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Industrial Heat Pumps in Switzerland

Application Potentials and Case Studies

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Zusammenfassung

In diesem Bericht werden 25 Fallstudien über erfolgreiche Anwendungen von Wärmepumpen in der Schweizer Industrie und im Bereich Fernwärme und grosse Gebäude vorgestellt. Die Arbeiten wurden im Rahmen des internationalen Projekts IEA HPT Annex 48 durchgeführt, das versucht, bestehende Marktbarrieren für industrielle Wärmepumpen zu überwinden.

Die meisten Fallstudien stammen aus der Lebensmittelindustrie, in der Wärmepumpen zur Erzeugung von Warmwasser, Heißluft oder Prozesswärme eingesetzt werden. Beispiele für die Herstellung von Schokolade, Käse, Essig, Gemüse, Fertiggerichten oder Fleisch werden beschrieben. Einige Fallstudien stammen aus der metallverarbeitenden Industrie sowie aus Kläranlagen und Thermalbädern.

Die Wärmerückgewinnung aus Kälteanlagen ist eine wichtige Wärmequelle und wird in mehreren Beispielen angewendet. Darüber hinaus wird oft gleichzeitig geheizt und gekühlt, so dass beide Seiten der Wärmepumpe zur Erhöhung des gesamten COP genutzt werden. Die berichteten COPs im Heizungsfall liegen im Bereich von etwa 2,8 bis 7,1 (Durchschnitt 4,0 bei 50 K Temperaturhub). Höchste Wärmevorlauftemperaturen von über 90 °C werden in einer Käsefabrik und einem Schlachthof durch Wärmepumpen bereitgestellt.

Potenzielle industrielle Anwendungen sind die Heißlufterzeugung und Luftvorwärmung für Trocknungsprozesse (d.h. Holz, Papier, Klärschlamm, Stärke, Ziegel und Heimtiernahrung) durch Abwärmenutzung und die Prozessdampferzeugung zur Sterilisation und Pasteurisation von Lebensmitteln (z.B. Milch) mit Kühlwasser oder feuchter Abluft. Um das große Prozesswärmepotenzial der Industrie weiter zu nutzen, ist eine zunehmende Integration von Hochtemperatur-Wärmepumpen notwendig. Einige Fallstudien zeigen, dass der Austausch von Gas- und Ölkesseln durch Wärmepumpen die CO_2-Emissionen um 30 bis 40 % reduzieren und große Mengen an fossilen Brennstoffen einspart.

Wärmepumpen mit grosser Heizleistung spielen eine wichtige Rolle in Fernwärmenetzen zur Warmwasserbereitung und Raumheizung. Als Wärmequellen werden Grundwasser, Seewasser oder Flusswasser, Luft, Geothermie, aber auch Abwärme aus nahe gelegenen Industrieanlagen genutzt.

Insgesamt haben die vorgestellten Fallstudien ein hohes Multiplikationspotenzial, da ihre Integrationslösungen auf andere Prozesse und Branchen mit ähnlichen Heiz- und Kühlsituationen übertragen werden können.

Hinweis: Dieser Bericht ist eine Neuadaption des Berichtes:

Arpagaus, C.; Bertsch, S.: Case Studies of Industrial Heat Pumps in Switzerland, Task 1 Report, IEA Heat Pump Technology (HPT) Programme Annex 48, Industrial Heat Pumps (Second Phase), October 31, 2019.

Résumé

Ce rapport présente 25 études de cas sur des applications réussies de pompes à chaleur dans l'industrie suisse et dans le domaine du chauffage urbain et des grands bâtiments. Les travaux ont été réalisés dans le cadre du projet international IEA HPT Annexe 48, qui vise à de surmonter les obstacles existants sur le marché des pompes à chaleur industrielles.

La plupart de ces études proviennent de l'industrie alimentaire, où les pompes à chaleur sont utilisées pour produire de l'eau chaude, de l'air chaud ou de la chaleur industrielle. Des exemples de production de chocolat, de fromage, de vinaigre, de légumes, d'aliments prêts à consommer ou de viande sont décrits. Quelques études de cas proviennent de l'industrie métallurgique, des stations d'épuration des eaux usées ainsi que des bains thermaux.

La récupération de chaleur des systèmes de réfrigération est une source de chaleur importante et est utilisée dans plusieurs exemples. De plus, le chauffage et le refroidissement sont souvent effectués simultanément, de sorte que les deux côtés de la pompe à chaleur sont utilisés ce qui augmente le COP total. Les COP de chauffage mentionnés varient d'environ 2,8 à 7,1 (moyenne de 4,0 avec un saut de température de 50 K). Dans une fromagerie et un abattoir, des températures d'alimentation en chaleur supérieures à 90°C fournies par des pompes à chaleur ont été observées.

Les applications industrielles potentielles sont la production d'air chaud et le préchauffage de l'air pour les procédés de séchage (bois, papier, boues d'épuration, amidon, briques et aliments pour animaux domestiques) par récupération de la chaleur perdue, ainsi que la production de vapeur pour la stérilisation et la pasteurisation des aliments (par exemple le lait) en utilisant de l'eau ou de l'air humide. Une intégration croissante de pompes à chaleur à haute température est nécessaire afin exploiter encore davantage le grand potentiel existant dans le secteur industriel. Certaines études de cas montrent que le remplacement des chaudières à gaz et à mazout par des pompes à chaleur peut réduire les émissions de CO_2 de 30 à 40% et ainsi économiser de larges quantités de combustibles fossiles.

Les pompes à chaleur de grandes puissances jouent un rôle important dans les réseaux de chauffage urbain qui fournissent de l'eau chaude et du chauffage aux utilisateurs locaux. Les eaux souterraines, des lacs ou des rivières, l'air, l'énergie géothermique, mais aussi la chaleur résiduelle des installations industrielles voisines sont utilisées comme sources de chaleur.

Dans l'ensemble, les études de cas ont un fort potentiel de multiplication car leurs solutions d'intégration peuvent être transférées à d'autres procédés ainsi qu'à d'autres industries ayant des situations de chauffage ou de refroidissement similaires.

Summary

This report presents 25 case studies on successful applications of heat pumps in Swiss industry and in the field of district heating and large buildings. The work was carried out within the international project IEA HPT Annex 48, which tries to overcome existing market barriers for industrial heat pumps.

Most case studies come from the food industry, where heat pumps are used to produce hot water, hot air or process heat. Examples for the production of chocolate, cheese, vinegar, vegetables, convenience foods, or meat are described. A few case studies are from the metalworking industry as well as from sewage treatment plants and thermal baths.

Heat recovery from refrigeration systems is an important heat source and is applied in several examples. In addition, heating and cooling are often carried out simultaneously, so that both sides of the heat pump are used to increase the overall COP. The reported heating COPs range from about 2.8 to 7.1 (average of 4.0 at 50 K temperature lift). Highest heat supply temperatures of over 90 °C provided by heat pumps were observed in a cheese factory and a slaughterhouse.

Potenial industrial applications are hot air generation and air preheating for drying processes (i.e. wood, paper, sewage sludge, starch, bricks, and pet food) by waste heat recovery and process steam generation for sterilisation and pasteurisation of foods (e.g. milk) using cooling water or humid exhaust air. To further exploit the large process heat potential of the industry, the increasing integration of high temperature heat pumps is necessary. Some case studies show that replacing gas and oil boilers with heat pumps can reduce CO_2 emissions by 30 to 40% and saves large quantities of fossil fuels.

Heat pumps with large heating capacity play an important role in district heating networks providing hot water and space heating. Groundwater, lake water or river water, air, geothermal energy, but also waste heat from nearby industrial plants are used as heat sources.

Overall, the case studies have a high multiplication potential as their integration solutions can be transferred to other processes and industries with similar heating and cooling situations.

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Management Summary

IEA HPT Annex 48: The project IEA HPT Annex 48 (Industrial Heat Pumps, Phase 2) initiated by the IEA HPT TCP (Technology Collaboration Programme on Heat Pumping Technologies of the International Energy Agency) attempts to overcome existing market barriers for industrial heat pumps. The University of Applied Sciences of Technology Buchs (NTB) participates in the project and informs the Swiss industry about the latest results, on behalf of the Swiss Federal Office of Energy (SFOE).

Goal of the study: The aim of this report is to present case studies of successful applications of industrial heat pumps in Switzerland.

Definition of an industrial heat pump: Based on the definition in IEA HPT Annex 48, the term “industrial heat pump" refers in this report to “heat pumps with >100 kW heating capacity applied for industrial processes but also for district heating and large residential buildings”.

Evaluation method: Various heat pump manufacturers, planners, consultants, and installers have been contacted to collect best practice case studies on heat pump technology and application. The industrial companies referred to in this report were open to disclose information about their heat pump application and provided technical data and informational material to illustrate and describe the case studies. The contact details of the respective contact persons are listed. In addition, other published information from the internet was also used as data source.

Market situation: In Switzerland, the number of industrial heat pumps is gaining in importance, as the sales statistics of the Swiss Heat Pump Association show. In 2019, around 181 heat pumps with a heating capacity of higher than 100 kW were sold in Switzerland. In Swiss industry, fossil-fuelled heat generation systems for heating and hot water production are still favoured, mainly due to relatively low gas prices and inexpensive gas boiler systems. A lower electricity to gas price ratio would encourage the further market penetration of industrial heat pumps. Major application potentials are in the food, paper, metal and chemical industries as well as in local and district heating networks.

25 case studies: In total, 25 case studies are presented covering different industries, district heating and large residential buildings (Table S1). The selected case studies correspond to a catalogue of different applications, which show the variety of possibilities. The case studies on district heating and large residential buildings are not part of the industrial sector, but are mentioned here because they include similar heat pump technologies.

Food industry: Most case studies are from the food industry, where heat pumps are used to produce hot water, hot air or process heat. Examples are described for the production of chocolate (heating and cooling processes), cheese (process heat), vinegar (fermentation, pasteurisation), vegetables (greenhouse heating, cooling of storehouses), fresh convenience foods (hot water from waste heat of the chillers), or meat (hot water for cleaning processes) (Figure S1, A).

In the food industry, heat recovery from refrigeration systems (i.e. condensers of refrigeration chillers) is an important heat source and is applied in several examples. In addition, heating and cooling are often carried out simultaneously, so that both sides of the heat pump are used advantageously and the overall COP increases. The operating temperatures are relatively low, so that heat pumps can be used in many manufacturing processes.

District heating: Large heat pumps play an important role in district heating networks in providing hot water (60 to 70 °C) and space heating (35 to 45 °C) for entire districts and neighbourhoods. Examples from various energy suppliers, municipalities and municipal utilities are described. In general, the heat sources used are natural resources such as groundwater (see e.g. Champagne in Biel or the city of Aarau), lake water (e.g. Lausanne) or river water (e.g. Les Vergers, Laurana), air (e.g. St. Jabkob district in Basel), geothermal energy, but also waste heat from nearby industrial plants (e.g. Feldschlösschen).

Other applications: Other case studies on industrial heat pumps are from the metalworking industry (heat treatment of metal parts, production of hot water and process heat from waste heat of cooling processes), as well as from sewage treatment plants (hot water from wastewater) and thermal baths (hot water from thermal wastewater).

Temperature levels: The highest supply temperatures of over 90 °C were observed in the case studies of the Gais cheese dairy in Appenzell and the slaughterhouse in Zurich (Figure S1, B). Heat pumps that supply heat of around 80 °C have been on the market for many years. However, in order to exploit the process heat potential of the industry, high temperature heat pumps (HTHP) need to be used. More than 26 electrically driven HTHPs from 15 manufacturers have been identified on the global market with supply temperatures above 90 °C, in some cases even above 120 °C and a maximum of 165 °C.

Heat pump producers: The heat pump manufacturers of the described case studies are Carrier, CTA, Enex, Friotherm, GEA, Johnson Controls, Kibernetik, Ochsner, Mayekawa, MTA, Scheco, SCM Frigo, Sulzer, Thermea, and Viessmann (in alphabetic order) (Figure S1, G).

Heating capacity and compressor types: The typical heating capacities of the examples range from several 100 kW to large capacities in the MW range, which are fed into district heating networks. Mainly piston, screw and turbo compressors are used (Figure S1, F).

Refrigerants: The main refrigerants used are R134a, R717 (ammonia NH_3), R1234ze(E) (hydrofluoroolefin HFO), R744 (CO_2), R245fa, and R410A (Figure S1, E). Classic cooling applications typically use NH_3 chillers, often with Sabroe compressors from Johnson Controls. With the stricter F-gas regulation, refrigerant selection will focus more on the use of low GWP refrigerants.

Efficiencies: The published heating COPs of the compression heat pumps range from about 2.8 to 7.1 (average: 4.0 at 50 K temperature lift). Figure S1 (C) shows (for 17 data points) a slight decrease between COP and temperature lift.

Energy savings and reduction of CO_2 emissions: The case studies show that successful heat pump integration has a positive impact on both energy costs and environmental impact (Figure S1, D). Replacing gas and oil boilers with heat pumps leads to a significant CO_2 reduction effect. Some examples show that CO_2 emissions are reduced by 30 to 40% and large amounts of fossil fuels are saved (Note: The numbers are based on manufacturer information and cannot be compared quantitatively, since system boundaries, etc. are not known).

Outlook: In the future, even more case studies have to be collected to demonstrate the application potential of heat pumps in industry, especially at higher temperatures, where a large application potential is expected in applications such as (low-pressure) steam generation, drying, preheating, distillation, pasteurization, sterilization, or cooking. In the examples, it is not known (or could not be checked) whether a pinch analysis was performed as basis for heat pump integration. A pinch analysis is recommended to analyze the entire system and find the most suitable integration point.

With the aim of further overcoming existing market barriers, the energy transition and the climate debate are having a significant impact on industry with the increased use of renewable energies to further reduce CO_2 emissions. This is a market opportunity for industrial heat pumps.

For future studies, it is recommended to collect data in a way that the studies are easier comparable. Evaluation criteria could be based on various factors of which the following are of particular interest from the perspecitve of potential future users:

- Industrial sector
- Maximum heat supply temperature
- Maximum heating and cooling capacity
- Low GWP refrigerant
- Simultaneous heating and cooling or skilful use of waste heat
- High energy and energy cost savings
- High reduction of CO_2 emissions
- Successful integration according to PinCH

By intensifying public relations work, information and training of experts in this field of energy supply for industrial companies, efforts are being made to make heat pump technology more visible and to highlight its application potential.

Benefits: The case studies in Switzerland are useful in order to identify possible multiplication effects of similar heat pump systems in other companies with similar heating and cooling situations.

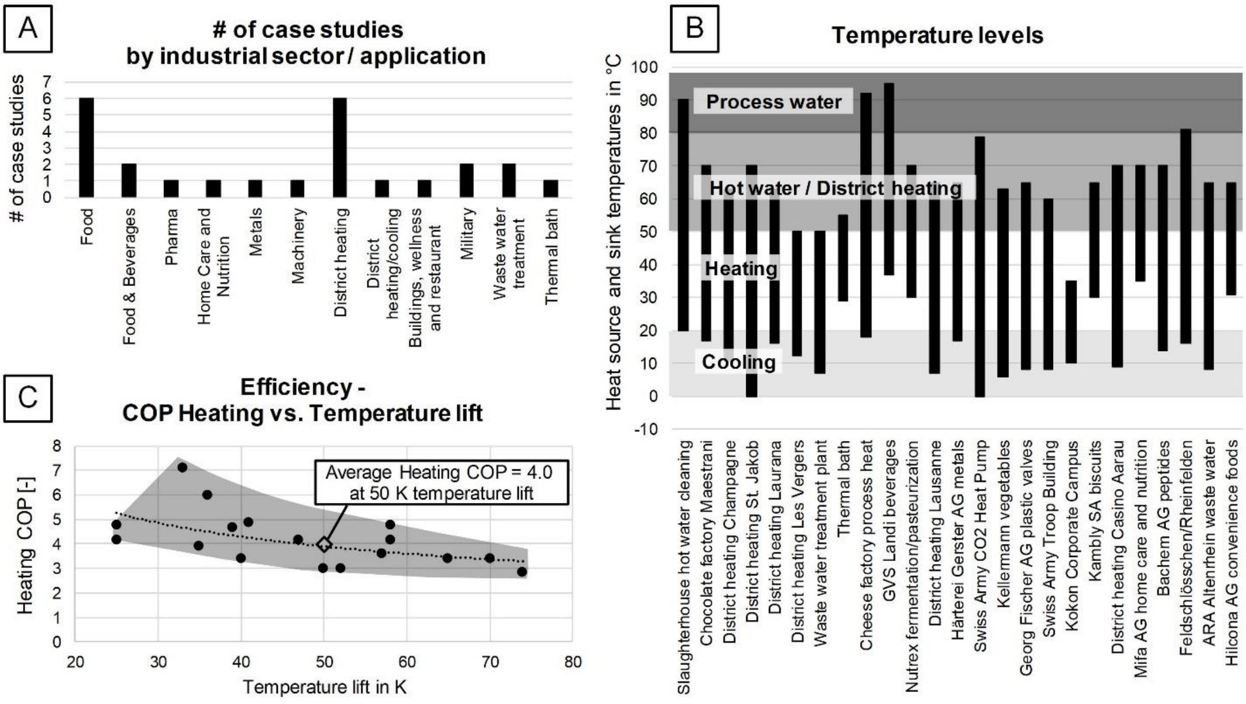
A learning effect for the Swiss industry is also expected from more than 350 case studies of the other participating IEA HPT Annex 48 countries (Austria, France, Germany, Denmark, Japan, and UK). The case studies are in practice and have a high multiplication potential, as their integration solutions can be transferred to other processes and industries.

Promising industrial applications of heat pumps are:

- Hot air generation and air preheating for drying processes (e.g. wood, paper, grass, sewage sludge, starch, bricks, and pet food) through waste heat recovery.
- Process steam generation (low pressure steam) for the sterilisation and pasteurisation of food (e.g. milk) using cooling water or humid exhaust air
- Hot water generation for washing and cleaning processes (e.g. food, meat, product washing) in combination with cooling generation
- Heat recovery by flue gas condensation in biomass and waste incineration plants
- Production of injection moulded components from plastics (heating in the extruder and cooling in the injection mould)
- Local and district heating networks (e.g. of municipal utilities and municipalities)

Table S1: Case studies of industrial heat pumps in Switzerland structured by company, location, industry/sector, application, integration level, heating capacity, and temperature range. The numbering CH01, CH02, CH03, etc. corresponds to the numbering in Table 5, and is also used in the table of contents to simplify finding the descriptions of the examples in the report.

Company, Location	Industry / Sector	Application	Integration level	Capacity (kW)	Temperature range (°C)		No.
Slaughterhouse, Zurich	Food	Hot water, cleaning water	Process	800	20	90	CH01
Chocolate factory Maestrani, Flawil	Food	Hot water, heating, cooling	Process	276	17	70	CH02
Cheese factory, Gais Appenzell	Food	Hot water, heating	Process	520	18	92	CH13
Kambly SA, Trubschachen	Food	Hot water for biscuit production	Process	471	20	65	CH23
Kellermann AG, Ellikon an der Thur	Food	Hot water for greenhouse heating	Plant	1'000	6	65	CH19
Hilcona AG, Schaan	Food	Hot water for fresh convenience foods	Plant	507	31	67	CH29
Nutrex, Busswil bei Büren	Food & Beverages	Vinegar fermentation and pasteurization	Process	194	30	70	CH15
GVS Schaffhausen Landi	Food & Beverages	Process/hot water, heating, cooling	Plant	63	37	95	CH14
Bachem AG, Bubendorf	Pharma	Heating and cooling of peptides	Process	480	14	70	CH26
R134a heat pump, Geistlich Wolhusen	Pharma	Hot water, heating	Plant	606	2	67	CH08
Mifa AG Mibelle Group, Frenkendorf	Home Care and Nutrition	Hot/cold water, heating, cooling	Plant	885	35	70	CH25
Härterei Gerster AG, Egerkingen	Metals	Process heat for hardening process	Plant	260	17	65	CH17
Georg Fischer AG, Grüsch	Machinery	Heating for production of plastic valves	Plant	382	8	65	CH20
Feldschlösschen, City of Rheinfelden	District heating, brewery	Hot water, district heating	Plant/Network	1'350	16	81	CH27
Champagne, Biel	District heating	Hot water, heating	Network	650	11	63	CH03
St. Jakob, Basel	District heating	Hot water, heating	Network	181	0	65	CH04
Laurana, Thônex	District heating	Hot water, heating	Network	338	14	63	CH09
Les Vergers, Meyrin	District heating	Heating of residential buildings	Network	5'000	12	50	CH10
City of Lausanne	District heating	Hot water for residential buildings	Network	4500	6	68	CH16
Casino Aarau	District heating/cooling	District heating and cooling network	Network	1'975	9	70	CH24
Kokon Corporate Campus, Ruggell	Wellness and restaurant	Hot water, heating	Building	341	10	35	CH22
Swiss Army, CO_2 HP Payerne	Military	Tap water and facility heating	Building	60	9	45	CH18
Swiss Army Troop building, Matt	Military	Hot water, heating	Building	270	8	60	CH21
ARA Altenrhein	Waste water treatment	Hot water for sewage sludge drying	Plant	2'840	8	65	CH28
Waste water treatment plant, Zürich	Waste water treatment	Hot water	Plant	410	7	50	CH11
Bad Zurzach	Thermal bath	Hot water	Plant	550	29	55	CH12



D

Savings	t CO_2/a	Energy savings
Slaughterhouse	510	2'590 MWh fossil fuels
Maestrani AG	179	n.a.
District Champagne	620	n.a.
District Laurana	1'746	1'435 MWh fossil fuels
Cheese factory Gais	n.a.	1.5 million kWh gas
GVS Landi	n.a.	26'000 L oil/a
Nutrex	310	up to 65'000 L oil/a
Härterei Gerster AG	160	800 MWh gas
Kellermann AG	960	n.a.
Kambly SA	100	25% energy
Casino Aarau	n.a.	40% energy by 2035
Mifa AG	960	20% energy
Bachem AG	300	n.a.
Feldschlösschen	n.a.	75% energy
ARA Altenrhein	3'000	n.a.

E

Refrigerants	
R134a	9
R717	7
R1234ze	5
R744	2
R245fa	1
R410A	1

F

Compressors	
Piston	15
Screw	7
Turbo	2
Scroll	1

G

Heat Pump manufacturers			
Carrier	1	Mayekawa	1
CTA	4	MTA	1
Enex	1	Ochsner	2
Friotherm	2	Scheco	2
GEA	2	SCM Frigo	
JohnsonControls	4	Sulzer	1
Kibernetik	1	Thermea	1
		Viessmann	1

Figure S1: Summarizing results of the case studies.

(A) Number of presented case studies by industrial sector/application.

(B) Heat source and heat sink temperatures of the heat pumps per case study.

(C) Heating COP of the heat pumps as a function of the temperature lift (17 data points).

(D) Savings in CO_2 emissions and energy thanks to heat pump integration.

(Note: The savings are not comparable. The numbers are based on manufacturer information).

(E) Type and frequency of refrigerants used in the heat pumps.

(F) Heat pump manufacturers and number of heat pumps applied in the case studies.

1 Introduction

1.1 Background to the IEA HPT Annex 48 project

The IEA HPT Annex 48 (Industrial heat pumps, Phase 2) is an international project within the framework of the IEA Technical Collaboration Program for Heat Pumping Technologies (TCP-HPT). The Institute of Energy Systems (IES) of NTB Buchs represents Switzerland on behalf of the SFOE and informs the Swiss industry about the current results.

The main objective of the IEA HPT Annex 48 project is to overcome remaining difficulties and obstacles to the large-scale market introduction of industrial heat pumps.

Participating project partners are:

- Information Centre for Heat Pumps and Refrigeration (IZW) e.V. (Germany, Operating Agent)
- Austrian Institute of Technology (AIT, Austria)
- Danish Technologial Institute (DTI, Denmark)
- Japan Electro-Heat Center (Japan)
- Ulster University (Northern Ireland)
- EPI Department EDF (France)
- EPFL (Industrial Process and Energy Systems Engineering, IPESE, Switzerland)
- NTB Buchs (Institute for Energy Systems, IES, Switzerland)

The project is divided into the following work packages (tasks):

- Task 1: Analysis of case studies and successful applications of industrial heat pumps
- Task 2: Structuring of information on industrial heat pumps and preparation of guidelines
- Task 3: Application of existing models for the integration of heat pumps in industrial processes
- Task 4: Communicating the potential of industrial heat pumps to policy makers, heat pump manufacturers, and system designers

Duration: 2017 - 2019 (36 months)

Website: https://heatpumpingtechnologies.org/annex48/

1.2 Defintion of industrial heat pumps

Within the IEA HPT Annex 48 project, “industrial heat pumps” are defined as “heat pumps in the medium and high power range and temperatures up to 200 °C, which can be used for heat recovery and heat upgrading in industrial processes, but also for heating, cooling and air-conditioning in commercial and industrial buildings.”

Based on this definition, in this report, the term "industrial heat pump" refers to "heat pumps with >100 kW heating capacity applied for industrial processes, but also for district heating and large residential buildings".

The heat pump technologies are comparable for these applications.

1.3 Gas price in Switzerland

The average gas prices of all Swiss gas network operators are monitored for nine standardised customer categories (Type II to X) on the website http://gaspreise.preisueberwacher.ch, which creates transparency on the Swiss gas market and makes it possible to compare prices between the various Swiss gas supply companies. The surveys can also be used to monitor price trends over several years.

Figure 1 shows that the gas price increased between 2012 and 2014 and declined from 2014 to 2017. The trend reversed at the beginning of 2018 [1]. Table 1 shows the gas prices for all customer categories on October 12, 2019. For a large industrial company (Typ X) the gas price is 6.37 Rp./kWh.

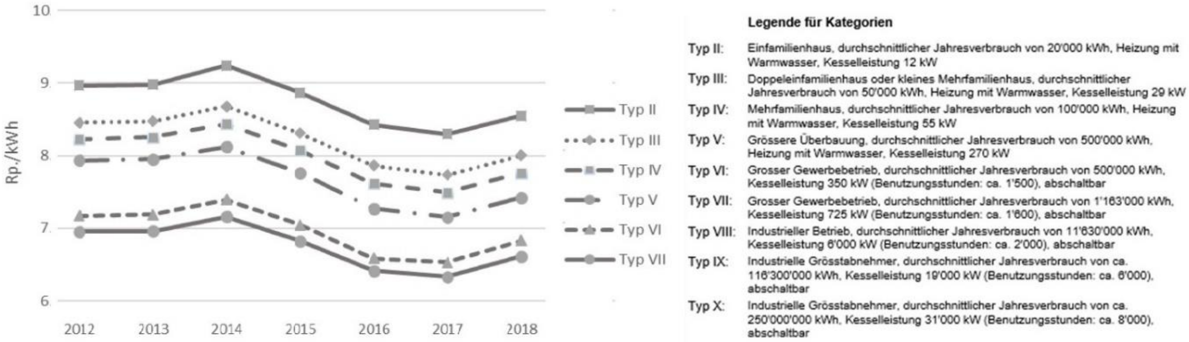


Figure 1: Average gas prices from 2012 to 2018 in Rp./kWh [1].

Table 1: Gas prices in Switzerland reported on October 12, 2019 (http://gaspreise.preisueberwacher.ch).

Customer categories		**Average gas price in Rp./kWh**
Type II	Single family house, 20’000 kWh	9.03
Type III	Small multi-family house, 50‘000 kWh	8.49
Type IV	Multi-family house, 100‘000 kWh	8.25
Type V	Larger building block, 500‘000 kWh	7.92
Type VI	Large commerical enterprise, 500‘000 kWh	7.38
Type VII	Large commercial enterprise, 1‘163‘000 kWh	7.10
Type VIII	Industrial company, 11‘630‘000 kWh	6.56
Type IX	Large industrial company, 116‘300‘000 kWh	6.35
Type X	Large industrial company, 250‘000‘000 kWh	6.37

1.4 Electricity price in Switzerland

The new Electricity Supply Act (StromVG) is in force since 2008. The law led to a partial liberalisation of the electricity market. End consumers with an annual consumption of more than 100 MWh are free to choose their supplier. The networks remain the monopoly of the electricity supply companies.

Many electricity suppliers do not have a unit price for all customers, but make their tariffs dependent on the quantity and timing of electricity consumption. Tariff structures can be complex and vary from supplier to supplier. To enable a price comparison, 15 predefined consumption categories are used (see Table 2). The average electricity price in 2019 in Rp./kWh for an average commercial enterprise (C3 with max. power consumption of 50 kW) is between 17,22 to 19,04 Rp./kWh).

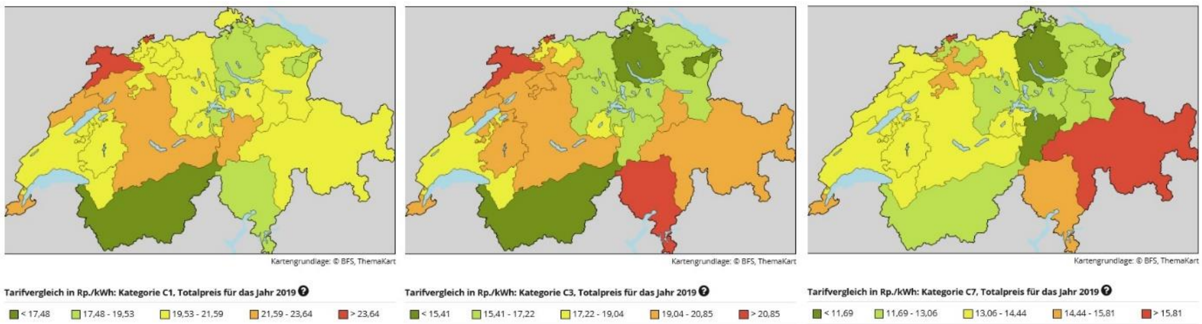


Figure 2: Average electricity prices from 2019 in Rp./kWh in different Swiss cantons for the industrial consumption profiles C1, C3, and C7 (https://www.strompreis.elcom.admin.ch/Map/ShowSwissMap.aspx).

Table 2: Consumption profiles of electricity in Switzerland and average electricity price in 2019 (www.strompreis.elcom.admin.ch).

Consumption profiles of typical households, commercial and industrial enterprises			Average electricity price in 2019 in Rp./kWh
H1	2-room apartment with electric cooker	1'600 kWh/a	22,38 - 24,74
H2	4-room apartment with electric cooker	2'500 kWh/a	20,32 - 22,46
H3	4-room apartment with electric stove and electric boiler	4'500 kWh/a	17,48 - 19,32
H4	5-room apartment with electric stove and tumbler (without electric boiler)	4'500 kWh/a	19,25 - 21,27
H5	5-room single-family house with electric stove, electric boiler and tumbler	7'500 kWh/a	17,01 - 18,80
H6	5-room single-family house with electric stove, electric boiler, tumbler and electric resistance heater	25'000 kWh/a	14,78 - 16,34
H7	5-room single-family house with electric stove, electric boiler, tumbler, heat pump 5 kW for heating	13'000 kWh/a	16,63 - 18,38
H8	Large, highly electrified freehold flat	7'500 kWh/a	18,56 - 20,52
C1	Very small commercial enterprise, max. power consumption: 8 kW	8'000 kWh/a	19,53 - 21,59
C2	Small commerical enterprise, max. 15 kW	30'000 kWh/a	18,81 - 20,79
C3	Average commerical enterprise, max. 50 kW	150'000 kWh/a	17,22 - 19,04
C4	Large commercial enterprise, max. 150 kW, low voltage	500'000 kWh/a	16,21 - 17,91
C5	Large industrial company, max. 150 kW, medium voltage, own transformer station	500'000 kWh/a	13,66 - 15,10
C6	Large industrial company, max. 400 kW, medium voltage, own transformer station	1'500'000 kWh/a	13,88 - 15,34
C7	Large industrial company, max. 1,630 kW, medium voltage, own transformer station	7'500'000 kWh/a	13,06 - 14,44

1.5 Electricity to gas price ratio

In 2018, the electricity to gas price ratio for a single-family house with heat pump (H7 = 17.51 Rp./kWh, II = 9.03 Rp./kWh), a large commercial enterprise (C4 = 17.06 Rp./kWh, VI = 7.38 Rp./kWh), and a large industrial company (C7 = 13.75 Rp./kWh, X = 6.37 Rp./kWh) are around 1.94, 2.31, and 2.16, respectively. Overall, the price ratio in Switzerland is lower than the average for the EU-28 countries of around 2.4, 3.3 and 3.0, which favours investment in electric heat pump systems.

Figure 3 shows the historical development of the relative cost of electricity to gas in Switzerland from 1960 to 2018. The lower the ratio, the better the competitive position for using heat pumps. As can be seen the ratio is lower than it has been in the past.

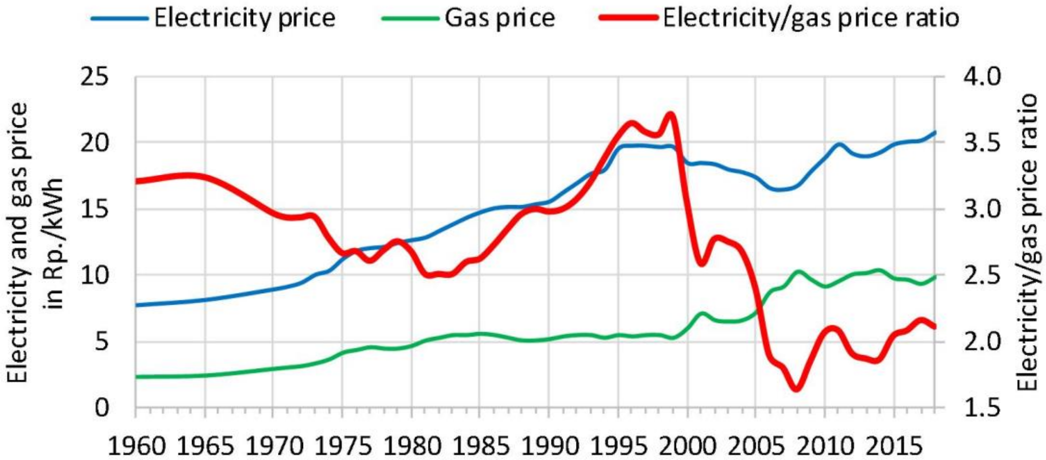


Figure 3: Development of electricity & gas prices and price ratio (secondary axis) in Switzerland from 1960 to 2018 (consumption profile: 20'000 kWh gas, 4'500 kWh electricity) [2].

Figure 4 gives an overview on the energy carriers used to supply the final energy demand in industry [2]. Electricity and gas are dominant, with 41% and 26% respectively.

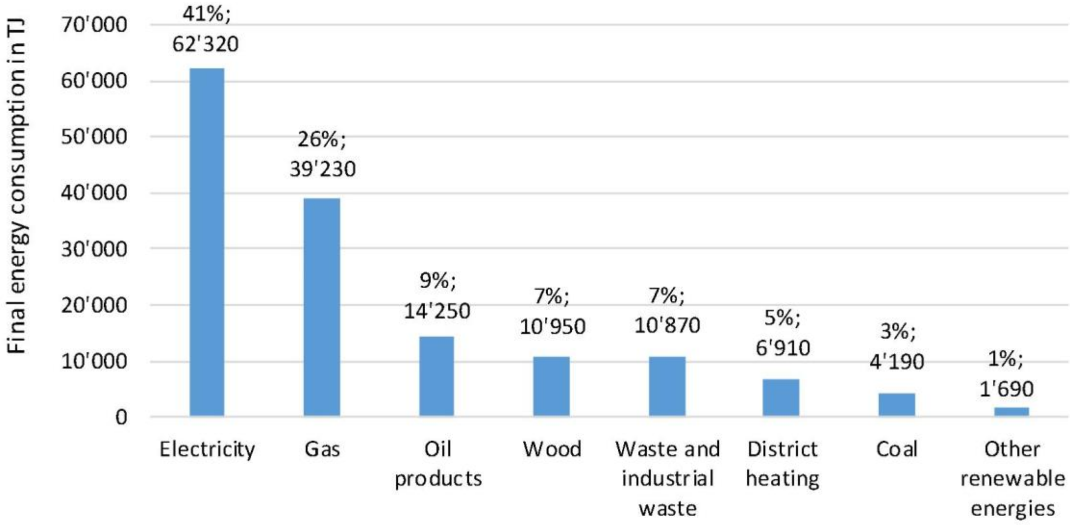


Figure 4: Industrial energy consumption in Switzerland by energy carriers according to the overall energy statistics (2018) [2].

1.6 Importance of industry sectors in Switzerland

To estimate the importance of the industrial sectors statistical data on Switzerland can be analysed [3,4]. Table 3 shows the number of Swiss market-oriented companies and the number of employees by industrial sector in 2016. For example, there are 4'400 companies manufacturing food, beverage and tobacco products with 99'300 employees. About 200 companies produce pharmaceutical products with 45'400 employees.

Table 3: Statistical data on the number of Swiss market-oriented companies and employees by economic activity in 2016 [3].

Market-oriented companies and employees by economic activity

according to NOGA 2008, in '000	2016 Companies	2016 Employees
Total	**586.2**	**4 414.3**
Sector 1	**53.6**	**157.5**
Sector 2	**90.6**	**1 083.3**
of which:		
Manufacture of food, beverage and tobacco products	4.4	99.3
Manufacture of textiles, apparel and leather goods	2.9	14.9
Manufacture of wood and paper products, and printing	9.8	69.1
Manufacture of pharmaceutical products	0.2	45.4
Manufacture of metal products	7.4	83.5
Manufacture of computer, electronic and optical products; watches and clocks	2.0	108.2
Manufacture of electrical equipment	0.8	33.0
Electricity, gas and steam supply	0.8	30.3
Construction of buildings and Civil engineering	8.9	109.8
Sector 3	**442.0**	**3 173.5**

FSO, Statistical Data on Switzerland 2019

Figure 5 gives an overview of the industries production account aggregated by sections. Construction provides the highest Gross Value Added (GVA), followed by the pharmaceutical industry, computer, electronic and optical products (incl. watches), and food and tobacco industry.

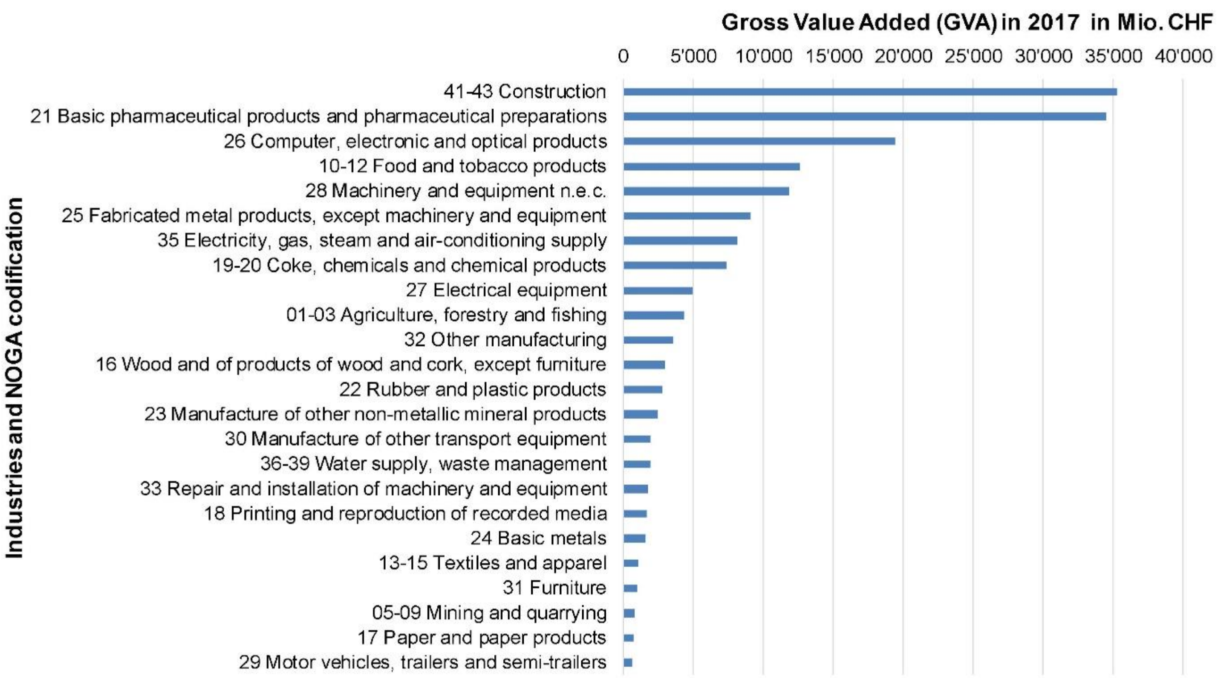


Figure 5: Industries Gross Value Added (GVA) in 2017 aggregated by sections [4].

1.7 Industrial process heat demand in Switzerland

The theoretical application potential for the use of heat pumps in industrial processes can be estimated from the heat demand of the individual industrial sectors and the temperature levels of the applied industrial processes. The graphs in Figure 6 show the distribution of the industrial heat demand in Switzerland by sector and temperature level. In addition to space heating and hot water, industry has a great need for process heat for manufacturing, processing and refining products. In general, process heat is supplied above about 80 °C.

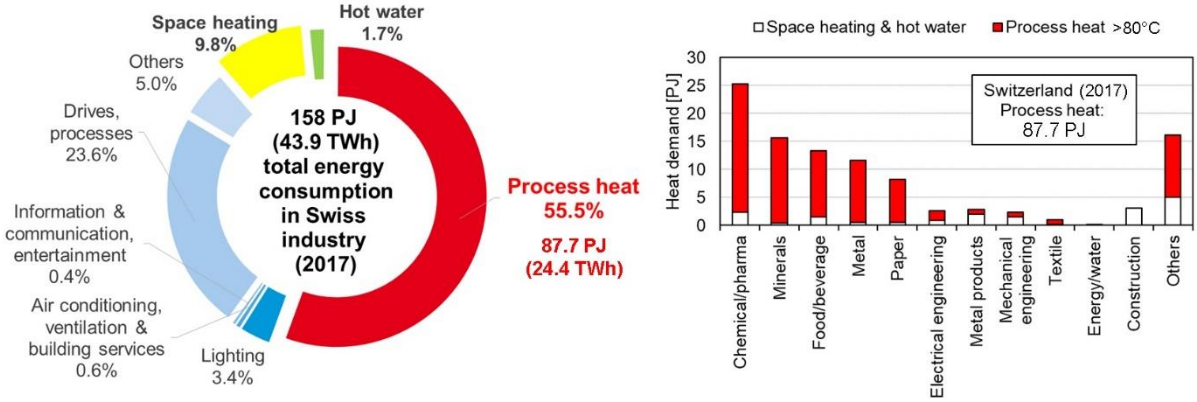


Figure 6: Industrial energy demand in Switzerland (2017) [5] by intended use and process heat demand divided by industrial sector and temperature range, showing the potential for industrial heat pumps.

According to the Swiss Federal Statistical Office [6], around 19% of total final energy consumption in Switzerland goes to the industrial sector (as of 2017). This corresponds to a total energy consumption of about 158 PJ, which is the largest energy consumer (Figure 6, left). The energy consumption of the industry can again be differentiated according to its intended use, with process heat (>80 °C) accounting for around 55.5% or 87.7 PJ (24.4 TWh) of the total heat demand. The most important potentials for process heat lie in the chemicals/pharmaceuticals, minerals, food/beverages, metal and paper sectors (Figure 6, right).

A market study [7] in 2017 on the use of large heat pumps in Swiss industry showed that the importance of industrial heat pumps will increase significantly over the next five years, particularly in the food, chemical, pharmaceutical and paper industries.

The largest research gap was identified in the areas of

- refrigerants (with low GWP) (46%),
- achievable temperature range (19%),
- component optimisation (e.g. temperature-resistant compressors) (15%),
- cycle optimization (12%), and
- demonstration projects (12%),

while the greatest development needs were found in the

- limited temperature range (58%),
- cost reduction (investment, maintenance, and operation) (42%),
- efficiency improvement (27%), and
- the provision of more (modular) standardized products (15%).

1.8 Annual sales of heat pumps in Switzerland

Figure 7 shows the number of installed heat pumps in the Swiss market for the last five years with the distribution of the heating capacity ranges. In 2019, a total of 23’980 new heat pump units were installed according to the sales statistics of FWS (Fachvereinigung Wärmepumpen Schweiz, www.fws.ch).

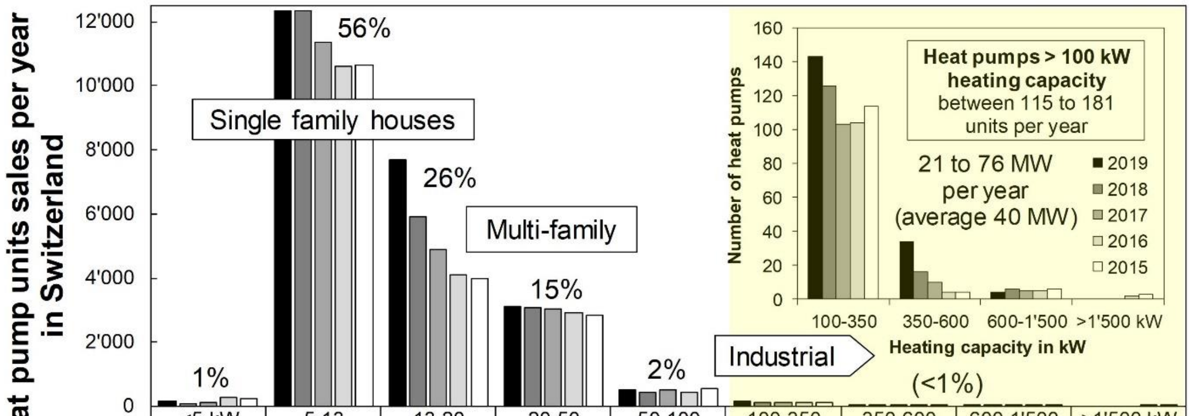
Domestic heat pumps with heating capacities of 5 to 13 kW dominate the Swiss heat pump market. According to the SFOE, the market share of heat pumps in the residential market (e.g. new single-family houses) is about 80%.

These figures show that heat pumps are well established on a small scale in Switzerland. However, on a larger scale, i.e. heat pumps for industrial processes, other heat generating systems are preferred using fossil fuels. Around 115 to 181 heat pump units with a heating capacity of more than 100 kW are newly installed annually. Part of those heat pumps is used in industry. However, the exact figures are not available because the units from various plant manufacturers such as Walter Wettstein AG Kältetechnik, Scheco AG, KAPAG Kälte-Wärme AG, Friotherm AG, etc. are not included.

Despite the rather small numbers of units, large heat pumps represent an important energy potential and numbers are rising. Overall, the installed number of heat pumps with >100 kW heating capacity corresponded to an average of about 40 MW per year in the last five years. Assuming an investment costs factor (incl. installation) of about 480 to 750 CHF/kW [7,8], a potential investment volume of 19 to 30 Mio. CHF can be estimated for industrial heat pumps (>100 kW, for industrial processes, district heating and large residential buildings) in Switzerland.

Unfortunately, there is no market data available with information on the temperature level of the heat pumps. Therefore, the number of heat pumps with high supply temperature (HTHPs) >100 °C is unknown, but assumed to be small due to the lack of products.

All over Europe, the number of industrial heat pumps installed is also largely unknown, as no sales figures are published by the EHPA (European Heat Pump Association) and there is no clear distinction made by the manufacturers between refrigeration systems and heat pumps.



	<5 kW	5-13	13-20	20-50	50-100	100-350	350-600	600-1'500	>1'500 kW
2019	141	12357	7700	3098	503	143	34	4	0
2018	84	12331	5920	3055	426	126	16	6	0
2017	97	11354	4896	3024	506	103	10	5	0
2016	268	10623	4116	2924	426	104	4	5	2
2015	215	10626	3986	2822	542	114	4	6	3

Heating capacity in kW and unit sales per year

Figure 7: Annual sales of heat pumps in Switzerland (2015 to 2019) in various heating capacities. Around 115 to 181 units are newly installed with a heating capacity of >100 kW (own figure, data source: www.fws.ch). Note: The sales numbers from plant manufacturers such as Walter Wettstein AG Kältetechnik, Scheco AG, KAPAG Kälte-Wärme AG, Friotherm AG, etc. are not included.

1.9 Barriers to the wider spread of industrial heat pumps

Despite the great ecological potential and the already commercially available heat pump products on the market, there are still some market barriers to the wider spread of industrial heat pumps. These include in particular [5,8–11]:

- Low level of awareness of the technical possibilities and economically feasible application potential of industrial heat pumps among users, consultants, investors, system planners, manufacturers and installers
- Lack of knowledge about the integration of heat pumps into existing industrial processes
- Tailor-made designs, i.e. small batch sizes (low economies of scale)
- Longer amortization periods than for gas or oil-fired boilers (required are ≤ 3 years). With lower electricity prices and higher gas prices smaller amortization periods are reached.
- Competing heating technologies (with fossil fuels at low energy prices)
- Requirements of heat storage to compensate for the time lag between demand and supply (e.g. heat pump for band load, gas boiler for heating peaks)
- Lack of available compressors for high temperatures and refrigerants with low global warming potential (GWP) and zero ozone depletion potential (ODP)

A major hurdle for the accelerated market diffusion of heat pump technology in the industrial sector lies in its cost-effectiveness. On the one hand, large heat pumps are individually and specially developed or products manufactured in small lot sizes. Larger batch sizes would increase productivity due to the economy of scale. A possible way would be a greater modularization of the heat pumps, so that some parts of the heat pump circuit or the hydraulic integration could be produced in larger quantities. If sufficient installation space is available at the customer site, several standard heat pumps could be connected to a large heat pump system.

Another hurdle lies in the lack of available compressors and refrigerants, which again increases prices. On this topic increased research effort has started worldwide over the last few years.

Finally, it is not always easy to implement a heat pump into an existing plant, since it needs well thought out integration on the heat sink and heat source side. In order to overcome this hurdle, successful integrations need to be demonstrated and published. The time lag between heat supply and availability of the heat sink in industrial processes is of crucial importance. The storage of the heat produced can help to optimise the non-simultaneous demand and waste heat utilization.

A pinch analysis is strongly recommended as a suitable method for mapping cold and hot processes, transparently illustrating the potential for heat recovery, and identifying a suitable integration point for a heat pump.

1.10 Investment costs

Wolf et al. [7,8] described the specific investment costs (including installation) of industrial heat pumps in Switzerland (> 500 kW thermal) as a function of the heating capacity in kW (see Table 4). The factor for mechanical compression heat pumps is around 480 to 750 CHF per kW of heating capacity. For larger plants (10 MW thermal), the investment costs including installation are around 265 to 425 CHF per kW. The achievable COPs for compression heat pumps depends on the temperature lift.

Table 4: Characteristics and specific investment costs of mechanically driven industrial heat pumps in Switzerland [7,8].

Nominal heating capacity	2 kW to 20 MW
Max. temperature	110 °C (160 °C)
COP at 40 K temperature lift	3.9 to 4.9
Max. temperature lift per stage	50 K
Average lifetime	20 years
Investment incl. installation (500 kW)	480 to 750 CHF/kW (450 to 700 EUR/kW)
Investment incl. installation (10 MW)	265 to 425 CHF/kW (250 to 400 EUR/kW)

2 Case Studies Framework

2.1 Framework for data collection

In order to improve the comparability of the different case studies, a framework was developed, which describes the case studies in detail (Table 5). Data on installation, heat pump, costs, effect, satisfaction and experience are collected. The framework contains the following information:

Identification

- Number #
- HPT Annex-#
- Name of the project
- Reference (URL/source of literature)
- Member country

Setup

- Industry, application
- Process applied
- Location, year of installation
- End user
- Heat pump manufacturer
- Contractor, consultant

Heat pump technology

- HP-technology, HP-system
- Working fluid
- Compressor type
- Number of units
- Heating capacity, cooling capacity
- Supply temperature
- Heat source and heat sink (inlet and outlet temperatures)
- Evaporation and condensation temperatures
- Thermal storage (if available)

Cost

- Heat pump
- Installation
- Annual operation in hours
- Annual maintenance

Effects

- Energy savings
- CO_2 emission reduction
- Energy cost savings
- Additional effects
- Remarks

2.2 Selection of best practice examples

A total of 25 Swiss case studies were collected in the framework this project (see Table 5). The case studies were evaluated by desk research and expert discussions with manufacturers and industrial companies, which are described in more detail in the following sections.

Some case studies of industrial heat pumps in Switzerland have already been presented at the IEA HPT Workshop in Tokyo [12] and at the ICR 2019 conference [13].

The case studies cover different industries, district heating and large residential buildings, which show the variety of possibilities. The case studies on district heating and large residential buildings are not part of the industrial sector, but are mentioned here because they include similar heat pump technologies.

Only heat pumps in operation were considered. The heat pumps are integrated into an industrial or commercial process. The individual companies have agreed to provide detailed information (e.g. pictures) in order to create appealing distribution documents.

The majority of the 25 examples come from the food industry (8 examples, 32%) followed by utilities that operate district heating networks (7 examples, 28%). The rest covers various industries such as pharmaceuticals (1), home care and nutrition (1), metals (1), machinery (1), buildings/wellness/restaurants (1), military (2), waste water treatment (2) and thermal baths (1).

The case studies from the food industry are:

- Cheese factory (process heat)
- Chocolate factory (heating and cooling processes)
- Vegetable producter (greenhouse heating, cooling of storehouses)
- Fresh convenience products (hot water from waste heat of the chillers)
- Vinegar (fermentation, pasteurisation)
- Meat producer (hot water for cleaning processes)
- Beverage producer (cleaning of bottles and wine tanks)
- Biscuits producer (hot water from waste heat recovery)

The heat sinks of the application examples include room heating, hot water, district heating and process heat. As heat sources waste heat from cooling processes (heat recovery), groundwater, lake water, river water, wastewater, geothermal energy and ambient air are used.

According to the Japanese colleagues in the IEA HPT Annex 48 project, possible decision criteria for best practice examples are as follows:

- High temperature application (> 100 °C)
- High heat capacity of heating and cooling (> 5'000 kW)
- Low GWP refrigerant
- Simultaneous heating and cooling or skilful use of waste heat (Yes)
- High energy savings (> 50%)
- High reduction of CO_2 emissions (> 50%)
- High energy cost savings (> 50%)

2.3 Case studies located in the Swiss map

Figure 8 shows the locations of the case studies on the Swiss map (Online link: https://de.batchgeo.com/map/Case-Studies-Switzerland). The locations are numbered according to the summarizing Table 5 and S1 (see Management Summary).

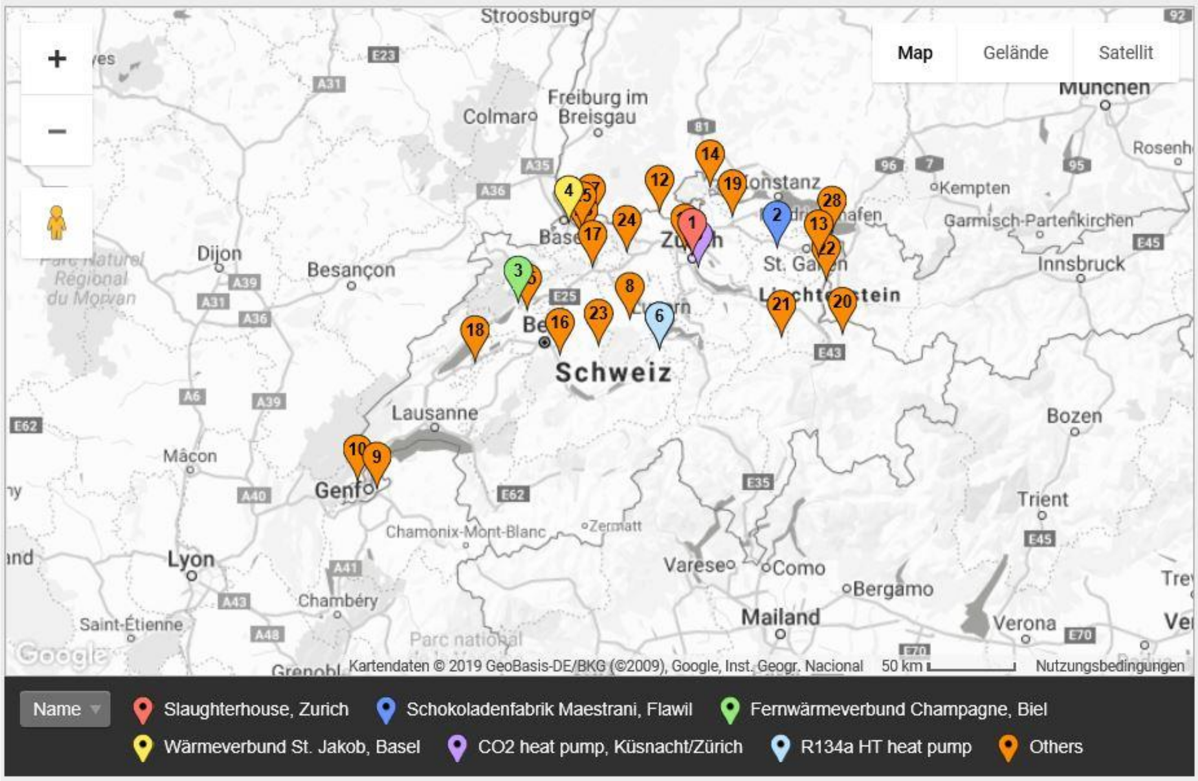


Figure 8: Swiss map with the locations of the described case studies of industrial heat pumps (https://de.batchgeo.com/map/Case-Studies-Switzerland). (Note: The graph does not represent the actual range of heat pump installations in Switzerland, but refers to the contact network).

There is also the possibility of publishing data in Switzerland at www.map.geo.admin. For example, there are already Swiss maps on thermal networks and heat/cooling demand in industry.

As part of the IEA HPT Annex 48 project, an interactive world map has been created on www.waermepumpe-izw.de/karte-europa with links to about 350 case studies and example projects of industrial heat pumps all over Europe and Japan.

Table 5: Case studies of industrial heat pumps in Switzerland structured by company, industry, application, integration level, capacity, and temperature range.

No	Year	Project name	Location	Industry	Application	Heat source	Heat source in/out (°C)	Heat sink in/out (°C)	Heating/ cooling capacity (kW)	Heat pump manufacturer	Refrige-rant	Comp-ressor	Efficiency	Costs (HP: heat pump, O: Annual operation, M: Annual maintenance)	Savings (energy, CO_2 emissions, energy cost)
CH01	2011	Slaughterhouse	Zurich	Food	Hot water, cleaning water	Waste heat (refrigeration, air)	W20/14	W30/90	800/564	Thermea	R744	Screw	COP 3.4	n.a.	2'590 MWh fossil fuels, 510 t CO2/a (30%)
CH02	2019	Chocolate factory Maestrani	Flawil	Food	Hot/cold water, heating	Water	W17/11	W60/70	276/184	CTA AG	R1234ze	Piston	n.a	HP: 140'000 CHF (excl. VAT)	179 t CO2 (2013 to 2020)
CH03	2017	Champagne	Biel	District heating	Hot water, heating	Water	W11/7	W48/63	650/474	CTA AG	R1234ze	Piston	n.a	HP: 280'000 CHF (excl. VAT)	620 t CO2/a
CH04	2018	St. Jakob	Basel	District heating	Hot water, heating	Air	Air -5	W55/65	181/ 111	CTA AG	R134a	Piston	n.a.	HP: 210'000 CHF (excl. VAT)	n.a.
CH09	2012	Laurana	Thônex	District heating	Hot water from waste heat recovery	Geothermal and waste heat recovery	W14-16/8	W58/63	338	Carrier	R134a	Screw	n.a.	M: 1'000 CHF/a (recommendation)	15% (input energy), 1'435 MWh fossil fuels, 1'746 t CO_2/a (42%)
CH10	2018	Les Vergers	Meyrin	District heating	Heating of residential buildings	Ground water	W12.5/7.5	W35/50	5'000/3'910	Friotherm	R1234ze	Turbo	n.a.	n.a.	n.a.
CH11	2014	Wastewater treatment plant	Zürich	Wastewater	Hot water	Cleaned wastewater	W7/2	W44/50	410	Scheco AG	R134a	Screw	n.a.	HP: 150'000 CHF, O: 4'500 h, M: 2'000 CHF without repair	n.a.
CH12	2008	Thermal bath	Bad Zurzach	Thermal bath	Hot water	Wastewater from thermal bath	W29/5	W47/55	550	Scheco AG	R134a	Screw	n.a.	HP: 250'000 CHF, O: 5'000 h, M: 3'500 CHF without repair	n.a.
CH13	2018	Cheese factory	Gaiss	Food	Hot water, heating	Waste heat from data center	W18/14	W82/92	520	Ochsner	R1234ze	Screw	COP 2.85 (W18/W92) COP 4.2 (W18/W65)	n.a.	1.5 million kWh of gas
CH14	2017	GVS Landi	Schaffhausen	Food & Beverages	Process water for disinfection and cleaning	Waste heat from room cooling	W37	W80/95	63	Ochsner	R245fa	Screw	COP Heating 4.2 EER Cooling 3.2	n.a.	26'000 L oil/a, 40% CO_2 emissions
CH15	2009	Nutrex	Busswil bei Büren	Food & Beverages	Vinegar fermentation and pasteurization	Heat from vinegar fermentation	W30	W70	194	Viessmann	R134a	Piston	COP 3.4	n.a.	up to 65'000 L oil/a, 310 t CO_2/a, 50 kCHF/a (energy cost)
CH16	1985	City of Lausanne	Lausanne	District heating	hot water for residential buildings	Water of lake Leman	W6-7	W26-28/50-65	2 x 4'500	Sulzer	R717	Turbo	COP 4.8	n.a.	n.a.
CH17	2013	Härterei Gerster AG	Egerkingen	Metals	Process heat for hardening processes	Waste heat from cooling water	W17	W65	260	CTA AG	R134a	Piston	n.a.	n.a.	80% (energy), 160 to CO_2/a, 800 MWh gas replaced by 190 MWh electricity
CH18	2016	Swiss Army CO_2 Heat Pump	Payerne	Military	tap water & facility heating	Outdoor air	A-9	W30/70	60	Enex	R744	Piston	n.a.	n.a.	n.a.
CH19	2012	Kellermann AG	Ellikon an der Thur	Food	Hot water for greenhouse heating	Groundwater and waste heat from cold rooms	W6/2	W53/63	1'000	Johnson Controls	R717	Piston	n.a.	n.a.	960 t CO2/a
CH20	2010	Georg Fischer AG	Grüsch	Technology	Heating for production of plastic valves	Water	W8/4	W65	382/252	SCM Frigo S.p.A	R134a	Piston	COP 4.8 (W10/W35) COP 3.0 (W10/W60)	HP: about 200'000 CHF	n.a
CH21	2015	Swiss Army Troop Building	Matt	Military	heating, hot water	Water	W8	W60	270/180	SK188W WPM	R134a	Piston	COP 3.0 (W8/W60)	HP: about 200'000 CHF	n.a
CH22	2013	Kokon Corporate Campus	Ruggell	Buildings, wellness and restaurant	heating, hot water	Water	W10/7	W27/35	341/275	MTA	R410A	Scroll	COP 4.16 (W10/W35)	HP: about 85'000 CHF	n.a
CH23	2017	Kambly SA	Trubschachen	Food	hot water for biscuit production	Waste heat recovery	W20-30/12-15	W40-55/65	471/350	Friotherm	R1234ze	Screw	COP 3.9 (471 kW:121 kW)	HP: 160'000 CHF, Installation: 350'000 CHF	25% (energy), 100 t CO_2/a (90%), 15% (energy cost)
CH24	2014	Casino	Aarau	District heating/cooling	District heating and cooling network	Ground water	W9/5	W45/70	1'975 (cooling)	Johnson Controls	R717	Piston	COP Cooling 6.9 (W34.4/W69) COP Cooling 6.2 (W3.3/W34.4)	n.a.	40% (energy) by 2035
CH25	2017	Mifa AG Mibelle Group	Frenkendorf	Home Care and Nutrition	hot/cold water, waste heat recovery	Waste heat recovery	W35/n.a.	W49/70	885 (cooling)	Johnson Controls	R717	Piston	COP Cooling 6.6 (W32.5/W69)	n.a.	20% (energy), 960 t CO_2/a (60%)
CH26	2016	Bachem AG	Bubendorf	Pharma	Peptides	Water	W14/8	W51/70	480/540	Johnson Controls	R717	Piston	COP 4.7 (W6/W45) COP 7.1 (W38/W71)	n.a.	300 t CO_2/a
CH27	2013	Feldschlösschen, City of Rheinfelden	Rheinfelden	District heating	Brewery	Waste heat from cooling water	W16/10	W50/81	1'350	Mayekawa	R717	Piston	COP 3.41 (W16/W81) COP 4.88 (W30/W71)	n.a.	75% (energy cost), 93% from 12 GWh fossil energy, of which 18% electricity
CH28	2007	ARA Altenrhein	Altenrhein	Wastewater treatment	Sewage sludge drying	Waste heat from wastewater	W8/2	W55/65	2 x 1'420	GEA	R134a	Piston	Annual COP 3.62 (B8/W65)	n.a.	3'000 t CO_2/a
CH29	2012	Hilcona AG	Schaan	Food	Fresh convenience foods	Waste heat from chillers	W31	W65	507/437	GEA	R717	Piston	COP 6.0 (W31/W67)	n.a.	n.a.

3 Case studies

The case studies are arranged according to heat pump manufacturer, energy contractor or planner. The numbering CH01, CH02, CH03 etc. corresponds to the numbering in Table 5 and is also included in the contents to simplify finding the descriptions of the examples in the report.

3.1 Ochsner Energie Technik GmbH

CH14 – GVS Landi in Schaffhausen – disinfection of bottling plant and wine tanks

Over the past two years, the agricultural cooperative association Schaffhausen (GVS) and its energy service provider Ennovatis Schweiz AG have implemented a number of projects to significantly reduce energy consumption [14]. In order to be exempted from the CO_2 tax, the company had to reduce its CO_2 emissions by 40% on the basis of different measures.

Figure 9 shows the GVS LANDI AG in Schaffhausen-Herblingen [15]. As the company has an active cooling demand throughout the year, a lot of waste heat is also generated in winter by the existing chillers, which are exhausted using air-coolers. The waste heat from these air-coolers is used as a heat source for a new high temperature heat pump from Ochsner (Type: ISWHS 60 ER 3, economizer cycle) (Figure 10).

Figure 9: GVS LANDI AG in Schaffhausen-Herblingen [15].

Figure 10: Ochsner heat pump (Type: ISWHS 60 ER 3, econimizer cycle) in the heat center of the agricultural cooperative association Schaffhausen (GVS) (Photos from ennovatis Schweiz AG).

On the heating side of the HTHP, the heat can be fed directly into a local heating network (80 to 85 °C) or it is needed for the production of process hot water for the disinfection of the bottling plant and the wine tanks (80 to 95 °C). The local heating network serves the entire production area of the company with several properties. The technical data of the heat pump are:

- Model type: ISWHS 60 ER3 with screw compressor and refrigerant ÖKO 1 (R245fa)
- Heating / cooling capacity: 63 kW / 48 kW
- Heat source: Waste heat from chiller (cooling of storage rooms) (37 °C)
- Heat sinks: Process water for disinfection of beverage filling plants and wine tanks (80 to 95 °C), district heating of production site (80 to 85°C), heating and cooling of warehouses
- COP heating: 4.2, EER cooling: 3.2

The benefits of this installation are obvious:

- CO_2 emissions significantly reduced and target achieved
- Approximately 26’000 litres of heating oil saved annually
- High performance figures are achieved

First operation was in 2017. The system is currently monitored by ennovatis energy management software. This means that additional optimisation potential can be implemented based on the recordings.

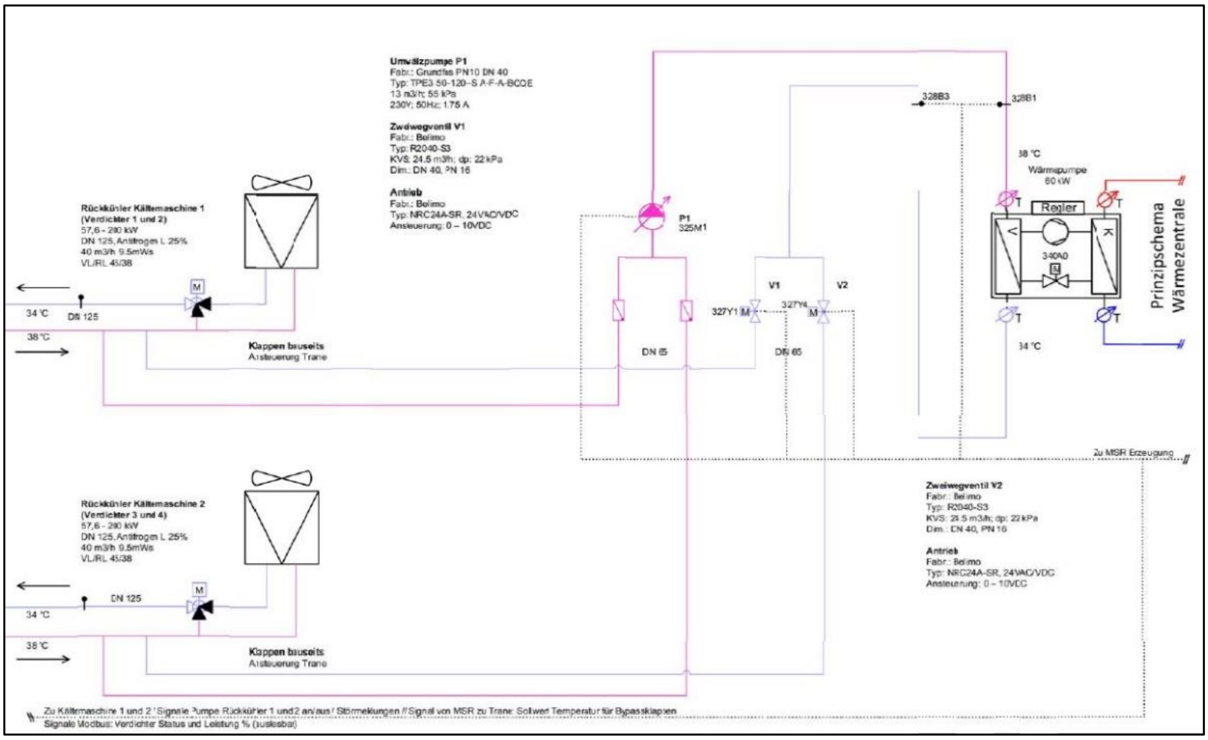


Figure 11: Principle drawing of the heat pump installation at the GVS Landi in Schaffhausen-Herblingen [15].

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CH13 – Cheese factory in Gais Appenzell

The mountain cheese factory in Gais Appenzell produces various semi-hard and mountain cheese specialties, as well as raclette cheese. The milk is supplied by approximately 60 milk suppliers from the Appenzellerland region. Approximately 10 million litres of milk are processed per year. The factory is connected to a district heating network, which is fed by waste heat from the neighbouring data center (see Figure 12).

Figure 12: Waste heat from the server cooling of the data center is fed into a district heating network at around 20 °C. The mountain cheese factory utilizes this waste heat as heat source in a HTHP to generate process heat for the cheese production [16].

A high temperature heat pump from Ochsner (Figure 13) converts waste heat (excess heat) at 20 °C as a heat source into process heat of up to 100 °C to process the milk for cheese production [16,17]. The water exits the heat pump at 14 °C before it flows back into the district heating network. This way, the cheese factory replaces the energy of around 1.5 million kWh of natural gas per year.

Heat pump type	IWWHS 570 ER6c2
HFO  R1234ze(E) (GWP of 6)	I: Industrial heat pump W: Water as heat source W: Water as heat sink H: High temperature heat pump S: Screw compressor 570: Heating capacity range in kW E: Economizer cycle R: Shell and tube heat exchanger 6: Refrigerant HFO R1234ze(E) c2: 2-stage compressor
Heating capacity	approx. 520 kW
Heat source	18/14 °C (in/out)
Heat sink	82/92 °C or 55/65 °C (in/out)
Heat source	Cooling water (waste heat) from the neighboring data center (16 to 20 °C)
Compressor type	2-stage screw with vapor injection
Refrigerant	R1234ze(E) (130 kg, safety group: A2L, mildly flammable)
First operation	2020/21 (using waste heat from the data center)

Figure 13: Ochsner high temperature heat pump (Type: IWWHS 570 ER6c2) with technical data [17].

The temperature levels of the process heat at the cheese factory are as follows:

- Waste heat recovery (i.e. washing, ventilation heating): < 42 °C
- Space heating and hot water (i.e. for cheese storage house): 65 °C
- Process heat 1 (i.e. for cheese vats, cleaning water): 92 °C
- Process heat 2 (i.e. for multi-purpose heater, pasteurisation): 105 °C

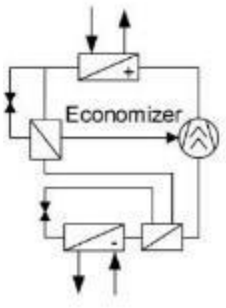
Table 6 shows the performance data of the heat pump at high and low temperature conditions in full and part load operation. Depending on the operating conditions, the COP of the heat pump is between 2.55 and 2.85 at 74 K temperature lift (W18-14/W82-92) and between 3.75 and 4.20 at 47 K lift (W18-14/W55-65). The economizer cycle of the heat pump with vapour injection into the two-stage screw compressor enables an efficient solution for high temperature lifts.

Table 6: Performance data of the high temperature heat pump at high and low temperature conditions [16,17] (* experimentally tested data,** extrapolated).

	High temperature (W18-14/W82-92)				Low temperature (W18-14/W55-65)		
Part load (%) (by slide valve control)	100*	75**	50**		100*	75**	50**
Effective part load (%)	100	81	62		97	75	54
Condenser capacity (kW)	520	419	321		505	390	279
Condenser water flow rate (m³/h)	44.7	36.0	27.6		43.4	33.5	24.0
Temperature difference condenser (K)	10.0	10.0	10.0		10.0	10.0	10.0
Evaporator capacity (kW)	338	264	195		385	293	205
Evaporator water flow rate (m³/h)	82.7	82.7	82.7		82.7	82.7	82.7
Temperature difference evaporator (K)	3.5	2.7	2.0		4.0	3.0	2.1
Compressor power (kW)	182	155	126		120	98	74

The economizer cycle provides the following main advantages:

1. High refrigerant mass flow at compressor outlet, resulting in high heating capacity (i.e., even at high temperature lifts and low evaporation temperatures).
2. Reduced compressor outlet temperature, which is positive with regard to the temperature limits.
3. Strong subcooling of the condensate to increase the COP.



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3.2 CTA AG

The company CTA AG from Münsingen (BE) was founded in 1981 and has 200 employees today. CTA is active in the areas of air conditioning, refrigeration, heating and service. More than 40 experienced service technicians are on 24-hour duty. CTA offers a wide range of heat pump products, for new buildings or refurbishments, for single-family and multi-family homes as well as large buildings and district heating systems.

CH02 – Heating and cooling for chocolate production at Maestrani

Maestrani is a family owned private company with about 150 employees. Every year, the company produces around 3’500 tons of chocolate. The product portfolio comprises around 300 different products, distributed among the three brands Minor, Munz, and Maestrani (Figure 14).

Figure 14: Company Maestrani Schokoladen AG in Flawil with chocolate product portfolio [18].

The production of chocolate and the requirements for air conditioning and temperature control during production are energy intensive. To reduce energy consumption from around 7’200 MWh in 2016 to 5’300 MWh in 2019, Maestrani has invested in a new, modern energy center [18,19].

Together with the Energy Agency for Economic Affairs (EnAW), a comprehensive package of measures was agreed, which commits Maestrani to reduce CO_2 emissions at its production site in Flawil by at least 179 tons between 2013 and 2020, in particular by reducing electricity and gas consumption for heating and process gas. The primary goal is to produce CO_2 neutral chocolate in the coming years.

Carnotech AG from Zofingen has planned the new energy supply with a modular "cold-guided" concept. The main challenges were to cover a wide temperature range from 5 to 70 °C, to combine cooling and heat generation efficiently, and to control the temperature precisely.

Figure 15: The three tailor-made water/water CTA heat pumps (Type: PC-42.604-W.W-1234ze-HT-LN). The machine room offers space for up to 8 machines with a final cooling capacity of 2 MW.

Since 2016, tailor-made water-water heat pumps from the Swiss company CTA AG in Münsingen have been implemented (Figure 15). Seiz Haus- und Industrietechnik AG from Flawil has professionally installed the systems. Part of the factory is supplied with energy, as well as the visitor centre "Maestrani's Chocolarium" with integrated shop, which has been opened in April 2017.

Today, three identical CTA heat pumps are in operation, generating cold (around 222 kW per machine) or heat (around 276 kW per machine) as required. Each heat pump is equipped with 4 reciprocating compressors and 2 refrigerant circuits. In its final configuration, the energy center can be extended to up to 8 machines thanks to its modular design, which corresponds to a cooling capacity of around 2 MW.

The environmental friendly refrigerant HFO R1234ze(E) with a very low global warming potential (GWP) was chosen. Since R1234ze(E) is slightly flammable (safety class A2L), the system is monitored and safely operated thanks to gas sensors, ventilation and alarming.

Figure 16 shows a simplified process diagram of the realized energy supply. The two storage tanks (cold storage 28 m^3 and hot storage 30 m^3) enable the compensation of temporal fluctuations depending on energy demand and demand.

The temperature levels of the individual production processes are:

- 5°C/11°C: production cooling and air conditioning of the production rooms
- 11°C/17 °C: cooling processes, room cooling, air-conditioning of "Chocolarium" visitor centre
- 45°C/35°C: recooling
- 55°C/45°C: heat recovery (WRG), conching machines (Figure 17), intermediate storage of products, space heating, hot water preparation, heating “Chocolarium”
- 70°C/60°C: fat and cocoa melting tanks, various decrystallisers, heating cabinets, air heater
- 80°/70°C: decrystallisers from various production lines, heat kitchen, pelletizing lines, coating line, test line

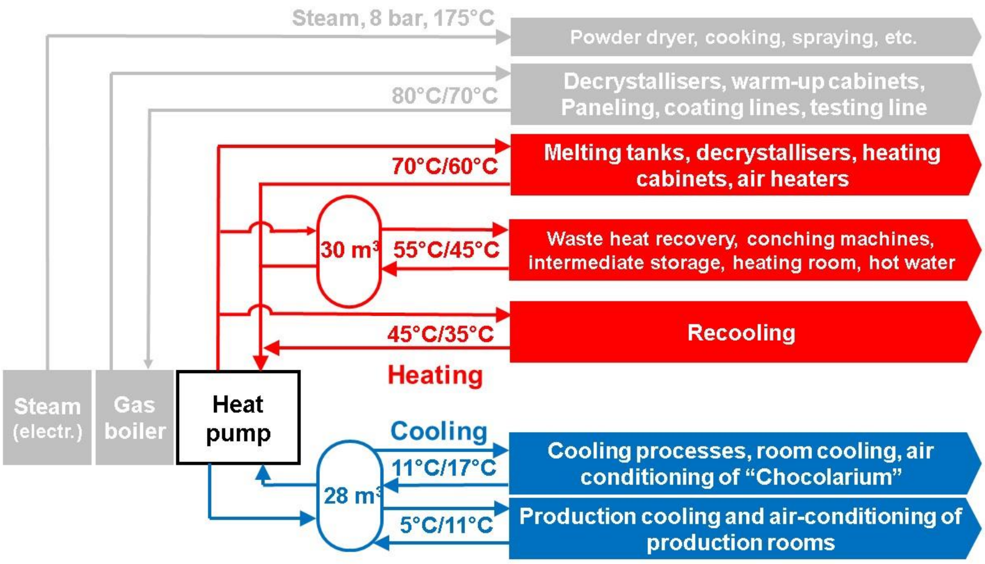

Figure 16: Simplified process diagram of the realized energy supply with cooling, heating and storage.

The chocolate production runs in 2-shift operation. Refrigeration is required continuously. The processes above 70 °C are covered by a gas boiler with a heating capacity of around 640 kW. When the chocolate production comes to a standstill during the Christmas holidays, the gas boiler is put into operation. It is also used for redundancy reasons and as an emergency heating system to bridge the gap between keeping the chocolate warm and the production process.
Finally, an electric steam generator with a heating output of around 400 kW and a compressed air system for pneumatic control of the production systems are in operation. Although there is no basic

steam load, steam can be made available at short notice as required, especially for the sugar dryers (8 bar, 175 °C), mould washing plant (5 bar, 159 °C), cooking plant (1.5 bar, 127 °C), chocolate banana production (1.35 bar, 126 °C) or spraying (1.05 bar, 120 °C).

Figure 17: Large conching machine in production. Agitator to keep the chocolate mass warm at 45 °C.

Table 7 shows six operating points for cooling and heating, which show the application limits of the heat pumps [19]. Heating COPs range between 2.85 and 4.12 for a temperature lift of W17/W70 and W11/W45 respectively.

Table 7: Six operating points for cooling and heating [19].

		Cooling				Heating	
Hot water inlet / outlet [°C]	35 / 45	45 / 55	60 /70		35 / 45	45 / 55	60 / 70
Cold water inlet/outlet [°C]	11 / 5	11 / 5	11 / 5		17 / 11	17 / 11	17 / 11
Cooling capacity [kW]	222.6	192.9	141.8		217.7	246.3	183.7
Recooling or heating capacity [kW]	289.8	269.3	225.0		273.0	329.2	276.2
Power consumption [kW]	70.4	80.0	87.2		57.9	86.8	96.8
COP heating	**4.12**	**3.37**	**2.58**		**4.71**	**3.79**	**2.85**
COP cooling	**3.16**	**2.41**	**1.63**		**3.76**	**2.84**	**1.90**
COP total	**7.28**	**5.78**	**4.21**		**8.47**	**6.63**	**4.75**

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CH03 – District heating network Champagne in Biel

Since May 2018, the district heating network in Biel's Champagne district supplies heat for heating and hot water (50/63 °C, max. hot water 75 °C) (Figure 18). The construction, financing and operation of the district heating network (1.6 km pipeline) is carried out by Energie Service Biel (ESB) in cooperation with AEK Energie AG [20]. The heat supply system consists of two tailor-made CTA*exklusiv* heat pumps (2 x 650 kW heating capacity) and a natural gas boiler (1’100 kW).

Figure 18: District heating network in Champagne [20].

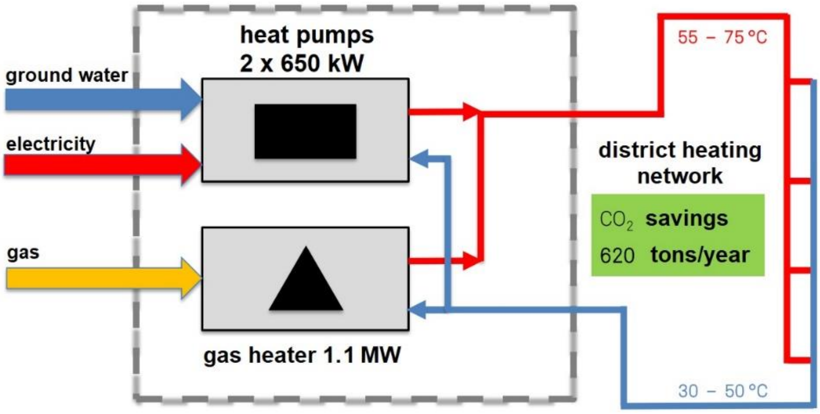

Figure 19: Heat supply system with two heat pumps (2 x 650 kW heating capacity) and a natural gas boiler (1’100 kW) saving 620 tons CO_2 per year [20].

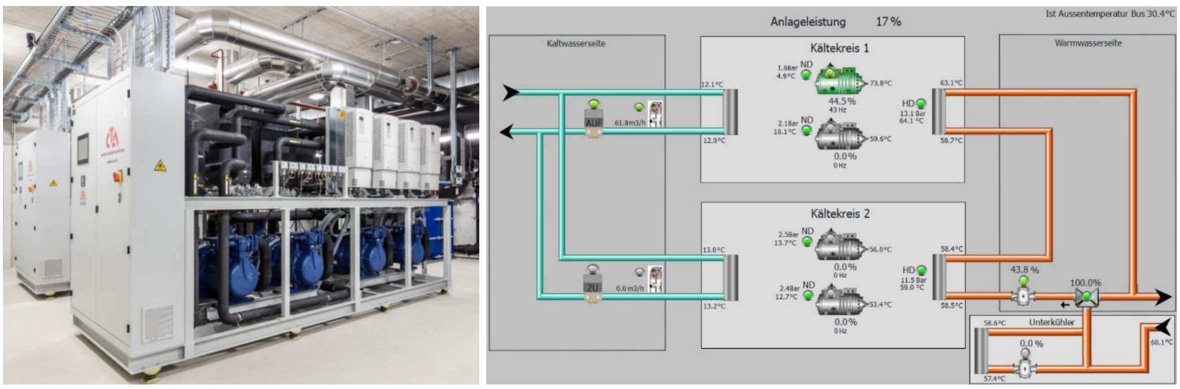

Figure 20: Two CTA*exklusiv* heat pumps with 4 speed-controlled reciprocating compressors (2 x 650 kW) [21].

The two tailor-made CTA*exklusiv* heat pumps are situatated in the heat center of Champagne using groundwater (11/7°C) (Figure 20). The two machines have a weight of around five tons each and deliver

650 kW of heating power per machine with their four speed-controlled reciprocating compressors. The climate-friendly refrigerant HFO R1234ze is used.

The heat comes from the groundwater, which is extracted at a temperature of 10 to 12 °C, and cooled by the heat pumps by 4 °C (Figure 21). The groundwater is transferred to the heat pumps via an intermediate circuit. This ensures that the sensitive groundwater has no direct contact with the refrigerant even in the case of leackage.

The Champagne heating network is a lighthouse project in many respects. First, the heat pumps are highly efficient. The heating COP is around 3.45 at W11/W63 (Table 8). In addition, thanks to the natural heat source, up to 620 tons of CO_2 can be saved per year compared to fossil heating [21].

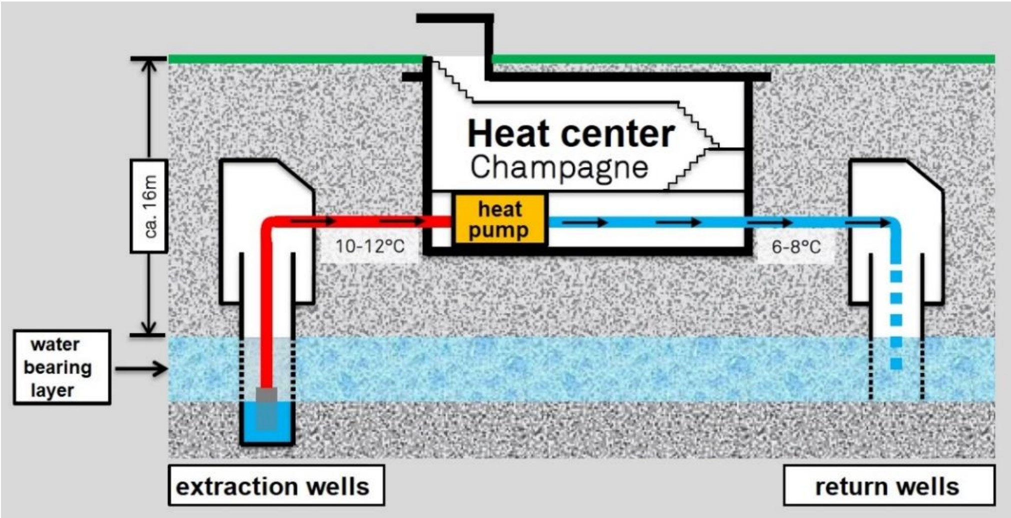

Figure 21: Scheme of groundwater extraction (around 6'000 L/min) in the heat center Champagne [20].

Table 8: Technical data of the heat pump (CTA-PHP-42.1124-2W.2WS-1234ze-HT) from CTA AG.

Operating point (part load)	100%	75%	50%	25%
Compressor frequency in Hz	60	45	30	30
Condenser inlet/outlet in °C	49.3/63.0	49.3/63.0	49.3/63.0	56.2/63.0
Evaporator inlet/outlet in °C	11.0/7.0	11.0/7.0	11.0/8.2	11.0/9.6
Heating capacity in kW	650.0	488.0	325.0	163.0
Cooling capacity in kW	474.0	360.8	237.9	118.6
Power consumption incl. frequency converter loss in kW	189.3	137.3	94.0	47.9
COP heating	**3.43**	**3.55**	**3.46**	**3.40**

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CH04 – District heating network St. Jakob in Basel

In 2018, IWB (Industrielle Werke Basel), the energy supplier of the city of Basel, installed two identical CTA*exklusiv* air-water heat pumps with 265 kW heating capacity each (total 530 kW) in the St. Jakob district heating network [22]. These replace a block heat and power plant powered by natural gas and thus contribute to a further reduction in CO_2 emissions from the heat supply in Basel. The district heating network supplies the St. Jakob football stadium, the St. Jakob garden swimming pool and the St. Jakobshalle (Figure 22).

Figure 22: The St. Jakob football stadium in Basel, the St. Jakob garden swimming pool and the St. Jakobshalle are all connected to the St. Jakob heating network [22].

Figure 23: Two CTA*exklusiv* air/water heat pumps with up to 265 kW heating capacity each. The installation provides accessibility for maintenance and service [22,23].

Each heat pump is equipped with four compressors, which enables operation on demand (Figure 23). There are two 11 m long air coolers on the roof of the building (Figure 24). These extract heat from the air and the heat pumps produce up to 70 °C of hot water, depending on the operating point (Table 9). This energy is transferred to a 42 m^3 storage tank from where the various consumers draw their heat [23].

Figure 24: One of the two 11 m long air coolers, which extract the source energy from the air [22].

In summer, the heat pumps cover the complete hot water consumption of the connected consumers. For temperatures higher than 5 °C (the average temperature in Basel is 10 °C) the machines produce hot water at 70 °C [23]. When the outside temperature is less than 5°C (and down to -5°C), the heat pumps still produce usable heat at 55 °C, which is used for hot water return heating. The remaining heating up to 80 °C is carried out in winter by two gas boilers, which are used to cover peak loads (bivalent heat generation) in the central heating system [22].

Table 9: Technical data of the air-water heat pump (CTA-PHP-42.612-B.WS-134-HT-LN) from CTA AG.

Operating point	A-5/W55	A5/W55	A5/W70
Outdoor source temperature in °C	-5.0	5.0	5.0
Condenser inlet/outlet in °C	47.8/55.0	55.0/65.0	60.5/70.0
Heating capacity in kW	180.5	265.0	251.9
Cooling capacity in kW	110.4	171.2	155.6
Power consumption in kW	73.4	98.0	100.8
COP heating	**2.46**	**2.70**	**2.50**

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CH17 – Heat treatment of metal parts at Härterei Gerster AG

The family owned company Härterei Gerster AG with around 100 employees, founded in 1950, is a contract hardening company for customers in the mechanical engineering and automotive industries that thermally hardens metal parts (Figure 25). The metal parts are heated up to 1'000 °C and cooled quickly to improve the material properties like wear and corrosion resistance. 50 oven systems and 50 inductive hardening systems are in place. The company spends an extraordinary amount of money on energy [24]. Together with the Energy Agency EnAW, Härterei Gerster AG has formulated and implemented various succes sful energy-saving measures [25].

Figure 25: Heating oven at headquarters of Härterei Gerster AG in Egerkingen (SO) [24,25].

The two natural gas-fired boilers were replaced by a heat pump (PHP-22.306-W.W-134-HT-LN, R134a, 260 kW) from CTA AG for almost half a million Swiss francs (Figure 26). The heat pump uses the waste heat from the industrial water network, which is used for cooling of all production plants, e.g. for the quenching process in vacuum furnaces, to supply heat (65 °C) to all rooms. Thanks to the heat pump, 800 MWh of natural gas can be saved (= 80% savings of gas consumption or 160 tons of CO_2 emissions). The waste heat is sufficient to supply the complete operation in summer by recovering the process heat. The payback time is almost ten years. Therefore, the canton Solothurn contributed 30'000 CHF to the project and the Swiss Climate Foundation 48'000 CHF [24].

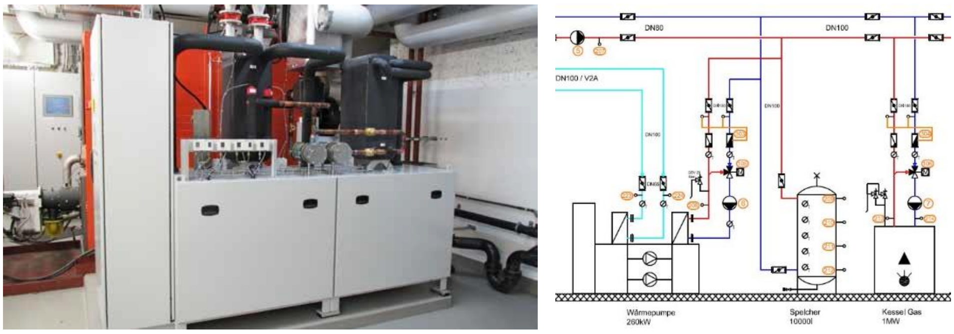

Figure 26: Heat pump (PHP-22.306-W.W-134-HT-LN) from CTA AG at Härterei Gerster AG [25]. Section of the schematic diagram with heat pump, 10 m^3 storage tank, and 1 MW gas boiler.

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3.3 Kibernetik AG

Kibernetik AG in Buchs offers ideal solutions for heating, cooling and energy saving. The history of the company began in 1965 with an innovation in ice cream production. Now, the product range includes ice machines, heat pumps, air conditioning systems, swimming pool heat pumps and photovoltaics.

Table 10 shows three reference water-water heat pumps in Switzerland from Kibernetic AG for heating (35 °C) and hot water supply (60 to 65 °C).

Table 10: Reference examples from Kibernetik AG (Buchs SG) of water/water heat pumps for large residential buildings.

Projects (reference) (No.)	Georg Fischer AG (CH20)	Swiss Army military building (CH21)	Wellness and restaurant Kokon Corporate Campus (CH22)
Location	Grüsch	Matt	Ruggell, Lichtenstein
Year of installation	2010	2015	2013
User (company)	Georg Fischer AG, Grüsch	Swiss Army	Kokon Immobilien AG
HP manufacturer	SCM Frigo (Italy)	SCM Frigo (Italy)	MTA (Germany)
HP model	SK 190S WPC (2 units)	SK 188W WPM (2 units)	Neptune NET 090
Contractor	Kibernetik AG	Bäbler Heizungen AG	Büchel Haustechnik Est.
Working fluid	R134a	R134a	R410A
Compressor	Reciprocating	Reciprocating	Scroll
Heating/cooling capacity in kW	382/252	270/180	341/275
Supply temperature (°C)	65	60	35
Heat source inlet/outlet in °C	8/4	8/n.a.	10/7
Heat sink inlet/outlet in °C	n.a/65	n.a/60	27/35
Thermal storage	heating/hot water	heating/hot water	Heating only
Heat pump costs in CHF	ca. 200'000	ca. 200'000	ca. 85'000
COP	**4.8 (W10/W35) 3.0 (W10/W60)**	**3.0 (W8/W60)**	**3.16 (W10/W35)**

CH20 – Hot water for plastic valves manufacturing at Georg Fischer AG

Georg Fischer AG is a leading global manufacturer of plastic valves for industry and drinking water distribution. In Grüsch, around 180 employees produce millions of valves per year. These are used to control, regulate and measure the flow of liquids in piping systems (Figure 27).

Figure 27: Georg Fischer Rohrleitugnssysteme AG in Grüsch producing plastic valves.

Figure 28 illustrates the hydraulic diagram of the heat pump installation at Georg Fischer AG in Grüsch. Two R134a heat pump units (Type SK 190S WPC from SCM Frigo) are installed in parallel together with a 1‘500 L storage tank and an oil-fired boiler for redundancy.

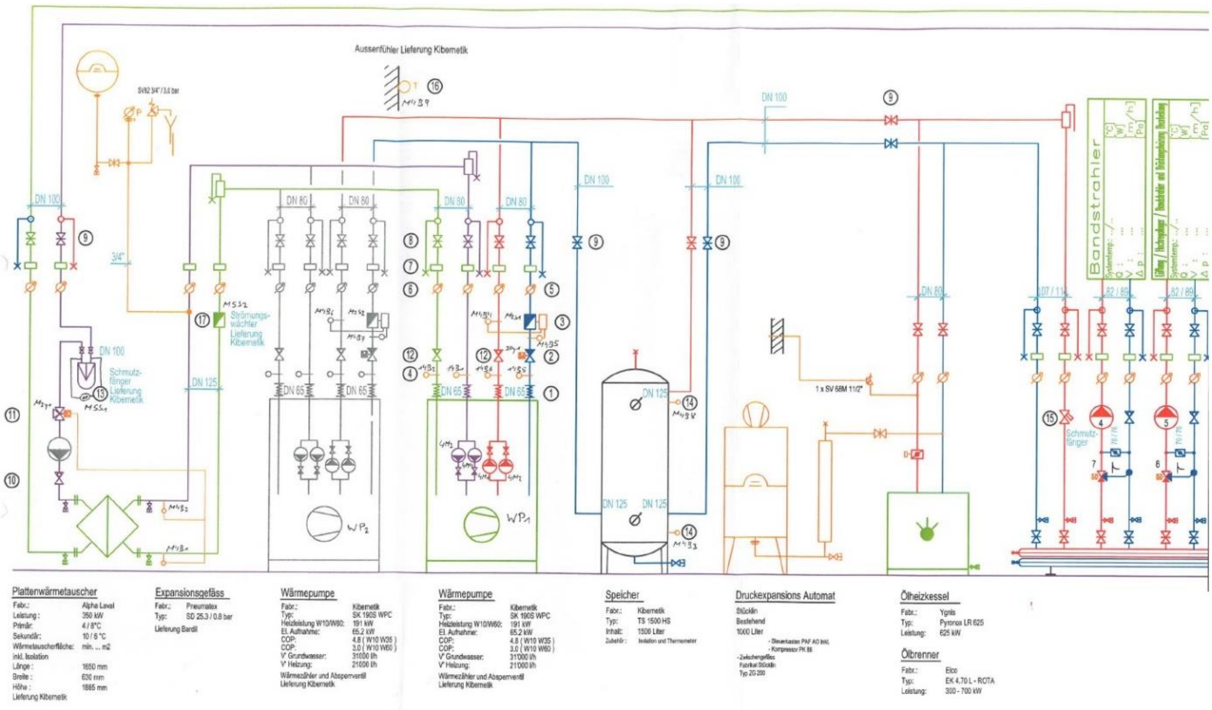

Figure 28: Hydraulic diagram of the heat pump installation at Georg Fischer AG in Grüsch (2 x SK 190S WPC from SCM Frigo with 191 kW heating capacity, COP 3.0, W10/W60).

CH21 – Heating and hot water for the Swiss Army troop building in Matt (GL)

The military shooting range and training site at Wichlen (Glarus) and the neighboring communities have training and accommodation facilities for 3 military companies of the Swiss Army. In Matt, the troop accommodation building has 326 beds (Figure 29).

Figure 29: Troop accomodation building of the Swiss Army in Matt with 326 beds (http://www.fnag.ch/referenzen5.html).

Hot water and heating is supplied with two groundwater heat pumps (SK 188 W WPM) from Kibernetik AG (135 kW heating capacity and 90 kW cooling capacity at W8/W60, COP of 3.0) and a 5‘000 L hot water storage tank (Figure 31). Figure 30 illustrates the hydraulic diagram of the heat supply center. The groundwater is fed to the heat pumps via a plate heat exchanger and a water/glycol intermediate circuit.

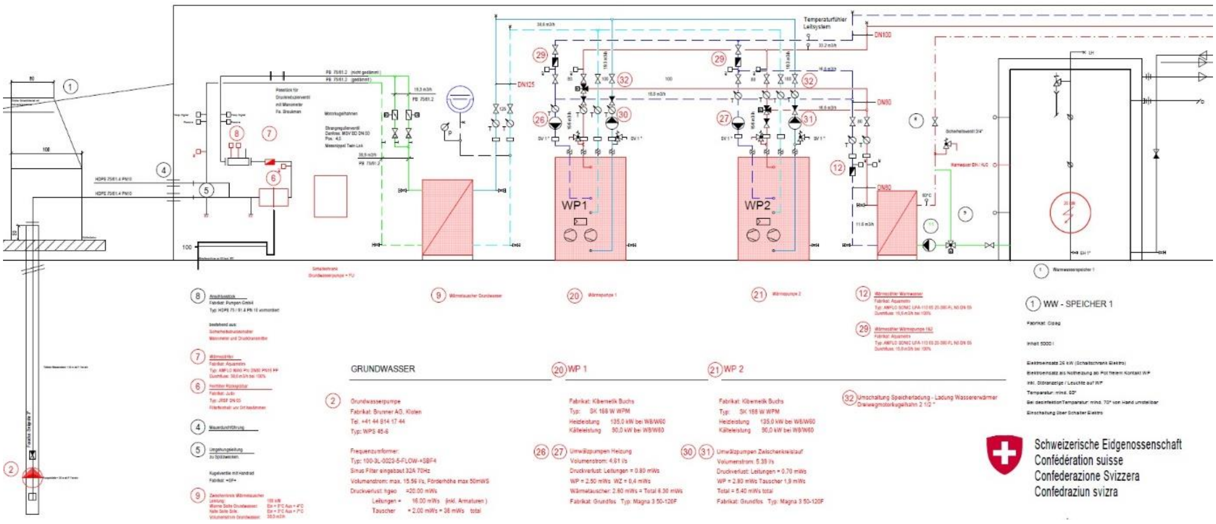

Figure 30: Hydraulic diagram of the heat supply at the troop accommodation building of the Swiss Army in Matt with two heat pumps from Kibernetik AG and a 5'000 L hot water storage tank.

Figure 31: The two groundwater heat pumps from Kibernetik AG and the hot water storage tank installed at the Swiss army troop accommodation building in Matt.

CH22 – Heating of the KOKON Corporate Campus buildings

The KOKON Corporate Campus in Ruggell (Liechtenstein) is a future-oriented workspace combining all amenities for employees (Figure 32). There are fully equipped offices of every size, 700 parking spaces, restaurants with a stylish ambience and sunny outdoor terraces, Kids Care, Fitness & Spa (Wellness) as well as an Event & Congress Center as an ideal location for events.

Figure 32: KOKON Corporate Campus in Ruggell (Liechtenstein) with workspace, restaurants and wellness.

For heating the buildings a water-water heat pump (Type: Neptune Tech NET 090 from MTA, Figure 33) with a heating/cooling capacity of 341/275 kW is installed [26]. The heat pump provides heat from 27 to 35 °C using 3 hermetic scroll compressors in parallel position and refrigerant R410A. With a heat source of 10/7 °C a heating COP of 5.17 is achieved.

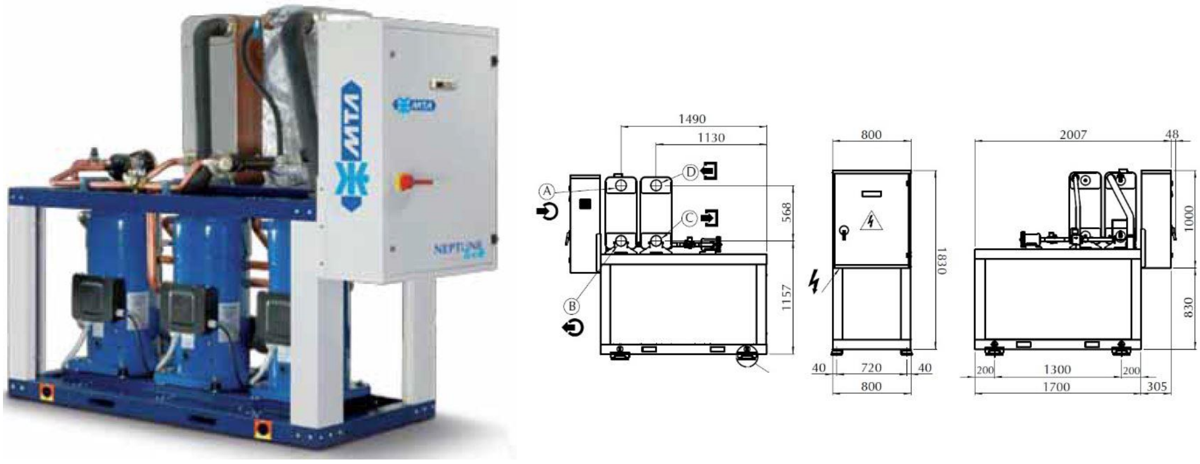

Figure 33: WTA Neptune Tech NET 090 heat pump with 3 hermetic scroll compressors positioned in parallel in one circuit (Dimensions L x W x H: 2.01 x 0.8 x 1.83 m) [26].

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CORPORATE CAMPUS

3.4 Viessmann (Schweiz) AG

The Viessmann Group is one of the leading international manufacturers of heating, industrial and cooling systems. The comprehensive product range offers individual solutions with efficient systems and capacities from 1.5 kW to 120 MW for all applications and fuel types. The family company was founded in 1917 and employs 12'300 people worldwide.

CH15 – Vinegar fermentation and pasteurization at Nutrex

Nutrex (meaning: NUT = Nutritio, REX = King) was founded in 1942 and is the leading supplier for vinegar in Switzerland. Since 1971, it is a division of the COOP Genossenschaft. With 15 employees, Nutrex produces approx. 8.9 million litres of vinegar per year in Busswil (Bern) of which 0.5 million liters are in organic (bio) quality [27]. More than 50 different vinegar varieties are sold for retail, caterers, restaurants and industry [28] (Figure 34).

Figure 34: Vinegar products of Nutrex made from wine, alcohol, apple juice and other fruit juices [27].

In 2008, COOP took the decision to achieve CO_2 neutrality within 15 years. Nutrex managed to achieve this goal already in 2009 by applying modern heat pump technology in its production site [29]. For the production of vinegar two specific processes are used: fermentation and pasteurization (Figure 35). These two processes fit perfectly for the application of a heat pump and serve as its heat source and sink. Vinegar fermentation occurs as the alcohol is converted into acid by bacteria. It is an exothermic reaction and stops when the mixture is getting too warm. To stabilize the process the large tanks need to be cooled at 30 °C over 10 days (Figure 36). On the other side, vinegar pasteurization takes place above 70 °C to obtain a non-perishable food.

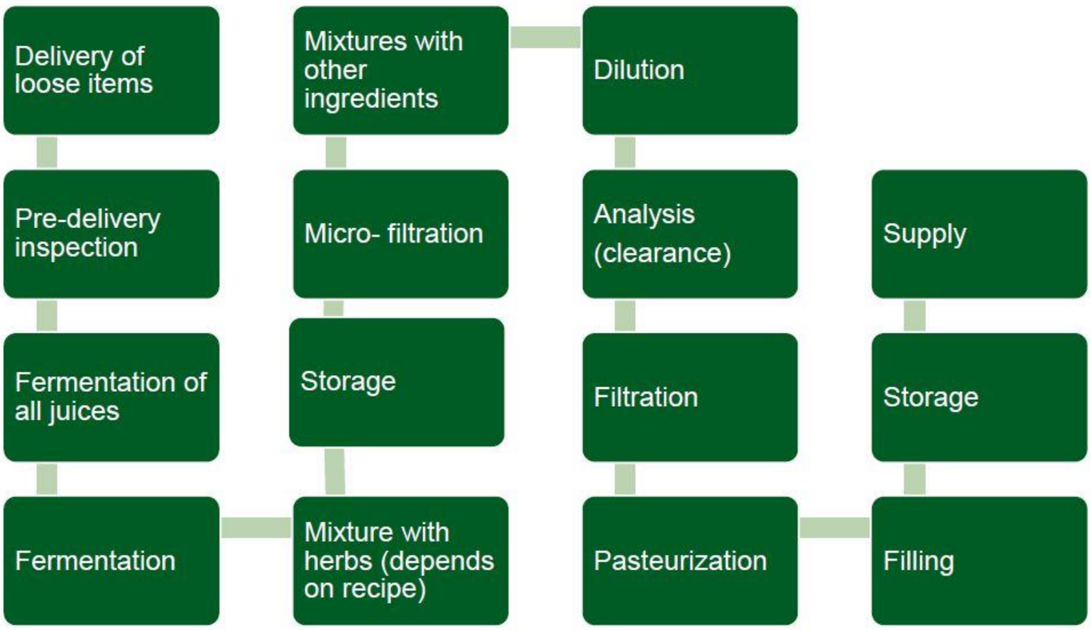

Figure 35: Production processes of vinegar with fermentation and pasteurization steps [28].

At Nutrex a heat pump (Viessmann, R134a, piston compressor) was installed with a cooling capacity of 136 kW and a heating capacity of 194 kW (Figure 36). The heat pump runs with a COP of around 3.4. Beside of the pasteurization, the produced heat is used for heating of the laboratory and of the building. Since the replacement of conventional oil heating in 2009, Nutrex has achieved a CO_2-free production. The use of the heat pumps has reduced the CO_2 emissions by approximately 310 tons/year and saves up to 65'000 liters of fuel/year [29]. The energy savings are about 50'000 CHF/year [30].

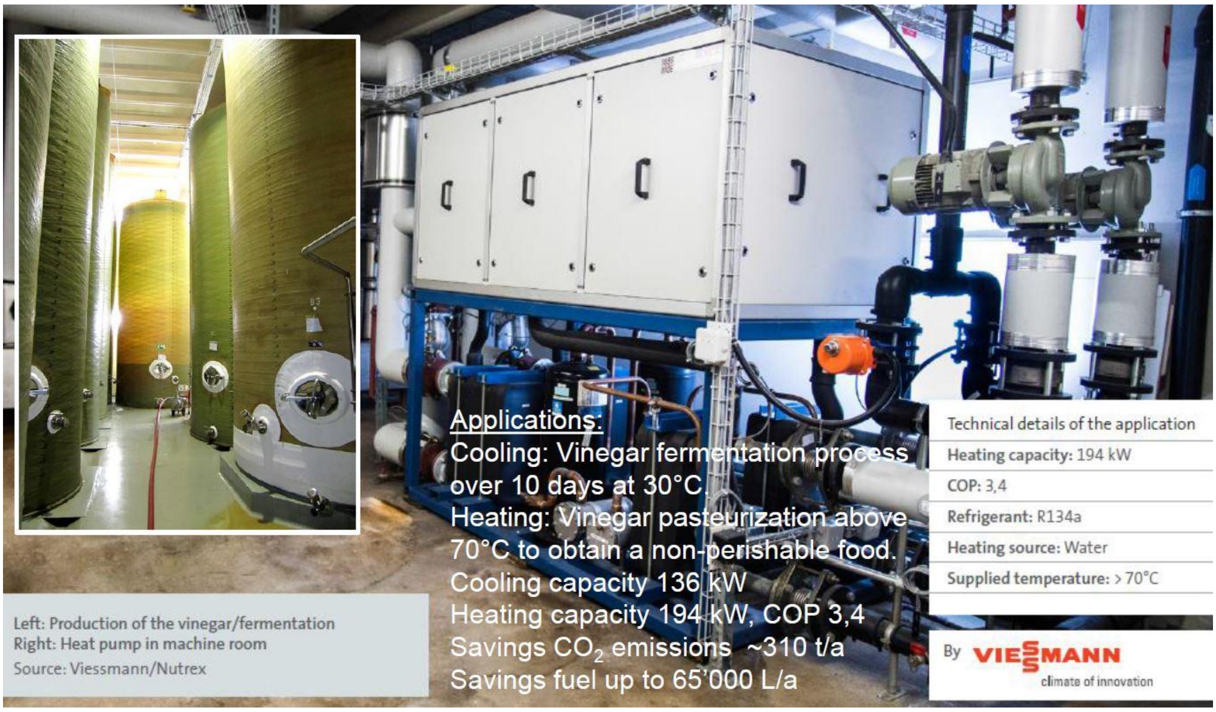

Figure 36: Vinegar fermentation and pasteurization using a heat pump from Viessmann [29].

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3.5 Friotherm AG

Friotherm originates from the Sulzer Group and offers heat pumps, refrigeration systems and services of high quality and reliability. Following a management buyout in 2005, Friotherm AG is an independent company located in Frauenfeld.

CH16 – District heating in Lausanne with large heat pumps

The Lausanne heat pump plant built in 1985 by Sulzer is one of the largest heat pumps in Switzerland [29,31]. Two 4.5 MW NH_3 heat pumps use the water of lake Leman (approx. 260 L/s at 6 to 7 °C) as heat source to supply heat in two district heating networks (e.g. the school and university in Lausanne) (Figure 37). The lake water is extracted from 65 m depth at 700 m from the beach. The water is cooled down by about 3 K in the evaporator and is released into a nearby river.

The two identical heat pumps have an economizer port for the oil-injected screw compressors. The two heat pumps can either be operated in series (two-stage heat pump) or in parallel (then one heat pump is on stand-by mostly) depending on the heating conditions. Ammonia was chosen mainly with regard to its excellent thermodynamic properties. A storage tank limits the start-ups of the heat pumps and thus mechanical wear.

The heat pumps supply 28 to 65 °C in a high temperature network and 26 to 50 °C in a low temperature network. For the peak loads, when the outside temperature is very low, the heat pumps are supported by two gas boilers. Measurements gave the following average Lorenz efficiencies of the heat pumps: 58.1% at 5/50°C, 59.7% at 6/45°C and 45.4% at 7/30°C [31], corresponding to heating COPs of about 4.2, 4.9, and 6.0 respectively.

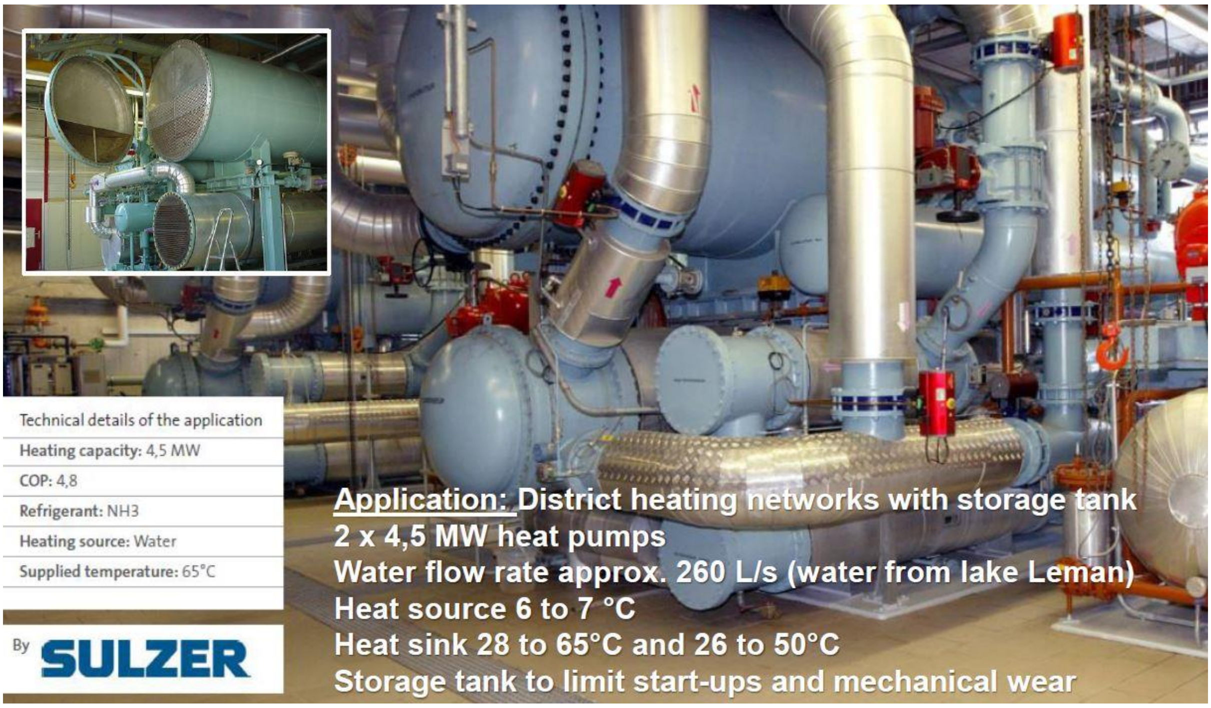

Figure 37: Two large NH_3 heat pumps in Lausanne (2x 4.5 MW) [29,31].

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3.6 Scheco AG

Scheco AG in Winterthur with 55 employees is a leading company in the refrigeration, air conditioning and heat pump industry in Switzerland. The company is a pioneer in refrigeration technology. The company has a long history dating back to 1865. In 1932, the first fully automatic refrigeration plants were built in Winterthur.

Today, Scheco AG serves a wide range of customers in the commercial, industrial and building technology sectors. Sustainable and reliable systems and equipment are planed, manufactured and documented in accordance with the applicable laws, guidelines and local regulations, in particular:

- ISO 9001
- Pressure Equipment Ordinance (2014/68/EU)
- Chemicals Risk Reduction Ordinance ChemRRV
- SN EN 378/1-4 Refrigerating systems and heat pumps
- Machinery Directive 2006/42/EC

For industrial customers various products and solutions are offered. Table 11 shows technical data of two case studies of industrial heat pumps for wastewater treatment in a sewage treatment plant and waste heat recovery in a thermal bath.

Table 11: Technical data of two industrial heat pumps from Scheco AG for wastewater treatment and waste heat recovery in a thermal bath [32,33].

Name of the project	**Sewage treatment plant (CH11)**	**Thermal bath (CH12)**
	Zurich, Switzerland	**Nordwest of Switzerland**
Year of installation	2014	2008
Application	hot water for district heating	hot water for thermal water
Process applied	heat recovery	heat recovery
Heat source	(cleaned) wastewater	wastewater
Heating capacity	410 kW	550 kW
Heat sink inlet/outlet	44/50 °C	47/55 °C
Heat source inlet/outlet	7/2 °C	29/5 °C
Compressor	Screw with integrated inverter for part-load control	Triple screw
Working fluid	R134a	R134a
Heat pump costs	150'000 CHF	250'000 CHF
Annual operation	4'500 h/a	5'000 h/a
Annual maintenance costs	2'000 CHF without repair	3'500 CHF without repair
Reference	[32]	[33]

CH11 – Heat recovery of the cleaned wastewater from a sewage treatment plant

Heat recovery from cleaned wastewater of a sewage treatment plant in Zurich supplies hot water for a local heating network. A heat pump from Scheco AG with a heating capacity of 410 kW that runs with R134a generates heating water of 50 °C from wastewater (heat source) with a temperature of 7 °C. The heat pump works with a compact inverter-controlled screw compressor, which enables a large control range with very good part load performance [32]. Figure 38 shows the screw compressor with the integrated inverter for part-load control and a 3D layout of the energy center. The heat pump costs amounted to around 150 kCHF. The annual maintenance costs are around 2 kCHF without repairs.

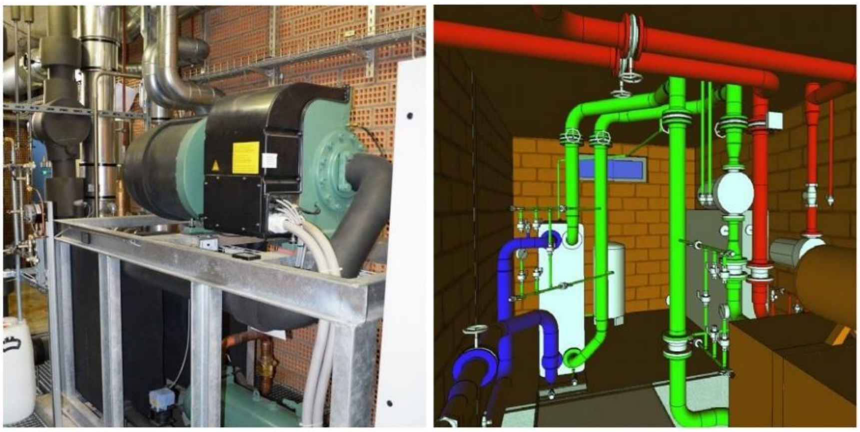

Figure 38: Screw compressor with integrated inverter and 3D layout of the energy center [32].

CH12 – Thermal bath with heat pump for heat recovery

There are around 30 thermal baths in Switzerland. Most thermal baths are committed to the sustainable use of resources in the fields of energy and climate protection. The aim is to further reduce energy consumption significantly over the next few years. Popular measures are:

- pool covering to reduce heat radiation over night,
- power saving with energy-saving lamps and LED lighting,
- shower heads, which reduce water consumption,
- sauna systems with special energy management, and
- the installation of heat pumps, which extracts energy from the used thermal water.

Figure 39 shows the installation of a water/water heat pump in a thermal bath in Northwestern Switzerland, which extracts the energy from the 29 °C used water of the thermal pools and raises it to a higher usable temperature level of 55 °C [33]. The heat is used to heat the pools and to prepare hot thermal water. The heat pump has three screw compressors and a heating capacity of 550 kW.

Figure 39: Installation of the new water/water heat pump for heat recovery of waste thermal water with two special cranes in the area of the thermal bath [33].

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3.7 EWZ Energielösungen

EWZ (Elektrizitätswerk Zürich) is the service department of the City of Zurich with around 1,200 employees and has been active in the energy market for 125 years. EWZ is responsible for the production, sale and distribution of energy. Various energy solutions are also offered. The company covers the entire range of services from planning, construction, operation and optimization of complex plants in the areas of heating/cooling supply, photovoltaics and medium voltage. Combined with the competence of energy consulting, this creates a comprehensive range of services for building owners and infrastructure operators.

CH01 – Heat pump system at the Slaughterhouse in Zurich

The slaughterhouse in Zurich opened as a municipal facility in 1909 and has been operated by the Schlachtbetriebe Zürich AG since 1995. The City of Zurich, represented by Umwelt- und Gesundheitsschutz Zürich (UGZ), is the owner of the site and the buildings. The slaughterhouse is located in a historic building in the middle of the city. 500 employees process more than 24’000 tons of meat annually [34]. Heat is mainly used for the production of hot water for cleaning processes (hygiene), domestic hot water, and space heating (50/30°C).

Since 2011, a heat pump system is in operation with 3 CO_2 heat pumps thermeco$_2$ HHR 260 (Thermea, Germany, today ENGIE) that delivers 800 kW heating capacity and water up to 90 °C (Figure 41). The heat pumps are driven by twelve transcritical GEA CO_2 compressors (HGX34/150-4 SH CO2 T) [35] (Table 12). EWZ planned and operates the heat pump system.

The heat pump system uses the waste heat from an existing ammonia refrigeration machine, an oil-cooled air compressor plant and fan-coil units. For this reason, the heat is collected in a waste heat buffer storage tank conneced with the heat pump evaporators. Apparently, the plant is the largest built in Switzerland [34]. The heated water is used for slaughtering and cleaning purposes and for feed water for a steam generator and the heating system.

The COP of the heat pump is 3.4 at 90°C/30°C [36]. The heating system is additionally supported by a gas boiler as back-up heater. The warm side of the heat pumps is connected with a hot water buffer storage. The processes are provided from this buffer storage.

With the heat pump, 2’590 MWh of fossil fuels can be saved per year. The annual reduction in CO_2 emissions is 510 tons, which is around 30 % lower than before using steam boilers. The environmentally friendly energy supply in the slaughterhouse makes an important contribution on the way to becoming the 2000-watt society of the city of Zurich.The case study serves as a model for numerous slaughterhouses in Switzerland and other countries.

Figure 40: Three CO_2 heat pumps of the type thermeco2 HHR 260 at the slaughterhouse in Zurich [35,37]

Table 12: Technical data of the heat pump system at the slaughterhouse in Zurich.

Machine type	3 x thermeco$_2$ HHR 260
Refrigerant	R744 (CO_2)
Compressors	12 x piston GEA CO_2 compressors (HGX34/150-4 SH CO2 T, transcritical)
Capacity control via master CPU	ajustable in 12 steps
Heating capacity	800 kW at 90 °C heat sink outlet / 30 °C heat sink inlet
Cooling capacity	564 kW at 20 °C heat source inlet / 14 °C heat source outlet
Energy savings	2'590 MWh fossil fuels
CO_2 emissions reduction	30% (510 tons CO2/a)

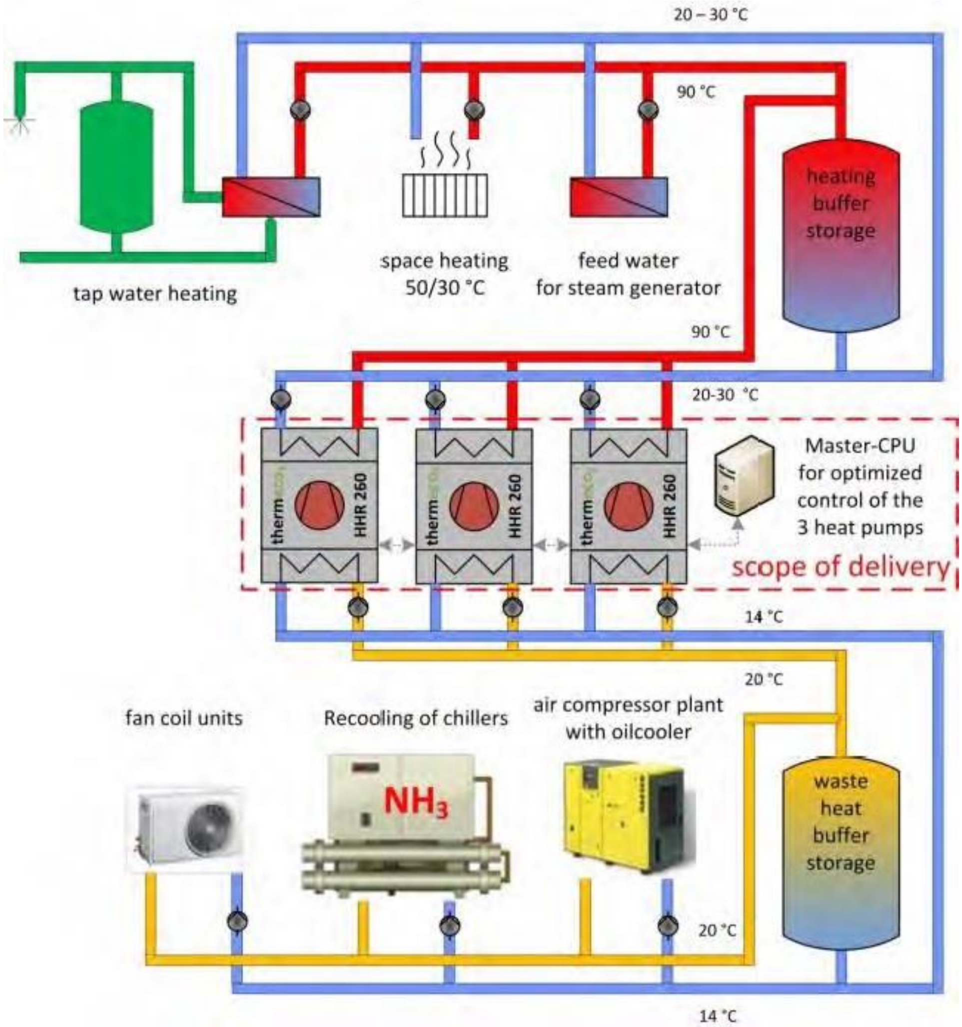

Figure 41: Function chart of the heat pump system at the Slaughterhouse in Zurich [36].

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3.8 Durena AG

Durena AG, founded in 1990, employs around 20 people in Lenzburg, Zurich and Altdorf and provides complete and high-quality energy engineering services. Durena AG does planning and site management of such projects from concept to construction and execution [38].

CH28 – Heat from purified wastewater for sewage sludge drying at ARA Altenrhein

A selected reference in the field of heat pumps is the waste heat recovery from wastewater for sewage sludge drying. In 2005, it was decided to replace the existing sewage sludge drum drying plant at the wastewater treatment plant ARA Altenrhein with a low-temperature belt drying plant. Durena AG was commisioned to implement a new plant concept. The cleaned wastewater is fed into a water basin. Automatic basket filters filter the water and two heat exchangers serve as hydraulic network separators (Figure 42). The liquid sludge is dewatered and then dried in low-temperature sewage sludge dryers [39]. Two identical heat pumps from GEA with 2x 1'420 kW heating capacity extract the heat from the wastewater and generate the heat for the two belt dryers (Table 13).

A hot water storage tank (30 m^3) absorbs short-term load fluctuations and extends the running time of the heat pumps. In addition, heat recovery from the nearby combined heat and power plants is integrated into the heat generation process. The two belt dryers are supplied with the necessary heat energy via 24 air heater groups. Due to the low drying temperatures of less than 60 °C, low-temperature sewage sludge dryers have various advantages:

- Waste heat from wastewater for dryer heating
- Fossil heat generation can be omitted
- Large quantities of CO_2 emissions are avoided

The generation of thermal energy for sewage sludge drying from wastewater is an economically and ecologically useful way. Operating experience confirms the high efficiency and availability of this proven technology.

Figure 42: Front view of the two heat pumps and plate heat exchangers for waste water with filter systems [38], [39].

Table 13: Technical data of the two GEA heat pumps [38].

Total heating capacity (S8/W65)	**2 x 1'420 kW**
Heat sink (hot water) inlet/oulet	55/65 °C (45/55 °C)
Heat source (wastewater) inlet/oulet	8/2 °C
Hot water tank capacity	30 m^3
Wastewater flow rate	344 m^3/h
Refrigerant	R134a
Annual COP	**3.62**
Reduction of CO_2 emissions	**approx. 3'000 t/a**

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3.9 SSP KÄLTEPLANER.CH

The team of SSP KÄLTEPLANER is developing ecological and economical solutions in the refrigeration industry for 25 years. As a specialist in refrigeration planning, the company has in-depth expertise in various market segments, such as planning of commercial and industrial refrigeration plants, integrated solutions for waste heat utilisation, heat pump systems, and development of analyses, energy studies and renovation concepts for refrigeration generation and distribution.

CH19 – Heating and cooling at the vegetable producer Kellermann AG

Kellermann AG in Ellikon an der Thur is one of the largest vegetable producers in Switzerland. The company produces lettuce and salad vegetables outdoors and tomatoes in glasshouses [40–42]. To support growth of tomatoes it is necessary to heat the air during a longer yearly period. Salad and vegetables need cooling for rapid cooling and storage. Convenience products require cooling for cold water (washing) and storage.

Figure 43: The logistics building of the company kellermann.ch in Ellikon bei der Thur [40].

An extension of the logistics building resulted in additional cooling requirement. At the same time, the greenhouses are heated throughout the year. An integral concept was developed by the company SSP KÄLTEPLANER.CH for a large, central cooling system with a heat pump to heat the greenhouses. The concept design included cooling and heating with just one ammonia (NH_3, R717) system using groundwater as heating source. The goals of the basic concept and design were [42]:

- Central refrigeration plant for about 1’000 kW refrigeration capacity, optimal for heat recovery and easy to maintain
- Highly ecological and effective technology with an environmental friendly refrigerant
- Cold distribution with glycol water
- Heat recovery 1’000 kW (ground water available)
- High quality standard for operation and plant safety.

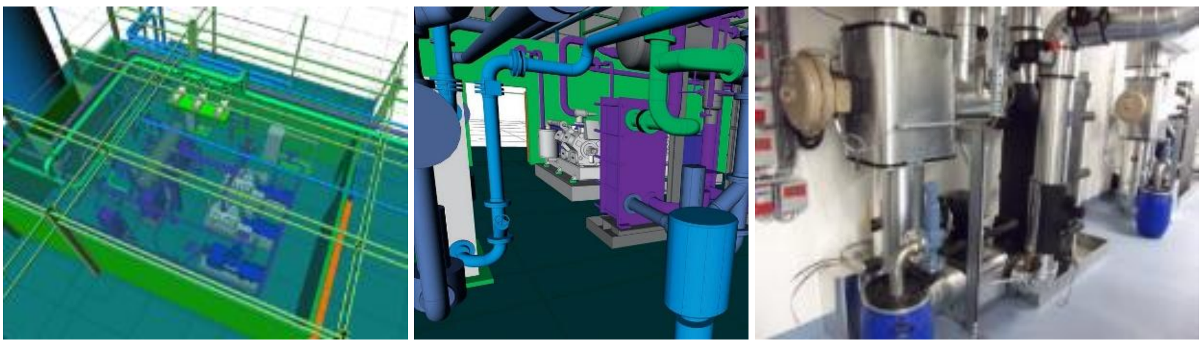

Figure 44: Cooling and heating with just one ammonia heat pump system (SSP KÄLTEPLANER.CH) [42].

The cooling and heating demand varies depending on the season and vegetable harvest quantity. In winter, for example, the cooling capacity demand decreases due to lower outside temperatures, while the heat requirement in the greenhouses increases accordingly. The system can respond to these changes with three different operating modes - either cooling or heating mode or combined cooling and heating mode. Figure 45 shows the principle drawing of the cooling and heating network [42]. The installed refrigeration system consists of two Sabroe low-pressure piston compressors (Type: SMC 112L, with permanent magnet motors and electronic variable speed inverters), one evaporative condenser and two plate evaporators. The system is filled with ammonia (R717) as refrigerant.

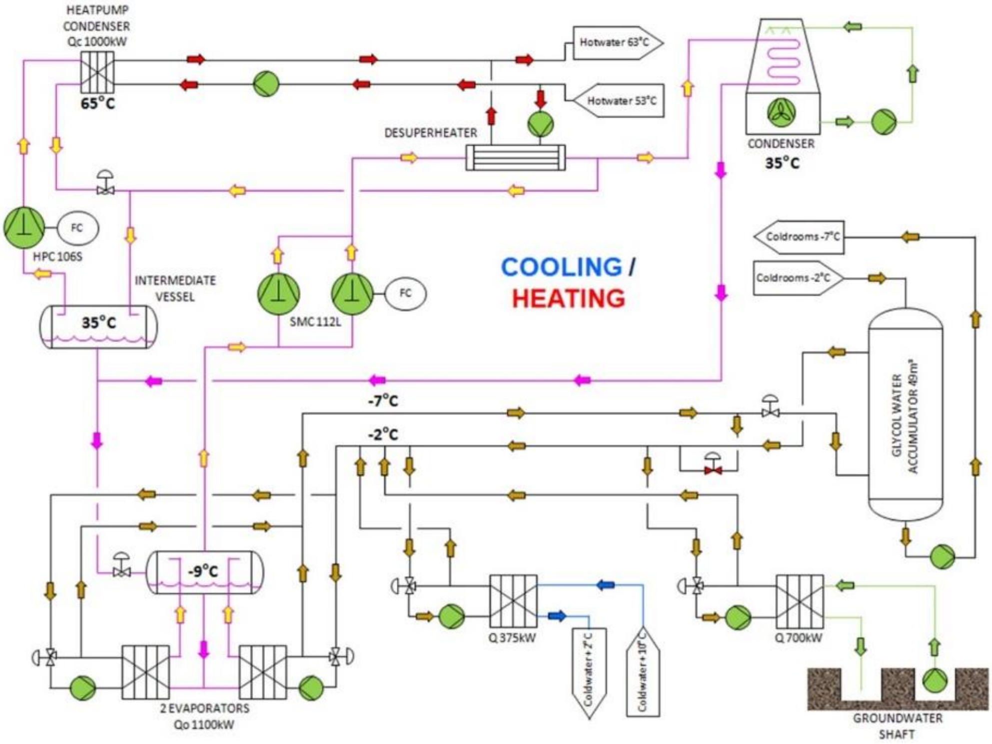

Figure 45: Principle drawing of the cooling and heating network [42].

Figure 46: Ammonia compressors from Johnson Controls of brand Sabroe (HPC version 106S, 40 bar) with permanent magnet motors and electronic variable speed inverters [40,42].

In pure cooling mode, the heat is absorbed via the two evaporators and dissipated via the condenser. The cooling COP_C is then 3.61 (-9°/+35°C) [40]. The cold produced is distributed via a glycol-water network at -7 °C for rapid cooling and coldrooms (with accumulator tank of 49 m^3). The cold water is cooled from 10 °C to 2 °C (at 40 m^3/h).

The coupling to the heating system is carried out via a desuperheater (max. 130 kW, 53 to 63 °C) or via an additional heat pump (1'000 kW), which consists of a Sabroe high-pressure piston compressor (HPC 106S, 40 bar), a condenser (65 °C) and an intermediate pressure tank (35 °C). The desuperheater is used to supply heat to the heating system continuously. The heat pump switches on if there is additional heat demand. The heating COP_H of the compressor is 7.57 (35°C/65°C) [40]. The greenhouses require an air temperature of approx. 60°C for heating.

If there is no cooling demand, like in winter, groundwater is used as the additional heat source (max. 700 kW). In pure heating mode, the COP_H of the heat pump process is 3.6. The total capacity of the refrigeration system is 1'100 kW and the total capacity of the heat pump 1'000 kW. To control the system a Siemens S7 controller is applied.

The coupling of the refrigeration with a heat pump system enables Kellermann to significantly reduce the costs of refrigeration and heat generation. The heat pump generates 4 to 5 GWh of heating energy per year. This saves the company about 500'000 m^3 natural gas for heating the greenhouses.

The environment benefits are a reduction of CO_2 emissions by 790 tons per year. If the heat pump is operated with "green electricity", the system even saves the environment 960 tons of CO_2 per year. The project has been supported by the private organisation Klimastiftung Schweiz and ProKilowatt, which is supported by the Swiss Federal Office for Energy (SFOE).

Table 14 list some other projects using similar ammonia (NH_3) heat pump installations planed by SSP KÄLTEPLANER AG.

Table 14: Other projects from SSP KÄLTEPLANER AG with industrial ammonia (NH_3) heat pumps.

Company	Industry	Application	Contact, Tel.
Bell Oensingen	Meat production	Domestic hot water	Stefan Zimmerli, +41 58 326 31 24
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3.10 Frigo-Consulting AG

Frigo-Consulting is a leading engineering company for refrigeration technology in Switzerland and one of the worldwide leaders in CO_2 refrigeration planning. The company is headquartered in Berne and has two branches in Switzerland (Lausanne, Zurich) and four branches in Europe (Italy, Poland, Romania and Spain).

CH18 – CO_2 heat pump for water heating in Swiss Army Training Hall

On behalf of the Swiss Federal Department of Defence, Civil Protection and Sport (DDPS) Frigo-Consulting implemented two CO_2 heat pump in the Swiss Army Training Hall of Payerne [43]. To meet the requirements of the Swiss army, the following technical criteria were of major importance for this project:

- Energy efficiency
- Ecological aspects
- High temperature levels
- Adaptation of the performance levels on demand

Figure 47 illustrates the two CO_2 heat pumps manufactured by the Italian company ENEX Srl. (www.enex.it). The Airheat heat pumps are designed to work at outdoor air conditions down to -9 °C. The application is facility heating and the production of hot tap water from 30 to 70°C. The air-water heat pumps run with piston compressors using CO_2 in a transcritical cycle. The total heating capacity is 60 kW. The hot water is distributed via a two networks at different operating temperatures.

Figure 47: CO_2 heat pump from ENEX and heat distribution for the Swiss Army Training Hall in Payerne [43].

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Ingenieurbüro für Kältetechnik FRIGO CONSULTING

3.11 eicher+pauli AG

Dr. Eicher+Pauli AG is a competent planner for energy and building technology since 1986. Today, more than 100 qualified employees work at several locations in Switzerland. The company plans comprehensive energy supply concepts for buildings, districts or entire cities, and implements the appropriate energy supply systems, such as large heat pumps, refrigeration systems and heat recovery. Dr. Eicher+Pauli AG is also a specialist in pipe construction and process energy for steam and hot water.

CH24 – District heating and cooling network Casino Aarau

The city of Aarau with about 20’200 inhabitants has set the goal of complying with the criteria of the 2000-Watt-Society by significantly reducing CO_2 emissions and the share of fossil fuels of the final energy demand for heat < 40% by 2035 [44]. On behalf of IB Aarau (Eniwa AG, Buchs AG), eicher+pauli designed an innovative cooling and heating system for the district heating and cooling (10 °C) network [45]. The owner and operator IB Aarau invested around 18 million CHF into the project [44].

Dr. Eichereicher+pauli AG planned and implemented the energy centre for the district heating (70 °C) and cooling network in an old civil defence facility under the casino parking lot in the middle of the city of Aarau (Figure 48). A chimney concept was implemented to ventilate the shelter, which leads about 100 m through the ground and finally along the facade of a cinema complex over the roofs.

Figure 48: City of Aarau with the district heating (1.2 km) and cooling (1.1 km) network. Tunnel for the heat network and two NH_3 heat pump (HPC108SV, SMC112LV, Sabroe) from Johnson Controls [45,46].

In the energy centre, around 80% of the required heat is generated practically CO_2-free with two NH_3 heat pumps (Sabroe) from Johnson Controls (cooling capacities/power consumption: HPC 108 SV, 1060/153 kW, COP 6.9 at 34.4/69°C, SMC 112 LV, 915/147 kW, COP 6.2 at 3.3/34.4 °C). The main heat source is groundwater (9/5°C), which is available in large quantities. A gas boiler heating system (2 x 1.7 MW capacity) serves as redundancy and is switched on to cover peak loads of the heat demand. Free-cooling extracted from the groundwater supplies the cold to the consumers. If free-cooling is not sufficient enough, the heat pump chillers are switched on. The combined heat pump/cooling system achieves a heating energy of 10’400 MWh and a cooling energy of 3’200 MWh.

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CH25 – Heating and cooling supply at Mifa AG in Frenkendorf (BL)

As part of the Mibelle Group, Mifa AG in Frenkendorf (BL) is a company of the Migros M-industry. Here, detergents and cleaning agents as well as margarines and edible fats are produced (Figure 49). In the Home Care and Nutrition segments, the company is number three on the European private label market [47].

Figure 49: Mifa AG in Frenkendorf produces detergents, cleaning agents, margarines and edible fats (Mibelle Group / Mifa AG).

eicher+pauli was commissioned with the renewal of the heating and cooling supply of Mifa AG in Frenkendorf (BL). For Mifa AG/Mibelle-Group and the Migros industry this means an important step into a sustainable future. A new energy center was built for around CHF 11 million with the following highlights [47–49] (Figure 50):

- Heat and cooling generation by means of combined heat pump / chiller with heat recovery
- Use of waste heat from compressed air production
- Reduction of gas consumption and CO_2 emissions by around 60% (960 tons per year)
- Reduction of electricity consumption by around 20%
- Reduction of water consumption by around 70%

The new energy center supplies two separate heating networks with temperatures of 110 °C (high temperature) and 70 °C (medium temperature for hot water and heating). In the high-temperature network, the fossil steam boilers have been replaced by efficient hot-water boilers, which also ensure peak coverage of the low-temperature network [47]. Waste heat from the compressed air system and the exhaust gas condensation is used for operation of the medium-temperature network.

Figure 50: New energy center of Mifa AG in Frenkendorf [47,48].

In total, the new energy centre contains 6 heat pumps and refrigeration units (Figure 51). The heating capacity of the heat pump is about 885 kW, the total cooling capacity of the minus and plus cooling 804 kW and 1'814 kW respectively (Table 15).

Table 15: Ammonia (NH_3) heat pumps from Johnson Controls (Sabroe) at Mifa AG in Frenkendorf.

Units	Compressor Sabroe	Temperature	Application	Capacity	Power	COP (cooling)
1x heat pump	HPC 106 SV (piston)	38/57°C, 49/70°C	Hot water, heating	885 kW	134 kW	6.6 (32.5/69°C)
3x refrigeration	SMC 116 LV	-29 °C	Process cooling	402 kW	79 kW	5.1 (-29/1 °C)
2x refrigeration	SMC 112 LV	4/2 °C	Ice water	907 kW	161 kW	5.6 (-1/32.5 °C)

Figure 51: The installed NH_3 compressors (Sabroe, Johnson Controls) in the energy center of Mifa AG at Frankendorf. Three compressors (JC/Sabroe SMC 116 LV) for the -29°C cold, two compressors (JC/Sabroe SMC 112 LV) for the ice water production with 2°C, and one heat pump (JC/Sabroe HPC 106 SV) for heat recovery providing 70 °C [47,48].

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CH26 – Heat recovery at Bachem AG in Bubendorf (BL)

Bachem AG, headquartered in Bubendorf (BL), is a global Pharmaceutical and Biotechnology Company specialized in the production of peptide-derived active pharmaceutical ingredients. The production plants require process cooling with high availability and operational reliability. As the demand for refrigeration has increased in recent years and the old plants were no longer able to meet this demand alone, eicher+pauli was commissioned to plan a new refrigeration supply system.

Two existing chillers (2 x Sabroe HPO 28 VSD, 237/284 kW heating/cooling capacity) were refurbished and are used to cover the peak load and redundancy. A new combined ammonia-powered chiller/heat pump was installed (8 cyclinder Sabroe HPO 28 VSD type [50]) to cover the increased demand and at the same time enable heat recovery [51]. The resulting regenerative heat energy is used for heating and domestic hot water. This saves around 300 tons of CO2 annually.

This concept ensures a reliable and safe cooling supply for production. An intelligent building automation system regulates the optimal interaction of the three heat pumps. The cold water (8°C flow, 14°C return) is fed into the cooling network via a pipeline from the new technical center.

Table 16: Ammonia (NH_3) heat pumps from Johnson Controls (Sabroe) at Bachem AG in Bubendorf.

Units	Compressor	Temperatures (refrigerant)	Application	Heating/ coolig capacity	Power	COP (heating)
2x (existing)	Sabroe HPO 28 VSD	6/45 °C	Process cooling	237/284 kW	50.4 kW	4.7
1x (new)	Sabroe HPO 28 VSD	38/71 °C	Heating/hot water	513/585 kW	72.6 kW	7.1

Figure 52: Headquater of Bachem AG in Bubendorf with Sabroe HP 28 VSD NH_3 heat pumps [51].

As a guideline the service and maintenance costs of a large NH_3 heat pump are approx. 2.5 to 3% of the system costs [52]. This means that sufficient money needs to be budgeted for compressor maintenance, which is carried out after 4 to 6 years, depending on the annual operating hours of the plant like 20'000 h, 30'000 h or 40'000 h depending on compressor type. The life expectancy of a large NH_3 heat pump is about 30 to 35 years [52].

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3.12 Gruner Gruneko AG

Gruner Gruneko AG, founded in 1974, is an independent consulting and planning company based in Basel with around 80 employees. Its core competencies are in the fields of building services engineering, energy systems and piping construction. The company offers private and public customers many years of experience and comprehensive expertise as a general and specialist planner. Qualified engineers provide customer-specific solutions in the energy technology sector.

CH27 – Waste heat recovery at Feldschlösschen Getränke AG in Rheinfelden

Feldschlösschen Getränke AG is the leading brewery and the largest beverage retailer in Switzerland with its headquarters in Rheinfelden (AG). Beer has been brewed on the hill above Rheinfelden since 1876 (Figure 53). Today the Feldschlösschen brewery produces around one million litres of beer per week [53]. Since 2000, Feldschlösschen is a subsidiary of the Danish Carlsberg Brewery Group.

Figure 53: Feldschlösschen Getränke AG in Rheinfelden with waste heat for the district heating network.

The annual energy consumption at Felschlösschen is a about 45 GWh, of which two thirds are heat and one third electricity [53]. The used fuels are natural gas, biogas from the in-house pre-treatment plant, alcohol from the dealcoholisation plant, and heating oil. The heat is required in various process steps during beer production. Around 40% is used in the brewhouse, where the wort is boiled and then cooled again. The two other major thermal energy consumers are the dealcoholisation plant (for the production of alcohol-free beer) and the tunnel pasteuriser (for pasteurising a large part of the production).

In cooperation with AEW Energie AG, the city of Rheinfelden and the Feldschlösschen brewery, a district heating network for Rheinfelden Mitte was built. Gruner Gruneko AG was commissioned by AEW Energie AG with the technical planning, execution and commissioning of the energy system [54]. In September 2014, the district heating network was put into operation. Figure 54 shows the principle diagram of waste heat recovery from the beer production for the district heating network.

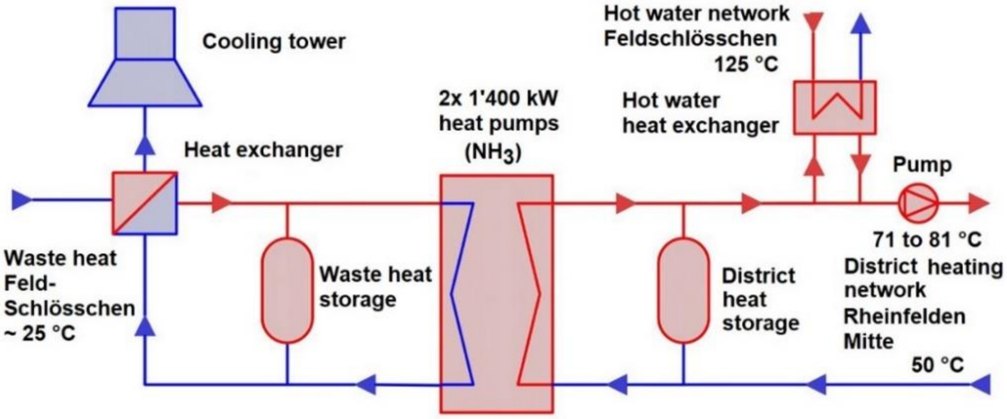

Figure 54: District heating network uses waste heat from beer production as heating energy. Overview of the waste heat utilization system with two NH_3 heat pumps and storage tanks (Gruner Gruneko AG [54]).

The new heating network Rheinfelden Mitte supplies more than 600 households all year with heating water for room heating and domestic hot water (Salmenpark complex, Schifflände area, and parts of the old town of Rheinfelden) [55]. In the buildings of the Feldschlösschen castle a heating center was built. The total capacity of the new district heating system is around 6‘000 kW. Over 6‘000 tons of CO_2 emissions can be saved annually.

Feldschlösschen has four cooling systems distributed over the entire brewery area. The waste heat from the brewery's cooling systems (refrigeration plants) and the the brewery's own wastewater is collected in a waste heat ring (Figure 54). The waste heat has a temperature of about 12 to 30 °C, depending on the beer production volume and season [55]. This waste heat is stored in low-temperature storage tanks in the cellar of the brewery house (Figure 55). The waste heat of around 25 °C is lifted up to 81 °C in winter and 71 °C in summer by two 1‘400 kW NH_3 heat pumps (Mayekawa MYCOM, N6HK-DD, N6M-DD) before it is fed into the district heating network. Over 90% of the heat is generated CO_2-free. The remaining heat (at peak load, emergency supply) is supplied by a gas-fired heat generation plant into the heat network. The heating COP of the heat pumps is about 3.41 in winter (W16/W81) and 4.88 in summer (W30/W71) (Table 17).

Figure 55: Storage tanks (3 x 58 m^3) for the waste heat and Mayekawa MYCOM compressor [54].

Table 17: Summer and winter conditions of the waste heat and district heating network.

Season	Waste heat (in/out)	District heating network (in/out)	Heating capacity district heating	COP (heating)
Winter	16/10 °C	50/81 °C	1’351 kW	3.41
Summer	30/24 °C	50/71 °C	1’296 kW	4.88

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3.13 Lemon Consult AG

Lemon Consult AG is a specialized engineering and consulting company for energy efficiency, sustainability and renewable energies in the field of buildings and technical installations. Since 2000, the Zurich-based company, with around 30 employees, successfully supports its customers with professional competence, new ideas and groundbreaking solutions.

CH23 – Kambly SA, Trubschachen – biscuit producer

The Swiss biscuit producer Kambly SA based in Trubschachen (Figure 56), renewed its energy supply system to eliminate oil for heating, reduce CO_2 emissions, and increase energy efficiency. The company Lemon Consult was commissioned to optimize the energy supply for heating/cooling and cold distribution [56].

Figure 56: Kambly SA in Trubschachen [56] producing biscuits.

In a first stage, the existing two oil boilers for process and building heat were dismantled and the old heat pump from 2002 was replaced by a new, more efficient, and larger heat pump with 471 kW heating capacity (Figure 57 and Figure 58).

Figure 57: Heat pump from Friotherm AG (Type X22HE-450A) running with screw compressor from Bitzer (CSH9573-180Y) and HFO refrigerant R1234ze.

The heat pump is from Friotherm (Type: X22HE-450A), which runs with a screw compressor from Bitzer (Type: CSH9573-180Y) and low GWP HFO refrigerant R1234ze. The waste heat from the air conditioning units and biscuit baking ovens is recovered at 20 to 30 °C and transformed to 65 °C by the heat pump for hot water generation for all buildings. To cover production-free times two condensing gas boilers with 450 kW heating capacity each are installed, additionally. The heat pump and a 6'000 litres stainless steel water storage tank have been installed in the old oil tank rooms [57]. With a power consumption of 121 kW a nominal heating COP of 3.9 is achieved (30W/65W). Overall, the new energy supply system with the heat pump saves 25% energy and led to a reduction in CO2 emissions of around 100 tons per year.

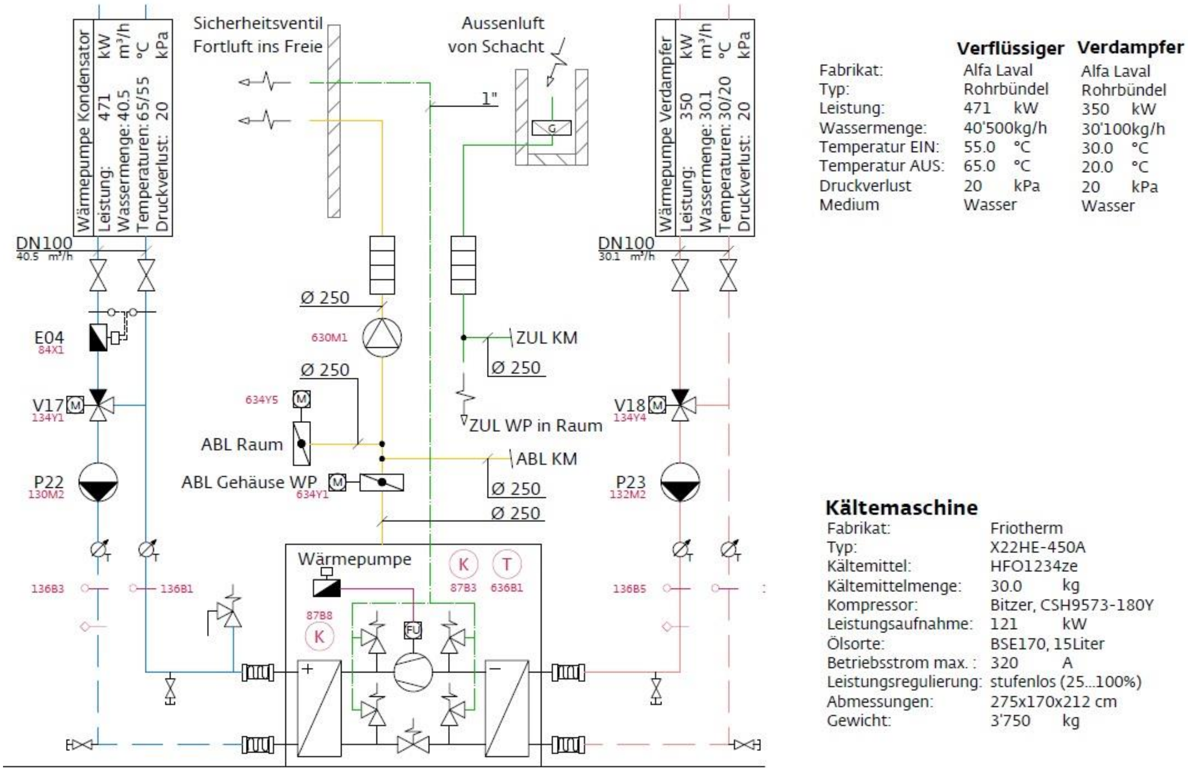

Figure 58: Principle drawing of the heat pump installation at Kambly SA.

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CH29 – Waste heat recovery from the refrigeration plant at Hilcona AG

Hilcona AG (Schaan, LI) is the market leader for fresh convenience foods in Germany, Austria and Switzerland with more than 2'000 employees. Founded in 1935 as a tinned food factory in Liechtenstein, the Hilcona Group today comprises a number of factories and several distribution sites. In Europe, the product range focuses on fresh pasta, muesli and menu components. The main export markets are Germany, France, Austria and the Benelux countries as well as Poland.

Figure 59: Hilcona AG in Schaan producing fresh convenience foods.

The installed refrigeration system for the production of the convenience foods in Schaan (LI), consists of a two-stage ammonia plant with two cooling networks at -8 °C (75/25 water/glycol mixture) and +8 °C (water). Three chillers are in place with a total cooling capacity of around 3'000 kW. Each chiller is specified with a cooling capacity of 980 kW driven by a Grasso RB-5A screw compressor. From the oil coolers, heat is extracted for heating and hot water (in: 45/50 °C, out: 65/70 °C).

A NH3 heat pump type GEA Grasso 65HP with 6 piston cylinders is used for waste heat recovery of the refrigeration plant. The heat pump has a heating/cooling capacity of 507/437 kW at 31/65 °C and feeds a 60 m3 storage tank for space heating and hot water. The evaluation of the energy costs and energy consumption in 2016 resulted in 5'805 operating hours with a heat production of 2.25 GWh and an electricity consumption of 0.37 GWh, resulting an annual average COP of 6.04.

Figure 60: Left: GEA Grasso 65HP wth 6 cylinders and oil separator for waste heat recovery. Right: GEA Grasso RB-5A chillers with screw compressor at Hilcona AG in Schaan (FL).

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Toblerone chocolate production at Mondelēz Schweiz Production GmbH

The US-American manufacturer Mondelēz International (formerly Kraft Foods) is one of the world's largest snacking companies and its portfolio includes chocolate, biscuits, gum and candy.

In Switzerland, the legendary Swiss chocolate Toblerone with honey and almond nougat are produced, as well as Stimerol and V6 brands. Toblerone is recognized by its triangular shape invented in 1908 by Theodor Tobler and Emil Baumann. Since 1985, all Toblerone products have been manufactured exclusively in Brünnen near Bern with around 220 employees around the clock.

The factory produces around 35'000 tons of chocolate per year. Toblerone is available around the world, 97 % of the production is exported. In the production, a heat pump is used with a heating capacity of 450 kW (COP 5.5, ~ 0.5 GWh/a). For reasons of confidentiality, no further information on heat pump integration is available.

TOBLERONE


Figure 61: Toblerone chocolate is manufactured exclusively in Brünnen near Bern.

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3.14 SIG (Services Industriels de Genève)

Services Industriels de Genève (SIG) is a Swiss infrastructure company based in Le Lignon in the municipality of Vernier. The company was founded in 1896. From 1896 to 1931, the company was under municipal control of the city of Geneva, since 1931 it has been under cantonal supervision. SIG supplies 225‘000 customers throughout the canton of Geneva with water, gas, electricity and thermal energy. It processes wastewater, recovers waste and offers services in the fields of energy and telecommunications.

CH09 – District heating network Laurana-Parc in Geneva

Laurana-Parc is a 12 multifamily building complex from the 1960s located in Geneva. Due to conformity to local legislation, the district heat production system needed a renovation in 2011, which implied the replacement of three oil boilers (cumulated thermal power of 3.3 MW) by three new gas boilers (cumulated thermal power of 9.8 MW, equipped with a two-stage heat recovery system) and a dual-source heat pump with a thermal power of 0.34 MW (14/60 °C, T_{evap}/T_{cond}).

Furthermore, in 2013, the district heating network was extend to connect approximately 20 other multifamily buildings of the city sector called Trois-Chênes. This 12 million CHF project was financed and executed by the local energy utilities “Services Industriels de Genève” (SIG) [58]. Figure 62 shows the renovated central heating center of Laurana-Parc with the installed heat pump from Carrier (30HXC 080, option 150 high temperature version) [58,59]. The heat pump works with refrigerant R134a is driven by a screw compressor that offers 6 part load stages (minimum power of 19%), a nominal heat output of 327 kW and a nominal COP of 4.3 (at 10/45°C, evap/cond) [58].

The heat sources for the heat pump are geothermal (borehole field of 44 heat exchangers of 300 m, total 13’200 m linear meters) and waste heat from the steam condensate of the gas boilers (1’800 m^3 waste heat water tank). In real operating conditions the average heat source temperatures are in the range of 14-16/8 °C (in/out) and sink temperatures about 58/63 °C (in/out), which result in a nominal heating capacity of 338 kW and COP of 3.45.

Figure 62: Central heating center at Laurana-Parc with the installed heat pump from Carrier (30HXC 080 - option 150 high temperature version). The heat pump uses R134a and runs with a screw compressor. The nominal heating capacity is 338 kW at 14-16/8 °C heat source and 58/63 °C sink temperature with a COP of 3.45 [58] (Photos from Conti & Associés Ingénieurs S.A. [59]).

The Energy Systems Group of the University of Geneva monitored the heating system for two years [58,60]. Figure 63 presents the energy balance from 1 October 2014 until 30 September 2015 and shows that 94% of the energy to the district heating is supplied by gas, 1.5% by geothermal energy and the remaining 4.5% by electricity. In total, the extended district heating network (with the sectors Laurana and Trois-Chênes combined) has a high linear density (7.3 MWh/m/year) and delivers heat for about 100'000 m^2 area of residential buildings with 2'500 inhabitants. 69% of the heat demand is for space heating and 31% for hot water.

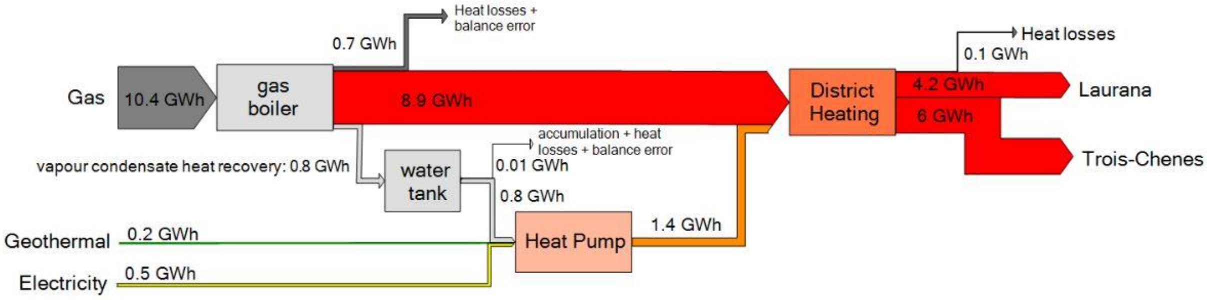

Figure 63: Sankey diagram of the heating system with annual flows measured from October 2014 to September 2015 [58,60].

For the monitored year, the measured seasonal performance factor of the heat pump was 3.0, which is explained by the high temperature heat production (average temperature lift ΔT of 45 K). The heat pump covered 30 to 60 % of the district heat demand (Laurana sector only). 30% coverage occured in winter, when the heat pump operated at full load 90% of the time, 60% occured in summer at part load. The CO_2 emissions associated with the boiler substitutions resulted in a reduction by about 42%. The heat pump saves 1'435 MWh fossil fuels per year (Table 18).

Table 18: Annual CO_2 emissions before and after the renovation of the district heating system (replacement of three oil boilers by three gas boilers and a dual-source heat pump [58].

CO_2 emissions before 2011	CO_2 emissions in 2014 to 2015 after the renovation	CO_2 savings by change from oil to gas boilers	CO_2 savings by change from gas boilers to heat pump	CO_2 savings total
4'114 t CO_2	2'368 t CO_2	1'229 t CO_2 (30%)	517 t CO_2 (12%)	1'746 t CO_2 (42%)

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CH10 – District heating network Les Vergers in Meyrin

In 2011, the municipality of Meyrin voted to build the „Les Vergers" eco-neighbourhood with more than 30 residential buildings containing 1'300 housing units, which is one of the largest eco-neighbourhoods in Switzerland [61,62]. For the heating of the buildings and domestic hot water supply the technical solution realized is based on a centralized heating center with a heat pump drawing its energy from the groundwater of the accompanying Rhône river (at a depth of 25 metres at 12 °C) and distributing the heat at around 50 °C to the buildings. Figure 64 shows the location of the district heating network in the thermal networks map suppied by SIG (Services Industriels de Genève).

In order to meet the Minergie A label applied to each building, photovoltaic solar collectors are installed on the roofs. This solution enables local renewable electrical energy generation to be partially supplied to the heat pump heating, auxiliaries and building ventilation. Overall, the district heating energy concept of Les Vergers reaches a rate of 80% renewable energy. In addition, the cold groundwater crosses the ZIMEYSA industrial zone and delivers cold energy, which allows consumers with cooling demand to significantly reduce their electricity consumption.

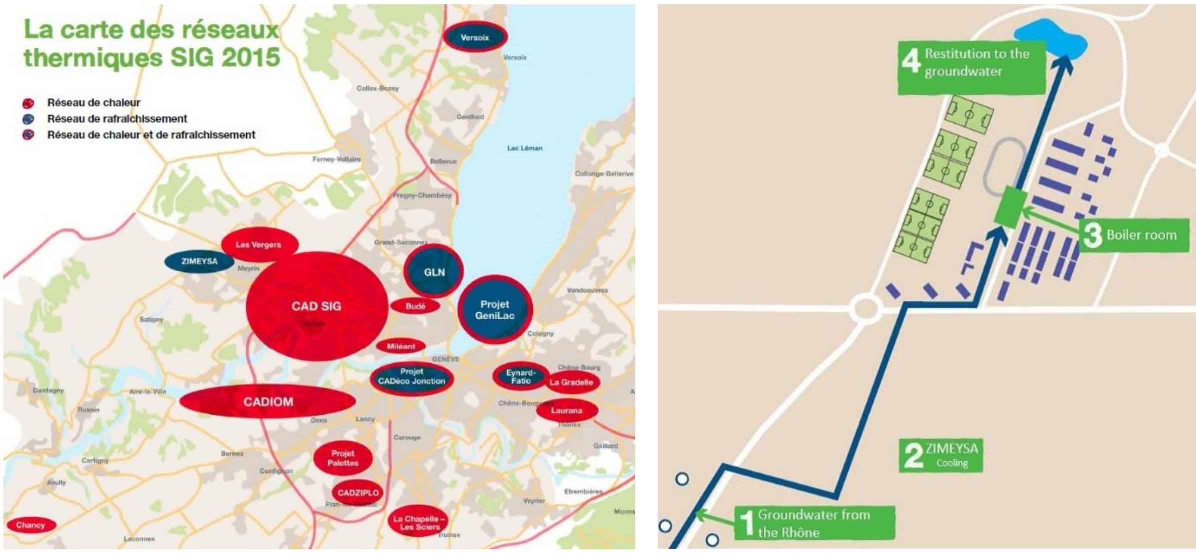

Figure 64: Thermal networks map suppied by SIG around Geneva with the heating network (red) in Les Vergers (Meyrin) and the cooling network (blue) in the industrial zone ZIMEYSA [61,62]

The installed heat pump is a Unitop® from Friotherm AG with 5 MW heating capacity and turbo compressor (Figure 65). Table 19 show the technical data. The used refrigerant is HFO R1234ze.

Figure 65: Typical Unitop® heat pump from Friotherm AG used for district heating networks.

Table 19: Technical data of the Unitop® heat pump from Friotherm AG at Les Vergers in Meyrin for the district heating network with 30 residential buildings containing 1'300 apartments.

Application	District heating of residential buildings heating and hot water supply
Year of installation	2018
Heat pump model	Friotherm Unitop
Refrigerant	R1234ze
Compressor	Turbo
Heating/cooling capacity	5'000/3'910 kW
Heat sink / source	Water / groundwater from Rhône river
Heat sink temperature (in/out)	35/50 °C
Heat source temperature (in/out)	12.5/7.5 °C

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5 Outlook and next steps

Based on the results of the IEA HPT Annex 48 project, the several next steps are planned.

5.1 Final Report Annex 48

The operating agent Dr. Rainer Jakobs (jakobs@izw-online.de) will compile a final report of Annex 48 in 2020 including all contributions of the participant countries Germany, France, Denmark, Austria, Switzerland, Japan, and the UK.

5.2 Website Annex 48

The operating agent will create an internet website Annex 48 in 2020 with up-to-date information on the working programme and an interactive world map with links to about 350 case studies and example projects.

Basis will be on the IZW-Website www.waermepumpe-izw.de and www.heatpumpingtechnologies.org.

5.3 Short report in a Swiss technical journal

A short report on the main Annex 48 results will be published by NTB in a Swiss technical journal in 2020.

5.4 White paper on Industrial Heat Pump RD&D program

On the initiative of the Dutch research institute TNO (www.tno.nl), NTB also participated in writing of a white paper on "Strengthening Industrial Heat Pump Innovation" for EU policy-makers involved in decarbonizing industrial heat. The white paper is an international cooperation between various European researchers from TNO (NL), SINTEF Energy Research (NO), Danish Technological Institute DTI (DK), Technical University of Denmark DTU (DK), Austrian Institute of Technology AIT (AT), Universitat Politècnica de València (ES), Research Institutes of Sweden RISE (SE), and NTB. The authors of the white paper are Dr. Robert de Boer (TNO), Andrew Marina (TNO), Dr. Benjamin Zühlsdorf (DTI), Dr. Cordin Arpagaus (NTB), Michael Bantle (SINTEF), Dr. Veronika Wilk (AIT), Prof. Brian Elmegaard (DTU), José Corberán, (UPV), and Jessica Benson (RISE). The white paper can be downloaded from the NTB website.

5.5 Participation in the creation of the VDI 4646 guideline

The results of IEA HPT Annex 48 have also an impact on a new VDI 4646 guideline (Verein Deutscher Ingenieure) entitled "Application of Large Heat Pumps". NTB takes part in the meetings of the guideline committee and provides input for the preparation of the VDI guideline. The expected publication date is 2021-01.

5.6 Projects by inquiries from the Swiss industry

In the course of the Annex 48 project, there were several inquiries from the Swiss industry regarding the practical implementation of heat pumps. In particular, there is interest in heat pump suppliers, training, research activities, process integration, and applications in the market. The projects focus on integration at different levels e.g. at process and supply level. In cooperation with the act Cleantech Agency Switzerland, a training seminar on “Energy Efficiency of Industrial Heat Pumps” for energy experts will be organized in 2020.

5.7 Research trends in the field of industrial heat pumps

Various research and demonstration projects in the field of industrial heat pumps were presented at the ICR 2019 conference in Montréal and the 2nd Symposium on HTHP in Copenhagen with the aims to achieve high heat sink temperatures mainly for drying processes or steam generation. Natural refrigerants and refrigerants with a low GWP such as HFOs are a popular research topic (e.g. studies on property data, heat transfer coefficients, etc.). The main experimental research trends are:

- **Japan (CRIEPI/Kobelco):** market launch of the first heat pump Kobelco HEM-HR115 (lower stage of SGH165) up to 115°C with refrigerant R1224yd(Z) (Amolea from AGC Chemicals)
- **Norway (SINTEF/NTNU):** focus on natural refrigerants: (1) hydrocarbons: propane/butane cascade HTHP, (2) turbo steam compressor, (3) hybrid heat pump (Osenbrück process) with ammonia/water mixture (NH_3/H_2O) for applications with large temperature glides
- **Denmark (DTU):** water as a refrigerant and different designs with steam compressors
- **Austria (AIT/TU Graz):** AIT focuses on the EU-funded DryFicieny project and Bamboo project with demonstration plants for steam generation, TU Graz focus on transcritical butane (R600) process up to 110°C for industrial waste heat utilisation
- **France (EDF/Mines ParisTech):** transcritical process with HFO R1234ze(E) for an open drying process (hot air up to 150°C)
- **Northern Ireland (Ulster University):** testing R245a and HCFO R1233zd(E) in a laboratory HTHP in the framework of the EU H2020-project CHESTER (Compressed Heat Energy Storage for Energy from Renewable Sources)
- **Spain (University Valencia/ISTENER Uni Jaume):** testing HFO refrigerants in a heat pump cycle with additional subcooler for the production of pressurized hot water (120°C) and steam
- **China (Shanghai Jiao Tong University):** testing a HTHP with water as refrigerant up to 150°C

It is encouraging to see that the topic of HTHP covered several sessions at the ICR 2019 conference in Montréal (17 lectures), a separate session with 7 lectures at the DKV 2019 in Ulm, and an entire day of presentations (15 lectures, 12 posters) with around 100 participants at the 2nd Symposium on HTHPs in Copenhagen. The recognized open research questions and needs for further development are:

- Extending heat source/sink to higher temperatures
- Testing of new environmentally friendly synthetic refrigerants for HTHP (e.g. HFO/HCFO)
- Application of natural refrigerants, such as hydrocarbons (R600, R601), CO_2 (R744) or water (R718)
- Improving heat pump efficiency (COP) (e.g. by multi-stage cycles, oil-free compressors)
- Development of temperature-resistant components (e.g. valves, compressors)
- New control strategies for higher temperatures
- Scale-up of functional models to industrial scale

5.8 Laboratory High Temperature Heat Pump (HTHP) of SCCER EIP

As part of the SCCER EIP project, a HTHP was developed in the laboratory at NTB providing heat up to 150 °C. Future work will investigate the suitability of various HFO and HCFO refrigerants with low GWP for use as alternative refrigerants in HTHP. Particular attention will also be paid to natural refrigerants, achieving higher temperatures, and low-pressure steam generation.

6 National and international cooperation

Within the framework of the Annex 48 project, important contacts to international research institutions in the field of heat pump technolgoies could be established. Overall, the participation in the Annex 48 expert meetings, workshops, and international conferences (ICR 2019, 2nd Symposium on HTHP, and DKV 2019) was very valuable and useful from a scientific point of view. There were further insights into the market potential of HTHP, application examples, marketable products, and a lively international exchange of knowledge. In addition, the contact network could be further expanded. Table 20 lists the main contact persons of the participating countries (Austria, Denmark, France, Germany, Japan, Switzerland, and UK) within the Annex 48 project.

Table 20: Main contact persons of the participating countries within the framework of the Annex 48 project.

Country	Name	Affiliation/function	Contact details
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The intensive interaction between the participants and the good cooperation led to a fruitful knowledge exchange and possible cooperation in the future. The elaboration of the case studies in this report has led to an exchange of knowledge at national level with Swiss industrial companies. A learning effect for the Swiss industry is also expected from about 350 case studies of the other participating countries, which will be summarized in the final report. The case studies have a high multiplication potential, as their integration solutions can be transferred to other processes and industries.

7 Publications

The following publications were prepared partially with the support of the projects Annex 48 and SCCER EIP.

- Schlosser F., Arpagaus C., Walmsley T.G., 2019, Heat Pump Integration by Pinch Analysis for Industrial Applications: A Review, Chemical Engineering Transactions, 76, 7-12 DOI:10.3303/CET1976002.
- Arpagaus, C.: Maestrani setzt auf Energieeffizienz, alimenta, 18/2019.
- Arpagaus, C: From Waste Heat to Cheese, HPT Magazine, Vol. 37, No. 2, 2019.
- Arpagaus, C., Bertsch, S.S.: High temperature heat pump in a Swiss cheese factory, Poster presentation, 2nd Conference on High Temperature Heat Pumps (HTHP), 9th September 2019, Copenhagen, Denmark. Published in: Book of presentations of the 2nd Symposium on High-Temperature Heat Pumps. / Zühlsdorf, Benjamin (Editor); Bantle, Michael (Editor); Elmegaard, Brian (Editor). SINTEF, 2019. 268 p. ISBN (Electronic): 978-82-594-3781-5.
- Arpagaus, C.: Industrial heat pump applications in Switzerland – Heat pump integration case studies, Workshop WS-4 Successful Applications of Industrial Heat Pumps, ICR 2019, 25th IIR Int. Congr. Refrig. August 24-30, Montréal, Québec, Canada, 2019.
- Arpagaus, C., Bless, F., Bertsch, S.S., Schiffmann, J.: Wärmepumpen für die Industrie: Eine aktuelle Übersicht, 25. Tagung des BFE-Forschungsprogramms "Wärmepumpen und Kälte", 26. Juni 2019, BFH Burgdorf (Vortrag).
- Arpagaus, C.: Industrial heat pump references in Switzerland – Examples (Task 1, first draft), IEA TCP HPT Annex 48 Meeting May 13-14, 2019, Tokyo, Japan.
- Arpagaus, C.: Hochtemperatur-Wärmepumpen für industrielle Anwendungen, 4. Internationaler Grosswärmepumpen Kongress, 8. Mai 2019, Zürich.
- Arpagaus, C., Bless, F., Uhlmann, M., Büchel, E., Frei, S., Schiffmann, J., Bertsch, S.S.: High temperature heat pumps, Heat Pumping Technologies for Commerical and Industrial Applications, Chillventa CONGRESS, 15 October 2018.

At the IIR Rankine 2020 Conference (July 26-29, 2020, Glasgow, https://ior.org.uk/events/rankine2020) the following further conference contribution has been accepted for publication:

- Arpagaus, C., Bertsch, S.S: Successful Application Examples of Industrial Heat Pumps in Switzerland, Paper ID 1183.

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