

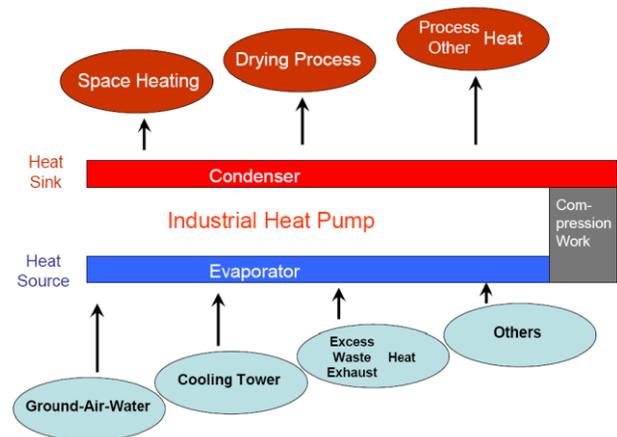
Application of Industrial Heat Pumps

Securing a reliable, economic and sustainable energy supply as well as environmental and climate protection are important global challenges of the 21st century. Renewable energy and improving energy efficiency are the most important steps to achieve these goals of energy policy. While impressive efficiency gains have already been achieved in the past two decades, energy use and CO₂ emissions in manufacturing industries could be reduced further, if best available technologies were to be applied worldwide.

Industrial heat pumps (IHP) are active heat-recovery devices that increase the temperature of waste heat in an industrial process to a higher temperature to be used in the same process or another adjacent process or heat demand

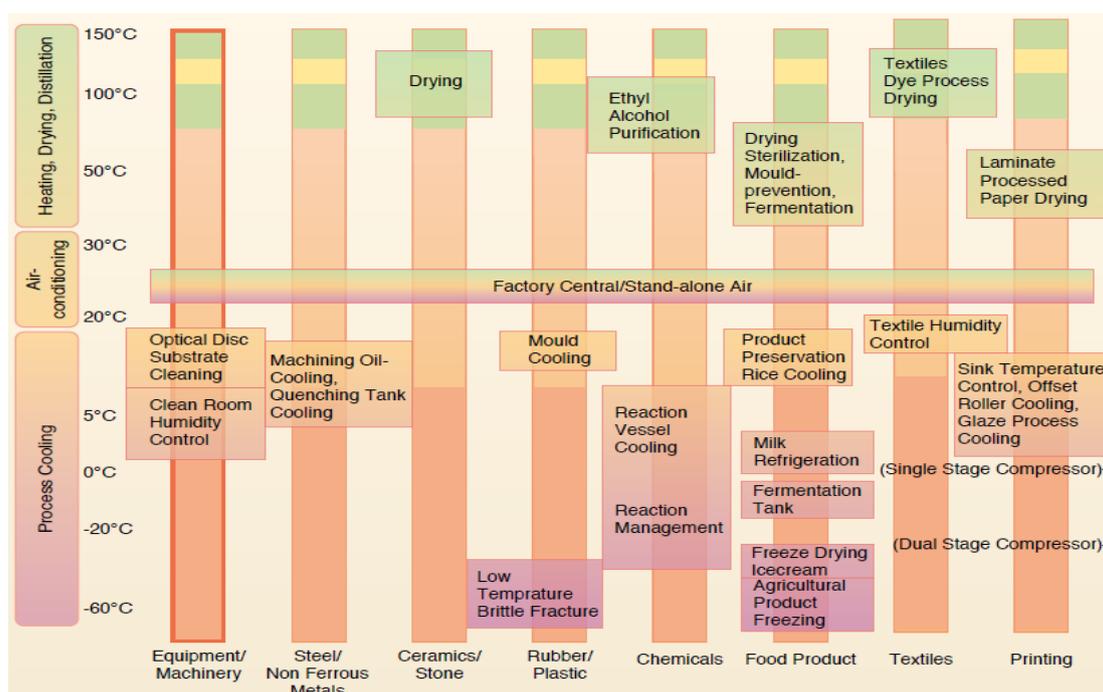
Annex 35 / 13

The IEA HPP-IETS Annex 35/13 "Application of industrial Heat Pumps", a joint venture of the International Energy Agency (IEA) Implementing Agreements "Industrial Energy-Related Technologies and Systems" (IETS) and "Heat Pump Programme" (HPP) has been initiated in order to actively contribute to the reduction of energy consumption and emissions of greenhouse gases by the increased implementation of heat pumps in industry.



The Annex 35/13 started on 01. April 2010 and expired on 30. April 2014, with 15 participating organisations from Austria, Canada, Denmark, France, Germany (Operating Agent) Japan, The Netherlands, South Korea and Sweden.

Industrial Heat Pump Applications



Barriers for application and solutions

Heat pumps for the industrial use are available on the markets in the participating countries in recent years, just very few carried out applications can be found. To distinguish the reasons were a part of the survey in the annex:

- **Lack of knowledge:**
The integration of heat pumps into industrial processes requires knowledge of the capabilities of industrial heat pumps, as well as knowledge about the process itself. Only few installers and decision makers in the industry have this combined knowledge, which enables them to integrate a heat pump in the most suitable way.
- **Low awareness of heat consumption in companies:**
In most companies knowledge about heating and cooling demands of their processes is quite rare. This requires expensive and time consuming measurements to find an integration opportunity for an industrial heat pump
- **Long payback periods:**
Compared to oil and gas burners, heat pumps have relatively high investment costs. At the same time companies expect very low payback periods of less than 2 or 3 years. Some companies were willing to accept payback periods up to 5 years, when it comes to investments into their energy infrastructure. To meet these expectations heat pumps need to have long running periods and good COPs to become economical feasible.
- **High temperature application**
Many applications are limited to heat sink temperatures below 65°C. The theoretical potential for the application range of IHP increases significantly by developing energy efficient heat pumps including refrigerants for heat sink temperatures up to and higher than 100°C.

The barriers can be solved, as shown in the results of the Annex: short payback periods are possible (less than 2 years), high reduction of CO₂-emissionen (in some cases more than 50%), temperatures higher than 100°C are possible, supply temperatures < 100°C are standard.

The integration of industrial heat pumps into processes

The methods of integration IHPs in processes range from applying rules by hand to far advanced mathematical optimization and are discussed in the literature. The Task 2 Report outlines specifically how the integration of IHPs in processes is supported by computer software, i.e. by modeling.

In order to 'update' the Annex 21 screening program in the sense of a modern development retaining the original goals, a proposal has been made that allows a consistent integration of a heat pump into a process based on pinch analysis. The basic elements of this concept are:

- Substitution of the problem table algorithm in pinch analysis by an extended transshipment model which allows a simultaneous optimization of utilities and heat pump.
- Approximation of the heat exchanger network as in the standard pinch analysis.
- Development of an algorithm for selecting of a hot and cold stream (may be of several hot and cold streams) to which the heat pump could be connected.
- Development of a heat pump data base to be used within the simultaneous optimization. Since this optimization is nonlinear a special algorithm needs to be developed that enables convergence.

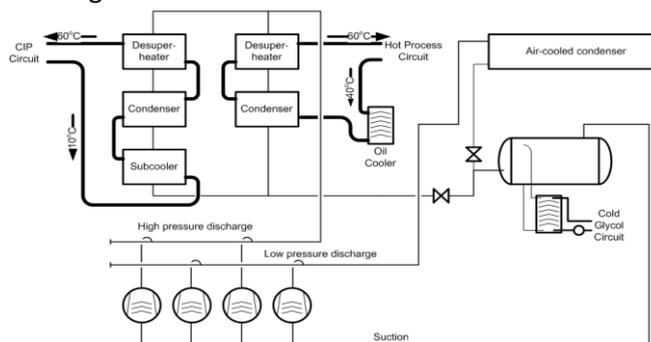
This concept of integrating a heat pump into a process is 'below' sophisticated mathematical optimization models and could therefore be considered as an **add-on** to the widely used programs based on pinch analysis enhancing their capabilities.

Examples of existing Installations

Heat pump in Food and Beverage industry - Combine heating and cooling in chocolate manufacturing (UK)

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

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



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

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



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

Nestlé can save an estimated £143,000 per year (166,000 € per year) in heating costs, and around 120,000 kg in carbon emissions by using a Star Neatpump. Despite the new refrigeration plant providing both heating and cooling, it consumes £120,000 (140,000 €) less electricity per year than the previous cooling only plant.

Another impact of the complete project (combined heating and cooling, additional gas boiler for the 90°C water peak demand, etc.) decreased the total water consumption from 52,000 m³/day down to 34,000 m³/day.

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

Hybrid heat pump at Arla Arinco (Denmark)

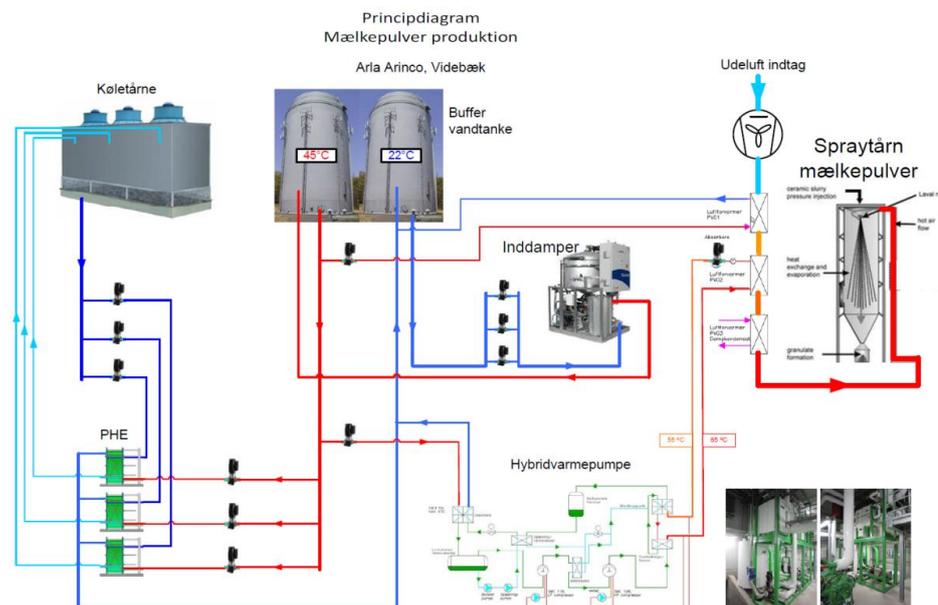
A heat pump of 1.25 MW was installed utilizing energy from 40° C cooling water – energy that was discharged to the environment prior to this project. The installed heat pump preheats drying air for milk powder to around 80° C through a water circuit.

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

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

The type of the heat pump is a Hybrid (compression/absorption) with the refrigerant NH₃/H₂O with a capacity of 1.25 MW.

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



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

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

Adoption of Heat Pump Technology in a Painting Process at an Automobile Factory (Japan)

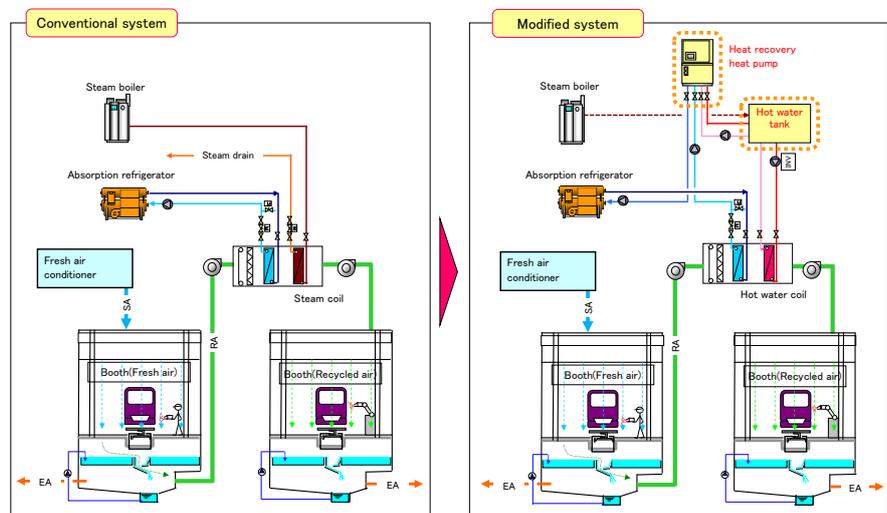
In a painting facility of an automobile factory, a great deal of energy is consumed by heating and cooling processes, the power supply, system controls, lighting, and so on. Generally, most primary energy sources are gas and electricity. Most heating and cooling needs in a painting process are supplied by direct gas combustion, steam, hot water, and chilled water generated by a refrigerator, most of the primary energy for which is gas. In terms of energy efficiency ratio, electrical energy was believed to be lower in energy efficiency than gas energy, because electrical energy uses only around 40 % of input energy while gas energy is able to use almost 100 % of direct gas combustion. However, heat pump technology has greatly improved, and the energy efficiency ratio is increasing accordingly, so highly efficient heat pumps have been introduced also into industrial processes in recent years.

There are three main advantages which we can gain from heat pump technology. The first is the heat recovery system, the second is efficient heat source equipment, and the third is simultaneous usage of cooling and heating, which is believed to be the most efficient usage. Simultaneous usage of heating and cooling can be applied to processes of pretreatment/electro-deposition, booth/working area air conditioning, and waterborne flash-off equipment. Hence, adoption of heat pump technology in this equipment is considered. The highest effect from adoption of heat pump technology in these cases is in booth recycled air conditioning and waterborne flash-off equipment.



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

The heat pump makes it possible for the system to reduce running costs by about 63 %, to reduce CO₂ emissions by about 47 % per month, and to reduce primary energy consumption by about 49 % per month as compared with the conventional boiler. Consequently, the pay-back period would be estimated at 3~4 years.



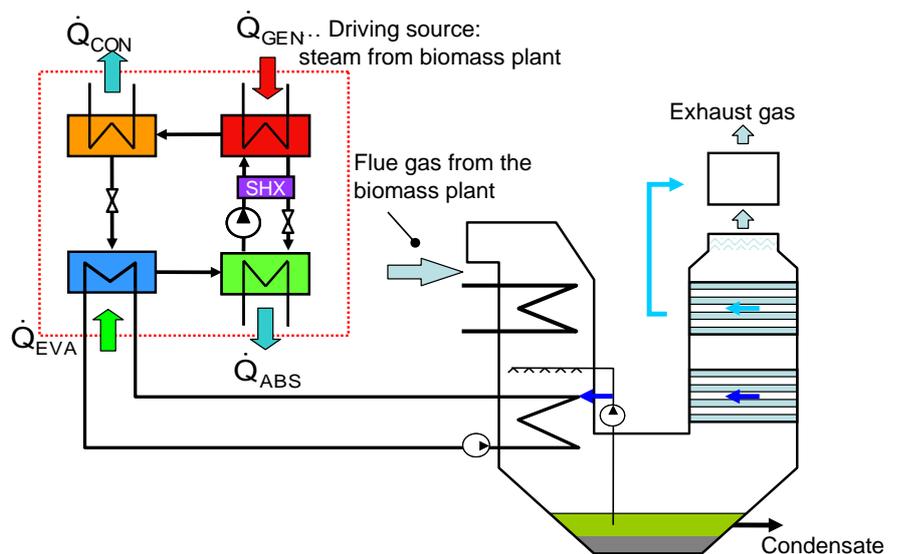
Absorption heat pump for flue gas condensation in a biomass plant

Schweighofer Fibre GmbH in Hallein (Austria) is a woodworking industrial company and part of the Austrian family enterprise Schweighofer Holzindustrie. Their core business is the production of high-quality cellulose and bioenergy from the raw material wood by an efficient and environmentally-friendly use. A biomass power plant including a steam generator supplies the in-house steam grid and covers the company's energy demand at the site. The capacity of this cogeneration plant, which is fired by 77 % of external wood and 23 % of in-house remnants, amounts to about 5 MW_{el} and 30 MW_{th}. Beside the in-house power supply of Schweighofer Fibre GmbH the biomass plant also delivers electricity for about 15,000 households and heat for the local district heating grid.



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

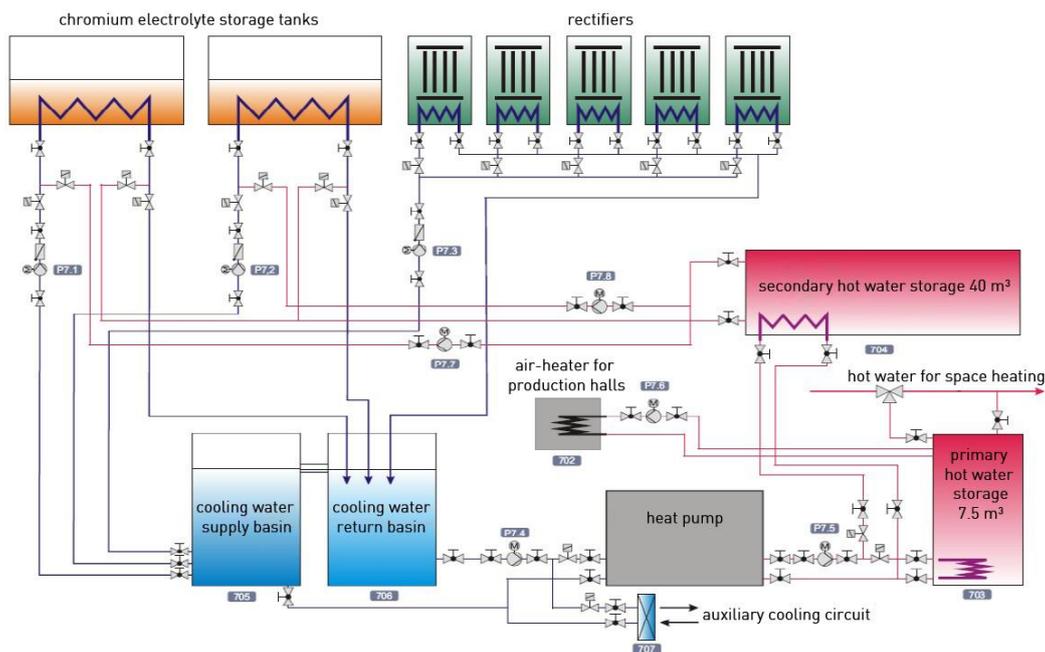
The applied AHP is a single-stage Water/LiBr absorption heat pump with a solution heat exchanger (SHX) and a heating capacity of ca. 7.5 MW. The driving source of the AHP is steam from the biomass heating plant at ca. 165 °C. According to the existing monitoring system the AHP operates with a seasonal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



The benefits are energy savings of ca. 15,000 MWh/a, a higher performance and no vapour discharge system is required.

Metal processing (Germany)

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



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

Slaughter House in Zurich (Switzerland)

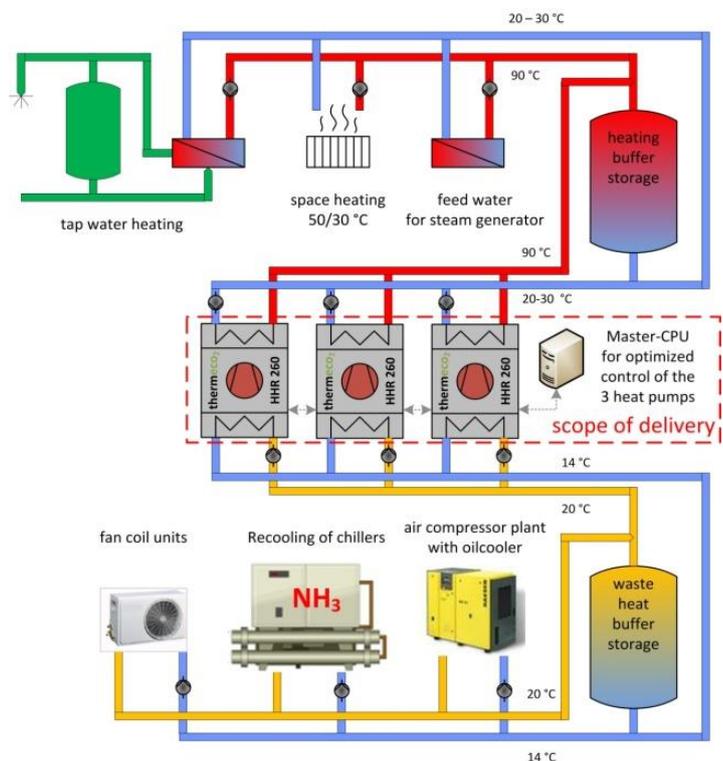
In 2011, a new thermeco₂ heat pump system for hot water generation and heating was put into operation in the slaughterhouse Zurich. With a capacity of 800 kW, the plant is the largest ever built in Switzerland. The thermeco₂ machines deliver the required 90 °C with better COPs compared to other refrigerants. The heat pump system is built up of 3 heat pumps thermeco₂ HHR 260.



The heat pump uses waste heat of an existing Ammonia refrigeration machine, an oilcooled air compressor plant and the installed fan-coil units as heat source. For this reason the heat is collected in a waste heat buffer storage connected with the heat pump evaporators. Because of the closed waste water circulating loop no special measures to avoid corrosion are necessary.

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

Because of the extremely low space requirement, this large heat pump system could be installed in a container system on the roof of the slaughterhouse in a short distance to urban residential development. Only authorized personal has access to the container and CO₂ sensors have been installed that activate an alarm when healthy concentration levels are exceeded.



All of the thermal energy for the slaughterhouse Zurich was previously provided with steam boilers. The customer's decision for a high temperature heat pump system with CO₂ as a refrigerant on this scale had several reasons. The efficiency advantages of the high temperature heat pump system clearly have priority. Running this heat pump plant the city of Zurich, represented by the Umwelt- und Gesundheitsschutz Zürich (UGZ) and the Elektrizitätswerk Zürich (ewz) as Contractor make an important contribution towards the "2000 Watt Society" of the city of Zurich. In the calculated overall balance of the slaughterhouse, CO₂ emissions can be reduced by approx. 30 %. By using the heat pump system, 2,590 MWh from fossil fuels can be saved per year, representing an annual reduction in CO₂ emissions of 510 tonnes.

R&D high temperature heat pumps

EDF France in cooperation with industry is working on the development of high temperature industrial heat pumps with new working fluids to reach temperatures higher than 100 °C:

Alter ECO Project

This project includes the development and industrial testing of HPs capable of operating at 140 °C in condensation mode, equipped with scroll compressors and working with a new blend.



Technical specifications :

- Condensation temperature : 77 to 140 °C
- Evaporation temperature : 30 to 60 °C
- Compressors max power : 75 kW_e
- Condenser max power : 200 kW_t



Publication: Experimental results of a newly developed very high temperature industrial heat pump (140 °C) equipped with scroll compressors and working with a new blend refrigerants.

The compressor power is 75 kW. The machine performances have been characterized to demonstrate the technical feasibility. For each evaporation temperature (from 35 to 60 °C by step of 5 °C), the condensation temperature is increased by step of 5 °C from 80 up to 140 °C.

Test campaigns over 1,000 hours were carried out in industrial-like conditions to demonstrate the reliability.

The efficiency of heat recovery up to 125 °C is demonstrated. Good performances are obtained. For higher temperatures, the technological feasibility is demonstrated but some further developments have to be carried out to increase the efficiency and the economic viability: 2 stage compressors (it is designed for a given pressure ratio), expansion valve, etc.

All this demonstrates the prototype reliability and the capacity to use this newly developed machine for industrial purposes.

PACO Project

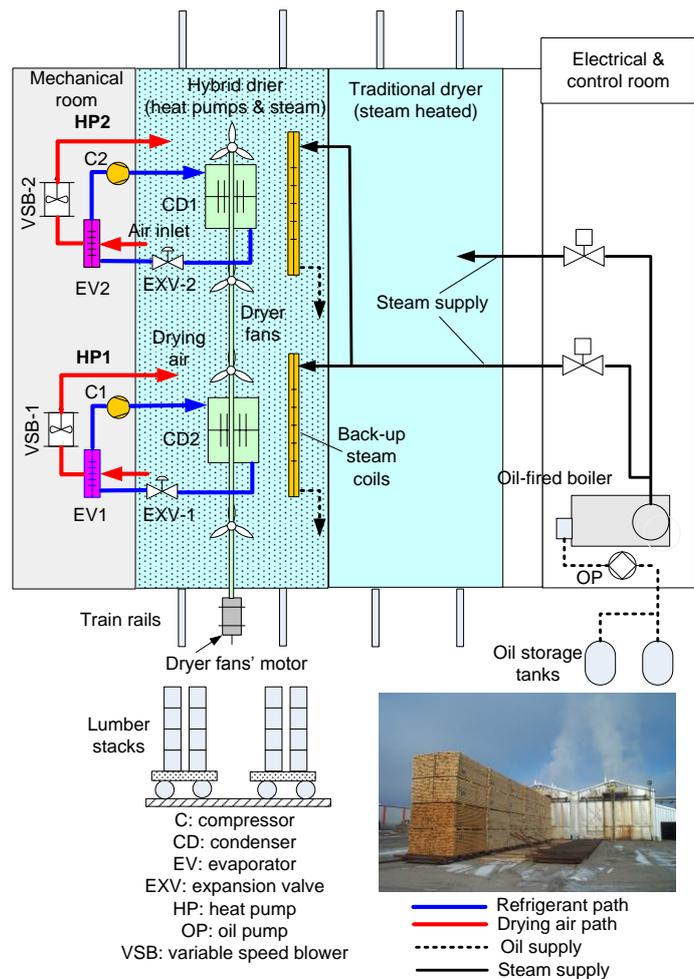
Heat pump using water as a refrigerant is an interesting solution for waste heat recovery in industry. Water is nontoxic, non-ignitable and presents excellent thermodynamic properties, especially at high temperature. Water HP development is complex, notably due to water vapor compression. The compression ratio of centrifugal and lobe compressors is low. It prevents gas temperature from rising more than 20 °C. For now, the only technical solution able to overcome this drawback with moderate costs is to put two lobe compressors in series. However, these compressors are less reliable than the others and their efficiency is low. Thus, the development of a novel water compressor is needed. Screw and centrifugal compressors



on magnetic bearings seem to be the most promising technology. Discussions with the compressor manufacturers, and the numerical simulations show that the COP can be increased up to 80 % if such a compressor is integrated on a water heat pump. The price of this prototype compressor is very high, but it should decrease with the development of the market. Thus, the payoff would be guaranteed and the water heat pump would become an industrial reality.

High-temperature drying heat pump

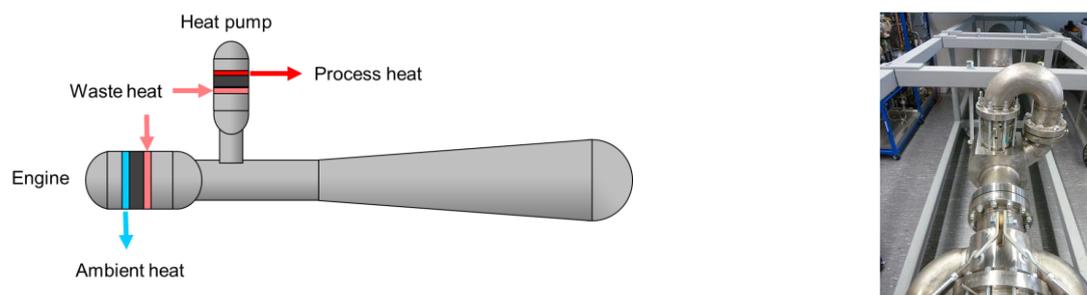
An industrial-scale, high-temperature heat pump-assisted dryer prototype, including one 354 m³ forced-air wood dryer with steam heating coils and two high-temperature heat pumps (see Figure) has also been studied in Canada. Finished softwood lumber is produced in standard sizes, mostly for the construction industry. Softwood, such as pine, spruce and fir (coniferous species), is composed of vertical and horizontal fiber cells serving as a mechanical support and pathway for the movement of moisture. These species are generally dried at relatively high temperatures, but no higher than 115 °C, and thus high-temperature heat pumps coupled with convective dryers are required. An oil-fired boiler supplies steam for wood preheating and supplemental (back-up) heating during the subsequent drying steps. The dryer central fans force the circulation of the indoor drying air and periodically change their rotation sense to make more uniform and, thus, to improve the overall drying process and the wood final quality. Each heat pump includes a 65 kW (nominal electrical power input) compressor, an evaporator, a variable speed blower and electronic controls located in an adjacent mechanical room. Both remote condensers are installed inside the drying chamber. The high-temperature refrigerant (HFC-236fa) is a non-toxic and non-flammable fluid, having a relatively high critical temperature compared to the highest process temperatures. Expansion valves are controlled by microprocessor-based controllers that display set points and actual process temperatures. The industrial-scale prototype demonstrates that, as a clean energy technology compared with traditional heat-and-vent dryers, the high-temperature heat pump-assisted dryers offer very interesting benefits for drying resinous timber. Its actual energy consumption effectively is between 27.3% and 56.7% lower than the energy consumed during the conventional (steam) drying cycles, whereas the average reduction in specific energy costs, compared to the average costs of the Canadian conventional wood drying industry (2009), is of approximately 35 %.



Thermo Acoustic Heat Transformer

Thermo acoustic (TA) energy conversion can be used to convert heat to acoustic power (engine) and to use acoustic power to pump heat to higher temperature levels (heat pump). The systems use an environmentally friendly working medium (noble gas) in a Stirling-like cycle, and contain no moving parts.

Although the dynamics and working principles of TA systems are quite complex and involve many disciplines such as acoustics, thermodynamics, fluid dynamics, heat transfer, structural mechanics, and electrical machines, the practical implementation is relatively simple. This offers great advantages with respect to the economic feasibility of this technology. When thermal energy is converted into acoustic energy, this is referred to as a Thermo acoustic (TA)-engine. In a TA-heat pump, the thermodynamic cycle is run in the re-verse way and heat is pumped from a low-temperature level to a high-temperature level by the acoustic power. This principle can be used to create a heat transformer, as shown below.



The TA-engine is located at the left side and generates acoustic power from a stream of waste heat stream at a temperature of 140 °C. The acoustic power flows through the resonator to the TA-heat pump, located on top of the resonator. Waste heat of 140 °C is upgraded to 180 °C in this component. The total system can be generally applied into the existing utility system at an industrial site.

Basic characteristics of refrigerants suitable for high temperature heat pump

Some development of the industrial heat pump using R-134a, R-245fa, R-717, R-744, hydro carbons, etc. has been made recently. However, except for R-744 and the flammables R-717 and HCs which are natural refrigerants with extremely low global warming potential (GWP), HFCs such as R-134a and R-245fa have high GWP values, and the use of HFCs are likely to be regulated in the viewpoint of global warming prevention in the foreseeable future. Therefore, development of alternative refrigerants with low GWP has been required.

At present, as substitutes of R-134a, R-1234yf and R-1234ze (E) are considered to be promising, and R-1234ze (Z) is attractive as a substitute of R-245fa. R-365mfc is considered to be suitable as a refrigerant of heat pump for vapor generation using waste heat, but its GWP value is high. Therefore, it seems that development of a substitute of R-365mfc should be furthered. The table below shows basic characteristics of the present and future refrigerants for IHPs.

Refrigerant	Chemical formula	GWP	Flammability	T _c °C	p _c M Pa	NBP °C
R-290	CH ₃ CH ₂ CH ₃	~20	yes	96.7	4.25	-42.1
R-601	CH ₃ CH ₂ CH ₂ CH ₂ CH ₃	~20	yes	196.6	3.37	36.1
R-717	NH ₃	0	yes	132.25	11.33	-33.33
R-744	CO ₂	1	none	30.98	7.3773	-78.40
R-1234yf	CF ₃ CF=CH ₂	<1	weak	94.7	3.382	-29,48
R-134a	CF ₃ CH ₂ F	1,430	none	101.06	4.0593	-26.07
R-1234ze(E)	CFH=CHCF ₃	6	weak	109.37	3.636	-18.96
R-1234ze(Z)	CFH=CHCF ₃	<10	weak	153.7	3.97	9.76
R-245fa	CF ₃ CH ₂ CHF ₂	1,030	none	154.01	3.651	15.14
R-1233zd		6	none	165.6	3.5709	n. a.
R-1336mzz		9	none	171	n. a.	n. a.
R-365mfc	CF ₃ CH ₂ CF ₂ CH ₃	794	weak	186,85	3.266	40.19

Operating Agent: Annex 35/13 Application of industrial Heat Pumps

Information Centre on Heat Pumps and Refrigeration (IZW e.V.)

IZW is a German society for the promotion of research and development of heat pumps and refrigeration, to contribute to the reduction of the primary energy consumption and CO₂ emissions and the improvement of the energy-efficiency and environmental protection at the heat production, refrigeration and in the manufacturing industry.



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Members:

What is the IEA Heat Pump Programme?

The Programme is a non-profit organisation funded by its member countries. It is the foremost worldwide source of independent information and expertise on environmental and energy conservation benefits of heat pumping technologies.

What is the aim of the Heat Pump Programme?

The aim is to achieve widespread deployment of appropriate practical and reliable heat pumping technology systems that can save energy resources while helping to protect the environment.

Why is that important?

The world's energy and climate problems are well known. The buildings sector is responsible for a very considerable proportion of greenhouse gas emissions. Heat pumps are a key technology in the solution to break this trend.

What needs to be done?

By disseminating knowledge of heat pumps worldwide, we contribute to the battle against global warming. In order to increase the pace of development and deployment of heat pumps for buildings and industries, we need to increase R&D efforts for heat pumps, and we need to implement long-term policies for further deployment of heat pumps.