Application of Industrial Heat Pumps

IEA Industrial Energy-related Systems and Technologies Annex 13
IEA Heat Pump Programme Annex 35

Task 5: Communication

Final Report

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Prepared by
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Contents

1 Introduction

Communication strategy has to be developed (target groups, objectives and means) based upon learning curves by continuous consolidation of the created content through extensive monitoring of projects

- Awareness of potential (energy conservation, greenhouse gases, eco footprint, etc)
- Develop independent information that can be used for policy developments on energy, environmental legislation
- Give recommendation on future developments
- Execute targeted workshops with relevant stake holders, conference presentations
- Communicate directly with manufacturers and end users
- Create a Web site with database – Best practice, overview of technologies
- Give input for training courses in relation to existing organizations.

These dissemination and communication activities should be openly available to every potential user in order to attain the essential objectives of the Implementing Agreements.

Task 5 “Communication” includes also publications of the participants referring to the topics of this Annex.

2 Country-Reports

2.1 Austria

2.1.1 Communication in Austria concerning HPP Annex 35

Within the Austrian cooperation and contribution on the HPP-IETS Annex 35/13 a communication strategy has been developed in order to attain the essential objectives of the Implementing Agreements. The Austrian dissemination and communication activities include papers/presentations and other publications concerning the topic industrial heat pumps (see chapter 2.1.1). Furthermore, the national communication strategy focused on giving and getting important information on the issue concerning the Annex 35/13 to and from relevant national stake holders:

- Within a national workshop the Austrian heat pump manufactures and community has been involved in the potential, application possibilities, challenges and technology trends of industrial heat pumps (see chapter 2.1.2).
- To reach the end users (the Austrian industrial and commercial companies), presentations of the benefits at relevant conferences as e.g. Zotter & Rieberer (2014) (see chapter 2.1.1) has been held, as well as a questionnaire (see chapter 2.1.2) has been developed and sent to the Austrian industry to indicate them to the possibility of using an industrial heat pump in their production.
- Involving relevant decision maker to this important topic, a national report about the activities and the results about the HPP-IETS Annex 35/13 will be prepared at end of the Annex and sent to the Federal Ministry for Transport, Innovation and Technology of Austria (see chapter 2.1.4).
- This national report will be free and publicly available at the web site www.nachhaltigwirtschaften.at/iea/ to grant a broad access. At this website further information about the aims and activities of the HPP-IETS Annex 35/13 are available (see chapter 2.1.4).

As a highlight of the Austrian communication activities, which have to be mentioned, is the successful initiation - based on the experience of the HPP Annex 35 - of a national R&D project (FFG-Pr. Nr.: 834614) concerning the development of a high temperature hybrid compression/absorption heat pump with an alternative working pair for recovering industrial waste heat.

2.1.2 National Workshop

A national workshop about the activities and issues concerning the HPP-IETS Annex 35/13 was held on Oct. 11, 2013 within the 9th Austrian Info-Day for Heat Pump Manufactures (see Figure 2-1).

Within this workshop the Austrian heat pump community has been informed about the activities of the HPP-IETS Annex 35/13, the application possibilities at relevant industrial branches, the economical and ecological potential, the technical issues and needs, as well as about the actual R&D trends of industrial heat pumps (see Figure 2-2). The work shop ends with a discussion about the economical objectives and future trends of industrial heat pumps. As recommendation on future developments, it has been summarized that the Austrian industry needs high-temperature heat pumps. Within this discussion, it was also pointed out, that beside the industry commercial buildings in Austria offer also a large potential for heat pump applications, as e.g. hotels.

Figure 2-1: Members of the 9th Austrian info-day for heat pump manufactures

Figure 2-2: *Presentation of the aims and activities of the IEA HPP Annex 35*

2.1.3 Questionnaire

In order to get in contact to the end users of industrial heat pumps a questionnaire have been developed and sent to the Austrian industrial and commercial companies. The sent questionnaires have two major aims, both to determine an overview of the actual energy consumption on the one hand and on the other hand to involve the industry with this topic.

Preliminary, about 360 companies in whole Austrian have been contacted via telephone. The questionnaires have been sent to all the companies, which have agreed to join with. But unfortunately, the number of completed, returned questionnaires has been rather poor despite repeated contact. Therefore, a branches selected analysis was not possible. However, according to the results of the questionnaire, for about 90 % of the asked companies (40#) measures to reduce the energy consumption are considered. The most important criteria for or against a measures for saving energy in the industry are the economical rentability and the reliability of the production process. For Austrian industry payback time should be no longer than 3 years and in exceptional cases no longer than 6 years at all.

According to this analysis, about 67 % of industrial companies know about the possibility to use heat pumps for their heat supply. But, the percentage of Austrian companies knowing about industrial waste heat recovery by heat pumps is lower. However, based on these results the relatively high investment costs and “long” payback periods were seen as the most important barriers by the industry. Furthermore, there is skepticism about the reliability of such systems, since experience of already installed plants are missing. Other barriers are a lack of know-how in Austria regarding the integration and operation of high-temperature heat pumps in different production processes, as well as a previously unattractive energy price situation. But, with an expectable increase in fossil fuel prices in future and a gain in experience the industrial heat pump will become much more attractive for the industry compared to conventional boilers.

2.1.4 National report (web site)

After the end of the IEA HPP-IETS Annex 35/13, a national report will be written to give a detailed overview of all the results, the Austrian contributions and activities of this Annex. This national report will be published by the Federal Ministry for Transport, Innovation and Technology of Austria (bmvit) via the public domain web site "www.nachhaltigwirtschaften.at/iea/" to grant a broad and generally access to reach a relevant spin-doctors and policy-maker. This web site also gives further information about the aims and activities of the HPP-IETS Annex 35/13.

The national report will include an overview of the energy situation in Austrian industry, the potential for reducing CO_2-emission in the industry using heat pumps and an overview of the available heat pump technology and R&D trends suitable for the industry. Furthermore, also an overview of possible barriers, legal standards as well as funding guidelines in Austria concerning the application of industrial heat pumps will be part of this report. A main part of the report will be related to application possibilities in different industry branches and processes, as well as the documentation of some realised plants in Austria.

The major aim of this national report is to overcome the mostly relevant barriers like e.g. missing experience and know-how., which hinder a wider field of heat pump applications in Austrian industry up to now.

The national report will be mainly addressed to the heat pumps manufacturer, the industry, consulting engineers and installers as well as policy makers for input to directives and legislation.

2.2 The Netherlands

The Legal Text for the Annex had Task 5 titled Communication in a broad sense of the definition. The goal was to develop a communication strategy (target groups, objectives and means) based upon learning curves by continuous consolidation of the created content through extensive monitoring of projects.

The objective of the Annex to reduce the use of energy and emissions of greenhouse gases by the increased implementation of heat pumps in industry, is to be reached by:

- Generating information for policy makers.
- Developing information for key stake holders in industry and its supply and consulting chain and for policy makers.
- Getting insight in business decision processes.
- Increasing the knowledge and information about IHP's, database and getting existing information available.
- Applying new technologies and identifying the needs for technological development
- Creating a network of experts.
- Finding synergy with renewable energy production to increase flexibility of the grid.

The dissemination and communication activities should be based upon a set of activities defined as:

- Awareness of potential (energy conservation, greenhouse gases, eco footprint, etc)
- Develop independent information that can be used for policy developments on energy, environmental legislation
- Give recommendation on future developments
- Execute targeted workshops with relevant stake holders, conference presentations
- Communicate directly with manufacturers and end users
- Create a Web site with database – Best practice, overview of technologies
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On international IEA level within the Annex unfortunately, although the Annex 35/13 project had been prolonged by one year, nearly none of the deliveries could be finished as foreseen, due to the fact that most participants in the Annex are more involved with R&D than with marketing

The report on The Netherlands will handle the topics as mentioned under the activities in the Legal Text, where an analyzes by the National Enterprise Agency in 2009 was the basis for the approach using traditional tools accepted in the market. A Dutch National Team with the main stakeholders supported this approach. As 'work in progress' this report is not the final stage of the work.

2.2.1 Introduction to the market

Technological development, the development tariffs for natural gas and electricity, the need to promote a green image and the increased government attention for excess heat will increase the interest for industrial heat pumps. Frontrunners in the market ranging from Lidl to Shell are well aware of the need for sustainable development and are already committed to highly ambitious goals. Dairy industry has developed their program on an Energy Neutral production chain. But what about the others?

In the approach of industry we must be conscious as reported under Tasks 1&2 of the fact that decisions in industry are based upon information that will be of different and tailor made contents. The energy conservation policy for industry from government has been largely based on the Voluntary Multi-Year Agreements (MYA) between Industrial Sectors and the Ministry of Economic Affairs. This approach is tailor made and worked out in Road Maps.

As a consequence four or even five different levels of information and approach can be distinguished in which heat pumping technologies can play an important role, being:

- Chemical industries active under the R&D innovation contract of ISPT (http://ispt.eu/roadmap/) is actively involved in developments of technologies as described under Task 3.
- Paper and pulp and other large sectors are approached through the MYA are also partly involved in ISPT. An important topic for these sectors is the bad economic situation of cogeneration through the negative spark spread giving new opportunities for process integration.

- Food industry is active on MYA-roadmaps and there is notable increase in applied heat pumps. An important topic is the F-gas regulation through a large renovation process is needed for the refrigeration and cooling in these sectors.
- Miscellaneous industries have a potential for heat pump applications which not yet structurally approached by policy or market suppliers. The number of applications is also growing but those are coincidences.
- Industrial areas with mixed occupants are almost all approached through local authorities, an approach which can be successful.
- Agriculture and the Greenhouse sector have already shown a lot of successful applications.

In general there two major obstacles which already noted in the start of the IEA Annex which is the fact that the knowledge of pinch and process integration is not broadly spread and almost lost for a large part of industry, nor the knowledge of heat pump applications and heat pumping technologies. It is not normal the policy and even within the capacities of RVO/Government to approach individual industries to convince these towards sustainability, nor is it possible within the framework of policy programs to give a long term commitment to an information structure. In order to reach the individual industries a closely knit network has to be developed and a process approach of a long distance runner is needed. Commissioned by RVO, Energy Matters therefore has analysed how market introduction of heat pumps in special but reduction of energy for making heat in general can be accelerated without continued support from the government. To overcome the barriers a voluntary program is basically as described under the Legal Text of the Annex:

- Information of the key users, to raise awareness of the saving potential and the potential for renewable energy
- Education, trainings of key users and Energy Auditors, where standardized methodologies and supporting tools are used within an integral approach based upon the Onion model for heat conservation;
- Develop best case studies and publish factsheets, conduct pilot audits and develop monitoring and a set of sector specific tailor made solutions;
- Partly financed company specific Energy Efficiency Plans based upon energy audits, which is a program run under the MYA. This program should focus on the re-use of waste heat within the process.
- Development of Long Term Sectorial plans (i.e. Roadmaps)
- Support scheme for tax reductions on the resulting investments
- Work with suppliers, as ideal partners to distribute information and specific know-how
- Roll out of newly developed technologies through support of demonstration and pilot projects.

Therefore as discussed under Task 2 checklists, software tool and standardized reports are developed. But also information of key users, pilot audits, case studies, education of auditors are addressed.

2.2.2 Market analyses

Most energy users are unaware of the large savings potential, both technological and economic, to reduce energy consumption. Therefore time and budget devoted to optimize energy efficiency of other systems than the key-production process is often zero. According to the energy managers of industrial companies these two points – lack of time and lack of budget – are the main barriers for implementing energy saving measures.

It is stated that information for the key users, to raise awareness of the saving potential and the potential for renewable energy is an important step in the process.

Very often the management does not realize the real costs of the energy consumption in their company and the possibilities of savings which can be achieved, but also the technical staff has low awareness of potential energy savings in industry. The costs of detailed energy audits are considered as too high. Therefore most companies are not willing to pay for audits, unless they already have a specific idea of certain measures to be implemented.

It is important to envisage in a communication strategy on heat pumps, that industrial companies only become active if one of its staff members is convinced and is able to present the heat pump as a sound and attractive business case to the decision makers within the company. Heat pumps can be part of the solution for a new project or renovation project in which excess heat is part of the challenge to be solved. As excess heat is often not seen as an economical problem, it will be the first challenge to get this topic on the agenda of the project engineers and decision makers within the company. Then the threshold for a company becoming aware of the solution with heat pumps should not be too high or too time consuming in the learning process.

Information should be readily available, tailor made and have easy tools for a first calculation or estimation.

Persons to be informed in the first stage are most likely project or process engineers, managers of the utilities or persons responsible for quality, working conditions and the environment (permits).

The next aspect to consider in a communication strategy on heat pumps is that it is impossible for one organization only, like RVO, to approach thousands of employees, hundreds of companies with tailor made communication on the advantages of heat pumping technologies for different processes. An intermediary organizational structure is needed. The question will have to be answered how such an organization can work and continue to work without financial support from government after the start and build up phases. Key stakeholders in the market will have to be attracted to join forces. It seems logical to involve heat pump suppliers/manufacturers and to let them take the lead. However these companies are often more active in refrigeration with limited knowledge of industrial processes.

Consultants have a common interest in the development of this market, are accustomed to process analyses and sometimes have basic awareness of pinch models.

The market deployment for industrial heat pumps already fosters successful new projects since the last five years as technological developments enter the market and boundary conditions are changing through environmental legislation and tariff developments of energy prices. These developments are often sector and process specific and need a tailor made approach to find the right leverage for interest in the heat pump solution. It is interesting to know that heat pumps are attractive to a certain part of the intensive greenhouse industry as it was possible to get a higher yield with less risk for plant diseases [snap niet wat hier staat]. This added value was the leverage needed. For industrial processes it will be the challenge to find similar strategies.

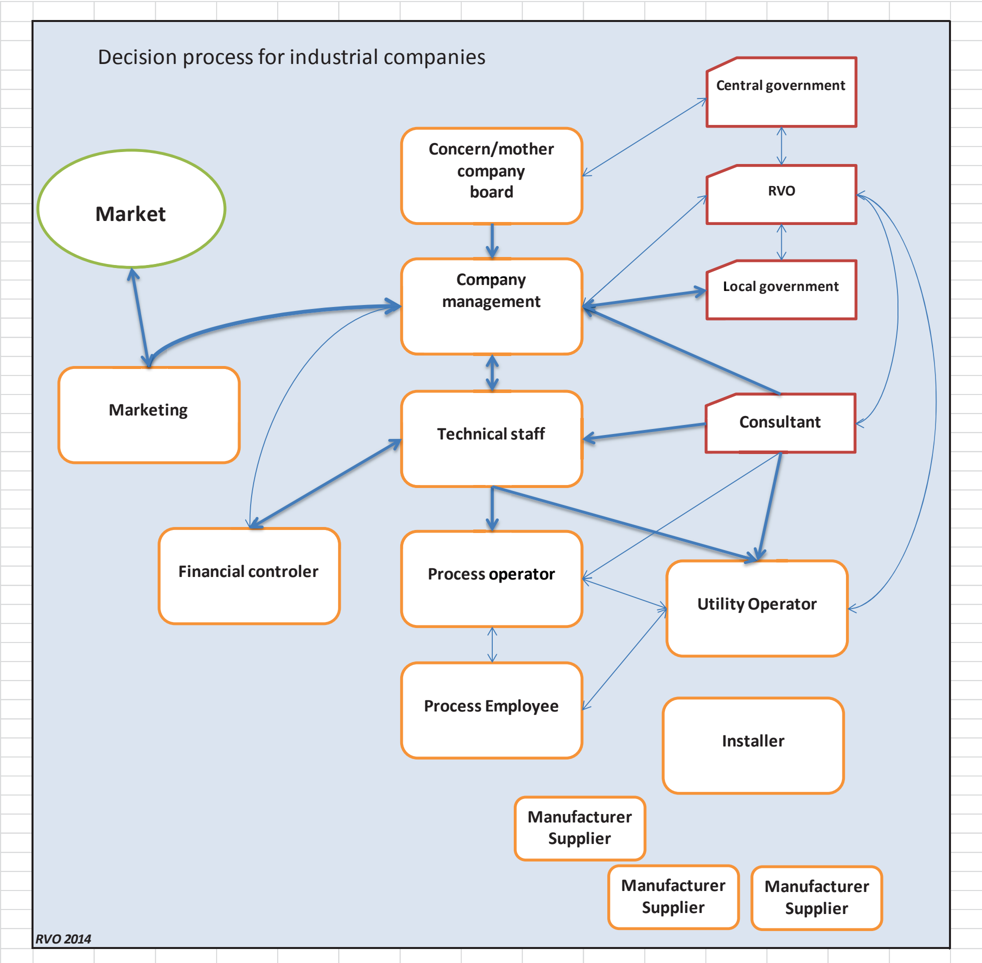

Figure 2-3: ***Communication network in industry***

Heat pumps are only economically viable when aligned with the business process and not compete with simple measures such as direct heating. The basic message is that 'Heat pumps offer opportunities in situations where excess heat is available which cannot be used directly'.

A basis for communication is and will be the availability of objective and unambiguous information. Information which is needed in order to evaluate the odds as well as give the characteristics of the available heat pump equipment which can be stored in a database and made available through a web site.

In the Einstein project parallel to the RVO analyses several factors are named that hinder further energy optimization of processes:

Competition of suppliers and trade companies: Suppliers of equipment for industry are very active on the market but are looking for sale of equipment and not for assistance to reduce energy consumption. Furthermore energy audits are conducted by design companies and wholesale trade enterprises. These companies do not have practical and professional experiences for an energy audit as this is not their core service.

Data acquisition problems: In many cases factories are unwilling to disclose energy-related data which are considered confidential, sometimes inadequate or unreliable measuring equipment is installed in factories. Furthermore companies often are not aware of the energy flows of their own processes and therefore they do not store properly relevant data and are not able to deliver reliable information as they have not the appropriate knowledge. For energy auditors it is difficult to get support of technical employees: sometimes they are considered as competitors or as a danger for their own job.

Evaluation: Sometimes neither the auditor nor the company have the measurement equipment necessary for evaluation of the saving measures and it is difficult to identify the characteristics of the machines and technical equipment on site. For the evaluation of the processes in different industrial sectors it is difficult for energy auditors to know all the relevant technologies and collect experience in all technical processes. All those problems make economical assessment and evaluation of selected options very challenging.

Implementation: At the end of the decision process expectations of short investment pay-back period and reluctance to implement changes because of possible impact on the processes are the main barriers to the implementation of saving measures. At the end clients simply do not implement proposed measures.

Problems on personnel level: Personnel may not be trained or experienced in energy saving measures. Furthermore the personnel have insufficient time to implement measures. The person responsible for energy any energy efficiency is not a part of the management team. Therefore, (s)he has limited organizational power and budget. Those problems may also be seen as barriers from management: reluctance to adopt current managerial procedures for energy efficiency and lack of a culture to make energy efficiency 'business as usual', i.e., to make energy management an integrated part of the management processes.

Cost evaluation case by case: Universal information on the cost of energy efficiency investments does not exist. Instead, each energy-saving measure has its individual cost depending on the local situation and is determined by the amount of supplementary work (rebuilding etc.) that has to be done to implement it.

Inexistent follow up: The follow-up after the energy audits or the implementation projects thereafter may have been inexistent. Supervision and maintenance work may have been neglected and, as a result, their energy performance has fallen.

2.2.3 Market developments and communication strategy (tailor made approach)

There a number of market developments which widens the opportunities for industrial heat pumps. An increase in the application of heat pumps is noticeable in the last five years after more than a decade of stand-still. External influences as well as technological developments can be credited:

- Process industry, mainly chemical industry with a focus on process intensification using advanced highly specific software models by large specialized engineering companies. Under the ISPT-program these companies are effectively collaborating on new processes and new innovative heat pumping technologies as described under Task3. The roll-out of these technologies are supported by governmental programs.
- Large industrial processes for specific sectors where large excess heat streams are produced like paper and pulp industry are often multi-nationals which have their own priorities and react on market changes, energy and feedstock prices with decisions often made at concern level. Due to the decline of the so-called spark spread, the difference in operating costs between CHP and heat pumps is considerably narrowed. A lot of CHP-installations after depreciation will therefore not be replaced as the investment will have an insecure economical basis. Paper and Pulp industry being an example. In those cases, there is more attention to the internal use of process heat and thus for heat pumps where drying processes and washing hot water processes are the logical applications. The approach in the Netherlands can be sector specific as companies are part of sectorial multi-year agreements with government. This approach has been piloted in paper and pulp and is based upon general and specific analyses of processes, workshops and training courses. Experience on this can be applied in other sectors. Especially in the greenhouse sector the combination of heat pumps and CHP increases the heating capacity and decreases the electricity output to the grid, therewith increasing the economy.
- In line with the requirements for the EU F-gas regulation many companies have to adapt their system or replace their refrigeration and/or cooling systems. This conversion, which has to be done before the end of 2015, and not to forget the new EU F-gas proposal (additional phase out in 2020), offers the opportunity to simultaneously use the heat from chillers for heating purposes. Manufacturers like IBK and Grasso are actively marketing this solution with the support of Netherlands Enterprise Agency and workshops/training courses for installers. For food industry Dairy industry is already on a pathway to Energy Neutral for the complete supply chain from cow to end user. Other sectors like meat industry have heat pumps defined as key technology. This approach should be broadened to other sectors. The first projects using condenser heat from cooling with add-on heat pumps are built but not yet common practice. The focus for communication is to catch up in closing the knowledge gap at to get the use of excess heat from cooling for heating purposes state of the art in industry by the end of 2015. A 'taskforce heat from cooling' is set up. This taskforce creates a website with project cases, hold seminars in the regions and workshops and training courses. The startup of this task force is funded by RVO and will be continued on commercial basis by consultants, installers and manufacturers.
- A large application potential of industrial heat pumps is still not used because of the limited supply temperatures of about 100 °C of commercially available heat pumps. If these supply temperatures could be increased, more industrial processes could be

improved in their energy efficiency. The main reason for the limited temperatures has been the absence of adequate working fluids. By using other than the traditional working fluids for refrigeration and new technologies heat pumps can lift to reach 120 °C and even higher. Both working fluids and new technologies are now getting out of the development phases into practice through first pilots and real life applications:

  - New refrigerants with low GDP and high temperatures are becoming available from international manufacturers.
  - Through the use of so-called "temperature glides" the heat/electricity ratio (COP) is significantly improved and the introduction of chillers with an additional compression step, which are perfect for the heating of hot water or cleaning process in process industries.
  - The early development of acoustic and thermochemical heat pumps and heat transformers the path towards even higher temperature ranges up to 250 °C.

- Increased performance, reliability and availability of heat pump technologies for commercial and domestic buildings make the application in business parks more attractive, the first industrial A+++ buildings with BREEAM appearing on the market. Business parks where small manufacturing companies and warehouses are located have a large potential which can be realized with the examples like Ecofactorij in renovation and development process of the area within the boundary conditions of Municipalities, developing master plans.

In general the Multi-Year Agreements with other sectors then the above should focus on pathways and on re-use of waste heat within the process. The existence of cooling towers within the industrial process shows where heat is wasted. A program focusing on ‘no more cooling towers’ can be developed

2.2.4 Conclusions

In line with the Legal Text of the Annex the undertaken activities focus on:

- *Awareness of potential (energy conservation, greenhouse gases, eco footprint, etc*) which is reported under Chapter 1 (Task 1) as follows:
  - Chemical Industry is active in ISPT-program and well aware of and active with innovative heat pumping technologies as described under Chapter 3/Task 3.
  - Paper and Pulp is extensively approached with regular sectorial works shops supported by the R&D-program of ISPT (Chapter 3/Task 3) and the KCPK (Knowledge Expert Centre for Paper and Pulp).
  - Food Industry is active under the MYA’s and within their Energy Conservation Roadmaps heat pumping technologies are taken up when relevant. Examples being meat processing, dairy and cheese making, greenhouses, etc.
  - Miscellaneous industries on clustered areas are approached through the website and by informing local city councils with information successes like Ecofactorij. Workshops are held on the Information Centre

    - Large forerunners are advertised as example like Lidl and Campina

- *Develop independent information that can be used for policy developments on energy, environmental legislation*. The Management summary of the report on Industrial Heat in the Netherlands is sent to the ministry of Economic Affairs which is developing a Long Term Vision on the heat infrastructure in the Netherlands.
- *Give recommendation on future developments*, this is described in the Management Summary and in the next paragraphs. These recommendations are discussed and being programmed in the activities of Netherlands Enterprise Agency.
- *Execute targeted workshops with relevant stake holders*, This is taken up by education and trainings of key users and Energy Auditors through their branch organization FEDEC, where standardized methodologies, like EPS, and supporting tools, like EINSTEIN, are used within an integral approach based upon the Onion model for heat conservation;
- *Communicate directly with manufacturers and end users.* As stated in the analyses of the market the scope of the approach and the target audience is large and cannot be covered by the Netherlands Enterprise Agency on the long term.
    - The market is approached through tailor made activities is described in paragraph 5.5.
    - Intermediaries are used a discussion platform 'Industrial Heat' is created organizing targeted workshops and seminars.
    - Partly financed company specific Energy Efficiency Plans based upon energy audits, which is a program run under the MYA. This program should focus on the re-use of waste heat within the process. This is not yet the case and Long Term Sectorial plans (i.e. Roadmaps) can be used for this attention.
    - There have been extensive discussions with manufacturers where during the Annex two manufacturers were awarded the NVKL-Innovation Award, therewith getting country wide attention.
- *Create a Web site with database*, two websites have been created during the Annex.
- *Best practice, overview of technologies*. At the start of the Annex it has been difficult to get sufficient information best practice applications, but running the Annex more and more information got in. A list of over 30 projects exists for which 20 Factsheets have been written. This database will be filled continuously and information will be spread to the target audience.

The Communication strategy is work in progress and not yet fully established.

Several approaches for process optimization in industry can be met with based upon the TRIAS Energetica. In chapter 2 it is discussed how to approach the different industrial sectors/companies. The Energy Potential Scan developed by Philips/Novem is a participative model to start the analyses of the industrial process. Unlike traditional energy audit approach, in EPS, company and energy consultants work together to analyze the possibility to conserve energy. This model is used in many countries worldwide to get awareness within companies to work on energy conservation.

In general the approach through the Multi-Year Agreements and the approach by local authorities should give permits for investments in new processes and technologies only upon the Best Available Technologies and process energy investments only on the TRI-AS-Energetica. A short list of sector specific technologies can be developed by RVO.

Supporting actions for this strategy are:

- Training courses on Energy Potential Scan and process integration through Einstein for consultants through Energy Matters and FEDEC.
- Data of technology in models within input from manufacturers. Several specific heat pump models and databases have become available in the Netherlands during the work on the Annex. These models must still be extended on international level in order to get The heat pump model based upon Excel would ideally be available on the Internet and could further be developed as a WIKI-approach where the market itself would fill in further details in the model and in the end applications could be hinged as factsheets to the model. This stage of development is not reached yet during the process of the Annex.
- Factsheets for several types of best practice applications have become available and will be published in linked to the mentioned heat pump model. This collection of fact sheets will be extended
- Training and education on process modeling based upon exergy and pinch at basic high school level and universities should be intensified and partly re-introduced.
- Workshops with key stake holders and decision makers can give a basic understanding of the real costs of the energy consumption in companies and the possibilities of savings which can be achieved.

These supporting activities should be clearly shown on a Web site which is not part of a governmental program but ideally supported and financed by the market.

3 Publications

The participants of this Annex published the following articles, reports etc.

3.1 Austria

Following a list of all Austrian papers/presentations or other publications on the issue concerning Annex 35/ 13 "Application of Industrial Heat Pumps" is given:

Fleckl T., Zottl A., 2013: *„Simulation tools for the integration of heat pumps in complex systems“* 9. Info-Tag für Wärmepumpenhersteller, Vienna, Austria, 11.10.2013 (in German: *Simulationstools zur Integration von Wärmepumpen in komplexe Systeme)*

Hoff C., 2011: *„High temperature heat pumps for industrial waste heat recovery”*– Bachelor Thesis at the Faculty of Mechanical Engineering and Economic Sciences, University of Technology Graz, written at the Institute of Thermal Engineering of , University of Technology Graz, Austria, 2011 (in German: Hochtemperaturwärmepumpen für industrielle Abwärmenutzung)

Moser, H.; Rieberer, R., 2010: *„Waste heat recovery due to flue gas condensing systems of biomass cogeneration plants“*- in: Cluster Forum "Abwärmenutzung in der Industrie". Nuremberg, Germany, 19.11.2010 (in German: Wärmerückgewinnung mittels Rauchgaskondensationsanlagen biomassebefeuerter Heizkraftwerke)

Rieberer R., 2013: *„IEA HPP Annex 35 – Industrial Heat Pumps – Overview“* 9. Info-Tag für Wärmepumpenhersteller, Vienna, Austria, 11.10.2013 (in German: *IEA HPP Annex 35 – Industrial Heat Pumps – Übersicht)*

Schachner T., 2012: *„Industrial heat pump applications in Austria - An ecological and economic comparison with conventional heat generators”* - Bachelor Thesis, Faculty of Mechanical Engineering and Economic Sciences, University of Technology Graz, written at the Institute of Thermal Engineering of , University of Technology Graz, Ausria, 2012

Zotter, G.; Rieberer, R., 2013: *„Technical, ecological and economical analyse of a heat pump application for waste heat recovery in a metal-working industrial plant“* – in Proc.: DKV-Tagungsbericht 2013. Deutscher Kalte- und Klimatechnischer Verein Hannover, Germany, 20-22.11.2013, ISBN: 978-3-932715-49-5 (in German: Technische, ökologische und ökonomische Analyse des Einsatzes einer Wärmepumpe zur Nutzung von industrieller Abwärme in einem metallverarbeitenden Betrieb)

Zotter G., Rieberer R., 2013: *„Industrial heat pumps – possibilities and potentials of in-plant waste heat recovery by heat pumps“* 9. Info-Tag für Wärmepumpenhersteller, Vienna, Austria, 11.10.2013 (in German: *Industrielle Wärmepumpe - Möglichkeiten und Potentiale der innerbetrieblichen Abwärmenutzung mittels Wärmepumpen)*

Zotter, G.; Rieberer, R., 2014: „Increase of the energy efficiency in Austrian industry due *in-plant waste heat recovery with heat pumps* by two examples*“* – in Proc.: Symposium Energie Innovationen 2014. Graz, Austria, 13-15.02.2014, ISBN: 978-3-85125-310-8 (in German: „Steigerung der Energieeffizienz in Österreichs Industrie durch innerbetriebliche Abwärmenutzung mittels Wärmepumpsystemen anhand zweier Beispiele

Zotter, G.; Rieberer, R., 2014: „In-plant utilization of waste heat by heat pumping systems“; in Journal: KI-Kälte-, Luft-& Klimatechnik, published 22.05.2014 (in German: „Innerbetriebliche Nutzung von Abwärme mittels Wärmepumpen*“*)

3.2 France

Sapora, 2010 — Sapora, E.: Heat Pump Integration in a Dairy. Workshop Industrial Heat Pump. Chillventa 2010, Nuremberg, 2010.

Bobelin, 2011 — Bobelin, D.: Experimental results of a heat pump using R245fa as working fluid. European Heat Pump summit, Nuremberg, 2011.

Pereux, 2012 — Peureux, J. L.: Very high temperature heat pump applied to Energy efficiency in Industry. ACHEMA 2012

3.3 Germany

3.3.1 thermea. Energiesysteme GmbH

Selected papers and presentations 2008 to 2014

Wobst, 2008 — Wobst, E., Oberländer, S., Nestler, W., CO2-Wärmepumpen großer Leistung – unverzichtbar für eine nachhaltige Wärmeversorgung, KI Kälte Luft Klimatechnik, December 2008

Wobst, 2010 — Wobst, E., CO2-Großwärmepumpen für den industriellen Einsatz VDI Wissensforum, Stuttgart, June 2010

Hübner, 2012	Hübner,.J., Oberländer, S., Wobst, E.: Energiekosten- und CO2-Emissionsreduzierung mit CO2- Hochtemperaturwärmepumpen thermeco2, HLH, Bd. 63, March 2012
Hübner, 2013	Hübner,.J., Energieeinsparung durch gekoppelte Wärme- und Kälteerzeugung, Die Kälte+Klimatechnik, November 2013
Oberländer, 2013	Oberländer, S., CO2-Hochtemperatur-Wärmepumpen in der Anwendung, Praxisbeispiele, European Heat Pump Summit, Nürnberg, October 2013
Hübner, 2014	Hübner, J., Energieeffizienz und Nachhaltigkeit in der Produktion und Gebäudetechnik TWK 10. Karlsruher Wärmepumpensymposium, February 2014

3.3.2 IER Stuttgart

Publications

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Wolf, 2012	Wolf, S.; Lambauer, J.; Blesl, M.; Fahl, U.; Voß, A.: Industrial Heat Pumps in Germany: Potentials, technological development and market barriers. Proceedings of the Eceee 2012 Summer Study on energy efficiency in industry, S. 543-550
Wolf, 2013a	**Wolf, S.; Fahl, U.:** Entwicklung einer Hochtemperaturwärmepumpe und Integration in einer Teilereinigungsanlage. In: Ingenieurspiegel (2013), Nr. 4, S. 36-38
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Wolf, 2014	**Wolf, S.; Fahl, U.:** Fortschritte beim Wärmepumpeneinsatz in der Industrie: Enorme Chancen nicht nur bei der Prozesswärme. In: Die Klima + Kältetechnik (2014), Nr. 2, S. 26-29

Talks

Lambauer, 2009	Lambauer, J.; Ohl, M.; Blesl, M.; Fahl, U.; Voß, A.: Aktuelle Forschungsergebnisse zu Potenzialen, Hemmnissen und Best-Practice-Beispielen von Groß-Wärmepumpen in der Industrie

und Gewerbe, Vortrag anlässlich des „10. Biberacher Forum Gebäudetechnik - Nachhaltiges Planen, Bauen und Betreiben von Gebäuden und Anlagentechnik“ am 11. und 12. März 2009 in Biberach, veranstaltet von der Bauakademie Biberach und der Hochschule Biberach, Studiengang Gebäudeklimatik, Biberach

Lambauer, 2010	Lambauer, J.; Ohl, M.; Blesl, M.; Fahl, U.; Voß, A.: Large scale industrial heat pumps – market analysis, potentials, barriers and Best-Practice-Examples, Vortrag gehalten anlässlich des Kick-off Meetings IEA IETS HPP Annex 13/35 „Application of industrial Heat Pumps“ am 26. April 2010 in Maintal, veranstaltet von IEA IETS HPP Annex 13/35, Information Centre on Heat Pumps and Refrigeration IZW e.V., Karlsruhe
Lambauer, 2011	Lambauer, J.; Wolf, S.; Fahl, U.; Blesl, M.; Voß, A.: Industrial (High Temperature) Heat Pumps in Germany. Market situation, potentials and technological development. European Heat Pump Summit 2011. Chillventa, 28.09.2011.
Wolf, 2012a	Wolf, S.; Lambauer, J.; Fahl, U.; Blesl, M.; Voß, A.: Industrial heat pumps in Germany. Potentials, technological development and application examples. ACHEMA Congress. DECHEMA. Frankfurt am Main, 13.07.2012.
Wolf, 2012b	Wolf, S.; Fahl, U.: Potenziale für den Einsatz von Hochtemperaturwärmepumpen in der Industrie in Deutschland. Seminar zu aktuellen Themen aus Energietechnik und Energiewirtschaft. Lehrstuhl für Technische Thermodynamik und Transportprozesse (LTTT). Bayreuth, 22.07.2012.
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Wolf, 2013a	Wolf, S.: Heizen und Kühlen mit industriellen Großwärmepumpen. Kolloquium Großwärmepumpen & Hochtemperaturwärmepumpen. Offenbach am Main, 16.04.2013.
Wolf, 2013b	Wolf, S.; Fahl, U.; Voß, A.: Development of an industrial high temperature heat pump and heat pump applications in the German industry. European Heat Pump Summit 2013. Nürnberg, 16.10.2013

3.4 Canada

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Minea, 2009b	Minea, V.: Avoiding failures of large-scale high-temperature drying heat pumps, Proceedings of The 6th Asia-Pacific Drying Conference (ADC2009) October 19-21, 2009, Bangkok, Thailand, pp. 179-187.
Minea, 2009c	Minea, V.: Challenging future of heat pumps, IEA Heat Pump Centre, Volume 27, No. 4/2009, pp. 8-12, December 2009.
Minea, 2010a	Minea V.: Improvements of high-temperature drying heat pumps, International Journal of Refrigeration, Volume 33, Number 1, 2010, pp. 180 – 195.
Minea, 2010b	Minea, V.: Improving integration and reliability of heat pumps in industrial drying processes, Proceedings of Sustainable Refrigeration and Heat Pump Technology Conference, Stockholm, June 13-16, 2010.
Minea, 2010c	Minea, V.: Improvements of High-Temperature Drying Heat Pumps, Proceeding of International Refrigeration and Air Conditioning Conference at Purdue, July 12 – 15, 2010.
Minea, 2010d	Minea, V.: Industrial heat pump applications in the Canadian energetic context. Annex 13-35 Workshop on Industrial heat Pumps, CHILLVENTA 2010, October 12th, Nürenberg, Germany.
Minea, 2011a	Minea, V.: INDUSTRIAL DRYING HEAT PUMPS. In: Refrigeration: Theory, Technology and Applications. 2011 Nova Science Publishers, Inc., pp. 1-70.
Minea, 2011b	Minea, V.: Industrial high-temperature heat pumps. First presentation at Électricité de France, ÉDF R&D, Département Éco-efficacité & Procédés Industriels, Centre des Renardières, France, 21 février 2011.

Minea, 2011c — Minea, V. : Industrial high-temperature heat pumps. Second presentation at Électricité de France, ÉDF R&D, Département Éco-efficacité & Procédés Industriels, Centre des Renardières, France, 15 juin 2011.

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Minea, 2012b — Minea, V.: Low-grade industrial waste heat recovery with CO_2 trans-critical heat pumps in cold climates, 10th IIR Gustav LORENTZEN Conference on Natural Refrigerants, Delft, The Netherlands, 2012.

Minea, 2012c — Minea, V.: Efficient Energy Recovery with Wood Drying Heat Pumps, Drying Technology, 30: 1630-1643, 2012.

Minea, 2012d — Minea, V.: DRYING HEAT PUMPS: FUTURE R&D NEEDS AND CHALLENGES, 18th International Drying Symposium (IDS 2012), Xiamen, China, 11-15 November 2012.

Minea, 2012e — Minea, V.: Valorisation des rejets thermiques industriels avec pompes à chaleur au CO_2, La Maîtrise de l’énergie, Volume 27, Numéro 4, hiver 2012, pp. 7-11.

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Minea, 2013e	Minea, V.: Heat Pump-Assisted Drying: Recent Technological Advances and R&D Needs, Drying Technology: An International Journal, 2013, 31:10, 1177-1189.

3.5 Japan

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Watanabe, 2012b	Watanabe C., Trends in industrial heat pump technology in Japan, IEA HPP Symposium in Nuremberg, Germany, 8 Oct. 2012, http://www.heatpumpcentre.org/en/hppactivities/hppworkshops/Nuremberg2012/Sidor/default.aspx
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Kando, 2012	Kando, M., Case Studies of High Temperature Heat Pump to the Industrial Field from System Study to Operation, Proc. of the 2012 JSRAE Annual Conference, F112, 2012 (in Japanese)
Shiba, 2012	Shiba, Y., Tanifuji, K., Nakayama, H. and Sakuraba, I., Development and Introduction of a Heat Pump for Washing Process, Proc. of the 2012 JSRAE Annual Conference, F114, 2012 (in Japanese)

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Matsuo, 2012 — Matsuo, M., Imori, M., Izumi, H., Koike, T., Hayashi, Y., Ishida, K., Heat Pump Introduction to Car Painting Booth Air-conditioning, Electro-heat, No. 185, 2012 (in Japanese)

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Horibe, 2011	A. Horibe, J.Yu, N. Haruki, A. Kaneda, A. Machida, M. Kato, Melting Characteristics of Mixtures of Two Kinds of Latent Heat Storage Material, Japan J. of Thermophysical Properties, Vol. 25, No. 3 (2011), p. 136-142 (in Japanese)

3.6 Additional literature about industrial heat pumps

Bantle, 2013	Simulation des Energieverbrauchs bei der Klippfischtrocknung mit konventionellem Trockner und Wärmepumpentrockner. Michael Bantle, SINTEF Energy Research, DKV-Tagung 2013, Hannover.
Gladis, 2014	Applications of Industrial Ammonia Heat Pumps with Single Screw Compressor Technolog,. Sam Gladis. 11th IEA Heat Pump Conference, 2014, Montreal.
Heyse et al., 2013	Hochtemperatur Absorptionswärmepumpen. Christoph Heyse, Armin Hafner, Trygve M. Eikevik; SINTEF Energy Research, DKV-Tagung 2013, Hannover.
Kleefkens, 2014	R&D ON INDUSTRIAL HEAT PUMPS, Onno Kleefkens. 11th IEA Heat Pump Conference, 2014, Montreal.
Minea, 2014	Efficient Process Integration and Cooling & Heating Energy Performance of Supercritical CO2 Heat Pumps, Vasile Minea. 11th IEA Heat Pump Conference, 2014, Montreal.
Nordman, 2014	INDUSTRIAL HEAT PUMPS IN DAIRY INDUSTRIES IN SWEDEN - CURRENT STATUS AND OUTLOOK, Roger Nordman. 11th IEA Heat Pump Conference, 2014, Montreal.
Pearson, 2014	INDUSTRIAL HEAT PUMPS: CASE STUDIES AND LESSONS LEARNED, Andy Pearson. 11th IEA Heat Pump Conference, 2014, Montreal.
Reissner, 2014	BASIC DEVELOPMENT OF A NOVEL HIGH TEMPERATURE HEAT PUMP SYSTEM USING LOW GWP WORKING FLUIDS, Florian Reissner. 11th IEA Heat Pump Conference, 2014, Montreal.
Richard et al, 2014	Techno-economic evaluation of combining heat pump and mechanical steam compression for the production of low pressure steam from waste heat, Marc-André Richard et al. 11th IEA Heat Pump Conference, 2014, Montreal.
Takayama, 2014	Development of High Temperature Water Circulation Type Heat Pump for Industries (Air-to-Water Heat Pump with Maximum

	Output Water Temperature of 90°C), Tsukasa Takayama et al. 11th IEA Heat Pump Conference, 2014, Montreal.
Wajima, 2014	DEVELOPMENT OF HEAT RECOVERY CENTRIFUGAL HEAT PUMP FOR INDUSTRIAL-USE, Kazuki Wajima. 11th IEA Heat Pump Conference, 2014, Montreal.
Watanabe et al, 2014	Pioneering Industrial Heat Pump Technology in Japan, Choyu Watanabe et al. 11th IEA Heat Pump Conference, 2014, Montreal.
Zotter, 2013	Technische, ökologische und ökonomische Analyse des Einsatzes einer Wärmepumpe zur Nutzung von industrieller Abwärme in einem metallverarbeitenden Betrieb. Gerald Zotter, René Rieberer, Technische Universität Graz, DKV-Tagung 2013, Hannover.

4 Annex-Meetings

No project without meetings. During the period one kick-off-meeting and six Annex-meetings were hold:

Kick-Off Meeting in Maintal
IEA HPP / IETS Annex “Application of Industrial Heat Pumps”
26.04.2010, 10:00 a.m. to 5:00 p.m.
ESaK (European Academy of Refrigeration and Air conditioning),
Senefelderstraße 3, D-63477 Maintal

First Meeting 2010 in Nuremberg
IEA HPP / IETS Annex 35/13 “Application of Industrial Heat Pumps”
11.10.2010, 5.00 p.m. to 7.00 p.m.
Exhibition Centre Nuremberg, Germany

First Meeting 2011 in Moret-sur-Loing
IEA HPP / IETS Annex 35/13 “Application of Industrial Heat Pumps”
16.06.2011, 13.00 – 18.00
EdF-R&D, Les Renardières, Moret-sur-Loing, France

Second Meeting 2011 in Nuremberg
IEA HPP / IETS Annex 35/13 “Application of Industrial Heat Pumps”
27.09.2011, 15.00 – 18.30
Exhibition Centre Nuremberg

First Meeting 2012 in Nuremberg
IEA HPP / IETS Annex 35/13 “Application of Industrial Heat Pumps”
10.10.2012, 16.00 – 18.00
Exhibition Centre Nuremberg,

First Meeting 2013 in Gothenburg
IEA HPP / IETS Annex 35/13 “Application of Industrial Heat Pumps”
17.03.2013. 19.30 - 22.30
Chalmers Teknikpark, Sven Hultins Gata 9D,
Gothenburg Sweden

Second Meeting 2013 in Nuremberg
IEA HPP / IETS Annex 35/13 “Application of Industrial Heat Pumps”
14.10.2013. 13.00 -16.30
Exhibition Centre Nuremberg

5 Workshops and Presentations

Several workshops and presentations concerning Annex 35/13 topics were held.

5.1 Nuremberg 2010 – Chillventa Congressing

Title of the event	**Workshop Industrial Heat Pump IHP**
When	12. October 2010, 9:30 a.m. to 1:00 p.m.
Where	Nuremberg Convention Center, CCN East
Target group	Engineering, marketing and sales personnel in commerce & industry Consultants, users and decision-makers in commerce & industry
Content	Overview Industrial Heat Pumps Market and Opportunities Components for Industrial HP
Chair	Prof. Dr.-Ing. Hans-Jürgen Laue Dr.-Ing. Rainer Jakobs, IZW e.V.

Presentation	Author
Current energy use and application of heat pumps in Swedish industry	Dr. Roger Nordmann SP & HPP Sweden
Industrial heat pump applications in the Canadian energetic context	Vasile Minea Hydro Quebec Research Institute CDN
Maximizing Capacity at Minimum Cost for Plate Heat Exchangers in Industrial or Commercial Application	Prof. Dr.rer.nat. Reinhard Radermacher CEEE University of Maryland US
System build up and selection of the 2-stage DAIKIN LuviType Plus Air-to-Water HP for multi-family houses	François Bruggemans Daikin Europe N.V.
Transcritical Heat Pumps for Raising of Low Temperature Heat on High Temperature Levels	Prof. Eberhard Wobst thermea. Energiesysteme GmbH Germany
HP integration in a dairy: how to recover waste heat to provide heating to the process	Ing. Eugenio Sapora EDF France EDF R&D, Eco-efficiency & Industrial Process Department,
Breakthroughs in Industrial Ammonia Heat Pumps	Sam Gladis Emerson Climate Technologies GmbH
Overview of the components for Industrial HPs	Mikhailov Anatolii Danfoss GmbH Germany

5.2 Nuremberg 2011 – European Heat Pump Summit

Title of the event	Workshop Industrial HP Application (Annex 35-13)
When	28.September 201, 11:10 a.m. to 5:30 p.m.
Where	Nuremberg Convention Center, CCN Mitte
Target group	Engineering, marketing and sales personnel in commerce & industry Consultants, users and decision-makers in commerce & industry
Content	Overview Industrial Heat Pumps Market and Opportunities Components for Industrial HP
Chair	Prof. Dr.-Ing. Hans-Jürgen Laue Dr.-Ing. Rainer Jakobs, IZW e.V.

Presentation	Author
Industrial (high temperature) Heat Pumps in Germany - Market situation, potentials and technological development	Jochen.Lambauer, U. Fahl, Blesl, A.Voß, IER, Stuttgart,Germany
New compressor technologies for commercial comfort (heating & cooling) applications	Sonia Vazquez, Luigi Zamana, Emerson Climate Technologies, Germany
Next generation low GWP refrigerant for high temperature HPs	Kostas Kontomaris, DuPont Fluorochemicals R&D, U.S.A.
Experimental investigation of a high temperature HP using HFC-245fa as working fluid for heat recovery in the industry	Eugenio Sapora, Damien Bobelin, EDF - EDF R&D, France
Industrial-sized, high-temperature heat pumps: technologies, barriers and implementation	Lars Reinholdt, et al., DTI and Grontmij A/S, Denmark
From waste heat to process heat	Bruno Vanslambrouck, Ignace Vankeirsbilck, Howest Belgium
Application issues and energy performances of industrial wood drying heat pumps	Vasile Minea, Hydro-Québec Research Institute, Canada
Industrial application of heat pumps; Examples of beneficial applications and areas best avoided	David F. Pearson, Star Refrigeration Ltd, United Kingdom
Design of borehole heat exchangers for commercial and industrial applications	Markus Hochstein, geoENERGIE Konzept GmbH, Germany
Heat pumps in industrial cleaning applications	Bjarke Paaske, Danish Technological Institute, Denmark

5.3 Frankfurt am Main – ACHEMA Congress

Achema Congress 2012
Session
Application of Industrial Heat Pumps
Improving energy-efficiency of industrial processes
21. June 2012, 10.30 – 13.00,
Messe Frankfurt/Main, Hall 4, Room Europe
Organized by
Information Centre on Heat Pumps and Refrigeration - IZW e.V.
International Energy Agency - IEA Agreements
"Heat Pump Programme" and
"Industrial Energy-related Technologies and Systems"

Presentation	Author
Proven applications in 2012 for Megawatt+ Heat pumps within a technical, commercial and sustainable framework	Dave Pearson, Director of Innovation, Star Refrigeration Ltd; Glasgow, UK Philippe Nellissen, Product Manager Industrial Applications Emerson climate Technologies GmbH, Aachen, Germany
Industrial Heat Pumps in Germany – Potentials, technological development and application examples	M. Sc. Stefan Wolf, e t al, Institute for Energy Economics and the Rational Use of Energy (IER), University of Stuttgart, 70565 Stuttgart, Germany
Heat pumps in industrial cleaning applications	Dipl.-Ing. Bjarke Paaske, et al , The Danish Technological Institute (DTI) 8000 Aarhus C, Denmark
Heat pumps using Ammonia – the megawatt range	Dipl.-Ing. Wolfgang Dietrich, Dr.-Ing. Ole Fredrich, GEA Refrigeration Germany GmbH Berlin, Germany
Very high-temperature heat pumps applied to energy efficiency in industry	J-L. Peureux, Sapora Eugénio, Damien Bobelin, EDF R&D, Eco-efficiency and Industrial Processes department Centre des Renardières 77818 Moret sur Loin

5.4 Nuremberg 2012 – Chillventa Congressing

Title of the event	**Chillventa Congressing – Symposium HPP**
When	08. October 2012, 9:30 a.m. to 5:00 p.m.
Where	Nuremberg Convention Center, NCC East

Following presentations refer to ANNEX 35-13 topics:

Presentation	Author
Trends in industrial heat pump technology in Japan	Dr. Choyu Watanabe, Central Research Institute of Electric Power Industry Japan
IEA HPP- IETS Annex 35/13 The role of heat pumps for industrial processes - Current status and annex achievements	Jochen Lambauer, IER, University Stuttgart, Prof. Dr. K. Lassmann Prof. Dr. H.-J. Laue, IZW e.V.

5.5 Nuremberg 2013 – European Heat Pump Summit

Title of the event	EHPS
When	15. & 16. October 2013
Where	Nuremberg Convention Center, NCC Mitte

Following presentations refer to ANNEX 35-13 topics:

Presentation	Author
CO_2 high-power heat pumps in application examples	Frank Glaser, Thermea. Energiesysteme GmbH, Germany
Experimental performance evaluation of new safe and environment friendly working fluids for high temperature heat pumps	Florian Reissner et al., Siemens Corporate Technology, Germany
Zero ODP, Low GWP Working Fluids for High Temperature Heat Pumps	Kostas Kontomaris,PH.D., DuPont Fluorochemicals R&D, USA
Spectrum: Heat pump with speed controlled screw	Rüdiger Roth, Cofely Refrigeration GmbH, Germany
Development of an industrial high temperature HP and HP applications in the German industry	Stefan Wolf; et al., Institute for Energy Economics and the Rational Use of Energy (IER), Germany

5.6 Montreal 2014 – 11th IEA Heat Pump Conference

Workshop
IEA HPP / IETS Annex 35/13
“Application of Industrial Heat Pumps”
12. May 2014, 8.30 – 12.00
Montreal / Canada
Hotel Queen Elizabeth, Room A

Presentation	Author
French Industrial Heat Pump Developments applied to Heat Recovery	J.-L. Peureux, F. Sicard, D. Bobelin, EDF R&D Eco-efficiency and

	industrial Processes Department
Pioneering Industrial Heat Pump Technology in Japan	Ch. Watanabe, Chubu Electric Power Co., Inc.
Industrial Heat Pump R&D works and applications in the Canadian energetic context: past achievements and future challenges	V. Minea, Hydro Quebec Research Institute, Canada
How Heat Pumps can be used to improve Energy Efficiency of Industrial Processes	M. Sc. St. Wolf, Dr. U. Fahl, Prof. Dr. A. Voß, Institute for Energy Economics and the Rational Use of Energy (IER), University of Stuttgart
Industrial Heat Pumps in Austria - Absorption Heat Pump in a Wood-Processing Company	R. Rieberer, G. Zotter Graz University of Technology, Institute of Thermal Engineering;T. Fleckl, A. Zottl Austrian Institute of Technology, Energy Department
Thermal Energy Network based on Heat Pumps	Minsung Kim, Gilbong Lee, Junhyun Cho, Young-Jin Baik, Ho-Sang Ra, Energy Efficiency Department, Korea Institute of Energy Research
Development of High Temperature Water Circulation Type Heat Pump for Industries (Air-to-Water Heat Pump with a maximum output of Water Temperature of 90 °C)	Tsukasa Takayama, Toshiba Carrier Corporation, et al.
Summary	R. Jakobs, IZW e.V.

5.7 Nuremberg 2014 - IZW-Kurs

Wärmepumpen für die industrielle Anwendung

(Vorträge zur erfolgreichen Anwendung IHP)
13.10.2014, 13:00 bis 17:00 Uhr
Messezentrum Nürnberg, Raum Oslo, NCC Ost // Lesson in German Language

Presentation	Author
Bewertung der Chancen und Risiken für den Einsatz von Industriewärmepumpen in Deutschland	Stefan Wolf, Institute for Energy Economics and the Rational Use of Energy (IER), University of Stuttgart
Einsatz von Hochtemperaturwärmepumpen zur Wärmerückgewinnung in Rauchgaskondensationsanlagen	Michael Hartl, AIT, Austrian Institute of Technology GmbH, Wien, Österreich
Erfolgreiche Integration von Wärmepumpen in industrielle Prozesse	Stefan Wolf, Institute for Energy Economics and the Rational Use of Energy (IER), University of Stuttgart
Hochtemperatur-Wärmepumpen à Grundlagen-Planung-Beispiele	Manfred Fricke, Ochsner GmbH, Erfurt
Hochtemperatur - Wärmepumpen mit dem natürlichen Kältemittel CO_2 - Zukunftssichere Lösungen für industrielle Anwender	Frank Glaser, thermea. Energiesysteme GmbH, Ottendorf-Okrilla
NH_3-Wärmepumpen für Industrie und Kommunen	Sigurd Schiller, Johnson Controls Systems & Service GmbH, Essen

6 Policy paper

The main results of ANNEX 35/13 are summarized in a policy paper. The concept was to have a brochure, summarising the main results of the annex work explained in a generally intelligible manner, which can be used by the members of the Annex and the IEA Heat Pump Centre.

The policy paper consists of

- Description of industrial heat pumps
- Applications
- Barriers and solutions
- The integration of IHP into process
- Case studies
- Research and development projects
- Contacts.

The members of Annex have the possibility to change the examples of R&D-projects and the case studies with examples representing their countries and regions or technologies, referring to them.

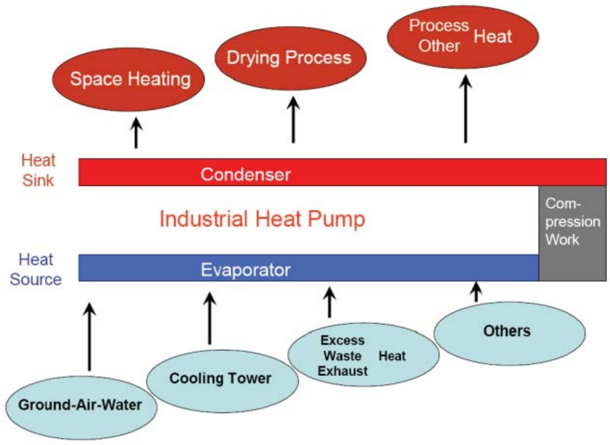
The complete policy paper is attached to this report.

APPENDIX:
Policy Paper

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 CO_2 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

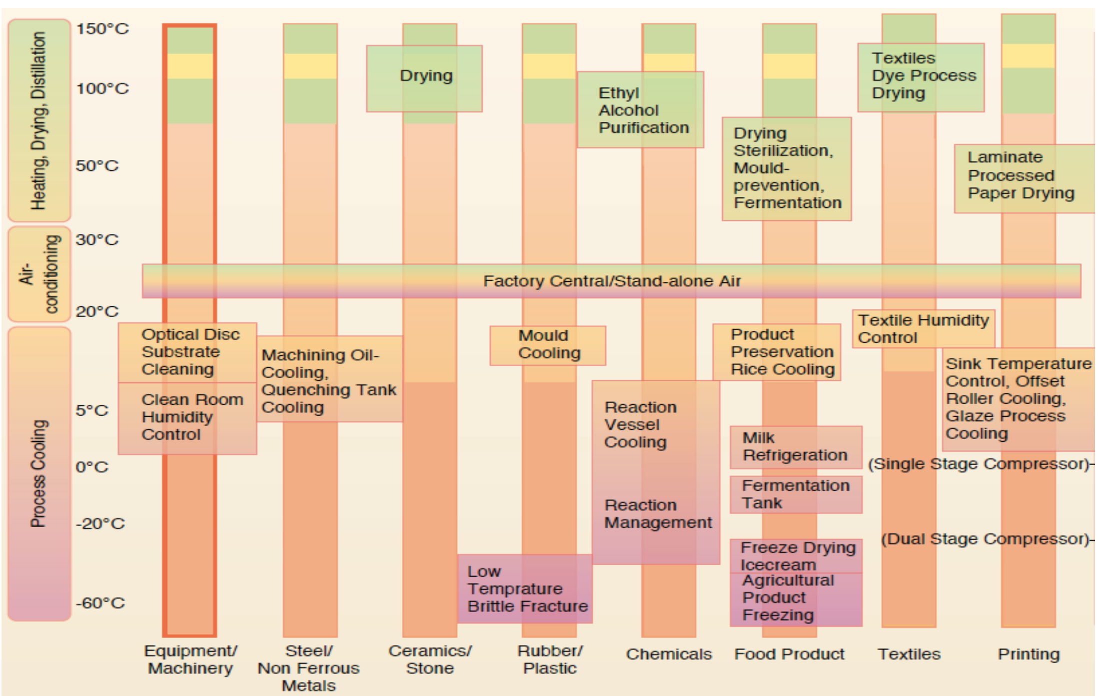


Annex 35 / 13

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 CO_2-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:

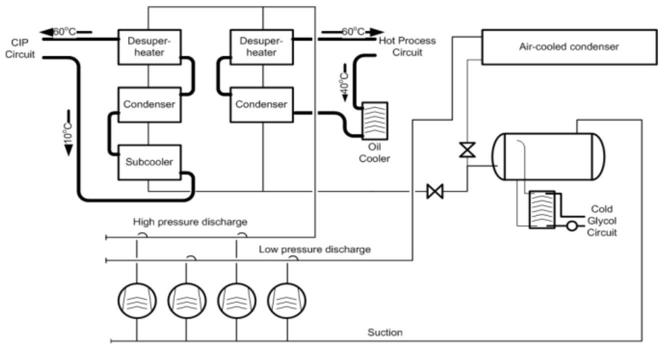
- Substitution of the problem table algorithm in pinch analysis by an extended transshipment model which allows a simultaneous optimization of utilities and heat pump.
- Approximation of the heat exchanger network as in the standard pinch analysis.
- Development of an algorithm for selecting of a hot 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 Nestle needs.

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

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

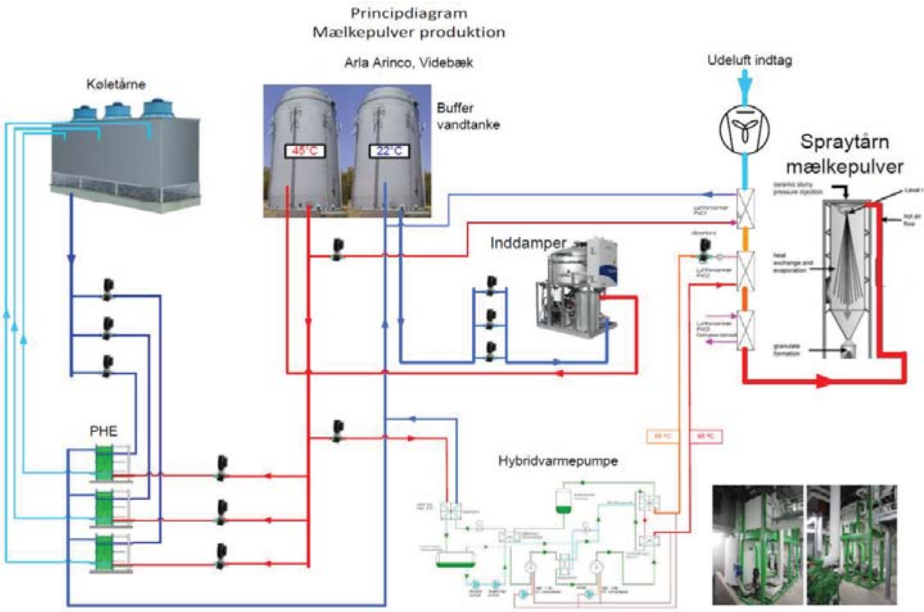
A heat pump of 1.25 MW was installed utilizing energy from 40° C cooling water – energy that was discharged to the environment prior to this project. The installed heat pump preheats drying air for milk powder to around 80° C through a water circuit.

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 NH_3/H_2O 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.

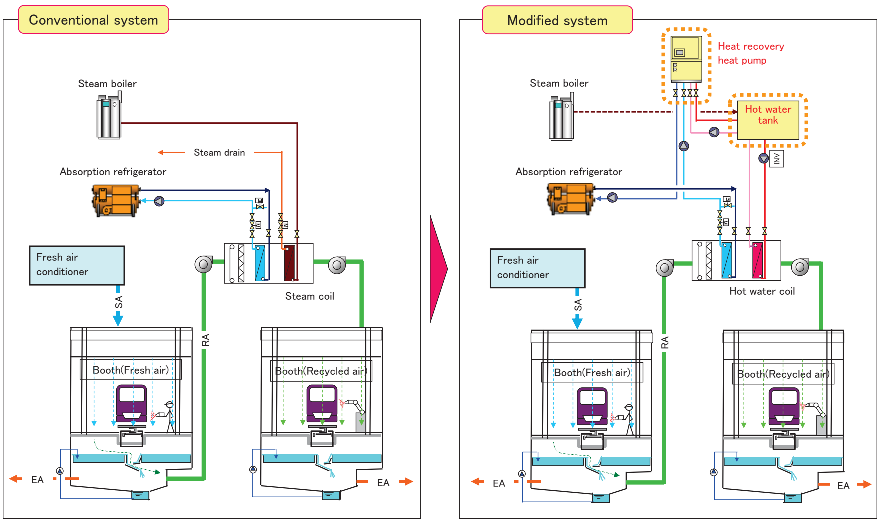
Adoption of Heat Pump Technology in a Painting Process at an Automobile Factory (Japan)

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.

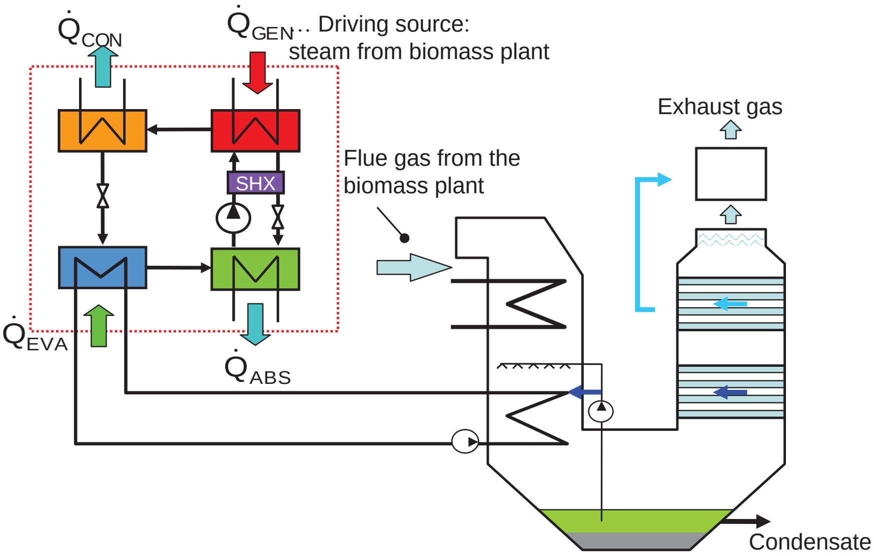
The heat pump makes it possible for the system to reduce running costs by about 63 %, to reduce CO_2 emissions by about 47 % per month, and to reduce primary energy consumption by about 49 % per month as compared with the conventional boiler. Consequently, the pay-back period would be estimated at 3～4 years.



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 remants, amounts to about 5 MW_{el} and 30 MW_{th}. Beside the in-house power supply of Schweighofer Fibre GmbH the biomass plant also delivers electricity for about 15,000 households and heat for the local district heating grid.

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

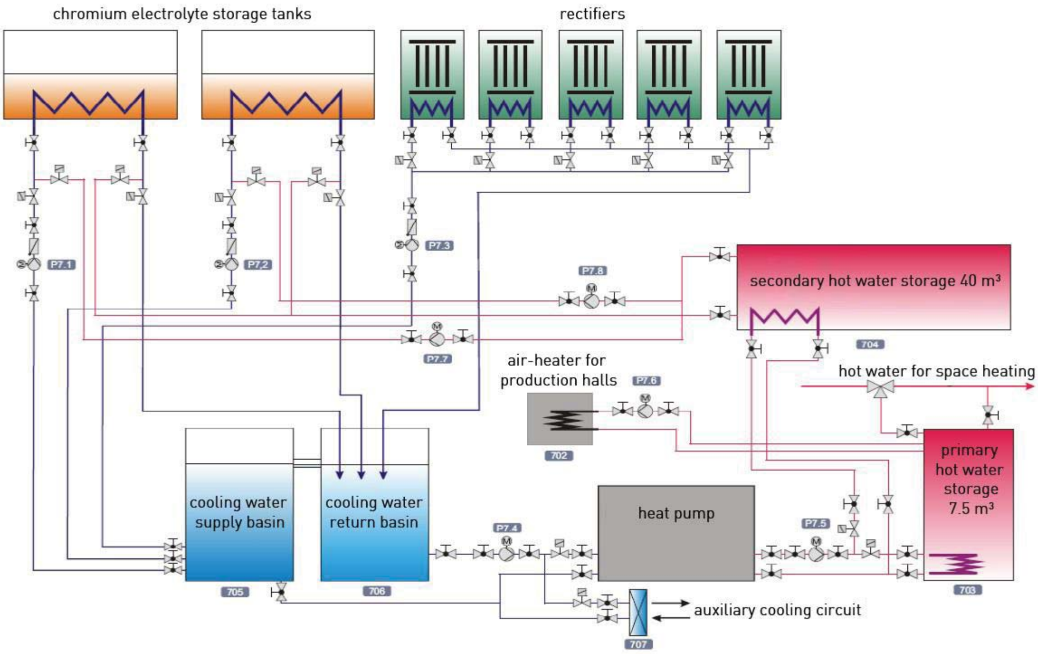


The applied AHP is a single-stage Water/LiBr absorption heat pump with a solution heat exchanger (SHX) and a heating capacity of ca. 7.5 MW. The driving source of the AHP is steam from the biomass heating plant at ca. 165 °C. According to the existing monitoring system the AHP operates with a seasonal 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.



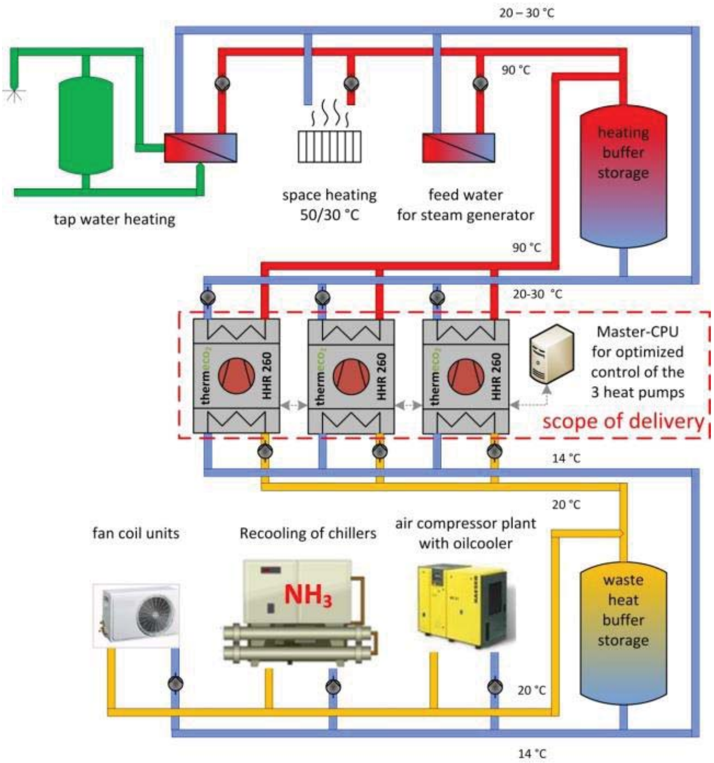
The company has increased the over-all efficiency of this process to more than 90 % by improving the electroplating process and integrating a heat pump to reuse the generated waste heat. By increasing the current density from 50 A/dm² to 90 A/dm² the efficiency of the electroplating process could be 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 thermeco$_2$ heat pump system for hot water generation and heating was put into operation in the slaughterhouse Zurich. With a capacity of 800 kW, the plant is the largest ever built in Switzerland. The thermeco$_2$ machines deliver the required 90 °C with better COPs compared to other refrigerants. The heat pump system is built up of 3 heat pumps thermeco$_2$ HHR 260.

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

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



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

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

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 kWe
- Condenser max power : 200 kWt

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.

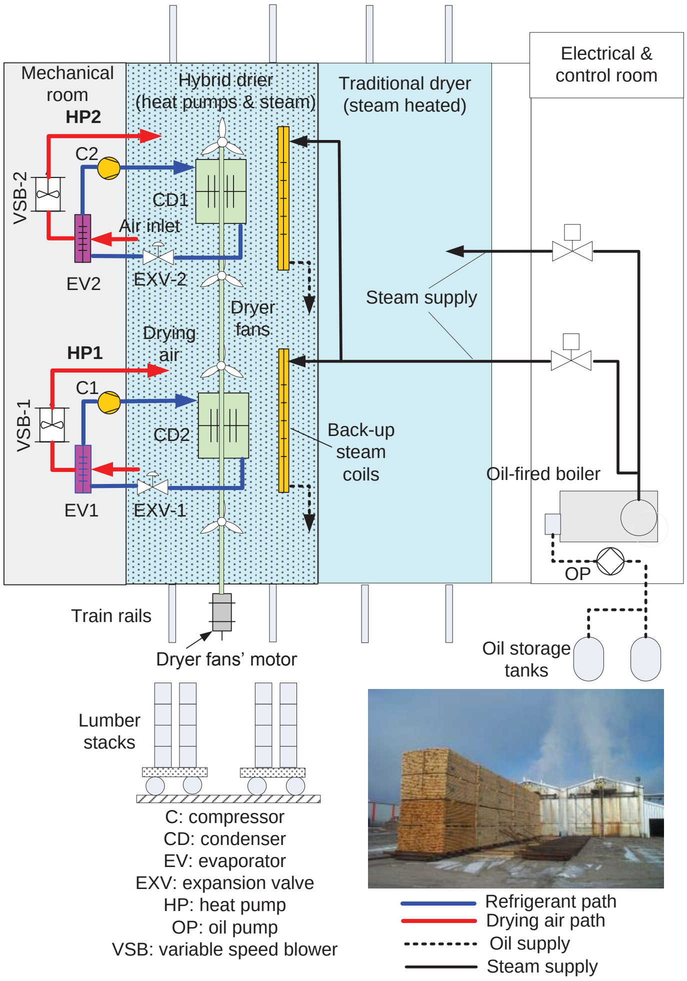
All this demonstrates the prototype reliability and the capacity to use this newly developed machine for industrial purposes.

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, theses 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

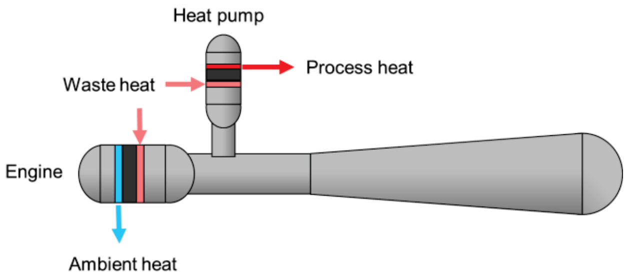
An industrial-scale, high-temperature heat pump-assisted dryer prototype, including one 354 m^3 forced-air wood dryer with steam heating coils and two high-temperature heat pumps (see Figure) has also been studied in Canada. Finished softwood lumber is produced in standard sizes, mostly for the construction 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	CH3CH2CH3	~20	yes	96.7	4.25	-42.1
R-601	CH3CH2CH2CH2CH3	~20	yes	196.6	3.37	36.1
R-717	NH3	0	yes	132.25	11.33	-33.33
R-744	CO2	1	none	30.98	7.3773	-78.40
R-1234yf	CF3CF=CH2	<1	weak	94.7	3.382	-29,48
R-134a	CF3CH2F	1,430	none	101.06	4.0593	-26.07
R-1234ze(E)	CFH=CHCF3	6	weak	109.37	3.636	-18.96
R-1234ze(Z)	CFH=CHCF3	<10	weak	153.7	3.97	9.76
R-245fa	CF3CH2CHF2	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	CF3CH2CF2CH3	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 CO_2 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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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.