can results in penalty charges from the dairy company.

The main opportunities identified in this project were:

a) improving the performance of the pre-cooler by increasing the number of plates and the cooling water flow rate;

b) optimising the operation of the pre-cooling system by the installation of a milk pump speed controller to give a more even flow of milk through the cooler; and

c) insulating the milk vat.

Pre-cooler

Each two degrees reduction of milk temperature out of the pre-cooler reduces chilling costs by $240 per year on a farm producing 15000 L/

day and justifies about $1400 of investment. An efficiently operating pre-cooler should reduce milk temperature to within 3 degrees of the water temperature. Greater investment is only justified if a shorter cooling time is required.

Variable speed milk pump

The installation of a variable speed drive system on the milk pump can reduce the milk temperature from the pre-cooler by smoothing the milk flow. In general, to decide if variable speed milk pump control is justified, a farmer needs to estimate the temperature approach (Section 6.2) of the plate cooler. This can be estimated from the external temperatures of the relevant pipes but not all farmers have equipment to do this. If the temperature approach is less than about 6°C it is very unlikely that cooling will be greatly improved by a pump speed controller. If the temperature approach is greater than about 12°C a controller might be economic for a farm processing at least 15,000 L/day. If the temperature approach is more than about 6°C and if the milk is not chilled quickly enough in the vat, then a milk pump controller is likely to assist in reducing the chilling time.

There was potential for the manufacturer to improve the milk pump controller by taking advantage of some features of modern variable speed controllers.

Heat Gain and Milk Vat Insulation

Milk vat insulation reduced heat gains (as opposed to energy usage) by milk vats by up to 80%. While insulation will improve energy efficiency, the amount of energy saved on most farms is likely to be relatively small and in many cases will not meet a 5 year payback criterion.

Based on the data measured at Coldstream Downs the annual saving was about $400. The capital cost was larger that the justified investment of approximately $2000 . In much warmer areas of New Zealand, the vat wrap is likely to be economic for energy savings alone.

Vat insulation might enable a farm to meet the milk chilling requirements more easily. If milk chilling is satisfactory on calm, cloudy days but not on warm, sunny, windy days then heat gain into the vat is the likely problem. Vat insulation is probably the most cost effective solution.

Pumping

There is no doubt that energy usage in the dairy shed can be reduced by designing pumping and piping systems to be as energy-efficient as possible. In the case of an existing dairy shed however, the saving in electricity costs is unlikely to be sufficient to encourage replacement of existing pumps or pipelines for that reason alone. In the case of a new shed however, it is well worthwhile considering the energy efficiency of each pump and piping system at the time of design and installation.

The dairy shed effluent pump is likely to have the largest motor and to consume the most electricity and should be the starting point when looking at saving pumping energy. Effluent pumps with significantly lower power requirement than the traditional centrifugal pump are in use on some farms already and are worthy of consideration for new installations.

Lighting

Energy use for artificial lighting can be minimised by making maximum use of natural light to light the dairy shed and by turning off the artificial lighting as soon as it is no longer needed.

Fluorescent lighting provides cost-effective general lighting for most dairy sheds and is particularly suited to herringbone sheds where the low roof does not permit the use of metal halide fittings. Where incandescent lamps (the traditional light bulb) are still in use, they should be replaced with compact fluorescent lamps or new linear fluorescent light fittings installed. Changing from incandescent to fluorescent lighting will reduce lighting electricity usage by 70% and will also reduce the cost of replacement lamps.

Metal halide light fittings are suitable for rotary platform dairy sheds where they can be mounted high enough above the floor.

In the yard, flood lights with quartz halogen lamps are often used. While these fittings are cheap to buy, the lamp life is short and they are not energy efficient. A 150 watt high pressure sodium or metal halide floodlight will provide more light than a 500 watt quartz halogen light and uses 70% less energy.

For a new dairy shed or a major lighting upgrade in an existing shed, a lighting specialist can provide a suitable design and estimate the savings that can be achieved by using energy efficient light sources.

Electricity

The generation of electricity on farm is unlikely to effective for most dairy farms but might be considered by enthusiasts or those with special resources.

There is a strong price signal for farms to change their load pattern to use more electricity at night. This would make more effective use of national and local infrastructure for the generation and distribution of electricity.

By heating water at night and having a 'day/night' tariff, electricity charges can be reduced by about $2000 per year. To make use of night rate electricity it is necessary to install a night switch that will match the management structure of the farm. Such a switch should be automatic but allow override for a short period. Cancellation of the override must also be automatic.

Time-of-use metering is not recommended based on current prices but this might change in the future.

11.2 Practical Advice

Some of the experiences and practical lessons learned from the project reinforce the need for farmers and farm owners to give proper consideration to installation issues, planning for work to be done, fault rectification and after-sales service.

In particular, key issues identified were:

- Co-ordinating trades - equipment installation often requires more than one type of tradesman.
- Establishing a fixed price for project work - preferably including the total cost of getting equipment installed and operating correctly.
- Correcting faulty installation work - supply and installation should include all work necessary to commission equipment and get it operating as the supplier intended.
- Staff training - untrained staff will not be fully informed of energy saving systems installed and how to use them to best effect.
- Information - owners and managers require good information, such as electricity use and milk temperature, to effectively manage their energy use.

The Study Team recommend that further consideration be given to developing a best practice guide for energy efficient dairy shed design and construction, including the technical and engineering components of equipment selection.

Such a guide will assist in addressing the above issues as well as enabling farmers and farm owners to make informed decisions when selecting equipment, and to ensure farm operations are as energy efficient as practicable.

11.3 Decision Making

Investment decisions fall into three distinct areas:

(1) Vacuum pump and variable speed control.

(2) Water heating and electrical tariff selection.

(3) Milk pre-cooling and chilling.

These are best considered in the order shown as the first decision can be made independently of subsequent decisions.

1 Vacuum Pump & Variable Speed Control

Tables 3.8 and 3.9 give an estimate of the likely energy and cost savings, and payback time from a new vacuum pump and/or variable speed control system.

2 Water heating

Quick Savings

To save energy costs due to heat loss, insulate any parts of the hot water system that are warm to touch and fix any hot water leaks. This could easily save up to $500 per year with very little investment.

Investment to save costs

Also consider doing any one, but only one, of the following. These are ranked in order of capital expenditure, not savings:

a) Change to night time hot water heating and day/night rate.

b) Change detergent to use more cold washes.

c) Add a heat recovery unit to heat water from the chiller condenser.

d) Add a heat pump to heat water, e.g. Mahana Blue.

e) Add a solar water heating system.

A decision flow chart for achieving affordable energy cost savings in water heating is given in Figure 11.1.

Because these options require different amounts of capital they can be compared by calculating the value over 10 years of operation. The calculation of net value takes into account energy savings, interest payments, depreciation and tax, and is made for a farm producing a peak of 15000 litres of milk per day and using 1200 litres of hot water.

a) Change to night time hot water heating and day/night rate. Over 10 years the net value of savings is estimated to be over $20000. This option provides economic benefit to the farm and electricity distribution company.

b) A cold wash system gave a range of savings that were very farm specific. The value of electricity savings after 10 years, without including changes in detergent cost, is approximately $5500.

c) The DTS heat recovery unit had a net value of savings after 10 years of about $10000. When the hot water usage is about 400

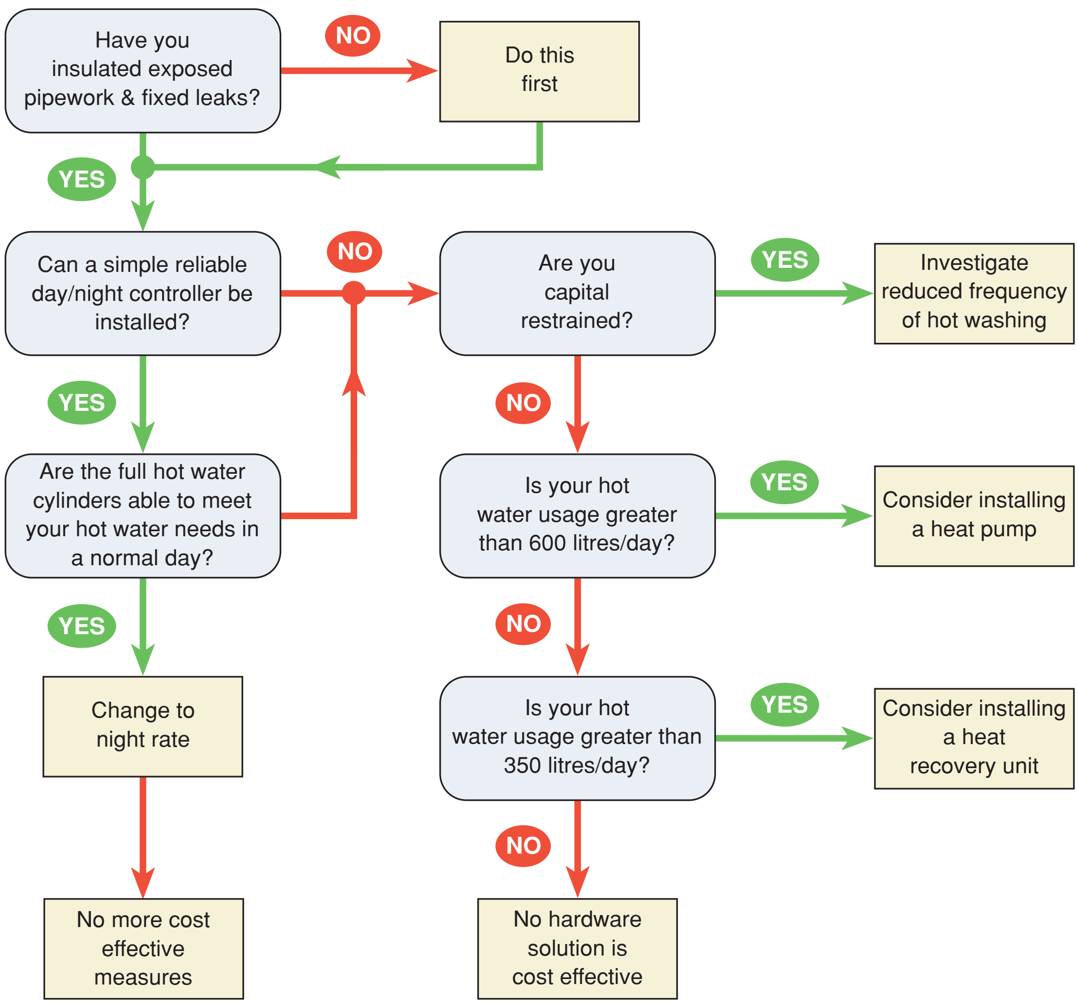

Table 11.1: Decision flow chart for achieving affordable energy cost savings in water heating

litres per day this saving drops to about $2000. Other systems are available, or are proposed.

d) Heat pump. The Mahana Blue system net value of savings after 10 years was estimated to be $11000. For a farm using 900 litres per day this saving reduces to $5200. There is no significant payback once the daily hot water consumption falls to about 600 litres.

e) The cost of a solar heating system for one hot water cylinder was $9300. The cost for enough panels for two hot water cylinders is estimated to be $15000. The best possible performance based on weather is that a solar system might provide 65% of the required hot water energy. Even in the best possible case the net value of savings after 10 years was substantially negative.

3 Milk Chilling

If a chiller system is running efficiently the cost of running the system is not easily reduced. In cooler parts of New Zealand no general recommendations are made for improvements if milk is being cooled to the dairy company's requirements.

Pre-cooler

If the temperature of the milk leaving the pre-cooler is more than about 6°C higher than the cooling water, energy and cost gains are possible by adding more plates, increasing cooling water flow rate and/or by installing a variable speed milk pump controller.

Heat Gain and Milk Vat Insulation

If milk chilling is satisfactory on calm, cloudy days but not on warm, sunny, windy days then heat gain into the vat is the likely problem. Vat insulation is probably the most cost effective solution. In warm areas of New Zealand, a vat wrap is likely to be economic for energy savings alone.

A Final Word

The project team has developed a significant amount of skill and knowledge relating to the measurement and analysis of energy and electricity use in dairy sheds. Data was analysed objectively to determine the energy saving and cost saving effectiveness of a range of practices and technologies that might be implemented.

The project was able to confirm the effectiveness of a number of technologies and hence give farmers the confidence to implement them.

A number of possible new opportunities were revealed during the project. There are many technologies that could be improved further to enhance their energy saving ability or their cost effectiveness, and continued development of these is recommended.

This will not be the last word on this subject. Changes in technology, and energy supply and demand will continue to provide new energy saving opportunities to be exploited.

Appendix A: Investment Decisions

It is useful to have a rule of thumb for simple payback years when evaluating investments.

To enable development of a simple rule, a complete calculation should be carried out.

It is assumed that

- a farm would need to borrow money from a bank
- the farm is making a profit and paying tax
- the tax rate is 30% from 2008.

The payback is affected by the amount of interest paid, the depreciation rate, the cost savings made and the change in taxation that profits or losses give.

Example

At the start of a season (June year 1) a farmer uses his farm company bank overdraft facility to purchase a new piece of equipment costing $10,000.

The bank overdraft rate is 10.5%.

The equipment has a useful lifetime as specified by the IRD of 12.5 years (e.g., for vacuum pumps) or 8 years for controllers such as variable speed drives.

IRD also give diminishing value depreciation (DV+20%) of 19.2% or straight line (SL) depreciation of 12.6% for milking plant. IRD say that either DV or SL can be chosen but DV seems to be more popular. The rates for control equipment such as a variable speed drive will be 30% for DV and 21% for SL.

Say the investment leads to a $2000 p.a. reduction in electricity costs. This might be expressed as a simple payback period of 5 years. The saving in the cost electricity is expected to increase by at least the rate of inflation which might be assumed to be 3% p.a.

It is assumed that the company is making a small profit and it paying tax at 30% (from 1 April 2008)

The net change in profit before tax is electricity cost reduction – interest cost – depreciation, i.e. in the first year,

$2000 – 1050 – 1920 = -$970

and therefore there is a tax saving of 30% of $970 = $291.

Thus the net reduction in profit after tax of the investment is $679 and there is a cash gain of

2000 – 1050 +291 = $1241

This amount is used to pay off the overdraft.

This calculation can be set up in a spreadsheet as shown in Figure A.1

This figure shows that with a simple payback time of 5 years, the actual payback time is about 8 years (the start of year 9) and net value at the end of 10 years (the start of year 11) is $5987.

The spreadsheet can be used to relate the simple payback time in years and depreciation rate to the net value after 10 years. This is shown in Table A.1. We can see that an investment with a simple payback of 6 years (i.e., $1666 cost reduction for a $10,000 investment) gives a net positive value after ten years. However an investment with a simple payback of 7 years is unlikely to be profitable after 10 years.

Based on this we can reasonably safely say a simple payback of 5 years will be profitable over a ten year period. From Figure A.1 it can be seen that a simple 5 year payback gives a positive profit at the start of the 9^{th} year.