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Commercial and Industrial Heat Pump application **IEA HPT Annex 35/48**

Abstract: 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 CO_2 emissions in manufacturing industries could be reduced further, if best available technologies were to be applied worldwide.
The project collected totally 39 examples of R & D-projects and 115 case studies. These examples show successful integration of heat pumps. Payback periods, which are lower than 1.5 years are possible in some cases. CO_2-emissions and energy cost can be reduce by more than 80 % in some cases.
There is a great potential for industrial heat pumps to reduce the energy consumption and related greenhouse gas emissions of the industry. However, further investigations are necessary to reduce the present barriers of the application of heat pumps in industry.

1 Background

The world rising greenhouse gas emissions and environmental concern set focus on energy conservation and use of renewable energy sources.
In this context, 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.
While the residential market may be satisfied with standardised products and installations, most industrial heat pump applications need to be adapted to unique conditions. In addition a high level of expertise is crucial. Industrial heat pumps are defined here as heat pumps in the medium and high power ranges which can be used for heat recovery and heat upgrading in industrial processes, but also for heating, cooling and air-conditioning in industrial, commercial and multi-family residential buildings as well as district heating. The main advantage to use heat pumps in industrial application is to recover waste heat, as to use free renewable energy sources.

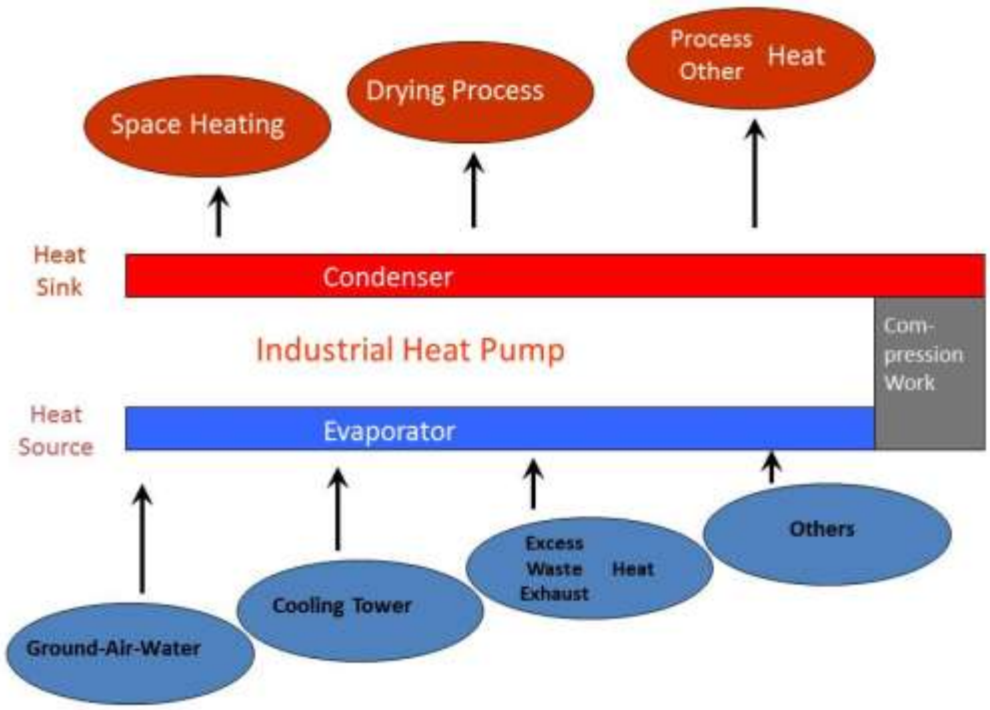

Figure 1: Possible heat sources and heat sinks for Industrial Heat Pumps (IHPs)

Annex 35/13 started on April 1, 2010 and was concluded on April 30, 2014, with 15 participating organizations from Austria, Canada, Denmark, France, Germany (Operating Agent), Japan, the Netherlands, South Korea and Sweden.
The Annex comprised an overview in the participating countries of the industrial energy situation and use, the state of the art and R&D projects in heat pumping and process technologies and its applications, as well as analysing business cases on the decision-making process in existing and new applications and in the wider application of industrial heat pumping technologies. The annex has been subdivided in the following tasks:

Task 1: Market overview, barriers for application

Task 2: Modelling calculation and economic models

Task 3: Technology

Task 4: Application and monitoring

Task 5: Communication.

The work programme has been mainly concentrated on collection of statistical energy and environmental data and information related to industry, as well as the present status of R&D and the application of heat pumps in industry. A total of 39 R&D projects and 115 applications of heat pump in industry - in particular the use of waste process heat as the heat source - have been presented and analysed by the participating countries.

2 Market overview, barriers for applications

The report summarized the present energy situation in general and the industrial energy use and related heat pump market subdivided into participating countries. Based upon these findings focus will be given to further work to meet the challenges for the wider application of industrial heat pumping technologies.
Although heat pumps for the industrial use became available on the markets in the participating countries in recent years, just very few carried out applications can be found. To distinguish the reasons for this situation, application barriers were also a part of the survey:

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 cost. 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:
From the technical point of view one barrier can be identified regarding to the temperature limits of most commercially available heat pumping units. 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.

On the other side, IHPs have the following advantages in comparison to heat pumps for space heating:

High coefficient of performance (COP) due to low temperature lift and/or high temperature levels
Long annual operating time
Relatively low investment cost, due to large units and small distance between heat source and heat sink
Waste heat production and heat demand occur at the same time.

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 CO_2-emissions (in some cases more than 50 %), temperatures higher than 100 °C are possible, supply temperatures < 100 °C are standard.

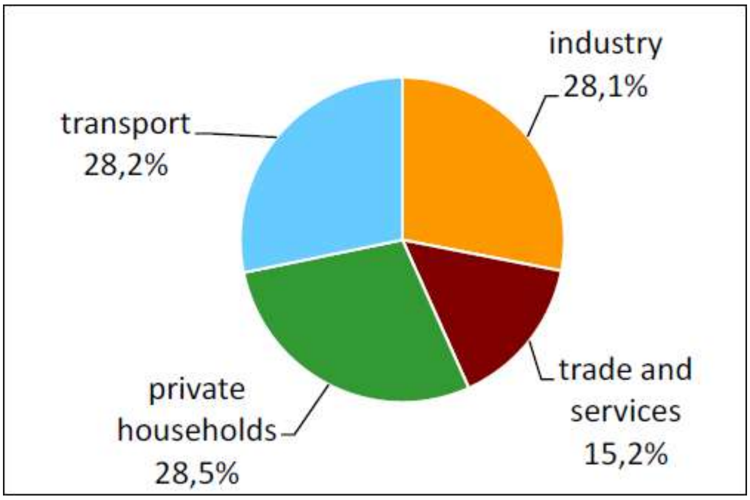

Figure 2: Final energy consumption (9,060 PJ) in Germany 2010 by sector /BMWi 2012/

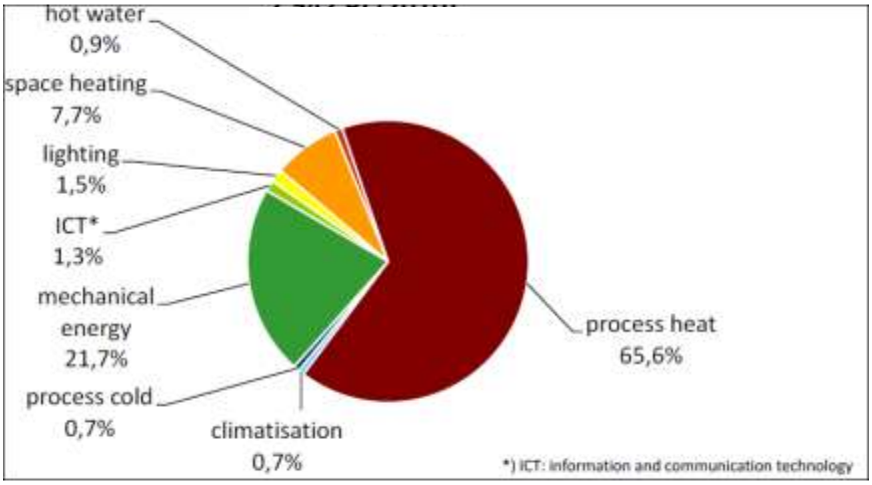

Figure 3: Final energy consumption (2,542 PJ) in the German industry 2010 /BMWi 2012/

The country reports show that the industrial energy consumption in the participating countries varies between 17 to 58 % with great differences of the manufacturing sectors:

For **pulp and paper** in Austria 20 %, in Canada 28 % and Sweden 52 %;

Wood needs in Austria, Canada, Denmark and Sweden between 3 and 8 % of the energy,

Metal production needs between 10 and 36 % (Germany),

Chemical and petrol industry between 8 and 59 % (Netherlands),

The energy demand of the **food industry** varies between 1 and 26 % (Denmark).

3 Technology

Commercially available heat pumps can supply heat only up to 100 °C. As industrial waste heat, available at low-temperatures, represents about 25 % of the total energy used by the manufacturing industry, R&D work has to be focused on high-temperature heat pumps able to recover heat at relatively low temperatures, generally between 5 °C and 35 °C for hot water supply, hot air supply, heating of circulating hot water and steam generation at temperatures up and higher than 100 °C.
EDF (France) is working on the development of high temperature industrial heat pumps with new working fluids to reach temperature higher than 100 °C. The three main projects are:

Figure 4: EDF projects to reach temperatures higher than 100 °C [01, p 302]

Some development of the industrial heat pump using R-134a, R-245fa, R-744, etc. has been made recently. However, except for R-744 which is a natural refrigerant 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 vapour generation using waste heat, but its GWP value is high. Therefore, it seems that development of a substitute of R-365mfc should be furthered.
Appropriate heat pump technology is important for reducing CO_2 emissions and primary energy consumption as well as increasing amount of renewable energy

usage in industrial processes. The expansion of industrial applications is also important for enhancing these effects further more. In particular, development and dissemination of high-temperature heat pumps for hot water supply, heating of circulating hot water, and generation of hot air and steam are necessary. Specific problem areas are:

Lack of refrigerants in the interesting temperature range

Lack of experimental and demonstration plants

4 Case Studies

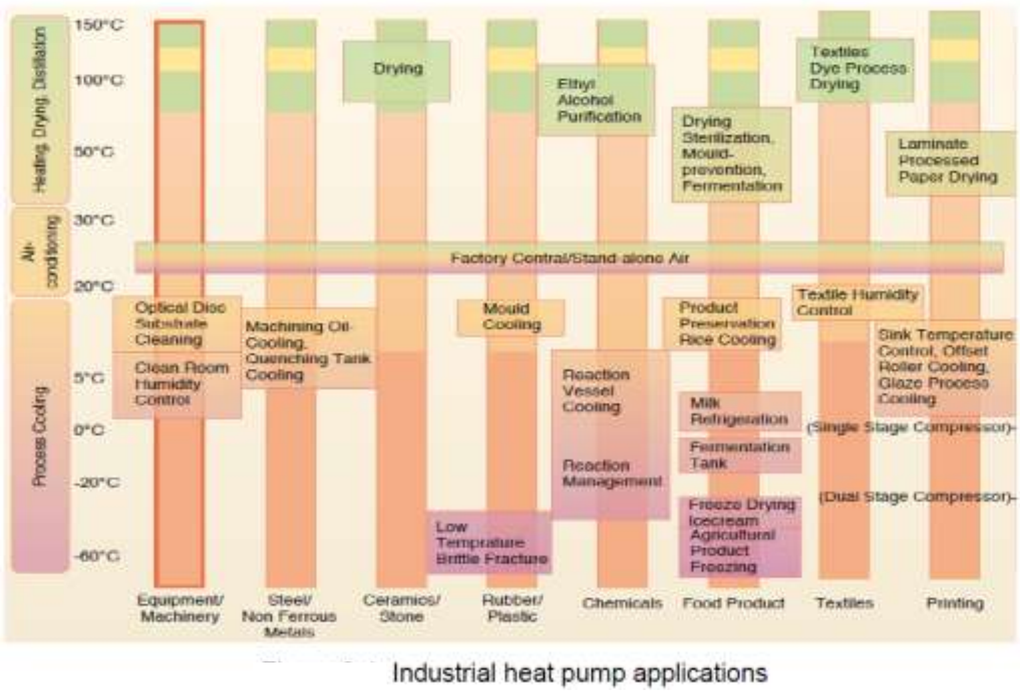

Figure 5: Industrial and commercial heat pump application [1, p 554]

The report focused on operating experiences and energy effects of representative industrial heat pump implementations, in particular field tests and case studies.

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

The economics of an installation depends on how the heat pump is applied in the process. Identification of feasible installation alternatives for the heat pump is therefore of crucial importance. Considerations of fundamental criteria taking into account both heat pump and process characteristics, are useful. The initial procedure should identify a few possible installation alternatives, so the detailed project calculations can concentrate on a limited number of options.

The commercially available heat pump types each have different operating characteristics and different possible operating temperature ranges. These ranges overlap for some types. Thus, for a particular application, several possible heat pump types often exist. Technical, economic, ecological and practical process criteria determine the best suited type. For all types, the payback period is directly proportional to installation cost, so it is important to investigate possibilities for decreasing these cost for any heat pump installation.

The case studies have tried to present good examples of heat pump technology and its application in industrial processes, field tests and commercial applications along with an analysis of operating data, when available, in accordance with the annex definition of industrial heat pumps, used for heating, ventilation, air-conditioning, hot water supply, heating, drying, dehumidification and other purposes.
The participating countries identify several projects and case studies in different application in which industrial heat pumps are used.

Industrial heat pump applications are rather seldom in **Austria** up to now; several applications in various industrial sectors have been identified. Eight examples and one feasibility studies are described in detail [1, p 419ff].

Canada's report [1, page 452ff] focuses on low- and high-temperature heat pump applications in small- and medium-sized industrial manufacturing processes, not only for heat recovery, but also for heating industrial buildings, when possible. These include food and beverage plants because they use large amounts of primary energy, mostly for heating, via gas-fired boilers to produce hot water and cooling processing operations via electrically driven mechanical refrigeration devices. Wood drying is a very important application in Canada.

Denmark reports about four projects from the food industry, district heating, green houses and the metal industry [1, p 485ff].

France identifies 10 projects with industrial heat pumps, eight in the food industry and two for district heating [1, p 499].

German partners report about 24 projects and case studies. Mainly (18) of them are located in Germany and represent several industrial branches [1, p 500ff].

Japan has many industrial heat pumps in practical use. Among the many installed cases, here they focus on heat pump technologies of simultaneous production of heating and cooling, vapour recompression, high temperature heat production and agricultural use because they are growing in sales and also expect further growth in the future. 6 cases were picked out as typical examples of above mentioned prospective industrial heat pump technologies and their details, such as backgrounds of installation, system specifications and effects from economic and energy saving points of view, are explained. In total, about 29 case studies are reported in factsheets [1, p 553ff + appendix].

In the industrial sector, as a solution for energy saving, the number of heat pump installation and operation increases in **South-Korea**. They identify 10 representative heat pump installation and operation cases in industrial sector [1 p 589ff].

Over the past 20 years several feasibility studies and project realizations of heat pump projects have been performed in **The Netherlands**. These are evaluated in this study. Some of them are more than 20 years running and they are still in use.
[1, p 601ff + appendix]

Selection of application around the world:

Application, Industry	Member Country	Year	System	Refrigerant	**C**ooling **H**eating **D**rying **W**aste heat	Heating Capacity	Supply tempe-rature	Pay back period	Reduction CO_2	Reduction energy/cost	Report page
Food: meat, sausage	A	eld	Mech Compr	R-134a	W	257 kW	55 °C		75%		420
Ice rink	A	2013	Mech Compr	R-717	W	413 kW	60 °C		75%		422
Food: brewery	A	2012	Mech Compr	R-717	W	370 kW	63-77 °C	5.7 a		64,000 €/a 18.3 %	426
Fish farm	CDN	eld	Mech Compr	R-22	H	109	10–12 °C	1.3 a			460
Wood drying low temp	CDN	eld	Mech Compr		D	5.6 kW	n. a.			21.5%	463
Wood drying high temp	CDN	eld	Mech Compr		D	2 x 65 kW	Up to 100 °C			50%	471
Washing metal items	DK	2011	Mech Compr	R-134a	H	25 kW	60 °C	2.5 a	20 t/a	50%	493
Food: Slaughter-house	D	2011	Mech Compr	R-744	C&H	800 kW	90 °C		510 t/a		500
Food: Dairy	D	2011	Mech Compr	R-717	W	3.45 MW	58 °C		30-40%		506
Coating Powder	D	2012	Mech Compr		D	240 kW	45 °C	5 a			531
Food: Malt production	D	2010	Mech Compr	R-717	D	3,250 kW	35 °C				546
Food: Brewery	D	2012	Mech Compr	R-134a	H	77 kW	55 °C	< 6 a			547
Food: Noodle production	Jap	2008	Mech Compr	R-744 trans.	C & H	C 56 kW H 72 kW	5 °C 90 °C	8.2 a	31%	25%	557
Transformer casing (painting)	Jap	2009	Mech Compr	R-744 trans.	D	110 kW	80–120 °C		13%	12%	565
Automotive (painting)	Jap	2009	Mech Compr	R-407E	D	566 kW	n. a.	3 – 4 a	47%	63%	569
Automotive – Washing process	Jap	2009	Mech Compr	R-134a	C & H	8 x 45.3 kW 6 x 22,3 kW	65 °C		86%	73%	575
Greenhouse	Jap	2010	Mech Compr	R-410A		6 x 18 kW	20 °C		63%	50%	580
Food: Drying of french fries	NL	2012	Mech Compr	R-717	D	880 kW	70 °C	4 a		70%	NL-06
Greenhouse Tomatoes	NL	2003	Mech Compr	R-134a	C&H	3 x 1.25 MW	42-50 °C	> 10 a	40-60 %	29%	NL-27

Figure 6: Selection of the case studies of different application and countries

The survey with a total of more than 150 projects and case studies has tried to present good examples of heat-pump technology and its application in industrial processes, field tests and commercial applications along with an analysis of operating data, when available, in accordance with the annex definition of industrial heat pumps, used for heating, ventilation, air-conditioning, hot water supply, heating, drying, dehumidification and other purposes.

5 Summary

There is a great potential for industrial heat pumps to reduce the energy consumption and related greenhouse gas emissions in the industry.
The main objectives of the project included market overviews in the participating countries, systems aspects and opportunities, apparatus technologies and system technologies.
The project collected totally 39 examples of R&D projects and 115 case studies worldwide, showing the successful integration of heat pumps in the industry and how to overcome barriers: Short payback periods are possible (less than 2 years), high reduction of CO_2-emissionen (in some cases more than 50 %), temperatures higher than 100 °C are possible, supply temperatures below 100 °C are standard.
Further main results are the lack of experiences with and the acceptance of industrial heat pumps integrated in industrial processes at different temperature levels, are the main barriers for their larger scale market introduction in many companies (and especially in SMEs).

6 Outlook

Main Goal of the new HPT-Annex 48 is to overcome difficulties and barriers for the market introduction of industrial heat pumps.
Based on the experiences and collected information the main priorities are:

Collected cases studies of industrial branches with a large potential, should be analysed through well-founded energy audits focused on waste heat recovery and an international information data base created
Development of a webbased information platform for heat pumps in the industry
Creating information material for IHP (training) courses
The **IHP potential** for more efficient use of energy and reduction of greenhouse gas emission should be prepared for policy makers
The development of a **simplified model for the integration** of a heat pump into a process
Arranging the information on heat pumping technologies for industry, for policy-makers, industrial planers and designers, stake holders as well as heat pump manufactures in such way that it will lead to a better understanding of the opportunities and using these in the right way for the reduction of primary energy consumption, CO_2-emissions as well as energy cost of industrial processes.

7 References

[1] IEA HPP Annex 35, Final Report, May 2015,
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www.heatpumpcentre.org
http://www.heatpumpcentre.org/en/projects/completedprojects/annex35/publications/Sidor/default.aspx
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