INDUSTRIAL HEAT PUMPS IN DAIRY INDUSTRIES IN SWEDEN - CURRENT STATUS AND OUTLOOK

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Abstract:
In this paper, a review of heat pumps use in the Swedish dairy sector is made. The impact on the energy consumption by introduction of heat pumps is made, and an outlook covers future potential and development needs to fully exploit the heat pump potential in the dairy industry. A case study exemplifies the potential energy savings that can be made in one dairy. Heat saving potentials in this case amounted to a total of 3400 MWh / year can be saved, corresponding to annual cost savings of 1.5 million SEK per year.

Key Words: heat pumping technologies, industry, dairy

1 INTRODUCTION

In this paper, a review of heat pumps use in the Swedish dairy sector is made. The impact on the energy consumption by introduction of heat pumps is made, and an outlook covers future potential and development needs to fully exploit the heat pump potential in the dairy industry. A case study exemplifies the potential energy savings that can be made in one dairy. Heat saving potentials in this case amounted to a total of 3400 MWh / year can be saved, corresponding to annual cost savings of 1.5 million SEK per year.

2 DESCRIPTION OF THE DAIRY INDUSTRY IN SWEDEN

The dairy sector in Sweden consists of 19 dairy companies with a total of 32 production sites. The total weighed milk in Sweden was 2,861,200 tons in 2012 [1]. The sector is dominated by ARLA, but also Norrmejerier and Skånemejerier have substantial production. The trend in the dairy sector is moving towards fewer and larger production sites in a high technology process industry fashion. Parallel to this, a number of small, specialized farm dairies exist, but their production, and associated energy use is very small in comparison to the large units. Production is divided into drinking milk and fermented milks, cheese, condensed milk and powder milk, and butters (Figure 1). The current trend in customer milk use is decreasing use of drinking milk and increased use of cheese. In 2012, the total energy use in the Swedish dairy processing industry was estimated at 725 GWh/yr [2]. since most of the energy use is allocated to heating or cooling of products, or intermediates, more efficient heat pumping technology could contribute to reducing the energy use.

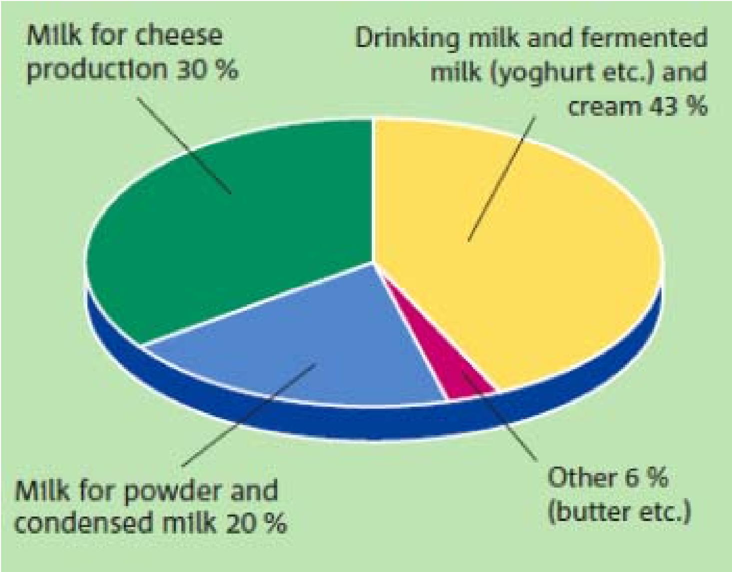

Figure 1. Production of dairy products in Sweden in 2012 [1].

3 HEAT PUMPS USED IN DAIRIES AT PRESENT

During 2012-2013, a project has been ongoing, mapping the energy use in a large number of dairies in Sweden. During this mapping, the current use of heat pumps has been investigated. Except for the use of heat pumps for the production of ice water for cooling (use of the cold side of the heat pump), the results show that most applications of heat pumps today is cascaded systems where the warm side of the ice water heat pump is used as a heat source for producing luke warm water for e.g. dishing purposes.

In the IEA HPP Annex 35 project, the Swedish contribution has been the project "Process integration study of heat pumps in the dairy process" which illustrated the potential to produce hot water for different hot water demands combined with satisfying the necessary cooling needs in the dairy process by using process integration techniques and heat pumping techniques. The project has significant novelty in that it combines the use of heat pumps and refrigeration technology in the dairy industry with process integration methods. Some results from this project are reported in section 5.Some other international projects have aimed in the same direction, e.g. [2,4].

Another project targeted the application of heat pumps in processing equipment under the umbrella of the national Effsys+ heat pump research programme. One example of a possible application is given in section 4.

4 POTENTIAL APPLICATIONS OF HEAT PUMPS

A typical dairy in Sweden might look like the one presented in **Figure 4**. Milk is weighed in, cooled to a proper storage temperature of around 2 °C. Then milk is pasteurized, cream is separated and sent to one more pasteurisation cell before filling, and milk is also filled. Some milk could be further processed to e.g. Fil or Yoghurt. In the pasteurisation process, regenerative heat exchangers are used, but also VTIS units are used in certain processes, e.g UHT processing of milk. For a more detailed description of the VTIS, please see []

Typical application areas of high temperature heat pumps in dairies include the use of low temperature excess heat from used dish water to produce fresh dish water of temperatures in the range of 75-91 °C, depending of the use sequence. For this purpose, the hot side of the ice water generating heat pumps could be used in cascade, as today, but with new types of heat pumps reaching the required temperatures. Another interesting use could be to produce steam for injection in VTIS units. Unfortunately, there is no knowledge today for the systematic introduction of refrigeration and heat pumps in new construction and retrofit, for example, dairy facilities. The process solutions that currently exist are based on specific solutions and have often arisen as ad hoc on individual occasions. The project aimed to develop general solutions and facts for the concept of processing solutions for high-quality foods that occur in the dairy industry, to thereby create credible argument for the increased use of heat pumps. Special attention was paid to more energy-efficient and cost-reducing solutions that can be achieved with new types of heat pumps that operate at high temperatures. The concept was evaluated from the perspectives of energy, production investment cost and product quality.

A list of at least two manufactures who have interesting products was identified, namely Kobe Steel [7] and SP Power [6]. There are several others with very interesting products, achieving temperatures of around 100 °C, but the two named manufacturers have commercially available products reaching well above this temperature.

The Kobe steel type is a R245fa based product with an integrated steam compressor, see **Figure 2**

Supply 0.2 to 0.8 MPaG steam , lifting up waste heat at 35 to 70dC.

Module Type	SGH 165
compressor	Semi Hermetic Inverter Twin Screw
refrigerant	mixture of HFC134a & HFC245fa
dimension	W 4400 mm x H 3180 mm x L 2810 mm
weight	7090 kg
performance : 0.6MPaG , source at 70 / 65 dC	
heating capacity	0.839 t/hr at 20 dC supply
power	253.9 kW
heating COP	2.5

Figure 2. Kobe steel type heat pump [7].

The SPPower type is quite different, it is a stirling engine type heat pump using helium as the heat transfer media.

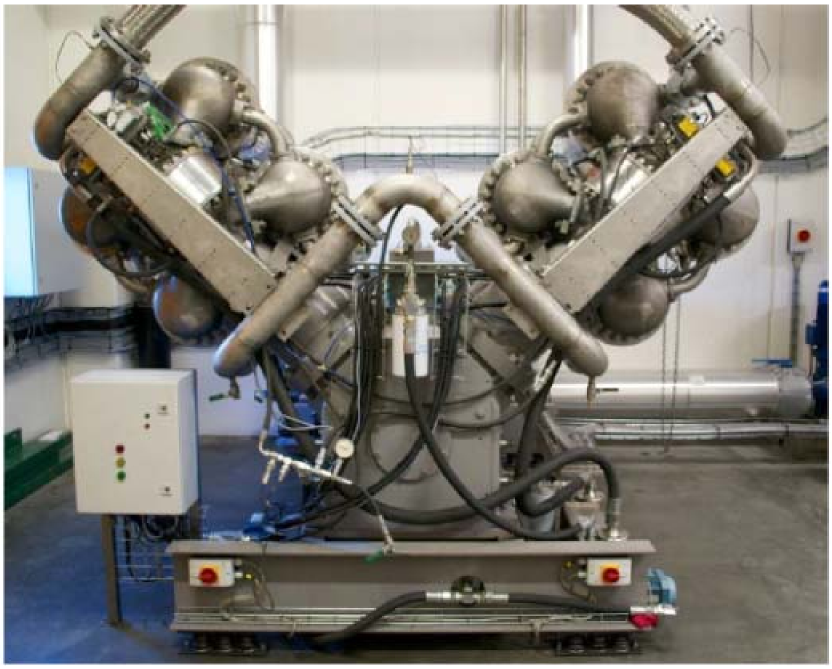

Figure 3. SPPower type heat pump.

Given the economic constraints used by leading manufacturers in the industry, the energy saving potential and cost efficiency of applying heat pumping technology in VTIS units was calculated. A rough estimate of potential savings has been made. It is then assumed that any heat pump has COP = 3. The adopted COP can be very different from what any real heat pump has for efficiency. It has been assumed there are no losses and that no start-up times to take into account. With an assumed operating time of 6300 hours per year, the cost savings range from 10 kEUR/yr to 610 kEUR/yr depending on which region is studied. The costs used are typical for four regions of the world. However, the assumed operational data of the heat pumps, and the installed prices needs to be studied in more detail in order to get a better precision of the result. At present, even if the cost savings could be considerable, the straight PBP is considered too long for the equipment manufacturer to be feasible.
As a result of the study, it was concluded that for better feasibility of industrial heat pumps in dairy processes, there is the need for the following developments:

- Better system integration, including buffer storage tanks,
- Lower investment cost, or new business models for heat pumps,
- Increased dissemination activities to inform plant managers about the possibilities of heat pumps.

The study has however raised the interest for heat pumping technology in the Swedish dairy industry.

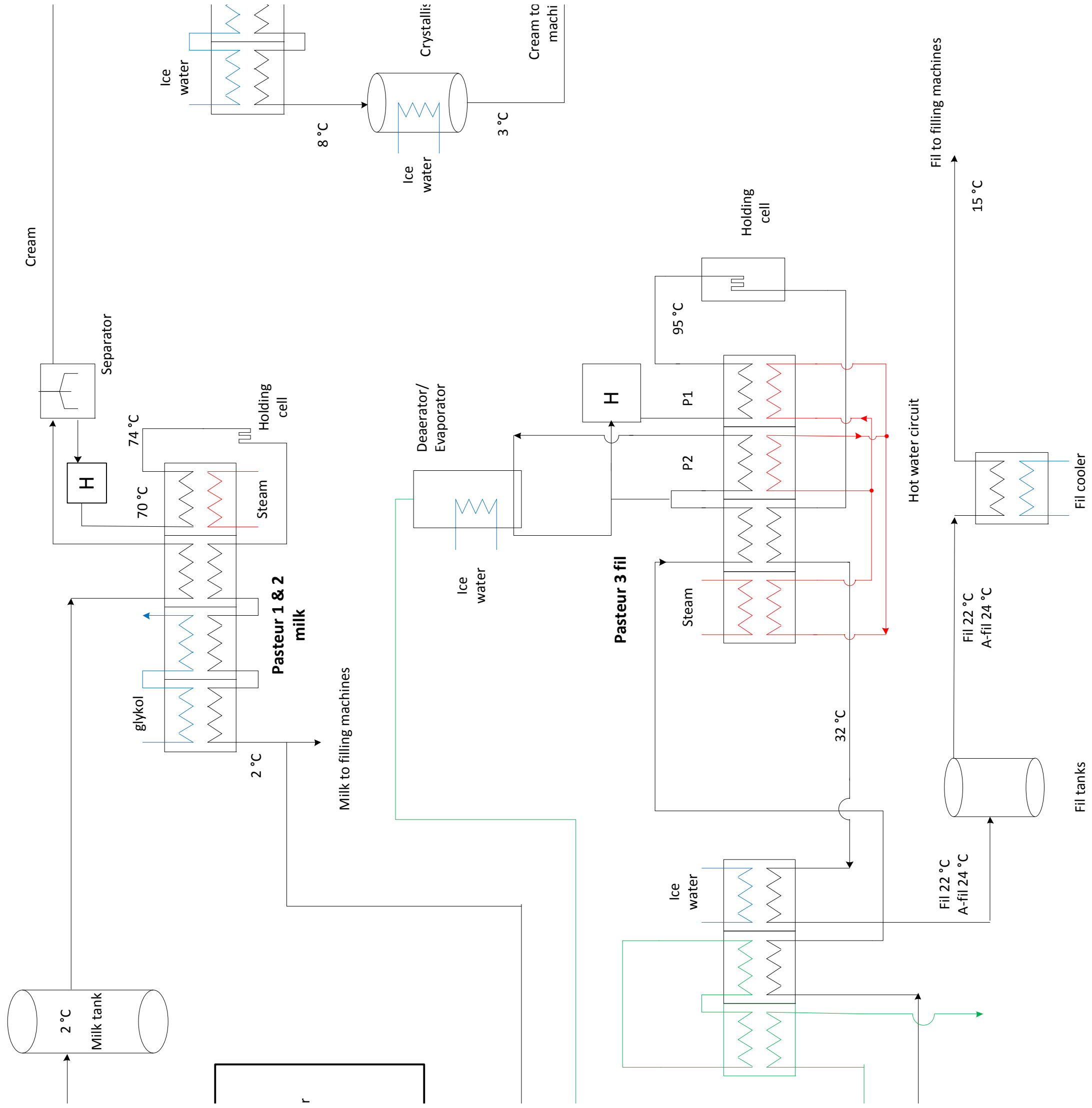

Figure 4. Typical process layout of a Swedish dairy. Fil is a product similar to yoghurt.

5 CASE STUDY

An analysis of opportunities for energy efficiency at the Arla dairy in Götene was made as part of the Sweden contribution to Annex 35 of IEA HPP []. In a first step, the energy data for the dairy was inventoried and compiled. This means how the heat demand and heat surplus in the dairy is distributed in temperature, size and time.
Based on the survey, the next step was to performa an energy efficiency study. This study was conducted with a process integration perspective where pinch analysis was used. This project mainly investigated the following possibilities:

- Heat exchange between product processes
- Heat exchange in the water system
- Heat Pump Solutions

These opportunities and others that emerged in the pinch analysis is the total outcome from the process integration study.
The dairy in Götene was founded in 1971 and produces, processes and stores dairy

products such as butter, cheese, and various kinds of spreads. Each year, 270,000 tons of milk is weighed into the plant, and is then processed.
We have applied the pinch analysis at Arla, Götene. One of the most important peculiarities of pinch analysis is that with the heat balances is possible to identify a temperature (pinch) of the process that divides the stream system in two parts, see Figure 5.

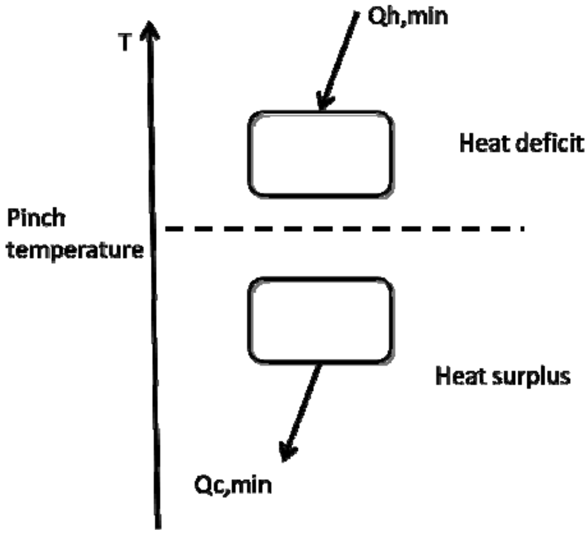

Figure 5. The pinch divides the process in two areas.

The following fundamental rules, which are schematically illustrated in Figure 6, can be set up:

- Do not cool any stream above pinch with external cooler. If that happens, then the equivalent amount of heat has to be added with an external heater.
- Do not heat any stream below pinch with an external heater. If that happens, then the equivalent amount of heat has to be dissipated by an external cooler.
- Do not transfer heat from a stream above the pinch to stream below the pinch, i.e. do not heat exchange streams above pinch with streams below pinch and vice versa.
  If so happens, the equivalent amount of heat that was exchanged must be added in an external heater above the pinch and cooled by an external cooler below the pinch.

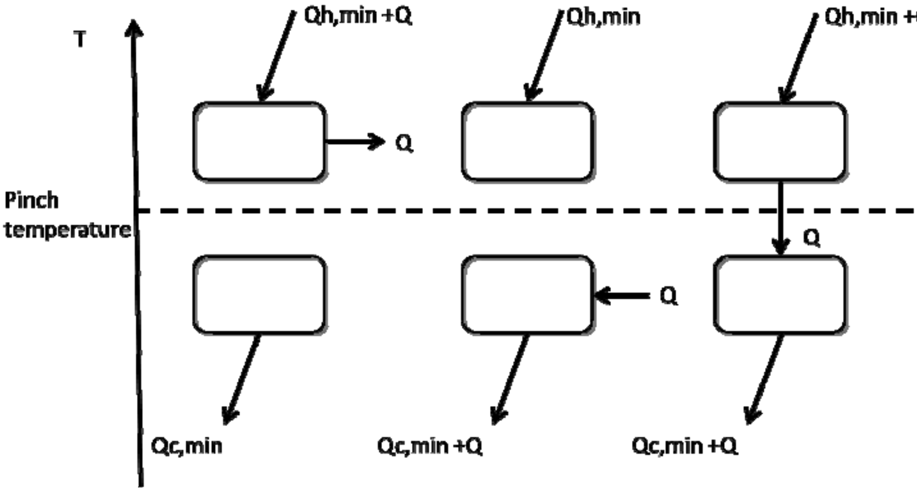

Figure 6. Visualization of pinch rules.

Working together with dairy staff, we identified and mapped the dairy's energy-using processes. Initially, a division of the production processes, dishing processes, water systems and chillers was made. Within each of these areas heating or cooling needs were identified through operational data and the time-schedule for production. Heat for heating and ventilation has only been briefly examined. A pinch analysis where both dishing processes and production processes are included were made for the factory based on average demands. Composite curves were also drawn up for each sub-process and dishing, and then analyzed for potential heat exchange opportunities or whether an existing utility can be replaced with another more low-grade utility, or excess heat. The energy efficiency measures that emerged from the analysis was proposed and discussed with Arla's dairy staff. The proposals should be viewed as rough estimates and as the basis for further investigation of possible measures.

Purchased steam in October 2010 was 2 856 MWh. Building heat demand represents about 385 MWh. The remaining amount, 2 471 MWh (process and arrays) corresponds to an external need of 3321 kW. Figure 7 shows that the minimum external heat demand for the studied process system is 2 614 kW and that its minimum cooling load is 3 068 kW (including chillers' condensers).

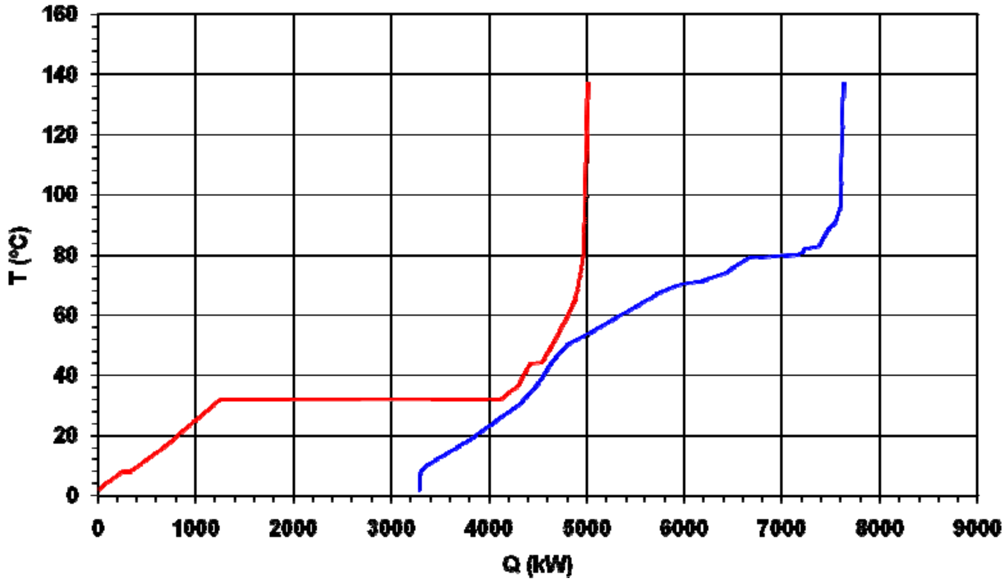

Figure 7. Composite curves for the whole dairy in October 2010.

Based on the Pinch analysis a list of possible improvement possibilities was presented to the dairy staff. It turned out that several of the possible heat exchange possibilities as found in the analysis had already been discussed, but rejected for various reasons. When constructing composite curves for chillers and dishing processes in isolation it can be seen that large amounts of excess heat is available at more than 30 ° C, and it comes mainly from the chillers condensers. The heat below 30 ° C is not so great, however, Figure 8 show that there is an external heat demand of about 2.5 MW at over 80 ° C.

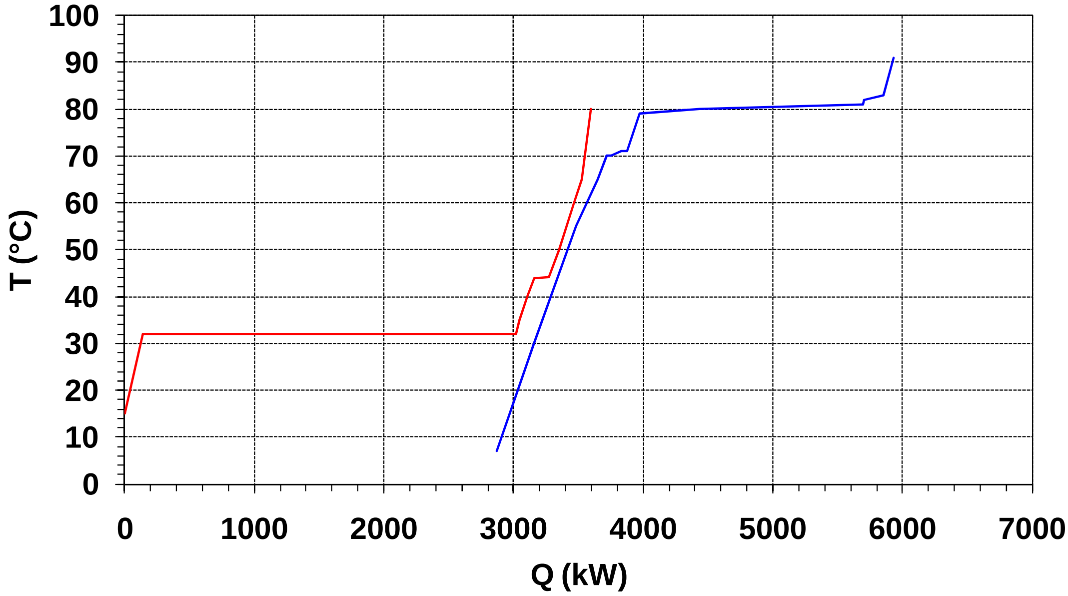

Figure 8. Composite curves for streams included in the washing process and chillers.

By using heat pumps, the condenser heat from ammonia condensers can be used as heat source for heat pumps producing hot dish water. This solution could save about 2 800 MWh of steam annually.

5.1 Requirements on heat pump with ammonia as refrigerant

The heat pump must use a heat source with a temperature of about 30 degrees, preferably higher if available. The cooling of the heat source is such that the ammonia evaporation temperature is 20 degrees C. Heat water is to be heated from 55 degrees to 80 degrees. The manufacturer of heat pumps gave us three options to study. These are shown in Figure 9. The difference between the three options is primarily the target temperature they can reach.

	Reach 80 degrees Option 1		Reach 85 degrees Option 2		Reach 90 degrees Option 3	
Heat source	399	kW	379	kW	477	kW
Heat capacity HP	580	kW	580	kW	712	kW
Operating time	6000	h	6000	h	6000	h
Annual heat supplied	3480	MWh	3480	MWh	4272	MWh
Price of steam	450	kr/MWh	450	kr/MWh	450	kr/MWh
HP electricity use	1088	MWh	1208	MWh	1410	MWh
Price of electricity	500	kr/MWh	500	kr/MWh	500	kr/MWh
Annual savings	1022	kSEK/yr	962	kSEK/yr	1217	kSEK/yr
COP VP	3,2	-	2,9	-	3,0	-
Investment cost HP	180 000	£	210 000	£	220 000	£
Investment cost HP	1,8	MSEK	2,1	MSEK	2,2	MSEK
Factor for civil engineering	2	-	2	-	2	-
Pound price	10	SEK/£	10	SEK/£	10	SEK/£
PBP	3,5	year	4,4	year	3,6	year

Figure 9. Evaluation of three heat pump options.

5.2 Auxiliary system for heat pump solution:

For the heat pump to have a stable and smooth operation, it may be necessary to have a collection tank for the heat source. This tank requires a volume of 34 m3 per hour which the tank should be able to buffer. A buffer capacity of four hours thus requires a tank volume of about 130 m3. The heating water to be stored at about 80 ° C requires a tank volume of 20 m3 per hour as this tank is to buffer. Four hours of buffering capacity thus requires approximately 80 m3 of tank volume. This solution also assumes that lukewarm water is separated into two temperature levels according to previous discussions, and that the temperature level of 55 ° C can deliver a flow of 5.5 kg / s

6 CONCLUSIONS

The projects has through a comprehensive analysis of the energy consumption in dairies observed:

- Case study: ARLA has by systematically working for a long time been working on the issue of energy efficiency , and many of the proposals for energy efficiency that has been identified have previously already identified by ARLA 's own staff , but many of these have fallen for process technical reasons.
- The opportunities to save energy by systematically working with hot water streams from the dishing equipment are significant. This is a general conclusion valid for a number of the studied dairies Solutions for how this could be implemented, and budgetary projections have been presented in the case study.
- The ability to replace a large amount of steam by integrating a heat pump for heating hot water to dishing equipment is also significant. Heat source can be chillers condensers. Proposal and budget calculations on this have been presented in the case study report.
- It is relatively difficult to make energy savings in dairy processes without making significant modifications to the process equipment. Such savings must be discussed with the equipment suppliers.
- Heat pumps have been relatively little used in the industry, and when used, they have mostly produced luke warm water instead of hot water.
- There is a growing interest for heat pumps in the industry, and technology is on the way that could significantly reduce the need for purchased steam.

7 ACKNOWLEDGEMENT

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