Application of Industrial Heat Pumps

IEA Industrial Energy-related Systems and Technologies Annex 13

IEA Heat Pump Programme Annex 35

Task 4:

Case Studies

Final Report

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Prepared by the

Participants of Annex 35/13

Contents

Appendix:

1 Summary

The participating countries itentify several realized projects and case studies in different application in which industrial heat pumps are used.

Industrial heat pump applications are rather seldom in **Austria** up to now, several applications in various industrial sectors have been identified during the IEA HPP - IETS Annex 35/13, as e.g.:

- Mechanical vapour recompression systems (MVR), e.g. in salt mining plants or in breweries
- Upgrading waste heat by compression heat pumps (CHP), e.g. in the metalworking industry
- Absorption heat pumping systems (AHP) for industrial refrigeration purposes driven by waste heat, e.g.in the food industry or in laboratories
- Gas-fired AHP for heating application of industrial buildings, e.g. in a brewery
- AHPs and CHPs for flue gas condensation in power plants in the wood working or energy supply industry
- HP systems in laundries.

Eight examples and one feasibility studies are described in detail.

Table 1-1: Overview of realized projects / factsheets in Austria

Industry	System	Thermal Capacity	Supply temperature	Effects
Food industry -meat	Closed compression	257 kW	55 °C	Reduction CO_2 emissions 75 %
Artificial Ice rink	Add-on closed compression	413 kW	60 °C	Reduction CO_2 emissions 75 %
Electronic manufacturing	Absorption and compression	n. a	n. a	Payback period 7.9 a
Brewery	Compression	370kW	77 °C	Payback period 5.7 a
Biomass cogeneration plant	Absorption	Ca. 7.5 MW	95 °C	Reduction CO_2 emissions 6,000 t/a
Freezer Warehouse	Cascade Compression	511 kW	n. a.	Payback period 5.4 a
Automotive production	Compression	2 x 146 kW	n. a.	Payback period 13.6 a
Multifunctional office building	Compression	3 x 693 kW	60 °C	Payback period 3.4 a
Process heating	Compression	Ca. 200 kW	n. a.	Payback period < 6 a

Canada's report focuses on low- and high-temperature heat pump applications in small- and medium-sized industrial manufacturing processes, not only for heat recovery, but also for heating industrial buildings, when possible. These include food and beverage plants because they use large amounts of primary energy, mostly for heating, via gas-fired boilers to produce hot water and cooling processing operations via electrically driven mechanical refrigeration devices. Because economic performance is greatly influenced by energy consumption efficiency, food plants are seeking ways to recover and reintroduce waste heat into various industrial processes.

Table 1-2: Overview of realized projects / factsheets in Canada

Industry	System	Thermal Capacity	Supply temperature	Effects
Food industry	CO_2 trans critical	Ca. 100 kW	75 °C	n. a.
Hospital	CO_2 trans critical	Ca. 100 kW	75 °C	n. a
Food industry	Compression NH_3	N.N.	Up to 93 °C	n. a.
Fish farm	Compression NH_3	190 kW	10 – 12 °C	Payback period 1.28 a
Wood drying Low temperature	Add-on closed compression	5.6 kW	n. a.	Reduction total energy costs by 21.5 %
Wood drying High temperature	Compression	2 x 65 kW	Up to 100 °C	Reduction total energy consumption up to 50 %
Poultry processing	Mechanical vapor recompression	N.N.	63 °C	Payback period 2.7 a
Cold warehouse	Mechanical vapor recompression	2 x 22.3 kW	70 °C	n. a.
Metallurgical plant – Cooling towers	Compression Water to water	17.6 MW	70 °C	n. a

Denmark reports about four realized projects see table below.

Table 1-3: Realized projects / factsheets in Denmark

Industry	System	Thermal Capacity	Supply temperature	Effects
Drying air for milk powder	Hybrid NH_3/CO_2	1.25 MW	Up to 85 °C	Payback period 1.5 a
District heating	Compression High pressure NH_3	4.0 MW	Up to 68 °C	Payback period 2.5 a
Heating of green houses	Compression High pressure NH_3	2.0 MW	Up to 90 °C	n. a.
Washing metal items	Closed compression	25 kW	60 °C	Payback period 2.5 a

France identifies 10 projects with industrial heat pumps, eight in the food industry and two for district heating.

Table 1-4: Overview of realized projects / factsheets in France

Industry	System	Thermal Capacity	Supply temperature	Effects
Food industry (8 projects)	Closed compression with NH_3	Up to 1.2 MW	65 °C	Payback period ~ 4 a

Heating network (2 projects)	compression	Up tp 6 MW	Up to 90 °C	Payback period ~ 4 a

German partners report about 24 realized projects and case studies. Mainly (18) of them are located in Germany and represents several applications/ industrial branches.

Table 1-5: Overview of realized projects / factsheets from Germany

Industry	System	Thermal Capacity	Supply temperature	Effects
Slaughter House	CO_2 trans critical	800 kW	90 °C	Reduction CO_2 emission 510 t/a
Cafeteria	CO_2 trans critical	52.7 kW	80 °C	Reduction CO_2 emission by ~50°%
Dairy	Compression High pressure NH_3	3.45 MW	Up to 73 °C	n. a.
Chocolate manufacturing	Closed compression	2 x 600 kW	60 °C	Reduction CO_2 emission 120 t/a
District heating	Compression High pressure NH_3	13 MW	90 °C	Reduction CO_2 emission 12,700 t/a
Surface Finishing		200 kW	90 °C	Payback period ~ 4 a
Prefabricated house manufacturing	Closed compression	180 kW	90 °C	Payback period < 5.5 a
Waste treatment	Gas absorption	500 kW	82 °C	Payback period 6.7 a
Automotive	Compression	1,683 kW	75 °C	n. a.
Coating Powder Production	Compression	240 kW	45 °C	Payback period 5 a
Production of plant and herb extracts	Compression	61.5 kW	50 °C	Payback period 10 a
Electronics	Compression	90 kW	70 °C	n. a.
Glass	Compression	64 kW	40 °C	n. a.
Mechanical engineering	Compression	20 kW	60 °C	Payback period 2 a
Wires production	Compression	220 kW	55 °C	Payback period 3.2 a
Sheet metals	Gas absorption	194 kW	60 °C	Payback period 4 a
Sheet metals	Compression	274 kW	60 °C	Payback period 6 a
Screw production	Compression	584 kW	Up to 58 °C	Payback period 2 a
Electroplating	Compression	143 kW	Up to 80 °C	Payback period < 4 a
Sheet metals	Compression	260 kW	65 °C	Payback period 3 a
Malt production	Compression	3,250 kW	35 °C	n. a.
Brewery	Compression	77 kW	55 °C	Payback period 6 a
Textile	Compression	137 kW	50 °C	n. a.
Stone and earths	Compression	110 kW	60 °C	Payback period 3.2 a

Japan has many industrial heat pumps in practical use. Among the many installed cases, here they focus on heat pump technologies of simultaneous production of heating and cooling, vapor recompression, high temperature heat production and agricultural use because they are growing in sales and also expected further growth in the future. 6 cases were picked out as typical examples of above mentioned prospective industrial heat pump technologies and their details, such as backgrounds of installation, system specifications and effects from economic and energy saving points of view, are explained. In total, about 29 case studies are reported in factsheets.

Table 1-6: Overview of realized projects / factsheets in Japan

Industry	System	Thermal Capacity	Supply temperature	Effects
Cheese production	Compression		75 °C	Power reduction
Freeze-dried food product manufacturing	CO_2 trans critical	92 kW	90 °C	Reduction CO_2 emissions and energy cost by 80 % and more
Noodle production	CO_2 trans critical	56 kW	90 °C	Reduction CO_2 emissions by 31 % and energy cost by 25 %
Noodle production	CO_2 trans critical	72 kW	90 °C	Payback period 8.2 a Reduction CO_2 emission by 43%
Chicken	CO_2 trans critical	80 kW	90 °C	Reduction CO_2 emissions by 65 % and energy cost by 88 %
Lettuce growing	Compression	4 x 28 kW (cooling capacity)	24 °C	Stable production
Brewery		111.6 kW	70 °C	Reduction of water supply energy by 18 %
Whisky and material alcohol	Vapor recompression (MVR, TVR)	4.2 t/h	n. a.	Reduction of primary energy consumption by 43 %
Paper making	CO_2 trans critical	40 kW	75 °C	Reduction CO_2 emissions by 50 % and energy cost by 42 %
Styrofoam molding	CO_2 trans critical	110 kW	90 °C	Reduction CO_2 emissions by 63 % and energy cost by 48 %
Pharmaceutical production	Compression	247 kW	45 °C	Reduction CO_2 emissions by 24 % and primary energy consumption by 24 %
Circuit breaker production	Compression	2 x 55.8 kW	65 °C	Reduction CO_2 emissions by 19 % and energy cost by 11 %
Transformer case production	CO_2 trans critical	110 kW	80 – 120 °C	Reduction CO_2 emissions by 19 % and energy cost by 12 %.
Automotive	Compression	566 kW	n. a.	Payback period 3 – 4 a Reduction CO_2 emissions by 47 % and energy cost by 63 %.
Automotive	Vapor recompression	300 kg/h	n. a.	Reduction CO_2 emissions by 79 % and primary energy consumption by 77 %
Automotive – Painting process	Compression	3,755 kW	n. a.	Reduction CO_2 emissions by 48 % and energy cost by 25 %.
Automotive – Washing process	Compression	8 x 45.3 kW 6 x 22.3 kW	65 °C	Reduction CO_2 emissions by 86 % and energy cost by 89 %
Greenhouse	Compression	6 x 18 kW	20 °C	Reduction CO_2 emissions by 63 % and primary energy consumption by 49 %

In the industrial sector, as a solution for energy saving, the number of heat pump installation and operation increases in **Korea**. They identify 10 representative heat pump installation and operation cases in industrial sector:

- Reduction in usage of steam for de-ionized (DI) water heating by installing a heat pump and heat exchanger
- Energy saving through installation of waste heat recovery heat pump
- District heating with a sewage heat source heat pump
- Heat which collects waste heat from a cooling system in an Internet Data Centre server room
- Energy saving through change from thermal vapour recompression (TVR) to mechanical vapour recompression (MVR)
- Steam generation through TVR and MVR
- MVR in a sugar refinery factory
- MVR in a reaction tower
- Reuse of waste steam to the process steam by TVR.

Over the past 20 years several feasibility studies and project realizations of heat pump projects have been performed in **The Netherlands**. These are evaluated in this study. Some of them are more than 20 years running and they are still in use.

Table 1-7: Extract of realized projects / factsheets in the Netherlands

Industry	**System**	**Thermal Capacity**	**Supply temperature**	**Effects**
Chemicals – Distillation of PP-splitter	Mechanical vapor compression	5.8 MW	n. a.	Payback period 2 a
Drying of potatoes	Compression	880 kW	70 °C	Payback period 4 a
Margarine production	Add on compression	1.4 MW	65 °C	Payback period 4 a
Brewery	Thermal vapor compression	n. a.	97 °C (?)	Payback period 2 - 3 a
Slaughterhouse	High pressure compression NH_3	440 kW	65 °C	Payback period 4 - 5a
Potato starch	Mechanical vapor compression	2.7 MW	n. a.	Reduction CO_2 emissions 10,092 t
Warehouse	Compression	252 kW	20 °C	Payback period < 5 a
Greenhouse Tomatoes	Compression	3 x 1.25 MW	42 - 50 °C	Reduction CO_2 emissions by 40 – 60 %

2 Introduction

Industrial heat pumps are a class of active heat-recovery equipment that allows the temperature of a waste-heat stream to be increased to a higher, more useful temperature. Consequently, heat pumps can facilitate energy savings when conventional passive-heat recovery is not possible.

The purpose of this case studies survey is to present good examples of heat-pump technology and its application in industrial processes in accordance with the definition of industrial heat pumps in Annex 35/13, "which are used for heat recovery and for heat upgrading or cooling/ refrigeration in industrial processes or for heating and cooling in industrial buildings".

The focus is on the most common applications, with guidelines for initial identification and evaluation of the opportunities being provided and as input to the market overview of software and calculation models of Task 2.

The most common industrial application of heat pumping is dehumidification drying of lumber. In this application, warm, humid exhaust air from a lumber-drying kiln is the heat source for a closed cycle mechanical heat pump that delivers heat to the incoming air. In addition to energy benefits, the lower operating temperature of heat-pumped kilns improves product quality; the heat pump removing VOCs (volatile organic compound) from the exhaust also provides an environmental benefit.

While lumber-drying applications are numerous, the size of the units is usually small in terms of the heat delivered. For example, 50 kW heat output would be considered a large application; however, industry is developing larger systems of 1.0 – 1.5 MW. Closed-cycle applications that are not for lumber drying range from 0.3 to 6 MW heat output, and typically heat streams, such as process liquids or air.

The most common large-heat-load application is vapour compression evaporation. In this application, evaporated vapour is compressed over a small pressure range and condensed to provide the energy to drive the evaporation process. Such systems deliver 6 MW to over 30 MW at a low cost.

Evaporators and flash-steam recovery systems frequently incorporate thermo-compression systems. For example, paper dryers commonly use thermo-compressors to recover flash steam from dryer condensate.

Absorption systems are commonly used in chilling applications as alternatives to mechanical chillers, rather than in heat pump applications.

3 Austria

Although industrial heat pump applications are rather seldom in Austria up to now, several applications in various industrial sectors have been identified during the IEA HPP - IETS Annex 35/13, as e.g.:

- Mechanical vapour recompression systems (MVR), e.g. in salt mining plants or in breweries
- Upgrading waste heat by compression heat pumps (CHP), e.g in the metalworking industry
- Absorption heat pumping systems (AHP) for industrial refrigeration purposes driven by waste heat, e.g.in the food industry or in laboratories
- Gas-fired AHP for heating application of industrial buildings, e.g. in a brewery
- AHPs and CHPs for flue gas condensation in power plants in the wood working or energy supply industry
- HP systems in laundries, etc.

In this report some selected realized plants (see chapter 3.1) as well as a feasibility study (see chapter 3.2) are described.

3.1 Examples of realized plants in Austria

This chapter gives a brief overview of selected heat pump applications of different types in the Austrian industry, as data were available:

- A closed compression heat pump in a meat industry plant for heating applications (see chapter 3.1.1)
- An add-on compression heat pump for a chiller of an artificial ice rink for heating application (see chapter 3.1.2),
- A combination of an electrical chiller and an absorption heat pump in an electronic factory for cooling purposes (see chapter 3.1.3)
- A closed compression heat pump in a brewery for heating applications (see chapter 0)
- An absorption heat pump in a biomass plant for heating applications (see chapter 3.1.5)
- A cascade compression heat pump for bi-generation purposes in freezer warehouse (see chapter 3.1.6)
- A compression heat pump for waste heat recovery in an automotive supplier plant (see chapter 3.1.7)
- A ground coupled heat pump for heating and cooling of a Multifunctional Office Building (see chapter 3.1.8)

3.1.1 Compression heat pump in a meat industry plant

Company	efef Fleischwaren GmbH (REWE Austria Fleischwaren GmbH)
Location	Schweizer Straße 75, 6845 Hohenems, Austria
Process application	Sausage manufacturing plant
Type of heat pump	Compression Heat Pump
Capacity	Heating Capacity ca. 257 kW
Reduction in CO_2 emission	75% (for the delivered heat by the HP)
Manufacturer/supplier	Cofely Kältetechnik GmbH
Pay back	No data available
More information/contact	Jürgen Furtner Cofely Kältetechnik GmbH, Langegasse 19, 6923 Lauterach; Österreich - Austria Tel.: +43-5574 6705-14, Fax: +43 5574 6705-22 Juergen.Furtner@cofely.info, www.cofely.info

Description of the plant

The meat factory efef Fleischwaren GmbH (REWE Austria Fleischwaren GmbH) supplying the retail and wholesale distribution in Austria, see Figure 3-1. Currently, around 150 people are employed. The crude products obtained from the slaughterhouse processed into finished products such as fresh meat, smoked or cured meats and packaged for retail sale. [Cofely, 2013]

Figure 3-1: Pictures of efef meat factory in Hohenems [efef, 2013]

1995/96 efef has expanded their location in Hohenems focusing in low energy consumption of their plant. Therefore an electrically driven compression heat pump has been considered for the usage of the waste heat from the central electrically driven chiller as well as other chillers and from the central air compressors for heating applications, as shown in Figure 3-2. This heat pump lifts up the temperature level of the waste heat at about 30 °C to an adequate level of about 55 °C for space, process and cleaning water heating. The heat pump consists of two separate condensers, one for space and process heating and the other one for cleaning water heating. Further also an adequate storage system for the maximum daily heat demand has been considered. About 100 m³ of cleaning hot water are required each working day and about 50 % of it is covered by the waste heat utilization and the other 50 % by a gas fired steam plant. [Cofely, 2013]

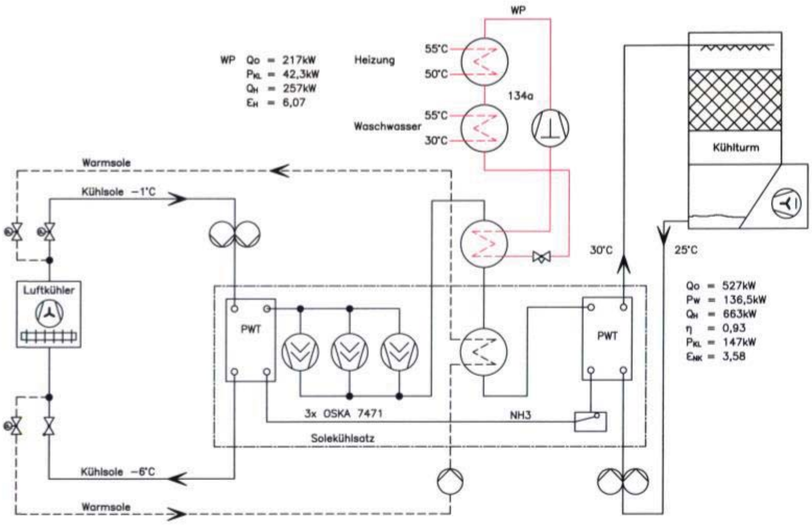

Figure 3-2: Process flow sheet of the heat pump including the waste heat sources at efef Hohen-ems in Austria [COFELY, 2012]

Specifications of heat pump [Cofely, 2012]

Description	Heat Pump	
Type	Single-stage R 134 a compression heat pump	
Heating capacity	Ca. 257 kW (ca. 55 °C)	
Cooling capacity	Ca. 217 kW (ca. 26 °C)	
Power consumption	Ca. 42 kW_{el}	
Heat source Description and temp	Waste heat from three air compressors and the condensation heat of one electrical chiller	Temp.: 26 °C
Heat sink Description and temp	Space heating and cleaning water	Temp.: 55 °C
Refrigerant	R-134 a	
Compressor type	Semi hermitical reciprocating compressor	
COP	Ca. 6.1	
Storage water tank	Yes	
Manufacturer of heat pump	COFELY GmbH	

Running experience, savings and economics

According to Cofely (2013) the customer is completely satisfied with the heat pump performance and operation.

3.1.2 Add On-Compression heat pump in a sports centre

Company	Eislaufbahn Gmunden www.sportzentrum.gmunden.at
Location	Fliegerschulweg 44, 4810 Gmunden– Austria
Process application	artificial ice rink
Type of heat pump	Add-on compression heat pump
Capacity	Heating capacity ca. 257 kW
Reduction in CO2 emission	75 %
Manufacturer/supplier	Cofely Kältetechnik GmbH
Pay back	No data available
More information/contact	Jürgen Furtner Cofely Kältetechnik GmbH, Langegasse 19, 6923 Lauterach; Österreich - Austria Tel.: +43-5574 6705-14, Fax: +43 5574 6705-22 Juergen.Furtner@cofely.info, www.cofely.info

Description of the plant

The sports centre of the city Gmunden in Austria also operates an artificial ice rink, as shown in Figure 3-3.

Figure 3-3: Pictures of ice rink in Gmunden [Gmunden, 2013]

As shown in Figure 3-4 waste heat from the ammonia (NH_3) chiller of the artificial ice rink can be used for heating application directly by an add on heat pump with a heating capacity of 413 kW or rejected to the ambient. The evaporating temperature level of the realized add-on heat pump is about 25 °C.

The heat sink of the add-on heat pump is a storage tank with a temperature level of about 60 °C, see Figure 3-4. The used NH_3 reciprocating compressor has a maximal electrical power consumption of 71 kW.

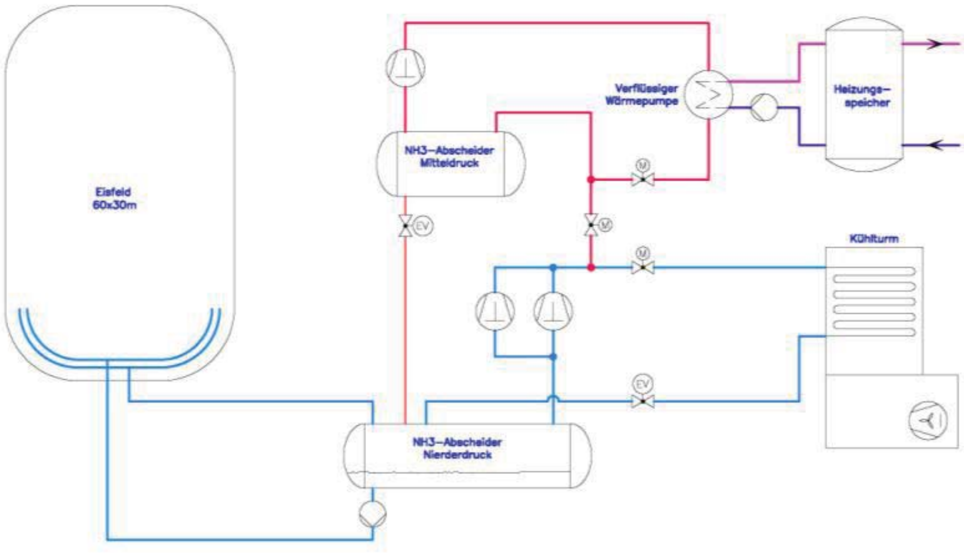

Figure 3-4: Process flow sheet of the add on heat pump of the chiller for the ice rink at Gmunden, Austria [COFELY, 2012]

Specifications of heat pump [Cofely, 2012]

Description	Add on heat Pump	
Type	Single-stage R 717 compression heat pump	
Heating capacity	Ca. 413 kW	
Evaporator capacity	Ca. 347 kW	
Power consumption	Ca. 71 kW_{el}	
Heat source Description and temp	Waste heat from an electrically driven chiller: Ammonia vapour from a middle pressure vessel	Temp.: ca. 25 °C
Heat sink Description and temp	Storage tank for space heating	Temp.: ca. 60 °C
Refrigerant	R-717	
Compressor type	Reciprocating compressor	
COP	Ca. 5.8	
Storage water tank	Yes	
Manufacturer of heat pump	COFELY GmbH	

3.1.3 Absorption and compression heat pump in an electronic factory

Project summary

Company	Seidel Elektronik www.seidel.at
Location	Frauentalerstr. 100, 8530 Deutschlandsberg– Austria
Process application	Electronic manufacturing factory
Type of heat pump	Absorption and compression Heat Pump
Running hours	No data available
Year of realization	2011
Primary energy savings (assumed)	168,627 kWh/a (40% of natural gas demand)
Manufacturer/supplier	- Frigopol - Yazaki
Pay back	7.9 a (calculated)
More information/contact	DI (FH) Karin Kölblinger sattler energie consulting GmbH Krottenseestr. 45, 4810 Gmunden, + 43 (0) 7312 / 73799 office@energie-consulting.at, www.energie-consulting.at

Description of the plant

SEIDEL Electronics is a manufacturer of custom-made solutions and an outsourcing partner for electronic and mechatronic products. Around 700 employees work in their locations in Austria, Hungary, Slovakia and Slovenia [Seidel, 2013]

At their factory in Deutschlandsberg in Austria (see Figure 3-5) with a production area of 7,200 m² approximately 350 people are employed. Also their R&D center for electronic and mechatronic assemblies manufacturing, as well as complete equipment installation and distribution are located there.

Figure 3-5: Seidel Elektronik in Deutschlandsberg (Seidel, 2013)

Initially the electrical energy consumption per year amounts about 450 MWh only for refrigeration purposes of the plant in Deutschlandsberg and about the same value of 460 MWh of natural Gas are required to cover the heating demand of this factory. In order to improve this situation besides several measures, like the electricity is only delivered by hydro power etc. a compression heat pump (see Figure 3-7) and an absorption chiller (see Figure 3-6) has been considered. The above mentioned compression heat pump is also used for process cooling in summer. The temperature level of the waste heat from the compressors amounts about 75 °C.

Figure 3-6: Absorption chiller at Seidel, Deutschlandsberb [klima:aktiv, 2011]

The waste heat from this heat pump as well as from the air compressors of the factory are used to drive the above mentioned absorption chiller for cooling purposes. For this a cold water storage tank is used.

Between summer and winter the heat pump is primarily used for heating, but surplus heat is used for driving the absorption chiller.

In winter the absorption chiller is out of operation and the required capacity for cooling processes is only delivered by the electrically driven heat pump and the waste heat is used for heating application.

Since the start-up of the operation of the heat pump and the absorption chiller the natural gas consumption is reduced by about 40 % [Seidel, 2012a] and according to Seidel [2012b] it was assumed that energy cost can be reduced by 16,000 to 18,000 € each year due to these applications. Comparable data are not available.

Seidel Electronic have a green vision, so they plan a CO_2–neutral production in Deutschlandsberg up to 2014 with further measures for a sustainable energy supply at their factory [Seidel, 2012b].

Figure 3-7: Compression heat pump at Seidel, Deutschlandsberb [klima:aktiv, 2011]

3.1.4 Compression heat pump in a brewery

Project summary

Company	Mohrenbrauerei August Huber Dr.-Waibel-Str. 2, 6850 Dornbirn, www.mohrenbrauerei.at
Location	Dornbirn – Austria
Process application	Brewery
Type of heat pump	Compression Heat Pump
Capacity	Heating Capacity ca. 370 kW
Year of realization	2012
Primary energy savings	1,426 MWh/a
Reduction in energy costs	64,067 EUR/a
Invest costs	365,000 EUR
Manufacturer/supplier	COFELY GmbH (WKÖ, 2012)
Pay back	5.7 a
More information/contact	Ralf Freitag Mohrenbrauerei August Huber Dr.-Waibel-Str. 2, 6850 Dornbirn, +43 (0) 5572 3777 leitung-produktion@mohrenbrauerei.at, www.mohrenbrauerei.at sattler energie consulting gmbh DI (FH) Martin Hinterndorfer Krottenseestr. 45, 4810 Gmunden, +43 (0) 7612 737 99 Martin.hinterndorfer@energie-consulting.at

Description of the plant

The Brewery Mohrenbrauerei is the oldest and most modern brewery in Vorarlberg, the most western province in Austria. Since 1834 the traditional company in Dornbirn is owned by the Huber family and produces approximately 218,000 hectoliters drinks per year. The product range includes beer, whiskey and lemonades. Further the Mohrenbrauerei also trades with wine, water, sodas and juices from Austrian and international manufacturers. [Klima:aktiv, 2012]

Figure 3-8: The Mohrenbrauerei in Dornbirn [klima:aktiv, 2012]

Energy efficiency and sustainability is still more than a mission for the Mohrenbrauerei. The management and the brewery's staff are involved in developing solutions and the implementation of energy efficiency measures. In recent years, optimizations in the areas of heating control, standby of PC devices and accessories and the air conditioning were already conducted. They also use alternative energy sources as electricity from solar panels. [Klima:aktiv, 2012]

Initially the brewery used gas fired steam plant with an annual natural gas consumption of 4,700 MWh/a and a boiler with an annual natural gas consumption of 900 MWh/a to cover the brewery's heating demand. [Klima:aktiv, 2012]

In order to improve this situation the Mohrenbrauerei decided to use the waste heat from their chillers with a high temperature heat pump for heating purposes instead of dissipating it to the ambient. This heat pump has a hating capacity of 370 kW and works with ammonia as refrigerant. The overall heat demand (space & process heating) is covered by this heat pump. Additionally, also water for the process water grid is heated up to 77 °C by the heat pump. [Klima:aktiv, 2012]

Figure 3-9: High temperature heat pump at Mohrenbrauerei in Dornbirn [klima:aktiv, 2012]

Figure 3-10: One of the heat storage tanks at Mohrenbrauerei in Dornbirn [klima:aktiv, 2012].

For a highly efficient use of waste heat additional heat storage tanks have been realized, one for the brew water and one for the heating grid, see Figure 3-10Figure 3-10. [Klima:aktiv, 2012)

With this application the Mohrenbrauerei saves 1,844 MWh/a of natural gas by consuming only 418 MWh/a of electrical energy for the heat pump operation, which means that the seasonal performance factor of this heat pump is quietly high [Klima:aktiv, 2012]

From an economical point of view it has to be mentioned that the payback time amounts less than 6 years. [Klima:aktiv, 2012]

Specifications of heat pump

Description	Heat Pump	
Type	Ammonia compression heat pump	
Heating capacity	370 KW	
Heat source Description and temp	Condenser waste heat from chillers	
Heat sink Description and temp	Space and brew water heating grid	Temp 77 °C
Refrigerant	Ammonia	
Storage water tank	Yes(two)	
Manufacturer of heat pump	COFELY Kältetechnik GmbH	

Running experience, savings and economics

Energy cost savings	64,067 EUR/a
Energy savings	1,426 MWh/a (18.3%)

3.1.5 Absorption heat pump for flue gas condensation in a biomass plant

Project summary

Company	Salzburg AG für Energie, Verkehr und Telekommunikation Bayerhamerstraße 16, 5020 Salzburg, Austria
Location	Salzachtalstraße 88, 5400 Hallein – Austria
Process application	Biomasse cogeneration plant
Type of heat pump	Absorption Heat Pump
Capacity	Heating Capacity ca. 7.5 MW
Running hours	Ca.7 500 $h_{operation}$/a (Ca. 6 200 $h_{FullLoad}$/a) Overall: ca. 37,000 $h_{operation}$ up to now
Year of operation	Since 09/2006
Primary energy savings	Ca. 15,849 MWh
Reduction in CO2 emission	6,000 tons/a
Manufacturer/supplier	INVEN Absorption GmbH
Pay back	According to Salzburg AG the application of the AHP is profitable
More information/contact	Dipl. Ing. (FH) Thomas Bergthaller Salzburg AG, Elisabethkai 52, 5020 Salzburg, Austria Tel. +43/662/8884-8862, Fax +43/662/8884-170-8862 thomas.bergthaller@salzburg-ag.at www.salzburg-ag.at

Description of the plant

Schweighofer Fibre GmbH in Hallein (Austria), see Figure 3-11, is a woodworking industrial company and part of the Austrian family enterprise Schweighofer Holzindustrie. Their core business is the production of high-quality cellulose and bioenergy from the raw material wood by an efficient and environmentally-friendly use. [Schweighofer, 2013]

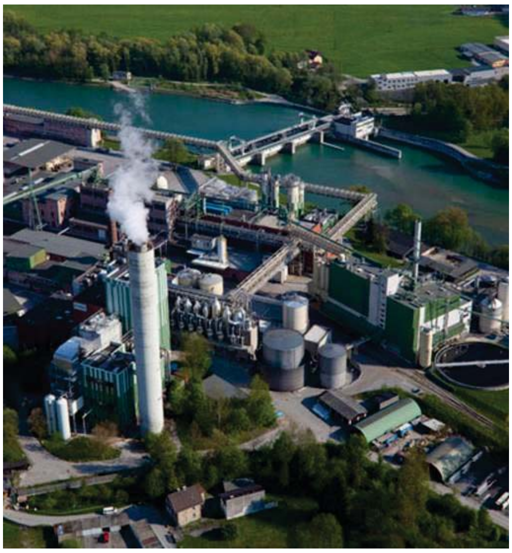

Figure 3-11: The Production Plant of Schweigerhofer Fibre GmBH in Hallein (Schweighofer, 2013)

A biomass power plant including a steam generator supplies the in-house steam grid and covers the company's energy demand at the site. The capacity of this cogeneration plant, which is fired by 77 % of external wood and 23 % of in-house remants, amounts to about 5 MW_{el} and 30 MW_{th}.

Beside the in-house power supply of Schweighofer Fibre GmbH the biomass plant also delivers electricity for about 15,000 households and heat for the local district heating grid.

The operator of this power plant in Hallein is the Salzburg AG (2013) which is a regional infrastructure provider of energy, transport and telecommunications. In 2006 an absorption heat pumping system (AHP) has been realized for the utilization of waste heat of the flue gas of the biomass power plant, shown in Figure 3-12.

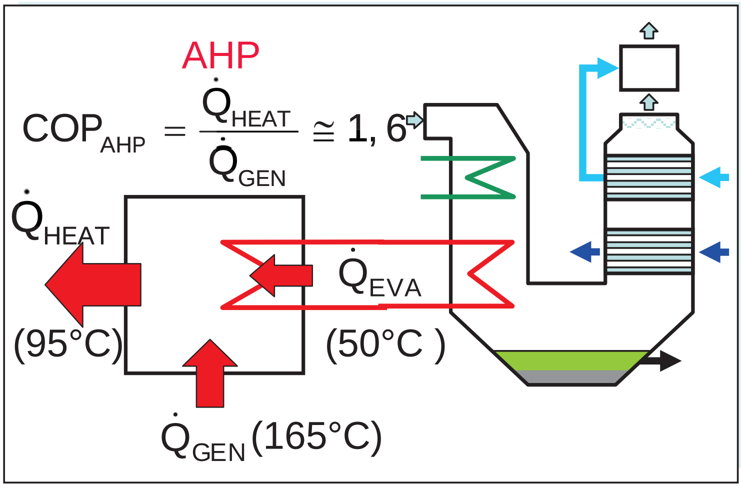

Figure 3-12: Process flow sheet of the flue gas condensation of the biomass plant in Hallein in Austria by using an absorption heat pump system (Rechberger, 2009)

The AHP offers the possibility to use the condensation heat of the flue gas by upgrading its temperature level, even thou the return flow temperature of the existing district heating grid is higher than the dew point temperature of the flue gas. At evaporating temperatures of the AHP lower than 50 °C the flue gas gets sub cooled below the dew point temperature. Hence, the temperature level of the condensation heat of the flue gas is lifted up to a useful level for the district heating. Otherwise, the condensation heat of the flue gas could not be used and would be dissipated to the ambient.

The applied AHP is a single-stage Water/LiBr absorption heat pump (Figure 3-13) with a solution heat exchanger (SHX) and a heating capacity of ca. 7.5 MW. The driving source of the AHP is steam from the biomass heating plant at ca. 165 °C. According to the existing monitoring system the AHP operates with a seasonal performance factor (SPF) of about 1.6. Due to the high efficiency and the high operating hours of the AHP this industrial heat pump application enables a significant fuel and emission reduction. Additionally to the ecological advantages this application offers an economical benefit for the operator of the plant.

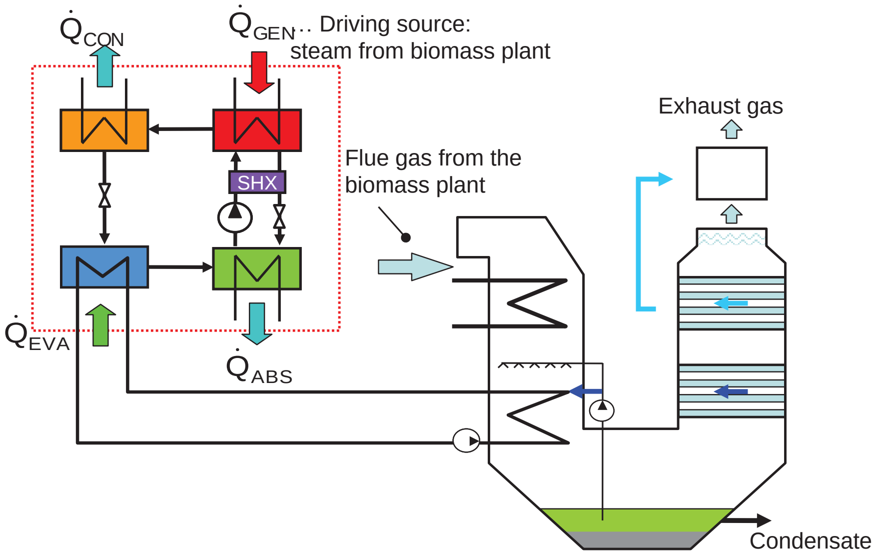

Figure 3-13: Process flow sheet of the absorption heat pump system for the flue gas condensation of the biomass plant in Hallein (Austria) (Rechberger, 2009)

Specifications of heat pump

Description	Heat Pump	
Type	Single-stage H_2O/LiBr - absorption heat pump	
Heating capacity	Ca. 7.5 MW (ca. 95 °C) at fullload	
Cooling capacity	Ca. 3.0 MW (ca. 50 °C) at fullload	
Power consumption	Ca. 4.5 MW_{th} (ca. 165 °C) at fullload Ca. 20 kW_{el} at fullload	
Heat source Description and temp	Flue gas	Temp.: 50 °C
Heat source Description and temp	Steam	Temp.: 165 °C
Heat sink Description and temp	District heating	Temp.: 95 °C
Refrigerant	Water	
Solvent	LiBr	
Compressor type	Absorption process (no compressor, one solution pump)	
COP_H	Ca. 1.6	
Operation hours	In total about 37,000 h and about 7,500 h per a	
Storage water tank	None	
Manufacturer of heat pump	INVEN Absorption GmbH	

Running experience, savings and economics

Energy cost savings	- Fuel cost - Cost for fuel storage - Cost for ash removal
Energy savings	- Ca. 15,000 MWh/a
Other savings	- Higher performance - Cost saving cause no vapour discharge system is required

Challenges and prospects

Potential	- Cogeneration plants
Other Possibilities of application	- Double-stage absorption heat pump systems - Compression heat pump systems for flue gas condensation
Application of heat pump solves process problems	- No vapour discharge system required
Application of heat pump increases the value chain	- Yes

3.1.6 Refrigeration plant and heat recovery optimization in a freezer warehouse

Project summary

Company	Daily Service Tiefkühllogistik GesmbH & Co KG Gewerbestr. 6, 4481 Asten www.daily.at
Location	Asten – Austria
Process application	Freezer warehouse
Type of heat pump	Compression Heat Pump
Year of realization	2011
energy savings	371,800 kWh/a
Reduction in energy costs	39,620 EUR/a
Invest cost	215,000 EUR
Pay back	5.4 a
More information/contact	Andreas Schilde Daily Service Tiefkühllogistik GesmbH & Co KG Gewerbestr. 6, 4481 Asten, +43 (0) 7224 67391, A.schilde@daily.at, www.daily.at sattler energie consulting gmbh DI (FH) Martin Hinterndorfer Krottenseestr. 45, 4810 Gmunden, +43 (0) 7612 737 99, Martin.hinterndorfer@energie-consulting.at

Description of the plant

Daily service is a commercial and non-proprietary logistics services company, providing the Austrian Market with frozen products. Achieving economic and environmental benefits to commercial and industrial customers is an essential element of corporate strategy. Since 2005 the company has improved its energy efficiency with different measures.

Figure 3-14: Daily Service Tiefkühllogistik GesmbH & Co KG in Asten [Klima:aktiv, 2012b]

In 2007 a new freezer warehouse with an efficient Ammoniak/CO_2 plant has been built. The waste heat from this cooling system is used for heating purposes. The consumption of electrical energy in 2010 is approximately 7,340 MWh/a and the heating demand 1,030 MWh/a. The Daily Services GmbH has four different cooling areas that need to be cooled around the clock. The cooling energy for the sorting hall and for the high bay warehouse is provided on the one hand by the NH_3/CO_2 cascade chiller and on the other hand by a R-22 refrigeration system. The consumption of the refrigeration systems for the adapted areas totals at approximately 3,870 MWh of electricity per year. Both refrigeration units are equipped with heat recovery, which decouple a total of heat of about 906,072 kWh/a. This heat is used for heating purposes in the administration buildings, workshops, offices and production. Additionally for the space heating about 119,923 kWh/a are required which are reheated by a direct electric heater. The defrosting of the evaporator of the R-22 system, which will be decommissioned, also requires approximately 7,045 kWh/a heat. The evaporators of the R-22 unit are defrosted electrically.

Figure 3-15: compression heat pump at Daily Service Tiefkühllogistik GesmbH & Co KG[klima:aktiv, 2012b]

The existing R-22 machine is relieved due to the poor COPs and shifts the load to the NH_3/CO_2 cascade as it is not operated at its capacity limits. Therefore two new evaporators are installed and at the same time four of the existing evaporators of the R-22-unit are shut down. Thus, the electric defrosting and the loss of refrigerant, which was created by the leaks in the old evaporators, will be avoided. By shifting the cooling operation from the R-22-unit to the NH_3/CO_2 cascade about 244 720 kWh/a electricity can be saved.

The new evaporator tare defrosted with waste heat and therefore no additional electrical power is required. The energy saving is amounts at approximately 7,045 kWh/a. The leakage losses of the unit and of the entire R22 system are reduced due to the migration from the R22 to the NH_3/CO_2 refrigeration system. The reduction of CO_2 emissions is approximately 227,300 kg/a (R-22 = 152 kg/a).

To recover the heat from the NH_3/CO_2 cascade a condenser with a capacity of 511 kW is installed. The heat demand of about 250,963 kWh per year can now be made fully available through this recovery due to a low temperature heating system. In addition also the operation of the old heat recovery and the backup heating with the direct electric heater are saved. Therefore the electric energy demand can be reduced by about 119,923 kWh / a. All savings apply only to electrical energy, as the current heat demand is covered from the heat recovery of the chillers.

Specifications of the NH_3/CO_2 – cascade compression heat pump [mycom, 2007a and 2007]

Description	Compression Heat Pump
Type	NH_3/CO_2 – cascade compression heat pump
CO_2-Cycle	
Cooling capacity	Ca. 305 kW_{th} (ca. -38 °C) at full load
Power consumption	Ca. 73.5 kW_{el} at full load
Refrigerant	R 744
Compressor type	C6HK
Swept Volume	193 m³/h
COP_C for refrigeration	Ca. 4.15
Manufacturer of compressor	Mycom
Speed	1,450 rpm
Condensing temperature	-5 °C
Evaporating temperature	-38 °C
Suction Pressure	1.08 MPa
Discharge Pressure	3.05 MPa
NH_3-Cycle	
Evaporator capacity	Ca. 410 kW (ca. -10 °C) at full load
Power consumption	Ca. 104 kW_{el} at full load
Refrigerant	R 717
Compressor type	Single stage screw compressor 13.6eMEE
Swept Volume	622 m³/h
COP_C for refrigeration	Ca. 3.94
Manufacturer of compressor	Mycom
Speed	2,950 rpm
Condensing temperature	35 °C
Evaporating temperature	-10 °C
Suction Pressure	0.29 MPa
Discharge Pressure	1.35 MPa

3.1.7 Optimization of cooling and heating supply in an automotive factory

Project summary

Company	Magna Auteca AG Elin-Süd-Straße 14, 8160 Krottendorf / Weiz, www.magna-auteca.com
Location	Krottendorf / Weiz – Austria
Process application	Automotive production
Type of heat pump	Compression Heat Pump
Capacity	app. 2 x 146 kW
Year of realization	2012
energy savings	444 100 kWh/a
Reduction in energy costs	21 360 EUR/a
Invest coste	290.000 EUR
Pay back	Ca. 13.6 a
More information/contact	Robert Schneider Magna Auteca AG Elin-Süd-Straße 14, 8160 Krottendorf / Weiz, +43 (0) 3172 / 5100-0, office.auteca@eu.magna.com, www.magna-auteca.com sattler energie consulting gmbh DI Peter Sattler Krottenseestraße 45, 4810 Gmunden, +43 (0) 7612 / 767 99-0, office@energie-consulting.at, www.energie-consulting.at

Description of the plant

Figure 3-16: Magna Auteca AG in Krottemdorf [Klima:aktiv, 2012c]

Magna Auteca Ltd. - an operation from the Magna-International-Group is the European market leader for mirror drive components. The production is located in Weiz with approximately 280 employees. The Magna Auteca AG produces annually about 18 million electric mirror drives and about 7 million electric Beiklapp drives for the Automotive industry.

The electric energy consumption in 2011 was approximately 4,635 MWh/a and the gas consumption approximately 691 MWh/a. The cooling system consists of two equally sized chillers (one chiller as redundancy), each with a maximum cooling capacity of 146 kW. These chillers operate with an average assumed COP of 2.5 – which means that they already run inefficiently. Around 45 % of the cooling demand is covered by the cooling towers. The electricity consumption for the cooling systems including cooling towers is about 88,500 kWh per year.

Figure 3-17: Cooling tower [klima:aktiv, 2012c]

Space heating is done by a natural gas fired boiler with a thermal capacity of 812-928 kW. This boiler is only used for space heating. The annual efficiency amounts to about 92 %. The major existing ventilation system has a nominal air flow of 60,000 m³/h and consists of a rotary heat exchanger, which recovers 70% of the exhaust heat. A second ventilation unit with a nominal air flow of 6,000 m³/h is currently supplied via a heating coil from the boiler. At an inlet air temperature of 21 °C the ventilation systems requires of about 457.400 kWh heat per year.

Currently four circulation pumps for cooling distribution are installed. 2 x P1 with 7.5 kW and 2 x P2 with 5.5 kW. The second pump is installed to get the redundancy. The consumption of the circulation pumps is about 75,500 kWh of electricity per year. The pumps for the cooling tower and for the transport of cold water to the buffer currently consume approximately 57,180 kWh of electricity per year.

The existing chillers are replaced by more efficient compression chillers. Additionally a new heat exchanger for heat recovery with free cooling function and frequency-control is equipped and a heat pump is purchased. The two new chillers have a nominal COP of 3.53 which is about 30% more efficient than the average COP of 2.5 of the existing chillers. The new Buffer tank, the new piping (including insulation) and the efficient pump station reduce the cooling demand by about 3% to 340,580 kWh/a. By the use of free cooling (COP 46) the new chiller only has to provide approximately 127,870 kWh of cooling per year, and is therefore less often in operation than before.

The waste heat from the chillers is used as heat source for the heat pump. The heat output at the higher temperature level can then be used for heating the supply air in the ventilation equipment. In the larger, existing ventilation equipment (air output 60,000 m³/h with rotary heat exchanger), a new heat recovery preheater is equipped and the heat from the heat pump can be used. In the second ventilation equipment (air capacity 6,000 m³/h) also the heat recovery preheater is supplied with heat from the heat pump.

Figure 3-18: high efficient pump [klima:aktiv, 2012c]

The actual amount of heat provided by the heat pump depends on the cooling operation and the heating demand. In total, about 260,360 kWh/a heat have been generated by the heat pump. The power consumption of the heat pump is approximately 70,080 kWh/a – based on the COP for heating (= 3.7).

The existing pumps are replaced by a highly efficient pressure rising facility. The new pumps are correctly designed on the basis of carried out demand measurements and are equipped with a frequency converter control. In the course of the renovation also the circulation pumps and pumps for the cooling tower and later free cooling will be replaced by new efficient pumps.

3.1.8 Ground Coupled Heat Pump Heating and Cooling System for a Multifunctional Office Building

Project summary

Company	STRABAG AG Donau-City-Straße 9, 1220 Wien www.strabag.at
Location	Vienna– Austria
Process application	multifunctional office building
Type of heat pump	Compression Heat Pump
Capacity	3x 693 kW
Year of realization	2003
Reduction in energy costs	80,700 EUR/a
Additional costs	273,700 EUR
Pay back	3.4 a
More information/contact	Andreas Zottl AIT Austrian Institute of Technology GmbH Giefinggasse 2, 1210 Vienna, Austria andreas.zottl@ait.ac.at http://www.ait.ac.at

Description of the plant

Figure 3-19: STRABAG HOUSE [Strabag, 2013]

The STRABAG HOUSE was constructed as a multifunctional office property. The 21,000 m² area of the 50 m high building is divided in 13 floors with about 18,000 m² office area and 3,000 m² for shops and commerce. The building is heated by floor convectors and cooled through micro perforated sheet-metal cooling ceilings.

Energy supply needed for heating and cooling is effected through a ground coupled heat pump system with an installed cooling capacity of 3*693 kW. The heat pumps are linked to a closed loop heat exchanger comprising of cast-in-situ driven piles integrated into the foundation. In total 68,000 m of PE-pipes were furnished partly in the foundation of the building and partly in 250 17m long cast-in-situ driven piles; the thermal energy is exchanged in 800 circuits. The system was designed in a way that the office and retail space require no additional power supply – apart from the electric power needed for the operation of the energy supply system.

For heating purpose the heat pump can be used on the primary circuit side to extract thermal energy from the ground via the foundation structures, which is then raised to a higher temperature level (heatingmode). In many cases the building can be cooled at virtually no cost through the direct use of the temperatures available in the ground. Here the heat transfer medium which circulates through the energy supply system is used directly for cooling purpose (free cooling mode).

If the underground temperatures do not allow free cooling, the installed heat pumps are used as refrigerator units and the ground is deployed as the heat sink for the heat pump system (cooling mode). The system was designed in a way that the office and retail space require no additional power supply – apart from the electric power needed for the operation of the energy supply system. Therefore the system operation can be distinguished into the four modes: heating, heating + free cooling, cooling + free cooling and cooling.

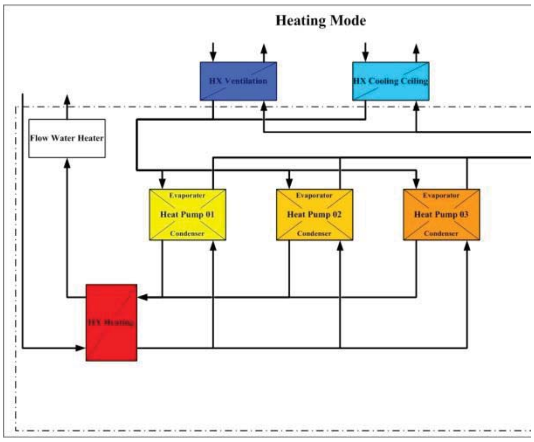

Figure 3-20: Schematic of heating mode [Presetschnik et al., 2005]

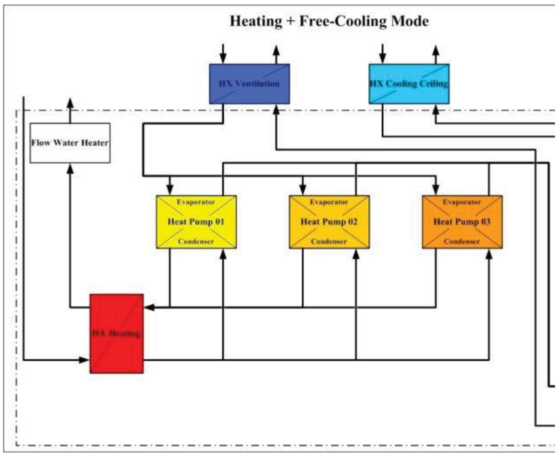

Figure 3-21: heating + free cooling mode [Presetschnik et al., 2005]

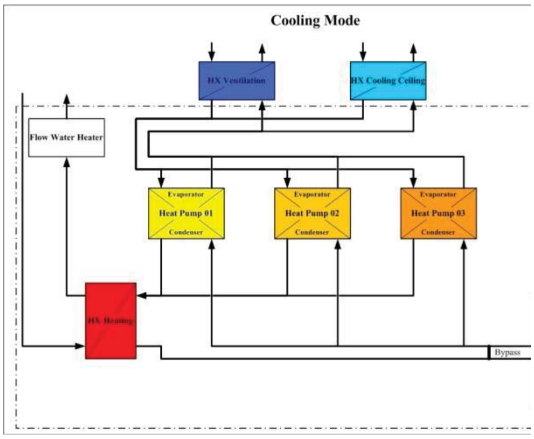

Figure 3-22: Schematic of cooling mode [Presetschnik et al., 2005]

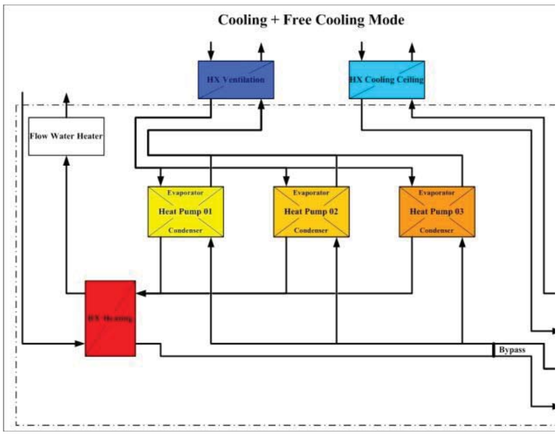

Figure 3-23: cooling + free cooling mode [Presetschnik et al., 2005]

Measurement Results

The monitoring of the energy supply system installed in the STRABAG HOUSE during the first two years of operation in the period 2003/2004 and 2004/2005 has shown that the system can accomplish the requirements with respect to the heating and cooling demand of the building. Less than one percent of the heating demand was supplied by the electric flow water heater.

Table 3-1: energy demand and SPF

	2004	2005	total	unit
Heating demand	2 700 849	2 991 357	5 692 206	kWh
Cooling demand	1 491 900	1 559 100	3 091 000	kWh
Electric energy	1 699 022	1 747 208	3 446 230	kWh
SPF	2.47	2.63	2.55	-

The results have shown a seasonal performance factor (SPF) of 2.55 for the total energy supply system in the first two years of operation. However the conditions especially during summer in a consequence of the final system adaptations have affected adversely the performance of the system. Do due adoptions of the control parameters the system shows a higher SPF in the second period of the monitoring.

The comparison of the system performance factors of the weekly evaluation shows that the system operations, depending on the average outdoor temperature for each calendar week, is a far more stable during the observation period 2004/2005.

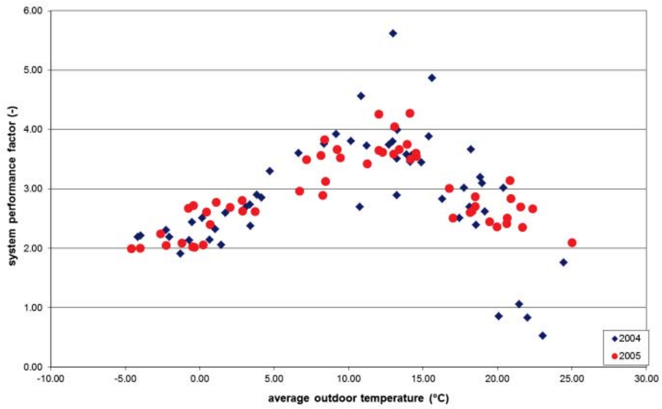

Figure 3-24: SPF comparison (Presetschnik et al., 2005)

Depending on the four different operating modes the system is operated with different efficiencies, the SPF of the total system is in a range between 2.26 and 6.55.

Table 3-2: SPF depending on operating mode

Operating mode	chiller	system
Heating	2.55	2.63
Cooling	2.58	2.26
Free-Cooling + cooling	1.81	7.81
Free-Cooling + heating	3.23	6.55

Less than two percent of the heating and cooling demand of the building was provided in the two free cooling modes. The utilisation of free cooling might be increased by the adaptation of the control set points of the energy supply system.

For future implementation of such a system it is recommended to decrease the flow temperature of the heating system to improve the performance of the energy supply system.

From an ecological point of view the installed system shows a favorable CO_2 balance compared to conventional heating and cooling systems based on natural gas, fuel oil or on the usage of district heating.

Building design criteria

application	space heating and cooling					
installed capacity	3 x 693 kW cooling capacity					
heat pump type	TRANE RTWB 222					
refrigerant	R 134a					
heat source	ground coupled system					
Details						
a) collector type	250 energy piles + 6,500 m^2 base plate					
b) energy pile length	17 m					
c) overall pipe length	68,000 m (800 parallel circuits)					
d) transfer medium	brine (antifreeze + water: -10°C)					
e) flow rate (m^3/h)	heating	90	chilled water	cooling	144	chilled water
		90	cold water		90	cold water
heating distribution system	heating	floor convectors	cooling	cooling ceilings		
supply temperatures (°C)	heating	outlet	55	cooling	outlet	15 / 7
		inlet	45		inlet	17 / 13
auxiliary heating	2 x 250 kW direct electric water heaters					

Technical data chiller

Type	water chiller, RTWB
machine size	222
cooling capacity	693 kW
electric power	172 kW
COP	4.03
refrigerant	R-134a
refrigeration cycle	2
refrigeration charge	2 x 74 kg
compressor type	screw-type compressor
number of compressors	2
evaporator type	tube bundle heat exchanger
cold water volume evaporator	560 litre
condenser type	flooded tube bundle heat exchanger
maximum water temperature	60 °C
minimum cold water temperature	-12 °C
maximum cold water temperature	15 °C

3.2 Feasibility study of an application in Austria

This chapter describes a possible but interesting application of an industrial heat pump in an Austrian metal working plant. Initially, a monitoring of the operation of the heat pump was planned and the documentation should be part of the Austrian contribution on the HPP Annex 35. But, unfortunately the heat pump has not been realized up to now, because the decision of the industrial company for or against the heat pump application is still outstanding due to internal reasons by the company.

3.2.1 Compression heat pump for waste heat recovery of a chiller in a metal-working plant

Project summary

Company	Umdasch Schopfitting (Former: Assmann Ladenbau GmbH) Ottokar Kernstock-Gasse 16 8430 Leibnitz
Location	Ottokar Kernstock-Gasse 16 8430 Leibnitz
Process application	Process heating
Type of heat pump	Compression Heat Pump
Capacity	Heating Capacity ca. 200 kW
Running hours	NOT REALISED YET Assumed ca. 4,000 $h_{FullLoad}$/a
Year of operation	NOT REALISED YET
Reduction in CO2 emission	Assumed 60 tons/a
Manufacturer/supplier	NOT REALISED YET
Pay back	< 6 a
More information/contact	Ing. Volker Vehovec T +43 3452 700 261 volker.vehovec@umdasch-shopfitting.com

Within the national R&D project “Promise Demo IF” (FFG-No: 825537), the possible integration of an industrial heat pump (IHP) in an Austrian metalworking industrial company has been investigated, which pointed out the big economical and ecological potential of industrial heat pump applications.

For this, a feasibility study for the utilization of the waste heat from an existing chiller by an IHP has been carried out. Also the energy efficiency and cost-effectiveness of the IHP has been analyzed to determine technical, ecological and economical criteria as a basis for the decision of the industrial company for or against the IHP application.

The possible application

The main objective of this project was to find an appropriate electrically driven IHP to increase the temperature of the condenser waste heat from an existing chiller at approximately 45 °C to 80 °C, to use it for the heat supply of the galvanic baths inside the industrial plant.

So far, the chiller is used to cool the welding plants inside the industrial plant. This compression chiller works uses R-22 as refrigerant and according to the supplier of the chiller, it has a nominal cooling capacity of 152 kW (see Table 3-3).

Table 3-3: Data of the chiller according to Fa. CLIMAVENTA [6]

Capacity of the Chiller WRAR 0702/B	in	Value
Nominal cooling capacity	kW	152
Cold water temperatures	°C	7 / 12
Max. electr. power consumption (@ambient temperature of 35°C)	kW	58
Max. possible heat capacity of the low temperature waste heat recovery	kW	208
Cooling water temperatures of the low temperature waste heat recovery	°C	45 / 40

The chiller (see Figure 3-25) exists of two parallel refrigerant cycles with one common evaporator and a heat exchanger in each cycle to recover low temperature waste heat from the chiller at approximately 45 °C, which was already used for the heat supply of a low temperature galvanic bath inside the company.

An analyses - by measuring the thermal and electrical energy flows from and to the chiller as well as the temperature levels of the internal and the external cycles, see Figure 3-25Figure 3-25 - has been carried out in order to identify the temporally available capacity and temperature of the useable waste heat of the chiller.

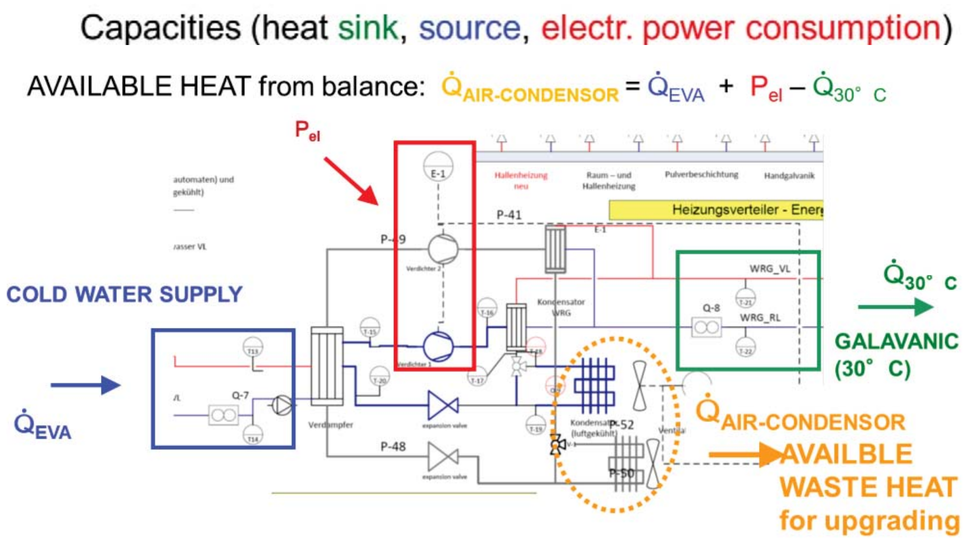

Figure 3-25: Schematic view of the existing chiller (Rieberer & Zotter, 2012)

The measurement showed that in average a waste heat capacity of ca. 70 kW at a temperature level of 40 °C is available at a usual utilization of the chiller. Reasons for this are a high part load rate of the chiller (even at full utilization of the welding plants) and that a share of the waste heat is already used to heat the low temperature galvanic bath.

Besides the availability of heat source also the "availability" of the heat sink has a major influence on the utilization of the IHP, because demand and supply have to fit together.

Primarily, the IHP should be used to supply process heat to the galvanic baths. Further investigations regarding the best integration of the IHP into the existing heating grid show that the primary return of the heating system should be used as a heat sink for the IHP. The main reason for this is that the average heating demand of the primary heating cycle is much higher than the heat capacity of the IHP and due to this fact all the available waste heat can be used by the IHP for the heat supply inside the industrial plant without any additional storage.

Based on this data and the statistical records of the operating hours of the chiller the expectable full-load hours of the IHP have been extrapolated at 4.000 h per a.

Theoretical analysis

Several HP systems with different refrigerants have been investigated for this application. Major thermodynamic properties for choosing a refrigerant as the volumetric cooling capacity, the level of high and low pressure, the discharge temperature of the compressor as well as the global warming potential (GWP) of the fluid itself has been compared to each. Furthermore, also the expected efficiency have been determined by calculating the COP for the given temperature levels.

According to Table 3-3, the highest COPs have been calculated for ammonia (R717) and water (R718). Both of them are natural refrigerants (GWP = 0). However, water has a very low volumetric cooling capacity and therefore it is not appropriate for this application. When using ammonia, its toxicity and flammability have to be taken into account.

R-245fa (Pentafluorpropane) is a high-temperature refrigerant and its saturation pressure allows high condensing temperatures. However, it has low volumetric cooling capacity and there are no “standardized” heat pumps with this refrigerant available on the market so far.

R-600a (Isobutane) has very low GWP und is promising for high-temperature applications due to its thermodynamic properties. The biggest withdrawal for its usage is its high flammability.

R-134a (Tetrafluorethane) is a conventional refrigerant for condensing temperatures below 85 °C. It is not flammable and not toxicity. However, when using this refrigerant its high GWP has to be taken into account.

A hybrid heat pump (compression/absorption HP) working with the mixture ammonia-water suits at high-temperature applications due to the fact that the high-side pressure of the process can be varied by changing the ammonia concentration in the sorption cycle. However, no standardized heat pump suitable for this application is available on the market yet.

Table 3-4: Comparison of different HPs and refrigerants

Scheme	Refrigerant	COP_H	p_{SAT} (80°C)	GWP	Toxicity	Flammable
		[-]	[bar]	[kg_{CO2-eq}/kg]	[-]	[-]
Cascade	R-134a	3.8	27.5	1300	No	No
Add-on	R-134a	4.6	27.5	1300	No	No
Cascade	R-245fa	4.2	8.3	950	Low	No
Cascade	R-600a	4.0	13.8	3		Yes
Cascade	R-717	4.3	43	0	Yes	Yes
Cascade	R-718	4.4	0.5	0	No	No
Cascade	NH_3-H_2O (Hybrid-HP)	3.8	Variable	0	Yes	yes

Manufacturer

Different manufacturers have been contacted concerning an offer for the heat pump. But only the Austrian supplier Cofely offered possibly plants for this application, a closed and an add-on heat pump. Two schemes of the heat pump integration were studied: Add-On HP and cascade HP (see Figure 3-26). As the refrigerant, R-134a was suggested.

According to Cofely their add-on HP would achieve a COP of approximately 4 and the closed compression HP approximately 3.5. The reason for this is that the available temperature level of the heat source is better utilized by the add-on HP than by a closed HP. However, the installation of the add-on HP would requires the substitution of the existing refrigerant R-22 by R-134a, which leads to a reduction of the cooling capacity of the chiller on about 30 %. Furthermore, the installation of the Add-On HP is a challenge from the technical point of view, as avoiding oil carry-over and more complex control system. Additional, also the investment costs of the add-on HP are higher than for the closed one.

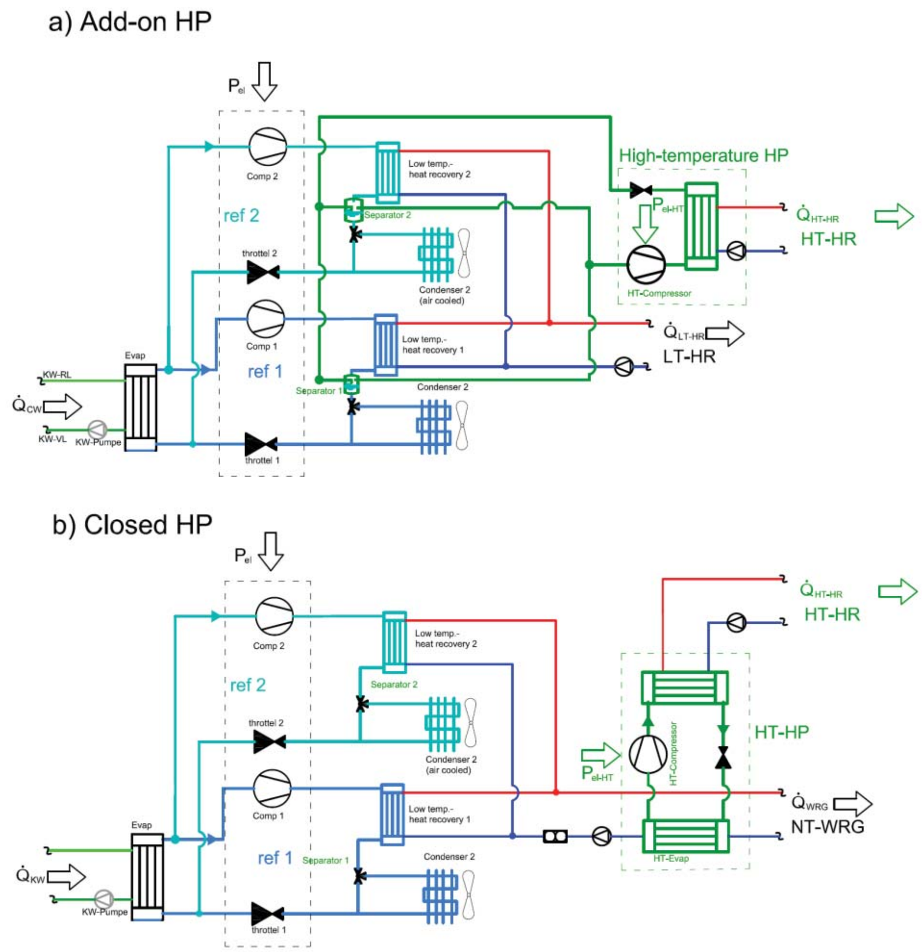

Figure 3-26: Investigated types of the heat pump (R-134a) integration: add-On HP (a) and closed HP (b)

Technical analysis

Taking these facts into account the closed R-134a HP will be preferred for the waste heat utilization. Figure 3-26(b) shows that the evaporator of the cascade HP is installed in the return pipe of the primary water circuit of the existing boiler, and not in the supply pipe, because of following reasons:

- If there is no demand on high-temperature heat, the waste heat of the R-22 chiller can be utilized by the low-temperature heat recovery system and/or rejected to the ambient by the existing air-condenser.
- The existing heat exchanger installed in the return flow of the low-temperature heat recovery system has a heating capacity of about 208 kW and is big enough to be used for both low-temperature and high temperature heat recovery.
- The R-22 chiller could be in operation without any constructional changes up to the substitution of the existing refrigerant (additional cost savings).

Economical and ecological analysis

Based on the offer of Cofely, the analysis of the cost-effectiveness of the cascade HP was carried out and it showed that the pay-back period is less than 6 years using static calculation and less than 7 years using dynamic calculation. Figure 3-27 shows the sensitivity analysis of the static pay-back period. It can be seen, that it depends strongly on the future gas and electricity prices, as well as on the SPF.

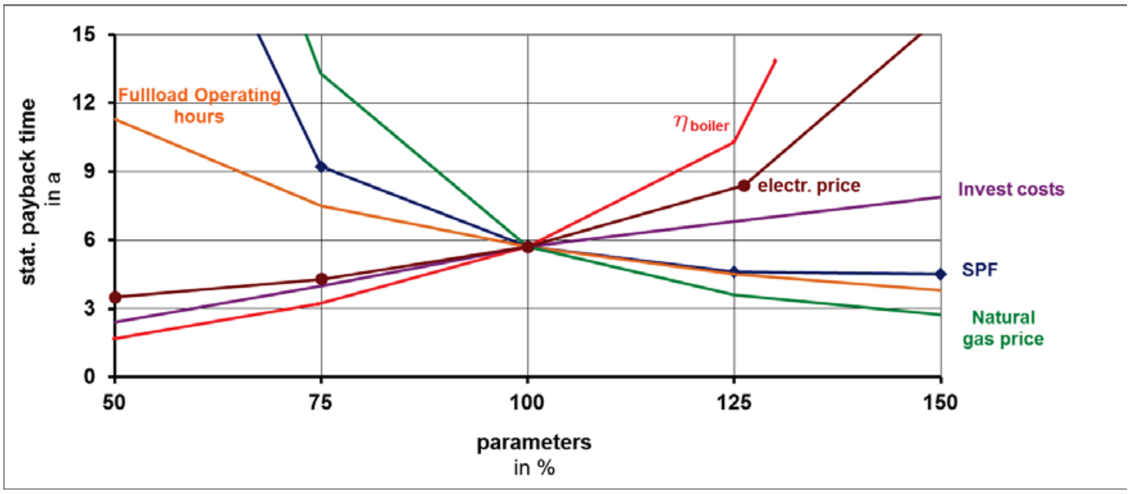

Figure 3-27: Sensitivity analysis of the pay-back period

Beside the economic benefit it has to be mentioned that this installation of the IHP allows a reduction of the CO_2-emmisions by approximately 60 tons per year compared to the existing gas boilers, which is a relative reduction of about 60 %.

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4 Canada

4.1 Introduction

Heat pumps contribute to global energy conservation and industrial productivity improvement, as well as to the reduction of greenhouse gas emissions. They are most cost effective in countries with low electrical energy prices compared to fossil fuel costs. This is not the case in Canada where industrial heat pumps have to be implemented in a context where prices of almost all primary energies (electricity, natural gas, oil) are relatively low and where *technical* (efficient use of heat generated and unreliable devices) and *legal* (lack of public or private incentives) issues are still barriers to the widespread application of IHPs. As a consequence, most Canadian companies are investing to improve production efficiency rather than reducing their specific energy consumption. However, there are promising industrial heat pump applications in Canada because large amounts of waste heat are available, especially from lumber dryers, liquid process effluents (24.2 %), process gases (12.7 % of total waste heat), refrigeration plants, cooling towers, evaporation processes, etc.

Prior to 1995, several hundred industrial heat pumps were developed and implemented in Canada, especially in the lumber drying sector, and also in the food industry, including dairies, poultry, sugar refining, breweries, liquor production and fish processing. For example, in 1993, 17 % of 14 investigated processes in more than 1900 individual plants were using industrial heat pumps based on the closed-vapour compression cycle, more than 90 % of which were used for lumber drying [Annex 9, 1990].

At the end of 2010, in 339 plants surveyed in Québec (Eastern Canada), Ontario and Manitoba (Central Canada), and British Columbia (Western Canada), 31 % of existing industrial heat pumps (26) were used for drying, 27 % for waste heat recovery, and 8% for evaporation processes with cooling capacities varying between 14 and 1050 kW. The future market penetration rate of IHPs in Canada is estimated at 5 % per year until 2030, ~ 80% of which could be closed vapour compression cycles and ~ 20 % mechanical vapour recompression systems [Minea, 2010].

Task 4 of the IEA Annex 35-13 project focuses on *operating experiences and energy effects* of representative in-country IHP implementations. According to the Annex legal text, successful case studies have to be presented along with an analysis of operating data, when available [Annex 35, 2010].

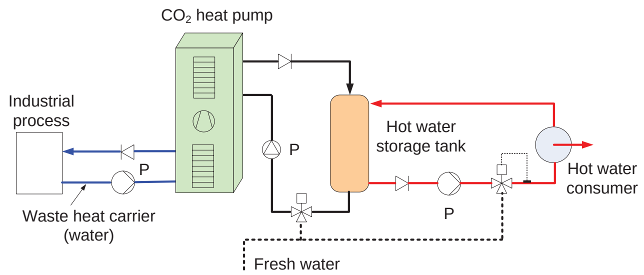
Canada's Task 4 country report focuses on low- and high-temperature heat pump applications in small- and medium-sized industrial manufacturing processes, not only for heat recovery, but also for heating industrial buildings, when possible. These include food and beverage plants because they use large amounts of primary energy, mostly for heating, via gas-fired boilers to produce hot water and cooling processing operations via electrically driven mechanical refrigeration devices. Because economic performance is greatly influenced by energy consumption efficiency, food plants are seeking ways to recover and reintroduce waste heat into various industrial processes.

In this context, the heat pump technology could be used extensively to recover heat from relatively low-temperature sources and bring it to higher temperatures, or recover *latent heat* from hot and humid air streams. Frequently, in order to increase the overall efficiency of such systems, heat exchangers and heat pumps are used together in two or multiple stage heat recovery configurations.

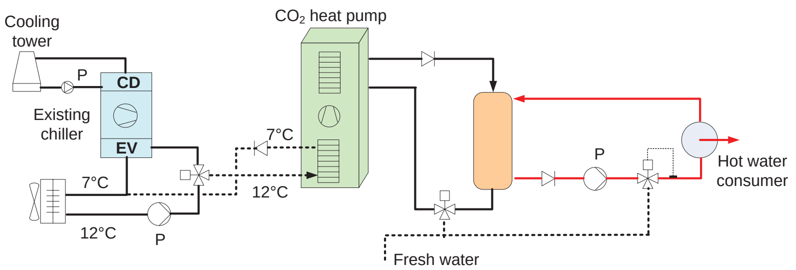
4.2 CO_2 trans-critical heat pumps

4.2.1 General

Many implementation options exist for CO_2 trans-critical heat pumps, several of them being recommended by the manufacturers themselves. For example, Figure 4.1a presents the implementation principle of CO_2 industrial heat pumps for recovering heat from liquid waste effluents [Mycom], and Figure 4.1b shows a typical heat recovery example from large industrial or commercial building air-conditioning systems. Figure 4.2a shows a system used to recover heat from groundwater in order to heat water for domestic purposes and/or industrial processes. In the case of cooling systems, including ice cold storage, it is also possible to recover heat to produce process hot water (Figure 4.2b). Also, CO_2 sub- or trans-critical heat pumps could be used for recovering heat in fish farming facilities (Figure 4.3a) and in pasteurization processes (Figure 4.3b) [Mycom]. Even if the number of CO_2 heat pump industrial applications is practically unlimited, each particular application needs a careful study prior to its implementation.



(a)



(b)

Figure 4-1: Industrial heat recovery with CO2 heat pumps; (a) from process waste heat; (b) from building air-conditioning systems [Mycom]

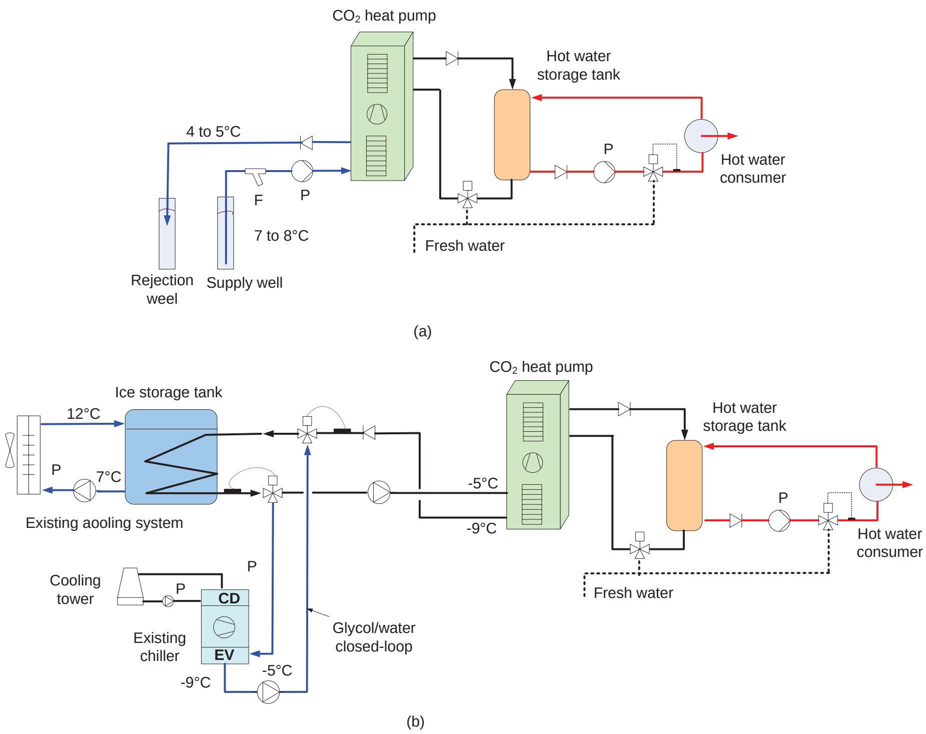


Figure 4-2: Industrial heat recovery with CO_2 heat pumps; (a) from groundwater; (b) from cold (ice) storage systems [Mycom]

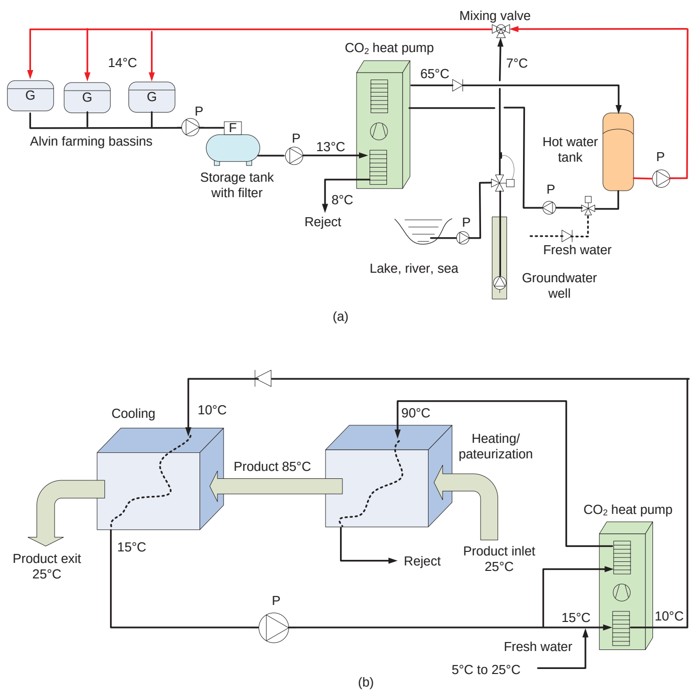


Figure 4-3:Industrial heat recovery with CO2 heat pumps; (a) in fish farming facilities; (b) in pasteurization processes [Mycom]

4.2.2 Food industry

Figure 4.4 schematically presents a CO_2 super-critical industrial heat pump recently implemented in a Canadian dairy plant [5, 6]. It is a 25 kW (compressor nominal power input) CO_2 trans-critical heat pump able to supply up to 100 kW of thermal power. The unit, adapted to the plant's actual process thermal conditions, provides hot water at temperatures varying between 60°C and 75°C by recovering heat from the plant's industrial process [Marchand, 2011], [Minea, 2013], [Lebeduin]. Because both heating and cooling thermal effects are used, the overall energy efficiency of the industrial process is further improved. The first results of the monitoring project will be available toward the end of 2013.

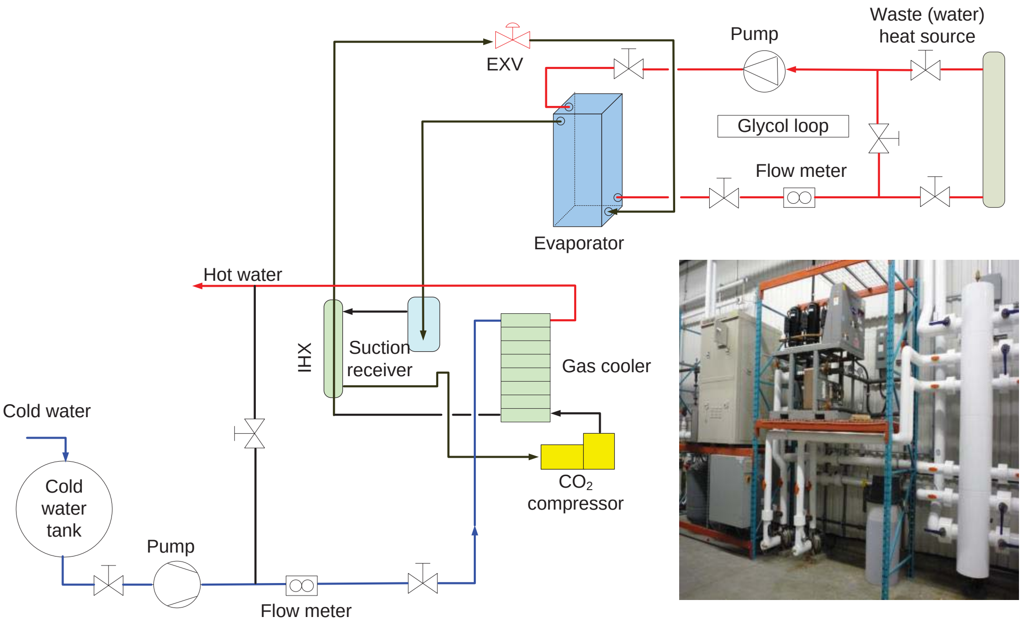


Figure 4-4: Schematic diagram of the first CO2 trans-critical industrial heat pump implemented in a Canadian dairy plant; EXV: expansion valve; IHX: internal heat exchanger [Marchand, 2011], [Minea, 2013], [Lebeduin]

A second Canadian dairy plant could integrate a similar 100 kW_{th} CO_2 trans-critical heat pump between two energetic systems, i.e. between a washing water closed-loop and a process water cooling loop (Figure 4.5) [Soteck, 2012]. The main purpose of this system is to reduce the annual consumption of fossil fuel. Process water at 12 °C (heat source) is circulated within a closed loop between the buffer tank and the heat pump evaporator. By recovering heat from this water loop, the heat pump produces cold water at 7 °C, able to cool a process fluid from 16 °C to 12 °C using a heat recovery heat exchanger. The cooling process provides additional energy savings to the heat recovery system and increases the system overall COP.

On the other hand, cold city water is heated inside the heat pump gas cooler up to 85 °C, prior to being supplied to the plant's washing loop via a storage tank. The heat pump runs only when the process closed loop is operational and, in case of trouble, the industrial processes will not be impacted because the heat recovery system is completely separated from the normal industrial process.

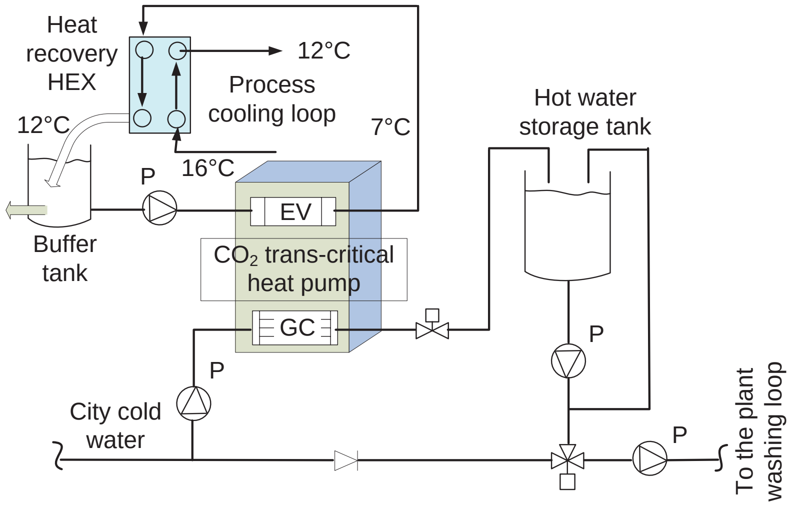


Figure 4-5: Schematic diagram of the CO2 trans-critical industrial heat pump implemented in the second Canadian dairy plant; EV: evaporator; HEX: heat exchanger; GC: gas cooler; GPM: US gallon per minute; P: pump [Minea, 2013], [Soteck, 2012]

4.2.3 Hospitals

As can be seen in Figure 4.6, CO_2 trans-critical heat pumps can also be implemented in hospitals requiring large quantities of process and domestic hot water [Minea, 2013], [Ecosystem, 2012]. In this case, the process and domestic water is heated within a double steam installation (Figure 4.6a). City cold water is heated up to 30 °C in a pre-heating heat exchanger linked to the building's mitigate water closed loop. The pre-heated water is then heated up to 65 °C in steam-to-water heat exchangers. The annual hot water consumption was estimated at about 8 million liters produced by burning 40,000 m^3 of natural gas in 80% efficient boilers [Minea, 2013], [Ecosystem, 2012]. Figure 4.6b presents the integration scheme of the 100 kW_{th} CO_2 trans-critical heat pump. Water from the existing building mitigate water closed loop (25 °C – 35 °C), being the heat pump's heat source, can be seen entering the heat pump evaporator and leaving it at temperatures between 20 °C and 30 °C. On the other hand, city cold water (at 5 °C in the winter and 12 °C in the summer) enters the heat pump gas cooler and leaves it at temperatures varying between 70 °C and 75 °C. The hot water storage capacity exceeds 5.5 m^3 while the instantaneous hot water demand is around 212 L/min, which is decidedly higher than what the CO_2 heat pump can produce. However, maximum daily hot water requirements are 34 L/min. only, and drop to 11 L/min at night. Consequently, the storage tanks can ensure continuous water consumption for more than 15 hours [Ecosystem, 2012].

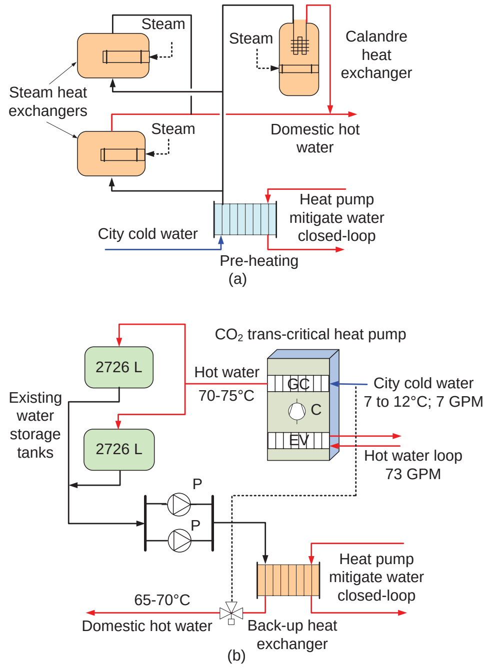


Figure 4-6: CO2 trans-critical heat pump implementation in a large Canadian hospital; (a) existing system; (b) proposed heat recovery system. EV: evaporator; GC: gas cooler; GPM: US gallon per minute [Minea, 2013], [Ecosystem, 2012]

4.3 Ammonia heat pumps

4.3.1 General

Preliminary laboratory tests [Minea, 2013] have helped validate the relevance of using single-stage ammonia heat pumps for heat recovery in industrial processes, as well as their energy performance. They have also demonstrated that, today, it is possible to correctly control the majority of safety issues (leakages, etc.). Figure 4.7a shows the integration principle of single-stage ammonia heat pumps in industrial processes, and Figure 4.7b shows this same principle in large industrial NH_3 refrigeration systems. Such units, equipped with high-pressure compressors and desuperheaters, may produce process hot water at 60 °C and 63 °C from cold water entering the system at 10 °C and 16 °C respectively [Vilter-Emerson].

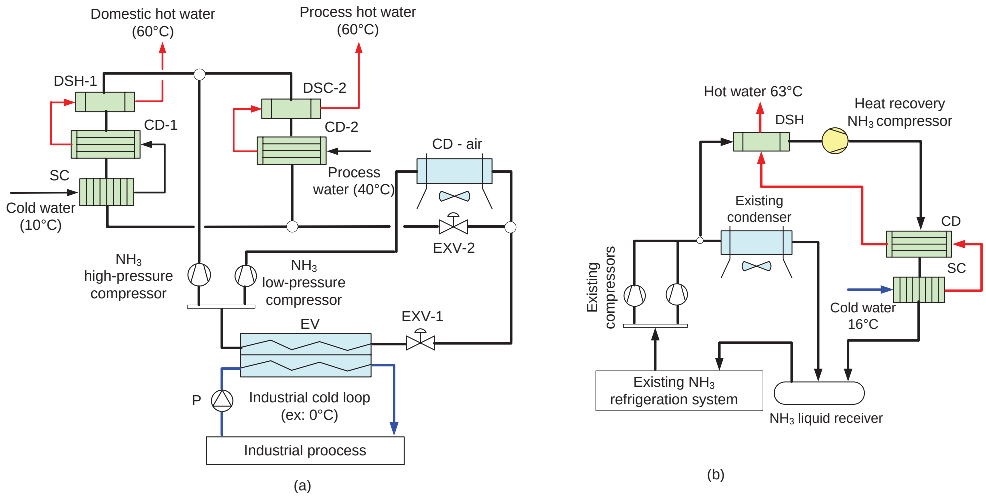


Figure 4-7: Heat recovery principle with single-stage ammonia heat pumps; (a) stand-alone system recovering heat from an industrial process; (b) integrated system recovering heat from an existing refrigeration system [Vilter-Emerson]

4.3.2 Food industry

Figure 4.8 shows the schematic diagram of a single-stage ammonia heat pump recently implemented in a new Canadian diary plant [Gosselin, 2013]. This ammonia heat pump, used for heating process water by recovering heat from the plant's ammonia refrigeration system, contains, among other standard components, a 150 kW ammonia compressor and a condenser that heats a brine (water/polypropylene – 10 %) closed loop. Heat is recovered from the superheated ammonia vapor coming from the existing ammonia compressors in a special heat exchanger and transferred to an intermediate hot water closed loop via a second heat exchanger. Since hot water isn't produced and consumed simultaneously, a large hot water storage system is provided. This heat recovery system allows the dairy plant to save up to one million equivalent kWh per year.

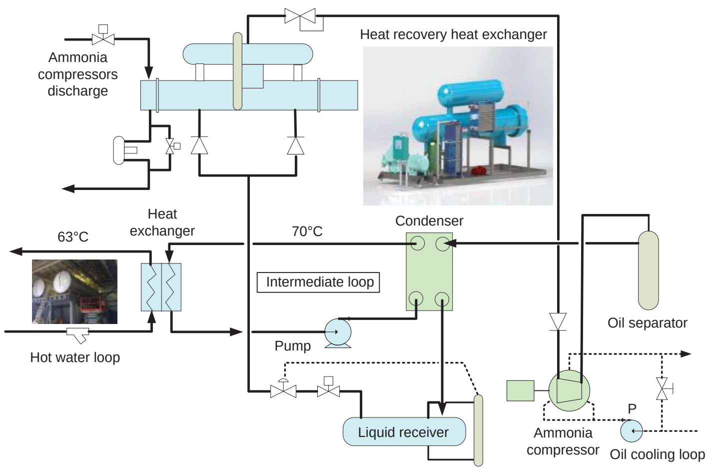


Figure 4-8: Schematic diagram of a single-stage ammonia heat pump implemented in a new Canadian diary plant [Gosselin, 2013]

The ammonia screw compressors available today on the market can work at higher pressures (≥ 45 bars) and condensing temperatures (Figure 4.9a) [Vilter-Emerson]. Consequently, two-stage ammonia heat pump cycles (Figure 4.9b) are feasible, being able to supply hot water at temperatures of up to 85 °C-90 °C by using industrial waste heat at relatively low temperatures. These two-stage ammonia heat pumps, equipped with desuperheaters, could recover heat, for example, from discharge gases in existing ammonia compressors and produce hot water at 85 °C from cold water entering the system at 10 °C to 20 °C (Figure 4.10a) or from sea, lake or river water (4 °C in the winter and 20 °C in the summer), in order to supply hot water at different levels (60 °C, 80 °C and 90 °C) to be re-used in industrial processes or for district heating (Figure 4.10b) [Vilter-Emerson]. Several feasibility studies aimed at implementing such advanced heat recovery two-stage, high-temperature ammonia systems in Canada are under way.

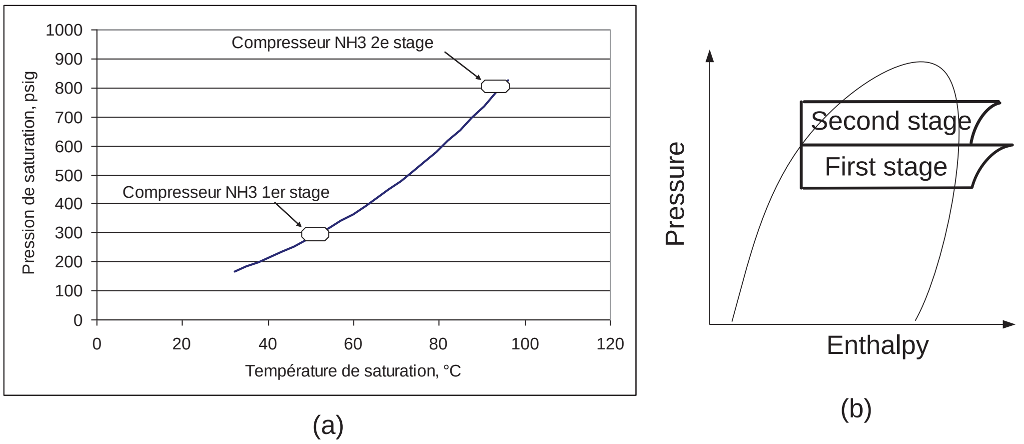


Figure 4-9: Ammonia screw compressors for industrial heat pumps; (a) two-stage thermodynamic cycles in p-h diagram; (b) pressure limits of first and second stage ammonia screw compressors [Vilter-Emerson]

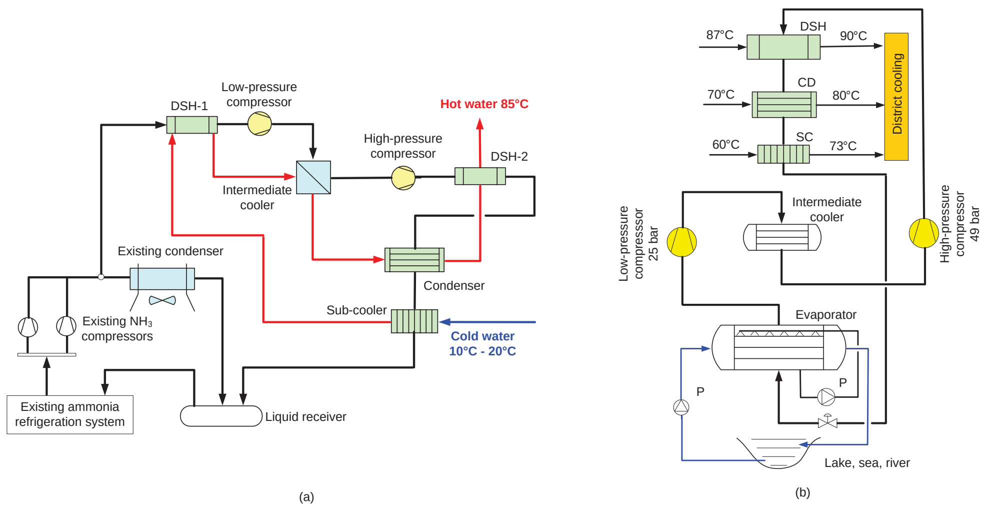


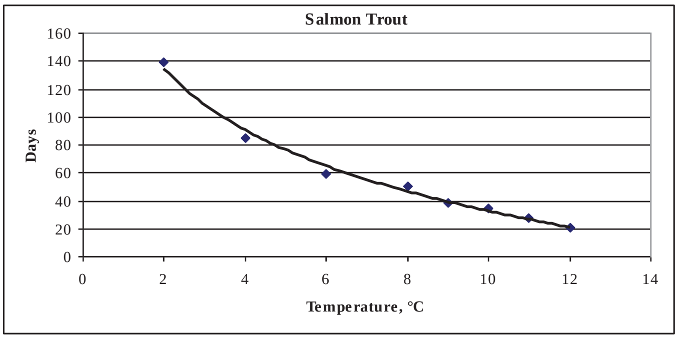
Figure 4-10: Heat recovery with high-temperature, double-stage ammonia heat pumps; (a) from refrigeration systems; (b) from lake, sea or river water [Vilter-Emerson]

4.4 Fish farms

Salmonid culture intended for the breeding, consumption and sport-fishing markets is growing in Canada. Conventional systems include oxygenation columns, plate heat recovery heat exchangers, water filters and pumps, and oil-fired water-preheating devices to improve productivity. Northern fishery companies use fresh, relatively cold surface or groundwater directly in incubation and fish nursery units, without any preliminary heating [Minea, 1996]. However, preheating the water would accelerate alevin growth.

In order to reduce and/or eliminate fossil fuel consumption and, thus, improve environmental performance, a six-month field study of a two-stage heat recovery system with passive heat exchanger (as a first stage) and water-to-water heat pump (as a second stage) has been conducted in a Canadian fish farming facility (Figure 4.11a) [Minea, 1998]. The main objective was to reduce energy consumption and costs, and increase the productivity of the industrial process by recovering and transferring heat between two high-flow rate streams, i.e. waste and fresh water. In other words, the cold groundwater, usually used in salmonid culture under cold climates, is heated with heat recovered from the process waste water in order to reduce the conventional alevin growth cycle. Figure 4.11b shows that, by increasing water temperature, for example, from 8 °C to 12 °C, the number of days required for 50% salmon trout hatching at a constant incubation temperature could be reduced from 50 to about 21 [Champagne, 1998].

(a)



(b)

Figure 4-11: (a) View of the fish farming building [Minea, 1998]; (b) number of days required for 50% salmon trout hatching at a constant incubation temperature [Champagne, 1998]

The fish nursery is the initial stage in the fish farming cycle, which leads to the production of young fish. The fry-rearing process begins when the eggs hatch and ends after about three months, when the fish reach a weight of about 5 grams or a length of 7.5 cm. For every cycle, several hundred thousand fertilized eggs are placed in incubation basins where water is generally maintained at a temperature varying between 6°C and 8 °C until hatching occurs. For incubation, water temperature is the most determining factor because the length of the process is inversely proportional to water temperature (see Figure 4.11b). Water temperature at the beginning of the alevins' rearing process is also important because it activates the metabolism and digestion, and stimulates the sac fry to eat more frequently and in greater quantities. The alevins' size also increases with both the oxygen saturation ratio and water-flow velocity. The fish nursery unit contains several breeding water pools with a total volume of 45 m^3 and a total water-flow rate of approximately 21 l/sec., about 50% of which is fresh groundwater.

In the two-stage heat recovery system implemented in Canada (Figure 4.12), about 10.5 l/sec. of fresh groundwater is pumped from deep ground wells through a plate heat exchanger, which raises its temperature by recovering energy from the waste water coming from the fish breeding pools. Then, the pre-heated fresh water enters the heat pump condenser where it is heated once again by the refrigerant, which recovers heat also from the waste water leaving the passive heat recovery heat exchanger. Therefore, the water-to-water heat pump uses waste water as a heat source and groundwater as a heat sink. Finally, the warmer fresh water is directed through an oxygenation system (not shown in Figure 4.12) where it mixes with the re-circulated water flow, prior to returning to the alevin basins. Waste water is discharged into an underground storage tank, and then to a river, without any environmental pollution. The vapor compression heat pump uses a HCFC-22 refrigerant and contains three parallel scroll compressors and a compact water-to-refrigerant evaporator and a condenser.

As can be seen in Figure 4.13a, the average temperatures of the groundwater entering the plate heat exchanger slightly decreased from 7.4 °C in October to about 6.8 °C in March, a normal but relatively negligible seasonal variation. The heat pump's monthly average coefficient of performance (COP), defined as the thermal energy provided to the process water supplied to the alevin basins divided by the total electrical energy consumed by the heat pump compressors, was about 6.1 during a continuous operation period of six months (Figure 4.13b), an excellent energy performance.

The average thermal efficiency of the first-stage heat recovery passive heat exchanger varied around 66%, and it provided more than 472,000 kWh of thermal energy to the groundwater, corresponding to an average seasonal thermal power of 109 kW.

In terms of energy, the fresh groundwater was first heated by the passive heat exchanger, which provided 64 % of the energy, and then by the heat pump, which provided 30.5 % over a six month production period (Figure 4.14). Heat pump heat recovery was made possible with a net power consumption of 45.8 %, while the water circulation pumps took 54.2 % of the total energy consumed. Consequently, the overall average coefficient of performance, calculated for the whole system, including both the passive heat exchanger and the heat pump, was 7.9 for two consecutive 3-month industrial production periods.

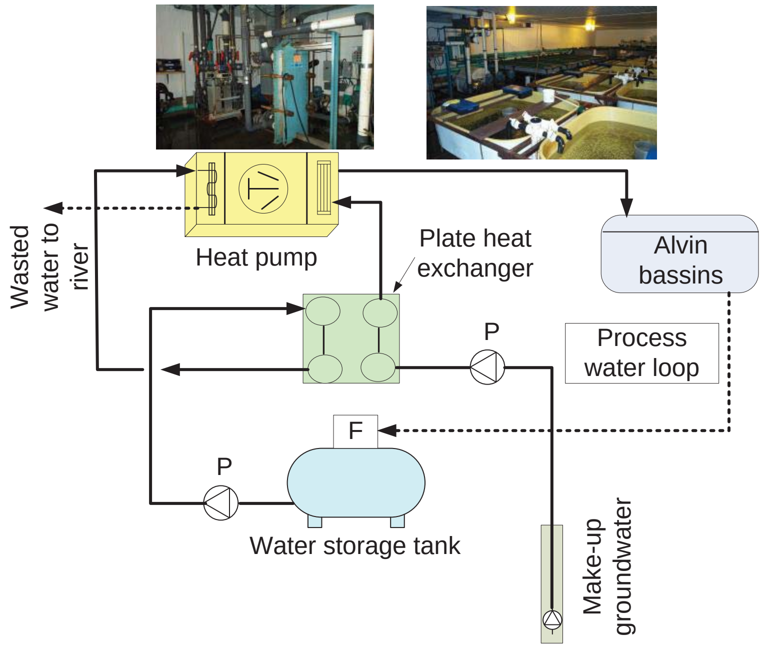


Figure 4-12: Two-stage heat recovery system implemented in a Canadian fish farming facility; T: temperature; P: pressure; W: power; HEX: plate heat exchanger; DE/RF: water & refrigerant flow meter [Morin 1996], [Collignon, 1998], [Minea, 1999]

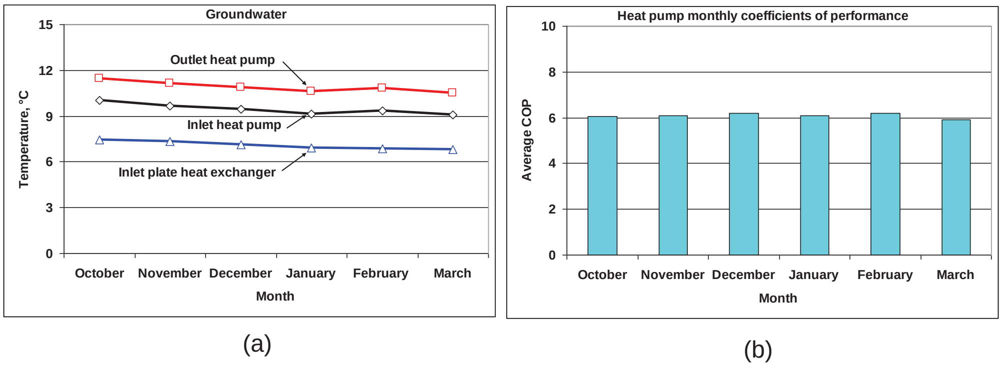


Figure 4-13:(a) Average monthly groundwater temperatures; (b) average monthly heat pump COP [Minea, 1998], [Minea, 1999], [Minea, 2002]

The comparison of the alevin growth rates with heated (10-12 °C) and unheated (7-8 °C) fresh water shows that the annual production of 5 gram rainbow trout increased by approximately 50 % using water that is 4 °C warmer. Moreover, the time period required for the rainbow trout to grow was 65 % shorter than that of conventional processes, leading to substantial improvements in the company's overall efficiency. In fact, with water temperatures increasing from 7 °C to 11 °C, the average alevin weight after a 90-day period increased from the usual 1.7 grams to 4.8 grams [Champagne, 1998]. Finally, the system simple pay-back period was estimated at 1.28 years, without taking the increase in fish production into consideration.

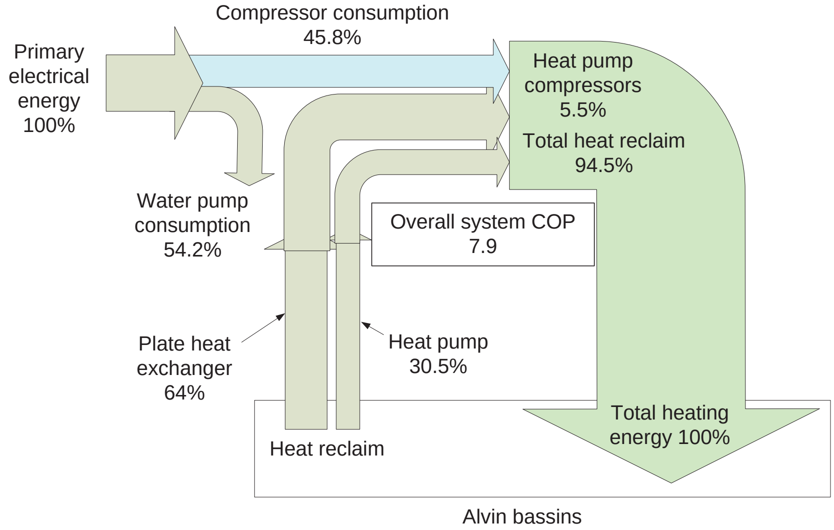


Figure 4-14: 6-month global energy balance of the two-stage heat reclaim system implemented in a Canadian fish farming facility [Minea, 1998], [Minea, 1999], [Minea, 2002]

4.5 Heat pump-assisted wood drying

About 45 % of the Canadian territory is wooded, representing 10 % of the planet's forests. The Canadian wood industry accounts for 3 % of the country's Gross Domestic Product, 10 % of total foreign trade, and 57 % of the annual commercial surplus. In Quebec (Eastern Canada), hardwood such as hard maple, yellow birch, oak, and white walnut represents 6.6 % of a market dominated by resinous species. Hardwood is usually dried at low temperatures (maximum 55 °C), a process that consumes up to 70 % of the total energy required for primary wood transformation. Usual energy sources for wood drying are fossil fuels (oil, natural gas, propane) and bark [Canada Statistics, 2002].

On the other hand, approximately 10 % of the Canadian soft wood production comes from the province of Quebec (Eastern Canada). About 2 % of this production is dried with *low-temperature* heat pumps and the rest through other technologies such as direct fire and the use of bark-, natural gas- or oil-fired boilers. Soft wood drying, highly profitable at high-temperatures, is essential to prevent warping and cracking. Usual energy sources for wood drying are fossil fuels (oil, natural gas, propane) and bark.

4.5.1 Low-temperature drying heat pump

Electrically-driven low-temperature heat pumps are usually used in combination with fossil fuels or electricity as back-up energy sources. About 25 % of hardwood dryers in Quebec are equipped with low-temperature heat pumps.

A 13 m^3 experimental forced air wood dryer with variable speed fans was equipped with a 5.6 kW low-temperature heat pump [Minea, 2006a], [Minea, 2011]. The heat pump (compressor, blower, evaporator, condenser, sub-cooler, refrigeration piping and controls) is installed inside a mechanical room next to the dryer chamber (Figure 4.15).The dryer contains steam and electrical heating coils. Steam is supplied at variable flow rates by a natural gas-fired boiler (with a thermal efficiency of 80 %). Inside the dryer, the air periodically flows in opposite directions to ensure uniform heating and drying.

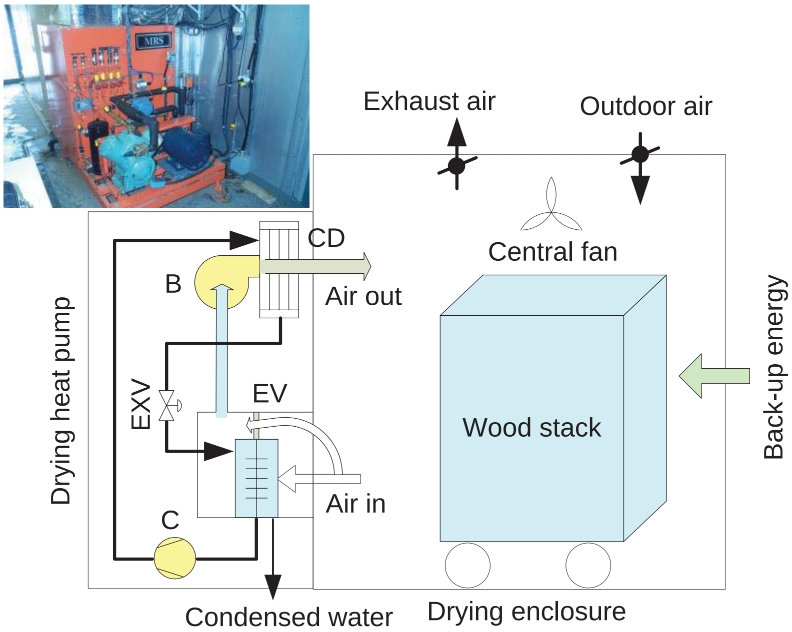


Figure 4-15: View of the low-temperature hardwood drying experimental heat pump [Minea, 2006a], [Minea, 2011]

4.5.1.1 Drying schedule and control

Dry- and wet-bulb temperatures inside the dryer, as well as the compressor running times, are scheduled based on the actual wood moisture content (Table 4.1). In the first step (preheating), the compressor is not running. The heating coils provide heat to increase the temperature of the wood stack. When the wet-bulb temperature reaches its set point, the heat pump starts and runs intermittently. For example, if the hourly operation percentage is set at 60 %, the heat pump will run for 30 minutes and will shut down during the next 20 minutes. The compressor running time increases when the actual wet-bulb temperature is higher than the upper set limit and decreases when it is below the lower set limit. When required, the dryer uses one of the back-up heating sources, i.e. electricity or steam. In addition, if the actual dry-bulb temperature is higher than its set point, the air vents open automatically and close when it drops below the set point.

Table 4-1: Example of a hardwood heat pump drying schedule

Drying step	Dry bulb	Wet bulb	Heat hump hourly running time
-	°C	°C	%
1 Preheating	37.8	32.2	-
2	37.8	32.2	100
3	40.5	33.9	85
4	43.3	34.4	75
5	46.1	34.4	65
6	54.4	34.4	75
7	57.2	35.0	85
8	60.0	35.0	100

4.5.1.2 Energy consumption and costs

Two all-electrical drying tests with a low-temperature heat pump and electrical back-up coils are presented (Table 4.2). The initial moisture content (dry basis), representing the weight of the water contained in the wood expressed as a percentage of its anhydrous mass, was 29.1 % (test #1) and 40.7 % (test #2) respectively. The total drying time, including the preheating steps, was 147.03 hours (6.12 days) (with yellow birch) and 240.67 hours (10 days) (with hard maple) respectively. The final moisture content (oven-measured, dry basis) was 7.4 % and 7.8 % respectively. The final moisture content is within normal ranges for hardwood drying. The heat pump (compressor and blower) accounted for 30% (test #1) (Figure 4.16) and 21 % (test #2) of the total electrical energy consumed respectively. The electric back-up coils accounted for 62 % (test #1) (Figure 4.16) and 61 % (test #2) of the energy consumed, and the dryer fan for 8 % (test #1) and 11% (test #2).

Two additional drying tests with the low-temperature heat pump and steam as back-up energy (hybrid test #3 and hybrid test #5), as well as a conventional drying cycle (test #4 - CONV), are also presented (Table 4.3). It can be seen that with hard maple, the total drying time of hybrid test #3, including the first (preheating) step, was 16.5 % longer than that of conventional drying test #4, while both final moisture contents were identical (7.5 %). However, the equivalent energy consumption of hybrid test #3 was more than 50 % lower than that of conventional test #4, which used natural gas as a heating energy source.

Table 4-2: All-electrical (heat pump with electrical back-up) drying tests

Test	Wood	Moisture content		Energy consumption			
-	-	MC_{in}	MC_{fin}	Heat pump		Dryer	
-	-	-	-	Compressor	Blower	Fan	Back-up electricity
-	-	%	%	kWh	kWh	kWh	kWh
#1	Yellow birch	29.1	7.4	747	151	229	1 828
#2	Hard maple	40.7	7.8	872	258	451	2 441

MC_{in} : initial moisture content; MC_{fin}: final moisture content

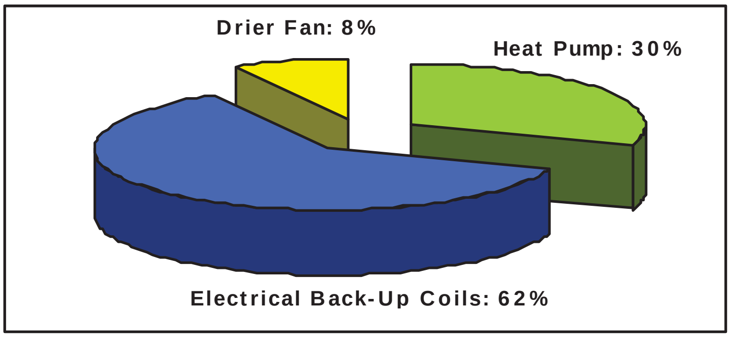


Figure 4-16: Electrical energy consumption distribution for all-electrical drying test #1 [Minea, 2006a], [Minea, 2011]

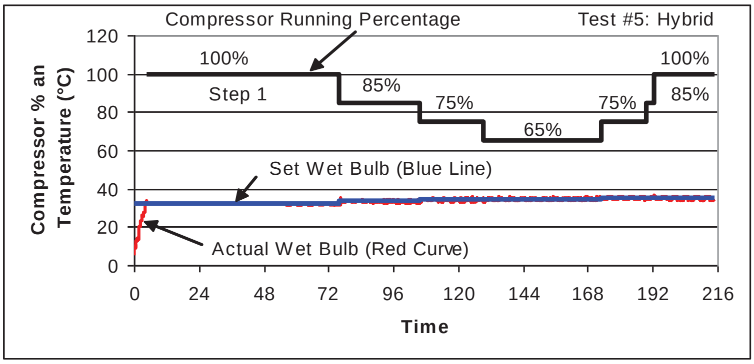
Table 4-3: Hybrid (heat pump with steam back-up) and conventional (steam) drying tests

Test	Hardwood species	Moisture content		Electrical energy consumption			Operation rate vs. cycle time	
-	-	MC_{in}	MC_{fin}	Heat pump		Dryer	Heat pump	Back-up
-	-	-	-	Compressor	Blower	Fan	Compressor	Steam
-	-	%	%	kWh	kWh	kWh	%	%
#3 - hybrid	Hard maple	31.1	7.5	650	129	360	65	39
#4 - CONV	Hard maple	36.4	7.5	-	-	638	-	70
#5 - hybrid	Yellow birch	75.9	7.6	902	201	400	84.7	40

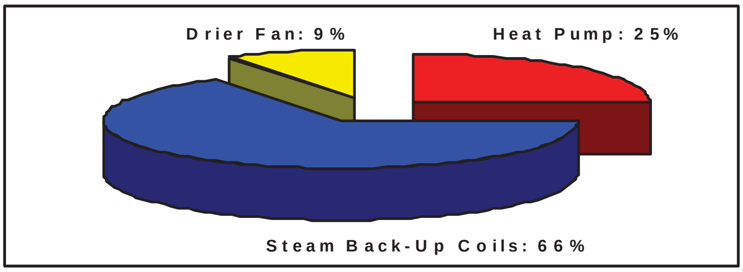
The intermittent operation of the heat pump was set prior to each step of the drying cycle. It was also frequently adjusted during the drying process in order to keep the actual wet-bulb temperature close to its set point. For hybrid test #5, Figure 4.17a shows the correlation between the heat pump's hourly percentages of operation and its settings and the actual wet-bulb temperatures. It can be seen that the actual wet-bulb temperature perfectly matched the set wet-bulb values with the intermittent operation of the compressor. Also, when the initial moisture content (MC_{in}) was relatively high (75.9 % - test #5), the compressor operated 84.7 % of the time. However, it ran only 65 % of the time when the MC_{in} was significantly lower (31.1 % - hybrid test #3). The heat pump (compressor and blower) accounted for 25 % of the total energy consumed, while the dryer fan and back-up heating (steam) accounted for 9 % and 66 % respectively (Figure 4.17b). The relatively high operating percentage of the steam coils can be explained by the poor thermal insulation of the experimental dryer and relatively high air leakage rates.

Compared to the energy consumed in conventional test #4 (719 m^3 of natural gas), the natural gas consumed in hybrid drying test #5 (350 m^3) was 56 % lower. Consequently, assuming a number of 40 drying cycles per year, natural gas savings would total about 15,000 m^3/year. Equivalent CO_2 emissions would consequently be reduced by 30.6 tons per year and per dryer. This takes into consideration approximately 40 kg of CO_2 emissions per year due to the additional electrical energy consumed by the heat pump. If 500 small-scale hardwood dryers with low-temperature heat pumps were installed, the annual reduction in CO_2 emissions would be 15,300 tons. This estimation was done for the Province of Quebec (Eastern Canada), where 97 % of the electricity produced is hydroelectric. In this case, the regional conversion factor is 0.00122 kg of CO_2 per kWh of electrical energy consumed.

Compared to the energy cost of the conventional drying cycle using natural gas (test #4 - CONV), the total energy cost (electricity and natural gas) of the drying cycles with low-temperature heat pumps is reduced by 20 % (all-electrical test #2) and by 23% (hybrid test #5) respectively (Figure 4.18).



(a)



(b)

Figure 4-17: Hybrid drying test #5; (a) compressor hourly running time (%) and set and actual wet-bulb temperatures; (b) distribution of energy consumption [Minea, 2006a], [Minea, 2011]

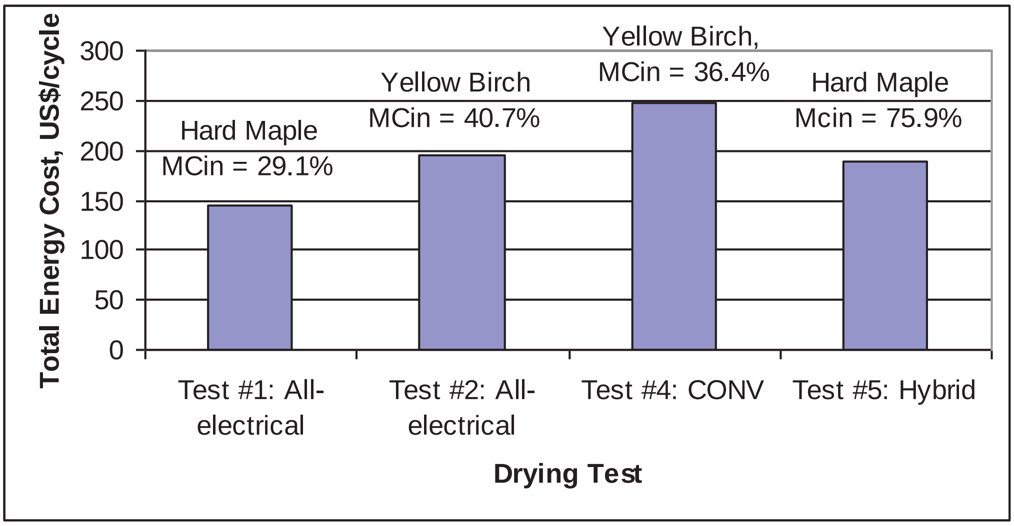


Figure 4-18: Drying cycle total energy cost (2007 US$); MCin: initial moisture content

4.5.1.3 Water extraction

The condensed water volume strongly depends on the wood initial moisture content (Figure 4.19). Test #1 (all electrical), with a relatively low initial moisture content (29.1 %), produced 2.5 times less water than hybrid test #5, where the initial moisture content was much higher (75.9 %). This result was obtained even though the initial quantity of dried wood (hard maple) was 33.6 % higher in all-electrical test #1 compared to the initial volume used in hybrid test #5.

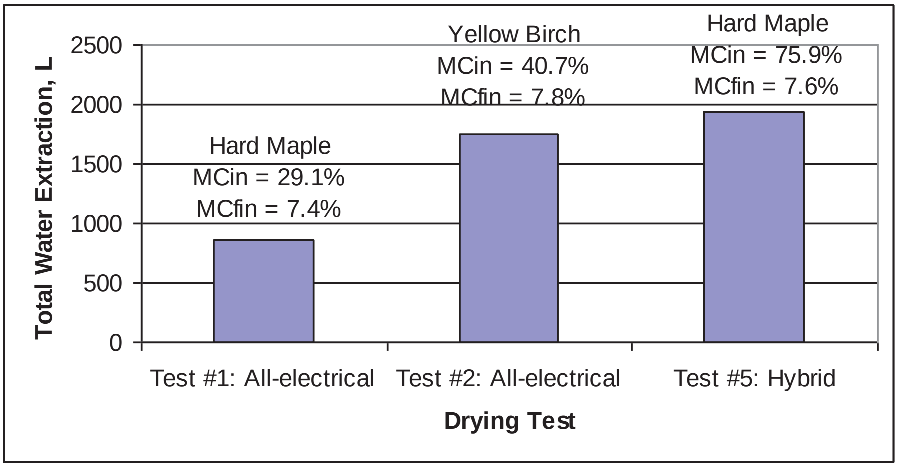


Figure 4-19: Total volumes of water extracted [Minea, 2006a], [Minea, 2011]

The fiber saturation point (FSP) is the physical state where the cell cavities are completely devoid of free water and their walls are still completely saturated. For hardwood, the FSP moisture content is about 25 % (dry basis). It can be seen that with an initial moisture content below 41 % (all-electrical test #1), the volume of water extracted below the FSP was much higher than the volume extracted above the FSP (Figure 4.20). However, when the initial moisture content was approximately 41 % (hybrid test

#2), the volume of water that condensed above the FSP was practically equal to the volume removed below this point. Finally, when the initial moisture content was significantly higher than 41 % (75.9 % in hybrid test #5), the volume of water extracted above the FSP was about three times higher than the water volume removed below the FSP.

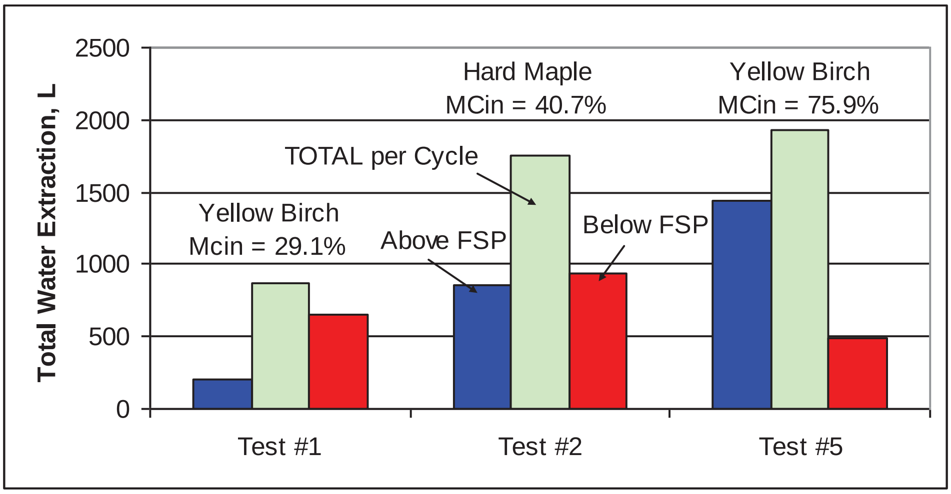


Figure 4-20: Total water extraction vs. the fibre saturation point [Minea, 2006a], [Minea, 2011]

4.5.1.4 Dehumidification rate

For every wood species and thickness, there is a safe drying rate at which moisture can be removed. In other words, there is a rate at which wood can be dried with little or no significant degradation or damage. On the other hand, the water evaporation rate depends on the amount of energy supplied and the capacity of the drying air to absorb moisture. To maintain a constant drying rate, the water molecules in the wood must be supplied with additional energy, or the drying air partial vapor pressure has to be lowered. This is achieved either by raising the temperature or reducing the relative humidity of the drying air. Exceeding a maximum safe evaporation rate increases the risk of drying defects (splits, cracks or checks). However, when drying is done at a rate substantially lower than the safe rate, there is also a risk of drying defects (increased warping, stains and uneven drying). For example, the safe drying rate for hard maple lumber in terms of moisture content loss per day is 6.5 %. Drying rates also provide a method of estimating drying cycle times. For conventional drying cycles, this parameter is usually expressed in terms of percent moisture content loss per day. Using a low-temperature heat pump as a dehumidifier, the drying rate is expressed in terms of average water extraction volume (L) per hour. In this case study the average water extraction rate per cycle slightly increased as a function of the initial moisture content. For example, with yellow birch, it increased by 10.3 % when the initial moisture content rose from 29.1 % (all-electrical test #1) to 75.9 % (hybrid test #5). However, the water extraction rates below the FSP decreased by a factor of 2.4 (test #1) and 3.4 (test #5) as compared to the respective rates above the FSP (Figure 4.21).The water extraction rate above the FSP is therefore not very sensitive to the total water volume removed. Actually, if we compare tests #1 and #5 with yellow birch, the water extraction rates above the FSP were practically similar (13 L/h and 14.5 L/h respectively), even though the total water volume removed during test #1 was more than five times lower than the volume extracted during test #5. On the other hand, below the FSP, the water extraction rates were proportional to the gap between the FSP and final moisture content (about 17.5 %), and practically equal (4 to 5 L/h), regardless of the dried species (yellow birch or hard maple) and the respective water volumes removed.

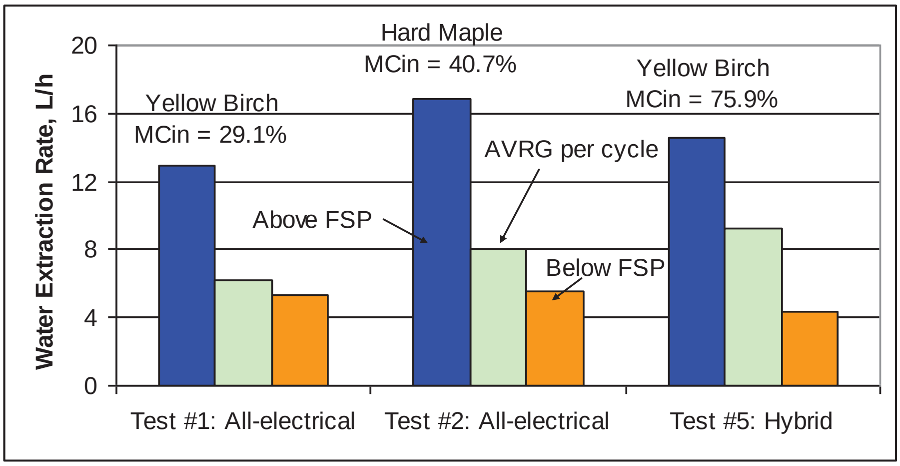


Figure 4-21: Water extraction rates vs. FSP; AVRG: average [Minea, 2006a], [Minea, 2011]

4.5.1.5 Dehumidification performance

The dehumidification efficiency of drying heat pumps is generally expressed in terms of the *Specific Moisture Extraction Rate* (*SMER*). This parameter represents the ratio between the mass of water extracted and the heat pump total electrical energy consumption (compressor and blower) (kg_{water}/kWh_{hp}). Laboratory tests show that above the FSP, the SMER was 2.5 kg_{water}/kWh_{hp} (Table 4.4), which is a very good performance for a dehumidification process. Table 4.4 also indicates at which moment, measured in hours, from the beginning of each drying cycle, the FSP was reached for each test. It depends on the initial moisture content. When MC_{in} was relatively low (29.1 % in test #1), the FSP was reached after 25 hours. When MC_{in} was higher (75.9 % in test #5), it was reached after 104 hours of operation.

Table 4-4: Dehumidification performance of low-temperature drying heat pumps

Test	MC_{in}	Specific moisture extraction ratio (SMER)			Comparison	-
-	Initial moisture content	Above FSP	FSP = 25%	Below FSP	Above vs. bellow FSP	Drying time
-	%	kg_{water}/kWh_{hp}	Hours*	kg_{water}/kWh_{hp}	Times	Hours
#1: all-electrical	29.1	2.06	25	0.82	2.5	138.3
#2: all-electrical	40.7	2.5	72	1.19	2.1	220.0
#5: hybrid	75.9	2.5	104	0.87	2.9	210.3

*From the beginning of the preheating step

4.5.1.6 Conclusions

A 5.6 kW low-temperature heat pump coupled to a 13 m^3 wood dryer was tested with electricity and natural gas (steam) as back-up energy sources. The heat pump electrical energy consumption (compressor and blower) varied between 25 % and 30 % of the total equivalent energy consumption during the all-electrical or hybrid drying cycles. The dryer fan generally accounted for 8 % to 9 % of the total drying energy consumed, and the electrical or fossil back-up energy between 62 % and 66 %. For initial moisture contents above 41 %, the total water quantity extracted above the fiber saturation point were up to 2.9 times higher than that removed below the FSP. Consequently, in these cases, the dehumidification efficiency of the low-temperature drying heat pump (SMER) was up to 3 times higher above the FSP than below that point. Finally, the hybrid drying cycles reduced natural gas consumption by 56 % and the equivalent energy costs by 21.5 %, compared to the conventional drying cycle with natural gas as a unique heating source.

4.5.2 High-temperature drying heat pump

High-temperature drying heat pumps offer many advantages such as lower energy consumption for each unit of water removed, accurate control of drying conditions, and enhanced product quality. Their limitations generally include the need for temperature resilient materials and fluids (refrigerants, oils, belts, etc.), regular maintenance, the risk of refrigerant leaks and higher initial capital costs compared to conventional dryers.

4.5.2.1 System configuration

The experimental site consists of two forced-air 354 m^3 wood dryers made of insulated panels, each equipped with 1500 kW steam heating coils (Figure 4.22). An oil-fired boiler with a 4,900 kW output capacity and 82% thermal efficiency supplies both dryers with high-pressure saturated steam for heating and spraying. One of these dryers is equipped with two 65 kW (compressor nominal power input) high-temperature heat pumps [Minea, 2011], [Minea, 2004]. A 56 kW multiple-blade fan with an outdoor motor forces the air flow through the stacks of wood at a rate of 1.5-2.0 m/sec. at the outlet. Wall deflectors and the inversion of the rotation of the dryer fan every 3 hours at the beginning and every 2 hours at the end of the drying cycles help maintain uniform ventilation. To avoid air implosion hazards, three air vents open when the central fan rotation changes direction and, also, when the actual dry-bulb temperature exceeds the set point. High-temperature heat pumps HP-1 and HP-2 equipped with variable speed blowers, compressors, evaporators, as well as electric and electronic controls are installed within an adjacent mechanical room. However, the condensers of both heat pumps are remotely installed inside the drying enclosure. Designed for industrial processes, the open, belt-driven compressors are equipped with oil pumps, external pressure relief valves and crankcase heaters. The refrigerant (HFC-236fa) is a non-toxic and non-flammable fluid, with a relatively high critical temperature above the highest process temperature, and a normal boiling point below the lowest temperature likely to occur in the system. Moreover, the saturation vapour pressure at the highest design temperature is not so high as to impose design limitations on the system. Expansion valves are incorporated into the microprocessor-based temperature/process controllers that display both set points and actual process temperatures.

This case study presents some of the results achieved when drying *white spruce* (test #70 and test #88) and *balsam fir* (test #176) with high-temperature heat pumps and steam (oil) as a back-up energy source (see Table 4.5).

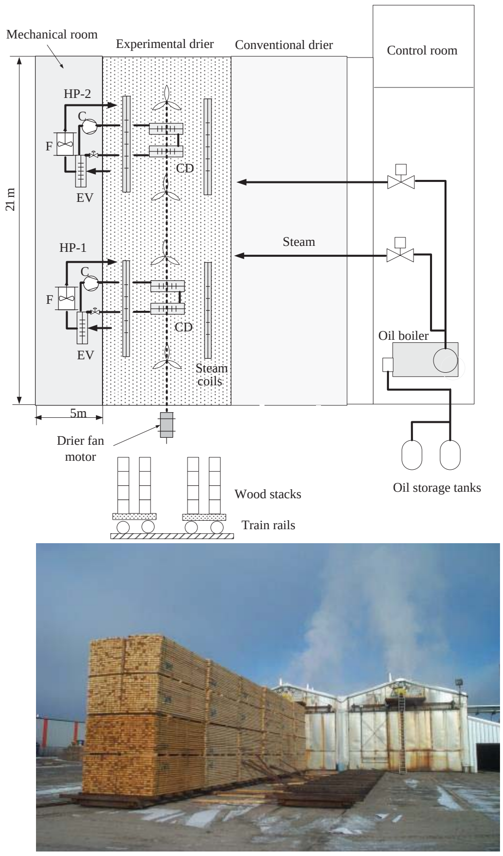


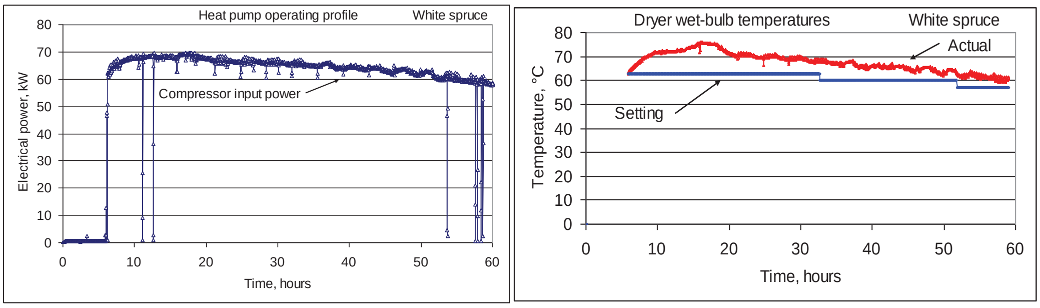
Figure 4-22: Schematic representation of the industrial-scale heat pump dryer and view of the site [Minea, 2011], [Minea, 2004]; C: condenser; CD: condenser; EV: evaporator; F: fan; HP: heat pump

4.5.2.2 Drying schedule and controls

All experimental drying cycles include 6 to 8 hour preheating steps at an average temperature of 93.3 °C in order to destroy the micro-organisms responsible for discoloring the sapwood. The drying conditions for each step were established based upon moisture content, type of wood species, dimensions and quality of the wood. For *white spruce*, which is normally easy to dry, when the initial moisture content was between 40 % and 25 %, the dry-bulb temperature was set between 82.2 °C and 85 °C and the wet-bulb temperature at 62.7 °C. At a moisture content below 25 %, the dry-bulb temperature was generally set at 79.4 °C and the wet bulb-temperature at 62.7 °C. With *balsam fir*, which is harder to dry, when the initial moisture content was above 30 %, the dry-bulb temperature was set at 82.2 °C and the wet-bulb temperature at 79.4 °C.

At moisture contents below 25 %, the set dry-bulb temperature reached 93.3°C whereas the wet-bulb temperature was 71.1°C. The dry- and wet-bulb temperature settings were changed at predetermined time intervals. For *white spruce*, steps 1 to 3 generally took 10 hours, step 4, 20 hours, and step 5, 10 to 20 hours depending on the wood actual moisture content. In the case of *balsam fir*, the first five drying steps each took 30 hours, while the 6th step took up to 15 hours. The goal was to stay within the average traditional drying cycle times for the same species of dried wood. Finally, when the indoor dry-bulb temperature was lower than the set point value, the steam valve opened gradually from 5 % to 100 % according to a time-based schedule to allow the temperature to return to the set point.

As can be seen in Figure 4.23a, the drying time for white spruce drying cycle #88 was 61.3 hours, without including the approximately 6 hour preheating step. The control strategy allowed the heat pump to shut down when the actual dryer wet-bulb temperature reached the set point (Figure 4.23b).



(a) (b)

Figure 4-23: (a) Heat pump operating profile during test #88; (b) profiles of the dryer wet-bulb set and actual temperatures [Minea, 2011], [Minea, 2004]

The heat pump compressors ran with a 65 kW electrical power input, and average compression ratios of 5.5. Stable suction and discharge pressures as well as an average refrigerant sub-cooling temperature of 8 °C were achieved. Condensing temperatures varied around 105 °C, about 20 °C above the kiln dry-bulb temperature. Evaporating temperatures ranged between 41 °C and 45 °C. The average relative humidity of the air entering the evaporators varied widely because of the periodical changes in the rotation direction of the central fan, and also decreased continuously over time. However, the relative humidity leaving the evaporators was almost constant at around 74 % to 88 %, except at the end of the cycle when it dropped to 70 %.

4.5.2.3 Energy performances

The wood moisture content prior to each drying cycle was generally in the range of 35% to 45% (dry basis) (Table 4.5). The average coefficient of performance (COP) of the drying heat pumps, defined as the useful thermal power output (W) divided by the electrical power input (W), varied from 3 to 4.6.

The total water extraction rates were 313 kg_{water}/hour (batch #70), 263.2 kg_{water}/hour (batch #88) and 178.8 kg_{water}/hour (test #176). These numbers do not include any venting moisture losses (on average, 90 kg_{water}/hour), but account for 5% of condensed water losses. The Specific Moisture Extraction Rate (SMER), defined as the amount of water extracted by the heat pump (kg) divided by the total energy input (compressor and blower) expressed in kWh, ranged from 1.46 kg_{water}/kWh (test #176) to 2.52 kg_{water}/kWh (test #70). The Specific Energy Consumption (SEC) ranged from 0.4 to 0.68 kwh/kg_{water}. These values do not include the energy consumed during the pre-heating steps, nor any allowance for the energy consumed by the kiln central fan or the venting moisture losses.

Table 4-5: Energy performances [Minea, 2011], [Minea, 2004]

Test #	-	#70	#88	#176
Parameter	Unit	-	-	-
Timber	-	White spruce	White spruce	Balsam fir
Drying time	HP-1	61.00	61.3	151.4
(excluding preheating steps) (hours)	HP-2	61.00	61.3	151.4
Average compressor power input (kW)	HP-1	65.12	63.36	61.0
	HP-2	62.78	58.50	57.14
Compressor energy consumption (kWh)	HP-1	3,972	3,884	9,235
	HP-2	3,830	3,586	8,651
Blower energy consumption (kWh)	HP-1	13.42	16.6	28.7
	HP-2	14.03	39.5	107.5
Water extraction (Liters)	HP-1	9,454	8,263	13,550
	HP-2	9,655	8,478	13,531
Final moisture content (%)	-	17.2	20.6	20.7
Average COP* (-)	HP-1	4.23	4.6	3.46
	HP-2	3.70	4.07	3.00
Average SMER** (kg_{water}/kWh)	HP-1	2.38	2.13	1.46
	HP-2	2.52	2.36	1.54
Average SEC** (kWh/kg_{water})	HP-1	0.42	0.47	0.68
	HP-2	0.40	0.42	0.64

* Based on the compressor and blower energy consumptions

Energy consumption during the dehumidification cycles with high-temperature heat pumps was 27 % to 57 % lower than with conventional (steam) drying systems. The average reduction in specific energy costs, compared to the costs of conventional wood drying cycles, was estimated at approximately 35 %.

The heat pump (compressor plus blower) accounted for 72% and the dryer central fan for 28% of the total energy consumed. The drying time required to obtain white spruce with an approximate final moisture content of 17% to 19% was about 2.5 days, while for balsam fir it averaged 6.3 days. Despite a longer drying time, the balsam fir drying process was less focused on drying speed than the white spruce drying process, as the main operating focus was to produce a high quality product. The specific cost for drying about 39,600 m³ of lumber was 14.75 US$/m³, including kiln operation, electrical and fossil energy consumption, equipment depreciation, insurance, etc. Energy cost only was 6.86 US$/m³. The objective was to reduce the specific energy cost by at least 40%.

4.5.2.4 Conclusions

As a clean energy technology compared with conventional heat-and-vent dryers, high-temperature heat pump dehumidifiers offer interesting advantages for drying soft timber wood. This paper presents the preliminary results of the development and field testing of two prototypes highlighting their thermodynamic parameters and preliminary energy performance as well as the first operating lessons learned. The average measured specific moisture extraction rate of the heat pumps was 2.35 kg_{water}/kWh (white spruce) and 1.5 kg_{water}/kWh (balsam fir), while the average coefficients of performance generally varied from 3.0 to a maximum of 4.6. Cycle time ranged from 2.5 days (white spruce) to 6.3 days (balsam fir), including the initial preheating steps. The refrigerant/oil mixture behaved well during more than 4000 hours of preliminary tests, showing good compatibility and chemical stability at condensing temperatures below 110 °C. Better insulated and well maintained dryers are necessary to obtain drying temperatures above 100 °C as well as reduce the drying time of resinous species by up to 25 % and total energy consumption by up to 50 %. The current goals of the study include using more corrosive resistant components and a variable speed central fan, as well as further optimizing the drying schedules and general dryer operation and maintenance. Finally, it is expected to help local Canadian equipment suppliers to promote research and development of the technology and develop an appropriate market strategy. Specifications for high-temperature heat pump dehumidifier kiln energy use and best-practice guidelines must also be produced.

4.6 Mechanical vapor recompression

A mechanical vapour recompression system has been studied, improved, and successfully implemented and tested in a Canadian metallurgical process consisting in transforming liquid copper into wire (Figure 4.24) [Bédard, 2002]. This MVR evaporator system is similar to a conventional steam-heated, single-effect evaporator, except that the vapour released from the boiling solution is compressed by the compressor. The compressor raises the pressure and saturation temperature of the vapour so that it may be returned to the evaporator as a heating medium. This reduces the steam needed to meet the evaporative load of the overall system.

The vacuum pump maintains a pressure of about 200 mbar inside the container, which corresponds to a water boiling temperature of 60 °C. The compressor (107.5 kW) increases the vapor pressure by 20 mbar and its temperature by 2°C between the evaporating and condensing sides. The evaporated water flow rate (15.8 m^3/h) represents about 97 % of the input product flow. At the same time, 3 % of the initial material quantity is discharged as a concentrated product. The metal recovery rate (copper, lead, sulphate) is as high as 95 %. The product is continuously re-circulated from the lower to the upper side of the container. Inside the heat exchanger, the compressed vapor condenses, and the liquid is pumped outside. A plate heat exchanger preheats the entering product by using heat from both the condensed and concentrated product leaving the container. The compressor consumes 7.8 kWh per ton of water evaporated, while the energy required by a conventional evaporation system is about 700 kWh per ton of water evaporated. Thus, the coefficient of performance, defined as the thermal energy supplied divided by the electrical energy consumed, is 86. However, during system operation, about 30 kW of thermal back-up power in the form of vapor (VIVE) is supplied on average to keep the temperature of the product being concentrated at a constant level. This operation increases the specific energy consumption to 9.9 kWh per ton of water evaporated. As a result, the system average COP drops to 68. However, this number doesn't include the energy consumed by the vacuum and other circulation pumps (total electrical power estimated at 60 kW) [Bédard, 2002].

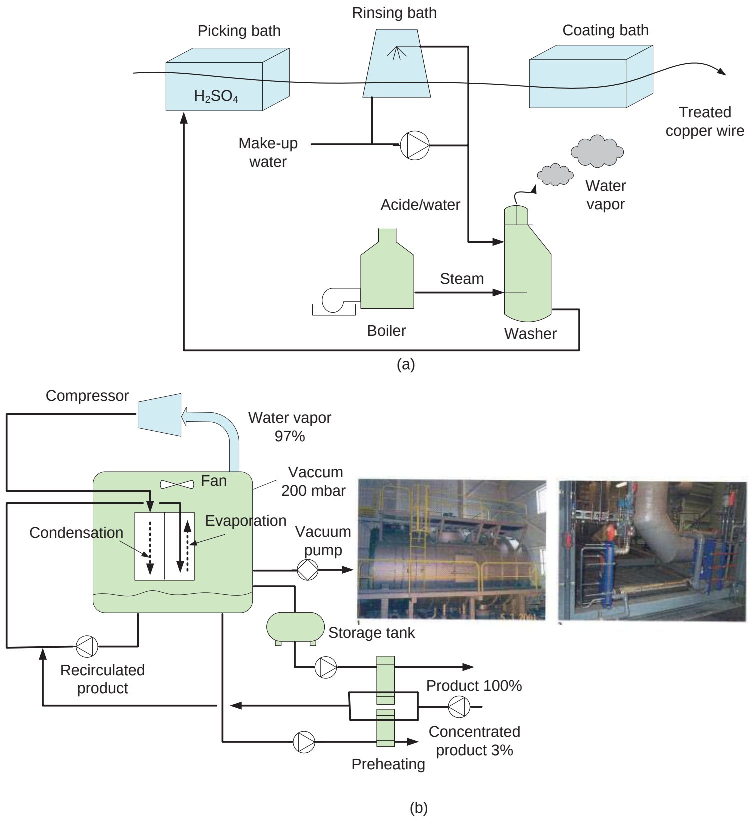


Figure 4-24: (a) Initial industrial process; (b) mechanical vapour recompression system [Bédard, 2002]

4.7 Poultry processing

For the industrial implementation of cascade heat pump systems, many practical options are available. As can be seen in Figure 4.25, the first stage of such systems may recover waste heat rejected by an industrial ice machine existing in a poultry processing plant [Caddet]. The cascade heat pump could therefore be the second stage of a heat recovery system, used to also recover heat from the condensers of an existing refrigeration plant through an intermediate closed loop. Cold water entering the system at 12 °C is heated up to 25 °C inside the pre-heating heat exchanger, and then up to 63 °C with the cascade heat pump, prior to being stored inside a storage tank and/or supplied to industrial processes or other consumers.

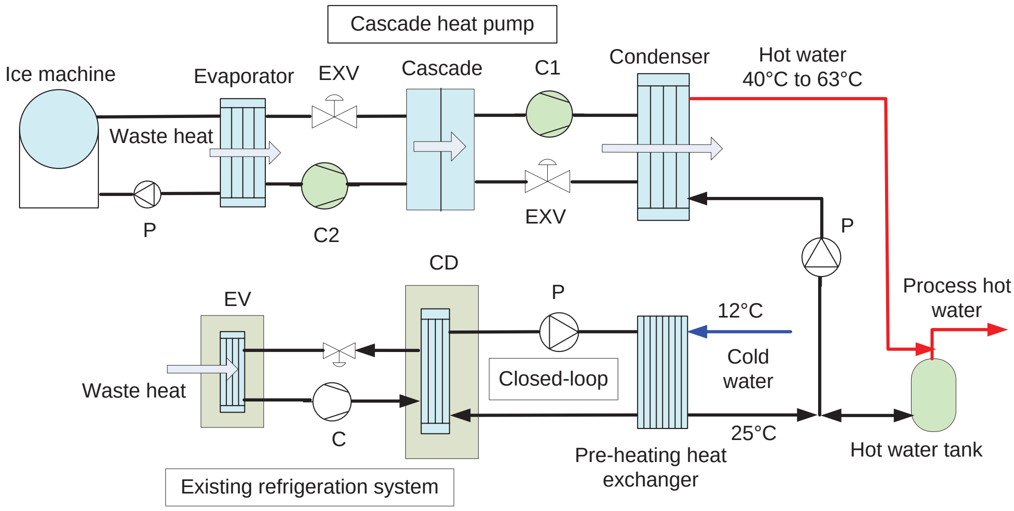


Figure 4-25: Schematic diagram of a cascade heat pump implemented in a Canadian poultry processing plant [Caddet]

The total investment cost of this heat recovery system (engineering, equipment, installation) was 165,000 US$ and natural gas annual savings of 330 m^3 have been achieved. The system overall COP has been estimated at 10.7, and the simple pay back period at 2.7 years [Caddet].

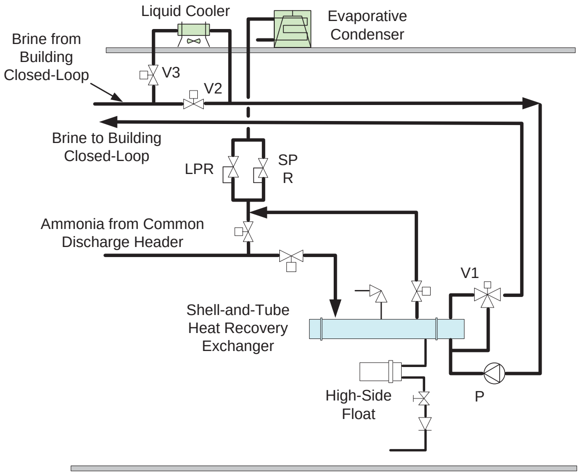
4.8 Cold warehouse

Ammonia refrigeration systems in small, medium and large cold storage warehouses operate with discharge and condensing temperatures that make it possible to efficiently recover heat normally rejected in the atmosphere by evaporative condensers. Heat recovered could be used for space (e.g. offices) and/or industrial hot water heating (e.g. neighbouring food processing plants).

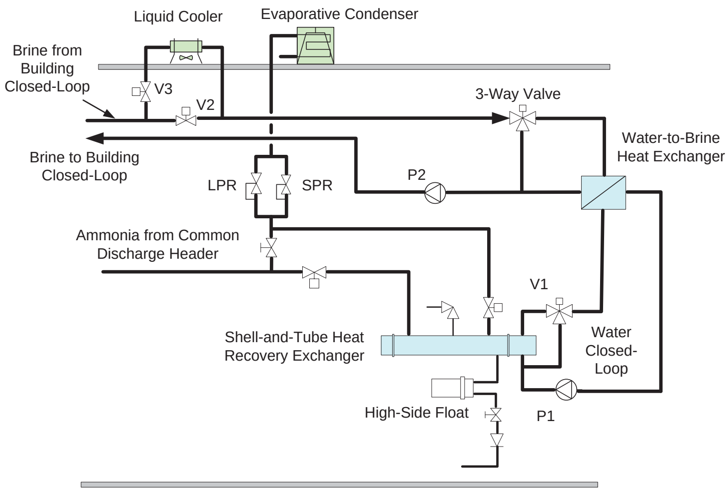
Such a heat recovery system was developed to recover heat from new retrofit ammonia compressors installed in a cold warehouse [Minea, 2007]. Five old ammonia compressors, which had reached the end of their useful life, were replaced with five new single-stage screw compressors having a total nominal refrigeration capacity of 1600 kW. Four of them operate at -33 °C, and the fifth one at -44 °C evaporating temperatures. Oil cooling and injection help keep the common discharge header at a relatively low temperature (around 52°C). During the week, all five new compressors operate simultaneously but, on weekends and holydays, only two compressors generally run 24 hours a day.

To recover part of the available heat rejected, i.e. 2361 kW, from the new ammonia compressor common discharge header, a two-stage heat recovery system with a desuperheater (as a first stage) and water-to-air heat pumps (as a second stage) installed in a closed loop, was designed. About 33.5 % of the available thermal power is recovered and used for heating a building service and office spaces with a total area of 12,250 m^2. When at least two compressors operate simultaneously, all the available sensible heat and up to 93.9% of the condensing enthalpy are recovered to meet 100 % of the building peak heating demand.

The desuperheater is a heat exchanger installed on the common discharge header of the five new single-screw ammonia compressors and 21 water-to-air heat pumps with nominal capacities varying between 2 and 8 refrigeration tons (1 ton = 3.517 kW) are connected to the building reverse closed-loop (Figure 4.26). In addition, two 22.3 kW (heating capacity) brine-to-water heat pumps are used for preheating industrial (washing) hot water for a neighbouring food processing plant (Figure 27). Each of these heat pumps uses 0.6 L/s of brine as a heat source flowing from the building closed loop at temperatures ranging between 15 °C and 25 °C. The maximum temperature of the process hot water leaving the system storage tanks may reach 70 °C.



OPTION A



OPTION B

Figure 4-26: Refrigeration section of the two-stage heat recovery system [Minea, 2007]; (a) option A; (b) option B; V: motorized valve; P: water or brine circulating pump; NO: normally open; NC: normally closed; LPR: large size pressure regulator; SPR: small size pressure regulator.

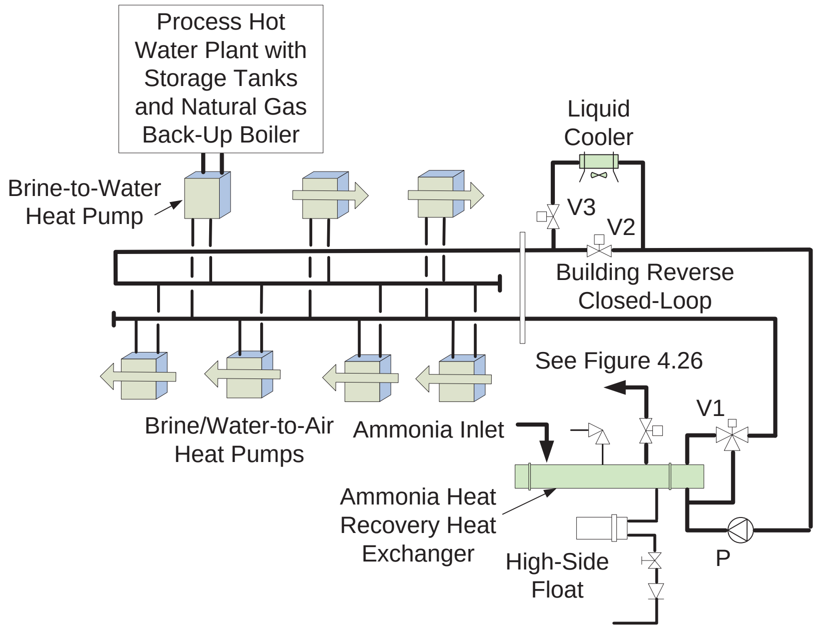


Figure 4-27: Configuration of the building brine closed loop [Minea, 2007].
V: 3-way motorized valve; P: brine circulating pump

4.9 Cooling towers

Relatively large amounts of low-grade waste heat are available in industrial cooling processes using cooling towers (or condensers). Cooling water entering the cooling towers at more than 30 °C year-around represents one of the most promising fields of application for industrial heat pumps. Several heat recovery system options have been studied and designed for a large Canadian metallurgical plant [Minea, 2006b].

In this metallurgical plant, exothermal chemical reactions occur in eight electrolytic reactors, while the evaporators and crystallizers are cooled by a water closed loop linked to three forced air-cooled cooling towers (Figure 4.28). The cooling water enters the cooling towers at an average temperature of about 40 °C and leaves them at 25 °C. The total flow rate of the cooling water is 2220 m^3/h, but about 1080 m^3/h are lost due to evaporation and 300 m^3/hr. due to purging [Salabery, 2003], [Salabery, 2004].

The heat recovery solution chosen was based on the assumption that 1066 m^3/h of cooling water, i.e. 48% of the total flow rate available on the site, would be used as a waste heat source for the plant heat pumps. In this case, two industrial water-to-water heat pumps are installed in parallel (Figure 4.29). By using about 4 MW of electrical input power, the thermal power recovered is 13.6 MW and the total thermal power delivered by the heat pump facility, is 17.6 MW. As a result, the total hot water flow rate supplied to consumers reaches 1536 m^3/h at a temperature of about 70 °C. The temperature of the return water is about 60 °C, and the heat recovery system overall coefficient of performance, is 4.33.

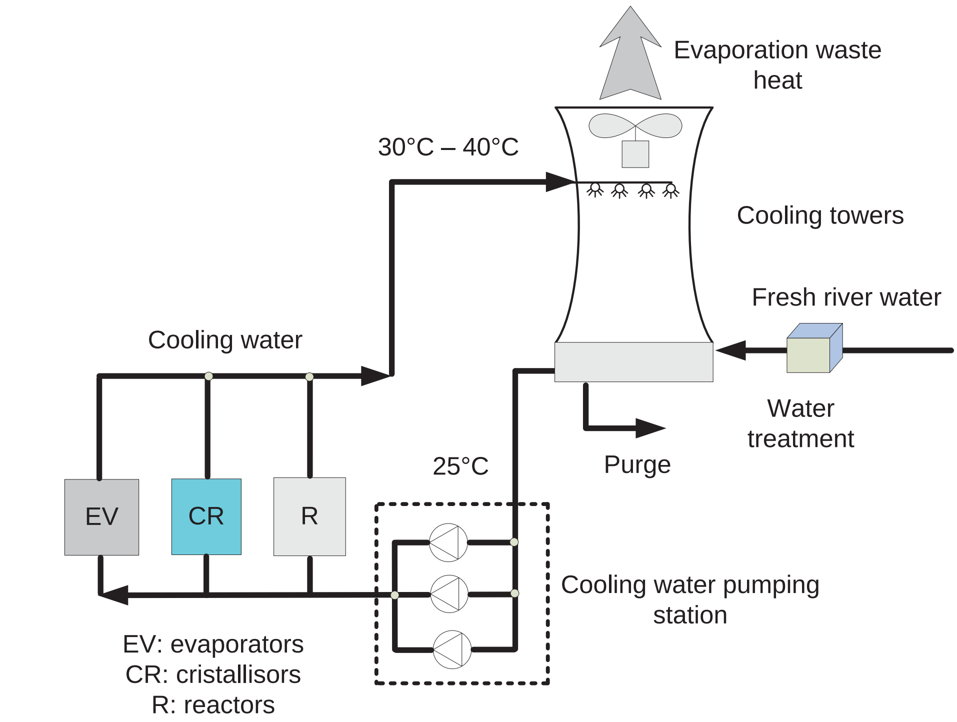


Figure 4-28: Schematic representation of the initial cooling water system of the plant [Salabery, 2003], [Salabery, 2004]

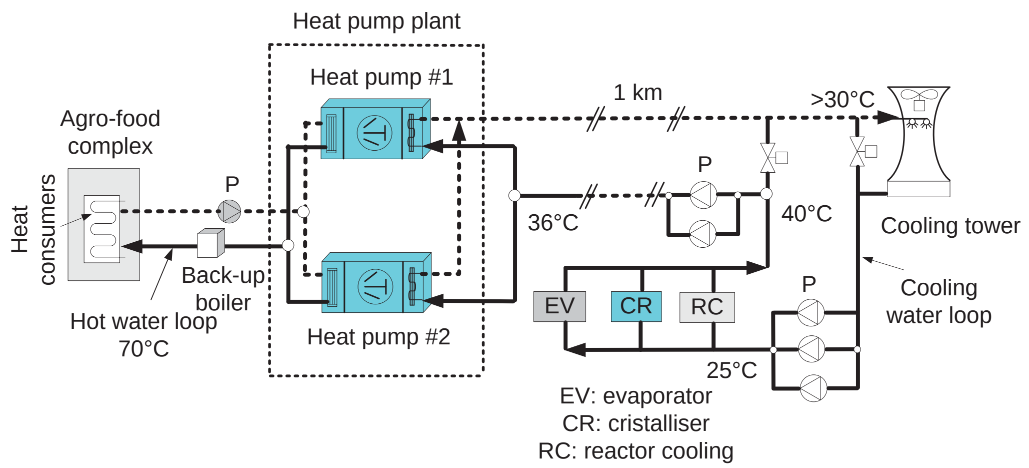


Figure 4-29: Heat recovery system with two parallel industrial water-to-water heat pumps at the agro-food complex [Minea, 2006]; P: water circulating pump

Another efficient option could integrate intermediate direct heat recovery heat exchangers and industrial heat pumps, as shown in Figure 4.30. In this case, the system could recover up to 100% of the available waste heat in order to meet all of the heating requirements of the industrial agro-food complex.

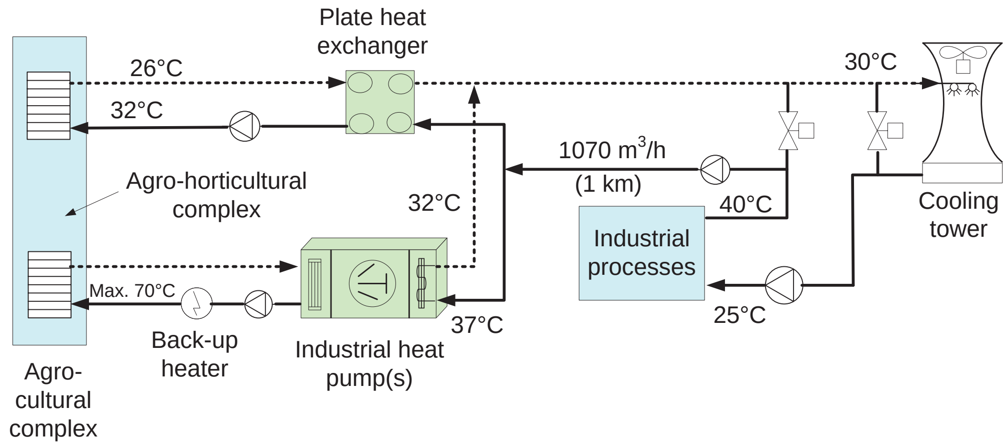


Figure 4-30: Combined heat recovery system with intermediate heat exchangers and industrial heat pumps at the agro-food complex [Minea, 2006b]

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5 Denmark

5.1 Hybrid heat pump at Arla Arinco

5.1.1 Summary

A heat pump of 1.25 MW was installed utilizing energy from 40° C cooling water – energy that was discharged to the environment prior to this project. The installed heat pump preheats drying air for milk powder to around 80° C through a water circuit.

The pay-back time of 2.3 years (1.5 years with energy grants included) indicates that large industrial heat pumps can be a profitable for both companies and society.

Another conclusion from the project is that engineering, design, construction, commissioning and operation of a heat pump plant of this size is comparable to that of industrial refrigeration plants.

5.1.2 Project information

Company	Arla Arinco
Location	Videbaek, Denmark
Process application	Drying air for milk powder
Type of heat pump	Hybrid NH_3/H_2O
Capacity	1.25 MW
Running hours	Approx. 7,400 per year
Year of operation	2012
Primary energy savings	Approx. 7.2 GWh per year
Reduction in CO_2 emission	Approx. 1,400 tonnes
Maintenance costs	Aprrox. 2 euros/MWh-heat
Manufacturer/supplier	Industri Montage
Pay back	1.5 years

5.1.3 Project characteristics and process design of installed system

The heat pump is installed in an application where ambient air is heated to 150 °C for drying milk powder. Previously this was done by a natural gas boiler. During the project the philosophy was to:

1. Minimize the energy demand
2. Incorporate direct heat exchangers as far as possible
3. Consider whether a heat pump is the best solution for the remaining energy demand

Following these steps it became obvious that the best solution would be a heat pump only doing part of the heating towards 150 °C. It was also noticed that pre heating of the ambient air was possible through direct heat exchanging utilizing cooling water from an evaporator. The installation was thus changed to consist of three stages where the first is preheating to 40 °C using cooling water, second stage is heating from 40-80 °C using the heat pump – also recovering heat from the cooling water and third stage is heating from 80-150 °C using the existing gas boiler. Due to fluctuations in cooling and heating demands, two buffer tanks have been installed eliminating variations in the cooling system and ensuring steady conditions for the heat pump.

The principle is shown on the figure below with the three heating stages on the right sight of the figure.

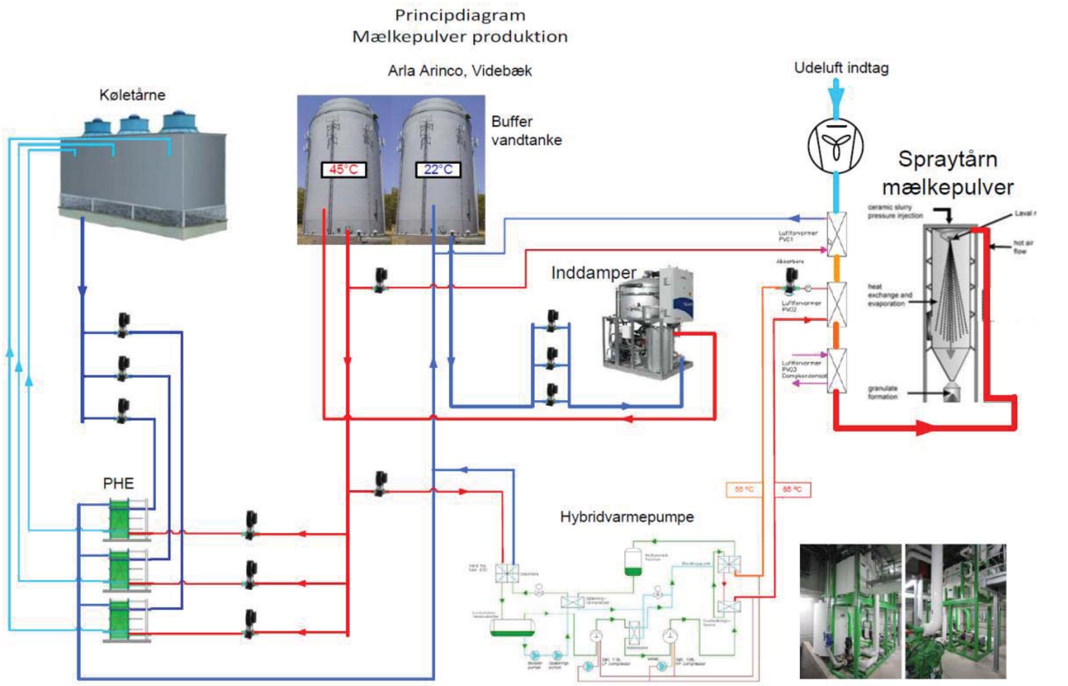


Figure 5-1: Principle

Existing cooling plants and NG boilers are kept for backup in case of failure or maintenance in the heat pump system.

5.1.4 Running experience, savings and economics

With a COP of 4.6 the heat pump approximately halves the energy cost compared to natural gas that is replaced. A high number of annual operation hours (around 7,400), ensures a considerable reduction in energy expenses. The analysis throughout the project also led to other energy reductions as well as direct pre heating of ambient air, thus the project as a whole caused substantial savings making this approach very profitable. Energy savings represent a tradable value in the Danish system for energy reductions. Because of the considerable amount of energy savings in this particular case, around half of the investment was financed through this value leading to a simple payback time of around 1.5 years and being very profitable from a life time perspective.

A few modifications were carried out during the first period of operation. This was primarily about the control strategy, where the heat pump itself and the surrounding part of the system did not correspond appropriate. Apart from this, the system has been functioning as planned.

5.1.5 Lessons learned and challenges

The owner is very happy with the system and the way this project was carried out. It has been clear that thorough energy analysis is crucial in these installations as reduced consumption and direct heat exchangers must be considered before installing heat pumps. This is very time consuming, but the direct savings found through this approach has paid for these working hours several times. If the analysis was not carried out the heat pump installed would have had twice the capacity and not be near as profitable.

5.1.6 Motive/grounds/rationale behind investment

Arla have ambitious goals to reduce energy consumption and CO_2 foot print. In order to assess possible solutions the company volunteered as a demonstration host in a heat pump project funded by the Danish Energy Agency. In this project a thoroughly energy analysis of the company's processes was conducted leading to direct energy savings as well as a basis for the heat pump installation.

5.1.7 Specifications of heat pump

Description	**Heat Pump**		**Back up**
Type	Two stage Hybrid NH_3/H_20		Gas boilers
Heating capacity	1,250 kW/unit (→°C, units)		
Cooling capacity	980 kW/unit (→°C, units)		
Power consumption	270 kW/unit (units)		
Heat source	Cooling water	45-20 °C 40 m^3/h	
Heat sink	Drying air (water circuit)	40-85 °C	
Refrigerant	NH_3/H_20 compression/absorption		
Compressor type	2 x standard reciprocating NH_3 compressors		
COP	4.6		
Operation hours	11,000		
Storage water tank	2 x 100 m^3	Temp 45-20 °C	
Manufacturer of heat pump	Industri Montage		
Supplier/consultant	Industri Montage		

5.2 NH_3 heat pump at Skjern Paper Mill

5.2.1 Summary

Skjern Paper Mill recovers waste heat from paper drying. The recovered heat is boosted to around 70° C using a heat pump and delivered to the district heating system in the city of Skjern. The paper mill use steam that is produced by natural gas boilers as a primary heat source. Apart from heat recovery at the drying process, heat is also recovered at the flue gas of the boilers. At the drying process heat is recovered through a combination of direct heat exchange and heat pumps. The heat pump system was put into operation in December 2012. Skjern Paper Mill supplies approx. 36,000 MWh of heat annually which equals 60 % of the consumption of the 3.000 households in the city of Skjern.

The heat pumps are installed at Skjern Paper Mill who also owns and operates the system. In this way the district heating plant has no operational responsibility for the heat purchased by Skjern Paper Mill.

5.2.2 Project information

Company	Skjern Paper Mill
Location	Skjern, Denmark
Process application	District heating
Type of heat pump	High pressure NH_3
Capacity	4.0 MW (5.4 incl. direct heat exchange)
Running hours	Approx. 8,000 per year
Year of operation	2012
Primary energy savings	Approx. 30 GWh per year
Reduction in CO_2 emission	Approx. 6.000 tonnes
Maintenance costs	Aprrox. 2 euros/MWh-heat
Manufacturer/supplier	Johnson Controls / Averhoff Energi Anlæg
Pay back	2.5 years

5.2.3 Project characteristics and process design of installed system

Skjern Paper Mill has been the developer of this project. The heat pump system recovers energy from moist drying air that was previously discharged directly to the ambient. Temperatures of the district heating system varies throughout the year but the district heating water is typically heated from approx. 37 °C to 68 °C. The moist drying air is between 50 °C and 55 °C with a relative humidity of 100 %. The temperature overlap between sink and source mean that the district heating water is preheated using a direct heat exchanger, while the heat pumps move energy in the temperature range which is not possible with direct exchange. The district heating network is coupled directly to the heat pumps and the system holds an accumulation tank to stabilize the production heat delivery. The heat pumps are three identical parallel coupled ammonia plants with a total output of approx. 4 MW. In combination with the direct heat recovery the total thermal output from the drying process is approx. 5.4 MW.

The principle is shown on the figure below.

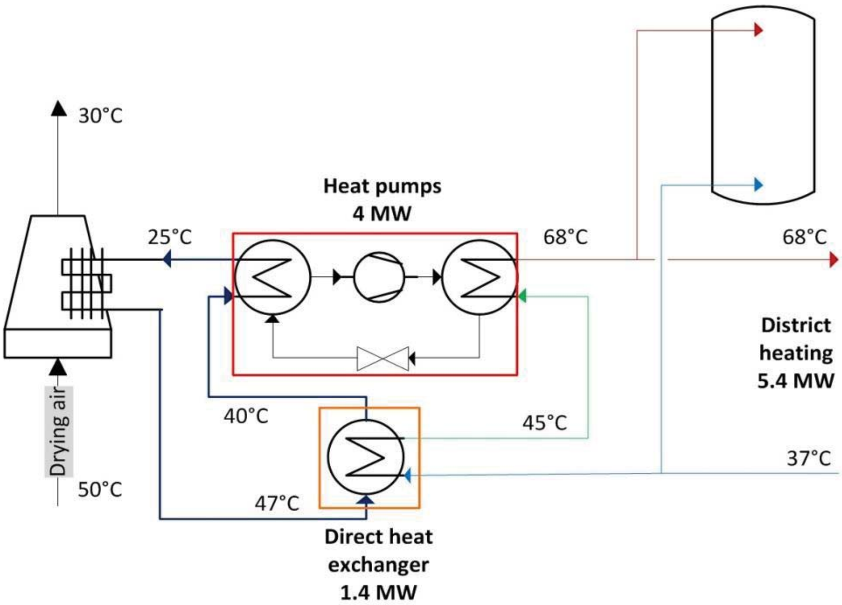


Figure 5-2: Principle

The district heating plant still holds the previous boilers as backup.

5.2.4 Running experience, savings and economics

Prior to installation of this system the Paper Mill and district heating company agreed on a fixed margin on top of the production cost. The Paper Mill guarantees a minimum COP of the system while the district heating company guarantees to purchase a certain amount of heat each year. This setup provides security for the investment at the Paper Mill, while the heat consumers in the city are guaranteed a low price for the heat.

The agreement between Skjern Paper Mill and Skjern district heating with this solid gross margin was settled in 2012 prior to commissioning of the plant in late 2012. In 2013 the tax system in Denmark was altered, meaning that a dynamic model of payment was preferable and chosen instead. In this approach the price is settled each month based on the actual production cost at the paper mill and the marginal heat production cost at Skjern district heating. The settlement price is always exactly in between, so that the profit at the paper mill corresponds to the savings at the district heating company.

5.2.5 Lessons learned and challenges

One of the components that have been particular important was the cooling surfaces, which cools moist drying air and recover heat. The air is corrosive and it was very important to find a product that can withstand aggressive environments. In addition the system is structured in a way which makes it possible to clean the heat exchanger in case of fouling.

One of the bigger challenges after start-up of the plant has been to ensure a delivery of heat from the paper mill to the district heating network. Due to unexpected stops such as a paper fracture that shuts the entire mill immediately when it occurs, it has been a challenge to ensure that there is no cold congestion in the district heating network. There have been some changes and adjustments in the first months after commissioning which solved the problems. Since the plant has not been operating for very long there is not sufficient experience of the service and maintenance to describe here.

The paper mill has become very aware of the temperature levels in the system as the heat pumps are an important source of income for the paper mill. In periods with extra high temperatures of the drying air or low temperatures in the district heating system, the COP of the total system have been as high as 11 while the capacity have been higher than the nominal 5.4 MW. The paper mill plans to establish a link between the heat pump system and the boilers. Heat recovery at the boilers happen at a much higher temperature than the district heating requires. By raising the temperature from the boilers and mix this with water from the heat pumps, COP and profit will be higher while the price of district heating is lowered.

5.2.6 Motive/grounds/rationale behind investment

The paper mill has ambitious goals to reduce energy consumption and CO_2 foot print. This solution meets these goals while being very profitable at the same time.

5.2.7 Specifications of heat pump

Description	**Heat Pump**		**Back up**
Type	3 x parallel coupled high pressure NH_3		Gas boilers
Heating capacity	1,335 kW/unit (→°C, units)		
Cooling capacity	1,065 kW/unit (→°C, units)		
Power consumption	270 kW/unit (units)		
Heat source	Drying air (water circuit)	40-25 °C	
Heat sink	District heating water	45-68 °C	
Refrigerant	NH_3		
Compressor type	3 x high pressure screw NH_3 compressors		
COP	5.0 (6.7 incl. direct heat exchange)		
Operation hours	10,000		
Storage water tank	1,250 m^3	Temp 37-68 °C	
Manufacturer of heat pump	Johnson Controls		
Supplier/consultant	Averhoff Energi Anlæg		

5.3 NH_3 heat pump at Knud Jepsen Nursery

5.3.1 Summary

Knud Jepsen is a Danish nursery with 120,000 m² green houses. The yearly energy consumption is 21 GWh of heat and 9 GWh of electricity. Heat and electricity is produced on natural gas CHP's, two oil boilers and one gas boiler. In the wintertime heat is added in the greenhouses and in the summer windows have to be opened to prevent high temperatures. Apart from the heat loss, opening the windows also allows pests to enter and CO_2 to escape.

The idea in this project was to utilize excess heat from the green houses via solar panels that can be angled to shade the greenhouses in warm periods. The solar panels are cooled by two heat pumps providing district heating for own use or for sale. Besides cooling the solar panels the heat pumps are also connected to flue gas coolers at the CHP's. The project was supported by the Danish Energy Agency and was initiated in 2012. The plants have been running since the summer of 2013 but as the heat pumps are only part of the installation concerning three different solar panel setups, focus so far have regarded the solar panels and operating experience of the heat pumps are not yet conclusive. A final report on the project can be expected within 2014.

5.3.2 Project information

Company	Knud Jepsen Nurcery
Location	Hinnerup, Denmark
Process application	Heating of green houses
Type of heat pump	40 bar NH_3
Capacity	2.0 MW
Running hours	?
Year of operation	2012
Primary energy savings	Approx. 3 GWh per year
Reduction in CO_2 emission	Approx. 600 tonnes
Maintenance costs	Aprrox. 2 euros/MWh-heat
Manufacturer/supplier	Johnson Controls / Averhoff Energi Anlæg
Pay back	?

5.3.3 Project characteristics and process design of installed system

The cooling circuit of the heat pumps is connected to both flue gas coolers and solar panels. The sink side is connected in series to the CHP's in order to use these for reheating after the heat pumps. The heat pumps take the heating water to around 60 °C while the CHP's increase the temperature to around 80 °C.

The system is sketched on the following figure:

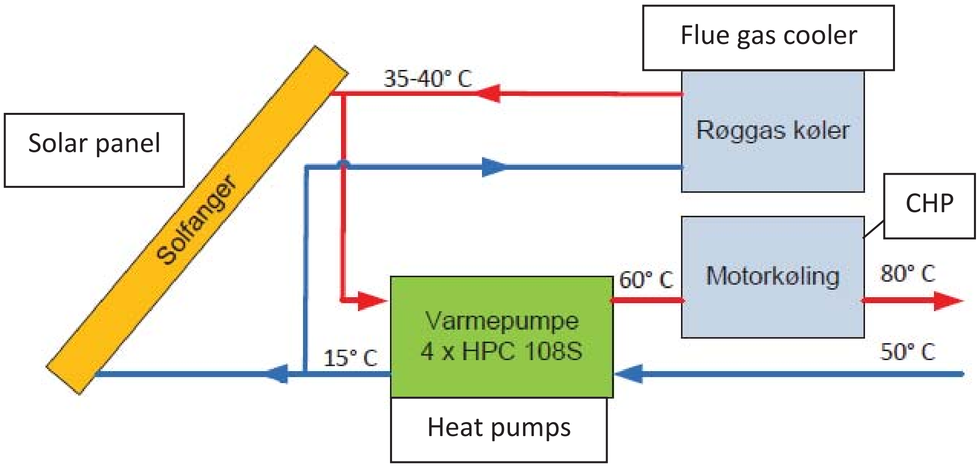


Figure 5-3: System

Depending on the solar radiation and capacity of the flue gas cooler, the cooling circuit is heated to around 35 °C. Utilizing the gas cooler enables the system to operate when there is no sun available. The water is heated through the heat pumps to 60 °C and then reheated to 80 °C in the CHP. The system is connected to two separate buffer tanks holding a total of 5,000 m^3. Two tanks allow separate storage of heat produced on heat pumps and CHP's, meaning that they can be operated individually to utilize fluctuating electricity prices.

The solar panels are fitted with wires so that they can be turned on or off like curtains whichever the plants in the greenhouse requires. In this way the panels can both collect the direct sun input and the convection heat from inside the green house.

5.3.4 Running experience, savings and economics

The system will reduce energy cost by lower heat production prices, reduced ventilation and less CO_2 consumption. The heat pumps have been running since the summer of 2013, but the system is not yet fully optimized as the fluctuating solar radiation and complex system layout require sophisticated control strategies. Due to this, economics and operating experience of the heat pumps are not yet conclusive. A final report on the project can be expected within 2014.

5.3.5 Motive/grounds/rationale behind investment

The project was initiated to reduce gas consumption and heat production cost due to low prices of electricity. Cooling of the greenhouses allow less ventilation thus less CO_2 consumption, which again reduce the gas consumption.

5.3.6 Specifications of heat pump

Description	Heat Pump		Back up
Type	2 x parallel coupled 40 bar NH_3		Gas boilers
Heating capacity	1,000 kW/unit (→°C, units)		
Cooling capacity	750 kW/unit (→°C, units)		
Power consumption	250 kW/unit (units)		
Heat source	Solar panels and flue gas	35-10 °C	
Heat sink	Water	50-60 °C	
Refrigerant	NH_3		
Compressor type	40 bar 8 cyl. reciprocating NH_3		
COP	4.0		
Operation hours	?		
Storage water tank	2 pcs. total 5,000 m^3	Temp 60 and 90 °C	
Manufacturer of heat pump	Johnson Controls		
Supplier/consultant	Averhoff Energi Anlæg		

5.4 Heat pumps in industrial washing applications

5.4.1 Summary

KSN Industries have been part of an R&D project developing heat pumps for the washing plants that KSN have been manufacturing for a number of years. KSN has seen an increasing focus from customers about energy optimization of production equipment. The washing processes are quite energy intensive and as they are usually electrically heated, there is a savings potential on energy cost. The project was carried out by KSN Industries, Grundfos and a number of advisers. Grundfos is the end user of a large number of these washing plants and very interested in this heat pump concept.

Through this project a demonstration plant was built and tested and it was verified that heat pumps in these applications can reduce energy consumption by 50 %. The heat pump is installed at one of Grundfos' washing plants in Bjerringbro. It recovers waste energy from the exhaust and recycles it back into the water of the same plant. The prototype is developed by the Danish Technological Institute in cooperation with KSN and the main challenges were finding suitable components, effective heat transfer and an optimal control system.

Other targets of the project were to uncover the potential for heat pumps in different types of washing processes and to disseminate this knowledge to manufacturers, energy consultants and end users.

5.4.2 Project information

Company	Grundfos
Location	Bjerringbro, Denmark
Process application	Washing metal items
Type of heat pump	R134a
Capacity	25 kW
Running hours	Approx. 5,000 per year
Year of operation	2011
Primary energy savings	Approx. 100 MWh per year
Reduction in CO_2 emission	Approx. 20 tonnes
Maintenance costs	Aprrox. 2 euros/MWh-heat
Manufacturer/supplier	KSN Industries
Pay back	2.5 years

5.4.3 Project characteristics and process design of installed system

The project focuses on washing plants for production companies where the washers are used to clean metal or plastic items after machining processes. The washers are typically located in direct continuation of processing machines, where the items are cleaned to remove oil residues and possible dirt from the machining. After washing the items are dried and proceed to further processing or assembly into the final product.

The idea is to design the heat pumps as independent units that can be applied in both existing and new plants. The heat pumps are located in their own cabinet and connected to washing plants via hoses or pipes. This requires only minimal interference with the washing plant, while the heat pump can be flexibly positioned near the washer.

The most common type of the washing plants are called “run through washers” as the items are led directly through after processing. The items are transported through the washer via a belt or a drum. The machines typically hold two washing areas – one with soapy water and one with rinsing water. And finally a drying zone. The picture below shows a “run through washer”.

Figure 5-4: „Run through washer"

Metal items leave the pressing machine on the right where they enter the washer and then exits on the left clean and dry. At the top right side of the washer is a ventilation system that removes moist air and keeps a slight negative pressure in the machine. This eliminates unwanted condensation around the machine.

The principle is illustrated in the figure below. However, with a flipped flow direction compared to the picture above.

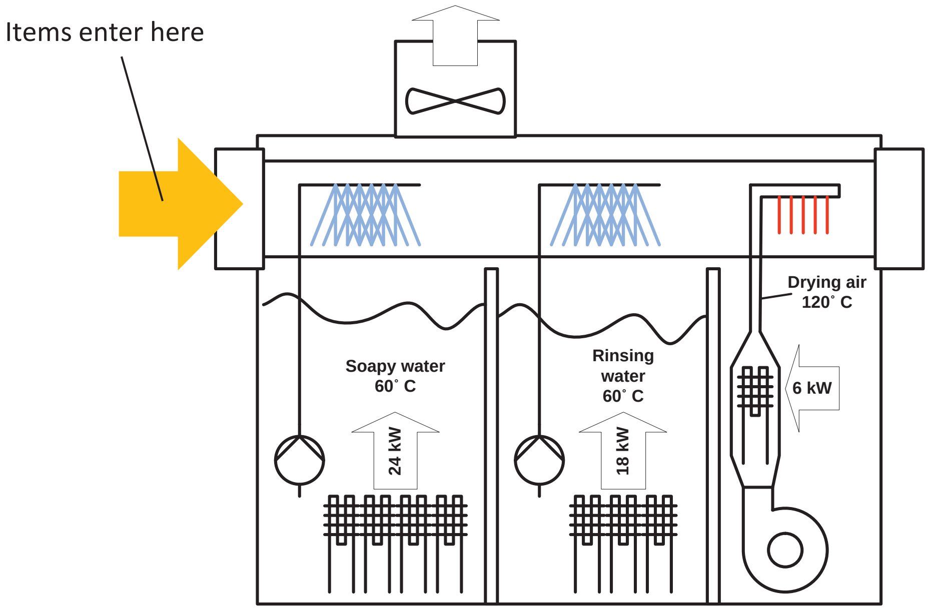


Figure 5-5: Principle

To maintain the set temperature of 60 °C in the two tanks, the washing plant is equipped with electrical heaters consuming a considerable amount of energy.

5.4.4 Implementation

In order to dimension the heat pump correctly it was important to know the exact energy consumption (and thereby average heat required) of the specific washing plant. The average energy consumption was logged during a representative period and the average heat demands of the two tanks were measured to 8 and 17 kW respectively.

To minimize refrigerant charge and risk of leaks, the entire cooling circuit is assembled inside the heat pump cabinet so that only hot and cold water enters the cabinet. A schematic drawing of the heat pump and washing plant is shown on the figure below:

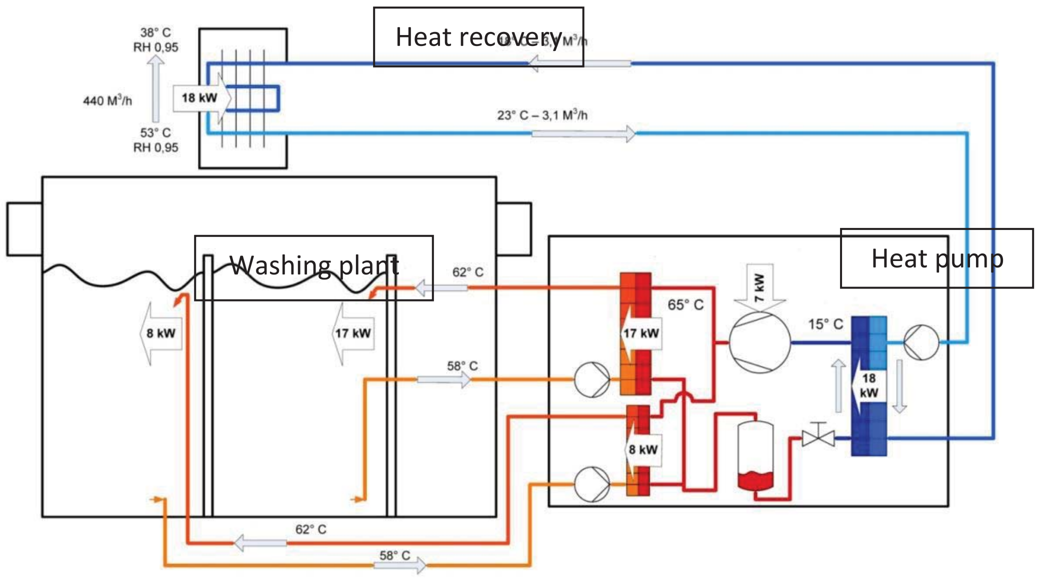


Figure 5-6: Principle

The two condensers in the heat pump are each connected to a tank at the washing plant. The evaporator is connected to a cooling surface that is installed at the filter mist of the washer.

The picture below shows the heat pump that is located next to a pressing machine and is connected to the washing plant through water pipes.

Figure 5-7: Heat pump

To verify the energy savings from the use of the heat pump, energy data for the washing process was recorded daily. In order to do a fair comparison it was important that the metal parts were the same throughout the period. At the same time, it is ensured that the water supply and temperatures are identical.

The results were showing that the heat pump reduced the total power consumption from approx. 31 kW to 15.7 kW equaling a reduction of 49 %. The heat pump has been tested under fluctuating conditions, and it has been proven that the chosen concept and control method have been successful. At the same time, it was proven that the expected energy savings of approx. 50 % can be achieved.

The cooling coil was expected to foul and lose capacity after a longer period of operation. This however has not happened. The coil has been inspected visually and still looks brand new. It is expected that the large amounts of water condensing at the cooling surface flushes dirt or particles off of it, thus cleaning it continuously.

5.4.5 Running experience, savings and economics

The demonstration project has shown that it is possible to apply heat pumps to halve the energy consumption of industrial washing plants. The function of the washing plants is very important for many manufacturing companies. Because of this the plant functionality has always been more interesting than low energy consumption, and it is only during the past few years, that the high energy consumption has been addressed. These washers have an average electrical consumption of 20-80 kW. With a high number of operating hours there is an economic incentive to reduce this consumption. Simple pay back periods will often be around 2 years. It is expected that there are about 3000 plants in Denmark alone.

5.4.6 Lessons learned and challenges

Throughout the project it became clear that correct dimensioning of the heat pumps and control strategy is important, however easy to assess following the correct approaches. In general these heat pumps are simple, easy to apply and reliable.

5.4.7 Motive/grounds/rationale behind investment

Most production companies have ambitious goals to reduce energy consumption and CO_2 foot print. These solutions meet these goals while being very profitable at the same time.

5.4.8 *Specifications of heat pump* (depending on application)

Description	**Heat Pump**		**Back up**
Type	Standard R134a using two condensers		Electrical heaters
Heating capacity	25 kW/unit (→°C, units)		
Cooling capacity	18 kW/unit (→°C, units)		
Power consumption	7 kW/unit (units)		
Heat source	Drying air (water circuit)	55-30 °C	
Heat sink	Washing water	60 °C	
Refrigerant	R-134a		
Compressor type	Copeland Scroll		
COP	3.8		
Operation hours	15,000		
Storage water tank	None		
Manufacturer of heat pump	KSN Industries		
Supplier/consultant	KSN Industries		

6 France

Industrial Heat Pump References

Industrial Sector	Sub sector	Starting	Working fluid	Thermal power kW	T Need °C	COP	Compressor	ROI
Food Industry	Cooked food	2012	R717	1000	65	4/5	reciprocating	~ 4 ans
	Milk	2011		1500			Screw	
	Meet	2011		1000			Reciprocating	
	Milk	2011		1200			Screw	
	Meet	2011		1000			Reciprocating	
	Meet	2011		800			Screw	
	Milk	2010		1200			Reciprocating	
	Milk	2013		?			Screw	
Tertiary	Heating Network	2013	Synth	6000	90		Centrifugal	
		2013		1000	65		screw	

7 Germany

7.1 Introduction

As reported in Task 3, thermea. Energiesysteme GmbH (www.thermea.de) developed high-temperature high-power heat pumps with the refrigerant carbon dioxide. Since 2011 they were introduced to the market and since that time the company sold and put into operation a greater number of the machines.

In the actual report two selected applications are described to illustrate the energy and environmental benefits of CO_2 as natural refrigerant.

7.2 Heat Pump Plant at the Slaughterhouse Zurich

7.2.1 General

On 1 November 2011, a new thermeco$_2$ heat pump system for hot water generation and heating was put into operation in the slaughterhouse Zurich. With a capacity of 800 kW, the plant is the largest ever built in Switzerland. The thermeco$_2$ machines deliver the required 90 °C with better COPs compared to other refrigerants. The heat pump system is built up of 3 heat pumps thermeco$_2$ HHR 260.

Figure 7-1**Fehler! Verweisquelle konnte nicht gefunden werden.** shows the schema of his plant. The heat pump uses waste heat of an existing Ammonia refrigeration machine, an oilcooled air compressor plant and the installed fan-coil units as heat source. For this reason the heat is collected in a waste heat buffer storage connected with the heat pump evaporators. Because of the closed waste water circulating loop no special measures to avoid corrosion are necessary.

The warm side of the heat pumps is connected with a hot water buffer storage. The consumer (warm water for slaughtering and cleaning purposes, feed water for a steam generator and the heating system) are provided from this buffer storage using their consumer pumps tailored to the particular demand.

Because of the extremely low space requirement, this large heat pump system could be installed in a container system on the roof of the slaughterhouse in a short distance to urban residential development. Only authorized personal has access to the container and CO_2 sensors have been installed that activate an alarm when healthy concentration levels are exceeded.

7.2.2 Technical data:

Refrigerant:	R744 (carbon dioxide)
Machine type:	3 x thermeco$_2$ HHR 260
Capacity control via master CPU:	adjustable in 12 steps
Total heating capacity:	800 kW at 90/30 °C
Total refrigerating capacity:	564 kW at 20/14 °C

Electrical power consumption:	237 kW
Heat pump COP:	3.4
Annual heating output:	2200 MWh
CO_2 emission reduction:	510 tonnes/year

CO_2 has the advantage of minimal safety requirements. The avoidance of costs for foundations and noise control measures is due to the low-noise and low-vibration operation of the thermeco$_2$ machines.

The risk for leakage is considered small by the customer as the installed system has been certified and optimized for high pressures. A fine performance graduation without loss of efficiency and the high reliability are further advantages of the technology supplied. Maintenance and repair costs for the heat pumps are also low due to the use of virtually maintenance-free compressors and the remote monitoring and control system.

7.2.3 Energetic and environmental improvement by the heat pump application

All of the thermal energy for the slaughterhouse Zurich was previously provided with steam boilers. The customer's decision for a high temperature heat pump system with CO_2 as a refrigerant on this scale had several reasons. The efficiency advantages of the high temperature heat pump system clearly have priority. Running this heat pump plant the city of Zurich, represented by the Umwelt- und Gesundheitsschutz Zürich (UGZ) and the Elektrizitätswerk Zürich (ewz) as Contractor make an important contribution towards the "2000 Watt Society" of the city of Zurich. In the calculated overall balance of the slaughterhouse, CO_2 emissions can be reduced by approx. 30 %. By using the heat pump system, 2,590 MWh from fossil fuels can be saved per year, representing an annual reduction in CO_2 emissions of 510 tonnes.

The first measurements show that these values are lifelike. The operating company ewz and thermea will do further measurements and register all running costs as a basis of a long time evaluation.

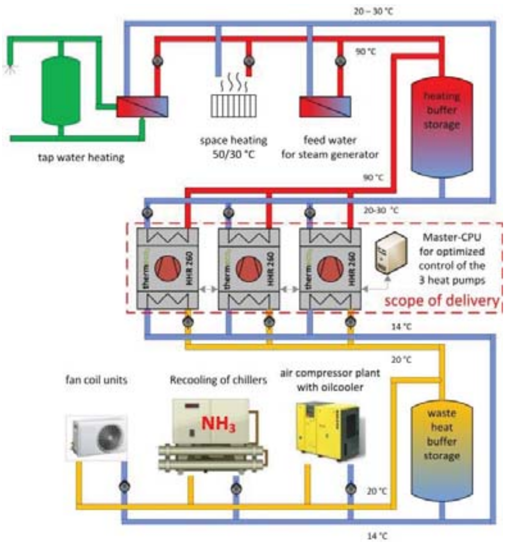


Figure 7-1: Function chart

7.3 Heat Pump Plant at the cafeteria at the University of Applied Sciences Soest, Germany

7.3.1 General

Using the example of the cafeteria at the University of Applied Sciences Soest with year-round warm water and occasionally heat supply by heat pump, 25% of heat costs are saved to the utmost satisfaction of the customer. Furthermore, the environmental impact was reduced to approximately 50%.

7.3.2 Technical Description

For the solution of the task, the machine type thermeco$_2$ HHR 45 in water/water conduction was selected in cooperation with the planner. It is the smallest type of thermeco2 HHR series, which consists of 10 basic types in the power range from 45 to 1,000 kW.

The high-temperature heat pump usable as a heat pump and for cold water/cold brine production is characterized by a robust design and a very compact construction. The machine is equipped with a frequency-controlled semi-hermetic reciprocating compressor operating on a transcritical CO_2 cycle with an internal heat exchanger. The special conduction with a frequency converter allows continuous power control with optimum adjustment of the supplied power to the power requirements.

The inner heat exchanger ensures high refrigerant inlet temperature into the compressor and with it also high outlet temperatures, which allow supply temperatures up to 90° C. In addition, some improvement in the coefficient of performance is achieved with the internal heat exchanger. The refrigerant injection into the evaporator is effected, as usual, by controlling the refrigerant superheat at the evaporator outlet. In addition, there is required a regulation of the high pressure, which is at transcritical process control determined by the refrigerant mass located on the high pressure side. The refrigerant receiver is installed on intermediate pressure level between the high-pressure control valve and the expansion valve. All the heat exchangers are designed as shell and tube devices, or in the lower power range, as a coaxial construction.

The hot water supply temperature is adjusted by a variable speed pump to the adjustable set point. Also with the variable speed pump in the heat source circuit it is possible to adjust to a constant chilled water supply temperature of 10 ° C.

A PLC integrated into the switchboard with a convenient touch panel takes over the control and regulation. The start screen of the touch panel displays the most important state variables. Additional sensor and control signals can be requeried via an appropriate menu. Even via the touch panel, the parameterization of the heat pump (performance, temperatures, pressure) within the permissible limits is possible. Error messages or exceedances are recorded in a message list.

The heat pump is equipped with all necessary safety devices for a safe operation according to DIN EN 378-2.

The main technical data are listed in Table 7-1.

Table 7-1: Technical Parameters

➢ Machine type	1 x thermeco$_2$ HHR 45 mit FU
➢ Heating capacity	52,7 kW at water inlet/outlet temperature 20°C / 80 °C at gas cooler
➢ Cooling capacity	39,1 kW at water inlet/outlet temperature 12 °C / 6 °C at evaporator
➢ Electr. power input	14,3 kW at abovementioned water temperatures
➢ COP	3,7 at abovementioned water temperatures

7.3.3 Integration of the heat pump into the heat supply

The exhaust air from the ventilation system of the canteen and the waste heat of the industrial refrigeration system function as a heat source. The exhaust air registers and the heat recovery of the chiller are integrated in series to the heat source circuit (Figure 7-2).

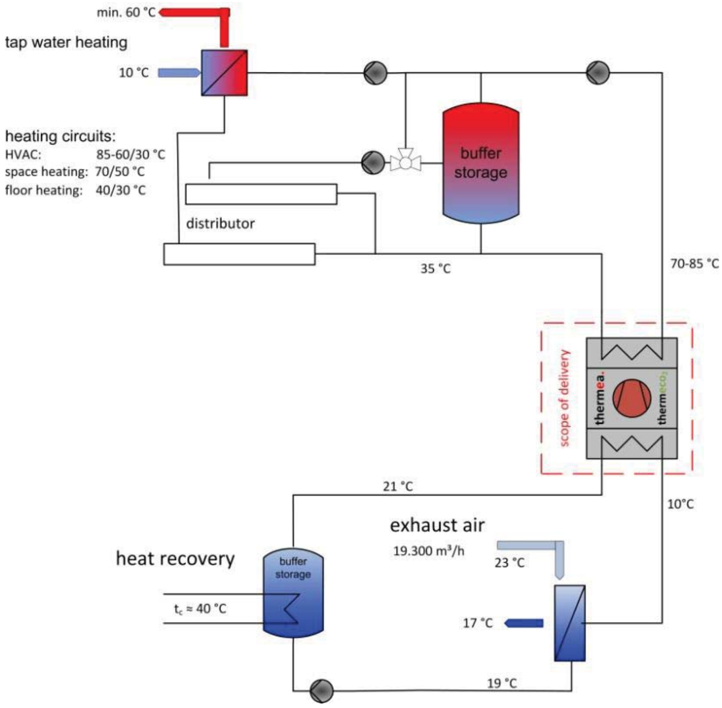


Figure 7-2: Function chart

The heat pump extracts heat from the source circuit, raises heat – depending on request - to a temperature level of 70° C to 85° C and loads hot water buffer storage. The storage decouples the overall system hydraulically and thermally.

The heat pumps works heat-conducted that means it is controlled by the charge state of the hot water storage. Demand-actuated, the consumer removes water for the heating distribution in the central section, while the water supply is coupled through an additional heat exchanger to the upper section of the storage. The planned consumer´s return temperature was on average 35 °C. By series connection with a floor heating at the end of the circuit, the return temperature could be lowered to about 5 K (measured values).

The heat pump system is running since March 2011 and operates reliably. In the future it will cover about 2/3 of the heat demand (Figure 7-3, yellow area). Moreover, the reduction of heat losses in the district heating network can be seen (Figure 7-3, red area). In summers, power losses do not occur any more. The achieved reduction of heat demand in the heating season 2010/2011 (Figure 7-3, blue area) is the result of previous modernization measures.

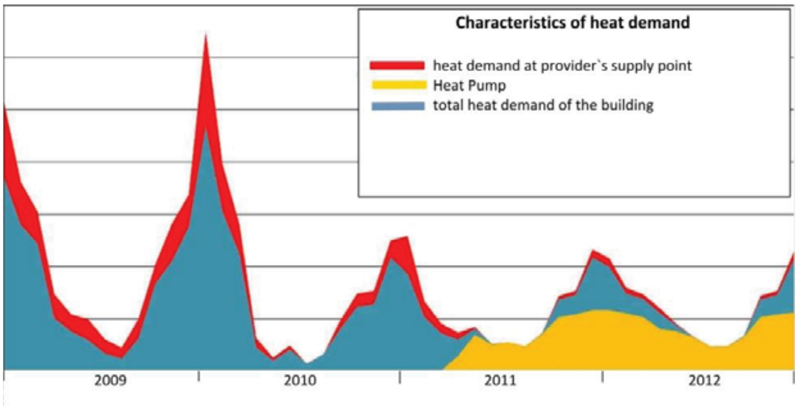


Figure 7-3: Gross margins of the heat pump

7.3.4 Heat cost savings and CO_2 emissions

In Figure 7-4 can be seen that the relatively high share of capital-bound costs is compensated by the lower consumption-bound costs. Taking into account a reasonable additional expense for maintenance of the heat pump, the annual full cost advantage is (including capital costs) for 15 years: 4.100 € / a. That means a saving of about 25 %. Basis for the calculation are heat costs from the district heating network to an amount of 70 €/MWh and 140 €/MWh of electric energy costs.

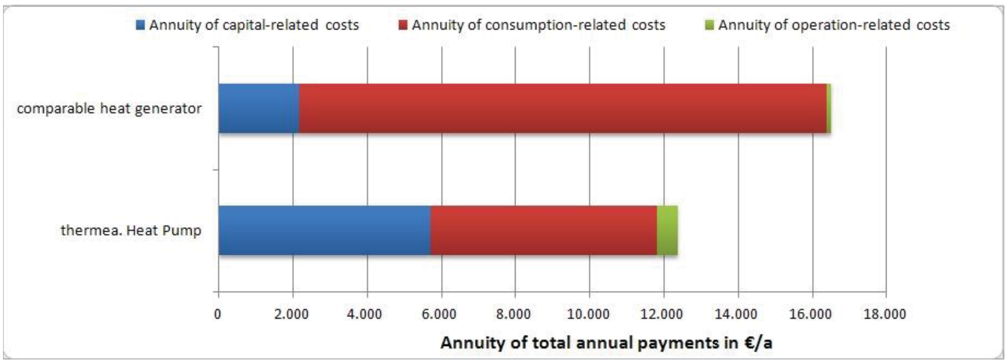


Figure 7-4: Comparison of costs

The specific CO_2 emissions in the heat supply from the district heating network are 0.39 kg CO_2/kWh. With the heat pump this value is reduced to 0.2 kg CO_2/kWh. That means approximately a halving.

The TEWI calculation according to EN 378-1 was made without consideration of the direct proportion with a conversion factor of 0.63 kg CO_2/KWh, and a seasonal performance factor of the heat pump of 3.2 for a lifetime of 15 years. The calculated emission for the heat pump is 400 tons of CO_2, while the district heating supply causes an amount of 790 t CO_2 for the same period. Thus, the use of heat pumps brings environmental discharge of 390 tons of CO_2.

7.3.5 Initial operating experience

After an operating time of about 2 years, there is satisfaction of the end user and the planner. The expectations regarding the technical parameters and the operating behavior are fully met and even exceeded them.

Figure 7-5 shows the behaviour of the most important temperatures over a period of 18 hours. The start of heating at 4 o´clock and the cafeteria´s closing at 16 o´clock are clearly visible. The temperature of the hot water forerun on the heating side is constantly 75 °C, while the return temperature varies according to the storage loading condition.

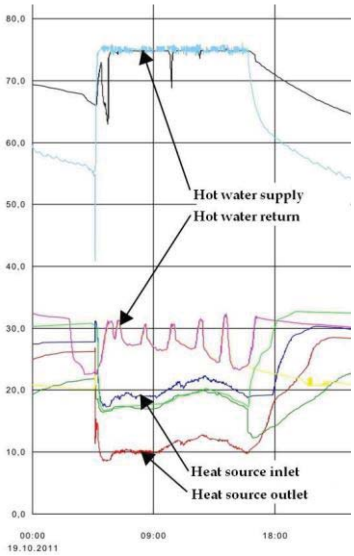


Figure 7-5: Selected temperatures

Additionally recorded curves are measured for control in the storage or in selected areas of the heat exchanger. The black curve of the hot water forerun represents the temperature behavior in the hot water storage above.

During the start-up time the behavior of the COPs at different operating states was precisely analyzed. It can be recognized that the COP is well above 3,5 at current operating conditions, heat source 20 °C / 10 °C at the evaporator and hot water 30 °C / 75 °C at the gas cooler. The coefficient of performance reaches a value of 3.2 as yearly average value.

The operator figures the major advantage of the heat pump thermeco$_2$ in comparison to other "conventional" machines in its flexibility. The heat pump can cover both evaporator and gas cooler-side an enormous temperature range, so that reserves for extreme operating conditions are always available. For example, in cold application a too small-sized cooler can be compensated by raising the flow just for a short time.

7.4 Summary

The two examples described show that at the current state of development of components for CO_2 as a refrigerant it is possible to build and operate reliable and energy-efficient high-temperature heat pumps. For the user the choice of CO_2 as a refrigerant means investment security because it is not affected by the increasingly stringent regulations of the so-called F-gases.

7.5 Heat pump installation in food and beverage industry: Dairy

(by P. Nellissen, Emerson Climates Technologies)

7.5.1 Background

Milk manufacturing process requires heating capacity for the process or also for some cleaning (pasteurisation, sanitary water, etc.). At the same time cooling capacity is required for some stage.

Norway's Dairy Cooperative Tine built a large new dairy in the Jæren region in the south west of Norway. It will be a gigantic facility covering 27,000 square meters, producing 200 million litres of milk annually mainly producing butter and cheese. Like most other industrialised processes, this facility will produce large amounts of waste heat. The concept was to initially install systems allowing heat recovery and also reducing CO_2 emissions by 30 - 40 % with this new dairy.

7.5.2 Company information

Category of industry Company	Food and Beverage processing: Dairy (butter and cheese)
Location	Jaeren, Norway
Year of installation	2011
Purpose	Heat recovery for hot water generation
Amount of production	200 million litres milk per year

7.5.3 Installed system

The heating plant is designed for not only fulfilling the dairies own demand of CIP water but is also connected to a local heating network which supply the heat to an adjacent new build green houses, which will be supplying 40 % of the cucumber and tomatoes to the Norwegian market. The heating system in the greenhouses are designed for a supply water temperature of 58 °C, this can be achieved with a heating COP above 9,0.

Using the waste heat to generate 25,000 MWh of cheap heat per year for the nearby greenhouses has secured a payback of the plant of less than 2.5 years. There are plans for connecting a local business estate to the heating network and increase the supply temperature to 73°C within the next couple of years. The heat pump is prepared for this increase in supply temperature.

Following capacities is required based on 3 low stage and 2 high stage compressors.

- 5400 kW @ -5°C required refrigeration duty, Condensing +37ºC
- 7200 kW @ 73°C required heating duty – COP 5.8
- 6900 kW @ 58°C required heating duty – COP 9.0

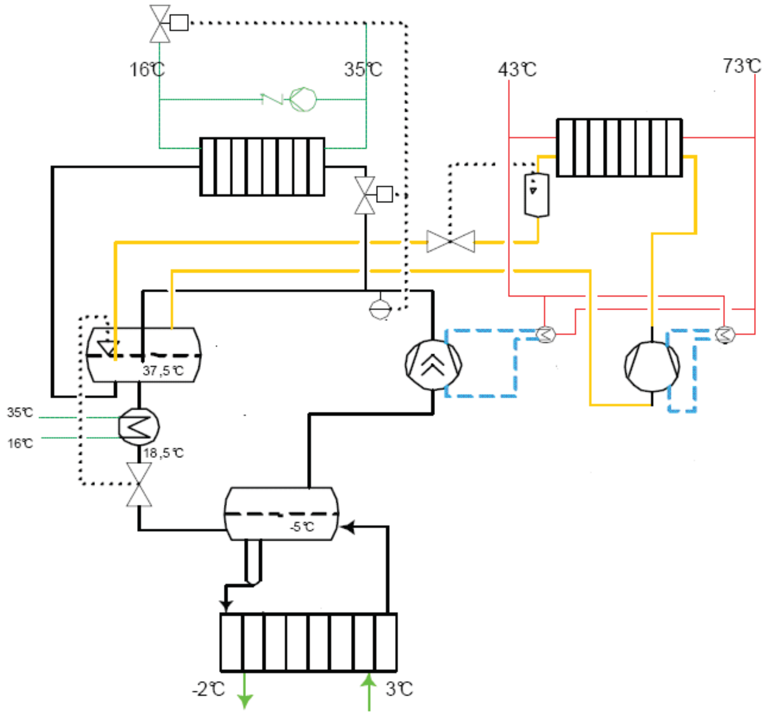


Figure 7-6: Configuration diagramme

Figure 7-7: Equipment appearance

7.5.4 Specification of Heat Pump system

The concept of the installations consists in combine cooling and heating systems. On one side, the cooling installation provides the cooling duty for the butter and cheese manufacturing process. On the other hand, the rejected heat from the refrigeration installation is used as heat source for the Neatpump.

Description	Heat Pump	Back up
Type	Combine heating and cooling installation	

Heating capacity	3450 kW(3600 kW)/unit (37.5→58 (73°C)°C, 2 units)		Boiler
Cooling capacity	760 kW/unit (-5°C→37.5 °C, 3 units)		
Power consumption	kW/unit (units)		
Heat source *Description and temp*	Condenser of the refrigeration installation	Temp 37.5°C °C	
		m^3/h	
Heat sink *Description and temp*	Hot water for the process and also for greenhouse heating	Temp. 58°C or 73°C	
		m^3/h	
Refrigerant	Ammonia		
Compressor type	Single Screw compressor		
Rated power of compressor			
COP	5.8 at 73°C and 9.0 at 58°C		
Operation hours			
Storage water tank	m^3	Temp. °C	
Targeted floor dimensions			
Manufacturer of heat pump	Star Refrigeration Ltd		
Supplier/consultant	Emerson Climate Technologies GmbH, Norsk Kulde		

7.5.5 Effects

NOT AVAILABLE AT THIS TIME

7.5.6 Challenges and prospects

This kind of installation proves that combined heating and cooling with an ammonia heat pump is a very attractive solution among existing only heating system.

This allows savings not only for heating cost but also

- in term of CO_2 emissions,
- in term water consumption
- On the total cost of energy per units manufactured
- for the future, the threat (F-Gas regulation in Europe) of using HFC in the refrigeration installation.

Combined heating and cooling can be applied on any industrial process requiring cooling and heating on different steps in their manufacturing process.

7.6 Heat pump in Food and Beverage industry - Combine heating and cooling in chocolate manufacturing

(by P. Nellissen, Emerson Climates Technologies)

7.6.1 Background

The existing cooling installation was using R22 as refrigerant which would be banned in the coming years. Previously one central coal fired steam generation plant served all of the individual end users, where high grade steam would be degraded to suit the processes. The Nestlé Halifax team completed an energy audit on their central coal fired boilers, the steam distribution and all of the end user heating systems throughout the factory. This enabled the team to clearly identify, grade and consolidate the various end user heating requirements which identified significant design and operational inefficiencies. The new concept was to simply heat the water to the desired process temperature and the heat pump would serve to provide hot water to end users requiring 60 °C and to preheat those operating in excess of 60 °C.

In parallel, the existing cooling installation, using R-22, would also have to be revamped because of the R22 future ban. Nestlé's global commitment to reduce the environmental impact.

7.6.2 Company information

Category of industry Company	Chocolate manufacturing Nestlé UK Ltd
Location	Halifax, UK
Year of installation	2010
Purpose	
Amount of production	2 x 600 kW

7.6.3 Installed system

Previously one central coal fired steam generation plant served all of the individual end users, where high grade steam would be degraded to suit the processes.

The chocolate manufacturing process also requires cooling capacity for certain steps of the process. These simultaneous demands for cooling capacity and heating capacity allowed the replacement of the heating and the cooling system by a combined cooling and heating installation. The idea was to install a Single Screw compressor Heat Pump combining Heating and cooling.

The Heat source consists in cooling process glycol from 5°C down to 0°C this evaporates Ammonia at -5°C and the heat pump lifts it to 61°C in one stage for heating. Process water is finally heated from 10°C to 60°C.

Based on the clients previously measured heating and cooling load profiles the analysis showed that to meet the projected hot water heating demands from the 'Total Loss' and Closed Loop' circuits, the selected heat pump compressors would have to produce 1.25 MW of high grade heat. To achieve this demand the equipment selected offers 914 kW of refrigeration capacity with an absorbed power rating of 346 kW. The combined heating and cooling COP, COP_{hc}, is calculated to be a modest 6.25. For an uplift of 17 K in discharge pressure the increase in absorbed power was 108 kW boosting the COP_{hi} to an impressive 11.57.

The diagram below describes the lay-out of the installation with the combined heating and cooling.

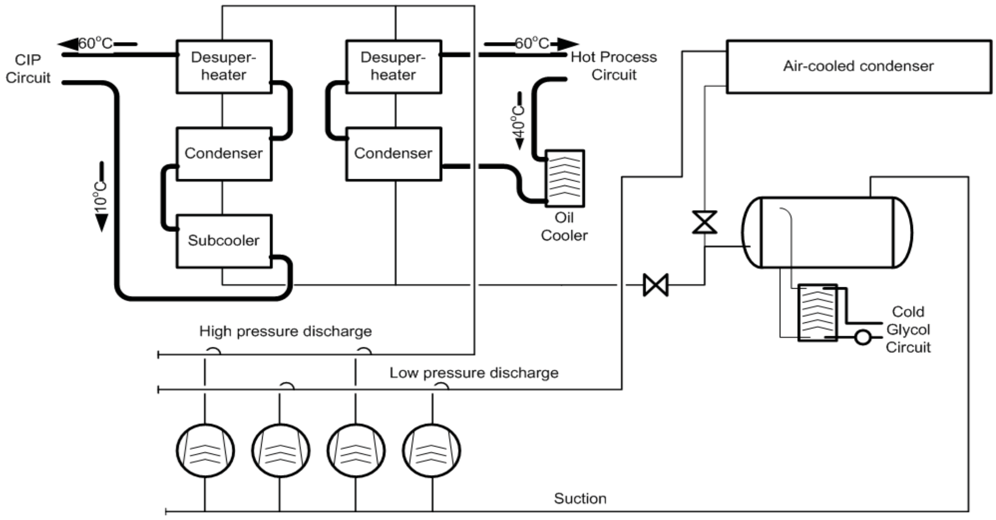


Figure 7-8: Configuration diagramme

The pictures below show the installations (the two compression units for the process cooling and the two heat pumps (with the full isolated oil separator in grey material).

7.6.4 Specification of Heat Pump system

A Pinch analysis was constructed that identified the major hot and cold streams for the factory. The stream data used for the Halifax analysis was stream lined to only include CIP water, high temperature closed heating and medium temperature closed heating.

Star Refrigeration, Vilter Manufacturing Inc (USA), Emerson Climate Technologies company, and Cool Partners (a Danish consultancy) formed a collaborative effort to devise a high pressure heat pump solution using ammonia and screws at 90°C. 60°C seemed a comparatively easy task by comparison but it was still ahead of it is time as it was asked to cover a wide operating pressure lift, taking heat from glycol at -5C and lift it to 60°C in one stage.

For the layout design and optimisation, software developed in collaboration with Cools Partners allows to rapidly and efficiently estimating the performances of the installation.

The table below provides more details about the heat pump installation:

<table>
<tr><th>Description</th><th colspan="2">Heat Pump</th><th>Back up</th></tr>
<tr><td>Type</td><td colspan="2">Single Screw heat pump</td><td></td></tr>
<tr><td>Heating capacity</td><td colspan="2">600 kW/unit (12→60°C, 2 units)</td><td></td></tr>
<tr><td>Cooling capacity</td><td colspan="2">1600 kW/unit (5→0°C, 2 units)</td><td></td></tr>
<tr><td>Power consumption</td><td colspan="2">kW/unit (2 units)</td><td></td></tr>
<tr><td rowspan="2">Heat source
Description and temp</td><td rowspan="2">With thenew system, heat can be taken from the 0°C process glycol and lifted to 60°C water in one stage for heating.</td><td>Temp 0 °C</td><td></td></tr>
<tr><td>m³/h</td><td></td></tr>
<tr><td rowspan="2">Heat sink
Description and temp</td><td rowspan="2">With the new system, heat can be taken from the 0°C process glycol and lifted to 60°C water in one stage for heating.</td><td>Temp. 60 °C</td><td></td></tr>
<tr><td></td><td></td></tr>
<tr><td>Refrigerant</td><td colspan="2">Ammonia</td><td></td></tr>
<tr><td>Compressor type</td><td colspan="2">Single Screw Compressor</td><td></td></tr>
<tr><td>Rated power of compressor</td><td colspan="2"></td><td></td></tr>
</table>

COP	Combined heating and cooling 5.46		
Operation hours			
Storage water tank	m^3	Temp. °C	
Targeted floor dimensions			
Manufacturer of heat pump	Star Refrigeration		
Supplier/consultant	Star Refrigeration, Emerson Climate Technologies		

7.6.5 Effects

The initial thinking for the customer was to get a 90°C hot water heat pump. Indeed, some application demand required 90°C. However the total demand for this temperature level was around 10% of the whole hot water consumption. Designing a heat pump installation for such temperature would not be interesting in terms of performances and efficiencies. It was decided to install the heat pump producing 60°C hot water. When the small amount of 90°C water is required, the incremental heat is supplied now by a small gas boiler heating up the water from 60°C up to 90°C.

In parallel, other alternatives for the heating were assessed like a central gas fired boiler, combined heat power or geothermal heat pump. Qualitative and quantitative assessments (cost, required existing installation upgrade, future site growth…) defined that the best alternative solution for this project was the heat pump. So a correct analysis and understanding of the real need for the installation allow installing the right answer to the real Nestle needs.

Nestlé can save an estimated £143,000 per year (166,000 € per year) in heating costs, and around 120,000 kg in carbon emissions by using a Star Neatpump.

Despite the new refrigeration plant providing both heating and cooling, it consumes £120,000 (140,000 €) less electricity per year than the previous cooling only plant.

Another impact of the complete project (combined heating and cooling, additional gas boiler for the 90°C water peak demand, etc.) decreased the total water consumption from 52,000 m^3/day down to 34,000 m^3/day.

The Nestlé system recently won the Industrial and Commercial Project of the Year title at the 2010 RAC awards.

7.6.6 Challenges and prospects

This kind of installation proves that combined heating and cooling with an ammonia heat pump is a very attractive solution among existing only heating system.

This allows savings not only for heating cost but also

- in term of CO_2 emissions,
- in term water consumption
- On the total cost of energy per units manufactured
- for the future, the threat (F-Gas regulation in Europe) of using HFC in the refrigeration installation

Combined heating and cooling can be applied on any industrial process requiring cooling and heating on different steps in their manufacturing process.

7.7 The World's Largest Natural District Heat Pump

(by P. Nellissen, Emerson Climates Technologies)

7.7.1 Background

Drammen is a town 40 km south west of Oslo (Norwegian Capital). During the last decade it has gone through a major transformation from being a rundown industrial town to a newly developed town centre with new hospital, housing, ice rink, hotels and shopping centre.

Drammen Fjernvarme KS was established in 1999, and is owned by Energiselskapet Buskerud (Buskerud Energy Company) and Fortum Holding. The same year Drammen Municipality decided to make connection to the district heating system mandatory in the concession area. This means that every new building larger than 1000 m²has to be built with a water-based heating system connected to the district heating system. Today the area that receives district heating has been expanded, and includes most of central Drammen

These new developments have all been connected to a district heating network. The first district heating plant in Drammen was installed in 2002 using 8 MW biomass boilers.

Knowing that the European Commission has designated heat pumps a renewable technology for heating and cooling, Drammen decided to use heat pumps and had several additional goals in mind for this capacity increase project:

- The supply water temperature from the heat pump would be 90°C
- The highest coefficient of performance (COP) possible the ratio of heat extracted compared to energy consumed.
- A technology solution with low annual operating and maintenance costs.
- A system using a non-ozone depleting refrigerant with zero global warming impact.

With the second phase of the district heating network extension being a 13 MW of heat pump duty (for the base load) and additional 2 x 30 MW gas fired boiler (backup for the peak duties) have been installed. The maximum network peak heat demand is 45 MW duty.

7.7.2 Company information

Category of industry Company	Drammen Fjernvärme KS
Location	Drammen, Norway
Year of installation	2011
Purpose	Hot water generation for district heating application
Amount of production	13 MW heating capacity at 90°C hot water

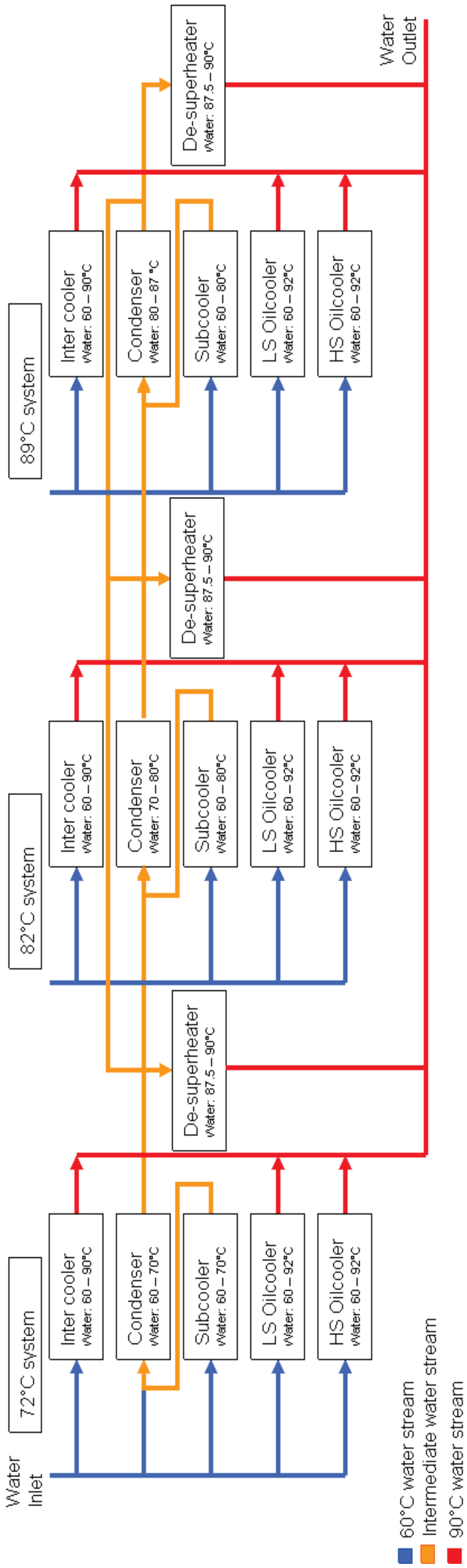
7.7.3 Installed system

The supply temperature of the district heating water varies across the year depending on the heat demand. In the summer time where there is a very small demand (less than 2 MW) the supply water temperature is 75°C, when the ambient temperature falls and there is an increase in heating demand, the supply water temperature increases up to 120°C at peak load. The return water temperature from the district heating loop is very steady at 60°C to 65°C all year around. When the gas boilers are being utilized they are working on a constant flow with temperature difference of 10°C between inlet and outlet. The water is then being mixed with the district heating water to achieve the desired outgoing temperature. To optimize the performance of the heat pump it was important to have variable flow system where the water is taken directly from the district heating return line as every degree subcooling is important and any degree overheating is wasted energy.

The heat source for the heat pump is sea water. Norway has a famous rocky coastline. The thermodynamic beauty of this landscape is that the water gets very deep just off the coast. When taking in the water at 40 m depth there is a constant water temperature of 8°C to 9°C most of the year. At this depth the water temperature is not affected by changes in the air temperature from +30°C in the summer to -20°C in the winter. The water intake pipe runs 800 m into Oslo Fjord and the return pipes are 600 m long to ensure that the 4°C outlet water is not mixed with the inlet water. The seawater pumps are situated on land but below sea level.

The seawater is cooled directly in spray chillers, where ammonia is sprayed across titanium pipes with the seawater inside.

The ammonia heat pump that has been installed on site consists of 3 x 2 stage single screw compressor systems in series each with a heating duty of approximately 4.5 MW.


Water Inlet
72°C system
82°C system
89°C system
Inter cooler
Water: 60 – 90°C
Condenser
Water: 60 – 70°C
Subcooler
Water: 60 – 70°C
LS Oilcooler
Water: 60 – 92°C
HS Oilcooler
Water: 60 – 92°C
De-superheater
Water: 87.5 – 90°C
Condenser
Water: 70 – 80°C
Subcooler
Water: 60 – 80°C
Condenser
Water: 80 – 87 °C
Water Outlet
60°C water stream
Intermediate water stream
90°C water stream

- Photo of equipment appearance

External view of the Drammen installation building

External view of the Drammen City

Internal view of the Drammen installation building: machine room

7.7.4 Specification of Heat Pump system - Design and installation process

For optimized performance of large scale heat pumps it is important to get the design right. The biggest challenge was to design the hot water flow through the heat pump to ensure that every kW is taken out of the system and at temperature where it is most useful.

With the water being heated from 60°C to 90°C the condenser part of the system is split into 3 off 2- stage systems working in series. The main water stream is being heated from 60°C to 69°C through the first condenser and from 69°C to 78°C in the second condenser and from 78°C to 87°C in the third condenser.

After the main flow has been heated to 87°C it is split into 3 streams going through the high stage desuperheater for each of the systems. The temperature is raised to 89°C through these heat exchangers.

Besides the main water flow there are separate streams of water going through subcoolers, high stage and low stage oil coolers and intercoolers. The intercoolers serve three purposes: they cool the superheated gas from the low stage compressors before entering the high stage compressors. Suction superheat reduces the isentropic efficiency of the compression. In addition the lower suction temperature gives rise to a lower discharge temperature thereby protecting the seals from too high a discharge gas temperature on the high stage compressors (maximum 135°C). The final reason of course is energy recovery.

With the main stream of water being mixed with the water from all auxiliary streams which has been heated to 92°C - 98°C the mixed outgoing water temperature from the heat pump is 90°C.

Although the three heat pumps are operating at different conditions the specifications for each of the three heat pumps are the same. This enables each of them to deliver 90°C water in case of a failure of one of the systems.

With 3 systems operating in a combination of series and parallel instead of simply parallel the average condensing temperature falls from 90°C to 80.5°C representing a 10% improvement in efficiency for the ammonia heat pump system.

Description	**Heat Pump**		**Back up**
Type	3 x 2 stage single screw compressor		
Heating capacity	4500 kW/unit (60→90°C, 3 units)		
Cooling capacity	kW/unit (10→5 °C, 3 units)		
Power consumption	kW/unit (2 units)		
Heat source *Description and temp*	Sea water	Temp 8°C m^3/h	
Heat sink *Description and temp*	District heating network	Temp 90°C m^3/h	
Refrigerant	Ammonia		
Compressor type	Single Screw		
COP	3.05		
Operation hours	8000 hours at different capacities		
Storage water tank	m^3	Temp °C	
Manufacturer of heat pump	Star Refrigeration Ltd		
Supplier/consultant	Emerson Climate Technologies/Vilter		

7.7.5 Effects

Based on 48,000 MWh per year at the following current gas prices in Norway are approximately £30 (35€) per MWh and the electricity prices is approximately £50 (58 €) per MWh. By using the ammonia heat pump: The total cost of electricity would be around 800,000 € per year vs. 2,000,000 € per year. There is an estimated saving of £1,042,289 (1,210,000 €) compared to using gas.

The global warming benefit of the ammonia heat pump is also significant. With a yearly equivalent CO_2 emission of 317 tons, this compares to burning gas which would give a CO_2 emission of 13,050 tons per year at the given usage profile.

Primary energy savings	1,210,000 €/year
Reduction in CO_2 emission	12,700 tons/year
Maintenance costs	
Manufacturer/supplier	Star Refrigeration Ltd.
Pay back	

7.7.6 Challenges and prospects

The main challenge for heat pump in general is to convert the heat source to the right heat level offering the best return on investment possible.

This type of installation shows that high temperature and also high heating capacity heat pump can be achieved using a natural refrigerant like Ammonia with the right compression technology.

This specific heat source (sea water at 8 °C) proves that the range of heat source for heat pump can be widened (sea water, river, waste process water, heat recovery,…) and can provide high COP allowing optimised return on investment. This type of installation is not limited to district heating applications but can be replicated to a large amount of installations with energy recovery/savings leading to operational costs decrease environmental positive impacts. **For example: distillation of ethanol or combined district cooling and desalination.**

References

- Emerson Climate Technologies + Star Refrigeration internal data
- Hoffman, & Pearson, D. 2011. Ammonia heat pumps for district heating in Norway 7 – a case study. Presented at Institute of Refrigeration, 7 April, London.
- http://www.youtube.com/watch?v=a6xMS_hBNKM
- http://www.youtube.com/watch?v=Imo-G7Dbito

7.8 Case Study – Surface Finishing

Finishing processes are used to influence the surface quality of work pieces. By the combined application of thin coatings, surface properties can be customized according to individual requirements. The range of surface treatments reaches from optical to technical finishes, like corrosion protection or an increased surface hardness.

7.8.1 Process description

In the finishing process coatings are applied to the surfaces of work pieces by galvanic or chemical processes. One of the most common galvanic surface finishings is hard chromium plating, which is also the core competency of the company considered in this case study. Hard chromium plating is used to apply a thin layer of chromium to a surface to improve both wear and corrosion resistance of a work piece. This is achieved by an increase of the surface hardness. The thickness of the chromium layer can vary from 5 to more than 1,000 µm depending on the operating conditions. To apply the chromium layer, the work piece is immersed into a bath filled with chromium electrolyte. Between the work piece and an anode an electric DC voltage is applied. By the electric field chromium ions are forced to accumulate on the surface of the work piece. To achieve a good surface quality current densities of 50 A/dm² are needed. One of the disadvantages of the hard chromium process is its low efficiency. In industrial-scale chroming plants only 20% of the energy is used for the actual creation of the chrome layer /Zimmer 2010a/. The other 80% are transformed into heat. As the process temperature has to be kept between 50 and 60 °C, cooling is needed during the electroplating phase. In between the chromium electrolyte has to be heated to compensate thermal losses.

7.8.2 Initial situation

The company considered in this case study runs several hard chromium plants and a large chemical-nickel plant. Beside the galvanic and chemical surface finishing the company also offers mechanical surface finishing.

To cover the cooling demand of the chrome baths and the current rectifiers the company runs a large centralized cooling system. A scheme of this cooling system is shown in Figure 7-10. Two large tanks with a volume of 30 m³ each buffer peak cooling loads. Thus the cooling water temperature can always be kept below 37 °C. As there is no speed controlled circulation pump installed, the whole cooling system is designed for this operating temperature. This means that the tank temperature is not allowed to vary largely in order to maintain constant temperatures in the hard chroming process.

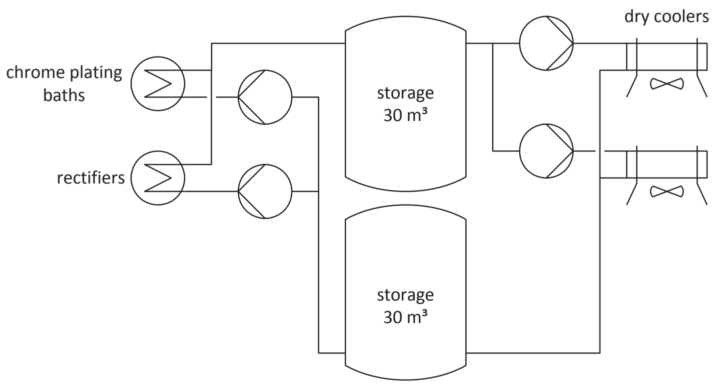


Figure 7-10: Scheme of the cooling system

The heat is emitted to the environment by means of two dry coolers. The cooling water flow and thus the cooling capacity can be adjusted to the cooling demand in six steps. Nevertheless the heat is rejected in short episodes from 5 to 10 minutes. As the storage temperature has to be kept in a range between 33 and 37 °C, the large volume of 30 m³ cannot create a large buffering effect.

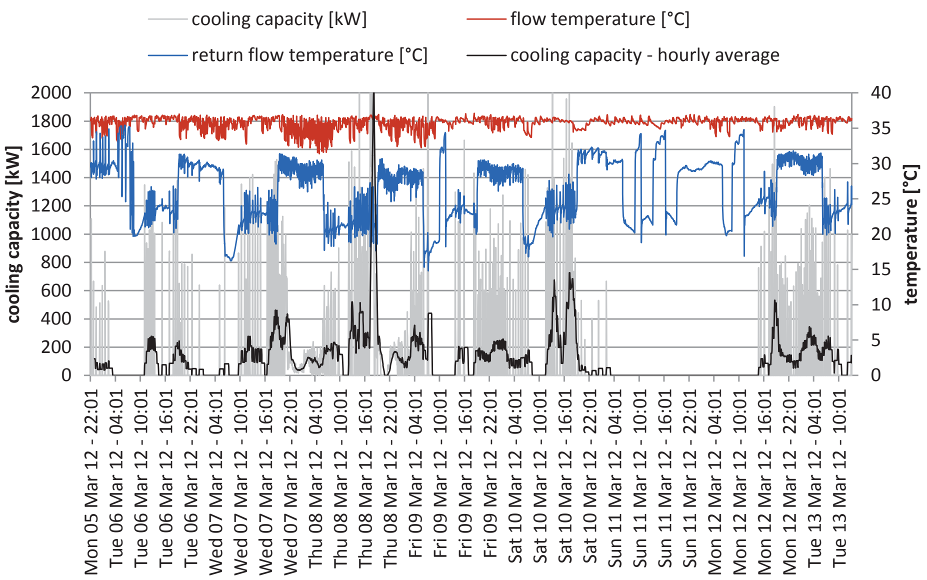


Figure 7-11: One week profile of the rejected heat of the cooling system

The rejected heat was measured over a time period of one week. The measurement results can be seen in Figure 7-11. The average hourly cooling capacity varies from 50 to 600 kW, while the absolute peak load reaches 3,290 kW. The average cooling load during the considered week was 376 kW. Assuming 2,500 operation hours per year, 671 MWh of waste heat are rejected to the environment. This estimate can be classed as conservative, as the company also produces on weekends, if large orders have to be processed.

While waste heat is rejected to the environment there is also a heat demand for space heating, hot water generation and process heat. Beside the chrome baths also the degreasing baths and the chemical-nickel plant need large amounts of heat at fairly low temperatures. An overview over process temperatures and the type of heating are shown in Table 7-2.

Table 7-2: Overview over possible heat sinks for a heat pump in the production line

process	temperature	type of heating
chemical-nickel bath	90 °C	hot water
degreasing bath	80 °C	hot water
chrome bath	55 °C	electric heaters

These processes are suitable heat sinks for a heat pump, because they have operating temperatures below 100 °C as well as an all-year heat demand. Since no data about the heat demand of these baths was available measurements had to be carried out for the chrome bath and the degreasing bath. The space heating demand is estimated based on the heating bills of the last 4 years.

- Degreasing bath: The bath is filled with 7.3 m³ cleaning solution. It has to be kept at a temperature of 80 °C for about 6,000 operating hours a year, since it is only shut off during weekends. In the start phase at the beginning of the week this bath has to be heated up within 4 hours according to strict factory specifications. The maximum heat performance measured in this starting phase was 180 kW. To maintain the operating temperature of 80 °C later on only 19.2 kW are needed. The bath is heated by a hot water circuit with a flow temperature of 115 °C and a back flow temperature of 100 °C. These high temperatures are only needed in the start phase. In the stationary phase, when only heat losses have to be compensated, heat is supplied in short bursts of 1 to 2 minutes in length. Considering the installed heat exchanger surface the flow temperature could be lowered to 90 °C during the stationary phase. In the course of one year 110 MWh are needed at 90 °C flow temperature.
- Chrome bath: The bath is filled with 12 m³ chromium electrolyte. Only during the chroming process a heat surplus is generated. In the intervening periods an electric heater maintains a bath temperature of 55 °C. For balancing the thermal losses a heating capacity of 20.8 kW is required. Since the chrome plating process takes just 23 % of the total operating time the yearly heat demand of the chrome bath amounts to 29 MWh. This heat is generated in a rather expensive way, as electric heaters are being used.
- Space heating: On the plant grounds there are two production halls and one administrative building that need to be heated in winter. An oil boiler covers the heat demand of 2.8 GWh per year. Since the air exchange rate of the production halls is fairly high due to toxic emissions of the chrome baths, there is also a large space heating demand. The space heating demand of production hall 2 amounts to 700 MWh/a. The heaters in the production hall are designed for a flow temperature of 70 °C. As this hall also houses the central cooling plant a share of the space heating demand could be covered by a heat pump using the waste heat of the cooling system.

No measurements were carried out for the chemical-nickel bath because a hot water flow temperature of at least 110 °C is needed to keep the bath at its 90 °C operating temperature. Taking into account the 35 °C heat source temperature, there was no heat pump system available that would have matched neither technically nor economically.

7.8.3 Proposed measures

The previously unused waste heat can be utilized by a heat pump. The 30 m³ cold water storage can be used as heat source. A heat pump with a cooling capacity of 147 kW and a SCOP of 3.8 could cover 23 % of the cooling load. Since the cold water storage temperature has to be kept in a small range below 37 °C, the operation time of the heat pump is rather limited. The installation of a speed controlled circulation pump would allow a much broader temperature range which would multiply the storage capacity. This could raise the share of the heat pump up to 44 %. With reference to Figure 7-11 the needed cooling capacity would approach the black line representing the hourly average.

Based on the conducted measurements two options were suggested:

- Option 1: Installation of a speed controlled circulation pump for the cooling network and a heat pump with 200 kW heating and 147 kW cooling capacity. The heat pump would cover 44 % of the total cooling demand and 35 % of the space heating demand of production hall 2.
- Option 2: Installation of a speed controlled circulation pump for the cooling network, a heat pump with 200 kW heating and 147 kW cooling capacity and a 2 m³ hot water storage. Furthermore the electric heater of the chrome bath would be replaced with a heat exchanger. The heat pump would supply the chrome bath with heat all year long. In winter the excess heating capacity of the heat pump would be used for space heating of production hall 2.

7.8.4 Economic feasibility

For both options economic feasibility studies were carried out. For both options an optimistic and a pessimistic scenario were calculated. The calculation was carried out in accordance with VDI guideline 2076.

7.8.4.1 Option 1:

The proposed system only delivers heat during the heating period in winter. It can cover up to 35 % of the space heating demand of production hall 2. The payback period would be 7 to 8 years and the internal rate of return would be 6 to 11 %. Thus this option is considered not economically feasible (see Table 7-3).

Table 7-3: Results of the economic analysis of option 1

	scenario	
	optimistic	pessimistic
investment costs	70,000 €	90,000 €
increase of energy prices	4 % p.a.	3 % p.a.
oil price (2012)	7 ct/kWh	7 ct/kWh
electricity price (2012)	14 ct/kWh	14 ct/kWh
SCOP	3.8	3.8
heat generation	290 MWh/a	290 MWh/a
system life	15 years	15 years
internal rate of return	11 %	6 %
payback period	7 years	8 years

7.8.4.2 Option 2

In the second option the heat pump also supplies heat to the chrome bath. Since this bath is electrically heated, the economic advantage of the heat pump is considerably larger. The heat pump also generates about 90 MWh more heat, as it is supplying the chrome bath all-year long. These aspects are reflected by a significantly higher internal return rate of 20 to 26 % and a shorter payback period of 3.5 to 4.5 years.

Table 7-4: Results of the economic analysis of option 2

	scenario	
	optimistic	pessimistic
investment costs	90,000 €	110,000 €
increase of energy prices	4 % p.a.	3 % p.a.
oil price (2012)	7 ct/kWh	7 ct/kWh
electricity price (2012)	14 ct/kWh	14 ct/kWh
SCOP	3.8	3.8
heat generation	380 MWh/a	380 MWh/a
system life	15 years	15 years
internal rate of return	26 %	20 %
payback period	3.5 years	4.5 years

The second option was considered economical feasible. The results were given to a planner for a detailed cost calculation. Despite positive results the company decided not to implement the heat pump system due to internal restructuring measures.

7.9 Case study – Prefabricated house manufacturing

A prefabricated house consists of several components that are built in a factory and assembled on the construction site. These components are mostly built using a light-weight structure. Mainly timber is used to build the frameworks for walls. It is one of the most used materials in the construction of a prefabricated house.

7.9.1 Process description

The timber has to be dried before it can be processed. The residual moisture content has to be reduced to 10 to 20 % to avoid cracks. The wood is placed in a drying chamber in which it is exposed to a hot and dry atmosphere for several days. The water contained in the wood migrates to the surface where it evaporates. By forced convection, a good transition of the moisture to the air is achieved. During the drying process the air temperature is lifted stepwise from 50 to 80 °C. In between the temperature is held at a constant value for long time periods of up to several days. To prevent drying damage, temperature and humidity have to be maintained in a well-defined framework during the whole drying process. If the humidity hits the upper limit, dampers in the ceiling of the drying chamber open to replace the humid air with fresh dry air. The actual drying phase is followed by a conditioning phase. In this phase moisture gradients over the cross-section of the wood are compensated. Subsequently the wood must be cooled down to at least 40 K above ambient temperature to reduce internal tensions and to prevent the wood from cracking /Trübswetter/.

7.9.2 Initial situation

The prefabricated house manufacturer considered in this case study uses large quantities of wood. To achieve the most complete possible utilization of this raw material the company has set up a chain of exploitation from wood drying to the sawmill. The residuals are used to fire a biomass power plant. The power plant is composed of two blocks having a total net electric output of 8.2 MW. The net electrical efficiency of the blocks is 21.7 % and 23.8 %. Block 1 is equipped with an extraction-condensation turbine. Before the steam enters the low pressure part of the steam turbine, it can be partly drawn off to be used for the heat supply of the factory. Thus, up to 5 MW of thermal power can be provided. In both blocks the steam is condensed in an air cooler at a temperature of 55 °C.

The heat provided by the biomass power plant is used for 4 wood presses and 27 drying chambers. In addition to that it is also used for space heating of production halls and office buildings in winter.

Since the wood presses are operated at a temperature of 120 °C, they are not considered as a heat sink for a possible heat pump system. Therefore they are not investigated further. The drying chambers are also supplied with heat at 120 °C, although these high temperatures are only needed in the startup phase and when the process temperature has to be raised. Most of the time, the inlet flow is mixed down to 65 to 90 °C.

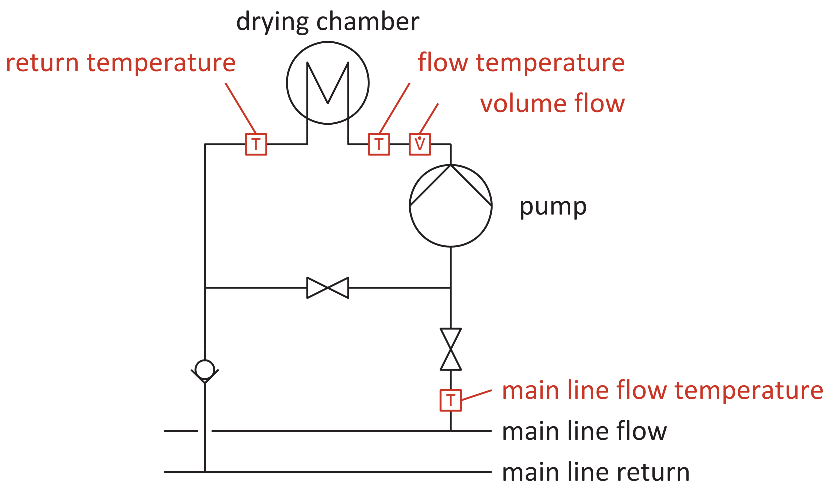


Figure 7-12: Heat supply system of the drying chamber

Figure 7-12 shows the heat supply system of the drying chamber. To prepare an energy balance, the temperatures and volume flows were measured in the points marked in red in Figure 7-13**Fehler! Verweisquelle konnte nicht gefunden werden.**. These measurements had to be conducted since there was no data on the energy consumption of one single drying chamber available. A total of two drying runs were analyzed. The duration of the first run was 15 days, while the second run took 21 days. The time necessary for drying depends on the amount of wood, the moisture content and the ambient air temperature. The diagrams in Figure 7-13 and Figure 7-14 show the flow temperature and the heat demand of the drying chamber.

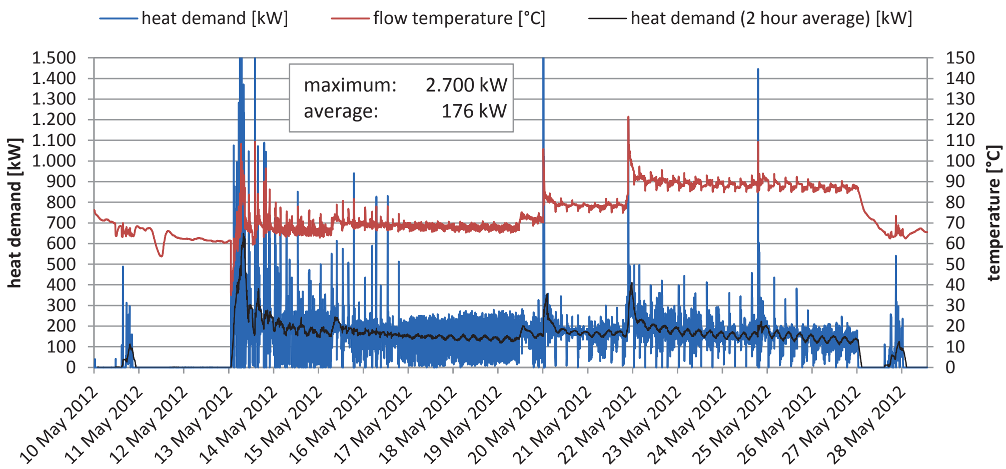


Figure 7-13: Measured data of the drying chamber – 1st drying run from 13th May 2012 to 28th May 2012

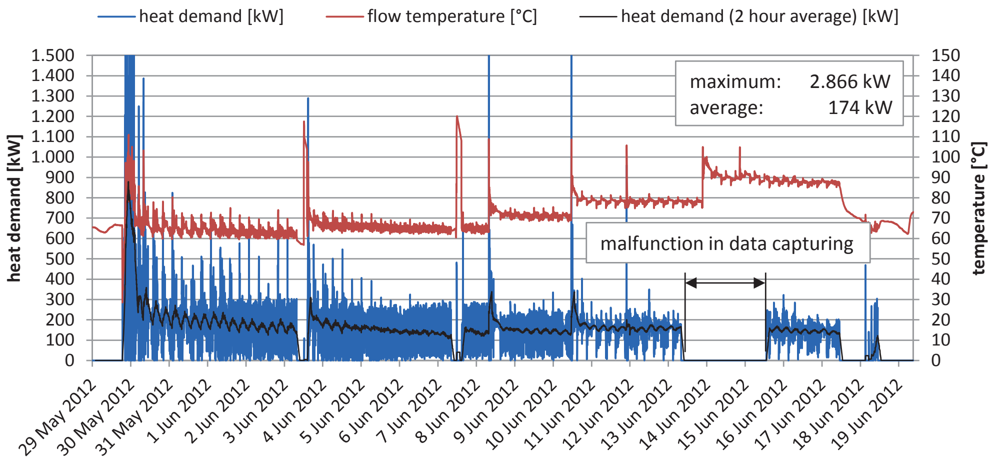


Figure 7-14: Measured data of the drying chamber – 2nd drying run from 29th May 2012 to 19th June 2012

High flow temperatures of more than 100 °C were only needed in the startup phase and when the process temperature had to be raised. During the startup phase, high temperature gradients between the heating circuit and the air temperature in the drying chamber lead to the transmission of high performances. The peak performance was as high as 2.9 MW. In the long-running drying phases the temperature is kept at constant values. In these periods an average heating power of 175 kW is needed. The flow temperature is raised in several steps from 65 °C to 90 °C.

7.9.3 Proposed measures

With an increase of the production, also the wood consumption and thus the heat demand for wood drying increased during the last years. Especially in winter the heat demand exceeds the maximum amount of heat that can be delivered by the biomass power plant. In this case an oil fired boiler would have to generate additional heat. To cover the additional heat demand in a more environmentally friendly and cost effective way, a heat pump system was proposed. The heat source for such a system would be the waste heat generated by the biomass power plant. The heat pump would be used to power the drying chambers during the long stationary phases in between the temperature lifts. Thus long running times with a constant load can be reached. The flow temperature during these phases varies between 65 and 90 °C. With a waste heat temperature of 55 °C, the heat pump would have to lift the temperature by 10 to 45 K. High temperature heat would only be needed during the startup and the temperature increase phases. During the long stationary phases a heat pump with a heating capacity of 180 kW could cover the entire heat demand of the drying chamber. Figure 7-15 shows the integration of the heat pump into the heating system of the drying chamber.

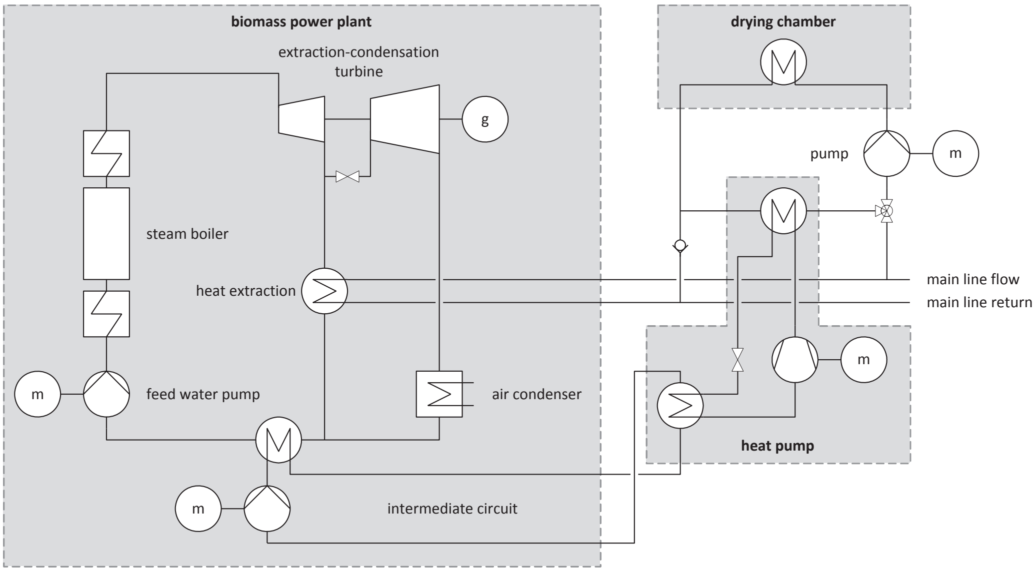


Figure 7-15: Integration of the heat pump into the heat supply system

7.9.4 Economic feasibility

The biomass power plant is currently generating the entire heat used in the company. Since the power plant is mainly fired with biogenic waste from the company's own production a heat pump could compete neither in economic nor in ecologic terms. Thus a heat pump could only be used to generate additional heat that is needed primarily in winter times. Here the heat pump system needs to compete with an oil fired boiler. Assuming a production expansion in conjunction with an increased heat demand, the heat pump could achieve a running time of 2,000 full-load hours per year.

For the described heat pump system an economic calculation was carried out according to the VDI Guideline 2067 /VDI 2010/. As reference heat source an oil fired boiler was considered. With a heating capacity of 180 kW the heat pump could cover up to 73 % of the drying chamber`s entire heat demand. To determine the influence of different assumptions a parameter variation was made. In Table 5-7 a pessimistic and an optimistic scenario are portrayed.

The internal rate of return of 16 to 24 % shows the economic feasibility of the heat pump system. Payback periods of 4 to 5.5 years could be reached.

Despite these positive figures the proposed heat pump system was not installed, because at the end of this analysis an increase of the heat demand was no longer assumed due to a prospected slight downturn of the order situation. Furthermore alongside the feasibility study for the integration of a heat pump other energy saving potentials were discovered that appeared to be more interesting from the economic point of view.

Table 7-5: Results of the economic analysis

	scenario	
	optimistic	pessimistic
investment costs	64,200 €	85,000 €
increase of energy prices	4 % p.a.	3 % p.a.
oil price (2012)	7.5 ct/kWh	7.5 ct/kWh
electricity price (2012)	9.5 ct/kWh	9.5 ct/kwH
SCOP	4.5	4.5
heat generation	360 MWh/a	360 MWh/a
system life	15 years	15 years
internal rate of return	24 %	16 %
payback period	4 years	5.5 years

7.10 Application of heat pumps in the German industry

A total number of 17 heat pump systems could be characterized in the German industry. These examples were picked, because they show opportunities for the application of heat pumps in different industrial branches and with a large variety of framework conditions. There are many more heat pump systems in operation, but they are either similar to the characterized systems or they are considered to be confidential parts of the production process. All of the characterized systems use industrial waste heat as heat source. Five of them provide process heat while the other eleven are used to generate hot water and space heating. The map in Figure 7-16 shows the geographic location of the surveyed companies.

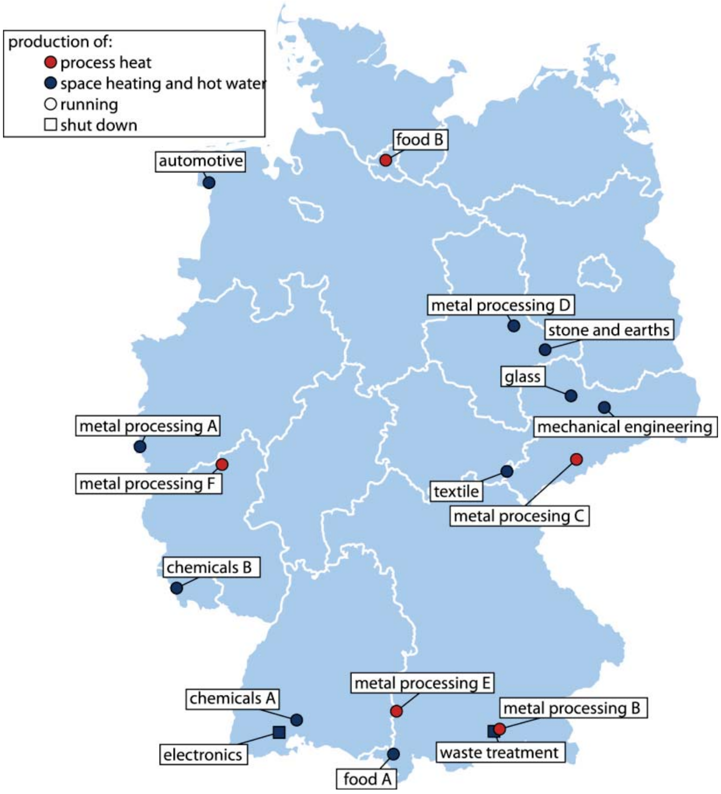


Figure 7-16: Heat pumps in the German industry

The surveyed companies can be subdivided into ten industrial branches. Figure 7-17 shows the number of companies per branch. With six examples the metal processing industry is more strongly represented than the other branches. Most of these six companies are using waste heat generated by machine tools especially laser cutting machines to generate heat for industrial processes or space heating.

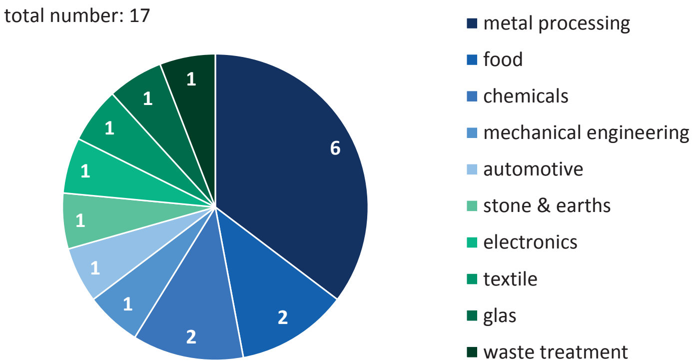


Figure 7-17: Represented industrial branches

Most of the surveyed systems have heating capacities between 100 and 500 kW. Figure 7-18 shows the distribution across different size classes. The largest heat pump is integrated into a malt production process. It has a heating capacity of 3.250 kW. The smallest heat pump has a heating capacity of 20 kW. It uses waste heat to generate hot water and space heating.

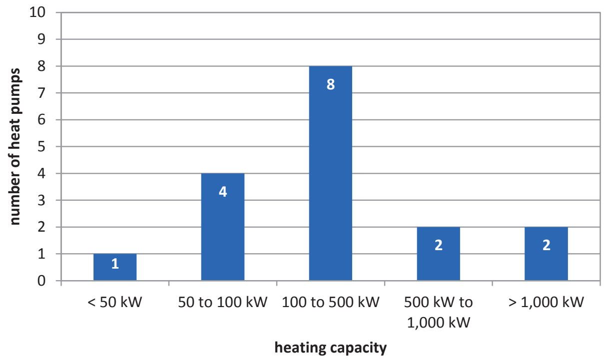


Figure 7-18: Heating capacity of the surveyed heat pump systems

Figure 7-18 gives an overview of all 17 characterized heat pump systems. It lists the name of the company operating the heat pump, the industrial branch, the kind of heat source and the heat pump manufacturer. The table is followed by descriptions of these heat pump systems. Those descriptions include pictures and integration schemes of the heat pumps as well as a standardized table for each heat pump that gives an overview of technical and economical key figures.

Table 7-6: Overview of the documented application examples

industrial branch	company	heat source	HP manufacturer
waste treatment	Vivo	composting plant	
automotive	Volkswagen	dip coating plant	Simaka
chemicals A	Emil Frei	powder coating production	Dimplex
chemicals B	Flavex	extraction plant	Junkers
electronics	Dunkermotoren	moulding machines	Combitherm
glass	Glasfabrik Thiele	workshop air	Dimplex
mechanical engineering	Gebr. Kemmerich	production processes	Klima Jentzsch
metal processing A	Flamm	production processes	SmartHeat
metal processing B	Ludwig Michl	production, servers	Robur
metal processing C	Purkart	lasers, furnaces	Combitherm
metal processing D	Schraubenwerk	induction press	Klima Jentzsch
metal processing E	Thoma	Chrome bath, rectifier	keine Angabe
metal processing F	Hennecke	laser	SmartHeat
food A	Hanspeter Graßl	cooling system, bottling plant	Arwego
food B	Tivoli Malz	malt kiln	
textile	Unternehmen	dyeing machine	Klima Jentzsch
stone and earths	Treibacher	electric furnace	Klima Jentzsch

7.10.1 Waste treatment (VIVO GmbH)

Vivo GmbH is a municipal waste management company. A yearly amount of 20,000 t of residual waste and 48,000 t of valuable and dangerous substances are disposed or processed by the company. In 1994 a bio waste composting plant was built in Warngau. This plant processes about 14,000 t of organic waste. The material is fermented for 21 days to produce biogas with a methane content of 55 %. This gas is collected and transported to a gasstorage. It is then used in a CHP plant to produce 2,500 MWh electricity per year. The heat generated by the CHP plant is used in the fermenters and to power a district heating network that supplies a nearby industrial park.

In addition to that an absorption heat pump was installed in 2005. The heat pump was run with natural gas and made use of the waste heat of a bio waste rotting plant on the same site. A cold water storage collected the waste heat generated at a temperature of 42 °C. The waste heat was upgraded to 82 °C to power the district heating network. The absorption heat pump provided a cooling capacity of 195 kW and a heating capacity of 500 kW. After the correction of minor malfunctions in the first months of operation, the heat pump reached 3,500 operating hours in the heating period from October 2005 to April 2006. Based on the heat input a COP of 1.47 was reached. Taking into account the combustion efficiency the over-all performance ratio was 1.31. The heat pump substituted a large part of the heat, formerly produced by a peak load oil boiler. With a heat production of 1,750 MWh per year, a payback period of 6.7 years was calculated. Furthermore CO_2 emissions were cut by about 160 t per year. The project was carried-out in cooperation with Bayerisches Zentrum für Angewandte Energieforschung e.V. (ZAE Bayern) and Ingenieurbüro J. Färber. It was funded by Deutsche Bundesstiftung Umwelt (DBU) with 60,000 €.

In 2011 the heat pump had to be shut down due to major corrosion problems. The very corrosive LiBr/water solution had destroyed the heat source heat exchanger and damaged the pipings. Due to the fact that the heat pump was manufactured by an Indian company major communication problems occurred. For repair and maintenance works a technician had to come from India. This technician didn't have sufficient knowledge of English, so an interpreter was needed to be able to communicate. Since VIVO GmbH was also not satisfied with the performance ratio, the heat pump was shut down /ZAE 2007; DBU 2008/. In modern absorption heat pumps however corrosion can be avoided by adding inhibitors to the LiBr/water solution. Furthermore a careful choice of materials also helps to avoid corrosion /ASUE 2009/.

Table 7-7: Fact sheet for Vivo GmbH

Industrial branch	Waste treatment – Composting of organic waste
Type of heat pump	Gas absorption heat pump
Heating capacity	500 kW
Heat source description	Waste heat from composting plant
Heat source temperature	42 °C
Heat sink description	District heating
Heat sink temperature	82 °C
COP	1,31
Refrigerant	not specified
Investment cost	174,200 €
Operating since	2005
Payback period	6.7 years
Contact	ZAE Bayern, Ingenieurbüro J. Färber, VIVO GmbH

7.10.2 Automotive (Volkswagen AG)

Volkswagen AG is one of the largest automotive manufacturing companies in the world. Its production site in Emden opened in 1964. It is mainly focused on the production of the model “Passat”. The 8,200 employees produce up to 1,200 cars per day /Volkswagen 2013/.

Within the production line the paint shop is one of the main energy consumers. In a cathodic dip coating process items to be painted are immersed in an electrically conductive dipping varnish. A direct voltage field is applied between the items and a counter electrode. Hereby the binder is precipitated at the item surface, in order to obtain a closed adhesive coating film. As this process has a positive energy balance, the paint bath has to be cooled continuously to keep the temperature at 30 °C. This cooling load is covered by a large heat pump with a cooling capacity of 1,188 kW. The heat is upgraded to a temperature of 75 °C. The maximum flow temperature offered by the heat pump is 88 °C at a hot gas temperature of 108 °C. The heat is used to provide hot water for different purposes. The heat pump achieves an integrated COP of 5.6 at an annual operation time of 6,720 hours. Apart from minor adjustments in the start-up phase, the heat pump works reliably and well /Volkswagen 2013/.

Table 7-8: Fact sheet for Volkswagen AG

Industrial branch	Automotive – paint shop
Type of heat pump	Electric compression heat pump
Heating capacity	1,683 kW
Heat source description	Cathodic dip coating
Heat source temperature	26 to 29 °C
Heat sink description	Hot water for different purposes
Heat sink temperature	65 to 75 °C
COP	5,6 (integrated)
Refrigerant	Fluid XPro II
Investment cost	not specified
Operating since	2012
Payback period	not specified
Internal rate of return	not specified
Contact	Volkswagen AG - Emden

7.10.3 Chemicals A (Emil Frei GmbH)

Emil Frei GmbH was founded in 1926 and developed from a wholesale for varnish and coatings to a producing company with five production sites. Two of them are situated in Germany. Main products are powder coatings, industrial coatings and electrodeposition coatings.

In 2009 the company was looking for a heating concept for their newly built logistics center in Bräunlingen. At the same location the company also produces powder coatings, what offered the chance to use a process cooling network as a heat source. In 2010 an integrated heating and cooling concept using a heat pump was implemented. The heat pump covers most of the heating demand of the production hall and the storage and shipping warehouse. The heating network runs at a temperature of 45 °C. At outside air temperatures below 0 °C an auxiliary oil heater is used to cover the rest of the heating load. As heat source for the heat pump a cooling water network is used. Through different production steps cooling water is heated up to 18 °C. The low temperature difference between hot and cold side of the heat pump ensures a heating COP of 5. In summer the heat pump is also used for cooling the production halls. Excess heat is then rejected to the environment. The payback period for this system is estimated to be 5 years. In 2010 23,000 € of fuel costs could be saved.

Table 7-9: Fact sheet for Emil Frei GmbH

Industrial branch	Other chemicals – Varnish and coatings
Type of heat pump	Electric compression heat pump
Heating capacity	240 kW
Heat source description	Coating powder production
Heat source temperature	18 °C
Heat sink description	Space heating
Heat sink temperature	45 °C
COP	5
Refrigerant	R404A
Investment cost	210,000 €
Operating since	2010
Payback period	5
Internal rate of return	18 %
Contact	Glen Dimplex GmbH

7.10.4 Chemicals B (Fkavex Naturextrakte GmbH)

Founded in 1986 Flavex Naturextrakte GmbH is now an expert in the production of plant and herb extracts. To protect the sensible active ingredients and aromatic substances the company uses the CO_2 extraction method. A scheme of the process is shown in Figure 7-10.

Supercritical CO_2 is used as extraction fluid, since it has a relatively low reactivity and the process temperatures can be kept low. The CO_2 gas is cooled and thereby liquefied. A pump raises the pressure to 500 bar. Before the liquid CO_2 enters the extraction chamber it is preheated. In the extraction chamber the CO_2 meets the plant material and active ingredients and aromatic substances are solved. This solution leaves the extraction chamber. An expansion valve reduces the pressure and the CO_2 evaporates while heat is supplied. Thereby the organic extracts are separated from the CO_2.

The extraction process needs cooling to liquefy the CO_2. A cooling water circuit supplies the plant with 16 °C cold water. The return flow has a temperature of 20 °C. The water is collected in a large storage tank with a volume of 30 m³. Since the temperatures were too low the waste heat was emitted to the environment until a heat pump was installed in 2009 to make use of this heat. It heats a new production building with a floor space of 2,000 m². To be able to supply the building with heat even on weekends and public holidays, when no waste heat from the process is available, a 45 m³ hot water tank was installed. The company was willing to accept a very long payback time of 10 years for the whole system, because it operates a similar heat pump system for 15 years now without any problems worth mentioning. In addition to that the new heat pump system saves up to 80 t CO_2 emissions per year /Bosch Thermotechnik GmbH 2011/.

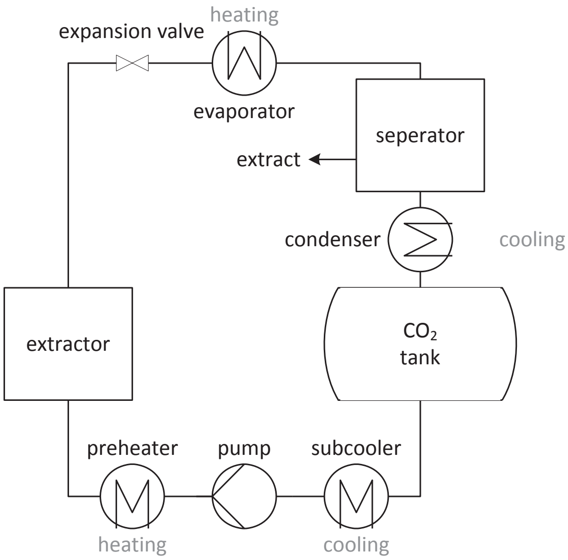


Figure 7-19: CO_2 extraction plant

Table 7-10: Fact sheet for Flavex Naturextrakte GmbH

Industrial branch	Chemicals – production of plant and herb extracts
Type of heat pump	Electric compression heat pump
Heating capacity	61,5 kW
Heat source description	CO_2 extraction plant
Heat source temperature	16 to 20 °C
Heat sink description	Space heating
Heat sink temperature	50 °C
COP	not specified
Refrigerant	R407c
Investment cost	210,000 €
Operating since	2009
Payback period	10
Internal rate of return	6 %
Contact	Junkers - Bosch Thermotechnik GmbH

7.10.5 Electronics (Dunkermotoren GmbH)

Dunkermotoren GmbH is a manufacturer of electric drives with 1,000 employees and an annual turnover of 150 million €. The company was acquired by Ametek in 2012.

In 2001 the company built a new production hall of 6,000 m² at their main site in Bonndorf. To cover the additional heat demand of the new building a heat pump was installed, so that the old oil powered heating system did not have to be extended. The heat pump recovered waste heat from injection moulidng machines at 25 °C and with a maximum cooling capacity of 66 kW. The temperature was lifted up to 70 °C to provide space heating in winter. To decouple heating and cooling demand, a large sprinkler tank was used to buffer peak loads. In the first year a monitoring of the heat pump system was monitored. The results showed that the heat pump system could cover 25% of the entire space heating demand. Due to restructurings of the company the injection moulding machines were taken out of service. With no heat source available anymore, the heat pump also had to be replaced by another heating system.

Table 7-11: Fact sheet for Dunkermotoren GmbH

Industrial branch	Electronics – Electrical drives
Type of heat pump	Electric compression heat pump
Heating capacity	90 kW
Heat source description	Injection moulding
Heat source temperature	25 °C
Heat sink description	Space heating
Heat sink temperature	70 °C
COP	3.7
Refrigerant	not specified
Investment cost	not specified
Operating since	2001
Payback period	not specified
Internal rate of return	not specified
Contact	Combitherm GmbH, Ingenieurbüro Jauch (Radolfzell)

7.10.6 Glass (Glasfabrik Thiele AG)

Glasfabrik Thiele AG was founded in 1984 in Schrotzberg and is now present in seven locations all over Germany. The company specializes on production and finishing of flat glass products. The company's largest production site with an area of 14,500 m² is situated in Wermsdorf. In 2007 the office building in Wermsdorf was extended from 200 m² to 450 m² office space. A heat pump system was installed to cover the resulting additional space heating demand. Furthermore the heat pump also generates 1,200 to 1,400 l of hot water per day.

Glass furnaces are emitting a lot of heat to the ambient air in the production hall. Therefore air conditioning is needed to keep the temperatures in a comfortable condition. To recover the heat emitted by the furnaces two air source heat pumps were installed directly next to them. These heat pumps suck in air at 25 °C and cool it down by 10 K. The heat pump system has a cooling capacity of 40 kW. At the condenser hot water is produced at 40 °C to be used for showers and space heating. Two thermal hot water storages of 400 l and 500 l are working as a buffer to decouple heating and cooling demands. The 500 l storage is used for space heating while the 400 l storage provides hot water for the showers. Pictures of the installation are shown in Figure 7-20. The investment costs for this system can be apportioned to 58,000 € for the heat pumps and 24,000 € for additional accessories and installation works. The total investment costs sum up to 82,000 € for the whole system /Dimplex 2012/.

Figure 7-20: Air source heat pump situated directly next to the glass furnace /Dimplex 2012/

Table 7-12: Fact sheet for Glasfabrik Thiele AG

Industrial branch	Glass – Glass finishing
Type of heat pump	Electric compression heat pump
Heating capacity	64 kW
Heat source description	Glass finishing, hot air near the production furnace
Heat source temperature	25 °C
Heat sink description	hot water, space heating
Heat sink temperature	40 °C
COP	3,8
Refrigerant	R404A
Investment cost	82,000 €
Operating since	2007
Payback period	not specified
Internal rate of return	not specified
Contact	Glen Dimplex GmbH

7.10.7 Mechanical Engineering (Gebr. Kemmerich GmbH)

Gebr. Kemmerich GmbH designs and produces metal parts. The company employs more than 1.000 employees at 5 locations. Since 1996 the tool-making division is settled in Niederau-Gröbern. In recent years the division specialized in metal forming processes.

In the production process CNC machines, laser cutters and eroding machines are used. These machines have been cooled by a conventional cooling system. In 2012 a heat pump was installed to recover the energy formerly wasted. The heat pump has a heating capacity of 20 kW and provides heat for space heating at 60 °C. When the heat demand exceeds the capacity of the heat pump an oil fired boiler is activated. Main focus of the system is to always provide enough cooling power. Therefore a cold storage was integrated into the cooling network. On the hot side storage for hot water was installed. Figure 7-21 shows a scheme of the integrated heating and cooling system. With installation costs of 25,000 € a payback period of 2 years could be reached /Klima Jentzsch GmbH 2013; FORM + Werkzeug 2013/.

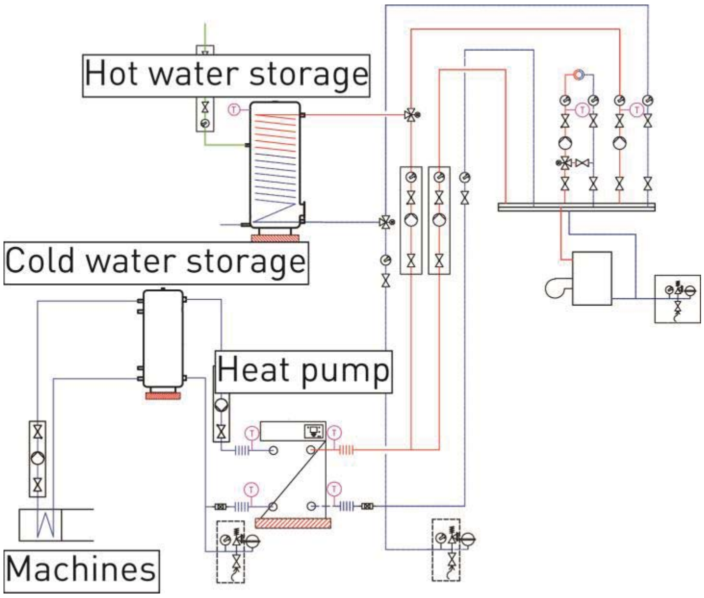


Figure 7-21: Integrated heating and cooling system at Gebr. Kemmerich GmbH /Klima Jentzsch GmbH 2013/

Table 7-13: Fact sheet for Gebr. Kemmerich GmbH

Industrial branch	Metal processing – tool manufacturing
Type of heat pump	Electric compression heat pump
Heating capacity	20 kW
Heat source description	Laser cutting, eroding and CNC machines
Heat source temperature	not specified
Heat sink description	Space heating
Heat sink temperature	60 °C
COP	3.7
Refrigerant	not specified
Investment cost	25,000 €
Operating since	2012
Payback period	2 years
Internal rate of return	50 %
Contact	Klima Jentzsch GmbH

7.10.8 Metal processing A (Flamm GmbH)

Flamm GmbH in Aachen is a manufacturer of precision wires for electronics industry and stamping and deep drawing parts for metal industry. The company was founded in 1982. Today it employs 45 employees in three-shift operation. Production hall and warehouse have a total area of 8,000 m².

Different processes generate waste heat at 27 °C. It is used as heat source for a heat pump with a heating capacity of 230 kW. With a COP of 5 the heat pump lifts the temperature up to 55 °C and thus covers the entire heat demand of the company. The total investment amounts to 70,000 € with yearly savings of 22,000 €. This is reflected in the rather short payback period of 3.2 years and a large internal rate of return of 29 %.

Table 7-14: Fact sheet for Flamm GmbH /Schreier/

Industrial branch	Metal processing – Wires for the electronics industry
Type of heat pump	Electric compression heat pump
Heating capacity	220 kW
Heat source description	Process water
Heat source temperature	27 °C
Heat sink description	Space heating
Heat sink temperature	55 °C
COP	5
Refrigerant	R134a
Investment cost	70,000 €
Operating since	not specified
Payback period	3.2 years
Internal rate of return	29 %
Contact	Güstrower Wärmepumpen GmbH

7.10.9 Metal processing B (Ludwig Michl GmbH)

Ludwig Michl GmbH designs and manufactures metal products. With 80 employees the company processes 1,000 t of sheet metal per year and achieves an annual turnover of 9 to 10 million euro /Ludwig Michl GmbH 2013/. Motivation for a complete restructuring of the heating and cooling system was the acquisition of two new machines that needed to be cooled. Before the company installed a centralized cooling system each machine emitted its waste heat into the production hall. Especially in summers this lead to unpleasantly high air temperatures. The additional heat emitted by the new machines even lead to malfunctions in machine control units due to overheating.

When new machinery was procured in 2007 also a new centralized heating and cooling system was installed. The central unit of the system shown in Figure 7-22 are five absorption heat pumps, operated in parallel. Each of them has a heating capacity of 34 kW and a cooling capacity 16 kW and is equipped with a pump on both sides. These pumps for hot and cold water are controlled by the heat pump control system, which is connected to a higher-level control system via mod bus. The higher level system controls the distribution of heating and cooling. Cooling is supplied to two laser cutting and welding machines, to an edging machine, to a server room and the production hall. The heat sources are connected in parallel to ensure a supply temperature of 20 °C. A 3 m³ stratified cold water storage allows a decoupling of volume flows of the heat pump and the cooling circuit. The heat pumps can be switched on/off individually to adjust the cooling capacity. Hot water is produced at 60 °C to cover the heat demand of a chamber washing system and a hot air dryer. Both machines are connected in series as the dryer can also operate with lower temperatures. The chamber washing system, however, is very temperature dependent. If the temperature of the washing solution falls below a critical value, the solution starts to foam up. Like on the cold side volume flows of the heat pump and the heating circuits are decoupled by a 1 m³ storage. In case of a heat surplus, the heat can be emitted to the environment via an air cooler. To save space in the production hall, heat pumps, hot water storage and air cooler are housed in a sea container next to the building. As this container is neither heated in winter nor insulated sufficiently to inherently prevent freezing of the water circuits, the heat pumps are operated in an active anti-freeze mode in winter. The heating and cooling system is operated monovalent. Therefore system failures have to be patched immediately to prevent a production break down. By connecting the control system to an e-mail notification system staff is enabled to react quickly.

In the first months LPG was used to power the heat pumps. After the local gas supplier had connected the company to the gas network, the energy supply was switched to natural gas. The costs of 50,000 € for the extension of the gas network were covered by the local gas supplier. The investment costs for the integrated heating and cooling system amounted to 125,000 €. The Project was funded by Deutsche Bundesstiftung Umwelt (DBU) with 30,000 €. The payback period for the investment was 4 years. Compared to the old system up to 40 % of the CO_2-Emissions could be saved /Ludwig Michl 2007, Robur 2008; Lehnhardt 2008/.

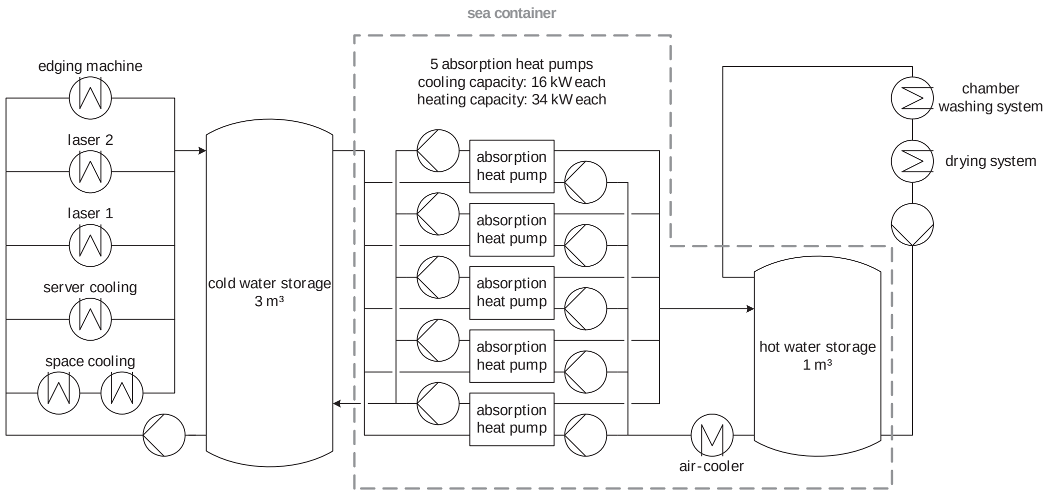


Figure 7-22: Heating and cooling system at Ludwig Michl GmbH

Table 7-15: Fact sheet for Ludwig Michl GmbH

Industrial branch	Metal processing – Sheet metal products
Type of heat pump	Gas absorption
Heating capacity	194 kW
Heat source description	Laser, server and space cooling
Heat source temperature	20 °C
Heat sink description	Washing process, drying process, space heating
Heat sink temperature	60 °C
COP	2,3 (integrated)
Refrigerant	R717 (Ammonia)
Investment cost	125,000 € (total investment)
Operating since	2007
Payback period	4 years
Internal rate of return	23 %
Contact	Ludwig Michl GmbH, Robur GmbH

7.10.10 Metal processing C (Purkart Systemkomponenten GmbH & Co. KG)

Purkart Systemkomponenten designs and manufactures metal products. In 2011 the company implemented a new integrated heat recovery system to reduce energy costs. Figure 7-23 shows a scheme of the new integrated heating and cooling network. Waste heat generated in production process is now used to cover the space heating and process heat demand. While waste heat from compressed air generation could directly be integrated into the heating network the temperatures of other heat sources are too low. Here a heat pump is used to upgrade the temperature to 60 °C to provide heat for space heating and industrial processes (e.g. phosphating and degreasing of metal parts). The heat pump extracts about 190 kW from a cooling network and cools down cooling water from 30 to 25 °C. Cooling is needed for a laser welding machine. To guarantee the cooling the old free cooling plant is kept as a backup system. In addition to the welding machine the exhaust gas from a curting oven is used as a heat source. The exhaust gas leaves the oven at temperatures of 200 to 300 °C. Formerly unused is it now condensed which raises the thermal efficiency of the oven to 99% based on the lower caloric value. In case there is no use for this heat can still be released by the old exhaust stacks. To buffer peak loads, a 16 m³ stratified storage is installed on both hot and cold side of the heat pump. Hereby heating and cooling demands are decoupled. The large volume of the tanks enables the system to run for 30 to 60 minutes without heat demand or supply. Monitoring and optimization of the plant performance could increase the operating time of the heat pump from 5 to 8 hours per day. Due to the high sensivity of the cooling of the laser welding machine hydraulic balancing had to be performed several times. The implementation of the heat recovery system now saves 33% of the total natural gas demand. Payback time for this system is expected to be 6 years assuming a return of 18% and an increase of energy prices of 3% per year /Preuß 2011; SAENA 2012; Brandenburg 2011/.

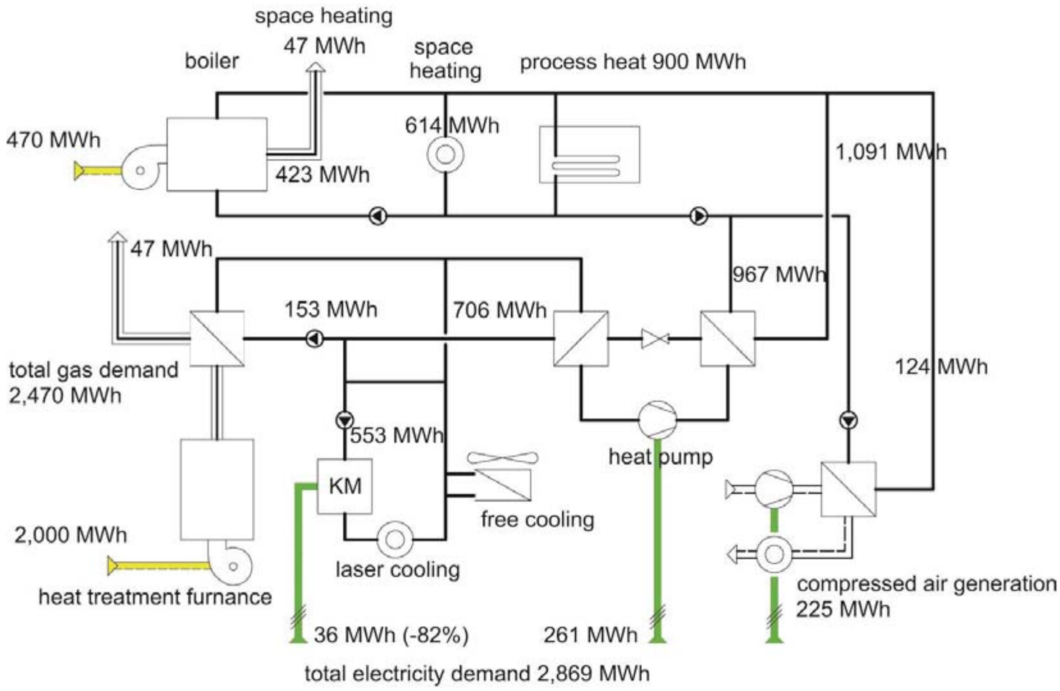


Figure 7-23: New heat recovery system with an integrated heat pump /Preuß 2011/

Table 7-16: Fact sheet for Purkart Systemkomponenten GmbH

Industrial branch	Metal processing – sheet metal products
Type of heat pump	Electric compression heat pump
Heating capacity	274 kW
Heat source description	Laser cooling and exhaust gas condensation
Heat source temperature	25 to 35 °C
Heat sink description	Space heating and process heat
Heat sink temperature	60 °C
COP	3.8
Refrigerant	R134a
Investment cost	570,000 € (for the whole system)
Operating since	2011
Payback period	6 years
Internal rate of return	15 %
Contact	FWU Ingenieurbüro GmbH, Combitherm GmbH

7.10.11 Metal processing D (Schraubenwerk Zerbst GmbH)

Schraubenwerk Zerbst is a producer of special screws with large diameters for rail fastening, wind turbines and other machinery. With 195 employees the company achieves a turnover of 38 million euro.

The production of screws starts with round rods that are pickled and degreased at first. An induction furnace heats the rods before a large press finally forms the screw head.

The coils of the inductive furnace have to be cooled continuously. The cooling system supplies cooling water at 20 to 23 °C. The waste heat from the inductive furnace raises the temperature up to 25 °C. The cooling water is collected in a large basin before it is pumped to cooling towers that reject the waste heat to the environment.

To recover a large share of this waste heat (up to 436 kW) a heat pump system consisting of two heat pumps with a heating capacity of 292 kW per unit was installed. The heat pumps use the cooling water basin as heat source. To be able to adapt to heating and cooling demands the heat pumps are installed in parrallel. Therefore the heat pumps can adjust their heating capacity in 8 steps. To avoid an immediate circuit a special evaporator with a high contamination tolerance was designed. The heat pumps deliver hot water for space heating of production and administrative buildings. When there is not enough waste heat available (e.g. at weekends) a 300 kW gas boiler covers the heat demand of the building /Klima Jentzsch GmbH 2013; Schraubenwerk Zerbst 2013/.

Table 7-17: Fact sheet for Schraubenwerk Zerbst GmbH

Industrial branch	Metal processing – Screw production
Type of heat pump	Electric compression heat pump
Heating capacity	584 kW
Heat source description	Metal induction press
Heat source temperature	20 to 23 °C
Heat sink description	Space heating
Heat sink temperature	40 to 58 °C
COP	3,5
Refrigerant	not specified
Investment cost	180,000 €
Operating since	2011
Payback period	2 years
Internal rate of return	50 %
Contact	Klima Jentzsch GmbH

7.10.12 Metal processing E (Thoma Metallveredelung GmbH)

Thoma Metallveredelung GmbH is an electroplating company that offers a various surface treatments. The company is a very active driver for the rational use of energy in the electroplating industry. In a research project funded by Deutsche Bundesstiftung Umwelt (DBU) with 110.000 € a concept for a new energy saving hard chromium line was developed. Chromium plating is a technique of electroplating a thin layer of chrome onto metal objects. This is done by immersing the objects into a bath of chromium electrolyte. By applying direct electric current, chromium is plated out on the object´s surface. Usually only 20 % of the electric energy are used to create the chromium coating. The remaining 80 % are converted into waste heat. As the electroplating process is very temperature-sensitive cooling has to be applied to the electroplating bath.

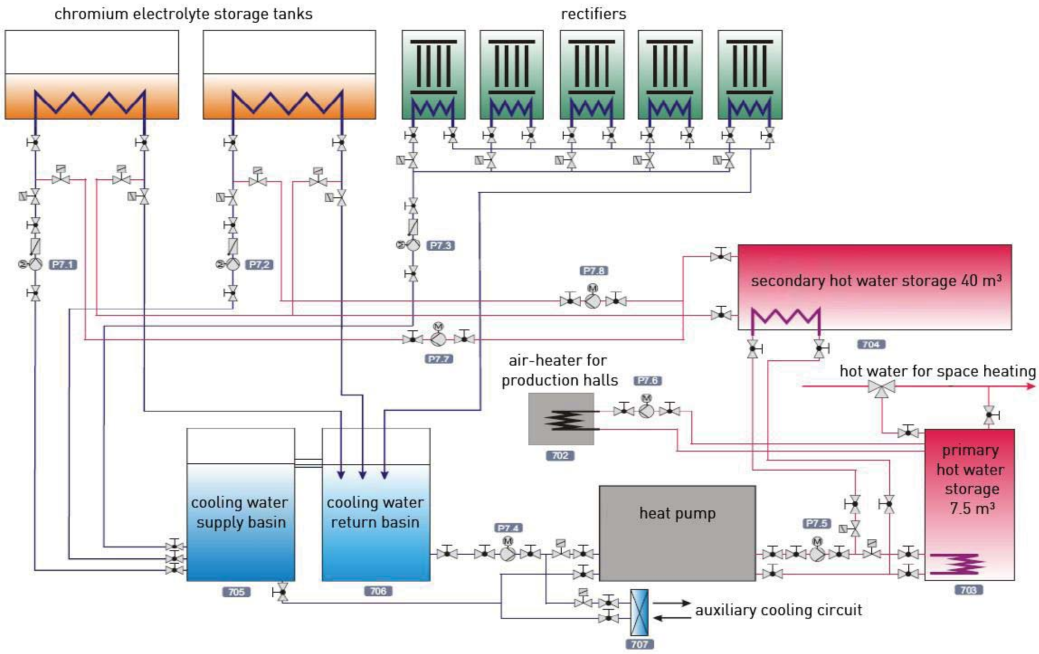


Figure 7-24: Circuit diagram of the heating and cooling system /Zimmer 2009/

Thoma Metallveredelung GmbH has increased the over-all efficiency of this process to more than 90 % by improving the electroplating process and integrating a heat pump to reuse the generated waste heat. By increasing the current density from 50 A/dm² to 90 A/dm² the efficiency of the electroplating process could be increased to 24 %. To maintain a good surface quality the temperature of the bath had to be raised to more than 60 °C. As the process still produces a large heat surplus, the electrolyte tanks as well as the current rectifiers are cooled by a water circuit. The cooling water returns to a collecting basin at a temperature of 60 °C. Because in the company there is no heat needed at 60 °C, the cooling water basin serves a heat source for a heat pump. The heat pump has a heating capacity of 143 kW and produces hot water at 75 to 80 °C. At this temperature level hot water is used for space heating and to supply others baths of the coating line. A 7.5 m³ storage serves as a buffer for space heating. Due to higher heating loads the process heat storage has a larger volume of 40 m³. Both heating and cooling system are operated bivalent. In case of a malfunction of the heat pump a groundwater well serves a heat sink for the cooling water, while an oil-fired heater covers the heating demand. The heat pump system covers 50 % of the heat demand and saves 150,000 l oil per year. Another positive effect of the new hard chromium line is significant process improvements. The coating hardness could be increased by 10%, while the plating rate could be increased by 80 %. For planning and implementation of the project experts from different engineering disciplines had to work together. The coordination of this work took a lot more effort than expected before. Nevertheless Thoma Metallveredelung GmbH is very satisfied with the result and plans to install similar heat recovery systems in their other coating lines. Furthermore the whole system was designed using standard components. In this way other electroplating companies can adapt the system without infringing property rights /Zimmer 2009, Zimmer 2010a, Zimmer 2010b; Hlavica 2010/.

Table 7-18: Fact sheet for Thoma Metallveredelung GmbH

Industrial branch	Metal processing – Electroplating
Type of heat pump	Electric compression heat pump
Heating capacity	143 kW
Heat source description	Process cooling
Heat source temperature	50 to 60 °C
Heat sink description	Space heating, process heat from bath heating
Heat sink temperature	75 to 80 °C
COP	3
Refrigerant	not specified
Investment cost	not specified
Operating since	2009
Payback period	less than 4 years
Contact	Thoma Metallveredelung GmbH

7.10.13 Metal processing F (Walter Th. Hennecke GmbH)

Hennecke GmbH is a metal processing company that offers a large spectrum of services from metal forming, surface treatment and welding to construction and logistics. In 2011 a new heat recovery system was installed. A 260 kW heat pump is the central element of this system. It provides cooling for 5 large CO_2 laser cutting machines that are operated all day long in three-shift operation. These machines have a power input of 80 kW each. More than 90 % of this power is turned into heat and has to be cooled. The five laser cutting machines together produce up to 375 kW heat at 27 °C. The heat pump provides a maximum cooling capacity of 180 kW and cools down the cooling water to 22 °C. It provides up to 260 kW heat at 65 °C to degreasing and phosphating machines. Two especially constructed stratified storages with a volume of 8,000 l buffer peak loads on the hot and the cold side of the heat pump. The old 400 kW gas heater is kept as an emergency reserve. The first months of operation showed that the heat pump could cover the entire heating demand at only 40 % load. To increase the operating hours the heat pump will also provide heat for showers and space heating for a newly built building with 1,400 m² of social and 2,500 m² of working space. In this final stage allows approximately 500 t of CO_2 to be saved /Hennecke 2013/.

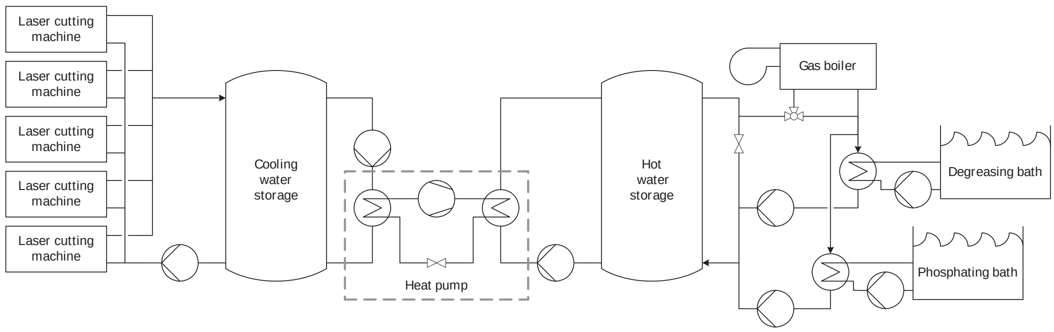


Figure 7-25: Integrated heating and cooling system at Hennecke GmbH

Table 7-19: Fact sheet for Hennecke GmbH

Industrial branch	Metal processing – sheet metal products
Type of heat pump	Electric compression heat pump
Heating capacity	260 kW
Heat source description	Laser cutting machine
Heat source temperature	27 °C
Heat sink description	Process heat for pretreatment for powder coating
Heat sink temperature	65 °C
COP	4
Refrigerant	not specified
Investment cost	85,000 € (heat pump only)
Operating since	2011
Payback period	3 to 4 years (whole system)
Internal rate of return	not specified
Contact	iQma energy GmbH & Co. KG; SmartHeat Deutschland GmbH; Henneke GmbH

7.10.14 Stone and earths (Treibacher Schleifmittel Zschornewitz GmbH)

Treibacher Schleifmittel GmbH is a producer of abrasives. The plant in Gräfenhainichen was acquired in 2001. Today the nearly 170 employees produce mainly zirconium oxide and corundum, which are needed for the production of abrasives or high temperature thermal insulations.

Reactive alumina is the basic compound for the corundum production. It is melted in an electric furnace that operates at 2,000 to 3,000 °C. The corundum is then cast into ingots. Once the ingots are cooled down, they are broken into smaller pieces. Further milling and sieving steps are necessary to achieve homogenous particle properties. Before packaging the corundum is mixed with additives and it is sieved for the last time.

To withstand the high process temperatures the electric furnace has to be cooled continuously. The cooling system is operating at 35 °C. Most of the heat is rejected to the environment by means of cooling towers. Since 2011 a small share of the cooling demand is covered by a heat pump with 80 kW cooling capacity. Due to impurities in the cooling water an immediate circuit was installed to protect the evaporator. On the hot side the heat pump provides heat for space heating at 60 °C. Two storages connected in parallel decouple heating and cooling demands. Figure 7-26 shows the integration scheme of the heat pump system. /Klima Jentzsch GmbH 2013/.

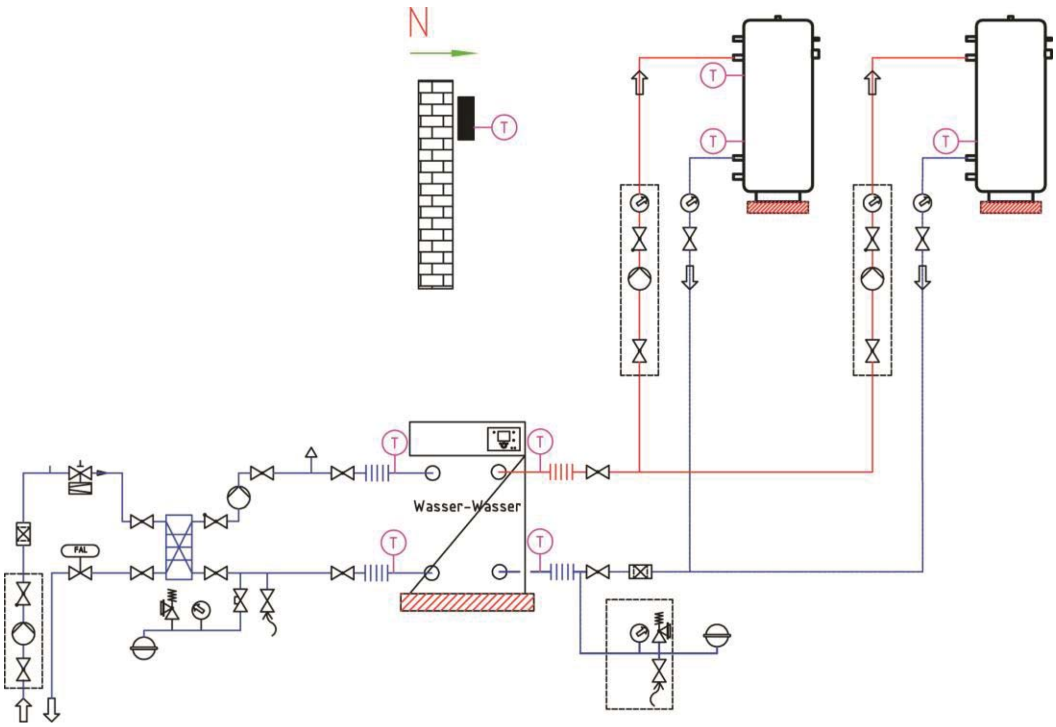


Figure 7-26: Integrated heating and cooling system at Traibacher Schleifmittel GmbH

Table 7-20: Fact sheet for Treibacher Schleifmittel GmbH

Industrial branch	Basic chemicals – Abrasives
Type of heat pump	Electric compression heat pump
Heating capacity	110 kW
Heat source description	Electric furnace
Heat source temperature	35 °C
Heat sink description	Space heating
Heat sink temperature	60 °C
COP	3.7
Refrigerant	not specified
Investment cost	72,760 €
Operating since	2011
Payback period	3.2 years
Internal rate of return	not specified
Contact	Klima Jentzsch GmbH

7.10.15 Food B (Tivoli Malz GmbH)

Tivoli Malz GmbH is holder of Global Malt GmbH & Co. KG and a mayor malt producer in Germany and Poland with an annual production of 400,000 t. At its production site in Hamburg the company installed a CHP plant in combination with a heat pump to lower energy costs. With an annual production of 105,000 t of malt the site accounts for more than one fourth of the company's production capacity /GlobalMalt 2013/.

Malt is a major ingredient for beer brewing. It is produced from cereal, which is left to germinate under humid conditions. The germination process is stopped by drying the germs in a kiln. This process typically needs a large amount of hot and dry air at 65 °C or above. Humid exhaust air is released at 28 °C. This waste heat stream can be used to preheat inlet air. This is usually carried out by means of recuperative glass tube heat exchangers. In addition to this branch technology standard Tivoli Malz GmbH integrated a heat pump to recover an additional amount of 2.7 MW waste heat. A very low temperature difference between heat source and heat sink leads to a high COP of 6. With Ammonia a natural refrigerant was chosen, because of its high volumetric capacity which results in a relatively little filling quantity and compact dimensions of the heat pump. The heat pump provides a heating capacity of 3.3 MW with about 6,000 operating hours at full load per year. Up to 3,000 l of water are condensed per hour. The inlet air is then further heated by a CHP plant that covers the total electricity demand of the production site. A gas powered auxiliary heater lifts the inlet air temperature up to 65 °C, before it enters the kiln /Mönch 2011; Tivoli Malz 2012; Brauwelt 2010/. The Project was funded with 340,000 € for 2.5 years by Deutsche Bundesstiftung Umwelt (DBU) /DBU/.

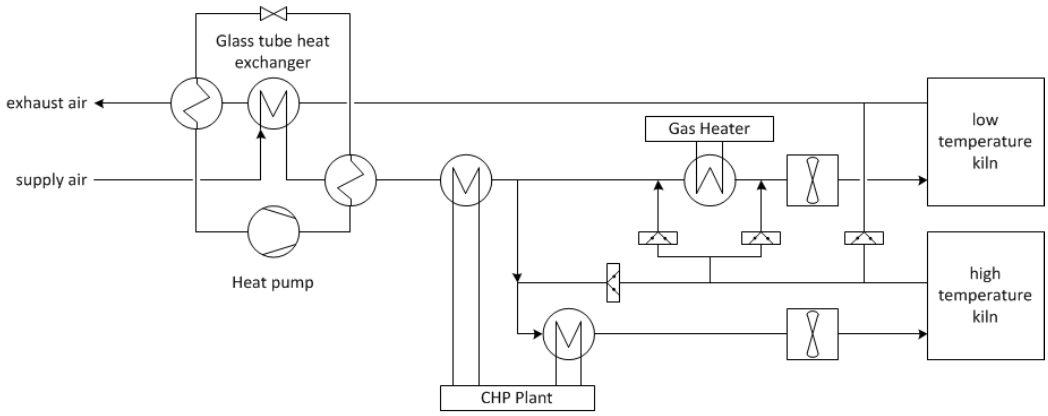


Figure 7-27: Process scheme of the energy supply for the kiln

Table 7-21: Fact sheet for Tivoli Malz GmbH

Industrial branch	Food – Malt production
Type of heat pump	Electric compression heat pump
Heating capacity	3,250 kW
Heat source description	Process exhaust air
Heat source temperature	23 °C
Heat sink description	Process heat for a kiln
Heat sink temperature	35 °C
COP	6.3
Refrigerant	R717 (Ammonia)
Investment cost	1,684,250 € (total investment for CHP, HX and heat pump)
Operating since	2010
Payback period	not specified
Internal rate of return	not specified
Contact	Tivoli Malz GmbH

7.10.16 Food A (Hanspeter Graßl KG)

Hanspeter Graßl KG is a small scale brewery that is marketing its beer under the brand name Schäffler Bräu in Missen.

Beer brewing is a multistage batch process. It is one of the most energy intensive production processes in the food industry. At first malt and water are heated in the mash pan. Stretch and enzymes are dissolved in the water. After the enzymes have turned the stretch into sugar the brew is heated up to 80 °C, which deactivates the enzymes. In the next step insolvable components are removed from the brew before it is cooked at 90 to 120 °C. A part of the water is evaporated in this step to concentrate the brew. After the cooking the brew is filled into fermentation tanks where yeast converts the sugar into alcohol. Since the fermentation process generates some heat the tank needs to be cooled to keep it at 5 to 15 °C. The temperature depends on the used yeast type. After the fermentation is completed the beer is filled into bottles.

In June 2012 the Schäffler Brewery installed a heat pump to recycle waste heat generated by the cooling plant and the bottle cleaning and filling plant. In case no waste heat is available the heat pump uses a ground water well as heat source. The heat pump system generates 200 MWh heat at 55 °C per year and covers about 80 % of the heat demand of a nearby restaurant and hotel. The investment cost of 31,667 € can be subdivided into the cost for the heat pump (26,667 €) and the cost for the heat exchanger (5,000 €). The payback period was calculated to be 6 years or less.

Table 7-22: Fact sheet for Hanspeter Graßl KG

Industrial branch	Food – Brewery
Type of heat pump	Electric compression heat pump
Heating capacity	77 kW
Heat source description	Waste heat from the cooling plant and the bottle filling plant
Heat source temperature	20 °C
Heat sink description	Space heating and hot water
Heat sink temperature	55 °C
COP	4.3
Refrigerant	R134a
Investment cost	31,667 €
Operating since	2012
Payback period	6
Internal rate of return	14 %
Contact	Arwego – Armin Schneider e.K.

7.10.17 Textile (PONGS Seidenweberei GmbH)

Pongs produces fabrics for technical and decorative purposes. Especially the dyeing of fabrics offers a large heat recovery potential. Exhaust air from the dyeing machine can be used as a heat source. In case of Pongs a special heat exchanger was designed to recover 110 kW heat for the 30 to 40 °C warm exhaust air. The heat pump delivers hot water for space heating at 50 °C with an average COP of 5.1. As the company is highly satisfied with the results, they already installed a second heat pump system for heat recovery /Klima Jentzsch GmbH 2013/.

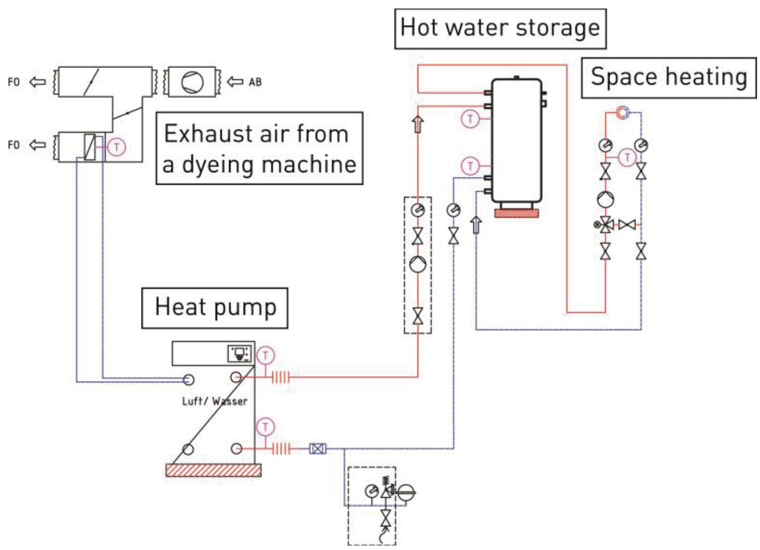


Figure 7-28: Air to water heat pump system at Pongs GmbH /Klima Jentzsch GmbH 2013/

Table 7-23: Fact sheet for PONGS Seidenweberei GmbH

Industrial branch	Textiles – printing and dyeing of textiles
Type of heat pump	Electric compression heat pump
Heating capacity	137 kW
Heat source description	Exhaust air from dying machine
Heat source temperature	30 to 40 °C
Heat sink description	Space heating
Heat sink temperature	50 °C
COP	5.1
Refrigerant	not specified
Investment cost	not specified
Operating since	2011
Payback period	not specified
Internal rate of return	not specified
Contact	Klima Jentzsch GmbH

7.10.18 Comparison and conclusion

The characterized heat pump systems show a wide range of application opportunities. Mostly industrial waste heat is used to generate heat for space heating. Therefore most heat pump systems generate heat at about 60 °C. The operation temperatures of the heat pump systems are given in Figure 7-29. The average heat source temperature is 28 °C. Heat source temperatures vary from 18 to 50 °C while the heat sink temperatures vary from 35 to 82 °C. The average heat sink temperature is 59 °C. The average temperature lift is 31 K. For one of the 17 examples data on temperatures was not complete.

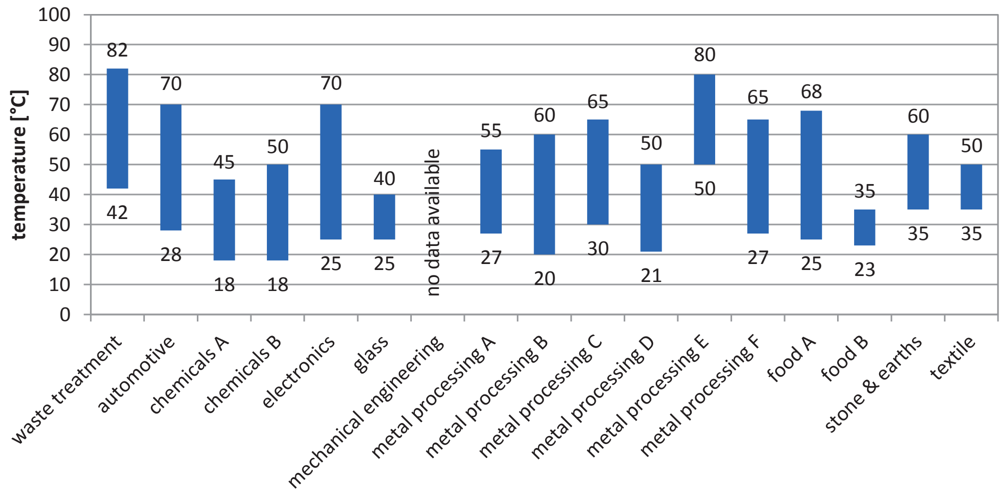


Figure 7-29: Operating temperatures of the surveyed heat pump systems

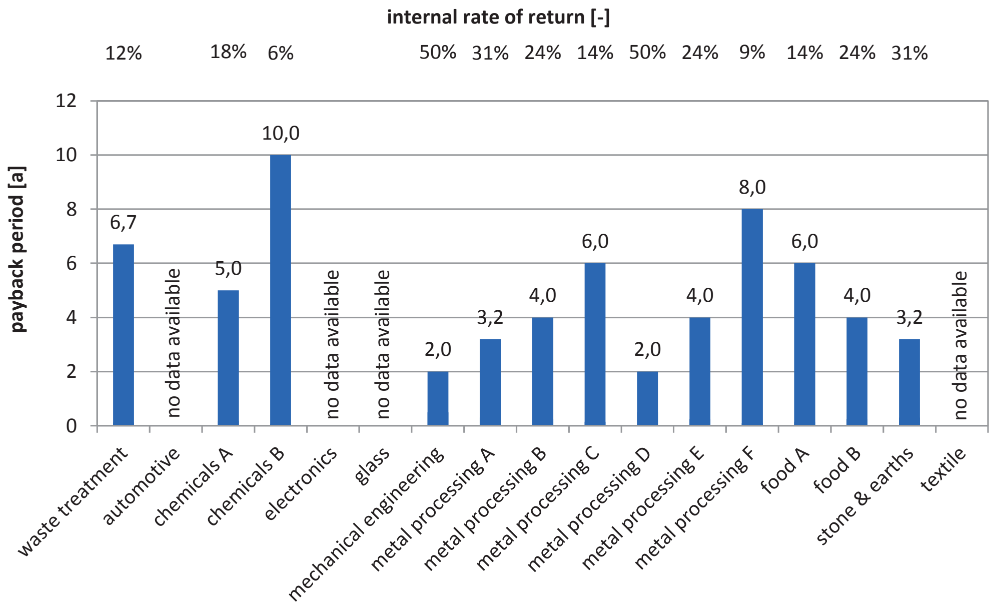


Figure 7-30: Economics of the surveyed heat pump systems

Economic data was just given by 13 companies, because it is often considered to be critical data. The documented payback periods are valid for the whole investment including peripheral components and planning and installation costs. Figure 7-30 gives an overview over payback periods of the documented energy efficiency measures. Payback periods vary from 2 to 10 years with an internal rate of return between 6 and 50 %. If looked at the internal return rate even a payback period of more than 6 years can be considered economical feasible.

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8 Japan

8.1 Introduction

In general, industrial heat pumps can be characterized by a high coefficient of performance (COP) achievable through the use of various types of exhaust heat, simultaneous supply of cold and hot energy, and long operating time through the year.

Heat pumps can be used for HVAC (heating, ventilation and air-conditioning), hot water supp supply, heating, drying, dehumidification and other purposes as shown in Table 8-1:

Table 8-1: Purpose of use of heat pumps

Purpose of use	Examples of application
HVAC	Factory HVAC, clean rooms, protected horticulture, plant factories
Hot water supply	Mechanical part washing, process liquid heating
Heating	Hot spring heating, snow melting, fish/eel farming, aquariums
Heating/cooling	Food manufacturing, electrocoating, plating, can manufacturing
Drying/dehumidification	Agricultural produce, marine products, printing, coating drying
Concentration/evaporation/distillation	Wort boiling, milk, sugar solution, amino acid
Heat recovery	Ethanol, cooling tower exhaust heat, rectifying tower exhaust heat

When heat pumps are used for industrial applications, the following considerations should be given:

- Clearly determine the temperature range and operating conditions of the heat utilization system
- Secure a good-quality absorption heat source, and pursue simultaneous usage of both heating (exothermic) and cooling (endothermic) as far as possible
- Supply heat at a proper temperature to the target process in a controlled manner
- Try to use the heat pump system in combination with a thermal storage system for effective operation

Figure 8-1 shows a chart of industrial heat pump applications:

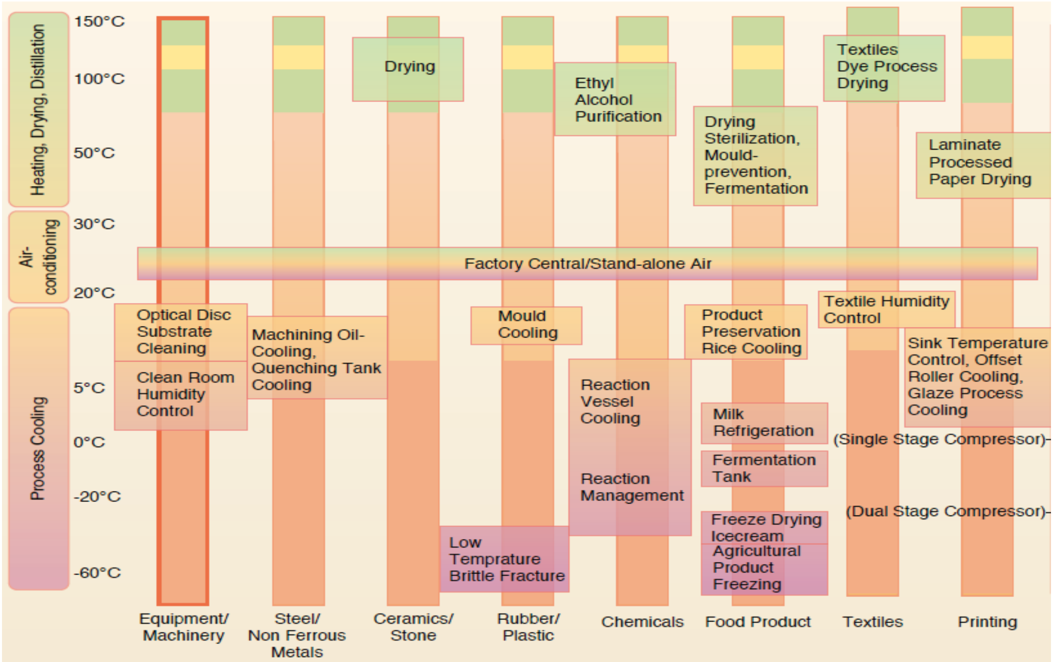


Figure 8-1: Industrial heat pump applications

Source: Masanori KANDO, Chapter 3, 'Examples of Application of Heat Pumps', Electro-Heat Handbook, "Recommended Electric-Powered Production Processes, Future Ages, Use More Electricity for Production", Japan Electro-Heat Center, 2010

Introducing heat pumps into the industrial sector can bring the following benefits:

1. “Steam reduction” by heat pumps
    - Factories generally use thermal energy in the form of steam. However, most manufacturers distribute steam from their energy center to individual production facilities through long steam piping. The steam system always involves heat loss from the piping and drain loss from the traps in addition to combustion loss in the steam boilers. It is said that only 30 to 50 percent of the steam generated in the energy center is effectively used.
    - Installation of a heat pump close to the place where heat is required can achieve more effective use of waste energy than the steam system.
    - Replacing conventional steam humidification of clean rooms with evaporative humidification (steamless) will save more energy than the steam system can do.
2. “Exhaust heat recycling”
    - Even exhaust heat, which has just been released to the atmosphere, can be collected and converted into higher-temperature thermal energy by heat pumps. Simultaneous cooling and heating with heat pumps will achieve substantial energy-saving.
3. “Thermal storage”: Save heat and use it whenever necessary!

- Storing cold and hot energy will allow supply of large amounts of heat at a constant temperature whenever necessary. Where both low- and high-temperature loads exist, the use of a simultaneous cold and hot water-producing heat pump in combination with cold and hot thermal storage tanks maximizes energy usage without wasting either.

Introducing heat pumps into the industrial sector can bring the following **economic** benefits:

1) Operating points of heat pumps

- A tip for successful operation of an exhaust heat recovery heat pump is to obtain a stable heat source. It is desirable that the heat pump can deliver thermal energy at a temperature as high as possible, and at a constant required flow rate.
- The temperature and flow rate of the hot water side are decided by the connected load. A hybrid system with boilers may be a good idea for better temperature control.

2) Operating condition

- With their high efficiency, heat pumps can bring benefits to running cost. A tip for maximizing the benefits is longer operating time (availability). Continual operation at as high efficiency as possible leads to a shorter payback period.
- Availability depends on the load balance between what is to be heated and what is to be cooled (exhaust heat). It is essential to design appropriate machinery and control systems that can be easily adapted to timing and variations (of temperature and flow rate) of both loads. If conditions are adequately satisfied, it would be possible to simultaneously produce cooling and heating energy, bringing substantial benefits.

3) Equipment and heat pump system

- The positional relationship between the loads to be cooled (exhaust heat) or heated and the heat pump substantially affects the initial cost of the overall heat pump system. If they are located close to each other, the piping system can be designed to be relatively small in scale.
- For some water quality or operating conditions, it may be necessary to plan supplemental devices such as indirect heat exchangers and thermal storage tanks. Careful preliminary discussion about coordination with existing equipment and overall system control is needed.

8.2 Examples of Recent Industrial Heat Pump Installation

We have many industrial heat pumps in practical use throughout Japan. Among the many installed cases, here we focus on heat pump technologies of simultaneous production of heating and cooling, vapor recompression, high temperature heat production and agricultural use because they are growing in sales and also expected further growth in the future.

In this section, 6 cases were picked out as typical examples of above mentioned prospective industrial heat pump technologies and their details, such as backgrounds of installation, system specifications and effects from economic and energy saving points of view, are explained.

A number of production processes require cold and hot water at the same time. A special feature of innovation surrounding the heat pump technology in recent years is a technology which can simultaneously produce hot water or hot air together with cold water effectively and easily. Good examples of the simultaneous cold water and 90 °C hot water production as well as the simultaneous cold water and 120 °C hot air production are shown in 8.3.1 and 8.3.3 respectively. In addition, chapter 8.3 explains an installation case of the heat pump system that can generate 65 °C circulating heating water and cooling water at the same time.

Effective use of less than 150 °C low-temperature waste heat still has much room to be developed. Vapor recompression systems are increasingly adopted to raise pressure and temperature of low-pressure vapor. However, when it comes to mechanical recompression systems, we have a problem of the large amount of power consumption. Therefore, an extensive use of the vapor recompression system has begun to be adopted by combining with the mechanical heat pumps. In relation to this, 8.3.2 is about the combined heat pump system of the mechanical and thermal vapor recompression reusing the low-pressure steam of 75 °C which is generated in distilling process. In addition, the adoption of heat pump systems with waste heat recovery is steadily growing in air-conditioning equipment. The 8.3.4 shows an example of the system for air-conditioning in 20 ~ 30 °C production processes.

Heat pump application in agriculture is one of the noteworthy features in recent years. The temperature and humidity control at a plant factory in ordinary commercial building is its good case example. However, residential heat pumps are mainly used for that purpose as the precise temperature and humidity control is strictly required and large heat loads are not necessary at most of the plant factories in Japan. On the other hand, in conventional outdoor greenhouses, the installation of heat pump systems is increasing as a replacement of heavy oil combustion boilers in accordance with increasing energy efficiency of heat pumps. The 8.3.6 shows the example for fruit cultivation which has high added values.

All the 6 cases picked out in this section succeeded in the great amount of reduction of energy consumption, running costs or CO_2 emission.

Appendix* is a factsheet that summarizes the cases from 8.3.1 to 8.3.5.

8.3 Examples of applications

8.3.1 Simultaneous hot/cold water producing heat pump for noodle-making

Background

Food processing consists of multiple processes at different temperatures such as cleaning, sterilization, boiling, cooling, freezing and drying. Traditionally, gas burners and heavy oil-fired steam boilers have been used as a heating source, and refrigerating machines have been used as a cooling source. Absorbing heat from the cold side and rejecting heat to the hot side is one of the most fundamental functions of heat pumps. If such absorbed heat and rejected heat produced by a heat pump are used simultaneously, the operating efficiency of the heat pump can be dramatically improved. To achieve this goal, heat pump systems that can produce hot and cold water simultaneously, and use them for cooling and heating, have been introduced in food processing plants. However, conventional compression heat pumps, which can only produce heat at around 60℃ at most on the hot side, can find only limited applications. Furthermore, the food processing industry faced an urgent problem of reducing heavy oil consumption, since the price of A-type heavy oil in Japan rose sharply from 2000 and reached a level as high as four times the 1999 price in 2008. Hence, a simultaneous hot/cold water producing heat pump capable of delivering water at 90℃ was developed, and is being introduced to sterilization and boiling processes in the industry.

Example of installation

8.3.1.1 Company Information

Location: Shikoku Island, Japan

Operation: Production of frozen noodles

Installed in: 2008

Purpose of installation: To reduce energy consumption for producing hot and cold water used in the noodle boiling process after noodle-making (80°C or higher), and the cooling process before freezing (around 5°C)

Production: Approx. 10,000 ton/year

8.3.1.2 Installed system

Frozen noodles are manufactured in production processes shown in Figure 8-2. The boiling process requires hot water not less than 80°C, which was traditionally supplied by steam boilers. The process is followed by a cooling process (5°C), which conventionally used a dedicated refrigerator.

Then, the noodle company introduced a heat pump that can produce hot water for the boiling process and cold water for the cooling process simultaneously. Figure 8-3 shows the flows of hot water, cold water and steam in the boiling and cooling processes. The process includes a steam boiler of 1500 kg/h, and two steam boilers of 1000 kg/h. There are two boiling pools having a capacity of about 3000L. The plant is operated over about 16 hours per day starting at 7 o'clock in the morning for about 250 days of the year.

Hot water (90°C) produced by the heat pump flows through a heat exchanger and is stored in a hot water tank. About 45 m$^{3/}$day of stored hot water (80 to 83°C) is delivered from the tank as demanded. The majority of the hot water in the tank is used to fill the boiling pools at the start of production in the morning. This helps reduce the peak load of the steam boilers. The boiling pools are reheated to the boiling temperature (98 °C) with steam from the steam boilers. The rest of the hot water in the tank is used to pre-heat the boiler feedwater. This brings benefits of lower steam boiler load as well as higher heat pump availability.

Cold water (5 °C) supplied by the heat pump is used to cool the additional water in the raw water tank (17 °C) for the cooling pools. This reduces the load of the refrigerating machine. Additional cooling to achieve the cooling temperature in the cooling pools (3 °C) is provided by the existing refrigerating machine.

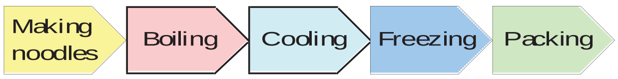


Figure 8-2: Production processes of frozen noodles

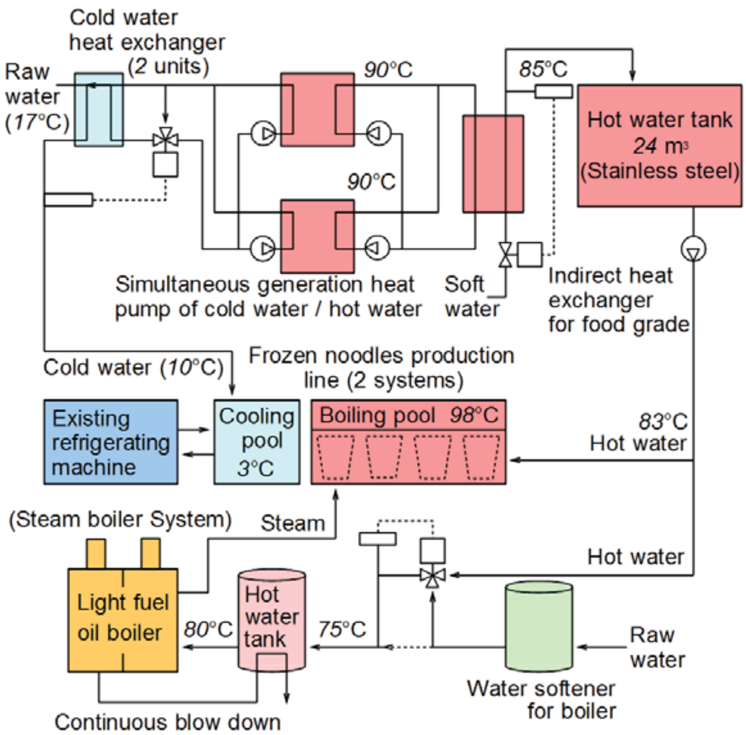


Figure 8-3: Heating and cooling system for producing frozen noodles

8.3.1.3 Specifications of heat pump

The appearance of the simultaneous hot/cold water producing CO_2 heat pump is shown in Figure 8-4. The heat pump specifications are listed in Table 8-2. The heat pump produces hot water through heat exchange between cold water, and CO_2 under supercritical pressure by the compressor. Cold water is used as a heat source for the heat pump evaporator to generate even colder water at the same time. The heat pump has a coefficient of performance (COP) of 3.0 on the heating side, and 2.1 on the cooling side. The total COP for simultaneous supply reaches 5.1.

Figure 8-4: Simultaneous generation CO_2 heat pump of cold water and hot water

Table 8-2: Specifications of CO2 heat pump refrigerator

Description	Specification
Heating capacity	71.9 kW/unit (20→90°C, 2 units)
Cooling capacity	50.1 kW/unit (10→5 °C, 2 units)
Power consumption	24.0 kW/unit (2 units)
Refrigerant	R744 (CO_2)
Compressor type	Reciprocating
Rated power of compressor	25 kW/unit (2 units)
Operating range	Delivery temperature of hot water 85 °C (3000 L/h) Delivery temperature of cold water 10 °C (5000 L/h)
Hot water tank	24 m^3

※Operating ranges are rated according to 17 °C entering-water temperature, 85 °C delivering-hot-water temperature, 10 °C delivering-cold-water temperature

8.3.1.4 *Effects of introduction*

Effects of introducing the simultaneous hot/cold water producing CO_2 heat pump are summarized in Table 8-3. The table compares the power required to produce hot water with the new heat pump against the required consumption of A-type heavy oil to produce the same amount of heat with steam boilers before installation of the heat pump. The hot water supply to the boiling pools from the heat pump reduces the heating load of the steam boilers, resulting in lower CO_2 emissions. The total CO_2 emissions reduction in the plant was estimated to be about 4 %. Placing importance on environmental performance, the company has introduced similar heat pump systems in three of its plants, other than this case, although the payback period is not short.

Table 8-3: Reduction of energy consumption and CO_2 emission (Only hot water supply)

Description		Heat pump installation	
		Before	After
Thermal balance of hot water supply	Additional light fuel oil without heat pump system [L/year]	93231	0
	Additional electric power with heat pump system [kWh/year]	0	307875
	Additional primary energy consumption [GJ/year]	3645	2965
	CO2 emission [t-CO_2/year]	253	100
Total energy balance	CO2 emission [t-CO_2/year]	325	185
	Initial cost for heat pump system[X10^3 Yen]	-----	45000
	Reduction of running cost [X10^3 Yen]	-----	5500
	Payout period of installation [Year]	-----	8.2

Conditions: Calorific valve - Light fuel oil: 39.1 MJ/L, Electricity: 9.63 MJ/kWh

CO_2 emission - Light fuel oil: 2.71 kg CO_2/L, Electricity: 0.326 kg CO_2/kWh

Unit price - Light fuel oil: 100 ¥/L, Electricity: 9.85 ¥/kWh

8.3.1.5 *Challenges and prospects*

Simultaneous supply of hot and cold water can enhance heat pump efficiency. However, the current heat pump system cannot deliver enough energy-saving to promote its introduction only from the viewpoint of energy efficiency. It is a must to improve performance and added value. The heat pump introduced in this case stores hot water during the night-time, and can deliver higher heating capacity during start-up in the early morning, allowing the steam boilers to be started up at a later time. One problem is that the heat pump has to be used as a preheating source for the steam boilers, because the upper limit temperature of hot water output is less than the 98℃ required by the boiling process. If a heat pump system with an even higher output temperature at a reasonable price were introduced into the plant, the production processes could be efficiently operated solely with the heat pump system, with an expectation for simpler facilities, safety achieved through electrification, and lower maintenance cost with no steam boilers.

8.3.2 Combined vapor re-compression system for alcohol distillation

Background

Steam boilers are popularly used as a heat source for production processes. Steam at lower pressure and temperature after use in production processes is usually released to the atmosphere. A vapor re-compression (VRC) system compresses pressure-reduced steam to regain the pressure and temperature suitable for the target production process. Japan promoted the introduction of VRC systems as an energy-efficiency technology after the oil crisis in the 1970's. Using VRC technology allows high-efficiency energy utilization. If there is a big difference in pressure between steam which is re-compressed and steam recycled for the process, however, more compression power is required. In some cases, electrical VRC cannot be introduced because of a receiving capacity limit of electricity. Therefore, as an attempt to expand VRC applications, a system which combines thermal vapor re-compression (TVR) and mechanical vapor re-compression (MVR) has been developed and is being introduced.

Example of installation

8.3.2.1 Company Information

Company name: Chita Distillery, Sungrain Ltd.

Location: Aichi Prefecture, Japan

Operation: Alcohol distillation

Installed: September 2002

Purpose of installation: To reduce the re-compression power for low-pressure steam recycled for heating of ethanol rectifying tower

Production: Distillation capacity 80 kL/day

8.3.2.2 Installed system

The company uses crude alcohol (95 % purity) and saccharine material to produce alcoholic beverage ethanol (not less than 95 % purity) and dehydrated ethanol (99.5 % purity) in production processes as shown in Figure 8-5. The production facility shown in Figure 8-6 used to consume as much energy as 10,000 kL/year in crude oil terms for 24-hour continual operation not less than 300 days a year. As shown in the illustration (a) of Figure 8-7, 95 vol.% ethanol solution with a condensation temperature of 78.3 °C was cooled and condensed at less than 75 °C to generate a large amount of hot water effluent at less than 75 °C, which was released to the atmosphere via a cooling tower. It was first attempted to modify the system as shown in Figure 8-7(b) so that ethanol condensation heat can be used to indirectly produce low-pressure steam, which can be re-compressed to have high pressure and high temperature for use as a heating source for the rectifying tower. In this VRC design, however, compression of low-pressure steam with an MVR system alone had a compression ratio of 3.5, which required a 700 kWh class motor. Finally the VRC design was suspended since the receiving capacity needed to be substantially increased to accommodate such a big motor. Another solution was therefore developed as shown in Figure 8-7(c). This new design includes a steam-driven TVR, which shares the heating boilers for the methyl tower, before the MVR to compress the vapor at a compression ratio of 1.7. The subsequent MVR further compresses vapor at a ratio of 2.1. The system can thus achieve vapor re-compression at a total compression ratio of 3.5. The MVR motor in this system consumes lower power than the previous design with MVR alone by 50 %. The company installed this system in one of its two distillation facilities with higher availability.

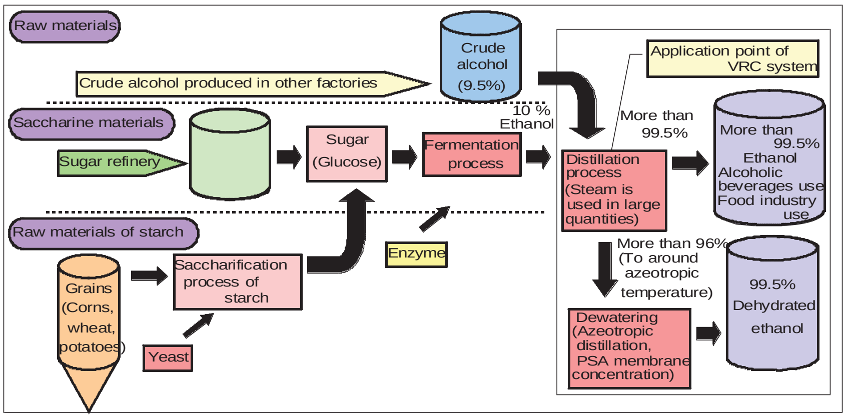


Figure 8-5: Alcohol production process

Figure 8-6:Appearance of rectifying tower

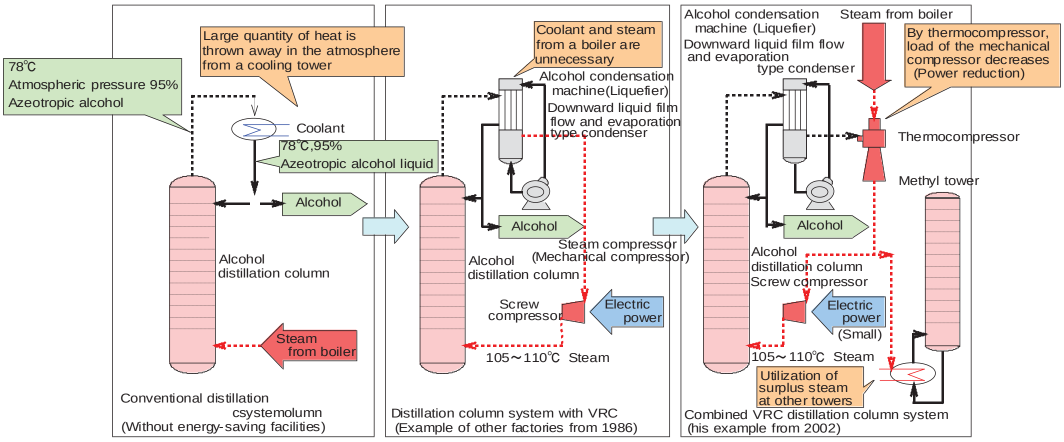


Figure 8-7: Applying RVC system to alcohol distillation process

8.3.2.3 Specifications of combined VRC system

Figure 8-8 and Figure 8-9 show the appearance of MVR and TVR which respectively make up the combined VRC system.

Table 8-4 shows the specifications of TVR and MVR. The MVR is installed after the TVR to make up the combined system. The TVR first compresses vapor at a compression ratio of 1.7, and then the MVR does the same at 2.1. The system can eventually deliver a compression ratio of 3.5 with both compressors.

Figure 8-8: Mechanical vapor re-compressor (MVR)

Figure 8-9: Thermal vapor re-compressor (TVR)

Table 8-4: Specifications of the combined VRC with MVR and TVR

Compressor	Description	Specification
TVR	Quantity of ejection steam	4.2 t/h
	Pressure of inhalation steam	0.039 MPa at 75°C
	Pressure of drive steam	1.5 MPa at 197°C
	Pressure of ejection steam	0.066 MPa at 88°C
MVR	Recovery quantity of steam	4.45 t/h
	Power consumption	350 kW
	Shaft power	250 kW
	Inlet pressure	0.066 MPa at 88°C
	Outlet pressure	0.137 MPa at 140°C

8.3.2.4 Effects of introduction

Table 8-5 shows energy consumption in crude oil terms and CO_2 emissions before and after introduction of the combined VRC system. The rectifying and methyl towers achieved a combined reduction of primary energy consumption and CO_2 emissions by 43%. The simple payout period is estimated to be three years.

Table 8-5: Reduction of energy consumption and CO_2 emission

Description		Installing combined VRC		Reduction effect [%]
		Before	After	
Primary energy consumption for steam [GJ/d]	Rectifying tower	338	218	▲56.3
	Methyl tower	161		—
Primary energy consumption for electric power [GJ/d]		0	68	—
Total primary energy consumption [GJ/d]		499	286	▲42.7
CO_2 emission [t- CO_2/d]		34.2	19.6	▲42.7

Conditions: CO_2 emission - Crude oil: 2.62 kg- CO_2/kL

8.3.2.5 Challenges and prospects

Combining TVR and MVR in the manner of this case can expand VRC applications, although both technologies were originally independent means to implement a separate VRC system. This combined VRC system has also been applied to beer breweries to recompress vapor from boiled wort. The system is expected to find application in other fields.

Combined systems are likely to involve higher design and installation costs, since their facility capacity and operating schedule often have to be adjusted on site for optimization. As more systems are installed, standardization and modularization may need to be considered.

8.3.3 CO_2 Heat Pump Air Heater for Drying Process

Background

A drying process is widely used in many production lines such as industrial material, chemical fertilizer, food and medical supplies, daily commodities, and so on. The drying operation and temperature depend not only on the physical properties or the condition of products, but also on the scale or the frequency of the process. As a way of shortening drying time, hot air at around 120°C is often used in the volatile dried type painting process. Boilers, burners or electric heaters were mainly used conventionally to generate hot air. If the heat source for the hot air is a heat pump which uses fluorocarbon as its refrigerant, applications were quite limited because the maximum output temperature of the heat pump was around 70°C. Then, heat pumps were developed to generate hot air up to 120°C with a CO_2 refrigerant, and have been gradually introduced to drying processes over 80°C.

Example of installation

8.3.3.1 Company information

Company name: Minami Electric CO., Ltd.

Location: Kagawa prefecture, Japan

Business: Manufacturing and painting of casings for electrical transformers

Amount of production: 35,000 units per year

Installed: September, 2009

Purpose of installation: reduction of fuel gas consumption for drying

8.3.3.2 Installed system

The painting and drying production process at the electrical transformer manufacturing factories is shown in Figure 8-10. Air circulated in the drying ovens after the electrodeposition process is heated up to about 170°C by LPG burners. The air circulated in the ovens after the top coating process is heated up to about 155°C. Partial ventilation is necessary to prevent the circulated air from contamination, which causes a decrease in the thermal efficiency of the facilities. In addition, exclusive chillers were used for keeping the temperature of the electro coating baths at 29°C. Hence, a heat pump that can pre-heat the fresh air and can assist cooling of the electro coating baths simultaneously and efficiently, was installed.

Figure 8-11 shows the flows of air and cooling water in the painting and drying system. Fresh air taken in from outside is first heated up to between 80 and 120 °C by the heat pump. After that, the air is heated further up to required temperatures by the LPG burners and used as drying air, as is shown in Figure 8-11. The pre-heating operation by the heat pump can provide a reduction of the heating load of the LPG burners. Water at 15 °C is supplied from the cold water tank to the evaporator of the heat pump as heat-source water, and is cooled. After cooling in the evaporator, cold water at 10° C returns in the reverse direction from the evaporator to the water tank.

This cooling action can reduce the chilling load of the chiller for temperature adjustment of the electrodeposition bath. If the cooling load of the electrodeposition bath is not sufficient to afford heat for the heat pump due to the low temperature of outdoor air in winter, it is designed to be able to recover waste heat from an air compressor as a supplemental heat source.

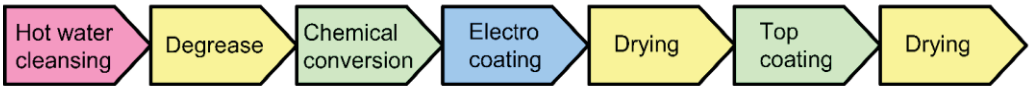


Figure 8-10: Painting and drying processes

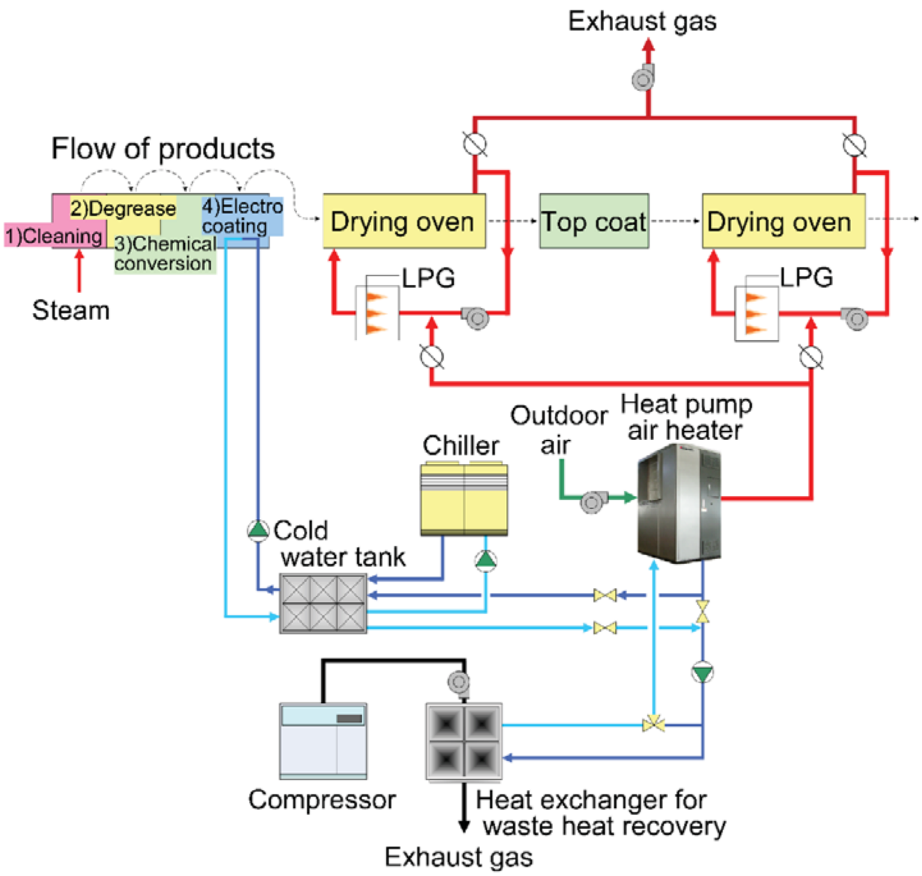


Figure 8-11: System flow diagram of drying process in painting application

8.3.3.3 *Specification of heat pump*

The specifications of the CO_2 heat pump air heater are listed in Table 8-6. Hot air is generated by heat exchange between supercritical CO_2 produced in the compressor, and fresh air for drying. Cold water can be simultaneously generated because the heat source of the heat pump is water. If there are demands for both hot air and cold water, the total COP can be further increased. Figure 8-12shows the relationships between the outlet temperature of the heat-source water, the heating capacity, and COP for heating when the inlet temperature of the fresh air is 20°C. Figure 8-13 shows the relationship between the outlet temperature of the heat-source water and the airflow rate. The heat pump system on site is shown in Figure 8-14.

Table 8-6: Specification of CO2 heat pump Air Heater

Description	Specification
Heating capacity	110 kW
Refrigerating capacity	35 kW (9.1 Refrigeration Tons)
Power consumption	32 kW
Refrigerant	R744 (CO_2)
Compressor type	Semi-Hermetic, Reciprocating, Two cylinders
Rated power of compressor	25 kW
Operating range	Delivery temperature of hot blast 80~120°C Delivery temperature of heat source water -9~35°C
Capacity control	Rotation control with inverter (30~65 Hz)
Dimensions	W1100×L1600×H2223 mm
Weight	Product weight 1948 kg (Operating weight 1954 kg)

※Capacities are rated according to 20 °C entering-air temperature, 100 °C delivering-hot-blast temperature, 25 °C delivering-water temperature of heat source

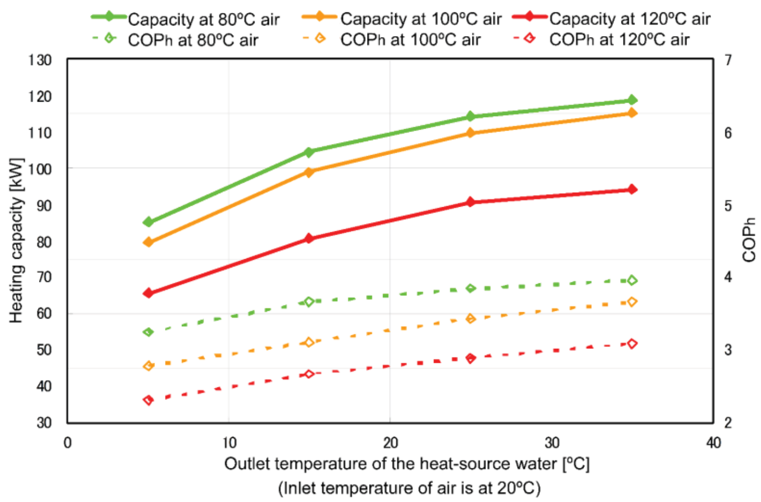


Figure 8-12: Relationships among the outlet temperature of the heat-source water, the heating capacity, and COP_h

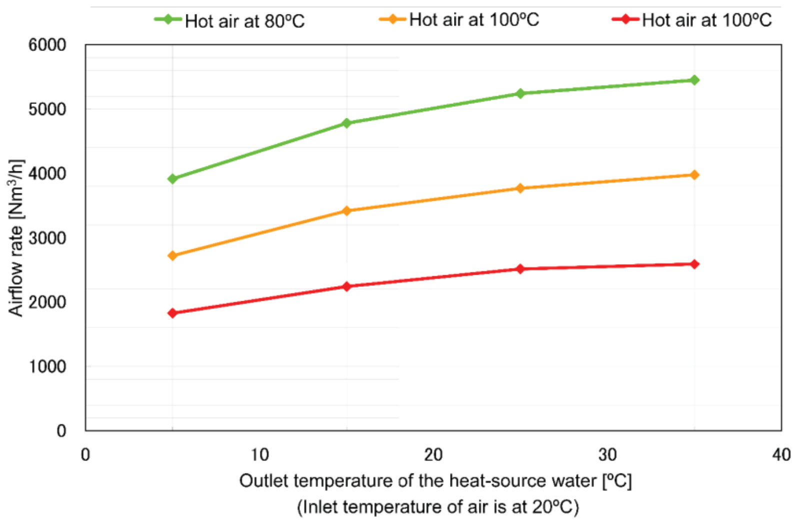


Figure 8-13: Relationship between the outlet temperature of the heat-source water and the air-flow rate

Figure 8-14: CO_2 heat pump air heater installation

8.3.3.4 Effect of introducing heat pumps

Energy consumption in the process before and after installation of the heat pump drying systems was measured to verify the effect of the installation. Conventional systems without heat pumps were measured on 7 and 8 December 2009, and the new heat pump systems were installed on 9 and 10 November 2009. Table 8-7 shows the results of the measured consumption of fuel gas and electric power. Energy consumption based upon primary energy equivalent was reduced by 3.0%, and the running cost could be reduced by 12%. Cold water in the tank is also used for cooling products after the drying process. Thus, the energy saving effect was improved by using the cold water and hot air more effectively.

Table 8-7: Reduction of energy consumption and CO2 emission

Description	Heat pump		Reduction effect [%]
	Not operated	Operated	
Operating time of drying furnace [h]	29.9	30.1	—
Gas consumption [Nm^3]	509.0	389.0	—
Average gas consumption [Nm^3/h]	17.0	12.9	▲24.1
Average electric energy consumption [kWh/h]	0.0	35.3	—
Primary energy consumption [GJ/h]	1.65	1.60	▲3.0
CO_2 emission [kg-CO_2/h]	103.7	90.2	▲13.1
Running cost [%]	100	88	▲12

Conditions: Performance of chiller for electro coating bath - Refrigerating capacity: 33.5 kW, Power consumption: 12.6 kW

Calorific valve - LPG: 97.0 MJ/Nm^3 (Density: 2.03 kg/Nm^3),

Electricity: Day 9.97 MJ/kWh, Night 9.28 MJ/kWh

CO_2 emission - LPG: 3.000 kg CO_2/Nm^3, Electricity: 0.326 kg CO_2/kWh

Unit price - LPG: 83 ¥/kg, Electricity: 9.85 ¥/kWh

8.3.3.5 Prospects

The efficiency of the CO_2 heat pump increases by operating with a large temperature range which includes the supercritical state of CO_2. In this installation example, the heat pump is used as a pre-heater because the required temperature of the drying air is higher than 120 °C. If the required temperature is lower than 120 °C, it would be possible to operate heat pumps alone, which also enables us to simplify the equipment and make it safer by using only electricity. Another possibility is to reduce the maintenance cost by using a boiler-less system if heat pumps could replace any steam heating system in the drying process.

8.3.4 Adoption of Heat Pump Technology in a Painting Process at an Automobile Factory

Background

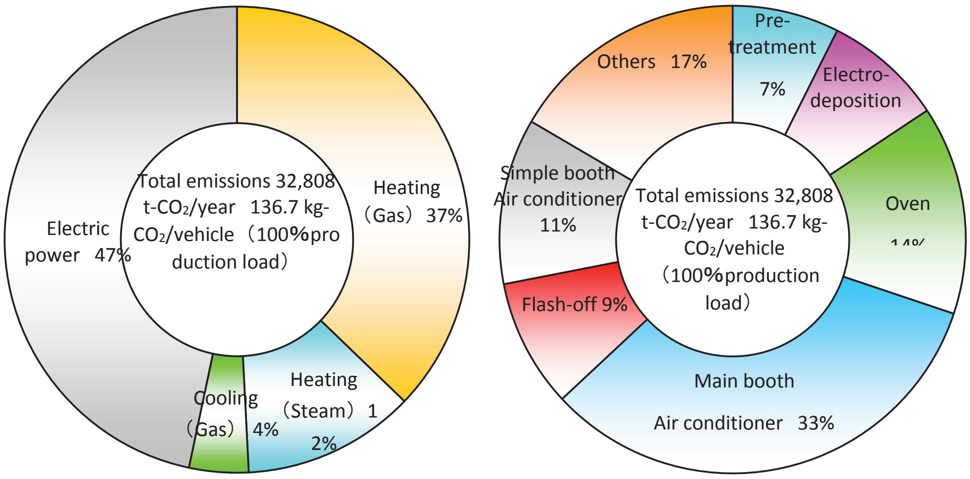
In a painting facility of an automobile factory, a great deal of energy is consumed by heating and cooling processes, the power supply, system controls, lighting, and so on. Generally, most primary energy sources are gas and electricity. Most heating and cooling needs in a painting process are supplied by direct gas combustion, steam, hot water, and chilled water generated by a refrigerator, most of the primary energy for which is gas.

In terms of energy efficiency ratio, electrical energy was believed to be lower in energy efficiency than gas energy, because electrical energy uses only around 40% of input energy while gas energy is able to use almost 100 % of direct gas combustion.

However, heat pump technology has greatly improved, and the energy efficiency ratio is increasing accordingly, so highly efficient heat pumps have been introduced also into industrial processes in recent years.

On an estimation basis, CO_2 emissions by heating gas were almost the same level as electric power in a painting facility model line where 24,000 cars a year were produced at an automobile factory in 2009 (Figure 8-15). Gas is mostly utilized as a heating source. If it is replaced by a highly energy-efficient system, it will save energy and reduce CO_2 emissions.

Further, according to CO_2 emissions by process, a large amount of emissions are from paint booth air conditioners which account for over 1/3 of the total.



a) Energy consumption by type (CO_2 basis) b) Emissions by process

Figure 8-15: CO_2 emissions in a Painting Process (estimated in 2009)

Figure 8-16 shows each process and its required heat temperature range in a painting process at an automobile factory. There are three main advantages which we can gain from heat pump technology. The first is the heat recovery system, the second is efficient heat source equipment, and the third is simultaneous usage of cooling and heating, which is believed to be the most efficient usage.

Simultaneous usage of heating and cooling can be applied to processes of pretreatment/electro-deposition, booth/working area air conditioning, and waterborne flash-off equipment. Hence, adoption of heat pump technology in this equipment is considered. The highest effect from adoption of heat pump technology in these cases is in booth recycled air conditioning and waterborne flash-off equipment.

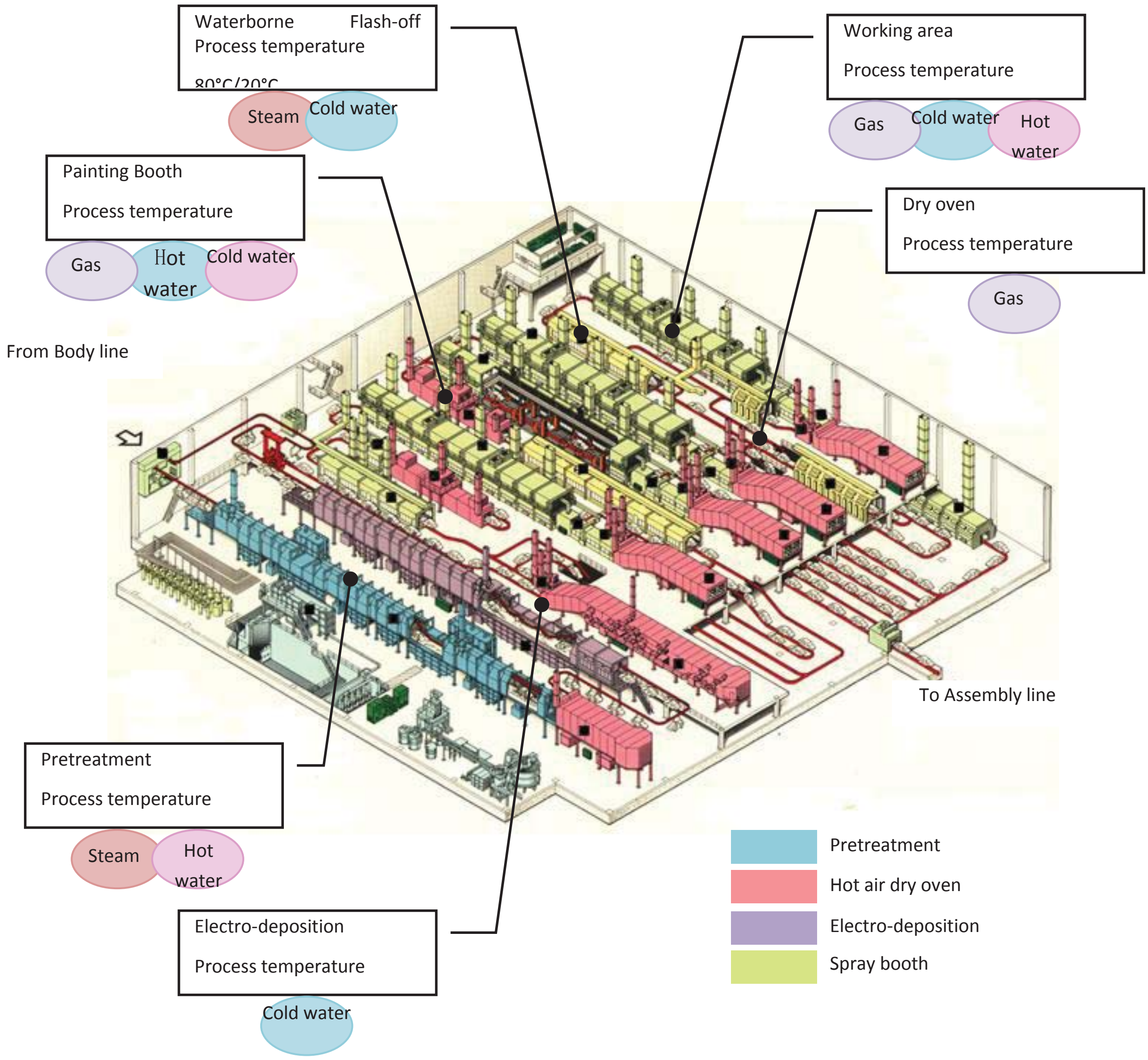


Figure 8-16: Required heat temperature ranges in a general automobile painting process

In this paper, heat pumps for booth recycled air conditioning are discussed along with energy conservation and reduction of CO_2 emissions.

Example of application

8.3.4.1 Company information

1 Place	Hino Motors, Ltd., Hamura No. 4 plant
2 Annual operating hours	4,880 hrs/year
3 Installed processes	Painting booth for finishing coat (base) and recycled air conditioning

Hino Motors, Ltd., is aiming to reduce CO_2 emissions on a company-wide level, and they paid attention to the painting process which occupied 40% of total CO_2 emissions in the

Hamura plant in 2010. Three companies, i.e., Hino Motors, Ltd., an engineering company [1)] and an energy company [2)] shared their knowledge about painting technology - knowledge of automobiles from Hino Motors, design of the painting plant from the engineering company [1)], and efficient exploitation of energy from the energy company [2)], and successfully "adopted heat pumps as a heat source for painting (finishing coat) booth air conditioning".

8.3.4.2 Installed system and specification of heat pump

The paint booth consists of two booths - one is a manned booth where fresh air is supplied. And the other is a robot booth where exhaust air is re-used. As a mist of fine paint is contained in exhaust air from the manned booth, the air inside can be re-used via wet cleaning by using a circulating water shower, which is called the wet recycle system. Because the booth's exhaust air is humidified via wet cleaning, the air is supplied to the robot booth with adjusted temperature and humidity after being dehumidified, and reheated in the recycled air conditioner. A schematic of the heat recovery heat pump system, its specification, and a photograph are shown in Figure 8-17, Table 8-8 and Figure 8-18 respectively.

Conventionally, the heat source system of a recycled air conditioner in the paint booth consists of a gas absorption refrigerator and a boiler. The recycled air conditioner was cooled by the gas absorption refrigerator, and reheated by boiler steam. In the meantime, the heat recovery heat pump enables us to supply both the heat for cooling and reheating concurrently. This modified system is provided to ensure system reliability and lower carbon emissions by utilizing existing equipment, such as the gas absorption refrigerator and the boiler, and also for backup purposes.

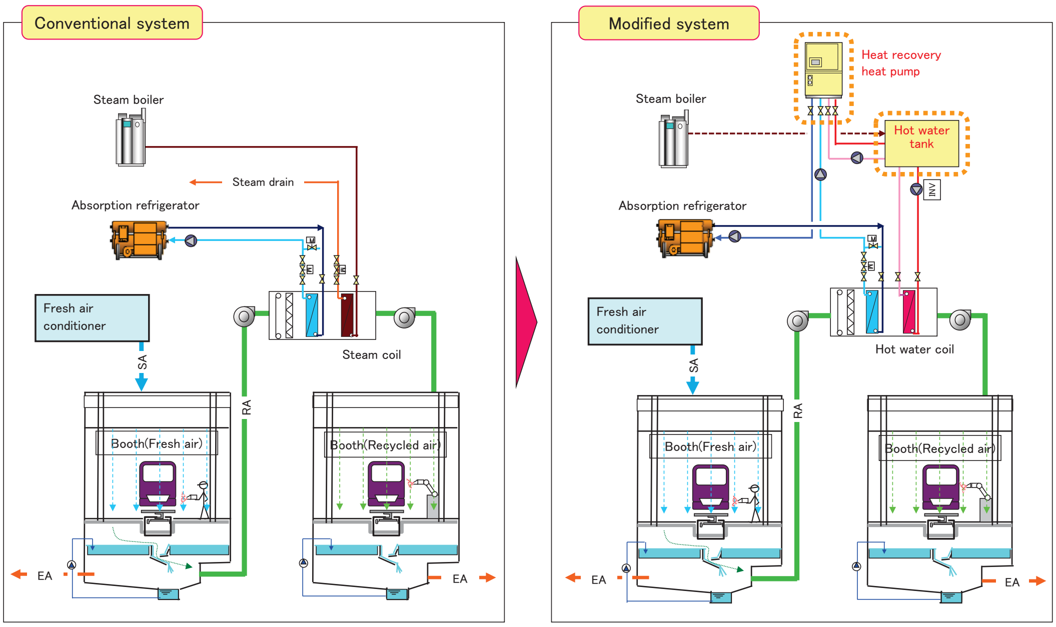


Figure 8-17: Schematic of painting system

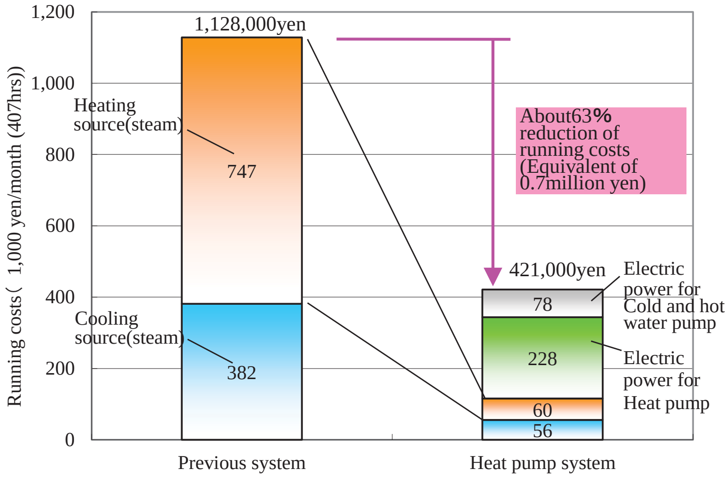
Table 8-8: Heat recovery heat pump specification

Type		HEM-150 II
Cooling capacity		456 kW
Heating capacity		566 kW
Refrigerant		HFC407E
Com-pressor	Starting-system	Inverter
	Type	Semi-hermetic Twin-screw
	Input	110.1 kW
Rated COP	Cooling	4.14
	Heating	5.14
Quantity		1

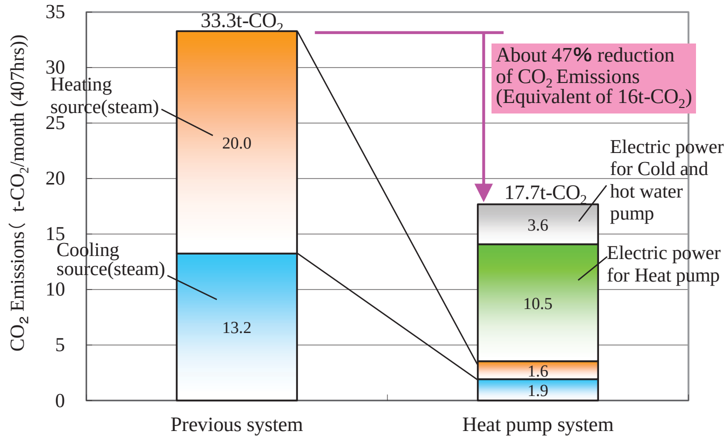
Figure 8-18: Heat pump equipment

8.3.4.3 Effect of introducing heat pumps

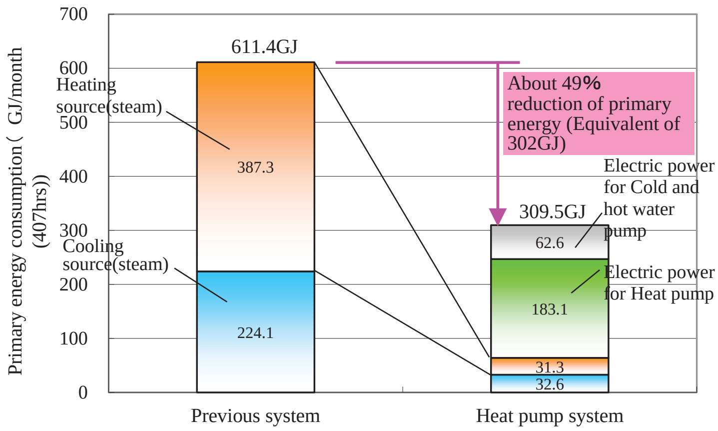
An estimation based on the measurement results on site after installation is shown in Figure 8-19. The heat pump makes it possible for the system to reduce running costs by about 63%, to reduce CO_2 emissions by about 47% per month, and to reduce primary energy consumption by about 49% per month as compared with the conventional boiler. Consequently, the pay-back period would be estimated at 3～4 years.



a) Running costs



b) CO_2 emissions



c) primary energy consumption

Figure 8-19: Effect of Adoption

8.3.4.4 Prospects

It was considered to utilize the existing boiler steam for the imbalance between cooling and heating loads when starting up the booth in winter. They have also installed a hot water tank so that they can have a heat source for providing steam directly.

In case of adopting a heat recovery heat pump system, it is common to install a cooling tower and for keeping the balance between cooling and heating loads. But in this case, they did not install a cooling tower, and instead utilized the existing refrigerator, aiming at the reduction of investment cost.

The adoption of heat pumps in recycled air conditioning is a case where full use was made of the heat pump's strengths - the good effects of installation, and easy introduction into the existing system - and it has well fitted the purpose of CO_2 reduction. When introducing heat pumps, it is indispensable to bring all the companies involved together. In this case, it was a collaboration between an automobile company, an engineering company, and an energy company.

References:

1. Taikisha Ltd. http://www.taikisha-group.com/
2. Tokyo Electric Power Company http://www.tepco.co.jp/en/index-e.html

8.3.5 Heat pumps for washing process

Background

Mechanical part manufacturing plants have a cutting process followed by a washing process where washing liquid is heated by an electric heater or hot steam from boilers to around 60°C (Figure 8-20). On the premises of some plants, the boiler room is located far from the building in which the washing process is installed. In this case, not only combustion loss and drain recovery loss but also huge heat loss from the steam piping substantially lowered total efficiency. To solve the problem, many of these plants desired to install high-efficiency heating equipment near the washing process for energy saving. However, a high-efficiency, oil mist resistant heat pump capable of delivering 60°C heating for production processes did not exist at that time. In this type of plant, the room temperature is higher than the outside air temperature because of heat generated by various devices within the plant. Thus, it is possible to implement a high-efficiency heat pump heating system using the air in the plant as a heat source. In the cutting process, cutting liquid was conventionally cooled by a small chiller. Exhaust heat from the chiller was released to the atmosphere, which further raised the ambient temperature in the plant. There was no system that used the cooling process exhaust heat for heating of the washing liquid as well. Then, General Heat Pump Co., Ltd. and Chubu Electric Power Co., Inc. jointly developed a heat pump for the washing process that could efficiently circulate and heat washing liquid used in the mechanical part washing process by using the exhaust heat in the plant.

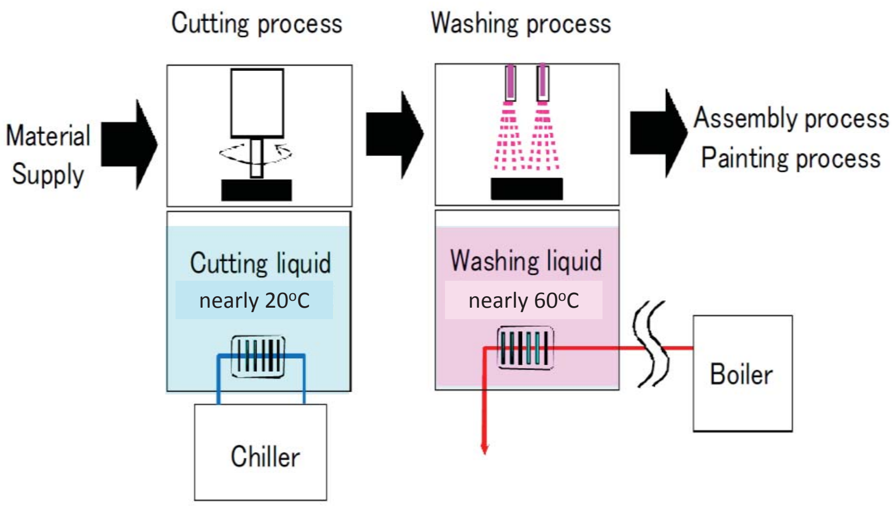


Figure 8-20: Cutting process and washing process

Example of application

8.3.5.1 Installed system and specification of heat pump

Figure 8-21 shows the appearance of the heat pump for the washing process. There are two types of heat pumps for a washing process: heating only, and cooling/heating. Table 8-9 shows the basic specifications of cooling/heating type heat pumps. Although not shown in Table 8-9, the heating-only heat pump has the same specifications (heating capacity, electric consumption and heating COP) as those of the cooling/heating type, except that the heating-only type cannot deliver cooling, and is slightly lighter than the cooling/heating type because it has no heat exchanger for water cooling.

In a popular mechanical part cutting process, cutting liquid is cooled and the temperature is maintained at around 20°C. After the cutting process, mechanical parts are subjected to a washing process where washing liquid is heated and the temperature is maintained at around 60°C. The heat pump for the washing process can simultaneously deliver heat energy of not less than 60°C for heating the cooling liquid, and cold water at 15°C suitable for cooling the cutting liquid. This simultaneous heating and cooling supply can only be achieved by absorbing the heat released during cooling of the cutting liquid, and then re-using the heat for heating of the washing liquid. The heat pump can use a refrigerant (R-134a), whose performance has been proven in large refrigerators and vehicle HVAC applications, to deliver high-efficiency circulation heating for the mechanical part washing liquid (washing liquid inlet temperature 60°C and outlet temperature 65°C). Further, as a countermeasure against oil mist that is generated in the cutting process and may lead to lower heat pump efficiency, a filter is installed in the heat exchangers so that the heat pump can be installed near the washing process (within the plant building). Figure 8-22 shows a proposed installation of cooling/heating type heat pumps. A desirable operation mode can be selected from simultaneous cooling & heating, cooling only and heating only to support any combinations of cutting liquid cooling, and washing liquid heating.

Figure 8-21: Heat Pump for Washing Process

Table 8-9: Specification of Heat Pumps for Washing Process

Heating※1	Capacity	22.3 kW	43.5 kW
	Electric Consumption	7.5 kW	14.8 kW
	Heating COP※2	3.0	2.9 kW
Cooling※3	Capacity	20.5kW	39.7 kW
	Electric Consumption	4.0 kW	7.9 kW
	Cooling COP※2	5.1	5.0
Simultaneous Cooling and Heating※4	Cooling Capacity	15.0 kW	29.1 kW
	Heating Capacity	21.8 kW	42.5 kW
	Electric Consumption	7.1 kW	14.0 kW
	Total COP※5	5.2	5.1
Refrigerant		R134a	R134a
Size (L×W×H)		1.3m× 0.7m× 1.9m	1.6m× 0.7m× 1.9m
Weight		600 kg	700 kg

※1 Ambient Temperature: 25°C DB/21°C B; Heat Pump Inlet Temperature:60°C,Outlet:65°C

※ 2 Heating COP = Heating Capacity (kW) / Electric Consumption (kW),

Cooling COP = Cooling Capacity (kW) / Electric Consumption (kW)

※3 Ambient Temperature: 25°C DB; Heat Pump Inlet Temperature 20°C, Outlet: 15°C

※4 Heat Pump Inlet Cool Water Temperature: 20°C, Outlet: 15°C

Heat Pump Hot Water Inlet Temperature 60°C,Outlet: 65°C

※5 Total COP = {Heating Capacity (kW) + Cooling Capacity(kW) } / Electric Consumption (kW)

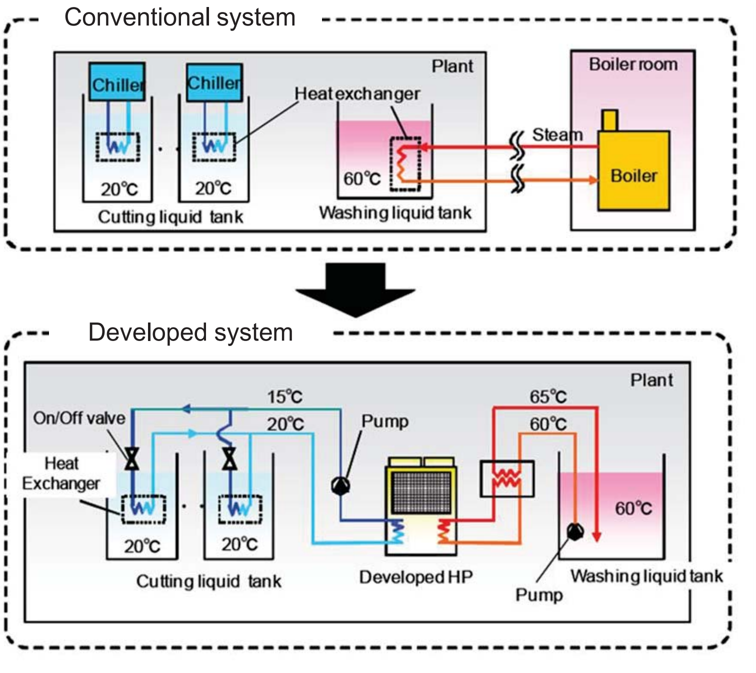


Figure 8-22: Developed Heat Pump System for Cutting and Washing Process

The heat pump for a washing process has the following features:

① Circulation heating suitable for heating of washing liquid

The use of the refrigerant R-134a, which is ideal for heating of washing liquid, achieved high-efficiency circulation heating of the washing liquid to maintain the temperature at 60°C (washing liquid inlet temperature 60°C and outlet temperature 65°C). Indirect heat exchangers such as immersion heaters can be used to accommodate even low-quality washing liquid.

② Substantial energy saving

The heat pump achieved a total COP of 5.2 under the simultaneous cooling and heating condition shown in Table 8-9. Figure 8-23 shows measurements of total COP under simultaneous cooling and heating conditions with various combinations of cold and hot water temperature. Raising the cold water temperature and lowering the hot water temperature within their respective allowable temperature range can substantially improve the COP. With its high total COP, the heat pump for a washing process allows you to substantially reduce energy consumption, CO_2 emissions and running cost from the level achievable by conventional thermal systems using boilers and chillers.

③ Oil mist-proof, and more user-friendly

In many plants, the washing process is located adjacent to the cutting process where high-speed tools are lubricated with cutting liquid, releasing oil mist in the building. If deposited on the air heat exchanger of the heat pump, oil mist may lead to reduction of efficiency. To prevent this, an easily removable filter has been added to the heat exchanger. Further, a touch-panel operator console provides better user-friendliness.

④ Accommodating unbalanced cooling and heating demands

The balance between cooling load and heating load in plants always changes with time, although the variation depends on the type of production process. For an application where a single heat pump is used to deliver cooling for cutting liquid and heating for washing liquid, how to accommodate such a load imbalance was an issue. With the simultaneous cooling & heating type, just switching between three modes, i.e., simultaneous cooling & heating, heating-only and cooling-only, can accommodate load balance variations.

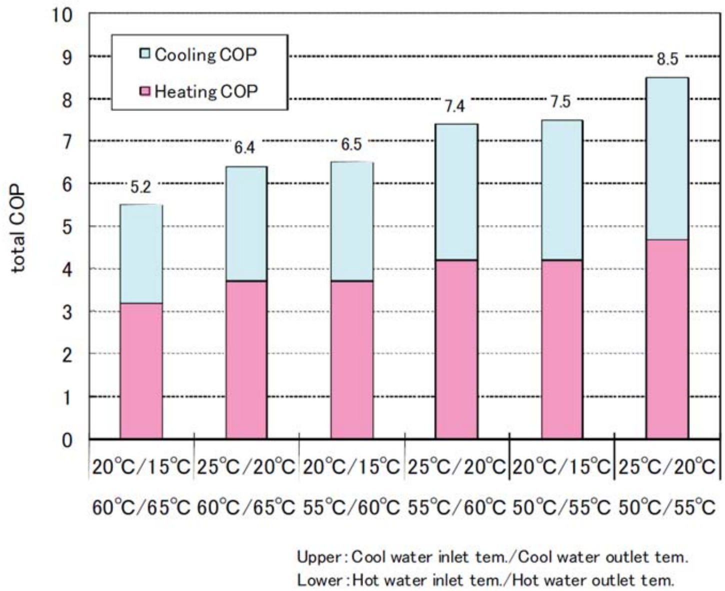


Figure 8-23: Relation between total COP and cooling/heating temperature

8.3.5.2 Effect of introduction

Aisin AW Co., Ltd., a Japanese automobile part manufacturer, introduced heat pumps for a washing process into its Gamagori Plant (Gamagori City, Aichi Prefecture) to apply them to the mechanical part production line including cutting and washing processes. Conventionally, the plant used air-cooled chillers to cool cutting liquid for the part cutting process and steam boilers to heat washing liquid for the washing process, which is located immediately after the cutting process. The existing thermal system using steam boilers had a long piping system and could only deliver very low energy efficiency due to huge heat and drain losses. Then, Aisin installed heat pumps for a washing process in a place very close to the production line. To begin with, a heat pump for a washing process was installed in 2009 as shown in Figure 8-24. After the effect was verified through field tests, 13 more heat pumps were installed in 2010. These 14 heat pumps consist of six cooling/heating type with a heating capacity of about 22 kW, and eight heating-only type with a heating capacity of about 43 kW. By introducing these heat pumps, the company realized a steamless thermal system for the overall plant. Table 8-10 shows the annual energy consumption and CO_2 emissions calculated from actual measurements. Although there is no significant difference in power consumption before and after the introduction of the heat pumps, the energy consumption, CO_2 emissions and running cost were respectively reduced by 73%, 86% and 89% from the level achieved by the existing system because the new system no longer uses heavy oil to burn the steam boilers.

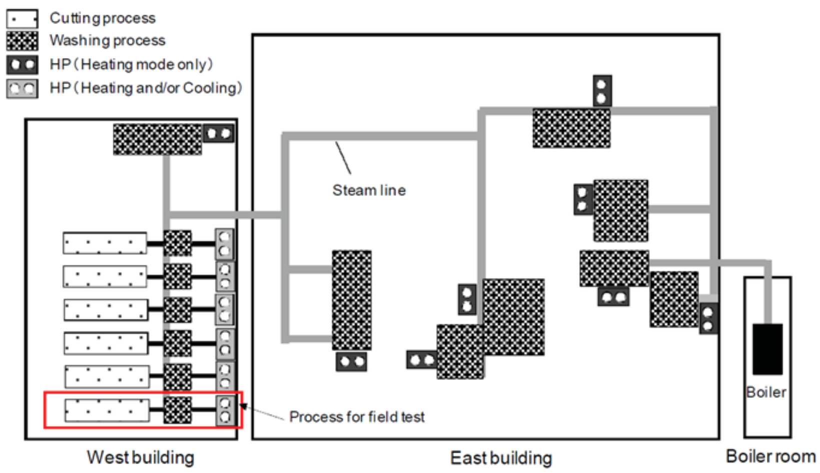


Figure 8-24: Ground Plan of a Mechanical Parts Factory where heat pump has been installed

Table 8-10: Effects of Introduction of Heat Pumps for Washing Process in a Factory

	Energy Consumption [GJ/year]	CO_2 Emission [ton CO_2/year]
Before Introduction of Heat Pumps	20,238	1,340
After Introduction of Heat Pumps	5,515	194
Reduction Rate	73%	86%

8.3.6 Applying the heat pump technology to agricultural production

Background

In Japan, about 73 % of the land is occupied by mountains. With the limited arable land, farmers try to raise the unit production and profitability by positively using greenhouses and plant factories to supply agricultural products regardless of the season (i.e., throughout the year). The energy consumption by agricultural production is shown in Figure 8-25. A-type heavy oil and kerosene, both of which are fossil fuel primary energy, jointly account for 85 % of total energy consumption. In particular, greenhouse cultivation consumes large amounts of energy, usually A-type heavy oil, for heating.

As heat pump technology has been substantially improved to offer higher energy efficiency in recent years, high-efficiency heat pumps available at a relatively inexpensive price have been introduced to production of flowers, fruit and other high-value-added products as an alternative to existing greenhouse heating technology. In addition to lower energy consumption and lower CO_2 emissions, the use of heat pumps in these applications can deliver quality-related benefits, i.e., a wider temperature setting range, and disease suppression by dehumidification.

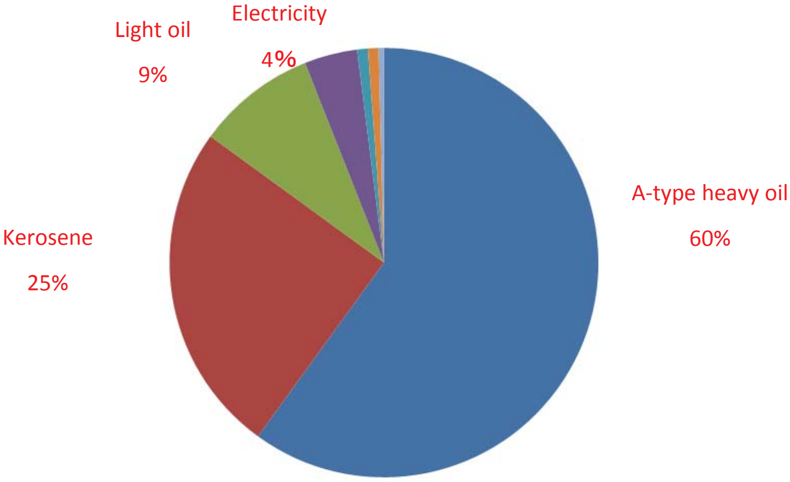


Figure 8-25: Energy consumption by agriculture and forestry (2008) 1)

Japan today has commercial greenhouses occupying a total area of about 50,000 ha. These greenhouses are heated by three major means: burning of petroleum fuel, using groundwater heat sources, and using petroleum substitutes such as gas and electricity. Figure 8-26 shows greenhouse installations by heating systems. According to the figure, 95 % of total installations are heated by hot-air heaters burning A-type heavy oil[2)].

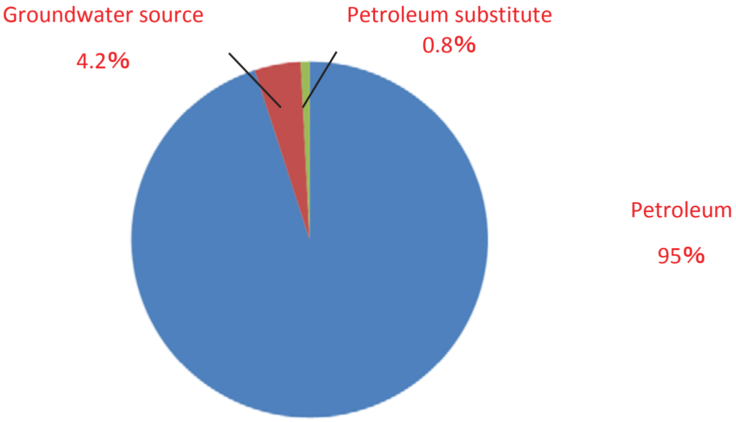


Figure 8-26: Greenhouse heating systems 2)

Since around 2008, agricultural heat pumps for greenhouse heating have been available in the market. Before introducing heat pumps, it is important to look into the power consumption, heating capacity and initial equipment cost of the product, to determine whether they can be used in combination with fossil fuel-fired heaters to deliver efficient operation, whether they provide easy humidity control, and whether they can be easily inspected and repaired. Particularly, it is more advantageous to apply heat pumps to high-temperature applications in which heating to 15 °C or higher is needed such as when growing roses, mandarin oranges or melons. This is because the higher the required heating temperature is, the larger the difference in heating cost between fossil fuel-fired heaters and heat pumps.

In the case described in the following, the company introduced greenhouse heat pumps with highest energy efficiency to achieve energy saving and CO_2emissions reduction.

Example of application

8.3.6.1 Company information

1	Company name:	Morita Farm, Kimitsu Horticulture (1173 Aoki, Futtsu City, Chiba Prefecture)
2	Completed in:	December 2010
3	Greenhouse information:	Three-quarter glass greenhouse (77 to 168 m^2): 7 houses
4	Product:	Melon
5	Design heating temperature:	20 °C
6	Existing heater:	A-type heavy oil-fired hot water boiler (thermal output 290.7 kW, 1 unit)
7	Heat pump installed (E'z Inc.):	"Aguri mo Guppy 55", twin type: 6 sets "Aguri mo Guppy", single type: 1 set

8.3.6.2 Installed system, and specification of heat pump

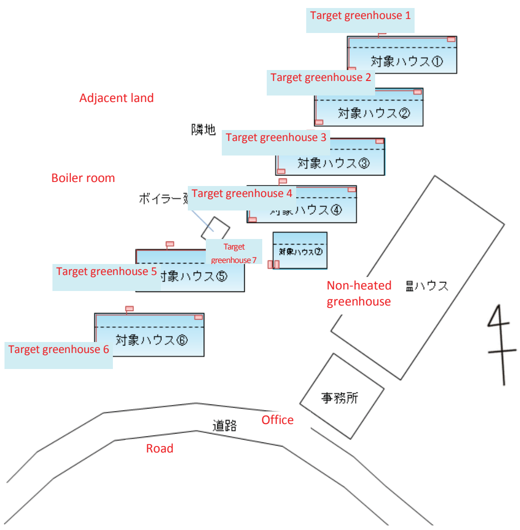
The purpose of introduction is to operate high-efficiency heat pumps for heating melon greenhouses so that existing fossil fuel heaters can be used just as an auxiliary option. The farmer aimed to reduce fossil fuel (A-type heavy oil) consumption by shortening the operation time of the existing heaters.

From the E'z Inc. catalogue 2008[3)], the company selected an agricultural heat pump with the highest COP and installed seven units in total. Based on the concept that the greenhouse indoor environment is equivalent to the usual outdoor environment, a housing of an "air-conditioner outdoor unit for shop/office applications" was combined with the heat exchanger and a high air-flow fan for usual outdoor units. With this design, a single type heat pump includes two fans, and a twin type has two indoor units so that they can be installed in separate places. Thanks to the "larger area" and "higher air flow" for heat exchange, the heat pump can deliver dramatically improved efficiency in heat exchange with air, achieving a high COP of 4.9 and substantially higher heating efficiency.

The heat pump also provides a wide temperature setting range: 7 to 30 °C for heating and 10 to 30 °C for cooling. By diverting the outdoor unit housing for air-conditioners, the heat pump can be operated even under the dusty environment in the greenhouses, showing high environmental resistance. The splash-proof and washability features made it possible to design a filterless heat pump.

The cultivation greenhouses have different roof heights on the north and south sides to let more sun shine in through the transparent roof panels, which is called "three-quarter greenhouse" (Figure 8-28). In Figure 8-28, greenhouses [1] to [6] have two twin type indoor units on the diagonal line each, and greenhouse [7] has one single type indoor unit in the same layout (Figure 8-28). Hot air from the heat pump indoor unit is driven by a circulating duct fan (3,600 m^3/h) into the main perforated polyethylene duct (ϕ450). Hot air then comes out of the many openings of its branch ducts (ϕ200), and spreads evenly over to make the temperature uniform within the greenhouse (Figure 8-29 and Figure 8-30, right). The outdoor unit for twin heat pumps is installed almost at the mid-point of the two indoor units (Figure 8-30, left). The specifications of the greenhouse heat pumps which were installed are shown in Table 8-11.

Heat pumps generally involve higher installation cost than fossil fuel heaters. To suppress the installation cost, the farm has established a hybrid heating system that uses fossil fuel heaters to meet the energy demand during the hours of peak load in a day, and uses heat pumps to cover the energy demand by the base load, successfully downsizing the total heat pump capacity. This hybrid heating system allows improving the shortcoming of air source heat pumps that the COP is lower at a lower outside air temperature.

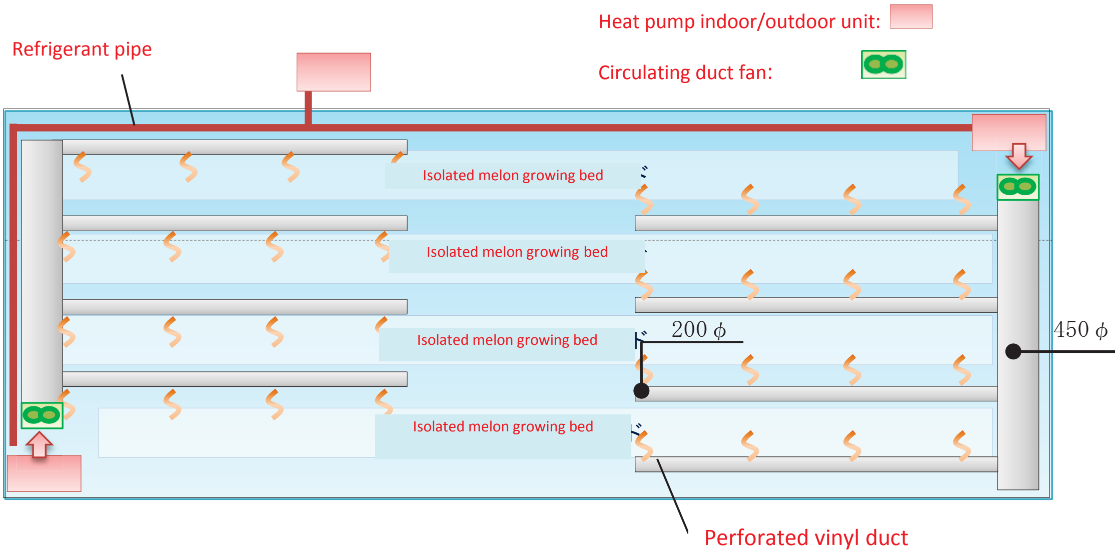


Target greenhouse:

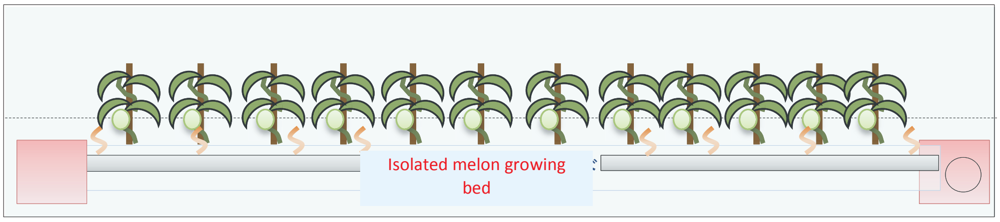
- ① to ④ 147m^2
- ⑤ and ⑥ 168m^2
- ⑦ 77m^2

Figure 8-27: Three-quarter greenhouse

Figure 8-28: Outdoor facilities and heat pump installations



a) Plan view



b) Cross section

Figure 8-29: Heat pump and duct layout in the greenhouse

Figure 8-30: Heat pump outdoor unit (left), Heat pump indoor unit and circulating duct fan (right)

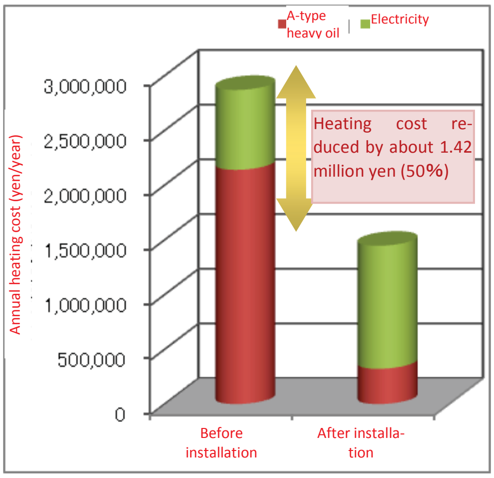
Table 8-11: Specifications of greenhouse heat pumps [3)]

		Aguri mo Guppy 55, Twin type	Aguri mo Guppy, Single type
Model		SPW-AGCHVPP180EN	SPW-AGCHVP180E
Cooling capacity		16.0 kW (12.5 to 28.0)	16.0 kW (7.3 to 21.3)
Heating capacity	Standard	18.0 kW (9.0 to 31.5)	18.0 kW (6.8 to 25.0)
	Cold climate	18.0 kW	18.0 kW
Refrigerant		HFC (R410A)	
Compres-sor	Capacity control	Inverter	
	Type	Totally enclosed rotary type	
	Output	5.5 kW	4.2 kW
COP	Cooling (standard)	5.48	3.86
	Heating (standard)	5.50	4.90
	Heating (cold climate)	3.77	3.20
Number of units		6 sets	1 set
Operating conditions (according to JISB8616)		● Cooling: Indoor suction air temperature 27°C DB, 19°C WB, Outdoor suction air temperature 35°C B ● Heating (standard): Indoor suction air temperature 20°C DB, 15° WB or less, Outdoor suction air temperature 7°C DB, 6°C WB ● Heating (cold climate): Indoor suction air temperature 20°C DB, 15°C WB or less, Outdoor suction air temperature 2°C DB, 1°CWB ● Amount of refrigerant: As shipped from factory	

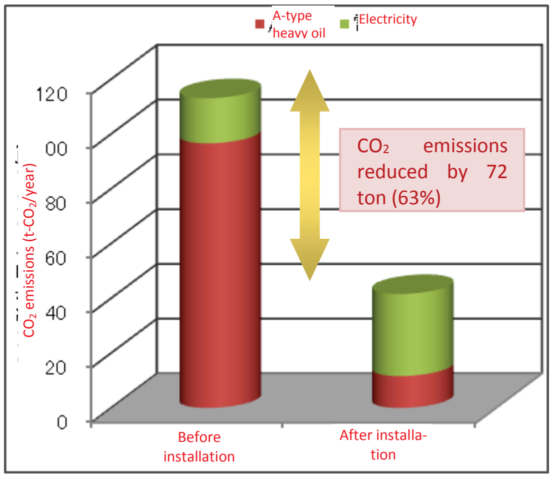
8.3.6.3 Effect of introduction heat pumps

The effect of introducing determined from the result of measurement after installation is shown in Figure 8-31. The transfer of heat source from A-type heavy oil to electricity has successfully reduced the annual operating cost by about 50 %, the annual CO_2 emissions by about 63% and the primary energy consumption by about 49 %. This means that the project investment of around 7,700,000 yen can be recovered in about 5.4 years through compensation by operating cost reduction.

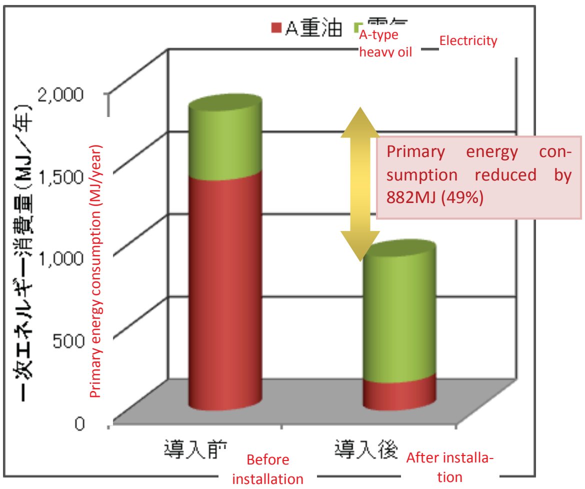
The temperature setting of melon greenhouses is as high as 20 °C. The longer the period in which melons are grown at a low outside temperature, the more the energy consumption reduction. The farm in this case cultivates melons even during the winter season. With this long cultivation period, the farm has successfully reduced A-type heavy oil consumption by about 88 %. On the other hand, power consumption increased by 82 % after the heat pumps were installed. The existing heating facility used a unit type hot water heating system with central hot water boilers and, if at least one of the seven greenhouses needed to be heated as shown in Figure 8-26, the boilers and circulating pumps had to be started, resulting in a very large thermal loss and very high power consumption by the thermal transport system. Actually the power consumption by the thermal transport system was about 55 % of that after installation of the heat pumps. However, now hot water is transported less frequently than before, so about 50 % of the apparent power consumption is eventually balanced out.



a) Operating cost



b) CO_2 emissions



c) Primary energy consumption

Figure 8-31: Effect of introducing heat pumps

8.3.6.4 Prospects

Before applying a heat pump to greenhouse cultivation, it is important to consider whether the heat pump can be efficiently operated in combination with fossil fuel-fired heaters for lower initial equipment cost, whether humidity can easily be controlled, and whether the heat pump can be inspected and repaired. In the case cited in this report, the installation brought substantial reduction effects, since the existing thermal facility used a unit type hot water heating system with central hot water boilers. It is desirable that heat pump technology will be further improved to feature even higher efficiency and lower installation cost.

Due to recent rising concern over the increasing risk of energy prices, renewable energy technologies have had a higher advantage and are expected to be more widely used. Further, it is important to enhance the public subsidy system for heat pump installation so that the high initial cost, which has impeded their introduction, can be recovered in a shorter period of time.

The biggest benefit of using heat pumps is controllability of both temperature and humidity, which allows year-round cultivation. This benefit can lead to higher yield of general product. Particularly, flower and fruit greenhouses are applications in which heat pumps have been increasingly installed, with an expectation for higher quality and higher yield of these high value-added products.

Source

"Analysis on CO_2 emissions of agricultural production, and effect of installation of heat pumps - Case study in Ibaraki Prefecture-", Master's thesis, March 2011, Graduate School of Systems and Information Engineering, University of Tsukuba

References

1) Edited from "Energy Balance Table", Statistics, Agency for Natural Resources and Energy, Ministry of Economy, Trade and Industry

2) General Government Statistics, Actual Area of Installed Heating Systems by System Type - Vegetable Greenhouses, Greenhouse Installations, and Statistics by Prefecture, Ministry of Agriculture, Forestry and Fisheries

3) E'z Inc. http://www.esinc.co.jp/agri/

8.4 Prospects

To increase the use of industrial heat pumps, it is essential to build up a track record of installation by promoting partial replacement of existing heat source equipment with heat pumps for the time being. Scheduled operation of production processes with heat pumps cannot be realized without ensuring the reliability of heat pumps. It is also important to prepare ourselves for the next step to promote R&D and commercialization of next-generation heat pump systems for which the use of heat pumps as a heat source is a prerequisite. To encourage replacement of existing heat source equipment, the support programs described in section 8.2.2, as well as the following discussion and development, are needed:

- Determining the actual waste heat and thermal demand
- Improving the heating efficiency of circulating hot water
- Improving heat transport and thermal insulation techniques
- Improving refrigerant leakage prevention, leakage detection and waste refrigerant recovery techniques, and enhancing their efficiency

- Reducing usage of rare metals (such as neodymium and dysprosium) and copper
- Enhancing efficiency of temperature control technology for agricultural applications

To commercialize and increase the use of next-generation heat pump systems, it is necessary not only to raise the output temperature and efficiency, and diversify heat sources, but also to discuss and develop the following points:

- Simulation and evaluation techniques of system characteristics
- Establishing safe use of mildly flammable refrigerants, and applying natural refrigerants to more applications
- Rare metal substitutes.

Basically, many manufacturers do not disclose their production processes. Hence, it is difficult to make examples of heat pump installation open to the public, or share information across industries. The cases introduced above could not be included in this report without understanding the arrangements made by heat pump users and manufacturers. We would like to express our gratitude for provision of information by those concerned. We expect that building up a track record of installation and information-sharing, as far as possible, will promote improvement of heat pump functionality and enhancement of efficiency, and create a virtuous cycle which will bring increasing benefit to the industrial society.

9 Korea

9.1 Introduction

Since the unique characteristics of Korean market such as wide-spread network of natural gas supply, low electricity price and floor heating culture, heat pump penetration rate is relatively low compare to other nations. However, recent environmental challenges of society, especially for the challenges related with energy security, have brought consensus on the energy saving potential of heat pump. In the industrial sector, as a solution for energy saving, the number of heat pump installation and operation increases. In this chapter, representative heat pump installation and operation cases in industrial sector will be presented.

9.2 Cases of heat pump systems that utilize waste heat (heat recovery)

9.2.1 Reduction in usage of steam for DI water heating by installing heat pump and heat exchanger

This case is about the reduction in steam and electricity used for heating process of DI (Deionized) water through installing waste heat recovery device of coolant in factory and heat pump and using the waste heat for the heating process of process water and DI water. In order to clean glass substrate which is main element of TFT-LCD, DI water is produced and used. The temperature level of water was classified as 28 °C and 45 °C depending on the target process. For the maximization of the efficiency of RQ (reverse osmosis) process which is one of main processes of DI water production, the temperature of industrial water need to be raise up to 28 °C before RQ process and 45 °C DI water is produce through 28 °C DI water heating. DI water is made from industrial water that is supplied by K-water.

In previous process for DI water heating, waste heat through heat exchanger from chilled water of a refrigerator which produces cold water of 5 °C is used. In case of emergency, water is heated by steam using LNG boiler. Used DI water is transferred to waste water disposal plant and rejected after physicochemical /biochemical treatment. When cold water is required in factory, chilled water is used to lower the temperature of high pressure side refrigerant and it then is circulated to the cooling tower to release gained heat to the atmosphere.

A heat pump is installed and by utilizing waste heat as low temperature heat source it generates hot DI water (15 °C) in the improved process. This is different from conventional method that uses heat from steam in order to produce hot DI water. In the conventional process, 45 °C DI water is produced from 28 °C DI water through steam heating and the refrigerator that used to produce cold water has waste heat that is rejected to the atmosphere through cooling tower. In the improved process the refrigerator is removed and a heat pump is introduced to reduce energy use by recycling waste heat that is used to release to the atmosphere before. The installation of heat pump cuts the

LNG usage for steam production which is needed for 45 °C DI water generation. In addition, the waste heat of coolant that used to be rejected to the atmosphere maximizes heating effect by connecting it to the heat exchanger that already existed at refrigerator coolant heat recovery cycle.

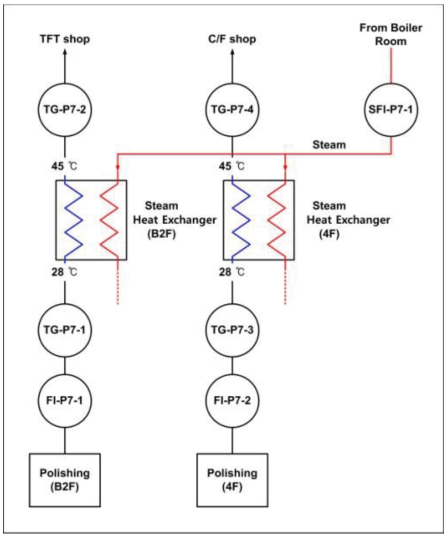


Figure 9-1: Previous process diagram

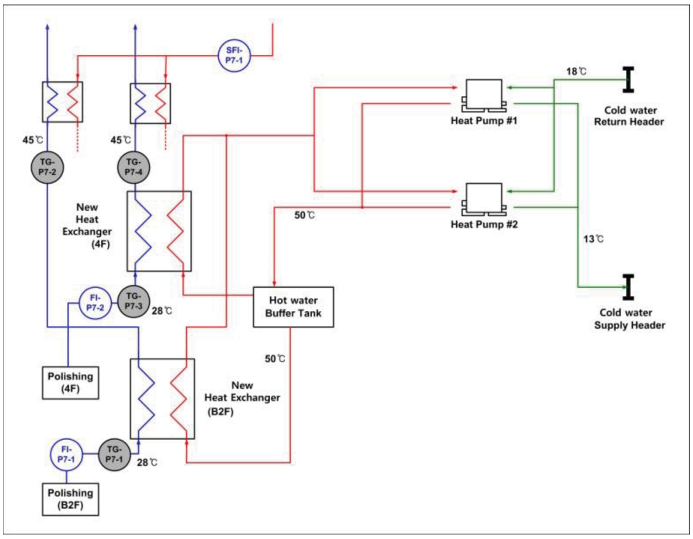


Figure 9-2: Improved process diagram

9.2.2 Energy saving through installation of waste heat recovery heat pump

This case is about generation of cold water and hot water of 60 °C through heat pump. This system was applied to textile factory. In conventional process, a refrigerator was used to produce cold water and steam from boiler was used to produce hot water. The Installation of a heat pump before steam heat exchanger preheats process water and reduces steam usage of existing steam heat exchanger, thus saving energy. In this case, the average annual reduction of CO_2 emission is expected to be 1,047 ton CO_2-eq.

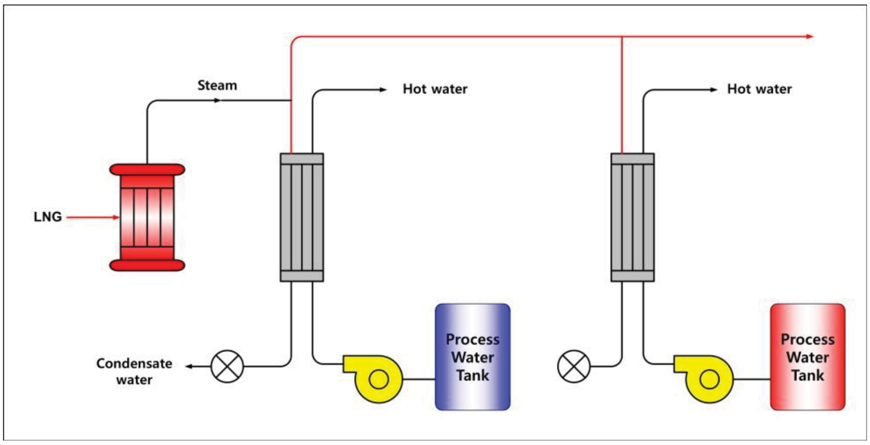


Figure 9-3: Previous process diagram

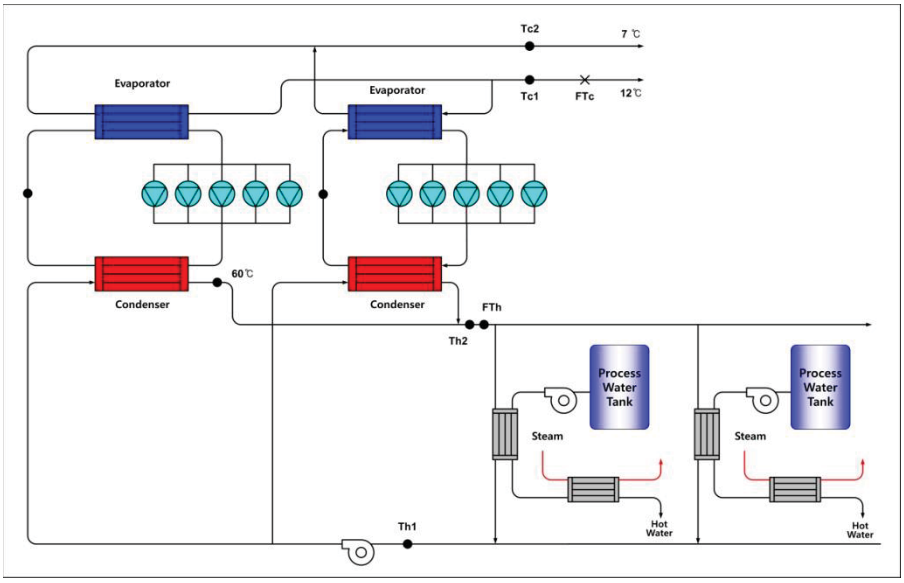


Figure 9-4: Improved process diagram

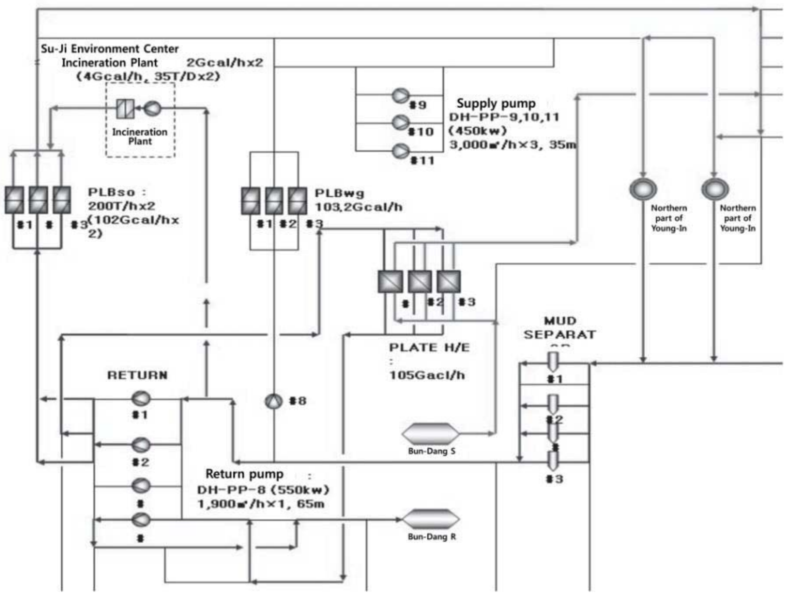
9.2.3 Sewage heat source heat pump (renewable energy facility) installation case in Yong-in

A plan was suggested for a partial utilization of wastewater from Respia in Suji in order to prevent local stream (Seongbok stream) depletion and scenery improvement. This plan was progressed for reduction of energy usage and active response for the Convention on Climate Change by using unused wastewater energy as a heating source through installing and managing related facilities.

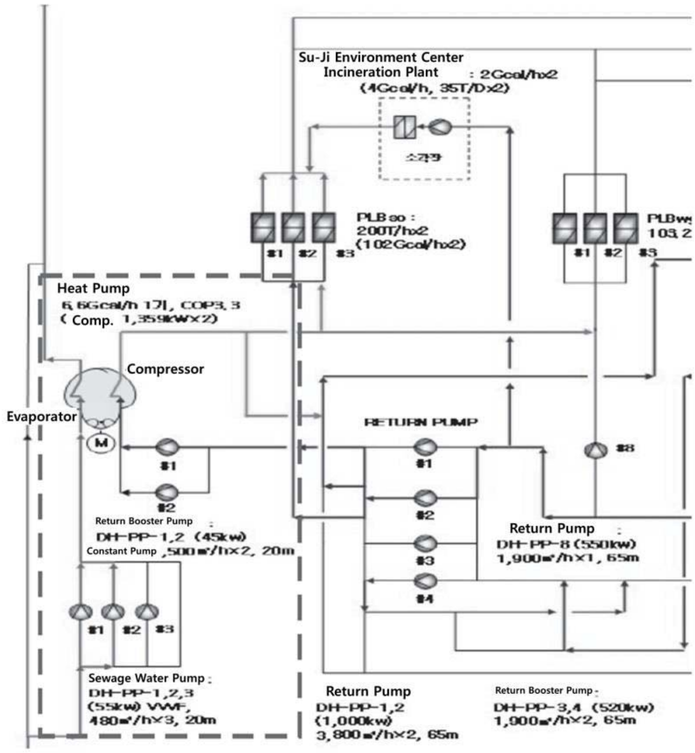
A district heating system of Respia in Suji provides steam of 100~110 °C to deal with the heating demand in Yong-in area using boiler system. After circulation, hot water of 50 °C is recovered which is transferred to heat exchanger of boiler again. The total area of the facility is 124,573 m² and the distance between the facility and heat source in Yong-in is 2 km.

Yong-in city established a plan of releasing treated sewage from Suji sewage treatment plant into the upper Seongbok stream in order to prevent dry stream and improve scenery. As a part of the plan, a heat pump was installed which utilizes Suji Respia unused energy as heat source for district heating in wastewater. This converts low-temperature and widely spread thermal energies such as geothermal energy, stream water, seawater, wastewater and other energies into high-temperature and intensive energy. Moreover, with a heat pump system, it is possible to produce hot and cold water simultaneously or independently. This system has a weak point that electric energy consumption is required to run compressor for gas compression. The annual CO_2 and power reduction were expected to be 5,719 t and 20,530,289 kW respectively.

Process schematic diagram before improvement



Process explanation:
System that provides heat of 100~110 °C to the places that require heating in Yong-in area through heat exchanging process with the steam from boiler. After the circulation, hot water of 50 °C is collected and transferred to the heat exchanger again.

Process schematic diagram after improvement

Process explanation: The recovered heat from sewage releasing place is transferred to the heat pump as a low temperature heat source. The generated hot water is supplied to the heating demand place in Young-in area.

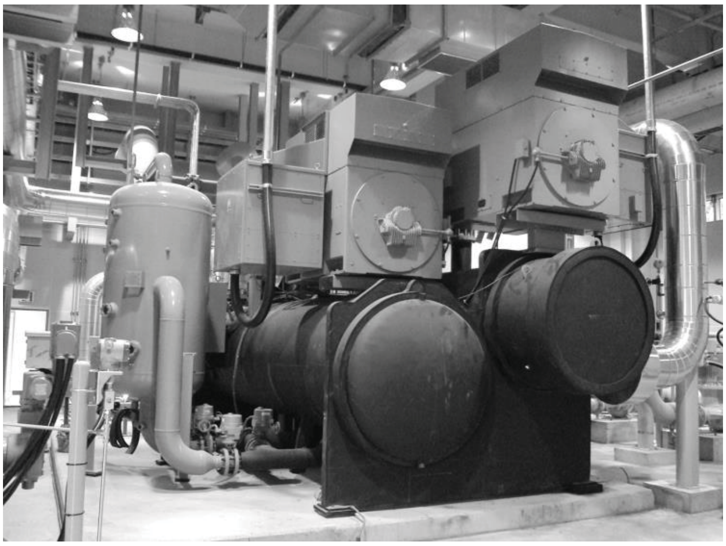


Figure 9-5: Installed heat pump

9.2.4 Energy saving case by utilizing a heat pump which collects waste heat from cooling system in IDC (Internet Data Centre) server room

A heat pump was used for hot water supply and heating in this case. The waste heat of coolant from IDC cooling system in computer room was collected and used as a heat source of AHU (Air Handling Unit) that controls temperature and humidity level of IDC server room.

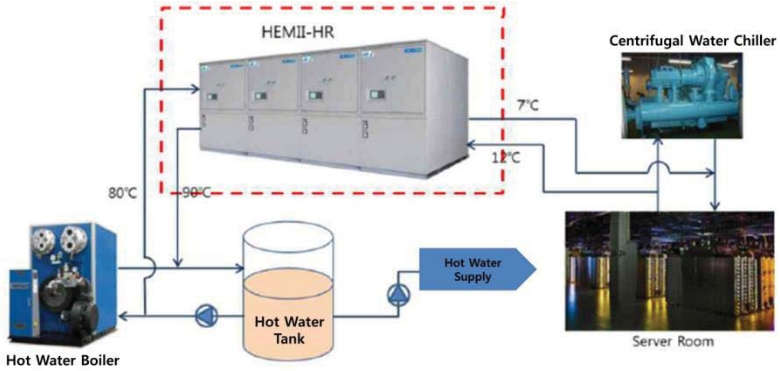


Figure 9-6: Diagram of cooling system of IDC server room with heat pump

9.2.5 Energy saving through change from TVR (Thermal Vapour Recompression) concentration facility to MVR concentration facility

TVR concentration system is waste heat recovery-type concentration system that takes high pressure steam as driving force for steam compression and reuses compressed steam as heat source for the discharge process. This process fits for the process, which concentrates materials of high boiling point. In addition, it also fits for high capacity processing. Since it evaporates circulating material by utilizing latent heat of evaporating steam, it can be applied to treat high concentration materials which have high possibility of scaling.

Improved process is high efficiency concentration system with MVR that intakes low-temperature waste steam as heat source into turbine-driven type compressor, compresses the steam, and reuses the output steam as a heating source of the production process. Due to the large available space inside of the heat exchanging tube and high vapour specific volume it is easy to separate vapour and liquid. In addition, a concentrated material drops in form of film inside the tube which yields high overall heat transfer coefficient and heat transfer efficiency. Moreover, it is suitable for evaporative concentration of materials of high sensitivity to thermal degradation because low-temperature concentration is possible and the product stays only for short time inside the tube as the velocity of fluid is increased by the evaporated vapour.

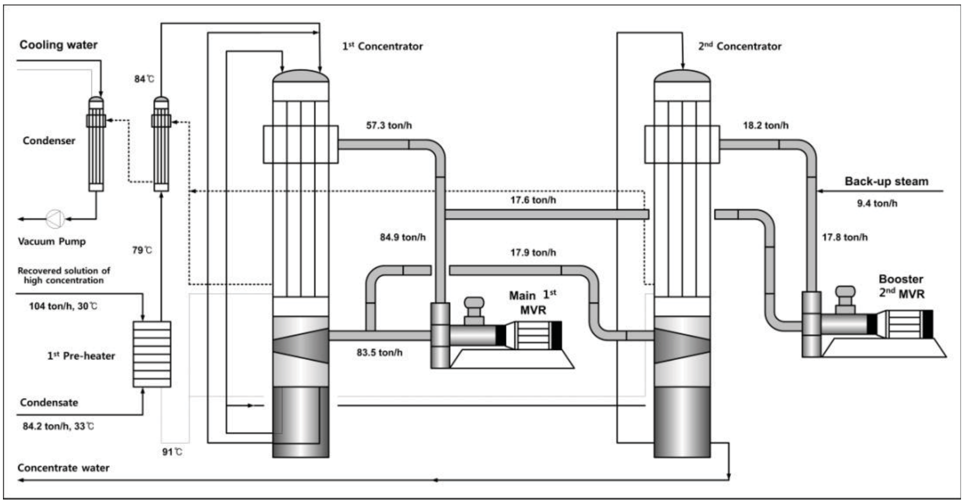


Figure 9-7: Improved concentration process with TVR

9.2.6 Energy saving case of the steam generation through TVR and MVR for heat recovery

This case is to reduce thermal loss from cooling tower where waste steam condenses by recycling waste steam through the installation of TVR and MVR and using recycled steam as the heat source of M,T-Line Stripper.

The MVR and TVR are installed to collect waste gas which is exhausted during the separation process of solvent in synthetic rubber production process. They generate usable low-pressure steam and substitute it with the supply steam from cogeneration plant. The main feature of conventional and improved process is represented in following table.

Previous Process	Improved Process
∘ Insert raw material/solvent during reaction (polymerization) process → ∘ Insert steam in order to separate solvent during reaction process → ∘ Lower part of stripper → hot water discharge → transfer to production process after stripper insertion	∘ Same as the previous process
∘ Upper part of stripper → vapour discharge → cooling tower → rejected as waste water after condensation	∘ Upper part of stripper → vapour discharge → plate heat exchanger → vapour-liquid separator → MVR (3-stages) → TVR → steam generation → reinsertion to M,T-Line separator

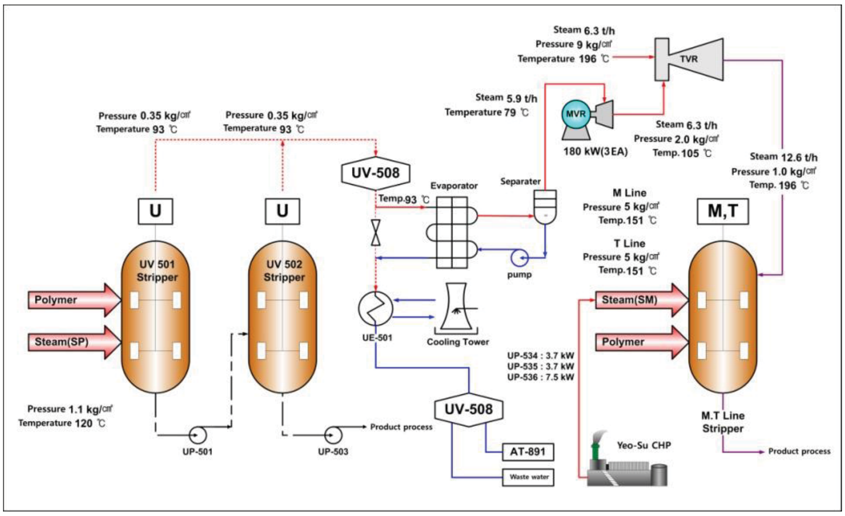


Figure 9-8: Diagram of energy saving process with MVR and TRV

9.2.7 Application case of high efficiency thin film dropping type concentration tube and MVR to a sugar refinery factory

In conventional process, a concentration tube is double effect tube of rising film type and is used as vacuum concentration of sugar solution. Waste steam which is generated from concentration tube is recycled as hot water generation for factory and condensate water is used as supply water to the boiler or rejected as waste water.

The improved process uses 1st MVR to recompress waste steam which is generated from 1st concentration tube and inserts the steam into 1st concentration tube again. A certain portion of waste steam from 1st concentration tube is recompressed by 2nd MVR and used as heat source of 2nd concentration tube and generated waste steam from 2nd MVR is and recompressed by 1st MVR and sent back to 1st concentration tube. Such utilization of MVRs that recycle waste steam from concentration tubes reduces input energy to entire process.

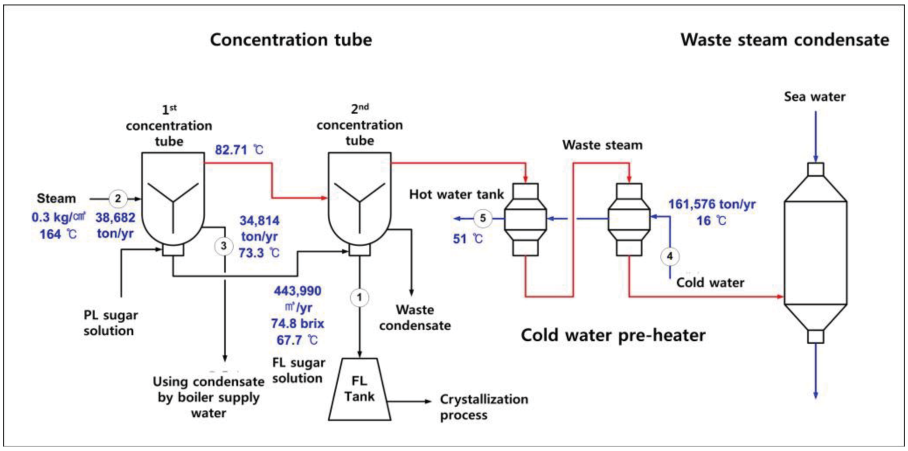


Figure 9-9: Diagram of previous process of sugar concentration

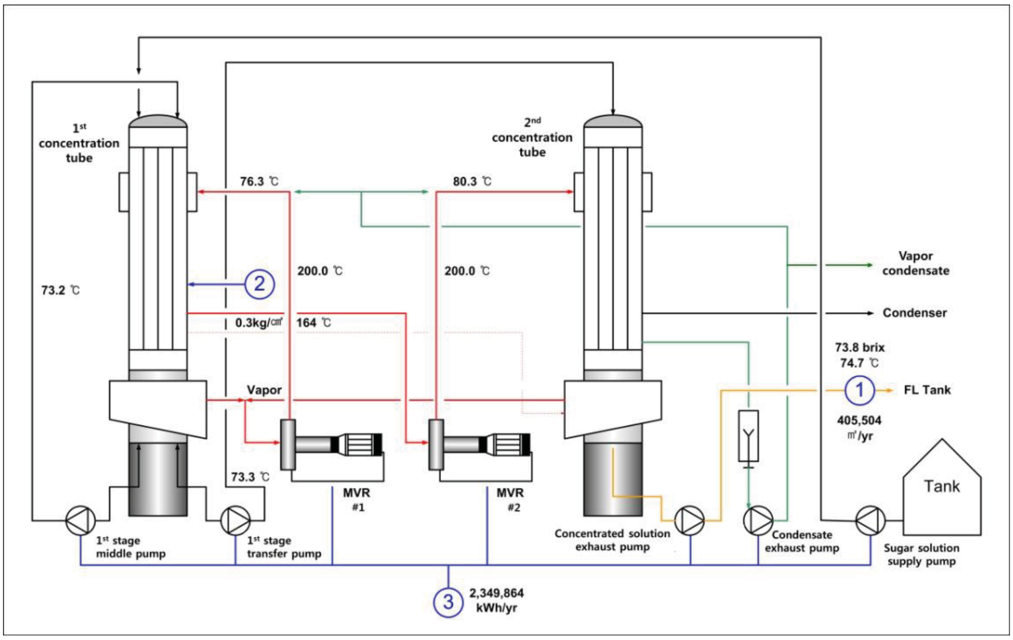


Figure 9-10: Diagram of improved process with MVR

9.2.8 Reduction of greenhouse gas emission through installation of heat recovery MVR in reaction tower

With the waste heat from the processes in a PC (Polycarbonate) factory, steam of the pressure of 1.9 kg/cm² is generated. This steam is recompressed up to 4.2 kg/cm² through mechanical vapour recompression (MVR). This makes it possible to contribute energy cost reduction and prevent global warming by stopping steam boiler operation of existing factory and cutting fossil fuel usage.

Yeo-su branch of Che-il Industries Inc. consists of an old factory that produces ABS, EPS resins and other product and a PC factory that manufactures PC (polycarbonate) which is made from DPC (diphenyl carbonate) by processing DMC (dimethyl carbonate) as a raw material. The old existing factory uses 3 steam boilers (Capacity: 25 tons/hr, pressure: 7 kg/cm²) to generate required amount of steam in production processes. The required steam of the PC factory is produced by one steam boiler exclusively for PC process (Capacity: 100 tons/hr, Pressure: 40 kg/cm²).

DPC process in PC factory produces DPC by inserting raw materials purchased from the outside and steam of temperature of 155 °C and pressure of 0.7 kg/cm² is discharged at the upper part of DPC reaction tower. The high-temperature discharged steam is cooled by cold water (CW) through a heat exchanger. After that, a certain amount of the steam re-circulates to the reaction tower and the rest is sent to the RP tank. Even though the high-temperature discharged steam of the upper part of DPC reaction tower has high thermal energy capacity of 14 million kcal/h, this energy is not efficiently reused because of the forced cooling process with coolant at cooling tower.

For the OVER-HEAD waste heat collection facility at DPC reaction tower, a steam generator and an MVR were introduced which intake steam of 1.9 kg/cm² and pressurize this steam up to 4.2 kg/cm². This system was proposed by Everland that is specialized for ESCO (Energy Service Company) investment.

The specification of PC process waste heat collection facility system is shown below. For the first localization of MVR facility in Korea, the turbo compressor, STG-1300 MVR from SeAHENT (Korean company) was chosen and construction was done as an ESCO investment.

The improvement through MVR is like followings. Above all, for the amount of annual energy cost, 6.05 billion wons ($5.64 millions) are saved through alternation of steam and 550 million wons ($0.51 millions) are added for power consumption. Therefore the net energy saving cost is 5.5 billion wons ($5.13 millions) per year. The energy saving amount through alternation is 8,476 TOE and additional power consumption is 1,668 TOE per year which makes net energy saving amount of 6,808 TOE annually. The expected payback period is 0.9 year.

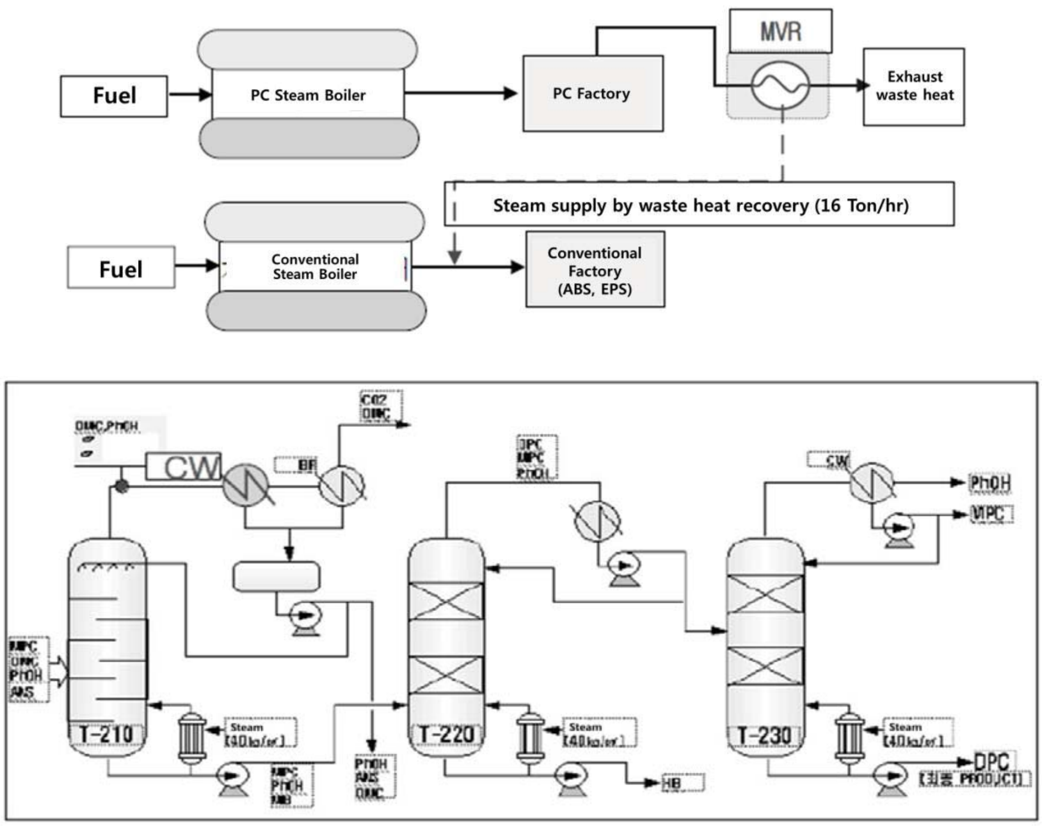


Figure 9-11: Process diagram

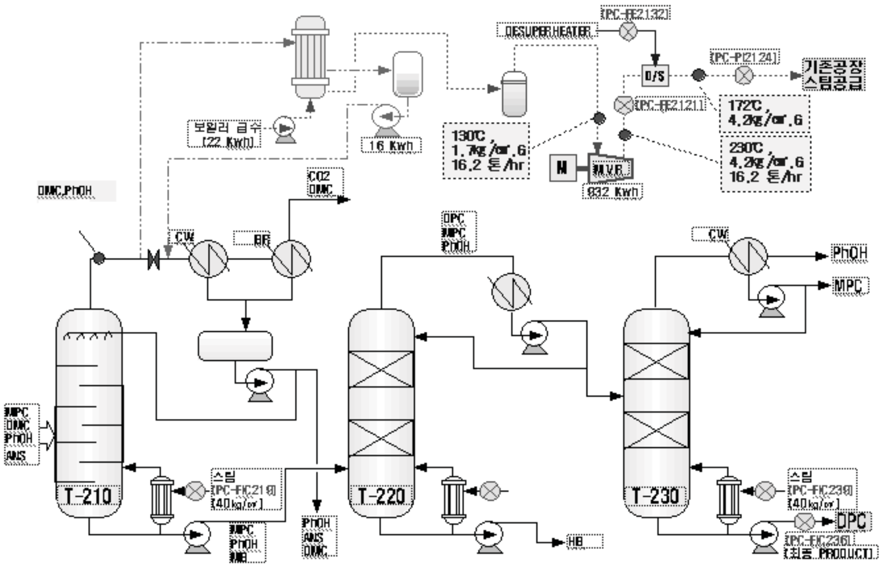


Figure 9-12: Improved process

9.2.9 Recycle of re-evaporated steam by installation of variable-type thermal vapour recompressor (TVR)

A thermal vapour recompressor (TVR) was installed to crumb slurry tank to collect re-evaporated steam and utilize it as heat source for Stripper (Solvent collector). So the amount of supply steam for Stripper heating was reduced.

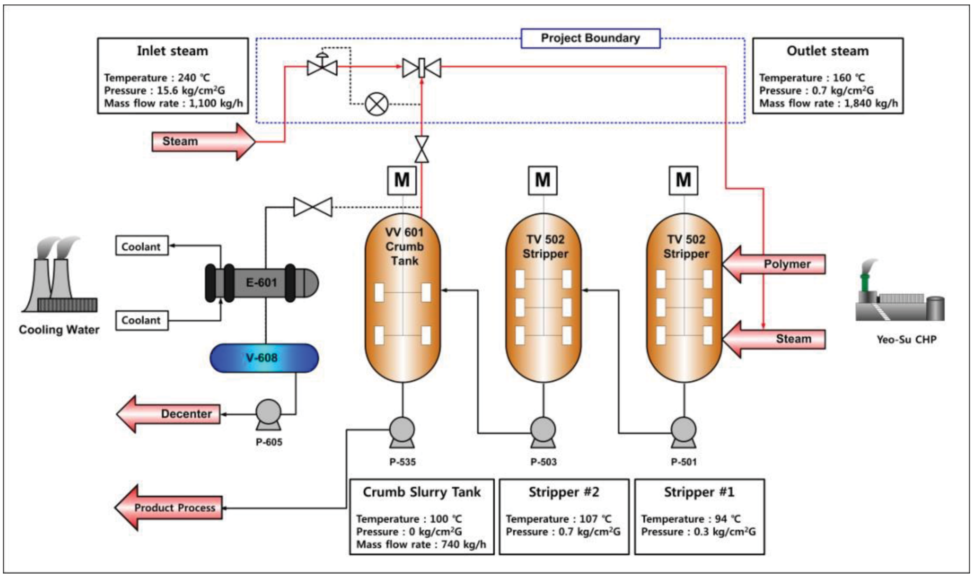


Figure 9-13: Improved process

9.2.10 Reuse of waste steam to the process steam by TVR

Previously, a plant received steam for the production process from a neighbouring co-generation plant. When there was need for additional steam, a steam boiler installed in a factory was used. The steam is provided to each process and recovered as a form of condensate water after its usage.

In the improved process, input energy can be reduced by recycling generated air vent steam (1 kg f/cm²) from condensate water collection system of plant and recompressing the steam up to 3 kg f/cm² through TVR (Thermo-Vapour Recompression).

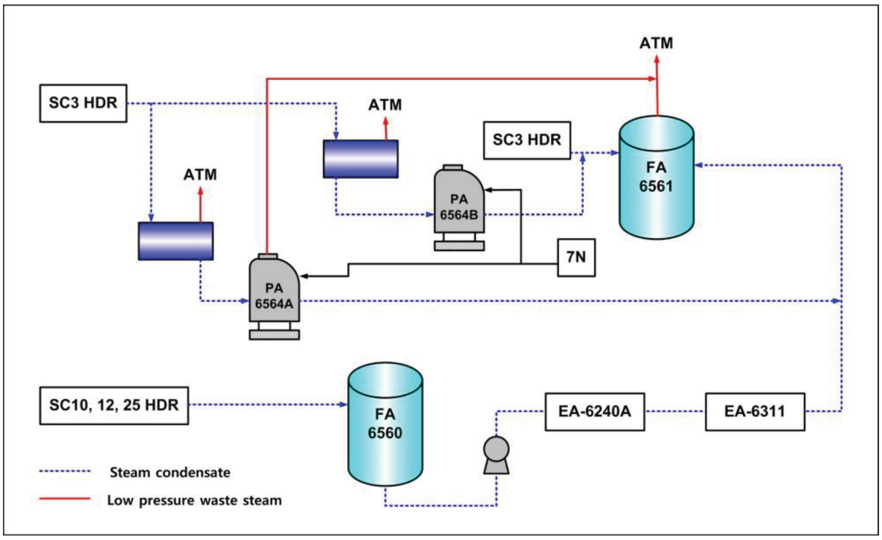


Figure 9-14: Improved process

10 The Netherlands

10.1 Example projects in Netherlands

Developing and dissemination of knowledge is important for successful growth of the application of heat pumps. To stimulate the application of heat pumps it is useful to analyze heat pumps which have been placed in the past and analyse how they operate in practice.

In this study the operation of these "older" heat pumps is analyzed. The research has been performed through contacts by phone and e-mail. In this study an inventory was made about; the experiences of the companies, if there have been any changes of the design over time, whether operating & maintenance of the installation is difficult (high level of knowledge, complexity, etc.), if promised energy savings are achieved and whether there are remarks which can be defined as lessons learned.

Over the past 20 years several feasibility studies and project realizations of heat pump projects have been performed. These are evaluated in this study.

The table below provides a summary of the results, which heat pumps are still in use and which are not. The reason is indicated when heat pump have been taken out of use.

All companies, whose heat pumps were described in the examined literature (22 cases) participated in this evaluation study. 5 projects were never realized, despite the fact that acceptable payback periods and significant energy savings were calculated in the feasibility studies.

Much has changed in the companies in the past 20 years like the closure of the plant, moving production abroad, no demand for the product produced, changes in operations, etc. As a result, 6 of the analyzed heat pumps have been removed. This had nothing to do with any possible malfunction of the heat pumps.

Factsheet	Company old/new name	location	process	Condition
	Oriental Foods	Landgraaf	Drying of Tahoe	Company closed
	Plukon	Asten Ommel	Slaughterhouse	Feasibility only
	Solphay/Dishman	Veenendaal	MDR on Aceton	End of production
	Purac Biochem	Gorinchem	MDR on lactose	End of production in NL
	Hartman/Jardin	Enschede	Garden furniture	Feasibility only
	ITB		Plastics	Feasibility only
	Quality Pack	Kampen	Crate washing	Company closed
	Beukema/Eska Graphic Board	Hoogezand	Paper drying	Feasibility only
	Huwa Bricks factory	Spijk	Brick drying	Feasibility only
	Frico	Sint Nicolaasga	Cheese evaporative drying	Company closed
	Hoogovens/Tata steel	IJmuiden	Heat Transformer	Corrosion problems
	ARCO/Lyondell	Botlek	MDR on Distillation	no data available
NL-01	Shell	Pernis	MDR on Distillation	running
NL-02	Unichema/Croda	Gouda	MDR on Distillation	running
NL-03	Hoechst	Vlissingen	MDR on Distillation	End of production in NL
NL-04	Campina	Veghel	MDR on evaporation	running
NL-05	De Graafstroom	Bleskensgraaf	MDR on evaporation	running
NL-11	Dommelsch Brewery	Dommelen	MDR on wort	running
NL-13	GPS	Nunspeet	Heating from condensor	running
NL-15	AVEBE	Ter Apelkanaal	MVR on patatoe starch	running
NL-16	Cerestar/Cargill	Sas van Gent	MVR on	replaced by new MVR
NL-17	Fapona/Berendsen	Apeldoorn	Laundry drying	running

Of the 11 remaining heat pumps, 10 are still in use. These are 8 Mechanical Vapour Recompressors (MVR), a Thermal Vapour Recompressor (TVR) and a heat pump, which uses the heat from the condenser of the refrigeration installation for process heat.

When the heat pump are still in use, the companies have, no more insight into why there ever was chosen for the heat pump given the long period since the investment decision. The heat pumps which are still in use are generally still running in their original design. They are running relatively many hours a year (5,000-8,000), usually at full load.

In several cases the maintenance is outsourced for reasons of complexity, high operating hours and capacity problems in the technical department. Operating the installation is generally regarded as a relatively simple. The installations have few problems and / or malfunctions. Companies have no insight on whether the system achieves its efficiency, or whether the intended energy savings have been obtained. They have no reference, given the initial situation is so far in the past. Below are a couple of remarks which have emerged from this study which should be taken into account for the application of heat pump technologies.

- When a steam-powered evaporation process is switched to an MVR, which is electrically powered, it must be taken into account that the ratio between heat and electricity demand shifts towards electricity. This is unfavourable for the use of gas turbines, when a company has these in use.
- A point of interest for heat pump installations which processes polluted water is that the heat exchangers require relatively high-maintenance when they have to process large quantities of polluted water.
- An additional advantage of a TVR, or a MVR is that these systems reduce the emission of odours, since all vapours are condensed.

The heat pumps generally run satisfactorily, this study provides no indications to suggest that there are major risks associated with the use of heat pumps in industrial environments.

Example projects are listed in factsheets as Appendix of this report.

10.1.1 Chemical industry[1]

Distillation is by far the most widely practised technique for separating mixtures in the chemical and petrochemical industry. Distillation columns are in many chemical plants the largest energy consumers. In a conventionally operated distillation plant, energy is used to heat in the reboiler and about 95% of this is released at the top of the column in the air or water cooled condenser. This energy is in most cases wasted.

The application of heat pumps is one of the most efficient technologies to reduce the energy requirement of distillation. Sulzer Chemtech has applied various types of heat pumps successfully in a number of industrial processes.

The energy costs can be reduced in several cases by 30 – 70%, involving less than two years payback time for the additional capital investment related to the installation of the heat pump. The environmentally friendly character of the heat pump process is apparent from the lower amount of CO_2 emitted while generating the electrical power required for the process. It is found that the CO_2 emission can be reduced by 60-80% depending (*a*) on the thermodynamic efficiency of the heat pump and (*b*) on the type of primary energy employed for power generation. In each investigated application of a heat pump, the additional investment costs compared to conventional distillation is paid back in less than two to three years thanks to the lower energy consumption. Moreover, in some cases the expansion of auxiliary facilities, like the cooling tower, the chilled water system or the boiler house can be avoided.

Heat pump systems can be implemented for new distillation units, as well as for revamp of existing plants.

In the process of direct vapor recompression (see Figure 10-1) the pressure of the vapor leaving at the top of column (C-1) is elevated in a compressor (T-1). This raises the dew point of the vapor following which it can be condensed in the reboiler (E-1). There are, however, applications where the medium in the column, and thus the vapor from the column top, is not suitable for compression (due to, for example, polymerization and corrosion). In these cases an additional, separate working fluid like water can be selected (see Figure 10-2). The water is evaporated in the condenser (E-2) of the column (C-1), the generated steam will be compressed in a compressor (T-1) and condensed in the

[1] I. Mészáros, Sulzer Chemtech Ltd,

reboiler (E-3). The water condensate is circulated back through a throttle valve into the condenser where it will be evaporated again.

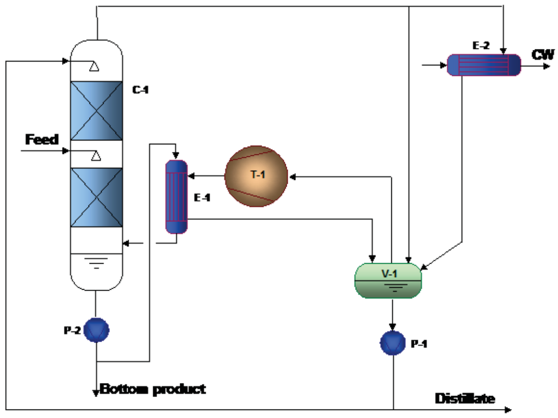


Figure 10-1: Scheme of distillation with direct vapor compression

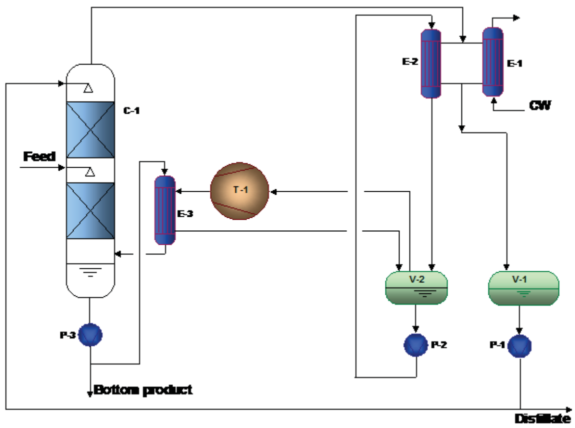


Figure 10-2: scheme of distillation with an indirect heat pump

Practical application criteria are given in Appendix 2, where also six cases are described [Kleefkens, 1996].

Three example projects are discussed. A fourth large example project which was already published in a paper in 1995 did not get the allowance to be published as according to the new management there was too much confidential and competative process information in the sheet.

NL-01 MVR for chemical process at PP-splitter for Shell in Pernis (see also Appendix 2)

At Shell Nederland Chemie on the location at Pernis (NL) products such as cleansers, solvents, fibres, resins and polymers are produced. These products are manufactured from raw materials produced in the refinery on the same site. Propylene is a key material in the production of a number of chemical products including polypropylene (PP) and solvents. It is obtained by distillation separation of propylene and propane in a so called PP-splitter column. In a conventional distillation the reboiler is heated by low pressure steam and the overhead vapours are cooled with cooling water.

In 1995 as a part of the modernisation of the whole propylene distribution system within the Shell site at Pernis, a new propylene-propane distillation column was built with the application of mechanical vapour recompression (MVR), built by Mannesmann Demag AG. This was done to save energy, reduce the use of cooling water and increase the yield of the distillation.

The heat pump as described is still running in line with the original design at 8650 hours per year at fixed speed. Maintenance is done by an external party as specific knowledge is required.

NL-02 - Croda in Gouda

Croda is produces special oleochemicals and derivates for a broad market of applications. In the separtion process for oleïne and stearine an MVR heta pump is used since 1994. The heat pump as decribed in the factsheet is till running to the design at 90% full load for 8000 hours/year.

Maintenance and service is contracted as a high level of expertise, not present at Croda, is needed. Once a year the process is stopped for that overhaul where mostly only cleaning of the system is needed and no parts are broken down or have to be replaced.

NL-03 Hoechst Vlissingen (see also Appendix 2)

Since 1982 three steam recompression systems have been in operation at the Hoechst production plant in Vlissingen. The heat pumps are a part of the process for the production of dimethyl-terephthalate (DMT). With the application of steam recompression, steam pressure is increased from 1.14 bara to 3 bara, which can be used in the low pressure steam system. The main goals for the application have been cost reduction and the possibility to work with a smaller steam production plant. Due to the recline in the PMT market worldwide the Hoechst plant was closed in 2007.

10.1.2 Food industry

Evaporators in dairy industry

The GEA handbook on Milk Powder Technology states that the transforming of a liquid product into a dry powder requires means the removal of practically all water, the amount of which often exceeds the weight of the final product. During the water removal the processed product is undergoing deep changes of physical structure and appearance, starting with thin water-like liquid and terminating with dry powder at the end of the process. Therefore, one single method of water removal cannot be optimal throughout the whole process, as also the product composition is different from one food product to another. In the food and dairy industry the following dehydration methods have been adopted:

- Evaporation:
- Spray Drying:
- Vibrating Fluid Bed Drying:

- Integrated Fluid Bed Drying:
- Integrated Belt Drying:

Each method should be adjusted to the properties of the processed material at each processing step. The more difficult the product, the more complex the plant.

As the development went on, the concentration was carried out in forced recirculation evaporators. In this evaporator the milk streams upwards through a number of tubes or plates. On the outside the heating medium, usually steam, is applied. The heating surface is thus increased in this system, but the evaporation surface is still limited, as the tubes and plates remain filled with product, which therefore becomes superheated in relation to the existing boiling temperature. Not until the product leaves the top of the tubes, are the vapours released and the product temperature decreases. For the separation of liquid and vapours, centrifugal separators were preferred. In order to obtain the desired degree of evaporation the product was recycled in the system. The concentration was thus controlled by the amount of concentrate discharged from the plant.

NL-04 Campina in Veghel

FrieslandCampina DMV in Veghel installed an energy-efficient evaporator that is the only one of its kind. It evaporates water from whey, allowing the lactose to crystallise spontaneously. By using smart technology, the current combination of mechanical and thermal evaporation techniques can be replaced by a single mechanical technique to cut energy consumption by an additional 60%. The heat released using this new technique is used so efficiently that cooling water is no longer needed. The discharged condensate is cooled until it reaches a temperature of 15°C. Approximately 35 technicians work on the installation. The new evaporator will become fully operational in October 2013. The construction and installation of the new evaporator is part of an extensive capital expenditure programme at Veghel, in which FrieslandCampina is investing over 60 million euros. The knowledge gained in developing this evaporator will also be put to use in future projects where there are similar cost savings to be achieved.

NL-05 De Graafstroom

The Cheese & Butter group produces and sells semi-hard Gouda cheeses in a number of varieties (Campina Holland Cheese) which is produced in Bleskensgraaf. Since 1992, Campina has supported the Dutch Long-Term Energy Efficiency Agreements for Industry (LTA-1 and LTA 2) covenants between the private sector and the government to realise the goals of (inter)national climate policy.

NL-06 McCain (see also Appendix 2)

In the summer of 2012, a heat pump is installed at a plant of a French fries producer. This heat pump will provide the majority of the energy needed for drying of French fries before they are baked. The used dryer type is a belt dryer that operates at a maximum temperature of 70 °C. The innovative application of a heat pump connected to a French dryer, invented by De Kleijn Energy Consulting, is the first of its kind. Energy savings as high as 70 % on the dryers energy consumption will be realized.

Refrigeration

Most of the waste heat is available from the condensing heat of refrigeration plants. The temperature level is between 30°C and 40°C. This energy source amounts to 28 PJ a year. Similarly the heat consumers have been investigated showing that 14 PJ is consumed by various processes at temperature levels between 60°C to 110°C. Some information of example projects is available, where one of the projects is a UK project by Grenco.

UK-01 Wiseman Dairies

The company of Robert Wiseman in UK was confronted by the choice of replacing the refrigerant R22 by a more environmentally friendly solution, or of investing in a completely new plant based on ammonia as refrigerant. Although planning revealed that an ammonia plant would operate more efficiently, the customer initially did not accept this solution owing to the long amortization period. Yet, in the end, GEA Refrigeration Technologies made an investment so attractive by an add-on, in the form of a heat pump, that Wiseman could not resist. The new system allows using the heat emitted by the refrigeration plant to be used for pasteurization of the milk – and the entire plant will now amortize itself in less than two years (Source: Grenco).

NL-08 Blue Band margarine factory Unilever Rotterdam (see also Appendix 2)

The Blue Band factory from Unilever, at the Nassaukade in Rotterdam is over 120 years old and at the moment the world largest factory for margarine with an output of more than 200.000 tonnes of margarine and 10.000 tonnes of peanut butter. Over that period of 120 years many changes in building, expansion and machinery have been done and a large overhaul of the complete production and building has never been undertaken creating a complex onoverzichtelijke situation. When in 2009 the boiler-room was going to be renovated the 40 years old steam boiler had to be replaced. Of the installed capacity more than 40% was not used because the new production lines have a lower energy use. As production had to go on a new boiler-house was designed near the old existing one.

NL-09 Thermal vapour recompression heat pump at Heineken Den Bosch

Heineken Den Bosch has installed a heat pump in the wort boiling house during a renovation. The heat pump is a thermal vapor recompression (TVR) type placed on the wort boilers. The TVR is used to reduce the energy consumption of the wort boiling process. The heat pump started operation early 2005. The savings on gas consumption and CO2 emission are considerable.

NL-10 Dommelsche Bierbrouwerij

NL-11 Export Slachterij Apeldoorn (Slaughterhouse) (see also Appendix 2)

The slaughterhouse at ESA for veal requires large amounts of hot water for room and machinery cleaning and for removing hair from veal skin, and a smaller amount for sterile water (90 °C). The heat pump has been installed in a slaughter house at a moment that the steam boiler had to be replaced. This created the opportunity to improve the hot water system efficiency. The heat pump is a 45 bar reciprocating compressor coupled to the high pressure side of a refrigeration plant with ammonia as refrigerant (see figure 1). The heat pump condenser heats up water up to 62.5 °C. The installation is running more than one year with great satisfaction and reliability.

NL-12 GPS (Gecombineerde Pluimvee Slachterijen)

GPS in Nunspeet is a slaughterhous for poultry. The condenser heat from cooling and refrigeration is used for process and space heating. The heat pump as described is running since 1994 with 3,750 hours/year of operation often in 65% partial load. Running the heat pump is simple, but maintenance is more complex and contracted out. There are no data available on the energy savings as there are no reference data.

NL-13 Sonac

Sonac in Suemeer processes animal offal and carcasses. The feedstock is after breaking an crushing to small particles heated to remove the liquids and water. MVR is used to heat this process. The heat pump is running since 1996 for 6,000 hours/year in full load. Running, servicing and maintenance are simple and robust done by the in house technical group. As the system is running to design the company expects that the foreseen energy savings are achieved.

NL-14 AVEBE Ter Apelkanaal

AVEBE is one of the largest potato starch producers in Europe with a yearly output of 500,000 tons of starch. The waste water streams from the production process are evaporated to the stage of protamylasse. A overall of 2,475.000 tons of water is evaporated in the process per year. In this part of the process AVEBE already in 1990 invested in energy efficiency measures where a mechanical vapour recompression heat pump was installed in the first phase of a three phase evaporator. The heat pump runs 5,000 – 6,000 hours/year largely in partial load of 65%.

Running is simple but servicing is contracted out. AVEBE estimates that the expected savings are largely achieved.

10.1.3 Misceleneous

Under this heading several industries are clustered which are of various types of processes.

NL-15 MVR for sludge drying at Sophus Berendsen Textiel in Apeldoorn

Berendsen Textiel in Apeldoorn is an industrial washing plant for industrial cleaning cloths. The evaporation of watery sludge streams is done through a process of mechanical vapour recompression and has replaced a process of water treatment with reversed osmosis. The heat pump as described in the original factsheet and in its original design is stil in use and makes 6000 running hours per year. It is running at 50 – 100% partial load. Every week the heat pump is stopped to be able to clean the heat exchangers while once a year the heat exchanger are replaced by new ones. Maintenance is done by in-house technical service department with the main attention at the heat exchangers and the composition of the waste water.

NL-17 Ahrend

No details available.

NL-18 SCM-TDC in Kampen

No details available.

NL-19 Brinks Metaalwaren

Brinks is specialist in: drilling, milling, thermal deburring and cleaning in serial batches ranging from 500 to 200,000 units. Maximum unit weight 20 Kgs. In the chain of production Brinks performs the role of process-supplier with the specialism of multi-spindle CNC processing, thermal deburring (TEM) and the specifically custom-made cleansing of products.

NL-20 Icerink in Enschede

In October 2008 a new indoor skating rink was opened in the city of Enschede. The refrigeration plant for this skating rink was designed, delivered and installed by IBK. CO2 was chosen as the secondary refrigerant. CO2 is easily detectable, sustainable and - above all -very energy efficient, since less pumping energy is required and pipes with a smaller diameter can be used. The residual heat of the refrigeration plant is used for the Zamboni, for the CH block and for the unique floor heating system, which is located under the skating rink.

NL-21 Wastewater treatment in Raalte

The temperature of the effluent of the wastewater treatment plant varies from 8 to 20 °C and thus contains thermal energy. Effluent is discharged into surface water. This is not an ideal situation, because the thermal energy has a negative effect on surface water. Furthermore, a potential source of energy is lost. In this project the water board Groot Salland and the municipality of Raalte want to use thermal energy from the effluent to heat the nearby swimming pool Tijenraan.

NL-22 LIDL Distributiecentrum Heerenveen

Lidl has built a large distribution centre near Heerenveen of 46.000 m². The project is one large building with several subsections like distribution centre, offices and technical rooms. The building was nominated 4 stars being Excellent in BREEAM according to the Dutch Green Building Council (DGBC).

No further information or specification of technologies is given.

10.1.4 Industrial areas

In the Netherlands other industrial areas are getting more and more sustainable. Information can be found on: www.energiezuinigebedrijventerreinen.nl.

NL-23 Ecofactorij industrial area

Ecofactorij in Apeldoorn is an industrial business area south of the City of Apeldoorn. The local authorities have the policy to develop this area as sustainable as possibly by creating the right boundary conditions for settling new companies. This has been described in the “Kwaliteitsplan Ecofactorij” (Qualityplan Ecofactorij). By investing in sustainability and renewables points are given with which rebates were given on the price of land.

Energy is within this sustainability approach an important topic as almost 40% of the point could be gained by investing in these. This has resulted in the fact that 80% of the companies and buildings are equipped with heat pumps and 20% with bio-pellet heating. As the business area is near the traffic junction A1/A50 in the middle of the country, logistic service providers like Sandds, Sils, Harbers and Grolleman Cold Store are settled at the Ecofactorij.

Initially the idea was to cluster companies on connecting to a common infrastructure of heat, waste heat and annual thermal energy storage with heat pumps. In the end the slower than expected development of the area and the larger than expected attraction for logistic distribution centres changed into an approach to individual sustainable and renewable solutions.

NL-24 Bakker Barendrecht – freezing store

A large distribution centre for fruit and vegetables requires a cooling capacity to maintain temperatures at 2ºC and 12ºC during the year. At the same time heat is required for ripening of bananas, defrosting of air coolers and water heating. Industrial heat pumps have been installed for cooling and simultaneously heating. The heat pumps increase the energy efficiency of the total plant and have reduced the investment costs for electricity supply equipment and heating installations.

NL-25 Bovendeert Shoes (see also Appendix 2)

The warehouse and headquarters of shoe store chain Bovendeert in Boxtel, contains, besides thousands of colourful shoeboxes and shoes, also an installation with highlighted technical features. Besides the accompaniment of an international automation standard type KNX to link an innovative and energy saving heat pump installation from LG Electronics on an advanced controlled electrical installation, a durable and comfortable installation concept arose.

10.1.5 Agriculture

The major energy user in the agricultural sector are greenhouses where heat pumps are becoming state of the art. Other sectors in agriculture are of interest too.

NL-27 Greenhouses (see also Appendix 2)

Since 1998 when the first idea wars reported on the 'closed greenhouse' concept several projects and experiments have been started. Some failed as there are different crops which have to be handled differently, but in the end the concept is now broadly accepted for most of the types of crops. All these applications are feasable because of the broad experience built up with ATES systems. Under NL-27 five examples are generally described.

In the period 2003-2013, in Dutch horticulture approximately 40 growers of various crops have implemented heat pumps in their greenhouses. In the following, we present 5 factsheets concerning the application of heat pumps in Dutch horticulture in the production of roses, tomatoes and orchids.

NL-27 a	Themato
NL-27 b	Anthura in Bleiswijk
NL-27 c	Hecostek in Biezenmortel
NL-27 d	Ermstrang
NL-27 e	Entius in Heerhugowaard
NL-27 f	Hoorn - Grenco

NL-28 ECO 200

No further information or specification of technologies is given.

NL-29 Onion at Broer in Creil

No further information or specification of technologies is given.

10.2 Integrated heat pump technologies

A very important part of the market is where suppliers of turnkey unit operations integrate heat pumping technologies into their product to make these more energy efficient. GEA-Grenco is one of the best examples where they have there drying processes almost always equipped with MVR type of heat pumps [Westergaard]. Sulzer Chemtec from Winterthur does the same for their distillation columns.

Smaller companies in Netherlands not so prominent in the market do the same. Examples are Reinders Droogtech, applying heat pumping technologies integrated in many of their dryers and Rhima integrate heat pumps in their crate wash units.

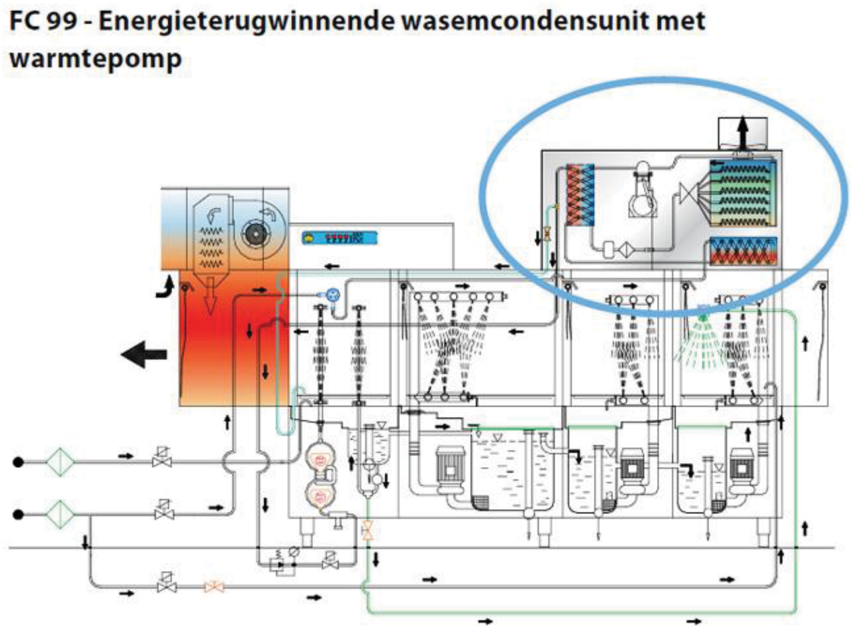


Figure 10-3: *Rhima crate washer*

Due to competative markets details of the two applications are not given. Information at:

www.droogtech.nl (Reinders Industrial; Plesmanweg 17; 7602 PD Almelo)

www.rhima.nl (RHIMA Nederland; Energieweg 4-6; 3762ET Soest)

10.3 What happened with projects on older factsheets?

This is to inform about some older projects that were published on factsheet in de mid nineties.

10.3.1 Efficient cooling system with heat recovery for Tofu production[2]

At the Lin Tahoe plant, tofu is produced by allowing soya bean milk to curdle at a temperature of 95°C. The process takes place in open vessels, which are checked visually. During the curdling process, a considerable amount of water vapor is released, which tends to condense inside the production hall. After the curdling, the product is pressed into blocks and cooled, originally from about 60°C to 14°C by pouring cold water over it, and then to 5°C in a cold storage chamber.

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[2] CADDET Project no. NL-92-011

Stricter demands from the health authorities mean that the product now has to be cooled to 7°C in one single stage, and that condensate from the production hall can no longer come into contact with the product. To meet these demands, a new, energy-efficient cooling system has been installed. A heat pump prevents condensation forming on the factory walls on cold days.

The cooling installation in the main production line consists of two parallel cooling vessels containing circulating cold water, through which blocks of tofu are passed by a conveyor belt. It takes about three hours to cool the blocks from their production temperature of about 60°C to their maximum storage temperature of 7°C. The water in the vessels is kept at a temperature between 2°C and 4°C by cold glycol flowing through the double wall of the steel cooling vessels.

The glycol in turn is cooled in an external cooling unit to a temperature of -2°C. In the cold season, the heat from the condenser of this cooler is used to heat the ventilation air of the factory hall. Apart from the improvement in the indoor climate of the factory, the enhanced temperature prevents the condensation of evaporated water. This condensate could otherwise make contact with the product and cause contamination.

The total investment for this project was USD 200,000 (1992), of which 60% is attributed to the new cooling system. Compared to the previous situation, the cooler saves 140 MWh/year and the heat pump 235 MWh/year. At an electricity price of USD 0.1/kWh, the investment resulted in a payback period of 5.5 years.

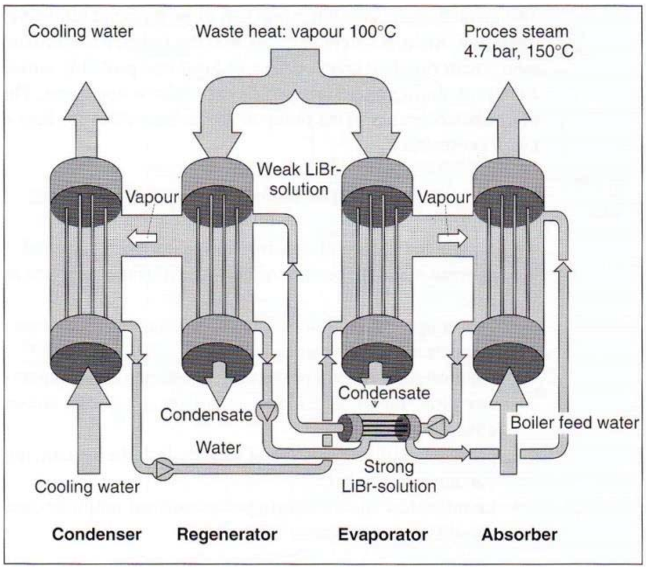
The heat pump was installed in 1991. The Lin Tahoe plant has since then been sold to Alpro Soja which in the end stopped production at the site.

10.3.2 Absorption Heat Pump, Type II Heat transformer in the chemical industry

The heat transformer was in operation with Dealmine in Delfzijl in an ethylene amine plant. It produced 11 tonnes of saturated steam at 145 °C and 4.6 bar at full load, and used saturated steam at 100°C to drive the system. The measured heating capacity was 6.7 MW at 11 tonnes of steam per hour, whilst 13.7 MW of waste heat was needed to drive the unit. The measured COP of was 0.49. The total power needed for circulating pumps etc. is 53 kW (less than 1 % of the output). At the time the system was installed (1985) the payback period was two years.

Prior to filling the system, the equipment was cleaned and tested for air leakage. Chromate-hydroxide was used as inhibitor in the LiBr circuit. The equipment operated for six months without problems, before interruptions occurred due to corrosion. Corrosion was first noticed in the heat-recovery heat exchanger, circulation pumps and steel tubes. Later, corrosion problems developed in the other heat exchangers. Due to the corrosion, performance and heat output decreased. The lower output was due to clogging of passages by corrosion products.

The heat-recovery heat exchanger is of the plate type, with titanium plates and ethylene propylene diene methylene gaskets. In the heat exchanger, crack corrosion occurred in the structure housing the gasket.



When the leakage became too great, a new heat exchanger with Ti/Pd plates was installed. That heat exchanger corroded after only a few hours of operation, due to flow-induced vibration causing stress corrosion. A new heat exchanger with Ti plates and safeguards to eliminate the plate vibration was later installed. During operation, clogging of the heat exchanger occurred due to the settling of corrosion particles. To reduce the extent of corrosion particles in the system, two filters have been installed. However, corrosion and fouling continue, and plates have to be replaced twice a year. The principal corrosion type is deposit attack. This causes the plate material to become brittle locally, and extremely sensitive to cracking.

In the evaporator, after seven months of operation, four stainless steel tubes were found to be leaking, and other tubes had suffered from pit corrosion. A new evaporator equipped with Ti tubes and CuNi-clad inner shell was then installed to tackle the problem. Inspection of the absorber showed that all unalloyed steel parts which were in contact with LiBr were covered with crusty corrosion products. Carbon steel parts, such as the shell, had suffered from galvanic effects. The absorber was again replaced, and carbon steel piping, which was in direct contact with the LiBr solution, was replaced with CuNi.

The canned weak solution pump had to be replaced after five months of operation. Stainless steel parts such as the inducer had broken, and the adjustment ring had cracked. The inducer had probably suffered from cavitation during operation, which led to stress corrosion. The same type of corrosion occurs in the pump as in the heat-recovery heat exchanger, i.e. deposit attack.

The heat transformer at the Hoogovens site was the second one installed in the Netherlands. The first one, at Delamine Delfzijl is definitively taken out of operation due to serious internal corrosion problems caused by the LiBr-solution and air-leakage. This corrosion phenomenon was studied extensively under a European project and has led to the following measures adapted in the Hoogovens design:

- minimize number of materials; exclusively CuNi, carbon steel and, for the plate heat exchanger, titanium are used.
- regular testing for high air tightness.
- flange connections are avoided to a maximum.
- continuous measuring of the oxygen content in the condensate (may not exceed 5 ppb).
- regular control of the composition of the working fluid and corrosion inhibitors
- continuous measuring of corrosion rates

- continuous filtering of LiBr-solution and condensate
- only N2 is permitted to fill up the vacumized part of the installation.

The heat transformer consists of four vertical shell and tube heat exchangers which are open connected in pairs (evaporator + absorber, regenerator + condenser). A rich LiBr-solution (63%) is mixed with water vapor in the absorber. The released heat is used to produce steam (2.7 bar, 130 °C) from boiling feed water (110 °C). The water vapor used in the absorber is produced in the evaporator at a pressure of 0.05 bar with waste heat of 90 °C. The lean LiBr-solution (60%) from the absorber is sent to the regenerator at a pressure of 0.5 bar to create a rich solution by evaporating water with waste heat of 90 °C. The rich LiBr-solution is directed to the absorber. The water vapor is condensed in a fourth heat exchanger with cooling water and pumped back to the evaporator. As well as the four large shell and tube heat exchangers, a compact plate heat exchanger is used to exchange heat between the rich and lean solution. The efficiency of the heat transformer is determined by the temperatures of cooling water, waste heat and steam.

At the Hoogovens site, large quantities of waste heat are released in the hot rolling strip mill. The furnaces are cooled with water of which the temperature is increased to 90 °C. Since 1991 the duty of this cooling water is no longer cooled in a cooling tower but is partly used in a heat transformer. Therefore transportation of cooling water takes place through pipelines to the heat transformer at 800 meters distance. The heat transformer cools the water from 90 down to 85 °C and produces steam at 130 °C and 2.7 bar. With 1,700 tonnes per hour waste water it is possible to generate 6.5 tonnes low pressure steam per hour. The saturated steam is superheated to 136 °C with middle pressure steam from the existing boiler and used in several processes at the cold rolling strip mill. The heat transformer is supplied by Rinheat OY from Finland. This company has great experience with this type of heat exchangers used for the heat transformer.

Economics: The heat transformer takes up 9 MW_{th} from the waste heat from the hot rolling strip mill. The produced steam is equal to 4.1 MW_{th}. The other part is cooled by cooling water (4.9 MW_{th}) of which the temperature increases from 20 to 26 °C. The power consumption of the several pumps is only 60 kW_e. The energy savings are 4.8 million m^3 natural gas when assuming an annual operation time of 8,000 hours.

The total investment was approximately 3.4 million €, of which 60% was spent on the heat transformer. The transportation system for 90 °C cooling water and adaptations in the existing steam system were 25 and 15 % respectively. The European Union and Novem have sponsored the project.

The heat transformer has only been in operation for several years as the high maintenance costs and the low availability and reliability made further operation in-economic. Due to process-changes where the temperature of the cooling water for the furnace was lowered, the heat transformer did not run optimally.

10.4 Literature

Westergaard — Milk Powder Technology, Evaporation and Spray Drying, ed. Vagn Westergaard, 5th Edition, GEA Process Engineering

Kleefkens, 1996 — Kleefkens O., Industrial Heat Pumps, MVR/TVR-systems in chemical industry, Dv3.4.39 96.11, ©Novem, Utrecht 1996.

APPENDIX

Japan

The Netherlands

1 A1 - Japan

1.1 Challenges and Necessary Support for Increasing the Use of Industrial Heat Pumps

1.1.1 Challenges for increasing use

Energy consumers in Japan can be roughly divided into three sectors: industrial, residential/commercial, and transport, which respectively consume about 44 %, 23 % and 33 % of the total energy (in FY2010). In terms of the increase rate of final energy consumption, the residential/commercial sector shows a much higher increase rate than that of the industrial and transport sectors. It is important to curb the consumption of the residential/commercial sector. However, the industrial sector still consumes most energy, which implies that the encouragement of energy efficiency technologies remains an important issue. About 90 % of the consumption of the industrial sector is the consumption by manufacturers, which mainly use energy for heating in production processes and their associated HVAC. Therefore, popular use of heat pumps by the industrial sector could be an extremely effective energy-saving measure in Japan. The sector is increasingly expected to introduce and encourage the use of heat pump systems.

The introduction of industrial heat pumps involves many challenges to be overcome. Technical challenges include higher system output temperature, lower heat source temperature, higher system capacity and efficiency, lower environmental load of refrigerants, and lubrication countermeasures. Social and economical challenges include lower system price, generalization/standardization, diversification of heat sources, public communication, and development/relaxation of laws and regulations. Particularly, price is very likely to be against performance. Appropriate planning of measures for developing and introducing industrial heat pumps with balanced price and performance is also important. For example, hot-water supply CO_2 heat pumps have been subsidized for installation in the residential/commercial sector. Thanks to the government subsidy, 3 million units were shipped in the decade from 2001.

In Japan, the introduction of industrial heat pumps has just begun mainly as a substitute for existing small once-through boiler systems. This means that these heat pumps are used for the production of high-temperature hot water or steam. To reach a stage in which new heat pump systems are designed and introduced, not as a replacement of existing boiler systems, public support, particularly by the government for research & development (R&D), commercialization and initial introduction, may be a key factor for wide spread use of the systems.

1.1.2 Current government support programs

R&D of heat pump technology is an important key factor for energy conservation in the residential/commercial, transport and industrial sectors including plant HVAC, humidification and drying applications. R&D in Japan has been positively supported by the government, particularly the Ministry of Economy, Trade and Industry (METI) and New Energy and Industrial Technology Development Organization (NEDO). For example, NEDO has specified key energy efficiency technologies to be intensively addressed (Figure 1-1), and annually subsidized about 10 billion yen for R&D of the technologies. Among these, next-generation heat pump systems were selected as a "cross-sector key technology" to be widely used because it increasingly found more applications in all of the industrial, residential/commercial and transport sectors.

Specific R&D challenges for the next-generation heat pump system include developing a high-efficiency refrigeration cycle, a new refrigerant, and innovative fundamental technologies related to high-efficiency heat exchangers and compressors. In addition, unused heat utilization, high-efficiency heat recovery/storage (simultaneous production of heating and cooling), expansion power recovery, light-load efficiency optimization, CFC-free refrigeration/air-conditioning systems, and other various system-related technologies including securing of heat sources and secondary circuit control methods, have been selected as R&D themes.

To achieve the prime target of enhancing the heat pump system efficiency to 1.5 times the current level in 2030 and double in 2050 (*1), a national project aimed at developing a super-high-efficiency heat pump is being separately promoted. As technologies for successful development, use of various types of unused heat, annual efficiency enhancement according to actual loads, maximizing the use of generated heat, and efficient production of high-temperature water/ steam or air were selected, and about 800 million yen was spent for the R&D subsidy in the year (FY2012). Furthermore, a high-temperature heat pump that uses exhaust heat or simultaneously produces high-temperature steam and low-temperature water as a substitute for existing boilers in factories was selected as a specific technical development theme, and is waiting to receive a subsidy. (*1. According to the Technology Development Road Map of "Cool Earth Innovative Energy Technology Program", industrial heat pumps producing 120℃ high-temperature heat should be targeted to achieve higher efficiency by 1.3 times the current level, and those producing 180℃ high-temperature heat targeted to exceed the efficiency of existing heating systems (such as boiler systems)).

One example of subsidy programs for introduction of heat pumps is the "Urgent project for promoting the introduction of next-generation heat utilization systems" (total budget 15.5 billion yen) by METI between 2012 and 2013. This project supports plants and facilities to introduce a next-generation heat utilization system to recover and re-use low-temperature waste heat at 300 °C or less released to the atmosphere from their running equipment. For example, low-temperature exhaust heat-driven absorption refrigerating machines and steam generating heat pumps are covered. The subsidy rate is up to a half of the applicable expense for recovery of waste gas/ steam at less than 140 °C, or up to one third of the same between 140 °C and 300 °C. The subsidy is expected to expand system demand by private companies and to make the system available at a lower price from mass production, leading to further demand expansion.

For Japan, with only limited fossil fuel resources, increasing the use of renewable energy is also an urgent matter. The country is promoting the development of a heat pump system utilizing unused thermal energy. In recent years, the government launched a subsidy program and conducted legal reform to encourage the development of heat pump systems using geothermal or sewage heat as a heat source. Sewers are expected to also serve as thermal ducts that crisscross all cities. While the residential/commercial sector mostly needs cold water supply during summer and hot water supply during winter, industrial processes require cold and hot water supply at a relatively constant balance throughout the year, which however depends on the type of process. Using sewage heat for industrial processes could help moderate the sewage temperature variation. Thus, expectation for industrial heat pump systems using sewage is gaining ground.

For example, the Ministry of Land, Infrastructure and Transport established the Act on Special Measures concerning Urban Reconstruction (which came into operation on July 25, 2011) to permit the use of sewage heat by private operators. The Ministry also launched the Water Environment Creation Project under the New Generation Sewage Support System and Next Generation Urban Improvement Projects to promote the introduction of heat pump systems using sewage heat, and the Town Making Subsidy to promote the introduction of regional cooling and heating facilities. The Ministry of the Environment conducted the Cool City Promotion Project [Underground Water and Ground Source Utilization] (2009), and Ground Source/Sewage Heat Pump HVAC Demonstration Test (from 2010) to promote the use of renewable energy with heat pumps, which was also expected to serve as heat island countermeasures. One example is a food product plant (Hokkaido) where a simultaneous cold (2℃) and hot (65℃) water-producing heat pump recovering geothermal heat as well as exhaust heat from refrigerators and septic tanks, was installed to supply cold water for vegetable washing, and hot water as a low-quality water supply for plant cleaning.

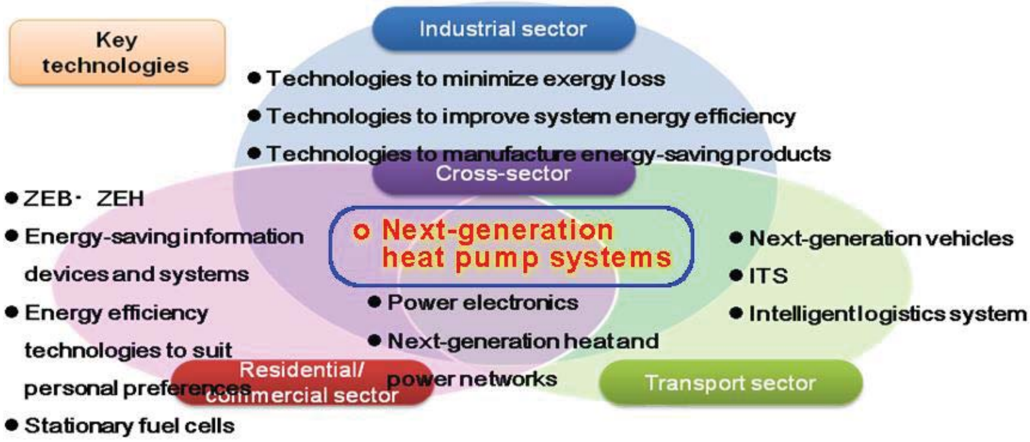


Figure 1-1: Thirteen “Key technologies” in “2011 Strategy for Energy Efficiency Technologies”

1 Appendix A2 - Japan

The tables below show a list of recent installations of industrial heat pumps. Shaded cases are detailed in the following sections.

Industry	Plant	Process	Heat use	Application	Purpose	Installed in	System overview	Effect
Food	Nakashibetsu Plant, Meg Milk Snow Brand Co., Ltd.	Cheese production	Thermal storage	Milk sterilization at 75 °C Quick milk cooling at 30 °C Cheese cooling (HVAC) at 10 °C	Strict temperature control for cheese production Power load levelling and higher-efficiency management through introduction of thermal storage systems	2007	Turbo refrigerator 1,395 kW (for ice making): 2 units Water-cooled chiller 240 kW: 2 units Ice storage tank 84 m^3	Daytime power use of approx. 3,700 kWh per day was shifted to night-time use to achieve power levelling. Utility contract power was reduced by 600 kW (approx. 2,600 kW -> approx. 2,000 kW)
Food	Sanda Plant, Cosmos Foods Company	Freeze-dried food product manufacturin g	Steam reduction	Food boiling Production line cleaning: hot water at 85 °C Building HVAC: cold water at 10 °C	Installation of 90 °C water producing equipment Hot/cold water supply to HVAC and processing lines from simultaneous hot/cold water producing heat pumps	2010	・Simultaneous hot/cold water producing heat pump (water source heat pump (WSHP) with CO_2 refrigerant): 3 units Heating capacity 92 kW (90 °C) Cooling capacity 69 kW (10 °C) ・Hot water tank 37.5 m^3 ・Chilled water tank 500 m^3	Hot water supply for food processing and plant HVAC were simultaneously achieved to reduce both CO_2 emissions and energy cost by 80 % or more.

Examples of Recent Industrial Heat Pump Installation

Industry	Plant	Process	Heat use	Application	Purpose	Installed in	System overview	Effect
Food	Tamura Noodle-Making Corporation	Noodle production	Thermal storage	90 °C hot water supply for preheating the noodle boiling pool (98 °C) Boiled noodle cooling: cold brine (-5 °C) for cooling ice storage tanks that supply cold water at 2 °C	Hot/cold water supply to noodle production processes CO_2 emissions reduction and energy cost-cutting with heat pumps	2008	・Simultaneous hot/cold water supply heat pump (WSHP with CO_2 refrigerant): 1 unit Heating capacity 56 kW (90 °C) Cooling capacity 38.2 kW (-2 °C) ・Hot water tank 15 m^3 ・Ice storage tank 4.1 m^3	・Heavy oil consumption was reduced by 70 %. ・CO_2 emissions were reduced by 31 %. ・Energy cost was reduced by 25 %.
Food	Plant in Shikoku Island	Noodle production	Steam reduction, Waste heat recovery	Hot water supply (83 °C) to noodle boiling pools (98 °C) and cold water supply (10 °C) to noodle cooling pools (3° C)	Hot/cold water supply to noodle production processes, CO_2 emissions reduction and energy cost-cutting with heat pumps	2008	・Simultaneous hot/cold water producing heat pump (WSHP with CO_2 refrigerant): 1 unit, Heating capacity 72 kW (90 °C), Cooling capacity 50 kW (5 °C) ・Hot water tank 24 m^3	・Primary energy consumption was reduced by 19 %. ・CO_2 emissions were reduced by 43 %.

Examples of Recent Industrial Heat Pump Installation

Industry	Plant	Process	Heat use	Application	Purpose	Installed in	System overview	Effect
Food	Osumi Plant, Kagoshima Kumiai Chicken Foods Co., Ltd.	Chicken product manufacturing	Steam reduction	Heating the hot water supply to steam boilers: 65 °C	Effective heating of high-volume water supply To eliminate dependence on steam boilers, and reduce the environmental load by introducing heat pump water heaters	2008	・Air source heat pump (ASHP) with CO_2 refrigerant: 1 unit Heating capacity 80 kW (65°C) ・Hot water tank 10 m^3	・CO_2 emissions were reduced by 65 %. ・Energy cost was reduced by 88 %.
Plant factory	Yasaikobo Co., Ltd.	Lettuce growing	Thermal storage	Plant factory HVAC (dry-bulb temperature 20-24 °C, relative humidity 60±10 %)	To install highly temperature/humidity controllable heat pumps to maintain the environment in the plant factory in a constant state.	2008	ASHP (cooling capacity 28 kW): 4 units	・Stable production ・High quality product ・Maintenance-free
Beverage	Kyushu Nitta Plant, Sapporo Breweries Ltd.	Beer production	Waste heat recovery	Hot water supply for cleaning and sterilizing tanks/ovens (70 °C) Cooling the heat by fermentation (-5 °C)	To recover heat by fermentation of beer, which has been wasted, produce hot water, and use it for cleaning and sterilization of tanks and ovens	2009 to 2010	Waste heat recovery heat pump 35 kW: 4 units Hot water supply capacity (70 °C): 111.6 kW Cooling capacity (-5°C): 81.6 kW	・Annual hot water supply energy was reduced by 18 %. ・Annual cooling energy was reduced by 14 %.
Beverage	Chita Distillery, Sungrain Ltd.	Whisky and material alcohol production	Steam reduction Waste heat recovery	Vapor re-compression	Energy-saving through re-compression, and reuse of vapor from alcohol distillation facilities	2002	Combined VRC system (mechanical and thermal vapor re-compression, vapor flow rate: approx. 4 t/h)	・Primary energy consumption was reduced by 43 %.

Examples of Recent Industrial Heat Pump Installation

Industry	Plant	Process	Heat use	Application	Purpose	Installed in	System overview	Effect
Paper making	Iwabuchi Facility of Tokai Mill, Oji Specialty Paper Co., Ltd.	Paper manufacturing by recycling broke	Thermal storage	Hot water supply to water tanks for supplying hot water to broke pulpers: 75 °C	Hot water supply to broke recycling process Reduction of waste vapor by supplying hot water from heat pump water heaters	2009	・ASHP with CO_2 refrigerant: 8 units Heating capacity 40 kW (75 °C) ・Hot water tank 25 m^3	・CO_2 emissions were reduced by 50 %. ・Primary energy consumption was reduced by 42 %.

Examples of Recent Industrial Heat Pump Installation

Industry	Plant	Process	Heat use	Application	Purpose	Installed in	System overview	Effect
Chemical	Saiden Chemical Industry Co., Ltd.	Adhesive production	Thermal storage	Cold water supply to reaction ovens: 9 °C	Stable supply of cooling water to reaction ovens To enjoy various benefits including CO_2 emissions reduction by introducing a chilled water storage system.	2005	・ASHP modules: 1 set Cooling capacity 800 kW ・Hot water tank 1,000 m^3	・CO_2 emissions were reduced by 50 %. ・Primary energy consumption was reduced by 32 %.
Plastic	Diachemical Co., Ltd.	Styrofoam molding production	Steam reduction Waste heat recovery	Hot air: 90 °C Cooling of hot effluent (70 to 80 °C)	Hot air supply at up to 120 °C To apply a hot air heat pump to drying process To contribute to lower CO_2 emissions and higher safety	2010	Hot air WSHP with CO_2 refrigerant: 1 unit Heating capacity 110 kW (90 °C) Operating range Hot air outlet temperature: 80 to 120 °C Heat source water outlet temperature: -9 to 35°C	・CO_2 emissions were reduced by 63 %. ・Primary energy consumption was reduced by 48 %.
Glass	Osaka Facility of Kansai Plant, Asahi Glass Co., Ltd.	High-quality glass production	Clean rooms	Hot and cold (7 °C) water supply for clean room HVAC	To improve the environmental performance and cost efficiency	2007	Turbo refrigerator (for cooling only): 2 units Turbo refrigerator (double bundle, hot/cold water supply): 1 unit	・CO_2 emissions were reduced by 26 %. ・Primary energy consumption was reduced by 16 %. ・Energy cost was reduced by 18 %.

Examples of Recent Industrial Heat Pump Installation

Industry	Plant	Process	Heat use	Application	Purpose	Installed in	System overview	Effect
Pharma-ceutical	Tsukuba Research Laboratories, Eisai Co., Ltd.	R&D of new drugs	Steam reduction Thermal storage Waste heat recovery Clean rooms	Hot water supply to reheating coils of HVAC using outside air equipped with evaporative humidifier: 30 °C	To replace steam humidification with evaporative humidification Use steamless air-conditioners to achieve energy-saving and cost reduction by breaking the "common sense for HVAC" in the pharmaceutical industry.	2008	・Steamless HVAC (using outside air), capacity 33,000 m^3/h: 2 units ・Small water source heat pump unit and others	・CO_2 emissions were reduced by 77 %. ・Energy cost was reduced by 82 %.
Pharma-ceutical	Daito	Pharmaceutical production	Clean rooms	Cold water supply for clean room HVAC (dry-bulb temperature 20 °C, relative humidity 50 %)	HVAC, production process temperature and humidity control To meet various applications and needs with modular heat pumps	2008	Modular ASHP Cooling 380 kW: 1 set Cooling 635 kW: 1 set Cooling 715 kW: 1 set	・CO_2 emissions were reduced by 67 %. ・Primary energy consumption was reduced by 53 %.

Examples of Recent Industrial Heat Pump Installation

Industry	Plant	Process	Heat use	Application	Purpose	Installed in	System overview	Effect
Pharma-ceutical	Tokushima Itano Plant, Otsuka Pharmaceutical Co., Ltd.	Pharmaceutical production	Waste heat recovery Clean rooms	Hot (45 °C) and cold (7 °C) water supply for clean room HVAC (room temperature 23 °C, relative humidity 40-60 % or low humidity 25-40 %)	Hot/cold water supply for clean room HVAC To realize advanced air rooms and energy- saving in the pharmaceutical plant using a simultaneous hot/cold water producing heat pump	2009	Simultaneous hot/cold water producing heat pump: 1 unit Hot 247 kW (45 °C) Cold 180 kW (7 °C)	Heavy oil consumption was reduced. ・CO_2 emissions were reduced by 24 %. ・Primary energy consumption was reduced by 24 %.
Mecha-nical	Fujinomiya Plant, Amada Co., Ltd.	Metalworking machinery production	Thermal storage	Cooling water supply (25 °C) to laser oscillators for laser machine operating test	To supply cooling water to laser machines To substantially reduce CO_2 emissions and primary energy consumption with turbo refrigerating machines and chilled water storage system	2007	Turbo refrigerator Cooling capacity 563 kW: 2 units	・CO_2 emissions were reduced by 81 %. ・Primary energy consumption was reduced by 68 %.
Mechanical	Togane Technical Center, Takubo Engineering Co., Ltd.	Coating machine production	Steam reduction Waste heat recovery	Simultaneous supply of hot/cold water to HVAC using outside air equipped with evaporative humidifier	To achieve higher air quality, CO_2 emissions reduction, cost- cutting and higher safety by making coating booths steamless	Unknown	Connected three ASHP modules (total cooling capacity 255 kW), Evaporative humidifier: 1 unit	・CO_2 emissions were reduced by 45 %. ・Primary energy consumption was reduced by 31 %.

Examples of Recent Industrial Heat Pump Installation

Industry	Plant	Process	Heat use	Application	Purpose	Installed in	System overview	Effect
Electric	Kami Plant, Terasaki Electric Co., Ltd	Circuit breaker production	Thermal storage	Hot water supply (65 °C) for heating plating baths (max. temperature 50 °C) and water baths (60 °C)	Heating of plating baths and hot water supply to water baths Lower energy consumption and lower maintenance by introducing heat pump water heaters	2009	・ASHP water heaters: 2 units Heating capacity 55.8 kW (65 °C) ・Hot water tank 4 m^3, 12 m^3	The use of the heat pump water heaters improved energy-saving and cost performance. ・CO_2 emissions were reduced by 19 %. ・Energy cost was reduced by 11 %.
Electric	Minami Electric Co., Ltd.	Transformer case production	Waste heat recovery	Hot air supply to drying process of high-durability coated transformers (80 to 120 °C) Cold water supply to electropainting process (5 to 32 °C)	Preheating (120 °C) of gas drying tower (170 °C)	2009	Hot air WSHP with CO_2 refrigerant: 1 unit Heating capacity 110 kW Operating range Hot air outlet temperature: 80 to 120 °C Heat source water outlet temperature: 5 to 32 °C	・CO_2 emissions were reduced by 19%. ・LPG consumption was reduced by 24 %. ・Energy cost was reduced by 12 %. ・Cold water can be recycled.
Automobile	Hamura Plant, Hino Motors, Ltd.	Production of trucks, buses, cars and other automobiles	Steam reduction	Hot/cold water supply for plant HVAC Heating of washing tanks	To raise the plant HVAC heat source efficiency To reduce environmental load and cost by replacing existing steam equipment with heat pumps	2007 and 2009	2007 ASHP Cold 90 kW: 5 units Cold 85 kW: 10 units 2009 ASHP Cold 95 kW: 6 units	The change of heat source brought a synergistic effect of lower steam demand and lower steam loss. ・CO_2 emissions were reduced by 30 %. ・Primary energy consumption was reduced by 32 %.

Examples of Recent Industrial Heat Pump Installation

Industry	Plant	Process	Heat use	Application	Purpose	Installed in	System overview	Effect
Automobile	Hamura Plant, Hino Motors, Ltd.	Production of trucks, buses, cars and other automobiles	Steam reduction Waste heat recovery	Simultaneous supply of hot/cold water to coating booth circulating HVAC	Energy-saving by simultaneous supply of hot/cold water	2010	Heat recovery heat pump (cooling capacity 456 kW, heating capacity 566 kW): 1 unit	・CO_2 emissions were reduced by 47 %. ・Energy cost was reduced by 63 %.
Automobile	Kameyama Plant, Koyo Heat Treatment Co., Ltd.	Production of automobile parts including bearings and steering	Steam reduction	Vapor re-compression	To reduce environmental load of effluent To reduce CO_2 emissions and improve environmental conservation by introducing heat pump vacuum evaporator	2005	Heat pump vacuum evaporator: 1 unit Evaporation capacity 300 kg/h	The treatment of water recyclable in the plant resulted in lower CO_2 emissions and better environmental conservation. ・CO_2 emissions were reduced by 79 %. ・Primary energy consumption was reduced by 77 %.
Automobile	Suzuka Factory, Honda Motor Co., Ltd.	Automobile production	Waste heat recovery	Plant HVAC	To replace deteriorated gas burning refrigerators with high-efficiency equipment	Unknown	High-efficiency turbo refrigerator, Cooling capacity 3,252 kW Heating capacity 3,755 W Hot/cold water tank	・CO_2 emissions were reduced by 48 %. ・Energy cost was reduced by 25 %.

Examples of Recent Industrial Heat Pump Installation

Industry	Plant	Process	Heat use	Application	Purpose	Installed in	System overview	Effect
Automobile	Gamagori Plant, Aisin AW Co., Ltd.	Automobile part production	Steam reduction Waste heat recovery	Heating of washing liquid in the washing process (65 °C) Cooling of cutting liquid in the cutting process (15 °C)	・To eliminate low energy-efficiency steam use for heating of washing liquid ・To use waste heat for cooling of cutting liquid	2010	・Circulating ASHP (Heating only type, heating capacity 43.5 kW): 8 units ・Waste heat recovery circulating heat pump (Cooling/heating type, heating capacity 22.3 kW): 6 units	・CO_2 emissions were reduced by 86 %. ・Primary energy consumption was reduced by 73 %. ・Energy cost was reduced by 89 %.
Electronics	Aizu Wakamatsu Plant, Fujitsu Facilities Limited	Pure steam, cold water and other utility supply to semiconductor plants	Steam reduction Waste heat recovery Clean rooms	Hot water supply to pure water manufacturing plants, production process HVAC, and cold water supply to manufacturing equipment	Waste heat recovery from turbo refrigerators Lower environmental load through the use of high-efficiency turbo refrigerators and waste heat recovery	2004 to 2006	Turbo refrigerator (heat recovery type): 3 units Cold: 4,219 kW/unit	Existing turbo refrigerators were replaced with the latest model. CO_2 emissions were reduced by 33 %. Primary energy consumption was reduced by 31 %.
Electronics	Chiba Plant, Showa Denko K.K.	Production of small hard disk media	Thermal storage Waste heat recovery Clean rooms	Cold water supply to clean room HVAC, and recirculation of waste heat hot water to pure water production facilities	High-performance HVAC for precision instrument production sites To use an ice storage system for clean room HVAC Energy-saving and cost reduction	2006 to 2007	Turbo refrigerator 3,516 kW: 3 units Ice storage tank 237 m^3	The ice storage system achieved HVAC with high cost efficiency and reliability.

Examples of Recent Industrial Heat Pump Installation

Industry	Plant	Process	Heat use	Application	Purpose	Installed in	System overview	Effect
Electronics	Yokkaichi Plant, Toshiba Semiconductor & Storage Products Company	Semiconductor memory production	Steam reduction Waste heat recovery Clean rooms	Cold water supply to fan coil units in clean rooms, and hot/cold water supply to clean room HVAC using outside air	Waste heat recycling in the plant To recover waste heat released from HVAC and production processes to substantially reduce CO_2 emissions and achieve a steamless HVAC system	2005	Turbo refrigerator	All waste heat within the plant can be effectively used. Steamless HVAC was achieved.
Electronics	Ise Factory, Panasonic Corporation	Control equipment assembly	Clean rooms	Clean room HVAC	To raise clean room HVAC efficiency To improve environmental conservation and energy-saving with high-efficiency heat pumps	2009	ASHP Cold 950 kW: 2 sets	CO_2 emissions were reduced by 59 %. Primary energy consumption was reduced by 31%.

Examples of Recent Industrial Heat Pump Installation

Industry	Plant	Process	Heat use	Application	Purpose	Installed in	System overview	Effect
Printing	Nikkei Tokyo Newspaper Printing Center, Inc., and Nikkei Kawasaki Annex, Inc., Nikkei Inc.	Newspaper printing	Thermal storage Waste heat recovery	Hot/cold water supply to HVAC systems for newspaper printing plants	To supply hot/cold water to HVAC systems for newspaper printing plants To achieve strict temperature and humidity control, CO_2 emissions reduction and energy- saving with thermal storage systems	2006	・Brine turbo refrigerator: 2 units Cold: 762 kW/unit (for ice making) ・ASHP (simultaneous hot/cold water producing): 1 unit Cold: 315 kW Hot: 355 kW ・ASHP （hot/cold water selectable): 1 unit Cold: 355 kW Hot: 425 kW ・Ice storage tank 135 m^3 ・Hot water tank 175 m^3	The two load peaks per day were leveled out to achieve CO_2 emissions reduction and energy-saving.

Source:

1. "Examples of heat pump installation in the industrial sector", Heat Pump & Thermal Storage Technology Center of Japan, Japan Electro-Heat Center

2. "Recommended Electric-Powered Production Processes, Future Ages, Use More Electricity for Production", Japan Electro-Heat Center, 2010

3. 'Possibility of energy-saving and carbon dioxide emissions reduction with vapor re-compression system -Ethanol distillation cases-', Maekawa Mfg. Co., Ltd., "Electro-Heat" No.155, 2007,

4. “LOWER CO_2 IN INDUSTRIAL PRODUCTION PROCESSES THROUGH THE ADOPTION OF HEAT PUMPS”, YUKIYASU DAIMON etc., 10th IEA Heat Pump Conference 2011, 16 - 19 May 2011, Tokyo, Japan

A 2

Factsheets on industrial heat pumps in Netherlands

NL-01 MVR System at Shell PP-splitter in Pernis

Summary

Propylene is a key material in the production of a number of chemical products including polypropylene (PP) and solvents. It is obtained by distillation separation of propylene and propane in a so called PP-splitter column. In a conventional distillation the reboiler is heated by low pressure steam or hot condensate and the overhead vapours are cooled with cooling water.

In 1995 as a part of the modernization of the whole propylene distribution system within the Shell site at Pernis, a new propylene-propane distillation column was built with the application of mechanical vapour recompression (MVR), built by Mannesmann Demag AG. This was done to save energy, reduce the use of cooling water and increase the yield of the distillation

Project summary/information

Company	Shell
Location	Pernis, Netherlands
Process application	Distillation in PP-splitter
Type of heat pump	MVR
Capacity	5.8 MW
Running hours	8650/year
Year of operation	October 1995
Primary energy savings	1,2 PJ/year
Reduction in CO_2 emission	67 kton/year
Maintenance costs	
Manufacturer/supplier	Mannesmann DEMAG AG
Pay back	2 years

Process description

Propylene is a key ingredient in a number of chemical products, including polypropylene and solvents. It is produced by the distillative separation of propylene and propane in a so called PP-splitter column. The splitter became into operation in October 1995 and produces polymer grade propylene with a purity of 99.5%. In a conventional distillation the reboiler is heated with low pressure steam or hot condensate and the overhead vapours are cooled with water.

With the application of MVR on the distillation column the overhead top vapours are used to heat the column at the bottom. In the MVR an electrically driven two stage fixed speed compressor, manufactured by Mannesmann DEMAG AG, increases the pressure of the top vapours which are then condensed in a condenser/reboiler with UOP Hi-flux double enhanced tubes to heat the bottom stream from the PP-splitter. The main part of the condensed overhead vapours is returned to the column as reflux, the remainder providing feed stock to downstream chemical plants.

Because the column can operate independently from a cooling fluid the temperature can be reduced and thus the column pressure can be reduced giving a better split between propylene and propane, increasing the relative volatility. The operating pressure is one of the primary process variables in optimizing the design for the separation of propylene and propane by distillation. The volatility ratio is significantly greater at pressures in the range of 3 – 10 bars, compared to the traditional values at 15 – 20 bars. The use of lower pressure prevents the use of cooling water and this problem is solved by using MVR. Because the column can operate independently of a cooling fluid, the column pressure can be reduced resulting in a better split between propylene and propane by the increase of relative volatility. The splitter thus produces polymer grade propylene with a purity of min. 99.5 wt %.

High reliability of the system has been achieved by the advanced process control system developed by Shell (Shell Multivariable Optimization Control). The SMOC process control system adjusts several parameters periodically. It sets the variables at given targets, taking into account the steady state and dynamic interactions between the variables.

Starting up procedure is initiated by purging with nitrogen and brought up to operational pressure by feeding in with propylene vapour generated in the de-ethanizer column from propylene storage.

Energy savings

Energy Heat pump drive energy (kWh/year):	50 400 MWh/year
Fuel:	Electricity
Energy output, useful heating (kWh/year):	401 600 MWh/year
Energy output, useful cooling (kWh/year):	352 000 MWh/year
Energy cost (EUR/kWh):	136 EUR/kW demand charge

The net yearly energy savings thus are 1,2 PJ/year (equivalent to 37.8 Mill m^3 of gas per year) at an operating time of over 8650 hours per year. CO_2 emissions reduction of 67 kton/year. In this calculation electricity is generated at an efficiency of 40% by gas-fired power plants.

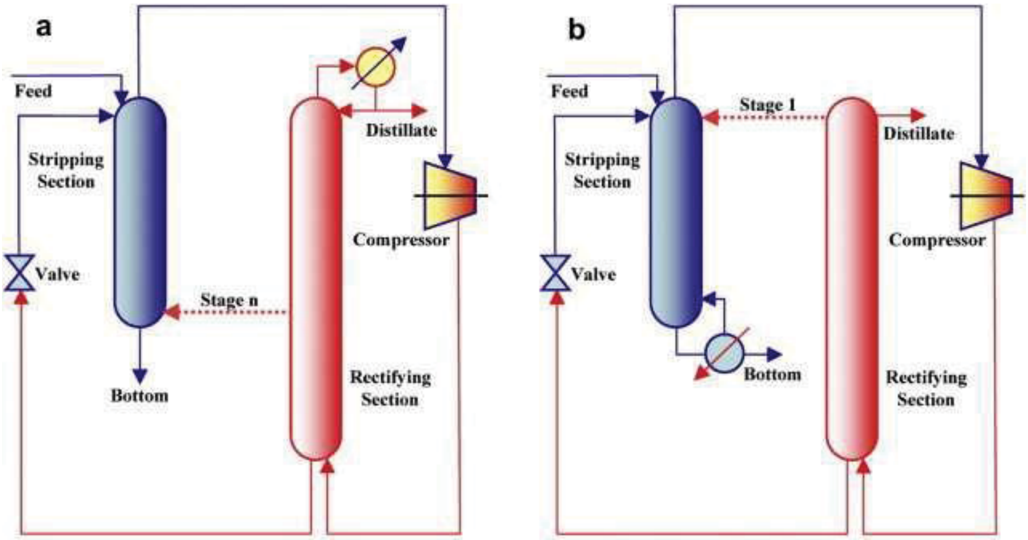
Operating experience

The heat pump as described is still running in line with the original design at 8650 hours per year at fixed speed. Maintenance is done by an external party as specific knowledge is required.

The system has a sophisticated level of automatic controls through the SMOC process control system. When it runs, it does not require much human effort to run. The start-up procedures are due to the process requirement rather complex but do seldom occur.

The energy conservation can be calculated if compared to another smaller PP-splitter at the same location which is run on hot condensate feed and top cooling water. This splitter needs 2.2 GJ per ton feedstock while the MVR-equipped splitter needs only 0.5 GJ per ton, being a savings of 77 %.

Maintenance problems have not occurred during the years of operation. The company has experienced the systems to have a very high reliability. Next to saving on heating, a considerable saving on cooling energy has been achieved, thus also reducing the use of surface water and disposing of waste heat on surface water.



NL-03 MVRR at Hoechst Chemical Vlissingen

Summary

Since 1982 three steam recompression systems have been in operation at the Hoechst production plant in Vlissingen. The heat pumps are a part of the process for the production of dimethyl-terephthalate (DMT). With the application of steam recompression, steam pressure is increased from 1.14 bara to 3 bara, which can be used in the low pressure steam system. The main goals for the application have been cost reduction and the possibility to work with a smaller steam production plant.

De produktie van de DMT-fabriek in Vlissingen-oost is sinds enkele maanden op een lager pitje gedraaid in verband met de teruglopende DMT-markt. DMT is een grondstof voor de chemische industrie.

Project summary/information

Company	Hoechst
Location	Vlissingen
Process application	production of dimethyl-terephthalate (DMT).
Type of heat pump	MVR
Capacity	
Running hours	
Year of operation	1982
Primary energy savings	
Reduction in CO_2 emission	
Maintenance costs	
Manufacturer/supplier	
Pay back	

Industry/process

The base chemical for the production of polyester is paraxylene ("PX"). Through an oxidation process, PX is transformed into pure terephthalic acid ("PTA") or dimethyl terephthalate ("DMT"), two forms of terephthalic acid. An amorphous polyester polymer ("APP") is then created by reacting either PTA or DMT with a di functional alcohol, most often mono-ethylene glycol ("MEG"). APP is used to generate a variety of end products, which can be segmented into six general categories:

- polyester packaging resin ("PPR")
- industrial fibres
- textile fibres
- non-wovens
- PET film
- engineering plastics.

DMT and PTA are terephthalates derived from PX. For nearly all end-uses, DMT and PTA are interchangeable. DMT is easier to recover and to purify but PTA needs lower capital and operating costs (less of raw material and by-product handling). Thus, DMT and PTA should be considered together in any relevant market assessment. Hoechst is active in the production of DMT only. Its share of the total terephthalate market (DMT and PTA taken together) was approximately [<10%]. Even if one would consider a separate market for DMT, the share of Hoechst of the 1997 Western European merchant market for DMT was only [between 10% and 20%]. In 1997 take over and cahnge to Invista and in 2007 end of production.

Description of the process: In the production of dimethyl-terephthalate (DMT) the first step is the oxidation of para-xylene C6H4(CH3)2 with air. The second step is the esterification of the oxidation product (paratoluic acid) with methanol, towards para-toluic acid, methyl ester. This intermediate is oxidised and esterified once again to the resulting DMT (second and third steps). To produce a product with a purity of 99.96%, the DMT is partly purified by distillation. The remaining impurities are removed by crystallisation. In the condenser of the methanol distillation column, steam is generated at 1.14 bara by condensation of the methanol reflux (15 tons/h, 106ºC, 4.2 bar). The generated steam is compressed to 3 bar in a two-stage centrifugal compressor (Linde GT040T2K1, 760 kWe) and supplied to the low pressure steam system. Interstage cooling between the two stages takes place and additional condensate is injected after the second stage of the compressor. A total of 7 tons/h of steam is delivered to the 3 bar steam system. The two-stage compressor is directly driven by a radial centripetal expansion turbine (Atlas Copco, ET410NS). Exhaust gases (19,000 Nm3/h) from the oxidation section of the DMT reactor (mainly N2 and CO2) are expanded from 5.5 bara to 1.25 bara. The outlet temperature is controlled by a by-pass over the expander. Besides this steam compression system, another system is in operation. Steam generated in two oxidators (4.2 and 3.9 bara) is compressed to 5 bara in two electric-driven centrifugal compressors (Atlas Copco GT026T1K, 131kWe and 132kWe). A total of 20 tons/h of steam is produced at 5 bara (=163ºC), which is delivered to the steam grid.

Energy savings

1 year 3 months. This is calculated roughly from the following: Steam driven system: investments EUR 295,000 with cost savings of approximately EUR 270,000 per year. The second system (two compressors): investment EUR 155,000 with cost savings of EUR 725,000 per year. These systems were newly built, so the investment costs are calculated on extra costs compared with traditional systems in a new plant.

CO_2 emissions reductions are 5.3 and 14.2 kton/year. These figures are calculated at assumed efficiencies for the steam boiler of 90 % and gas fuelled power generation of 52% and at a running time of 8,000 hours. Energy savings are for the steam driven heat pump calculated at 3 million m^3/year of gas equivalent and for the two electric driven systems at 8 million m^3/year.

Operational experience and other comments

The systems are considered as very reliable. Although heat pumps in general are seen as difficult and not very reliable, the heat pumps at Hoechst were not really recognized as such because maintenance costs are extremely low. There have been no operational problems. Extremely short payback times can be achieved by installing heat pumps at new-built plants from the beginning. Heat pumps should in the case of MVR systems be marketed as compressors, integrated in systems.

NL – 08 HT-Heat Pump at the Blue Band Factory in Rotterdam

Summary

The Blue Band factory from Unilever, at the Nassaukade in Rotterdam is over 120 years old and at the moment the world largest factory for margarine with an output of more than 200,000 tonnes of margarine and 10,000 tonnes of peanut butter. Over that period of 120 years many changes in building, expansion and machinery have been done and a large overhaul of the complete production and building has never been undertaken creating a complex situation. When in 2009 the boiler-room was going to be renovated the 40 years old steam boiler had to be replaced. Of the installed capacity more than 40 % was not used because the new production lines have a lower energy use. As production had to go on a new boiler-house was designed near the old existing one.

Project information

Company	Unilever
Location	Rotterdam; Netherlands
Process application	
Type of heat pump	Compression add on heat pump
Capacity	1400 kW
Running hours	5000
Year of operation	2011
Primary energy savings	
Reduction in CO_2 emission	1.600.000 kg
Maintenance costs	
Manufacturer/supplier	Grenco
Pay back	2 years

Project characteristics and process design of installed system

The production line for margarine and peanut butter uses various heat and cold streams for the process:

- Hot water at several temperature levels
- Steam
- Warm water for space heating
- Ice water
- Freezing from an ammonia system at -23°C

All of the hot water and steam is generated by the old steam boiler on which the heat demanding processes run independent from each other and can run on partial load. The complete energy demand of the existing factory has been mapped and simulation and pinch models were used to design the new heat generating process. The basic thought is to make the plant as energy friendly as possible and robust for the next decade with a focus to use as much waste heat when occurring as possible. The heat demand could be split into low temperature heat (< 70°C) and high temperature heat (> 90°C).

For the low temperature heat the condenser heat from the NH3 chiller is used in a Grenco add-on heat pump to generate temperatures up to 80°C.

This construction is called an add on heat pump. It is a mechanical heat pump that uses the refrigerant of an existing refrigeration system, in this case Ammonia. With the use of an add on heat pump the pressure of the gaseous Ammonia is increased. This causes the refrigerant to condensate at a higher temperature. In this case the add on heat pump is used to heat a water circuit up to 65 °C. Application of a heat pump enables several processes to benefit from the waste heat of the refrigeration system. Therefore energy savings can be realized as well as a reduction in CO_2 emission.

In this project a COP (coefficient of performance) of 5 is realized, or: every kW that is used by the compressor delivers 5 kW of useful heat. An additional advantage of the add-on heat pump is that the load of the existing condenser is reduced.

The installation has the following specifications:

- Heat capacity: 1,400 kW at a temperature of 65 °C of the heated water
- Heating COP: 5.5
- Annual hours of operation: 6,000
- Annual energy savings: € 220,000
- Annual reduction of CO_2 emission: 1,600,000 kg
- Pay back time: ca. 2 years

De Energy Enhancer add-on heat pump is a GEA Grenco innovation. They won the NVKL cooling award 2012 with this innovation. The system is especially designed to be integrated in existing cooling or refrigeration systems with Ammonia as a refrigerant. At this moment the condensation temperature can be increased to a maximum of 90 °C with the use of a heat pump. Through a heat exchanger this energy is delivered to the medium that requires it.

For the high temperature heat a cogeneration gas engine is used with a steam boiler as back up. In partial load situations heat can be exchanged between the two systems

NL-06 Drying French fries at McCain in Lelystad (NL)

Summary

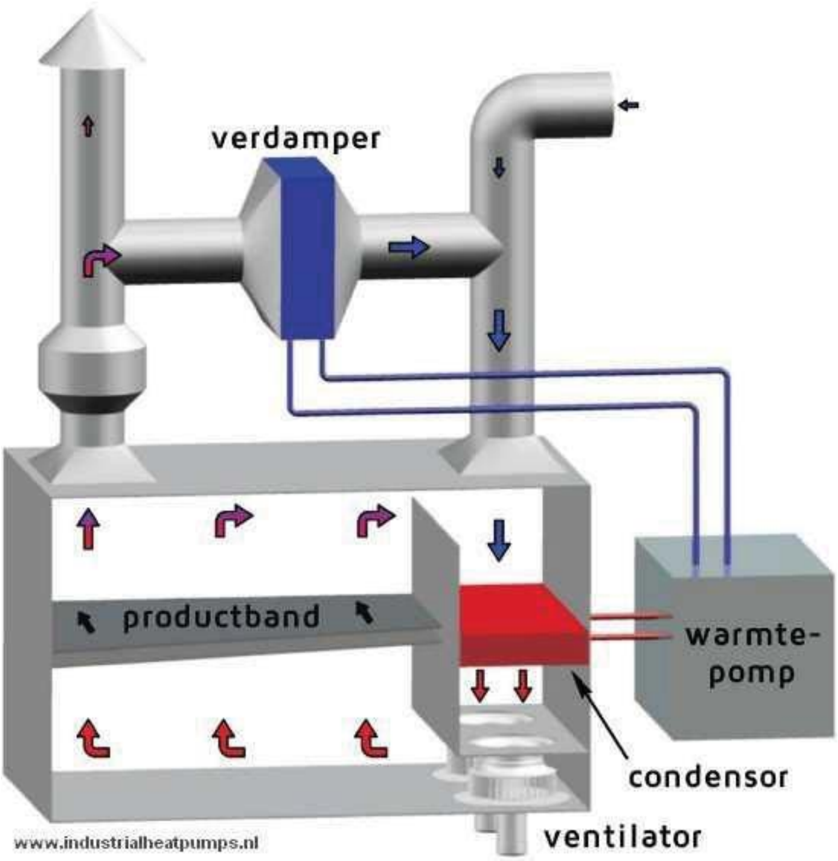
In the summer of 2012, a heat pump is installed at a plant of a French fries producer. This heat pump will provide the majority of the energy needed for drying of French fries before they are baked. The used dryer type is a belt dryer that operates at a maximum temperature of 70 °C. The innovative application of a heat pump connected to a French dryer, invented by De Kleijn Energy Consulting, is the first of its kind. Energy savings as high as 70% on the dryers energy consumption will be realized.

Project information

Company	McCain Foods
Location	Lelystad
Process application	Dying of patatoes
Type of heat pump	Compression Heat Pump
Capacity	880kW
Running hours	4000
Year of operation	2012
Primary energy savings	
Reduction in CO_2 emission	
Maintenance costs	
Manufacturer/supplier	Kleijn/Gea Grenco
Pay back	4 years

Process design of installed system

The principle of operation for drying in conventional dryers can be divided in two parts. The first step concerns fresh outdoor air that is being brought inside the dryer and heated. Secondly, the air is circulated over the wet product. During circulation it picks up moisture from the wet product due to which its humidity increases and its temperature decreases. The energy contained in this humid air flow may make it a useful heat source. Standard procedure is to exhaust this used air or dehumidify it.



Most of the humid and cold air is recirculated when the innovative heat pump is applied. The air is cooled below condensation point and, thus dehumidified at the evaporator of the heat pump. The pressure and temperature of the refrigerant are increased with the use of a compressor. This energy is released into the dryer air, at the condenser site. Due to the application of a heat pump large energy savings can be obtained. Furthermore, the drying process is less influenced by outdoor air conditions. A more stable drying process increases the quality of the French fries.

The heat pump uses Ammonia as its refrigerant. This is a natural refrigerant with which high efficiencies can be obtained. Another advantage is the fact that considerable knowledge about this refrigerant is present in the food industry: Ammonia is very commonly applied there.

Two reciprocating compressors are used: a Grasso 45 HP and a Grasso 65 HP. These compressors have a continuous capacity control. Their COP in this process depends on the drying conditions and varies between 5 to 8.

The heat pump dryer is designed as an ammonia pump system. In the engine room, compressors, separator and pumps are situated. Evaporators are situated on the roof and connect the ducting for exhaust and fresh air with each other. Condensers are installed inside the dryer.

Running experience, savings and economics

The heat pump is designed to condensate 1.500 kg of water per hour. If this quota is reached an annual energy saving of 800.000 Nm^3 of natural gas is obtained. The payback time is than 4 years. This particular project has a shorter payback time since financial support is given by the so called SBIR program of AgentschapNL (the Dutch government).

NL-11 Slaughterhouse for veal, The Netherlands

Summary

Export Slachterij Apeldoorn, part of the Alpuro Group, produces a broad selection of veal products for the retail business worldwide. This production needs large amounts of hot water for the cleaning of production rooms and machinery and for removing hair from veal skin, and a smaller amount for sterile water (90 C). The heat pump has been installed in a slaughterhouse at a moment that the steam boiler had to be replaced. This created the opportunity to improve the hot water system efficiency.

The heat pump is a 45 bar reciprocating compressor coupled to the high pressure side of a refrigeration plant with ammonia as refrigerant (see figure 1). The heat pump condenser heats up water up to 62.5 °C. The installation is running more than one year with great satisfaction and reliability.

Project information

Company	Export Slachterij
Location	Apeldoorn, Netherlands
Process application	Slaughterhouse for veal
Type of heat pump	Electrical compression heat pump
Capacity	440 kW
Running hours	
Year of operation	September 2009
Primary energy savings	/year
Reduction in CO_2 emission	/year
Maintenance costs	
Manufacturer/supplier	IBK Koudetechniek
Pay back	years

Project design

A new system was designed with three smaller warm water boilers and a high temperature heat pump on top of the refrigeration plant operating at -10°C refrigerating temperature.

This refrigerating plant has a cooling capacity of 1,200 kW, at a condensing temperature of 23°C, which is the suction pressure of the high temperature heat pump. The condensing temperature of this heat pump is 65°C, producing hot water at 62.5°C. The COP on heating appeared to be approximately 6.7. The heat pump compressor is a six cylinders piston type compressor, frequency controlled, extracting only part of the discharge gasses. The heat produced at 65°C amounts to 500 kW. This heating capacity heats up a water flow from 15°C up to 62.5°C.

The superheated discharge gasses of the regular refrigerating installation have to be cooled down to almost saturation at 23°C in order to avoid extreme discharge temperatures of the heat pump. This gas desuperheater (= heat pump suction gas cooler) is cooled by high pressure ammonia liquid (23°C) from the condensers of the regular refrigeration plant (see figure 2 upper left vessel). The discharge gas of the heat pump is cooled by heat pump condensate (65°C) in vessel V22. The municipal water intake is heated up from 15°C to 62.5°C in two stages, first by a liquid subcooler E25 and compressor head cooler E70 and secondly by the condenser E24. The water is stored in a 100 m^3 insulated water tank.

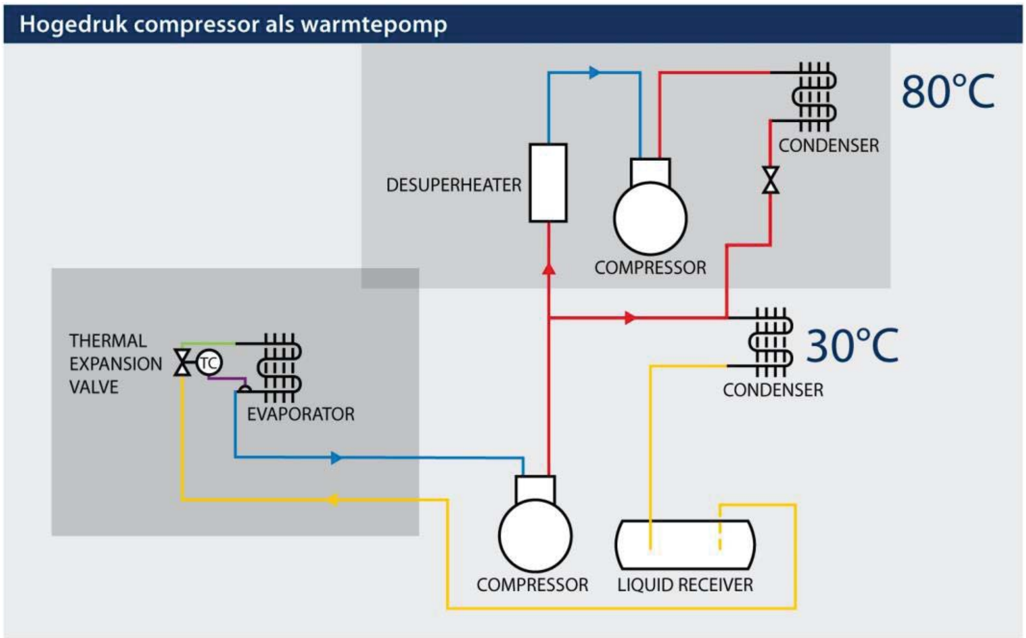


Figure 1: Principle of a high temperature heat pump on top of a refrigeration plant for process heating

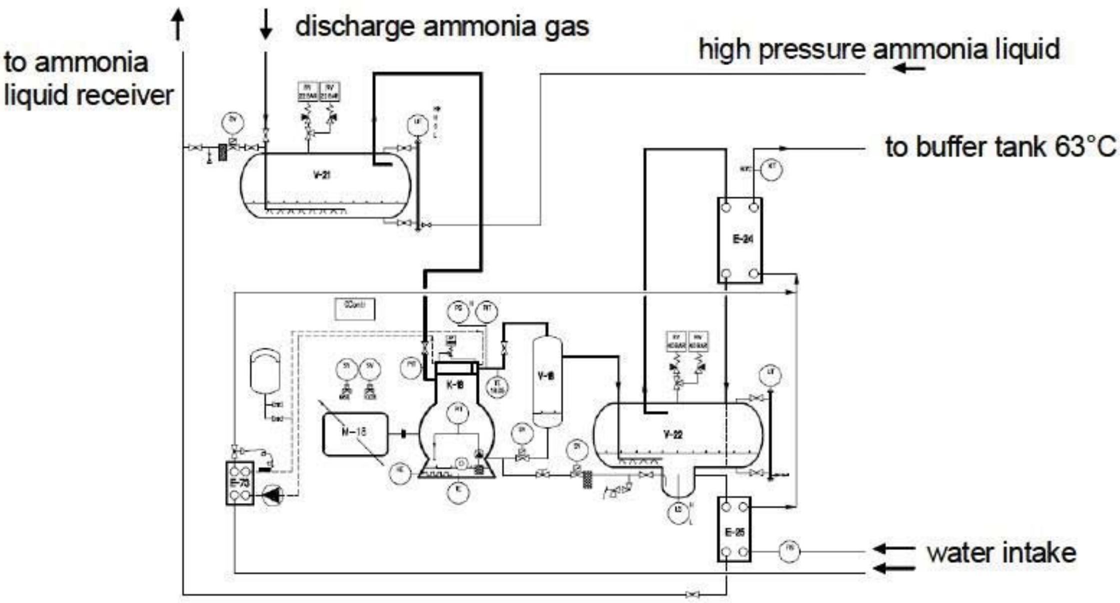


Figure 2: Heat pump layout in practice, ammonia high temperature compression and water flow from intake to buffer tank.

The slaughterhouse requires a hot water flow for dehairing and cleaning of the production areas at the end of the day. The water demand varies a lot during the day. The storage hot water tank is sufficiently large to cope with the variations.

Hot water boilers are connected to the water system of the heat pump as back up system and to heat the water up to 90°C for sterilization water for knives cleaning.

The water flow circulating in the boilers however is separated by a plate heat exchanger from the water flow running through the heat pump. This heat exchanger appears to be required since the warm water boilers became damaged by severe calcification.

The heat of the heat pump is released into a water cooled condenser. The discharge temperatures are above 90°C causing severe calcification of the heat exchanger surfaces. This is prevented by the use of the desuperheater heat exchanger cooled by the condensed ammonia liquid at 65°C. This heat exchanger has been installed in the discharge line of the heat pump.

The heat pump started operation in September 2009 and is running 16 hours per day, approximately 4000 hours per year at almost 100% capacity. By comparing gas consumption figures during the last years, it showed that the gas consumption was reduced by 50%.

On theoretical basis the energy saving by the heat pump is 65% compared with a hot water boiler for this field application as shown in table 1. The electrical energy consumption of the heat pump is included in this calculation. The CO_2 emission is reduced by 50%.

Table 1: MJ primary energy and CO_2 emission reduction by the heat pump in comparison with a hot water boiler

Heat production options		Heat pump 23°C/65°C	Hot water boiler
Heat demand	kW	500	500
COP heat pump		6,7	
Boiler efficiency	%		90
Operating hours	hours/y	4.000	4.000
Primary energy use	MJ/y	2.686.600	8.000.000
CO_2 emission	kg/y	200.150	450.000

The electricity consumption is increased by the operation of the heat pump but the condensing temperature of the refrigeration plant is reduced by 4K, resulting in a better efficiency and energy savings of the refrigeration plant. In addition, the heat pump reduces the load on the evaporative condenser of the refrigeration plant. This creates a saving in water and chemical water treatment costs of approximately euro 6,000 € per year.

Organization

The project is implemented by IBK Koudetechniek B.V. (IBK Refrigeration) in Apeldoorn.

Financially

The simple payback time is approximately 4 to 5 years. The project is subsidized by reduction of companies taxes according to a Dutch energy efficiency investment program.

Lessons learned

The three boilers were initially integrated in the hot water system of the heat pump. Severe calcification took place in these boilers, causing break downs. For this reason the boiler water loop and the fresh water loop through the heat pump were separated by a plate heat exchanger. Water quality have to be checked to be able to control calcification of heat exchangers during heating.

NL-15 MVR for sludge drying at Sophus Berendsen Textiel in Apeldoorn (NL)

Summary

Berendsen Textiel in Apeldoorn is an industrial washing plant for industrial cleaning cloths. The evaporation of watery sludge streams is done through a process of mechanical vapour recompression and has replaced a process of water treatment with reversed osmosis.

Berendsen handles 200.000 cleaning cloths per day. The processes are ISO 9001:2000 and ISO 14001 certified and the company has been awarded the FTN energy award and the MVO innovation award.

Project summary/information

Company	Sophus Berendsen
Location	Apeldoorn, Netherlands
Process application	Sludge drying process for cleaning cloths
Type of heat pump	MVR
Capacity	
Running hours	8650/year
Year of operation	October 1998
Primary energy savings	40T/year
Reduction in CO_2 emission	kton/year
Maintenance costs	
Manufacturer/supplier	
Pay back	2 years

Process description

At the moment of renovation the company was looking at expansion from 1,200 tonnes to 3,000 tonnes of cloth handling with technologies that could increase the economy by reducing operational and energy costs with a special focus on the waste water streams.

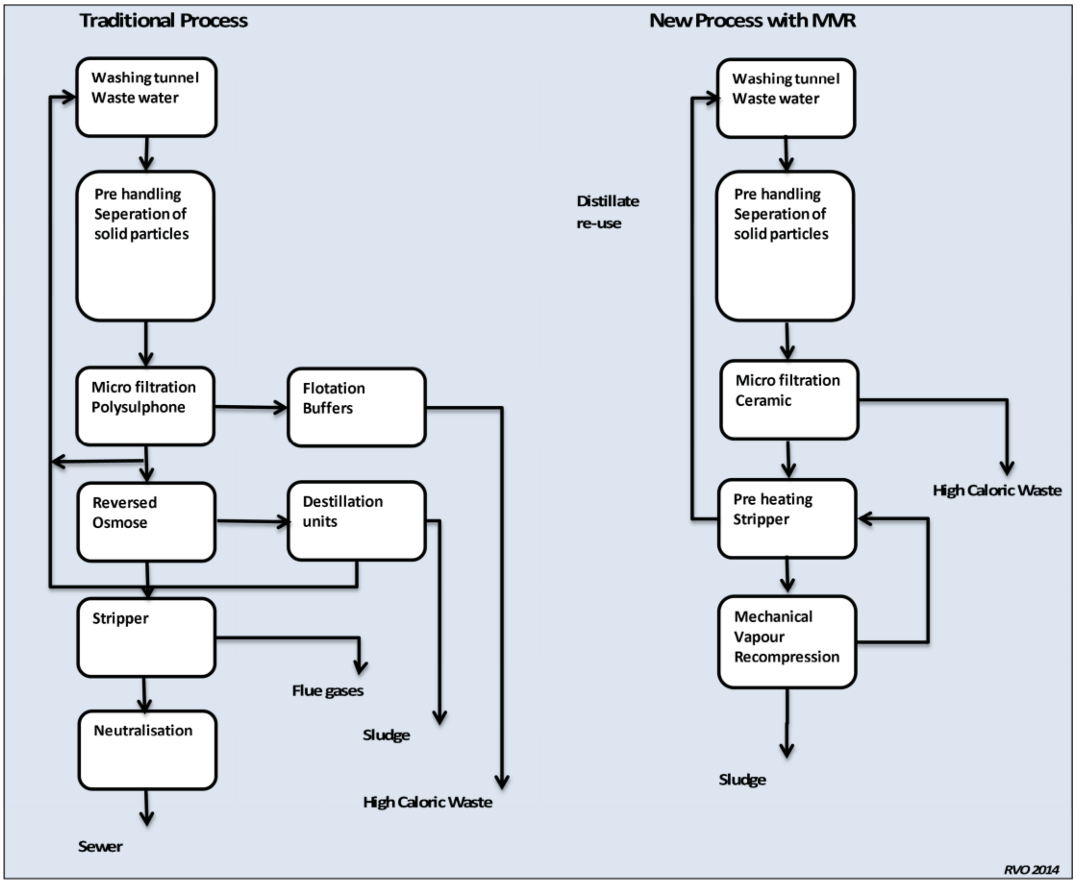
At the industrial washing process waste water streams are released containing heavy metals, hydrocarbons and other polutants, like chemicals. These waste water streams are purified first by pre- cleaning units consisting of polysulphone micro-filtration and reversed osmose untill the needed effluent quality is achieved. The sludge concentrate from the reversed osmose, with a 33% concentrate, was further condensed by a steam driven evaporator. Per m^3 of effluent about 1 ton of steam is needed. The the waste water from the osmose stage is drained to the local sewer system.

This original process was state of the art in the nineties, but was energy intensive and highly sensitive and costly on maintenance, especially on the cleaning of the membrane section. The overall energy use at a capacity of 1,200 tonnes cloths handled was 586,000 m^3 of gas (20TJ).

In the new process the polysulphone micro filtration is replaced by ceramic filtration which gives considerable reduction in maintenance. Next to that the steam driven evaporator is replaced by an evaporator with mechanical vapour recompression. The condensate from the MVR is used as pre-heating for the washing process. The new process saves 90% on the use of water and 1.162.000 m^3 of gas, being 86%.

The total investments in the project for extension of the process were € 1.434.250, whereas the additional investments for the MVR was € 454.550. The savings on energy are € 221.150 and on operational costs € 172.750. Additional gain is the lesser use of cleansing agents in the process.

Technical development by USF Waterbehandeling Zoetermeer and MVH Partners in Pollution Control at Uden.



Evaluation of heat pump

The heat pump as described in the original factsheet and in its original design is still in use and makes 6,000 running hours per year. It is running at 50 – 100 % partial load.

Every week the heat pump is stopped to be able to clean the heat exchangers while once a year the heat exchanger are replaced by new ones.

Maintenance is done by in-house technical service department with the main attention at the heat exchangers and the composition of the waste water. The company does not have figures on the running efficiency of the heat pump.

In the start up the main problems were with the fouling of the heat exchangers.

NL-25 Bovendeert warehouse in Boxtel Netherlands

Summary

The warehouse and headquarters of shoe store chain Bovendeert in Boxtel, contains, besides thousands of colourful shoeboxes and shoes, also an installation with highlighted technical features. Besides the accompaniment of an international automation standard type KNX to link an innovative and energy saving heat pump installation from LG Electronics on an advanced controlled electrical installation, a durable and comfortable installation concept arose.

Project summary/information

Company	Bovendeert Shoes
Location	Boxtel
Process application	Warehouse
Type of heat pump	Air Source compression
Capacity	224 kW Cooling 252 kW Heating
Running hours	8650/year
Year of operation	2013
Primary energy savings	n/a yet
Reduction in CO_2 emission	n/a yet
Maintenance costs	n/a yet
Manufacturer/supplier	LG – Centercon B.V. – Elin Installations
Pay back	Less than 5 years when compared to conventional installation with gas boiler and cooling only air-conditioner

Process description

The applied LG Electronics Multi V Heat Recovery system plays an important role in the concept. It is a three -pipe heat-recovery heat pump system that can simultaneously cool and heat different rooms. The heat extracted in the cooling mode, is directly used for indoor spaces with a heating requirement. In total 4 LG Multi V outdoor units are situated on the roof and all connected as one system.

The outdoor unit is connected to 23 ceiling concealed duct units, which are connected to tailor made discharge jets. The system is also connected to 4 LG Hydro kits that are located indoor in the technical area of the property. The Hydro units provide warm water to feed the low temperature underfloor heating system. In this way the total climate system and the warm water preparation for the entire building is provided by the combined heat pump system and no gas is required.

Thanks to the advanced heat pump technology with inverter controlled compressors, this system with Hydro Kits saves up to 77 % energy compared to conventional heating systems. Due to hydro kits a 50 % reduction of CO_2 emission is made. In order to ventilate the building efficient and effective, Elin Installations also installed 7 pieces of 1000 m^3/h CO_2-controlled LG ECO-V heat recovery ventilation units.

The logical choice for the Multi V Heat Recovery system was done keeping in mind the heat and cooling demand of the warehouse as per the offices, loads may vary. Thus, this system can make the offices warm and comfortable and at the same time keep the shoes in the warehouse at a lower temperature and minimum humidity because they thrive better at it.

It was decided to optimize the control and operation of the units and climate system to be integrated into a building management system that is based on the globally standardized KNX protocol. The link between the heat pump system, underfloor heating and KNX has not previously been achieved in Europe. All system's parts are working together to optimize comfort, control and energy savings. For example, the ventilation units are controlled by KNX controlled CO_2 sensors. Presence and motion detection controls both the lighting and the climate, for each room or area individually. If there is no one in for an hour, the climate system is switched off or the heating system is switched to "low settings".

In the evening the "all off" function switches the system to "Night mode", the lights and the air conditioning off and the alarm is triggered. In the morning, intelligent cooperation between systems provides an achievement of the desired temperature at the desired start time. When the underfloor heating system will not get to the desired value at the right time, the concealed duct units will support to reach the required temperature settings. System integrator Elin also created separate summer and winter settings in the system. In summer the system does not heat, but the air conditioning cools all rooms. Such integrated smart control strategy is even more energy saving than the also energy saving control strategy of LG Electronics Heat Pump system it selves.

Specifications of heat pump

Description	Heat Pump	Back up
Type		
Heating capacity	252 kW (Outside Air 7°C Inside Air 20°C)	
Cooling capacity	224 kW	
Power consumption	63 kW	
Heat source	Outside air minimal -25°C Temp °C	
Refrigerant	R410a	
Compressor type	Hermetic Inverter Scroll 12pcs	
COP	4,18	
Operation hours	24hrs a day	
Storage water tank	1 m^3 35 Temp °C	
Manufacturer of heat pump	LG Electronics, Korea	
Supplier/consultant	Centercon B.V. Rotterdam, Elin Boxtel	

Project characteristics and process design of installed system

- New build warehouse and office.
- Ability to full exchange heat inside the building. Cooling offices and heating warehouse and vice versa.

Motive/grounds/rationale behind investment

The newly build warehouse and office needed to be very energy efficient, no use of gas boilers. No gas connection in the building. Full electric heat pump.

Design and installation process

The installation was done by Elin installations in Boxtel who has don the Electrical Mechanical installation including the system integration and control in the KNX standard

Running experience, savings and economics

With the power consumption of about 200000 kWh is not a big number compared to the size of the building with around 5000m² on three floors.

Lessons learned

Customer is very happy with the installation and the energy consumption. Temperatures in the building are very good with the combination of floor and air heating and cooling. This ensures a stable temperature in the building. All excess heat can be used in the warehouse to heat the air.

NL-27 Heat Pumps in Greenhouses

Summary

In the period 2003-2013, in Dutch horticulture approximately 40 growers of various crops have implemented heat pumps (most of them in combination with ATES – Aquifer Thermal Energy Storage) in their greenhouses. They comprise the following crops a.o.:

- Roses (2x)
- Tomatoes (3x)
- Orchids (Phalaenopsis) (8x)
- Freesia (2x)
- Anthurium (2x)

In the following, we present a factsheets concerning the application of heat pumps in Dutch horticulture in the production of tomatoes.

a. Heat pump application at a commercial nursery for tomatoes

Project description

Company name *)	Commercial nursery for tomatoes
Location / production area	Berkel & Rodenrijs; 54.000 m2
Process / Application	Growing tomatoes
Type of Heat Pump	30HXC285 Carrier
Capacity	1250 kW-th per heat pump, 3x HP in total
Operational hours	15000 hours = average of 5000 per heat pump; 3 heat pumps operating
Year of commissioning	2003
Energy savings	29%
CO_2 emission reduction	40-60%
Maintenance costs **)	N/A
Manufacturer / supplier	Innogrow
Simple Pay Back Time **)	14,9 years

*) Companies cooperated in this project on the basis of anonymity

**) if such data are available

Specifications of the heat pump

Type		water-cooled, condenserless chillers using screw compressors	
Heating capacity (total)		1,250x3=3,750	kW/unit (3 units)
Cooling capacity (total)		1,100x3=3,300	kW/unit (3 units)
Power consumption		240x3=720	kW/unit (3 units)
Heat Source	Temperature	20	°C
	Flow	240	m^3/h
Supply Temperature		42-50	°C
Refrigerant		R134a	
Compressor type		twin-screw compressor	
COP		5.2	
Buffer tanks		1,800 m^3 (3x 600 m^3) at 55 °C (maximum)	

Specifications of back up system

Gas fired boilers are used to provide additional heat when the capacity of the other systems (ATES) is insufficient. It is also used to provide backup in the event of any breakdown. Two gas engines (CHP's of 650 and 300 kWe respectively) were used to generate electricity to power the heat pump and fans. The relative high temperature water produced by the CHP was used to heat the conventional (open) part of the greenhouses. However, due to market conditions in The Netherlands (low electricity prices / feed in tariffs) the CHP is used less and less.

Project characteristics of the company

- Description of the existing situation

Until 2003 this horticulturist grew his tomatoes in a traditional ('open') greenhouse using a combination of a gas fired boilers and CHP to generate the required heat. The total area of this greenhouse was 54,000 m^2. No lighting is applied during the production, so the electricity consumption is relatively low.

- Description of the implementation of the heat pump

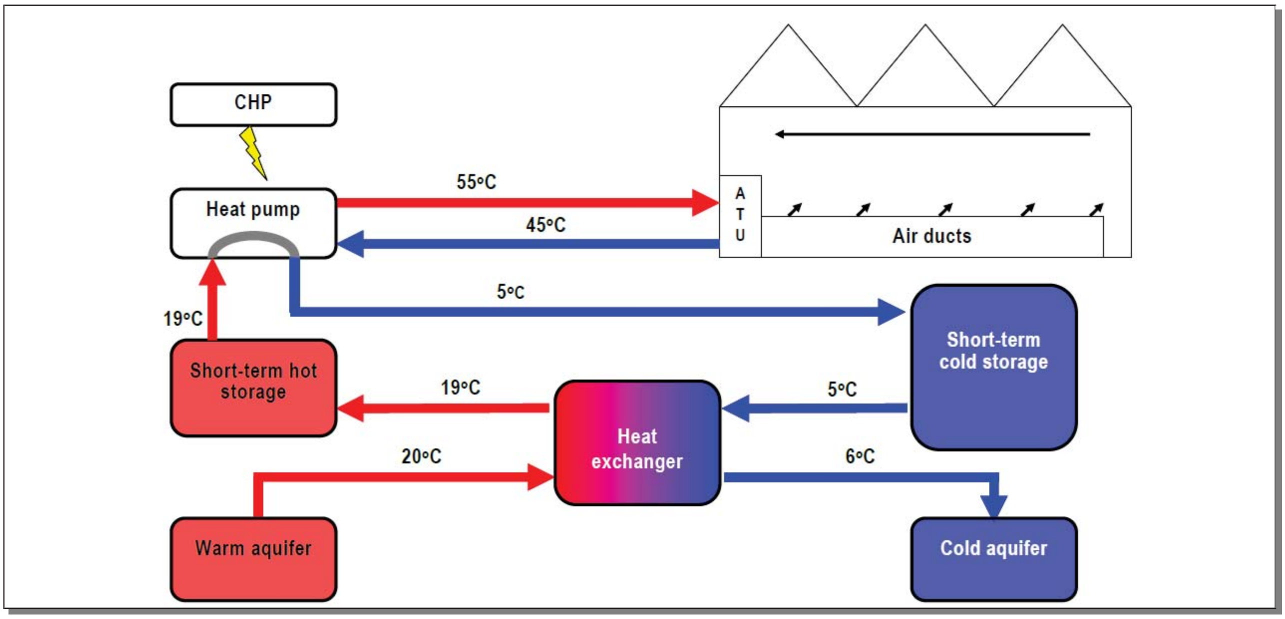
Cultivation of tomatoes in the new situation takes place in a (semi-)closed greenhouse, using a heat pump and ATES. This new concept is applied on 14,000 m2 of the total area of 54,000 m^2 (40,000 m^2 remaining as it was). By the end of 2003 this horticulturist –as the first grower in The Netherlands!- began to operate his ATES-system. The heat sink/source used at this company is an aquifer. Air humidity and temperature are controlled by a ducted ATU (Air Treatment Unit, see picture), using low temperature heat exchanger/heaters.

The company originally utilized the closed greenhouse (Gesloten Kas®) concept that was developed by the Dutch environmental/engineering consultancy Innogrow B.V.. The concept utilizes the fact that during the summer a greenhouse vents off more heat (solar gain) than it requires in the form of fossil fuel heat during the winter. Therefore, if the summer heat can be captured and stored until it is required during the winter significant reductions in fossil fuel use can be achieved. In the summer cold water (6˚C) is drawn from a borehole and passed through water- to-air heat exchangers in the greenhouse. The recovered warm water (around 20˚C), is returned to the aquifer via a second 'warm' borehole. When heat is required during the winter a heat pump recovers the heat from the warm aquifer water boosting it to 45-55˚C. This in turn leads to the production of cold water (6˚C) that is stored in the aquifer and used the following summer for cooling. The concepts results in a heat excess in the closed section of the greenhouses which – after seasonal storage- is used in the other (open) sections of the greenhouse and is partially supplied to an adjacent greenhouse farmer (from October to April).

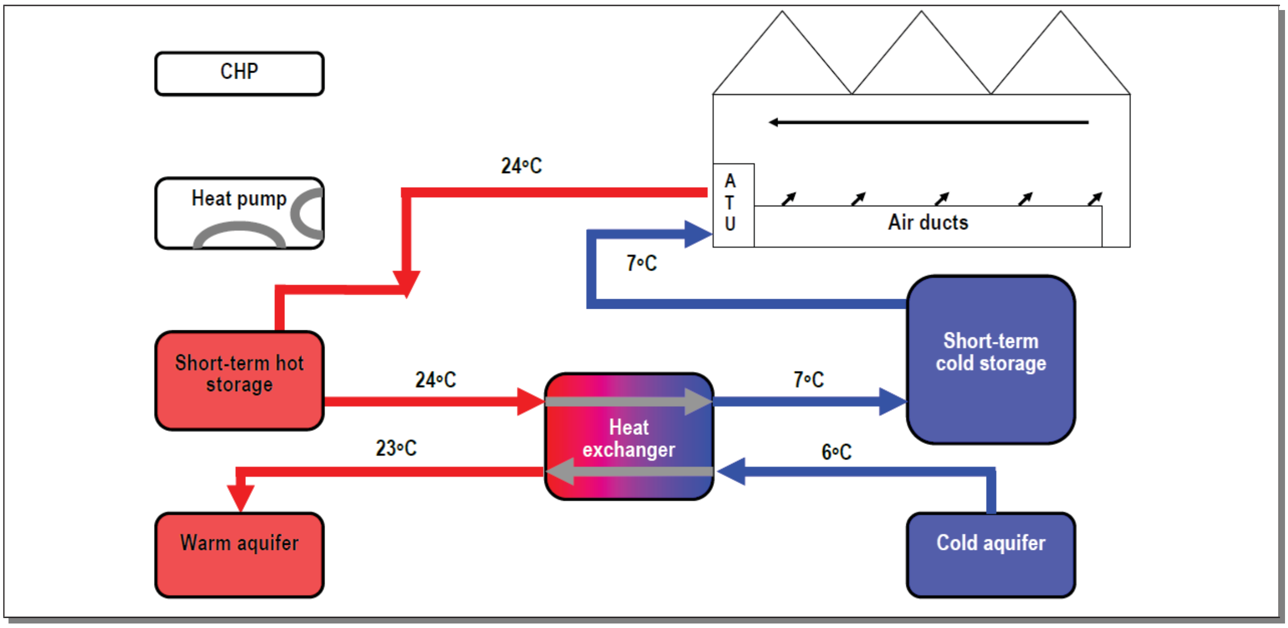
An important benefit of cooling in this way is that the vents do not open in the summer and CO2-levels can therefore be maintained at higher levels than would normally be possible. A significant yield (17%) increase results. A reduction in pest and disease incidence is also claimed due to reduced pest invasion (no venting) and more reliable, accurate and uniform temperature and humidity control.

Graph (simple schematic of the installation)

Installation at heating mode (during winter)



Installation at cooling mode (during summer)



Running experience, savings and economics

- Energy cost savings: approximately 29%
- Energy savings: approximately 30-40%
- Reduction of CO_2 emissions: approximately 40-60%

ITEM	
Investment costs	EURO/m^2
CHP & aquifer	75
ATU & heat storage	40
Total investment costs	115
Operating costs	EURO/m^2 per annum
Energy saving – 200 kWh/m^2 (36% for entire nursery)	5,00
Increased yield (9% for entire nursery)	3,50
Minus extra annual costs (entire nursery)	6,50
Net gain	2,00

Other savings i.e. less use of water, higher performance or yield of the system

The closed greenhouse concept results in better temperature and humidity control of the cultivation process and hence in an improved crop management. It also enables higher CO_2-concentrations inside the greenhouses, which in turn results in higher crop yields (17% increase) and better crop quality. This also results in an 80% reduction of pesticide use, reduced pest and disease incidents.

Lessons learned

Overallviewofowner/userofthesystem:aretheyhappy,wouldtheydoitagain?

- In the next project the horticulturist would refrain from all unnecessary technology which makes the project needlessly complicated . For example, an additional "TSA" (heat exchanger) that allows him to add condenser excess heat to the warm side of the aquifer would not be installed in a next project.
- Essential to the success of the project is the quality of the aquifer and boreholes. Therefore, it is important to select an experienced and trustworthy "manufacturer" of boreholes.
- The application of an (ducted) ATU (for heating, cooling and dehumidification) instead of the traditional rail heating system enables the horticulturist to generate more air movement inside his greenhouse. These increased dynamics result in a more homogeneous climate in the greenhouse and especially a different micro-climate (relative humidity; RH!) at the micro-level of the plants themselves.

The measured RH in the (bulk of the) closed greenhouse can therefore be maintained at a higher level than in traditional greenhouses: in this 'static' situation the plant itself experiences a higher RH than measured. Due to this the productivity can be increased by higher CO2-concentration, higher temperature and controlling towards maximum photosynthesis.

- The 'trick' of crop production in a (semi-)closed greenhouse is that it requires a totally different way of operating and production philosophy than in a traditional greenhouse: the horticulturist needs to learn to grow all over again.
- Cultivation with a few % "over pressure" in the greenhouse (especially in winter) reduces the 'drop of coldness' from the glass and contributes to a more homogeneous climate as well. Also, it is more difficult for insects and pests to enter the greenhouse.
- All in all this horticulturist is very satisfied with his ATES-heat pump system, because –on top of the resulting energy savings (29%) and increases in crop yield (17%) and quality- it gives him much more flexibility to deal with the dynamic energy markets.
- For a new project, this horticulturist would certainly apply ATES and heat pumps again in his greenhouse .

Do's and don'ts, attention for pit holes, etc.

- It is important for any horticulturist who's new to these type of systems to invest serious time - starting with the first days of operation- to thoroughly learn to operate the system and the new settings of the climate computer in close cooperation with the supplier/installer of the ATES-system. Only then, the horticulturist will learn to understand the consequences and possibilities of cultivation under higher temperatures, CO2-concentrations and relative humidity. This will enable him to understand the complex interactions between crop/plants and greenhouse climate and allows him to truly optimize and control his production and crops.

- It is important to select an installer/system supplier (and/or a consultant) who has his roots in the horticultural sector and not just some installer only with experience with heat pumps, CHP and other energy systems.

Literature & sources

Interview with Theo Ammerlaan by Krijn Braber & Charles Geelen (Infinitus Energy Solutions)

Raaphorst M., (2005) Optimale teelt in de gesloten kas – Teeltkundig

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NL 27 b Greenhouse for breeding and propagating Anthuria

Summary

The installation consists of a heat pump and an aquifer thermal energy system and is applied to provide heating and cooling to create a temperature and humidity controlled environment for the critical stage in the propagation of Anthuria.

Project information

Company	Anthura
Location	Bleiswijk
Process application	Climatisation of pot plants in greenhouse
Type of heat pump	Ground source compression heat pump with Aquifer Thermal Energy Storage (ATES)
Capacity	2x1300 kW heating 4 MW total cooling capacity with ATES system
Running hours	6000 hrs/yr heat pump heating 4000 hrs/yr ATES cooling
Year of operation	2009
Primary energy savings	30 TJ/yr
Reduction in CO_2 emission	1600 ton/yr
Maintenance costs	40.000 euro/yr total guarantee
Manufacturer/supplier	Energy Total Projects b.v. (ETP)
Pay back period	4 years, excluding subsidies

Project characteristics

A new 100,000 m^2 greenhouse was built by Anthura in 2009 to produce the small Anthurium plants that are supplied to growers all over the world.

30 % of the greenhouse consists of a climate controlled 'closed greenhouse' environment where the young plants are subjected to a temperature treatment in order to promote the formation of leaves and flower butts. During this critical phase a tight control of humidity levels is required to achieve optimal quality and minimum process time.

The heat pumps have been developed for high efficiency, using frequency controlled compressors and economisers to achieve a 20% higher efficiency than standard available units.

The ATES system consists of 3 cold wells and 3 warm wells. The water is pumped back and forth between the warm and the cold wells, with each well providing 90 m^3/h of ground water.

For heating, cooling and dehumidification of the air in the greenhouse, 120 custom built air treatment units where fitted in the 30,000 m^2 closed greenhouse with heating and cooling coils and frequency controlled fans with air streamers.

Energy Total Projects (ETP) designed the heat pump system and the aquifer thermal energy system along with the air treatment units and supplied this as an entire operational system.

Compared to the conventional alternative with chillers and a gas fired boiler, 60% energy is conserved while increasing production and quality of the plants.

Supplier characteristics

ETP is a systems supplier of specialized heat pump technology for several applications in buildings, industry and agriculture. The heat pumps are supplied with a variety of heat source modules, ranging from aquifer systems and deep geothermal wells to exhaust gasses and surface water.

In the last 10 years, ETP has fitted their special developed heat pumps and source modules in almost 200 projects with a total capacity of ca. 100 MWth.