

Recovering heat from milk cooling systems saves energy on Swiss dairy farms

Markus Sax, Annett Latsch, Thomas Anken

On conventional dairy farms, around 50% of the electrical energy demand is used for cooling milk and heating water for cleaning equipment. The widely used circulation cleaning systems require cleaning water to be heated to approx. 80 °C, a process which accounts for at least 20% of dairy farm energy consumption. At the same time, waste heat generated by milk cooling systems is dissipated to the surroundings. This study focuses on circulation cleaning systems, as boiling water systems are rarely used in Switzerland. By recovering heat from the milk cooling system, it is possible to pre-heat the cleaning water to approx. 50–55 °C and shorten the milk cooling time. As regulations require milk to be cooled quickly to maintain its quality, this is particularly useful, especially in summer when ambient temperatures are high. Trials conducted on nine commercial dairy farms have shown that incorporating a heat recovery system (HRS) into the milk cooling system can save around 47% of the electrical energy demand compared with using a conventional electric boiler to heat the cleaning water. The HRS can also shorten the milk cooling time and reduce the electrical energy consumption of the cooling unit by around 14%. However, it is important to ensure that these systems are correctly installed and regularly maintained.

Keywords

Energy efficiency, heat recovery, milk cooling, cooling system, water heater

The cooling of milk and the cleaning of milking equipment and bulk tanks have a significant impact on milk quality and must therefore meet statutory requirements. Freshly milked milk enters the tank at an average temperature of around 34 °C and is cooled to around 4 °C to minimise the growth of bacteria and germs (SAPALI et al. 2014, MURPHY et al. 2013). In Switzerland, milk collected daily must be cooled to no more than 8°C within two hours, or, in the case of 48-hour collection, no more than 6 °C, in accordance with the Swiss Ordinance on Hygiene in Milk Production (SCHWEIZERISCHER LANDMASCHINEN-VERBAND 2019, VERORDNUNG (EG) NR. 853/2004, VHYMP 2005). The milk is generally cooled using a cooling unit with a closed refrigeration circuit, which dissipates heat from the tank to the surrounding air. Liquid refrigerant in the circuit flows through pipes in the base of the tank, evaporates and absorbs heat from the milk. From the milk tank, the refrigerant, now in a gaseous state, flows to the compressor where its pressure increases and its temperature rises. From there, it passes through to the condenser, where it releases its heat to the atmosphere. A large amount of energy is needed to dissipate the heat to the atmosphere via the condenser, especially on hot summer days with high outside temperatures. This increases the risk of failing to meet stipulated milk cooling times, potentially leading to impairment of milk quality and causing buyers to impose penalties.

In most cases, electrical energy is used to cool milk and heat water for cleaning. For hygiene reasons, all milk contact surfaces, such as milking units, milk pipelines, milk tanks, etc., must be thor-

oughly cleaned with hot water after each use. This is to remove milk residues, which encourage the growth of undesirable microorganisms (SAPALI et al. 2014, MURPHY and BOOR 2019, PALUDETTI et al. 2018). The cleaning process for milking equipment in the parlour can be broken down into three stages: pre-rinse, main wash and final rinse. To achieve the desired cleaning effect, water in the return line must exceed 60 °C at least once the main wash and have a minimum temperature of 50 °C at the end (SCHWEIZERISCHER LANDMASCHINEN-VERBAND 2019). Most cheese dairies demand a temperature of 55 °C in the return line. If the milk is used to produce raw-milk cheese, the return water must have a minimum temperature of 60 °C for at least three minutes (SCHWEIZERISCHER LANDMASCHINEN-VERBAND 2019). In most installations, the cleaning water is heated to over 80 °C to ensure that the required temperature at the end of the main wash is reached. Cleaning water is normally heated with an electric boiler, as was the case with all the farms in this study, which made it easier to compare the energy demand for water heating across individual farms. The cleaning water continually cools due to the difference in temperature between the boiler and associated pipework and that of the ambient air. As the installations remained the same before and after installation of the heat recovery system, with only an additional hot-water cylinder required upstream of the boiler, these heat losses were ignored in this study. A diagram of the milk cooling and water heating equipment is shown in Figure 1.

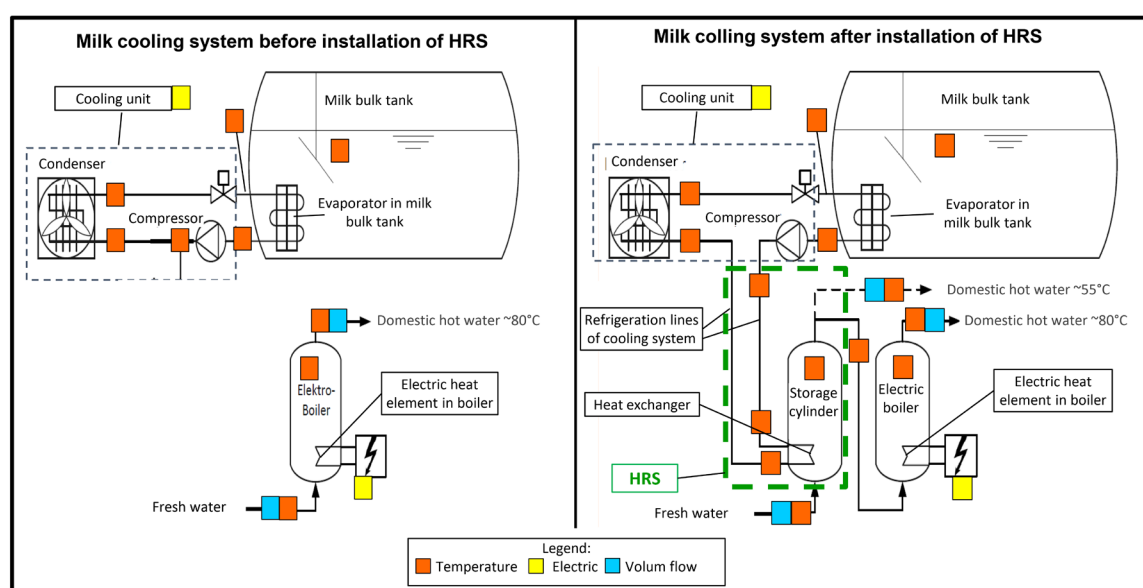


Figure 1: Milk cooling system before (l) and after (r) installation of a heat recovery system (comprising storage cylinder upstream of the boiler incorporating heat exchanger connected to the refrigerant lines of the cooling system); the measurement points for temperature, electricity, and water flow are highlighted in colour

These two processes – milk cooling and water heating – consume between 44 and 54% of a dairy farm's electrical energy demand, with milk cooling often accounting for the larger share of approx. 25–30% (CORSCADDEN et al. 2014, RAJANIEMI et al. 2017, UPTON et al. 2013).

According to the literature, milk cooling requires approx. 25 Wh per kilogram of milk and water heating approx. 50 Wh (RAJANIEMI et al. 2017, TODDE et al. 2018, GIE ÉLEVAGE BRETAGNE 2018). Aside from system settings and water volumes, these substantial differences in energy demand can also be attributed to heterogeneous installations, e.g. different thermal insulation, pipe lengths, dimensions.

Another factor is the milk collection interval, since a 48-hour collection saves a cleaning stage compared with a daily collection (EDENS et al. 2003). SHINE et al. (2018) calculated the cleaning-water consumption to be approx. 0.15 l per kilogramme of milk, while KRAUSS et al. (2016) and EIDE (2002) estimated it to be 0.34 l and 0.30 l, respectively. These large differences in cleaning-water consumption can often be traced back to the milking equipment and tank settings, which are fixed by the maintenance engineer during (usually) annual servicing. The lower water consumption cited by SHINE et al. (2018) can also be attributed to an irregular and larger hot-water cleaning interval for the milking equipment.

The efficiency of the electric boiler also has an influence on the electrical energy demand, estimated by UPTON (2010) to be 0.79, by SANFORD (2003) at 0.7–0.85 for standard boilers, and by CORSCADDEN (2014) at 0.7–0.98. The efficiency rate expresses the ratio of electrical energy input to thermal energy output, taking into account radiation losses. In addition, a 1 mm thick limescale deposit on the electrical heating elements can increase the boiler's electrical energy demand by around 10% (EIDE 2002, SHINE et al. 2017). Furthermore, large variations in cleaning-water temperature impact the energy demand (MURGIA et al. 2013, DAIRY FARMERS OF CANADA 2010, CUTHBERTSON 2006), which in this study ranged from 55 to 85°C.

A heat recovery system can reduce the electrical energy demand for water heating by 20 to 60% by extracting heat from the cooling milk and using it to preheat the cold water (PARMAR et al. 2020). Systems that incorporate heat recovery generally have two hot-water cylinders installed in series. The first contains a heat exchanger through which the refrigerant from the cooler flows, heating the cold water to around 50–55°C (CORSCADDEN et al. 2014, RAJANIEMI et al. 2017). The preheated water is then heated to the final temperature of around 80°C by means of an immersion heater in the second hot-water cylinder (electric boiler). Since hot water is mainly used for cleaning the milking equipment and milk tanks, this cylinder can have smaller dimensions, which reduces radiation losses and lime-scaling. Despite the large energy savings for water heating, enquiries to various installers revealed that, due to increased costs in Switzerland, only around a quarter to a third of new installations currently incorporate a heat recovery system. The respondents estimate that less than a third of the milk cooling systems on Switzerland's 17,000 dairy farms have a heat recovery system.

With an HRS, most of the heat extracted from the cooler is transferred to the water in the first cylinder. The efficiency of the cooler is expressed as the dimensionless value (kWh/kWh) or alternatively, the COP (coefficient of performance). The COP describes the ratio of heat (kWh) extracted from the cooling milk to electrical energy (kWh) input to the cooler. The milk cooling COP largely depends on the cold water and ambient air temperatures and the system design, and ranges from 1.60 to 2.91 (MURPHY et al. 2013, RAJANIEMI et al. 2017, VAN DER BRUGGEN et al. 2019, GODSKESEN et al. 2012). In practice, the COP can vary widely. Due to suboptimal design and, in some cases, poor maintenance, milk cooling systems on dairy farms often have a low COP values.

The aim of this study was to determine the energy-saving potential for heating water and cooling milk on commercial dairy farms in order to better analyse their efficiency under real-life conditions. To do this, we measured the electrical energy demand of nine existing milk cooling and water heating systems before and after installing an HRS. The findings should assist with funding schemes and provide a decision-making tool for increasing the energy efficiency of installations.

Material and methods

Situation on the trial farms before installation

Nine dairy farms in Eastern Switzerland (cantons of Thurgau and St. Gallen) with conventional milking parlours and insulated milk bulk tanks were chosen for the study. Milk was collected from these farms either daily or every two days. After the tanks are emptied, they are automatically cleaned with cold rinsing water and hot washing water from the boiler and suitable sanitising products.

All farms had a conventional milk cooler which dissipated heat to the atmosphere via a condenser. In each case, water was heated overnight in a separate electric boiler. The temperature of water in the boilers ranged from 61 to 83°C. The energy demand of the electric boiler and milk cooler was measured on all farms before and after installation of the HRS (Figure 1). The studies were conducted from April to September 2018.

To determine any possible influence of herd size on the efficiency of power and water consumption, we selected farms with different annual milk yields ranging from 126,000 kg to 475,000 kg and between 22 and 65 lactating cows. The farms' milk yields ranged from 7,000 to 8,900 kg per cow per year. Table 1 shows the herd size, milk yields, and milk cooling COP measured after installation of the HRS for all the farms in the study.

Table 1: Key figures for the nine farms

Farm No.	Number of lactating cows after installation of HRS	Milk yield per day in kg/d	Milk cooling COP after installation of HRS
1	22	531	1.84
2	25	595	1.40
3	31	650	1.70
4	30	715	2.02
5	33	736	3.12
6	50	1,125	2.39
7	52	1,245	1.98
8	55	1,414	2.42
9	65	1,661	2.59

Installation of HRS on all farms

On all farms, an additional hot-water cylinder was installed upstream of the electric boiler (Figure 1), in which heat extracted from the cooling milk is transferred from the refrigerant to the cleaning water via a heat exchanger. Downstream from this cylinder, the refrigerant enters the cooler, where heat may still be discharged to the atmosphere via the condenser, depending on the set-up. Thus the cleaning water is preheated to around 50–55°C in the first hot-water cylinder containing the HRS. The water temperature is then further increased to the required 80°C by means of an immersion heater in the electric boiler. Thus the farms have cleaning water at 80°C from the electric boiler and water at approximately 50°C for other purposes from the upstream hot-water cylinder. On some of the farms, the existing boilers were replaced with new ones because they were outdated and, in some cases, faulty.

Measurement concept

Data were collected from all farms over a period of at least two weeks before and after installing the HRS. This was done by fitting energy meters (Carlo Gavazzi, EM24 DIN, Lainate, Italy) to the critical electrical energy consumers; the electric boiler and the cooler (Figure 1). To record water volume and temperature, combi-sensors (Ahlborn, FVA 645 GV40QT, Holzkirchen, Germany) were fitted in tank flow and return pipes that had threaded connections (boiler and cylinder). For water pipes with press-fit connections, surface sensors (Thermasgard, ALTF2 PT100, Nürnberg, Germany) were mounted on the pipes and packed with insulation to minimise the effect of the ambient temperature. The temperature measurement data was collected continuously and stored on the data logger (Ahlborn, Almemo MA8590, Holzkirchen, Germany). The sensor specifications are summarised in Table 2. The volume of milk in each tank was measured during emptying using the flow meter integrated into the tanker. A collection note was generated automatically and assigned to the respective tank. The external air temperature and the air temperature in the room where the milk tank is housed were measured with temperature and humidity sensors (Ahlborn, FHA646-1, Holzkirchen, Germany) one-minute intervals and stored locally.

Table 2: Sensor specifications

Measurement parameters	Sensors	Measuring unit, measuring range of the sensors	Measurement accuracy
Electric Energy of boiler and cooling unit	EM24 DIN, 3 Phasen, Carlo Cavazzi, Lainate, Italy	1 impulse pro Wh	±1%
Water flow and water temperature at the taps	Combination sensor FVA645 GV-40QT, Alborn, Holzkirchen, Germany	2 to 40 l/min 0 bis 100°C	±1.5% ±1 °C
Surface temperature of water and refrigerant pipes	ALTF2 PT100, Thermasgard, S+S Regeltechnik, Nürnberg, Germany	−30 to 110°C	±0.5 °C
Temperature in milk bulk tank	FPA30K20L0020 Almemo D6, Alborn, Holzkirchen, Germany	−30 to 150°C	±0.3 °C
Ambient temperature	FHA646-1, Almemo, Alborn, Holzkirchen, Germany	−20 to 80°C	±1 °C
Data logger	MA85909, Almemo, Alborn, Holzkirchen, Germany	SD-card 512 MB	

Correcting the temperature of surface-mounted sensors

Analysis of the temperature data indicated a time lag when measuring the temperature rise (to a maximum) at the pipe surface as hot water was withdrawn. This time lag was attributed to warming of the pipes and to the sensor's delayed response time. It was corrected by applying the maximum temperature of the respective hot-water withdrawal at the start of the measurement. The reason for this is that water flowing from the boiler was initially hot but got colder with increasing withdrawal. When the maximum temperature was reached, which generally happened after 2–3 minutes, the actually measured values were applied to take account of any fall in temperature in the water boiler during large withdrawals (Figure 2).

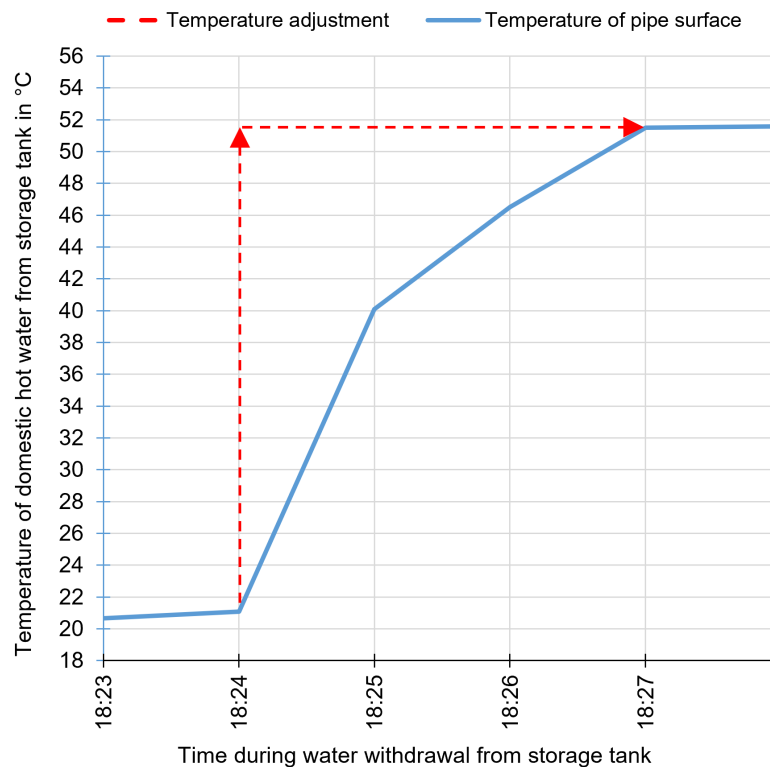


Figure 2: In the case of surface-mounted temperature sensors, due to the warming of the pipes etc., the maximum temperature (correction temperature) of a withdrawal was initially used to calculate the amount of heat, rather than the 'surface-sensor temperature' actually recorded

Calculation formulae

After milking, the milk flowed into the milk tank at a temperature of approx. 31–35°C and was cooled to a temperature of 4–8 °C. The heat energy (Q_M) from the cooling milk is calculated according to the following equation 1:

$$Q_M = c_{p \text{ milk}} \times \rho_{\text{milk}} \times m_M \times \Delta T \quad (\text{Eq. 1})$$

$c_{p \text{ milk}}$ = specific heat capacity of milk (3980 J/kg·K), ρ = density of milk (1.03 kg/l), m_M = mass of milk (kg), ΔT = temperature difference from start to end of milk cooling (assuming milk flows into the milk tank at approx. 33°C and is cooled to approx. 4°C, giving a temperature difference of 29 Kelvin).

The heat energy extracted from the milk during cooling divided by the electrical energy demand of the cooler gives the *COP* of the milk cooler and is calculated as follows:

$$\text{COP} = Q_M / W \quad (\text{Eq. 2})$$

Cooler *COP* (dimensionless);

Q_M = amount of heat extracted from the cooling milk (kWh);

W = electrical energy demand of the cooler (kWh)

The boiler *COP* was calculated from the amount of heat energy in the hot water divided by the electrical energy demand of the boiler:

$$\text{COP} = Q_W / W \quad (\text{Eq. 3})$$

Boiler *COP* (dimensionless);

Q_M = theoretically calculated heat energy in the hot water on withdrawal from the boiler (kWh);

W = electrical energy demand of the boiler (kWh)

The amount of energy in the cleaning water (boiler and storage cylinder) was calculated theoretically using equation 4:

$$Q_H = c_p \times m_W \times \Delta T \quad (\text{Eq. 4})$$

c_p = specific heat capacity of water (4,182 J/kg·K),

m_W = mass of water (1,000 kg/m³),

ΔT = temperature difference between water flow and return of boiler and storage cylinder (K).

The following formula was used to calculate the theoretical energy saving due to the reduction in boiler temperature:

$$E_S = (\Delta T_1 - \Delta T_2) / \Delta T_1 \times 100 \quad (\text{Eq. 5})$$

E_S = electricity saving due to reduction of boiler temperature (%),

T_1 = difference between boiler temperature before temperature reduction and cold water;

T_2 = difference between boiler temperature after temperature reduction and cold water (K).

The following formula was used to calculate the efficiency of the boiler:

$$\eta = w / Q_W \quad (\text{Eq. 6})$$

η = efficiency of the boiler (dimensionless);

w = energy demand of boiler (kWh);

Q_W = theoretically calculated energy content of the boiler water (kWh).

Results

Cleaning-water demand

The average daily demand for cleaning water across all test farms ranged from 150 to 440 litres, and daily milk production from 531 to 1,661 l/day. Converted to 1 kg of milk, this equates to a cleaning-water demand of around 0.33 l/kg_{milk} before installation of the HRS and just under 0.31 l/kg_{milk} after, which amounts to a reduction of at least 8%. The differences before and after the installation of the HRS were small on most farms. However, on three farms, the retrofitted heat recovery system significantly reduced cleaning-water consumption (Figure 3).

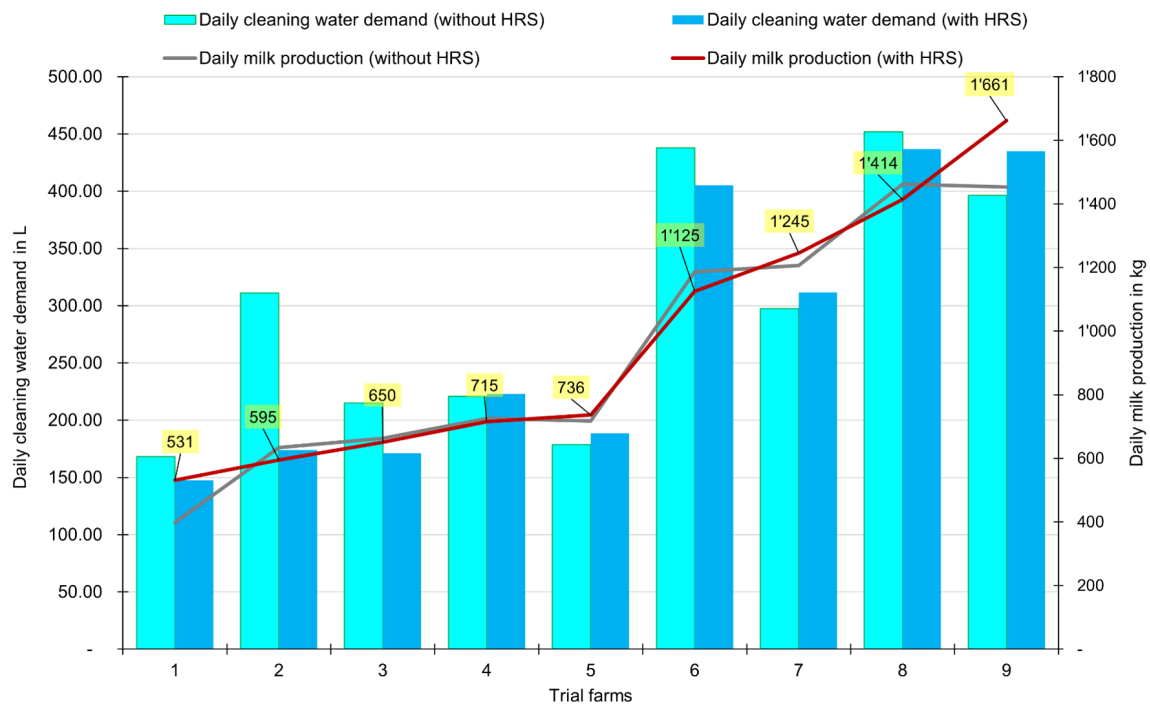


Figure 3: Average daily cleaning water demand and average daily milk production before and after installation of the HRS during the measurement phases

Regression analysis for cleaning-water demand

The daily demand for cleaning water correlated very closely with daily milk production. The spread of values showed no differences between farms producing smaller or larger amounts of milk (Figure 4).

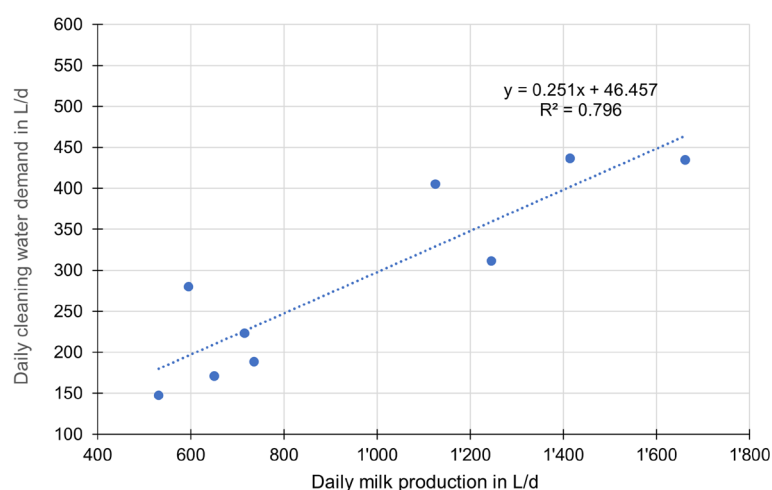


Figure 4: Regression analysis for daily cleaning water demand based on daily milk production after installation of the HRS

Electrical energy demand of boilers

The electrical energy demand for the provision of hot water for cleaning decreased on all farms after installation of the HRS. On average, 27.44 Wh per kilogram of milk were used before installing the HRS and 14.46 Wh after, which amounts to a mean saving of around 47% (Figure 5).

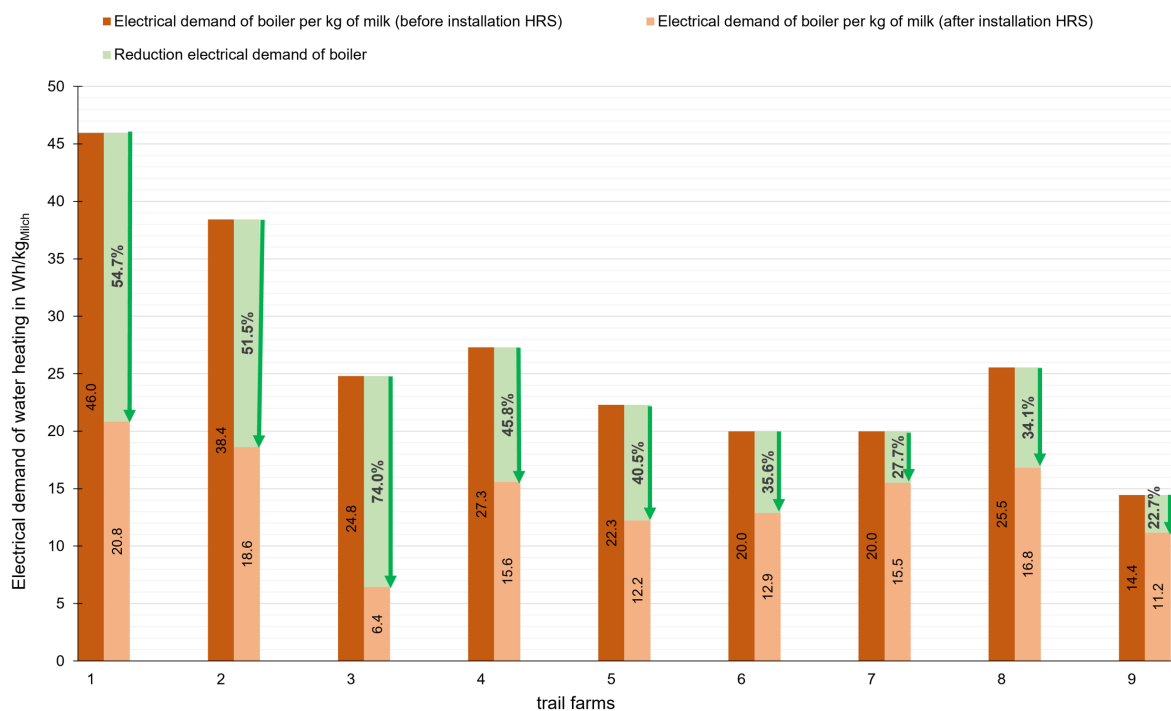


Figure 5: Electrical energy demand of the electric boilers for heating cleaning water before and after installation of the HRS across all nine farms

Electrical energy demand of coolers

Retrofitting the HRS reduced the electrical energy demand of the coolers from 18.2 to 15.6 Wh/kg of cooled milk on average (Figure 6). This amounted to a saving of around 14%. Only one system recorded a higher energy demand after the installation.

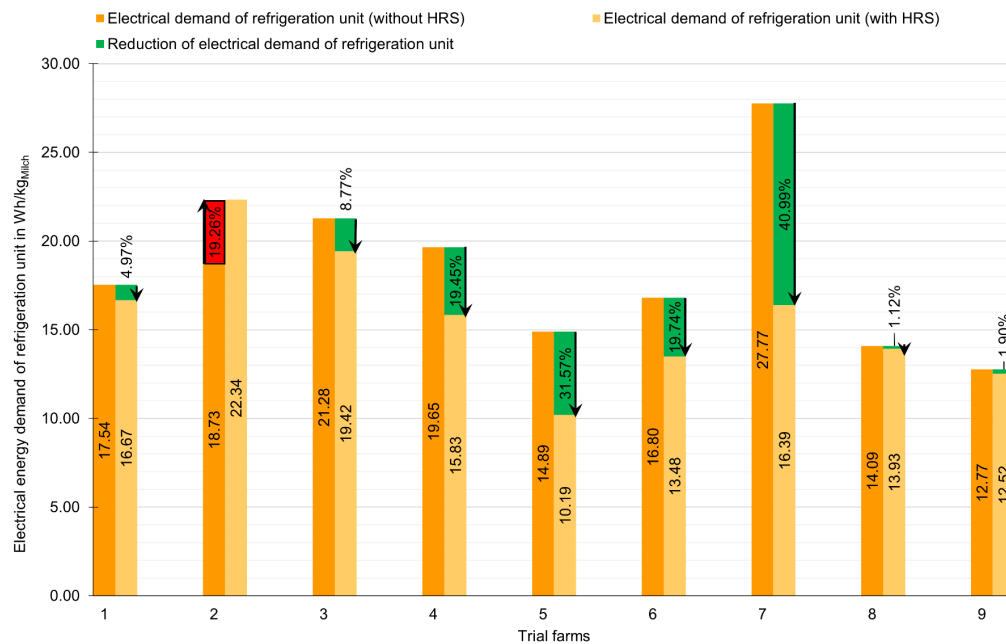


Figure 6: Electrical energy demand of the coolers before and after installation of the HRS

Regression analysis of the COP of the milk cooling process

The COP of the coolers after installation of the HRS and their electrical energy demand per kg of cooling milk correlate closely. The COP of the milk cooling systems after installation of the HRS ranges from 1.4 to 3.1 and correlates closely with the energy demand for milk cooling.

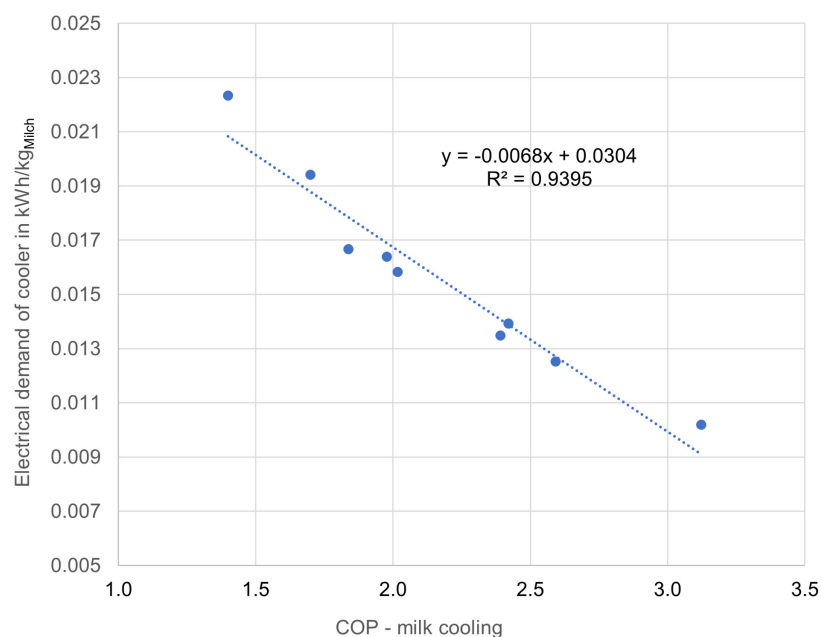


Figure 7: Milk cooling COP and electrical energy demand of coolers in kWh per kg of cooling milk

Discussion

The calculated mean demand for cleaning water across the nine farms at $0.33 \text{ l/kg}_{\text{milk}}$ before installation of the HRS and just under $0.31 \text{ l/kg}_{\text{milk}}$ after is comparable with the findings of EIDE (2002) (0.3 l) and KRAUSS et al. (2016) (0.34 l). The flushing volumes for the milking systems are set by the specialist installer and subsequently adjusted by the maintenance engineer at specified intervals. The volume of cleaning water required varies greatly depending on the specific product and the type of installation. These settings cannot be changed by the farmer. This is to ensure optimal cleaning of the milking equipment and tanks (DAIRY FARMERS OF CANADA 2010).

A farm comparison shows a very close correlation between demand for cleaning water and daily milk production ($R^2 = 0.8$). This is plausible, since higher daily milk production rates require larger milking parlours to ensure that each milking does not take too long. Accordingly, larger tanks are needed to cool and store the freshly milked milk. The overall daily demand for cleaning water thus increases linearly with increased daily milk production.

On three farms, the demand for heating water fell sharply after installing the HRS. One of the main reasons for this was that the temperature of the cleaning water had been too low prior to installation of the HRS. In particular, the boiler on Farm 3 had a substantial build-up of limescale, which restricted the temperature in the boiler to a maximum of $55\text{--}60^\circ\text{C}$. This meant that more cleaning water per cycle was needed to achieve the required cleaning standard. On Farms 5, 7 and 9, the demand for cleaning water increased after installing the HRS. This could be because the automatic cleaning processes adjusted the volumes to the demand. On Farm 9, the farmer explained that before retrofitting the HRS, the volume of cleaning water had been set too low due to insufficient boiler capacity.

The results presented in Figure 6 for the electrical energy demand of the boiler for heating the cleaning water show that installing the HRS resulted in a significant saving of around 47%. The mean electrical energy demand for heating the cleaning water of $14.5 \text{ Wh/kg}_{\text{milk}}$ approximated the value published by EDENS et al. (2003) ($14.4 \text{ Wh/kg}_{\text{milk}}$), and was below the mean of $16.25 \text{ Wh/kg}_{\text{milk}}$ (range from $9.7\text{--}22.8 \text{ Wh/kg}_{\text{milk}}$) obtained by RAJANIEMI et al. (2017). UPTON et al. (2013) reported a mean energy demand of $9.83 \text{ Wh/kg}_{\text{milk}}$, and the literature review by SHINE et al. (2017) points to a figure of $9.45 \text{ Wh/kg}_{\text{milk}}$, although neither of these two studies state how often per day/week the milking equipment is cleaned with hot water.

After installation of the HRS on Farms 1 and 2, the temperature of the cleaning water fell from 89 to 83°C and from 68 to 61°C respectively without impairing cleaning quality. According to equation 5, this reduction in temperature equates to an energy saving or approx. 9% for Farm 1 and 20% for Farm 2. As a result, the electrical energy used to heat cleaning water was reduced by a further $1.9 \text{ Wh/kg}_{\text{milk}}$ (9% of $20.8 \text{ Wh/kg}_{\text{milk}}$) on Farm 1 and $3.8 \text{ Wh/kg}_{\text{milk}}$ (20% of $18.6 \text{ Wh/kg}_{\text{milk}}$) on Farm 2.

Farm 3 achieved the greatest saving on the electrical energy demand of the boiler, which was attributed to the heavy limescale deposits on the immersion-heater elements before installation of the HRS. The limescale insulated the heating elements, restricting the hot-water temperature to just 56.8°C , which meant that the cleaning standards could not be met. According to BRUGGEN et al. (2009) and GODSKESEN et al. (2012), a limescale deposit of just 1 mm is sufficient to increase the electrical energy demand by approximately 10%. Furthermore, the ageing and poorly maintained electric boiler had a poor efficiency rating of approx. 0.74 (calculated according to equation 3), which is at the lower end of the range described in the literature.

The electrical energy demand of the coolers decreased on eight farms after installation of the HRS. The mean value was 15.6 Wh/kg_{milk}, which is close to the figure cited by SHINE et al. (2020) of 15.3 Wh/kg_{milk}. The dissipation of heat from an air-cooled condenser to the surroundings largely depends on the condensing temperature and on the ambient air temperature. If the difference between these two variables is too low, less heat is transferred from the condenser to the air flow per unit of time. Before installation of the HRS on Farm 7, heat dissipation from the condenser was hindered by the unsuitable location of the cooler. This had been installed directly under the roof covering (fibre cement) of the south-facing barn. The mean ambient temperature around the cooler during evening milk cooling was around 31 °C, resulting in above-average cooling times and correspondingly higher electrical energy demand. HARRINGTON et al. (2018) stated that coolers consume over 40% less energy at an ambient temperature of 16 °C than at 32 °C for the same cooling performance. RAJANIEMI et al. (2017) obtained a similar saving with a reduction in ambient temperature from 35 to 17 °C. This explains the higher electrical energy demand of the cooler on Farm 7 before installation of the HRS. On Farms 4 and 6, the very dusty cooling fins on the condensers restricted heat dissipation to the surroundings. During installation of the HRS, maintenance work was carried out on the coolers, which included cleaning the condensers. On Farm 5, the exhaust air downstream of the condenser was vented to outside via a narrow duct, the walls of which were partially covered with thick deposits. At the end of the duct were partially closed shutters. On these three farms, the high flow resistance of the exhaust air downstream of the condenser resulted in longer cooling times. On Farm 2, an insufficient amount of refrigerant was added to the cooler after installation of the HRS, which also led to longer cooling times and a higher electrical energy demand.

The efficiency of the milk cooling systems is expressed by the COP (coefficient of performance), which describes the ratio of heat energy extracted from the milk to electrical energy input to the cooler. Equation 2 is used to calculate the milk cooling COP. After installing the HRS on the nine test farms, the COP ranged from 1.4 to 3.12, with an average of 2.16. These values fall within the ranges indicated by LUDINGTON et al. (2004) (1.6–2.91), MHUNDWA et al. (2017), and RAJANIEMI et al. (2017) (2.0). As stated above, faulty installations or deferred maintenance led to longer cooling times and thus also to poorer COP values.

The relationship between the electrical energy demand of the cooler and the COP values of the milk cooling process correlates very closely. Thus, the COP could simply be determined from the amount of milk produced and the power consumption of the cooler and used to monitor the equipment. The COP of the cooling process depends heavily on the temperature difference between the heat-emitting and heat-absorbing medium. Because the storage cylinder mainly contains cold water at the start of milk cooling, the cooler can dissipate the heat more easily via the heat exchanger in the cylinder than via the ambient air. The storage cylinder and boiler must be correctly dimensioned to ensure an adequate supply of cold water at the start of cooling.

In 2023, there were at least 17,000 dairy farms in Switzerland producing approximately 3.3 million tonnes of milk. Assuming an average energy saving of just under 13 Wh/kg_{milk} (27.45 to 14.46 Wh/kg_{milk}) for heating cleaning water with the aid of an HRS, this would amount to an annual energy saving of approximately 43 GWh of electricity across Switzerland as a whole. Broadly assuming that around one third of dairy farms have already installed an HRS, that still leaves a saving of around 28 GWh.

The results of this study demonstrate the efficiency of an HRS for milk cooling. In Switzerland, a funding programme for retrofitting an HRS to existing milk-cooling equipment was implemented by AgroCleanTech (Lindau, Schweiz, www.agrocleantech.ch). The results of this scheme showed that installation costs per unit ranged from EUR 5,000 to EUR 9,000 for annual milk yields of 150,000 to 500,000 kg. Based on electricity costs of 0.23 EUR/kWh, the resulting payback times were 5 to 7 years, which is consistent with our findings.

Conclusions

The study involving nine farms clearly shows that the installation of a heat recovery system (HRS) can reduce the electrical energy demand for heating cleaning water by 47% and the energy demand of the milk cooler by 14%. More rapid dissipation of heat from the cooler to the water led to a shorter cooling time, also making it easier to satisfy the quality requirements for milk cooling. Despite the wide variety of installations, all retrofitted heat recovery systems resulted in significant energy savings. Detailed analysis of the nine test farms showed that correct installation and timely maintenance of milk-cooling and water-heater equipment have a major impact on electrical energy demand. Farmers often neglect cleaning the condenser and checking the refrigerant level, as confirmed by different service technicians. It would be interesting to explore the reasons for these large differences in installations in a follow-up study. The significant differences confirm that the installation, operation and maintenance of these systems vary considerably and suggest that untapped potential for energy savings remains. Clearly, it pays to plan, install, operate and maintain systems diligently. This study shows that a heat recovery system can greatly improve the energy efficiency of farms so retrofitting one is worthwhile!

Milking and milk-cooling systems from well-known international companies such as Boumatic, DeLaval, Lemmer Fullwood, and GEA were installed on the test farms. As the installation instructions are mostly very similar internationally, the results of this study should readily transfer to other countries, as confirmed by comparisons with the literature. It is assumed that the high degree of variation between different systems will be replicated abroad, as the literature clearly shows.

References

- Corscadden, K.; Biggs, J.; Pradhanang, M. (2014): Energy Efficient Technology Selection for Dairy Farms: Milking Cooling and Electric Water Heating. *Applied Engineering in Agriculture*, pp. 375–382, <https://doi.org/10.13031/aea.30.10403>
- Cuthbertson, H. (2006): Hot water, energy and the milking centre. Ministry of Agriculture, Food and Rural Affairs, Ontario, Canada
- Dairy Farmers of Canada (2010): Canadian Quality Milk on-Farm Food Safety Programm. Reference Manual, Dairy Farmers of Canada, Ottawa, Canada
- Edens, W.C.; Pordesimo, L.O.; Wilhelm, L.R.; Burns, R.T. (2003): Energy Use Analysis of Major Milking Center Components at a Dairy Experiment Station. *Applied Engineering in Agriculture* 19(6), pp. 711–716, <https://doi.org/10.13031/2013.15659>
- Eide, M.H. (2002): Life cycle assessment (LCA) of industrial milk production. *The International Journal of Life Cycle Assessment* 7(2), <https://doi.org/10.1007/BF02978855>
- GIE Élevage Bretagne (2018): Réduire les consommations d'électricité des élevages laitiers Bretons. https://www.gie-elevages-bretagne.fr/admin/upload/8_PAGES_ECO_ENREGIE_LAIT_VF.pdf, accessed on 12 May 2025

- Godskesen, B.; Hauschild, M.; Rygaard, M.; Zambrano, K.; Albrechtsen, H.-J. (2012): Life cycle assessment of central softening of very hard drinking water. *Journal of environmental management* 105, pp. 83–89, <https://doi.org/10.1016/j.jenvman.2012.03.030>
- Harrington, L.; Aye, L.; Fuller, B. (2018): Impact of room temperature on energy consumption of household refrigerators: Lessons from analysis of field and laboratory data. *Applied Energy* 211, pp. 346–357, <https://doi.org/10.1016/j.apenergy.2017.11.060>
- Krauß, M.; Drastig, K.; Prochnow, A.; Rose-Meierhöfer, S.; Kraatz, S. (2016): Drinking and Cleaning Water Use in a Dairy Cow Barn. *Water* 8(7), pp. 302, <https://doi.org/10.3390/w8070302>
- Ludington, D.; Johnson, A.; Kowalski, J.; Mage, A.; Peterson, R. (2004): Dairy farm energy management guide: California. Rosemead, CA, USA, Southern California Edison
- Mhundwa, R.; Simon, M.; Tangwe, S. (2017): Comparative analysis of the coefficient of performance of an on-farm direct expansion bulk milk cooler. In: 2017 International Conference on the Industrial and Commercial Use of Energy (ICUE), 15–16 Aug 2017, Cape Town, South Africa, IEEE, pp. 1–7
- Murgia, L.; Todde, G.; Caria, M.; Pazzona, A. (2013): A partial life cycle assessment approach to evaluate the energy intensity and related greenhouse gas emission in dairy farms. *Journal of Agricultural Engineering* 44(2s), <https://doi.org/10.4081/jae.2013.279>
- Murphy, S.; Boor, K. (2019): Sources and Causes of High Bacteria Counts in Raw Milk: An Abbreviated Review. <https://dairy-cattle.extension.org/sources-and-causes-of-high-bacteria-counts-in-raw-milk-an-abbreviated-review/>, accessed on 12 May 2025
- Murphy, M.D.; Upton, J.; O'Mahony, M.J. (2013): Rapid milk cooling control with varying water and energy consumption. *Biosystems Engineering* 116(1), pp. 15–22, <https://doi.org/10.1016/j.biosystemseng.2013.05.007>
- Paludetti, L.F.; Kelly, A.L.; O'Brien, B.; Jordan, K.; Gleeson, D. (2018): The effect of different precooling rates and cold storage on milk microbiological quality and composition. *Journal of dairy science* 101(3), pp. 1921–1929, <https://doi.org/10.3168/jds.2017-13668>
- Parmar, P.; Lopez-Villalobos, N.; Tobin, J.T.; Murphy, E.; McDonagh, A.; Crowley, S.V.; Kelly, A.L.; Shalloo, L. (2020): The Effect of Compositional Changes Due to Seasonal Variation on Milk Density and the Determination of Season-Based Density Conversion Factors for Use in the Dairy Industry. *Foods* (Basel, Switzerland) 9(8), <https://doi.org/10.3390/foods9081004>
- Rajaniemi, M.; Jokiniemi, T.; Alakukku, L.; Ahokas, J. (2017): Electric energy consumption of milking process on some Finnish dairy farms. *Agricultural and Food Science* 26(3), <https://doi.org/10.23986/afsci.63275>
- Sanford, S. (2003): Heating Water on Dairy Farms. <https://learningstore.extension.wisc.edu/products/heating-water-on-dairy-farms-p143>, accessed on 12 May 2025
- Sapali, S.N.; Pise, S.M.; Pise, A.T.; Ghewade, D.V. (2014): Investigations of waste heat recovery from bulk milk cooler. *Case Studies in Thermal Engineering* 4, pp. 136–143, <https://doi.org/10.1016/j.csite.2014.09.003>
- Schweizerischer Landmaschinen-Verband (2019): Fachgruppe Hofeinrichtungen / Melktechnik. <https://slv-asma.ch/service-finder/fachgruppen>, accessed on 19 May 2025
- Shine, P.; Scully, T.; Upton, J.; Shalloo, L.; Murphy, M.D. (2018): Electricity & direct water consumption on Irish pasture based dairy farms: A statistical analysis. *Applied Energy* 210, pp. 529–537, <https://doi.org/10.1016/j.apenergy.2017.07.029>
- Shine, P.; Upton, J.; Sefeedpari, P.; Murphy, M.D. (2020): Energy Consumption on Dairy Farms: A Review of Monitoring, Prediction Modelling, and Analyses. *Energies* 13(5), p. 1288, <https://doi.org/10.3390/en13051288>
- Todde, G.; Murgia, L.; Caria, M.; Pazzona, A. (2018): A Comprehensive Energy Analysis and Related Carbon Footprint of Dairy Farms, Part 1: Direct Energy Requirements. *Energies* 11(2), p. 451, <https://doi.org/10.3390/en11020451>
- Upton, J.; Humphreys, J.; Groot Koerkamp, P.W.G.; French, P.; Dillon, P.; Boer, I.J.M. de (2013): Energy demand on dairy farms in Ireland. *Journal of dairy science* 96(10), pp. 6489–6498, <https://doi.org/10.3168/jds.2013-6874>
- Upton, J.; Murphy, M.; French, P.; Dillon, P. (2010): Dairy Farm Energy Consumption. <https://www.teagasc.ie/media/website/rural-economy/farm-management/DairyFarmEnergyConsumptionDairyConference2010.pdf>, accessed on 12 May 2025

van der Bruggen, B.; Goossens, H.; Everard, P.A.; Stengée, K.; Rogge, W. (2009): Cost-benefit analysis of central softening for production of drinking water. *Journal of environmental management* 91(2), pp. 541–549, <https://doi.org/10.1016/j.jenvman.2009.09.024>

Verordnung (EG) Nr. 853/2004 (2004): Verordnung (EG) Nr. 853/2004 des Europäischen Parlaments und des Rates vom 29. April 2004 mit spezifischen Hygienevorschriften für Lebensmittel tierischen Ursprungs, <http://data.europa.eu/eli/reg/2004/853/oj>, accessed on 12 May 2025

VHyMP (2005): Verordnung des EDI über die Hygiene bei der Milchproduktion (VHyMP). Eidgenössisches Departement des Innern, Bern, Schweiz

Authors

Dipl.-Ing. Markus Sax and **Dipl.-Biol. Annett Latsch** are research associates, and **Dr. Thomas Anken** is the deputy head of the Forschungsgruppe Nachhaltigkeitsbewertung und Agrarmanagement, Digitale Produktion bei Agroscope, Tänikon 1, CH-8356 Ettenhausen. E-Mail: markus.sax@agroscope.admin.ch