Department of Primary Industries

Climate Change Research Strategy - Energy Efficiency Solutions

On-farm Energy Pilot Case Study – Boondabah Holsteins, Jones Island and Manning Valley Dairy, Wingham

Two farms, Boondabah Holsteins and Manning Valley Dairy, installed solar powered glycol refrigeration and chilled water storage systems with heat recovery and system controls to reduce peak electricity demand and energy costs. The project was conducted as part of the NSW DPI Energy Efficiency Solutions On-farm Energy Pilot program and was managed by Dairy NSW.

The NSW DPI's Energy Efficiency Solutions Project implemented 7 pilot projects across 8 sites to demonstrate innovative technologies and practices to improve on-farm energy efficiency, energy security and productivity while reducing on-farm energy use, costs and emissions. The pilots were implemented at farms located across NSW in intensive sub-sectors including dairy, horticulture and feedlots. A rigorous evaluation process was undertaken to select proponents to participate in the pilot projects, with NSW DPI contributing 50% of total project costs. This case study summarises findings from a thermal storage project conducted at two sites, Boondahbah Holsteins at Jones Island and Manning Valley Dairy at Wingham.

Context

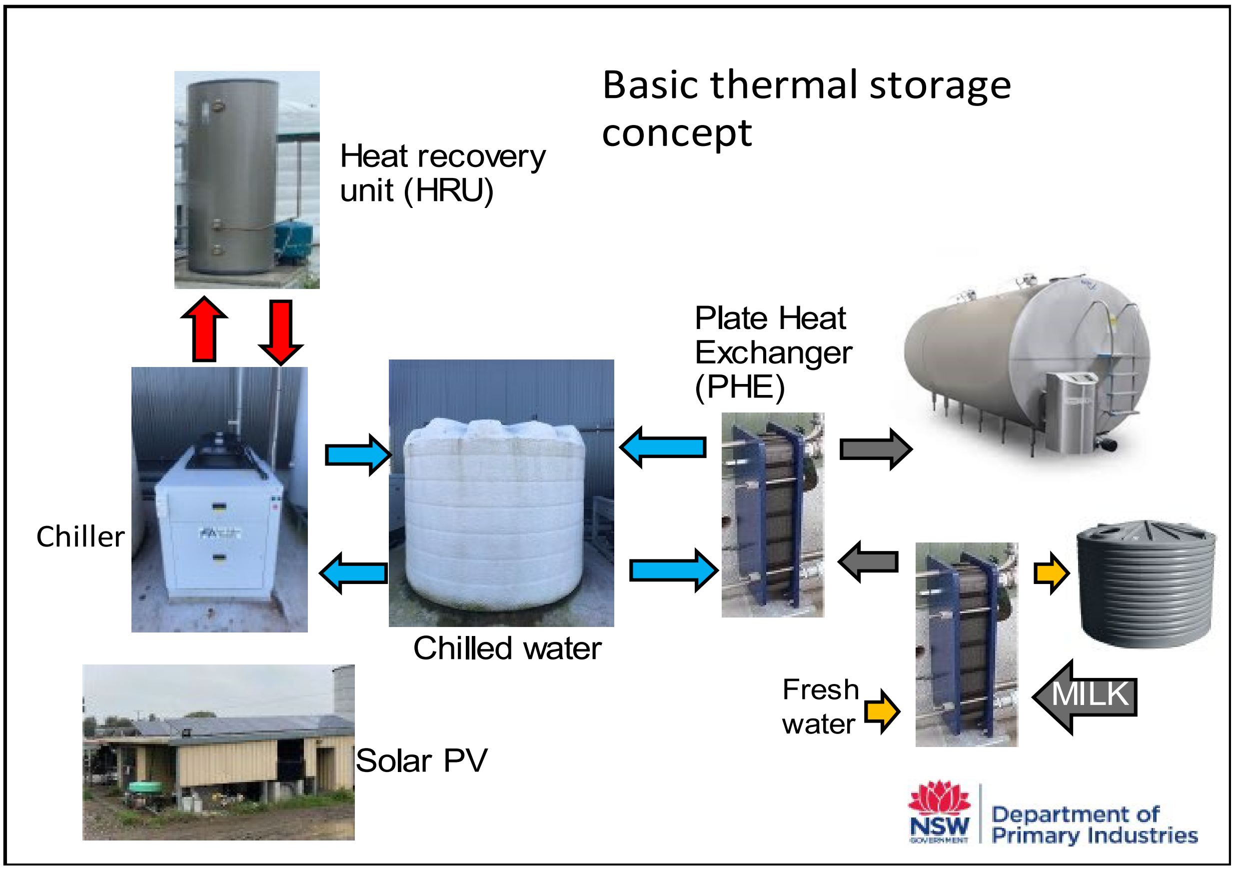
Electricity usage in a dairy typically peaks during morning and afternoon milking times when most equipment in the dairy is in operation. Cooling milk is a large proportion of this load.

Solar PV generates most electricity during the middle of the day, when many dairies are not in operation. For many dairies installation of solar PV does not off-set a high proportion of electricity usage during milking times.

Pilot concept

The concept of the thermal storage project is to use electricity generated by solar PV to chill water during the daytime, store the chilled water in an insulated tank and use the chilled water during milking times to cool milk using a plate heat exchanger (PHE).

Pilot concept diagram



Characteristics of thermal storage systems with solar PV

Thermal storage (chilled water) provides the opportunity to harvest solar PV energy to cool milk rather than grid power.

However, use of chilled water introduces “losses” in the system:

- the temperature differential at each plate heat exchanger
- losses from the insulated storage tank
- the electricity used by the circulating pumps.

Therefore, if adopted, it is essential to harvest as much solar energy as possible to offset these inefficiencies.

- An important part of any thermal storage project is a heat recovery unit on the chiller to pre-heat water before it flows into the boiler at the dairy, reducing energy usage from the grid.
- To ensure the adequate design of the chiller system, it is important to understand the efficiency of the 1st stage PHE in the milk line using fresh cold water in the dairy.

The thermal storage systems used on the DPI pilot farms were designed to adapt existing cooling systems and to use cost effective components commonly used in the dairy industry, such as chillers, insulated tanks and plate heat exchangers. Ice-banks are another form of thermal storage system for cooling milk and have significant advantages over liquid systems, since ice also stores energy as latent heat (i.e., energy needed to melt ice into water). However, the DPI pilots were set up to explore a perceived potentially cheaper option with equipment or modifications to systems already set-up on many dairy farms.

Recommendations for dairy farmers considering thermal storage with solar PV

Lessons learnt from pilot projects:

1. **Ensure solar PV output matches the sizes of compressor in the chiller and circulating pumps** (i.e., check kW draw not just kWh output)

Many solar PV systems are designed based on kWh generated to match kWh usage in the dairy. While this is important, it is also essential to check that the kW output from the solar PV (winter is the critical period) substantially covers the kW drawn by the chiller and circulating pumps.

At the same time, chiller and pump sizes should be selected to run for 5-7 hours during the day to capitalise on the solar PV generated. If the chiller selected only runs for 2-3 hours during the day, only a small proportion of the solar PV generated can be utilised in the cooling of the chilled water.

It would be better to select a smaller chiller and pumps that run for longer period (5-7 hours/ day). The chiller and pumps that run for longer would have lower kW draw, resulting in smaller solar PV required.

2. Check efficiency of 1st stage PHE

With an efficient 1st stage PHE, the milk output can be within minimum of 2-3°C of the cooling medium.

As an example:

Typically, the chiller system needs to reduce milk to 11°C before it enters the vat.

If the 1st stage PHE is working efficiently with fresh river (or town) water at 20°C, the milk can be cooled from 36°C to 23°C. However, if the 1st stage PHE is not working efficiently the milk output can be 32°C (or more): the extra thermal load on the chiller system is almost 50% more.

Chiller load depending on 1st stage PHE efficiency:

- 1st stage working efficiently: 23°C to 11°C, a drop of 12°C
- 1st stage not working efficiently: 30°C to 11°C, a drop of 19°C
- The extra 7°C cooling required is almost 50% more cooling load on the chiller.

The design of the chiller and solar PV should take into account realistic temperatures achievable in the 1st stage PHE (critically during the summer, when the coolant may be elevated in temperature).

3. Careful selection and timing of circulating pumps essential

Electricity usage (kWh and kW draw) by the circulating pumps can be 25-35% of the total chiller usage.

- Careful selection of pumps is essential for energy efficiency and can significantly reduce the overall electrical load (kW) and usage (kWh)

- Typical target pump efficiency of 65-70%, motor efficiency of 90%
- It is also essential selected pumps are robust and easily serviced by local technicians
- Chilled water storage should be designed to minimise the volume and flow rate for the pumps to service

Control of the pump needs to match the operating times of the chiller; if the pumps are running for longer than necessary electricity would be wasted.

4. Heat recovery unit

Recovering the heat from the coolant in the chiller forms a significant (>30%) proportion of the potential benefits of any thermal storage system.

- Water can be pre-heated to up to 60°C, reducing hot water electricity requirements by up to 65%.

5. Check power factor of new equipment

For electricity tariffs based on kWh usage, power factor does not impact on the electricity bill for grid usage

BUT, the solar PV system needs to supply the “apparent” power (or kVa), which takes power factor into account: kVa = kW/ power factor.

For example: if the power factor of the equipment is 0.71,

the “apparent” power required = kW/ 0.71 = kW x 1.4

In other words, if the overall power factor is 0.71, the solar PV needs to deliver 40% more power than the kW rating on the equipment. A power factor of 0.90 is typically considered adequate.

- Power factor correction equipment can be installed to overcome lower power factors
- Careful selection of new equipment (particularly pumps) with higher power factors
- Installation of a larger solar PV system to cover the extra load.

6. Check there is adequate capacity in transformer for any equipment upgrades

Installation of chillers and pumps for the thermal storage system may increase the total draw on the transformer at the dairy. A transformer upgrade can be costly and must be factored into the project cost assessment.

7. Ensure the final system delivers your priorities

Setting up a thermal storage system to maximise the use of solar PV is complex and needs the careful consideration of many factors which are across several disciplines. It is essential that your priorities are fully understood by your refrigeration technician, the solar PV designer, and the contractors responsible for system installation.

8. System monitoring

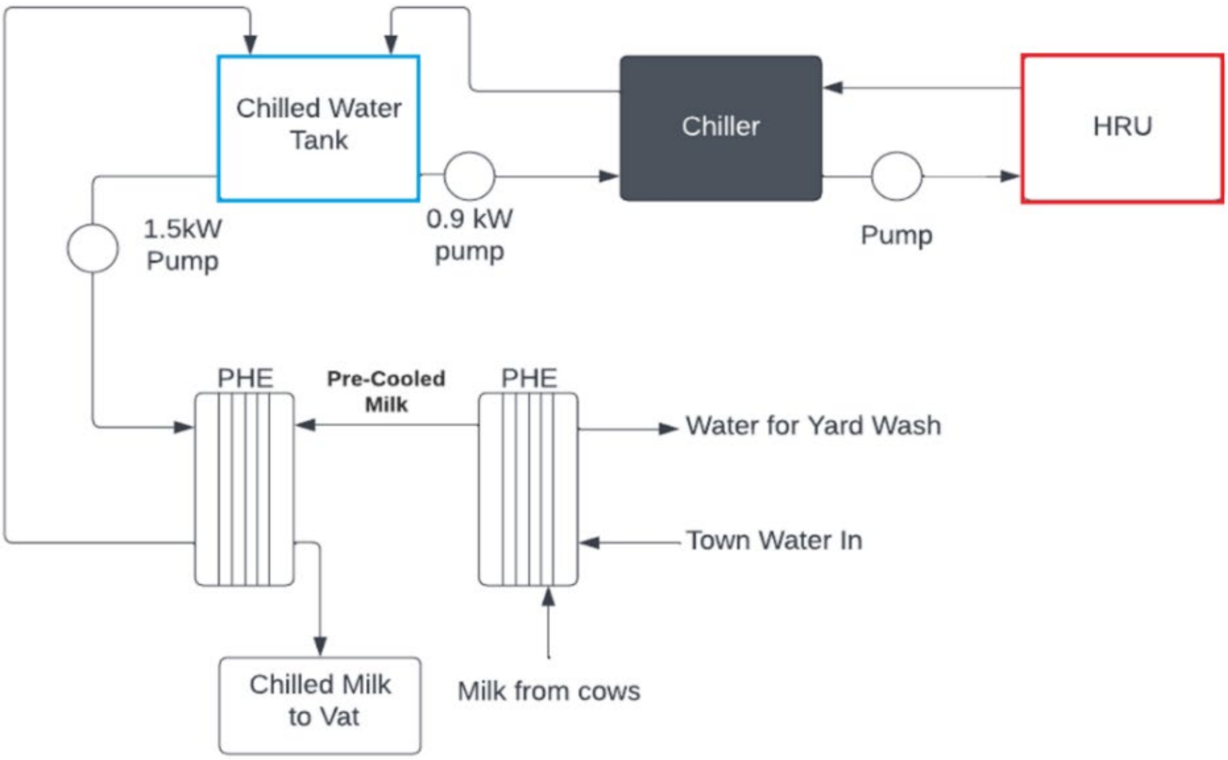
System monitoring can be very worthwhile to optimise solar PV usage by the chillers and pumps. Installing current transformers (CTs) to measure electricity use in specific electrical circuits (e.g., chiller, pumps, hot water system) provides data to assess the performance of the system and to identify fine-tuning of the timing of equipment run times.

NSW DPI THERMAL STORAGE PILOTS

Two pilots, Boondabah Holsteins and Manning Valley Dairy (MVD), were established with slightly different set-ups, illustrated in the diagrams below:

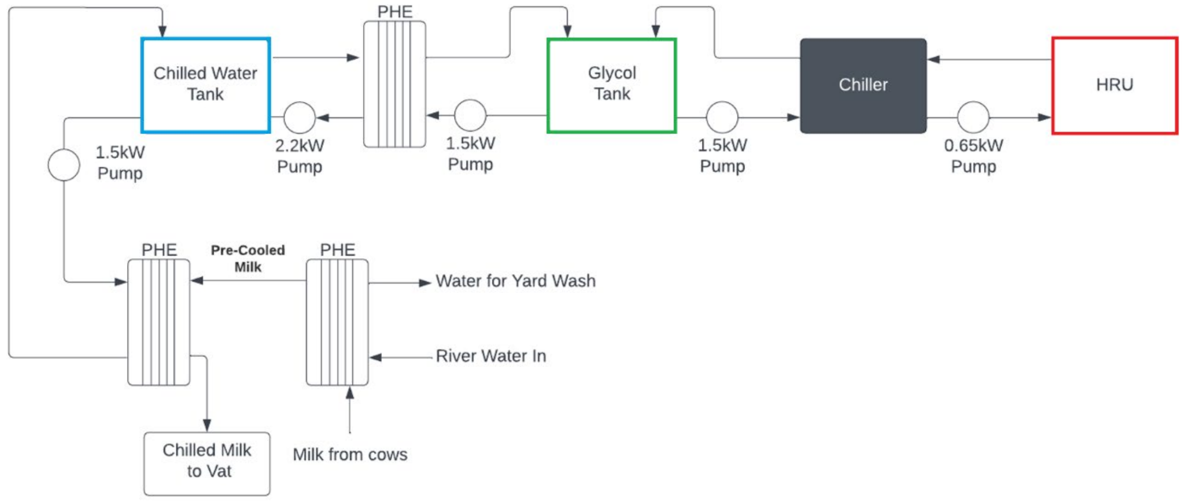
***Boondabah*: a simpler set-up with fewer "losses"**

- Chilled water was cooled to 8°C by the chiller during the day using solar PV and stored in an insulated tank.
- During milking the chilled water was pumped through a plate heat exchanger (PHE) to chill milk to 11°C
- The DX vat completed the milk cooling to 4°C.



MVD**:** an extra PHE using glycol was installed to allow for future expansion; this system has higher "losses"

- Glycol was cooled to 2°C by the chiller during the day using solar PV and stored in an insulated tank
- During the day the chilled glycol was pumped through a PHE to chill water to 4°C
- During milking the chilled water was pumped through a PHE to chill milk to 8°C
- The DX vat completed the milk cooling to 4°C.



Pilot results

The financial results of the pilot projects did not come close to the expectations detailed in the feasibility study, the reasons for which are listed below. However, there were a range of benefits achieved by the projects including:

- Electricity cost savings
- Milk cooled within industry (time) standards
- Improved milk quality
- Improved reliability
- Reduced maintenance
- Deferred capital costs.

Influencing factors which contributed to shifted project outcomes

Detailed monitoring of the electricity usage in the pilot dairies provided some insight into why the original energy expectations were not met.

1. **Higher capital costs**: for both pilots the capital costs were significantly higher than estimated.

   Boondabah: Implementation costs were 50% higher than estimated due to the decision to purchase new vats at a cost of $48,000 instead of using the existing vats as originally scoped. Project management fees also were not included in the feasibility study. These additional costs were partially offset by a reduction in costs for the PV system.

   MVD: Implementation costs were 33% higher than estimated, primarily due to transformer and switchboard electrical upgrades which were not originally expected, as well as additional project management fees.

2. **1st stage PHE with fresh water**

   Boondabah: the 1st stage of the PHE was not working as effectively as expected due to adjustments of its operation. As a result, the chiller had a 50% higher cooling load.

   MVD: the PHEs were working as efficiently as expected.

3. **Circulating pumps**

   As a result of pump selection and changes to chilled storage tank design, the usage of the circulating pumps usage was significantly higher than anticipated.

   Boondabah: the circulating pumps represent 30% of the total milk cooling electricity usage.

   MVD: the circulating pumps represent 35% of the total milk cooling electricity usage.

4. **Chiller and solar matching**

   The sizes of the selected chillers and solar PV systems changed from the original concept design. In operation, the kW generation of the solar PV was often lower than the fixed chiller kW demand, , resulting in higher grid electricity usage.

   Boondabah: the kW draw by the chiller does not match the maximum kW generated by the 12kW solar PV system

- Chiller draws 7.5kW for 3 hours in the middle of the day
- Peak outputs: typically 8 kW for 1 hour in summer, but only 4 kW in winter
- Boondabah's solar PV system also generates significantly less than expected, potentially due to a panel or inverter fault

MVD: the kW draw by the chiller does not match the maximum kW generated by the 54kW solar PV system

- Chiller draws 25kW for 4 hours in the middle of the day
- Peak outputs: typically 40 kW for 1 hour in summer, but only 20 kW in winter.

5. **Power factor**

Boondabah: a power factor of 0.73 was measured, which means an extra 36% electricity is required to run the equipment in the dairy.

MVD: a power factor of 0.70 was measured, which means an extra 40% electricity is required to run the equipment in the dairy.

Overall, the dairies participating in the pilot considered the projects to be worthwhile despite the deviations during implementation. Simon Scowen, manager at Manning Valley Dairy, said of the thermal storage concept, "We utilise power that we produce in the middle of the day and transfer that energy usage through to our milking times". Sam Nicholson from Boondabah Holsteins, commenting on how the thermal storage concept allows dairies to benefit from solar generation said, "Whatever we can do that utilises the sun, it's free energy right there."

A short video about this project can be viewed at https://www.dpi.nsw.gov.au/dpi/climate/energy/clean-energy/on-farm-energy-pilot-projects

Acknowledgments

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Climate Change Research Strategy - Energy Efficiency Solutions

On-farm Energy Pilots - Thermal Storage Project Development Process Guidelines

Two farms, Boondabah Holsteins and Manning Valley Dairy, installed solar powered glycol refrigeration and chilled water storage systems with heat recovery and system controls to reduce peak electricity demand and energy costs as part of the NSW DPI On-farm Energy Pilot program. This document can be read in conjunction with the project case study and provides guidelines for thermal storage project development from scoping to commissioning.

The thermal storage pilot project development process highlighted various points during the process from concept design through to installation and operation which impact expectations and performance. The guidelines below summarise the important considerations to keep in mind especially during planning, design, equipment selection, installation, and commissioning to minimise the energy consumption of any new equipment. Some become more practical and worthwhile with larger farm sizes. These include:

1. Establish project priority objectives in line with farm goals
2. Consider the overlap of upgrades with other parallel projects
3. System design for simplicity and reliability
4. Know the numbers for your milking operations and optimise them
5. Careful pump selection to match expected system flow rates from the upgrade
6. Design thermal storage to maintain separation of cold and warm water
7. Select a high-performance chiller with appropriate size and control
8. Solar PV sizing and operation to match equipment
9. Maximise your heat recovery and hot water system
10. Protect your investment

1. Establish project priority objectives in line with farm goals

Planning is key at the start of any major project or change to operations, as is looking ahead at how it may impact on any future knowns or unknowns. By assembling project motivations and any overlaps with other objectives, goals, and drivers, they can be incorporated into the design process and assist with setting the project expectations. This includes considerations such as:

- Quantifying business goals, such as expansion of herd, long-term plans for the farm
- Managing overlaps with the equipment of other systems which are at end of life
- Establishing the priority and trade-offs between additional milk cooling redundancy and ongoing maintenance and energy usage
- Managing any other simultaneous upgrades that may be required (e.g., electrical cabling/switchboards, vat replacements, hot water system, vacuum pumps)
- Quantifying any qualitative benefits where possible (e.g., improved product quality, time and maintenance savings).

2. Consider the overlap of upgrades with other parallel projects

While weighing up the value of additional milk cooling redundancy, the impacts in terms of maintenance, energy productivity, and how it's managed also need to be considered. If redundancy is required, consider if this can be provided in the form of backup rather than direct cooling of the vat all the time. When refrigeration is centralised heat recovery outcomes are also improved.

All the overlapping costs and benefits can be considered together and prioritised to establish what must be done now and what can be staged over time. This helps to manage cash flow particularly when a primary objective is to minimise capital costs, deferring some upgrades or minimising redundancy. Parallel project costs can also be handled as one-offs or from expected operational spend. Where payback is an important consideration for financing, consider the marginal costs for any equipment which already must be replaced.

3. System design for simplicity and reliability

The reliability of the system should be a top priority to reduce potential failure points that result in downtime and callouts. The capability of local suppliers to service, maintain, and fix any technical issues or control faults also needs to be considered so that emergencies can be quickly dealt with which avoid milk loss through system malfunction, the cost of which can quickly overcome any system efficacy gains from the investment.

This can be achieved by simplicity of design which reduces total quantity of components and complex control points to speed up any fault finding and parameter tuning. As such, simpler time clock scheduling of chiller equipment (e.g., 9/10 AM to 2/3 PM) may provide most benefits which outweigh the benefits of more complex controls between systems. Reduced components and control boards also makes it more practical for the critical service providers to keep spares for those unexpected 4 AM call outs.

4. Know the numbers for your milking operations and optimise them

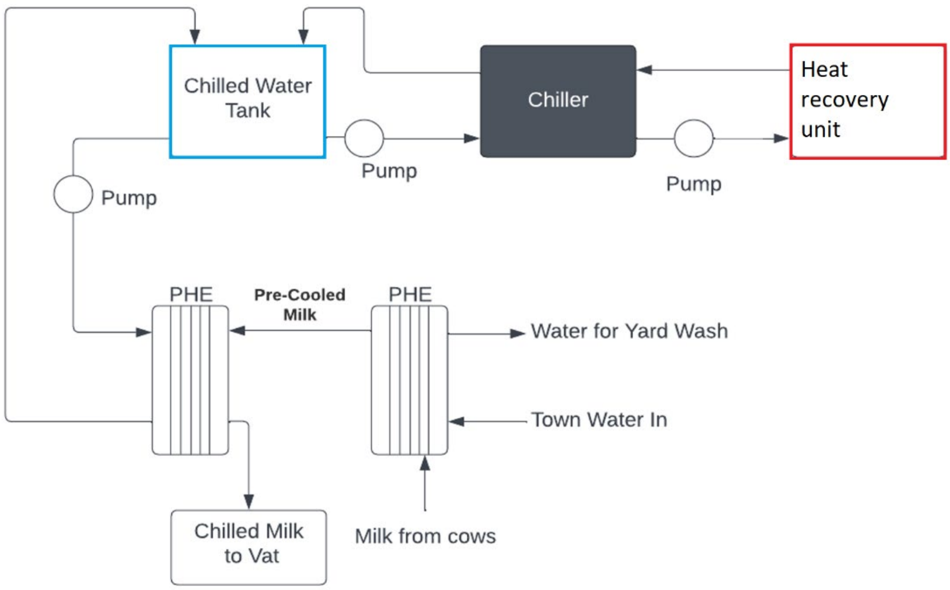
For the proposed system to operate at peak performance, the interconnections need to be thermally balanced to maximise effectiveness of each stage and reduce unexpected energy consumption. Firstly, this means evaluating the performance of the existing 1st stage plate heat exchanger (PHE), and its manufacturer design specifications will provide useful reference points if available.

Measured values for flow rate of the milk and the cooling water, as well as temperatures in and out are used to determine the PHE effectiveness in practice and if any adjustments to flow rate or number of plates need to be made. It's also worth noting that vacuum pumps with variable speed drives (VSD) provide more consistent flow and control over the milking process as well as assist with design.

The following illustrates reasonable expectations across both PHEs during everyday usage.

- With an efficient 1st stage PHE, the milk output can be within minimum of 2-3°C of the cooling medium temperature.
- Typically, the chiller system should reduce the milk to 11°C before it enters the vat.
- If the 1st stage PHE is working efficiently with fresh river (or town) water at 20°C, the milk can be cooled from 36°C to 23°C. However, if the 1st stage PHE is not well utilised, the milk output may still be higher than 32°C, with the following effect on the chiller system:
    - 1st stage working efficiently: chiller cools milk by 12°C (23°C to 11°C)
    - 1st stage not working efficiently: chiller cools milk by >19°C (30°C to 11°C)
    - The extra 7°C cooling required is almost 50% more cooling load on the chiller
- If the fresh water source for 1st stage is kept in a tank, keep as cool as possible such as under cover from direct sun and refilled overnight at cooler times.

The above provides critical detail towards sizing of the 2nd stage PHE, the thermal storage, the chiller, and associated flow rates. Components are typically sized according to atypical conditions including max milk volumes and higher fresh water temperatures in Summer but should also be tuned to regular conditions to maximise the 1st stage effectiveness. The flow diagram below shows the milk flow of milk through the cooling stages, and the supporting components involved in thermal balancing.



5. Careful pump selection to match expected system flow rates from the upgrade

Starting from measurement of the milk flow rates, the previous steps assist with determining the cooling system flow rates which, should be as low as possible to reduce excess pumping power and mixing within buffer tanks. Choosing a lower flow rate for single passes through PHEs will increase the temperature difference between inlet and outlet and reduce the total water volume required for each batch.

For example, this could mean that the chilled water tank temperature could be lower than 8°C and be maintained throughout each milking. Consequently, the temperature of the milk entering the vats can also be lower than 11°C. Without reducing accordingly the pumping flow rates and durations, pump energy usage can be as high as 30% of total refrigeration load. To adjust these flow rates and temperatures in practice, the use of valves will keep capital costs lower, while VSDs can provide more precise control and lower operating costs for key pumps.

The flow from the chilled water tank to the PHE is a key control point, as this likely requires frequent adjustments according to temperature measurements of the town water and milk. For effective operation of each loop, the selected pump needs to be suitable for the upstream pressure and not just the desired flow rate. Manufacturer pump curves will indicate the associated energy input to achieve the required flow rates within the system’s expected pressures.

Careful pump selection should:

- Be robust, readily available, and easily serviced by local technicians
- Account for head pressures and pipe losses
- Typically target a pump efficiency of 65-70%, motor efficiency of 90%, and have a high power factor
- Use the expected system flow rates, as determined by the milk flow rates and PHE design
- Aim for lower flow rates to improve cooling effect and reduce total volumes and run times
- Have flow control via valves for lower cost with smaller farms, and VSDs for key pumps with larger operations
- Align operation times with chiller for cooling water and milking for providing cooling.

6. Design thermal storage to maintain separation of cold and warm water

To maximise the utility of any thermal storage, the cold and warm should be kept separate, which is especially true for the chilled water as well as the glycol buffer and any fresh/town/river water storage used for the first stage of cooling. This separation combined with lower flow rates will also reduce required pump runtimes and associated energy use.

Where separate warm and cold tanks is impractical, then the supply and return connections of the tanks should be set for stratification. Typically, cold supply to the bottom and warm returns to the top with appropriate speed/velocity distribution at the tank inlets will maintain separation at all operating points so that only the required volume for use or cooling is accessed and returned similar to the functionality of a battery. As a result, the available chilled water temperature could be kept lower than 8°C throughout milking to enable lower milk temperatures into the vat.

The size of cold storage can be calculated starting with the required volume for each milking, in conjunction with expected flow rates and PHE design ratios (chilled water to milk). At a minimum the tank needs to hold at least enough chilled water volume for the single largest batch of cooling demand (e.g., a hot afternoon in Summer or a large morning milk volume in Spring). The volume can be recharged between milkings during the day, or overnight to take advantage of off-peak grid electricity rates. To allow for growth of herd size, the cold storage volume should be increased to match expected production. To recharge only from solar PV, the storage volume and potentially the solar PV and chiller sizes would also need to be increased to match.

7. Select a high-performance chiller with appropriate size and control

As the most critical part of the system, various considerations contribute to good chiller selection. This includes choosing a chiller with the highest coefficient of performance (COP), as well as capability for part-load operations either through turndown control via VSD of the compressor, or multiple/staged compressors.

These options enable better matching of the cooling supply against demand and available solar production, reducing operational costs of refrigeration through better long-term performance. Where possible a COP which well-exceeds any existing refrigeration equipment will provide more operational cost benefits. The manufacturer specification should be between 2-3, while tuning the operating parameters in practice will push this to the higher end of the scale.

The cooling size of the chiller should consider current milk production volumes as well as any anticipated growth. Utilise the measured flowrates of the milk alongside the proposed 2nd stage PHE ratio to determine the volume of cooling water required per milking. This volume will be the minimum required to be cooled by the chiller in the set duration between milkings during peak sun (e.g., 9/10AM-2/3 PM).

The above assists with determining the cooling capacity of the chiller, which alongside the expected COP will outline its electrical capacity. The added electrical demand of the chiller alongside auxiliary components including pumps need to be considered together against the available headroom of the existing electrical supply and retain a comfortable buffer to avoid transformer upgrades. To keep electrical demand down, the chiller shouldn't be actively chilling tank water during milking.

Any expected thermal losses in the system also need to be considered while sizing equipment, including the glycol loop when providing vat cooling. The glycol storage should also be large enough to maintain vat temperatures without frequent cycling of the chiller. Depending on the overall electrical demand, the chiller can run during milking or afterwards to keep the glycol cool. Alternatively, a 3rd stage PHE could be used to cool the milk down further to 4°C by the glycol before entering the vats.

8. Solar PV sizing and matching to equipment

In addition to sizing a solar PV system according to the energy generation (kWh) against energy consumption, it's also essential to match the expected electricity solar output (kW) against the refrigeration demands (chiller compressors + pumps), for peaks, averages, and minimums to avoid excessive grid demand.

Additionally, the selected chiller operation and pump sizes should be selected to run for longer durations over 5-7 hours of the day to capitalise on the solar PV generation time, rather than to recharge the chilled water tank in a shorter duration of 2–3 hours would only utilise a small proportion. Therefore, a smaller chiller (or one with turndown capability) which runs for longer periods would be more beneficial than a larger one and enables a smaller solar PV system.

While power factor (PF) may not impact the cost of grid electricity for smaller farms, it will still result in a higher volume of energy consumption particularly from the solar system than otherwise expected. A PF of 0.9 is considered good, while 0.7 might occur in reality as a greater drain on the solar system by as much as 43%. With the increased inductive loads from refrigeration and pumps on site, PF correction may prove financially beneficial, particularly where the measured PF is lower than 0.85. Alternatively, a larger solar PV system may be required to cover the additional load.

9. Heat recovery and hot water system

Recovering the heat from the chiller refrigerant forms a significant (>30%) proportion of the potential benefits of any thermal storage system. Water can be pre-heated to up to 60°C, reducing hot water electricity requirements by up to 65%.

Sizing the hot water system is important, identifying the volume required per milking/day and the appropriate set temperatures per storage tank and function. While the general hot water tank temperature of +90°C is required for general dairy usage, the amount that's required for vat cleaning can be held separately at 65-70°C which alone can reduce hot water energy use by up to 30%. This further enables the heat recovery to provide the right volume of pre-heated water for each purpose and minimise grid consumption.

10. Protect your investment

As this upgrade touches on almost every aspect of the dairy shed, protection of this investment will maximise its potential benefits. Accordingly, key measurements including milk and cooling water temperatures and flow rates will provide visibility to enable continuous commissioning of each system. These values enable adjustments to maximise cooling effect through the PHEs during milk cooling and tank recharge, particularly in line with seasonal variability of milk production and ambient temperatures. Multiple internal tank temperatures will be required as a chiller control set point as well as to indicate charge level.

Additionally, electricity sub-metering of equipment provides insights into operation to confirm schedules, electricity demand, alignment with available solar PV, and highlight any unexpected usage. This especially includes the chiller, with value-add from metering of hot water, solar PV generation, and vacuum pumps to monitor and adjust scheduled runtimes. Finally, to maximise equipment lifetime and reliability, new refrigeration should be installed undercover from the elements and out of range from flooding risks.

Acknowledgments

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