INDUSTRIAL HEATPUMPS
IN THE NETHERLANDS

IEA HEAT PUMP PROGRAMME ANNEX 35

VERSION 080514-0.8

INDUSTRIE ZIT ER WARM BIJ..

Door de hogere kosten voor warmte zal de industrie de komende jaren veel aandacht moeten besteden aan het verminderen en hergebruik van (rest-) warmte om concurrerend te kunnen blijven.

De meeste industrieën leveren producten met dezelfde temperatuur als hun grondstoffen. Toch heeft de Nederlandse industrie veel aardgas en elektriciteit nodig om de grondstoffen te verwarmen en vervolgens weer af te koelen. De uitdaging is om de warmtekringlopen gesloten te houden zodat er geen of nauwelijks additionele warmte nodig is. Dat dit niet overal gebeurt heeft te maken met de historie van lagere gasprijzen en lage kosten van warmte uit warmtekrachtcentrales. Nu deze centrales uit de gratie raken vanwege de lage elektriciteitstarieven ten opzichte van hoge gastarieven lopen de interne kosten van warmte op. De tijd is rijp om ook voor warmte gesloten kringlopen te creëren.
Technisch gezien zijn daar vele mogelijkheden voor. Sommige daarvan, bijvoorbeeld warmtewisse-laars en mechanische damprecompressie, horen al lang tot conventionele technieken. Sinds kort zijn er ook warmtepompen die vanuit restwarmte stoom kunnen produceren.

De industrie zit er warm bij. Overal waar koeltorens staan, waar oppervlaktewater thermisch wordt belast en waar schoorstenen hete rookgassen in de atmosfeer brengen liggen mogelijkheden tot warmteterugwinning. Daarbij is het van groot belang dat de warmte eerst intern wordt ingezet en pas daarna wordt gekeken naar mogelijkheden van uitkoppeling naar de buren. Een hulpmiddel als pinchanalyse moet weer van stal worden gehaald om de kansen in kaart te brengen. Voor kleinere bedrijven kunnen softwarepakketten als “Einstein” worden ingezet om thermal audits betaalbaar te maken. Eerdere audits tonen aan dat er vaak nog een aanzienlijk potentieel is om energie en kosten met betaalbare maatregelen te besparen.

Jan Grift, Energy Matters, 8 mei 2014

CONTENT

MANAGEMENT SUMMARY

MANAGEMENT SUMMARY

Industrial heat pumps are defined as active heat-recovery apparatus that increases the temperature of an excess heat stream in an industrial process to a higher temperature to be used in the same process or another adjacent process or heat demand. The heat pump is used to increase the energy efficiency of the process and in a lot of cases also increases the process efficiency and quality and yield of the product. Industrial heat pumps are in most cases not considered as renewable but as energy conservation technologies. To increase the temperature with an industrial heat pump an external source of energy is used as driving force. This can be electricity, gas or another fossil fuel or thermal energy (i.e. heat). In Industry the most common applications are: Mechanical Compression; Mechanical Vapour Recompression, Thermal Vapour Recompression and Absorption. Each of these heat pumps have specific characteristics and application areas.

Potential

In the Netherlands heat pumps of different types can be applied in all levels of industry ranging from bulk distillation in chemical industry to the level of milk processing at the farm or growing tomatoes in greenhouses and steamproduction in paper and pulp. In every application the approach will have to be based upon the Trias Energetica. In industry a systematic approach in improving the energy efficiency of industrial processes is based upon the onion-model developed in industrial heat technology.

The potential with industrial heat pumps for energy conservation and reduction of CO2-emissions in the Netherlands is enormous and at this moment not naturally a part of policy papers nor for a large part under the attention of industry itself. On the other hand there is a lot of attention for the use of industrial waste heat in the Rotterdam area. A first, most logical, solution to this waste heat problem is to reuse the heat within the same process through process integration or at the same site. In an ideal process that will be within the process unit otherwise technology will have to be applied to transform the heat coming out of the process to a common carrier. This being high pressure steam or electricity generated by a high temperature heat pump or an ORC.

There is an ample availability of models and methodologies, as chapter 2 of this report shows and technologies as chapter 3 and 4 show, to be able to reduce the energy use economically.

Industrial processes and sectors

In this report four levels of industrial processes which each have their own tailor made approach have been defined:

- 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 it is estimated that the combination of VRC, HIDiC and novel heat pumps would lead to an estimated 820 MW savings, which is almost 35% of the reboiler duties of all across the pinch columns in the Netherlands, being 28 PJ's.
- Large industrial processes for specific sectors where large excess heat streams are produced like paper and pulp industry being with 26 PJ. Under the ISPT-program the first internationally innovative heat pump pilots are set up (8 PJ).
- Food industry where drying through evaporation and simultaneous heating and cooling are core processes has an overall energy use for heating of more than 62 PJ. Evaporators with MVR are more and more state of the art in dairy industry. In other sectors heat pump integrated dryers are applied, but not yet common practice. The first projects using condensor heat from cooling with add-on heat pumps are built but not yet common practice. The potential energy conservation is 14 PJ by the use of high temperature add-on heat pump on refrigeration plants.
- Business parks where small manufacturing companies and warehouses are located. The overall energy use on existing areas with a size of 10 - 50 ha is 170 PJ which is 6% of the overall Dutch energy use. There is however small success with energy conservation and the application of renewable energy at industrial areas for mixed/miscelanous use. A few examples like the Ecofactorij show the potential for heat pump applications

For the Netherlands more specific the Greenhouse sector is an important industrial sector with a large potential for heat pump applications.

Market developments

There are market developments that widen the opportunities for industrial heat pumps. An increase in the aplication of heat pumps is noticable in the last five years afte more than a decade of stand-still. External influences as well as technological developments can be credited:

- Due to the decline of the so-called spark spread, the difference in operating costs between CHP and heat pumps are considerably narrowed. It is to be expected that a lot of CHP-installations after depreciation will not be replaced. 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. 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.
- A large application potential of industrial heat pumps is still not used because of the limited supply temperatures of about 1000C 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 1200C 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 2500C.
- Increased performance, reliabilty and availability of heat pump technologies for commercial and domestic buildings make the application in businessparks more attractive, the first industrial A+++ buildings with BREEAM appearing on the market.
- The large manufacturers and suppliers of industrial refrigeration in the Netherlands are discovering the heating market.

R&D, manufacturers and innovation

R&D in the Netherlands on industrial process innovation is for a large part supported by the Ministry of Economic Affairs through the ISPT Innovation Program. Major players in this programm are the Dutch process industry, TU Delft and ECN. The focus on heat pumping technology as one of the key technologies is logical and has a long track record starting with basic research now reaching the pilot phase.

The ISPT program acknowledges that the main bulk separation processes within chemical and refining industry are distillation, absorption/desorption, and crystallization. The thermodynamic efficiency of these processes is usually very low (<10%). Significant reductions in energy consumption are expected by using innovative heat pump concepts for removal and supply of heat from/to a separation process. New developments in distillation heat pump technology are therefore aimed at novel heat pumps with a higher economic range and at new heat integrated configurations. In the Netherlands these developments are:

- Thermo Acoustic Heat Pump at ECN
- Compression Resorption Heat Pump at TU Delft
- Absorption Heat Pump
- Heat Integrated Distillation Columns at TU Delft

Most of these long running R&D projects are on the brink of a real life pilot and close to market introduction. Dutch manufacturers are involved in the first high temperature pilot in paper and pulp industry.
In chapter 1 of the report an overview is given of the state of the art with manufacturers and suppliers. The very innovative approach of these companies give them a potential worldmarket which could be exploited by continuation of the IEA Annex.

Communication models and market approach
For the Netherlands there are in many industrial sectors Multi Year Agreements on energy efficiency and renewable energy applications. This approach is based upon information models developed in the past and for some models used worldwide.
Several approaches for process optimisation in industry can be met with based upon the TRIAS Energetica. In order to decide which optimisation model to use the approach to industry is based upon the needs and trending topics within the company (that can be very local), within the sector (competition) or through legislation (F-gases for refrigeration) and market developments (less economic growth) or tariffs (less economic cogeneration through negative spark spread). But also the philosophy to become energy neutral for the whole supply chain (dairy industry in Netherlands) or become frontrunner in renewables (Lidl supermarkets).
Based upon these aspects a flexible communication strategy can be developed and the model to use is chosen. An important starting point is getting trust within the company starting at management level (sometimes middle management). These managers need a simple decision model and prove that the effort and investment will realise sufficient results. The Energy Potential Scan (EPS) 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 analyse the possibility to conserve energy. This model is used in many countries worldwide to get awareness within companies to work on energy conservation. The next step in the process is to get or generate sufficient data by monitoring and measurements, then the industrial process is optimized. Without applying a heat pump optimisation can often be achieved by new valves, other setpoints in pressure and temperature and new electromotors. The approach is from inside to the outside of the process according to the onion model. Then if all data are known, dependent on the complexity of the process a choice is made in process optimisation models. Simple: arrow diagram; More Complex: Einstein pinch approach; Complex: Advanced modelling with expensive programs.
In industry a high level of sector specific expertise for system design, process integration and planning is crucial to be able to increase the awareness of possibilities for heat pumps and to select between the alternatives. In many sectors software on process integration and design play an important role. To be able to integrate a heat pump at the right place a basic knowledge of the process pinch methodology has to be available.
However, this is not always the case also with larger process industries as it is seemingly a complex approach needing a lot of high level expertise. A lot of software available for process integration analyses however is not used for a large part of industry with smaller processes as the software is often too complex or too expensive for small consultancies.
Even worse is the fact that although Dutch Government thinks that process integration broadly introduced in the nineties is an accepted tool, this is not the case anymore for the larger part of industry, with exception of course for chemical industry.
This was noticed at European level also, therefore the initiative was taken to develop the Einstein tool in order to be used for companies with relatively simple processes. These can be scanned in a few days on the potential heat integration, the internal use of waste heat, heat pumps, cogeneration and renewables like solar heat and bio-energy. The Einstein tool is still fully under development and needs as well as other software tools the right and objective information on heat pumping technologies. In the Netherlands this tool financed by RVO is communicated to the market in one day training courses and projects.
The tool is furthermore integrated in the approach starting with the Energy Potential Scan to be able to get participation and at the end by a heat pump model describing the possibilities of heat pumping technologies. Example projects are giving information on where and what. Interesting is that all three models ranging from simple to complex can use the same simple excel based information model has been developed by Netherlands Enterprise Agency (RVO) and should be further expanded in Phase 2 of the Annex. The information model for distillation in chemical industries is more complex and derscribed by Infante Fereira et. al.

Annex overview
Under the IEA Implementing Agreements on Industrial Energy Systems and Technologies (IETS) and Heat Pumping Technologies (HPP) a collaborative Annex has been started in 2009 on Industrial Heat Pumps. In the past already two annexes dealing with industrial heat pumps were executed under the IEA Implementing Agreement on Heat Pumping Technologies.
The objective of the annex is to reduce the use of energy and emissions of greenhouse gases by the increased implementation of heat pumps in industry, 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 objectives will be achieved by common studies performed by the participants for each country.
This report on the application of heat pumps in the Netherlands is a consequence of these objectives and in line with the tasks defined under the Annex.
Task 1: Market overview, barriers for application
Task 2: Modeling calculation and economic models
Task 3: Technology
Task 4: Application and monitoring
Task 5: Communication
The report is based upon studies and work funded by the NEW, MJA and EI programs run by Netherlands Enterprise Agency (RVO) for the Ministry of Economic Affairs.
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TASK 1

MARKET OVERVIEW

Industrial processes in general need higher temperature levels. Recent developments of heat pumps focus on higher delivery temperatures of heat and a high temperature lift (difference between low (source) and high (delivery) temperature). Another trend is that industrial producti-on processes require lower temperatures for heating. Application of heat pumps may therefore grow in the near future and contribute to further CO_2 emission reduction.

1. MARKET OVERVIEW

Industrial processes in general need higher temperature levels. Recent developments of heat pumps focus on higher delivery temperatures of heat and a high temperature lift (difference between low (source) and high (delivery) temperature). Another trend is that industrial production processes require lower temperatures for heating. Application of heat pumps may therefore grow in the near future and contribute to further CO_2 emission reduction.

Bottle necks for this growth are the unfamiliarity with heat pumps of engineers and process designers, the complex level of integration of the installation in existing plants, the high investment costs, some experiences with unreliability in old projects, lack of references and lack of knowledge of the new higher temperature options. For successful introduction of high temperature heat pumps in industry, bundling and distribution of knowledge is of important. Process designers, engineers, consultants, contractors and end users need to be familiar with the heat pump technology, the possibilities, the advantages, good references and being aware of the do's and don'ts.

In a study by KWA commissioned by AgNL [1] the following subjects have been described:

- an overview of the heat pumps options in various industrial sectors and energy consumption
- recent technological developments around industrial heat pumps after 2000
- a number of case studies of industrial heat pumps after 2000

1.1 | Application

Potentially large energy savings are possible through the application of heat pumps in the industry. Developing and dissemination of knowledge is important for successful growth of the application of heat pumps. To stimulate the application of heat pumps it is useful to analyze heat pumps which have been placed in the past and analyse how they operate in practice. Over the past 20 years there were several several feasibility studies and heat pump projects supported by the TIEB and SPIRIT programs of Novem (the predecessor of RVO) which were reported upon.

A study has been undertaken to look into the operation of these "older" projects looking into the experiences of the companies, whether there have been any changes of the design over time, whether operating & maintenance of the installation is difficult (high level of knowledge, complexity, etc.), if promised energy savings are achieved and whether there are remarks which can be defined as lessons learned.

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

Table 1.1 Overview of older heat pump projects

All companies described participated in this evaluation study. Striking is that those projects described as case and feasibility studies supported by governmental subsidies (TIEB) were never realized, despite the fact that acceptable payback periods and significant energy savings were calculated in these studies. For the other projects much, has changed in the past twenty years, like plant closures, moving production, no demand for the product, changes in operations, etc. As a result six of the analyzed heat pumps have been removed for reasons which have nothing to do with any possible malfunction of the heat pumps.

Of the eleven remaining heat pumps, ten are still in use. These are eight Mechanical Vapour Recompressors (MVR), one Thermal Vapour Recompressor (TVR) and one heat pump which uses the heat from the condenser of the refrigeration installation for process heat. Most of these are now described in new factsheets in chapter 4 of this report. Only one company was not participating with new data.

Companies with a running heat pump have generally no idea why a heat pump was chosen, given the long period since the investment decision. Most of the heat pumps still run according to their original design, having relatively high operating hours (5000-8000 hours/year) and mostly in full load. In several cases the maintenance is outsourced for reasons of complexity, high operating hours and capacity problems in the technical department. Operating the installation is generally regarded as a relatively simple. The installations have few problems and/or malfunctions. Companies have no insight on whether the system achieves its efficiency, or whether the intended energy savings have been obtained. They have no reference, given the initial situation.

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

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

After a long period of 'silence' there seems to be renewed interest in the market since 2010. A number of new Industrial Heat Pumps have been installed resulting in the short list of projects. These projects are described in fact sheets under chapter 5.

1.2 | Heat pump potential

In the Netherlands, heat pumps of different types can be applied in all levels of industry ranging from bulk distillation in chemical industry to the level of milk processing at the farm or growing tomatoes in greenhouses and steam production in paper and pulp. In every application, even for domestic buildings, the approach will have to be based upon the Trias Energetica in industry, a systematic approach in improving the energy efficiency of industrial processes is the onion-model developed in industrial heat technology.

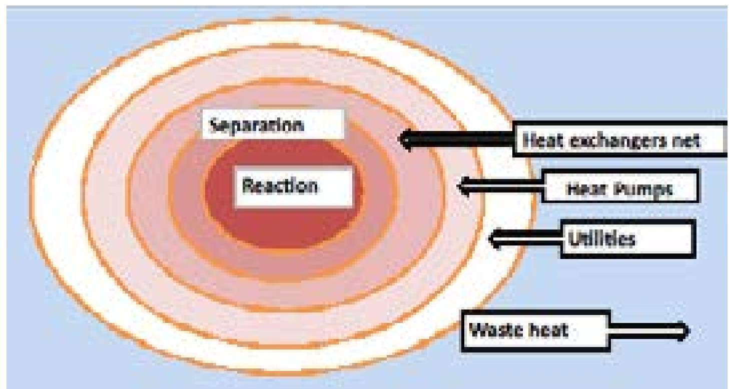


Fig 1.1 Onion model for energy efficiency improvement [15]

This model will be discussed further in chapter 3 of this report. The main industrial sector in the Netherlands is the chemical industry located in some concentrated areas around the Rotterdam harbor. The other main industrial sectors are the food industry and the greenhouse sector. Manufacturing industry used 1344 PJ in 2006. The balance of the different energy carriers is shown in the next table.

	Heat (PJ)	Power (PJ)	Feedstock (PJ)	Conversion loss (PJ)	Total (PJ)
Food & drug industry	62.8	24.8	0.2	3.7	91.5
Textile industry	3.3	1.4	0	0	4.7
Paper & board industry	24.7	13.3	0	3.7	41.7
Chemical industry	261	36	455	21	773
Refining	116	9.6	0	62.1	188
Building materials	26.8	5.2	0.1	0.1	32.2
Basic metal industry	38	12.6	73.3	13.6	138
Metal products	19.0	15.9	15.5	0	50.4
Rubber & plastic products	7.7	9.4	0	0	17.3
Other	0	0	7.6	0	7.6
Total	559	128	552	105	1344

Table 1.2 Primary Energy use in Dutch industrial sectors

Interval	Chemical + Refining (%)	Basic metal + metal products (%)	Other (%)
< 100°C	5	15	29
100-250°C	11	0	38
250-500°C	27	5	13
500-750°C	21	0	0
750-1000°C	26	10	0
> 1000°C	10	70	20

Table 1.3 Temperature levels of heat demand

Knowledge of heat pump technologies is an important building stone in further increasing the heat efficiency of industrial processes. But knowledge is not the final piece; it's only the beginning of a whole transition process. Companies have a lot of options for energy conservation and generation and decision space, which can lead to taking no explicit decision. The challenge is to organize competition among technology solutions that leads to more explicit decision making. Decisions on applications of heat pumps are made in competition with investments on other technologies or in other parts of the industrial process.
Until recently, heat in many industrial sectors has been by-product of electricity from cogeneration and therewith heat had a low economic value. Cogeneration has been a very 'hot' technological solution in the past decades for quick gains in energy conservation. Due to the strong competition from cogeneration in industry as a heat source, only a few heat pumps were installed in the past 15 years, except for vapor recompression in distillation columns. In addition, compression heat pumps were not suitable for temperature levels higher than 80^{o}C. Nowadays there a number of developments which widens the opportunities for industrial heat pumps:

- Due to the decline of the so-called spark spread, the difference in operating costs between CHP and heat pumps has been considerably narrowed. It is to be expected that a lot of CHP-installations after depreciation will not be replaced. 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.
- By using other than the traditional working fluids for refrigeration and new technologies heat pumps can lift to reach 120^{o}C.
- Through the use of so-called "temperature glides" the heat / electricity ratio (COP) is significantly improved.
- The introduction of chillers with an additional compression step, which are perfect for the heating of hot water or cleaning process.
- The early development of acoustic and thermochemical heat pumps and heat transformers the path towards even higher temperature ranges up to 250^{o}C

These technological developments do not or barely reach the industry. In addition, heat pump suppliers generally have a backlog by the negative experiences in the commercial and domestic building sector.

Another important aspect also is that heat pump suppliers, knowing the possibilities of alternatives, are in most cases the last link in the supply chain, where consultants and installers often lack the knowledge in finding good economic solutions. An important issue therefore is how technology suppliers, technical personnel and management, that takes the investment decision, communicate with each other. It is the experience that management is less interested in the technical side and much more in solutions for the company. Newly developed heat pump technology has been analysed in four major business cases in the chemical industry. The experience gained here leads to the conclusion that more is needed than knowledge on technology only. A 'technology marketing' process is needed to be able to discuss on the same level as industrial management decision making. Knowledge, skills and competence have to be developed in that process. The approach is further discussed in chapter 5 of this report.

1.2.1 | Chemical industry – distillation (D. Bruinsma and S. Spoelstra)[03]

Distillation is the main separation technology in refineries and the chemical process industry, because of the attractive purification characteristics, the high production capacity and turndown ratio, and the straightforward design procedures. More sophisticated techniques have become state of the art to handle streams with less favourable thermodynamic properties, in particular small relative volatilities and azeotropic mixtures. The high energy demand in bulk distillation columns (1-100 MW) and the low thermodynamic efficiency (5-10%) remain the major drawbacks. A number of improvements have been developed over the years, directed at reducing both operating and capital cost.
In extractive distillation (ED) a solvent or separating agent is added in order to increase the relative volatility of the components to be separated. In azeotropic extractive distillation the separating agent is used to break the azeotrope. As a consequence, the reflux ratio, column diameter and reboiler duty can be reduced and/or the column height can be lower. Commercial low volatility solvents include sulfolane, triethylene glycol (TEG), NMP and NFM. The recovery cost of the solvent is an integral part of the economy of extractive distillation processes. ED is particularly effective for relative volatilities below 1.2. Industrial examples of ED processes are purification of aromatics in petrochemistry, butadiene recovery in naphtha cracking and separation of cycloparaffins from naphtha.
Instead of affecting the thermodynamics of the system also selection of the column internals is a way to increase distillation efficiency. Random and structured packings with specific surface areas from 250 up to 900 m2/m3 are continuously being improved with the objective to optimize stage height, pressure drop, liquid load, and turn down ratio. The main recent advancements in tray columns focus on high-capacity trays with centrifugal devices or structured packing demisters although at the cost of an increased pressure drop. Since the 1980's dividing wall columns (DWC's) have been introduced, which allow

the separation of three component feeds in a single column leading to interesting reductions in both energy consumption and investment cost. Recently even more complex DWC's have been constructed to separate four component mixtures in pure products.
In contrast to improvements of the VLE or the column internals, both inside the column, a number of energy reducing measures can be considered outside the column by addressing the reboiler and condenser. These include side reboilers, dephlegmators and heat pumps. Side reboilers use waste heat at a lower temperature than the bottom reboiler and thus increase the exergetic efficiency. Dephlegmators or reflux condensers are compact heat exchangers, such as PFHE's, used to reduce energy consumption in low temperature gas separations. Heat pumps lift the temperature level of the top vapour in order to use this as the heat source for the reboiler.
Heat pumps for distillation purposes can be divided in three types: mechanically driven, heat driven and heat transformers. Mechanically driven heat pumps can be found, among others, in the following types:

- Vapor recompression heat pump (VC)
- Mechanical vapor compression heat pump - Subcritical and Transcritical (MVR)
- Thermal Vapor Recompression HP (TVR):
- Compression-resorption heat pump (CRHP)
- Absorption heat pump (AbHP) and Adsorption heat pump (AdHP)
- Thermoacoustic heat pump - linear motor driven (THP)
- Heat Integrated Distillation Column (HIDiC)

Across the pinch distillation in the Netherlands

Distillation in NL	
Total $Q_{reboiler}$ (GW)	2.36
Total $Q_{condenser}$ (GW)	2.39
Average $T_{reboiler}$ (^{0}C)	128
Average $T_{condenser}$ (^{0}C)	69
Average ΔT_{column} (^{0}C)	59

An analysis was made of the distillation heat pump potential in the Netherlands, leaving out columns that do not cross the pinch and oil refinery columns. The data show that the total heat pump potential is in the order of 2.4 GW and that the average temperature lift over the column is 59^{0}C. These data are given in Table 1 (J. Cot and O.S.L. Bruinsma, Market survey, Heat pumps in bulk separation processes (2010), ECN report 7.6548.2010.0xx).
Figure 1.2 represents the distribution of the reboiler duties in the Netherlands for columns with increasing temperature lift; only those columns that cross the pinch have been included.

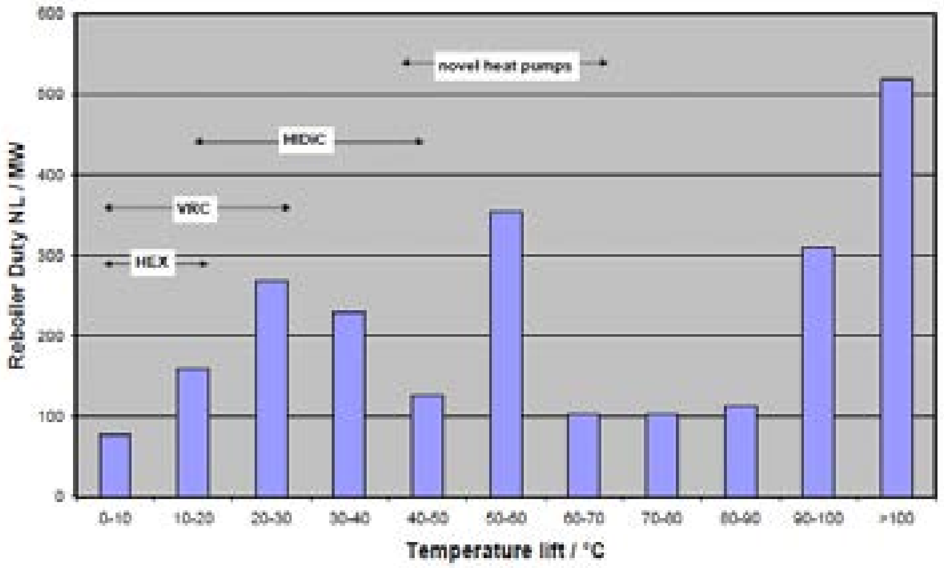


Fig 1.2 Reboiler duties for across the pinch columns in the Netherlands (2006)

In the graph four recommendation regions are identified:

- Temperature lifts below 200^{0}C compact heat exchangers with small ΔTHEX are crucial for the performance of the heat pump system
- VRC's should be applied below 300^{0}C, which covers about 23% of the across the pinch columns
- HIDiC's are probably interesting for temperatures in the range 15-450^{0}C, about 29% of the across the pinch columns, partly overlapping with VRC but with a higher savings efficiency
- Novel heat pumps for temperature lifts of 45-700^{0}C, would contribute an additional 21%

Based on this analysis the combination of VRC, HIDiC and novel heat pumps would lead to an estimated 820 MW savings, which is almost 35% of the reboiler duties of all across the pinch columns in the Netherlands.

1.2.2 | Food industry

With an energy use of more than 62PJ in heat , the food industry is a large sector in the Netherlands with these main sub sectors: Dairy (18.0), Patatoes processing (8.7), Margarine (7.6) and Bakeries (4.8). Cooled Warehouses are a specific but important sector. Within these sectors processes like drying and cooling are the main process operations with a lot similarities in process.

Evaporators in dairy industry
The GEA handbook on Milk Powder Technology [4] states that the transforming of a liquid product into a dry powder requires means the removal of practically all water, the amount of which often exceeds the weight of the final product. During the water removal, the processed product is undergoing deep changes of physical structure and appearance, starting with thin waterlike liquid and terminating with dry powder at the end of the process. Therefore, one single method of water removal cannot be optimal throughout the whole process, as also the product composition is different from one food product to another. In the food and dairy industry the following dehydration methods have been adopted:

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

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

Refrigeration
An in depth study [1] has been done into the potential for heat pumps in the industrial sectors that use considerable amounts of refrigeration. Residual or waste heat available

in the food sector is shown in table 1.4 for temperature and PJ primary energy per year. The various heat sources of the waste heat are listed in the table. Most of the waste heat is available from the condensing heat of refrigeration plants. The temperature level is between 30°C and 40°C. This energy source amounts to 28 PJ a year. Similarly the heat consumers have been investigated, showing that 14 PJ is consumed by various processes at temperature levels between 60°C to 110°C. There is more residual heat available than required.
In this view, the heat demand of the food sector of 69 PJ in total can be reduced by 14 PJ by the use of high temperature add-on heat pump on refrigeration plants.

Heat Pumps applications and potential

Sector	Total primary energy consumption (2006)	Total electrical energy consumption (2006)	Total heat (2006)	T residual heat available	Residual heat available	Delivered by	T heat consumers	Reuse heat consumption	Consumed by	Electricity consumption by refrigeration	Available condensing heat (T~30°C)
	PJ	PJ	PJ	°C	PJ		°C	PJ		PJprim/j	PJ/j
Sectors industry											
Cooled warehouses	2,4	2,2	0,2	35	2,8	condensers refrigeration	60/ 60	0,1	building, water	2,0	2,8
Rubber and plastic	9,6	7,4	2,2	35	1,6	cooling tower, condenser refr	60	0,1	building, rubber	0,9	1,6
Potatoes processing	8,7	2,0	6,7	30-120	4,0	eg. steam pealing, condensers refr.	70-110	1,2	pasteurizer, dryer, blancheur	1,1	1,5
Cacoa	2,3	1,1	1,2	60-70	0,15	cocoa milling	120	0,25	preheating air for drying	0,1	0,2
Fruit and vegetables	2,9	1,4	1,5	70-120	0,6	condenser, blancheur, sterilizer	70-90	0,5	blancheur, building	0,4	0,6
Coffee production	0,9	0,5	0,4	30,0	0,1	condensers refrigeration	70	0,1	building	0,1	0,1
Margarine, Fats and Oils	7,5	0,6	6,8	35	0,3	condensers refrigeration	60	1,0	tank storage, pipe tracing	0,2	0,3
Meat processing	4,3	2,8	1,5	35	1,8	condensers refrigeration	75	0,25	hot water cleaning	1,3	1,8
Dairy	18,0	5,0	13,0	40-60	2,5	brüden condensate from evaporators	60	1,8	spray dryer	1,8	3,2
Soft drinks	1,0	0,5	0,5	30	0,1	cooling section pasteurizers	60	0,1	pasteurizers	0,0	0,0
Beer industry	3,5	2,0	1,5	35, 100	1,2	condenser, wort boiling	70-110	0,6	pasteurizers, wort boiling, building	0,5	0,8
Bakeries	4,8	1,8	3,0	30, 200	0,3	condensers, flue gas oven, boilers	35-75	1,0	air preheating, building, water, dough rising	0,3	1,4
Fish processing	0,8	0,6	0,2	30,0	0,5	condensers refrigeration	60	0,1	building, hot water	0,3	0,6
Biscuits, confectionary, chocolate, icecream	2,0	0,8	1,2	30, 200	0,6	condensers refr., ovens	60-100	0,5	pasteurizers, water, cookers, storage raw materials	0,4	0,6
Other food	69	40	29,0	30-70	9,0	various	70-90	6,0	various	6,0	12,6
Total Food	158	69	49		36			14		16	28
Chemical industry specialized products	10,2	4,0	6,2	various			various			0,8	1,6
Oil and gas production	40,8	10,5	30,0	50		compression gas	50		building	1,3	3,9
Chemical industry bulk	300	75	225,0	various			various			3,0	6,4
Refining	140	24	116,0	various			various			3,6	6,5
Other industry	104	16	88,0	various			various			1,3	2,6
Total Other	890	138	465							11	26

Table 1.4 Overview of available condensor heat in Dutch industry

The feasibility of high temperature add-on heat pumps depends on an analysis of:
- Residual heat, heat demand and electricity demand
- Energy monitoring of maximum and minimum capacities, average values, operating hours.
- An an integral approach, evaluate the competing technologies such as high efficient hot water boilers, combined heat and power (CHP) plants. Heat pumps are more flexible than a CHP, since they are available in small sizes and can operate efficiently in part load.
- Investments, replacement of heating equipment

From a sustainable point of view: refrigeration installations should not be installed without the use of condensing heat (such as desuperheater heat, condensing heat at 30°C, add on with high temperature heat pump >80°C).

1.2.3 | Paper and pulp [5]

The paper and pulp sector is with 26PJ a significant energy user in the Netherlands and currently ranks fourth in the industrial sector for its energy use. This 26PJ is primarily used for gas to power cogeneration systems conversing this into 17 PJ's of heat. This heat is then after being used as process heat dumped into the environment as heat from drying (11PJ), losses from conversion (4PJ and into the waste water (2PJ). Energy costs in paper and pulp in the Netherlands are 15 - 35% of the variable costs of production.

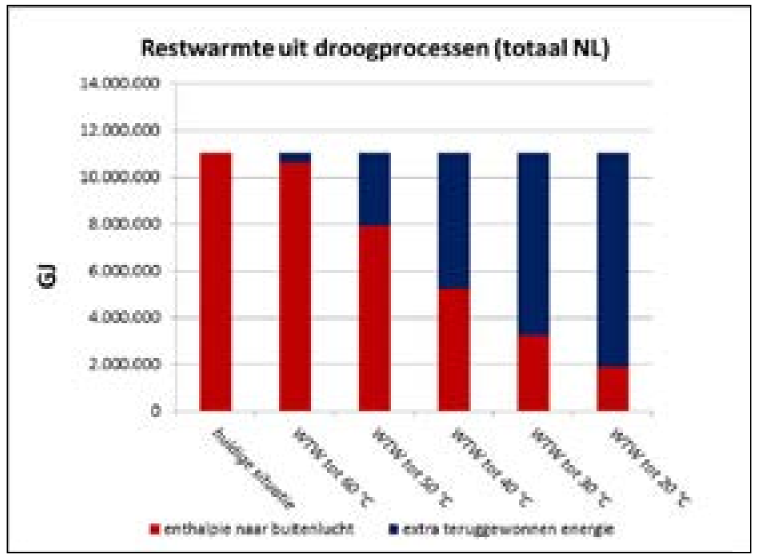


Fig 1.3 Waste heat and temperature levels in Paper and Pulp

Manufacturers have under the Multi Year Energy Agreement with the ministry of Economic Affairs constantly been working on energy efficiency for the production processes, which lead from 1990 onwards to the wide spread application of cogeneration. Several studies have been executed in the nineties of the last century to find the right solution for the application of heat pumps, but due to the low costs of process heat an economical investment was not feasable. Due to the decline of the so-called spark spread, the difference in operating costs between CHP and heat pumps have considerably been narrowed. It is to be expected that a lot of CHP-installations after depreciation will not be replaced. In those cases, there is more attention to the internal use of process heat and thus for heat pumps. A first R&D project has in 2013 lead to a 250kW's pilot project with a high temperature heat pump proiducing steam at 120ºC re-using the waste heat from the drying section. This option at this moment seems only viable for larger paper & pulp industries. According to the CEPI statistics (2012) there are in Europe some 350 paper industries of the size.
There are various possibilities to recover thermal energy from steam and waste heat in the paper drying process. These include:
- Mechanical vapor recompression and reuse of the superheated steam in the drying process;
- Use of heat pumps to recover waste heat;
- Recovering heat from the ventilation air of the drying section and using this heat for the heating of the facilities when needed.

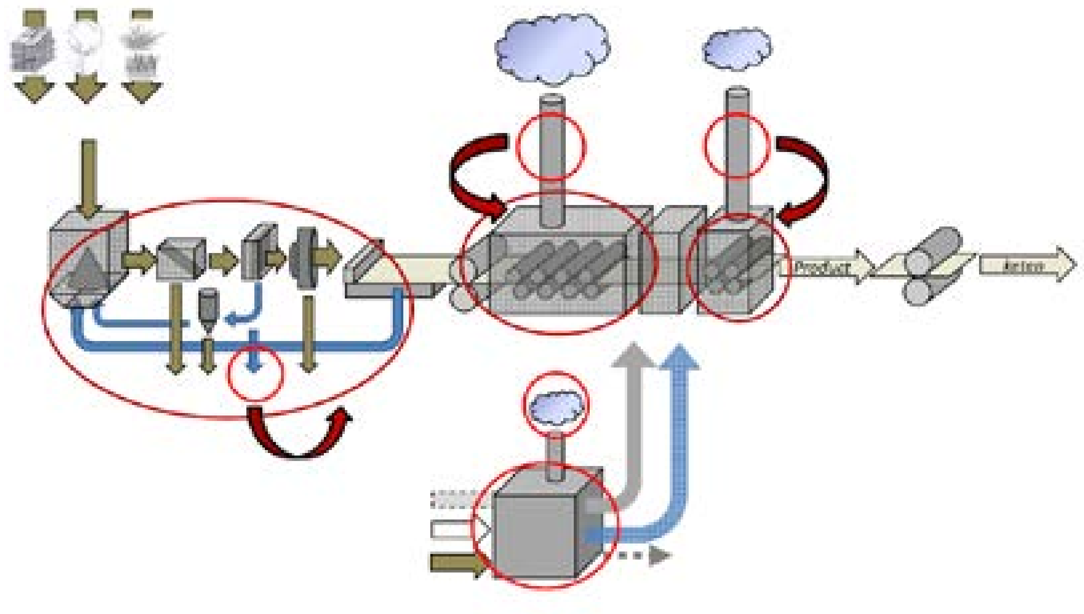


Fig. 1.4 Waste heat streams that can be used (source KCPK [5])

The challenge is to find the right solutions to re-use in the process. As paper and pulp processes are rather big, the best option is to re-use the heat close to where the waste heat appears.

1.2.4 | Miscellaneous industrial areas (www.energiezuinigebedrijventerreinen.nl)[6]

There is small success with energy conservation and the application of renewable energy at industrial areas for mixed/miscelanous use. This is remarkable as there are many economical options for renewables and conservation. Where heat pumps in Netherlands are state of the art in commercial buildings, this is not yet the case at these mixed industrial areas.
The overall energy use in existing areas with a size of 10 - 50 ha is 170 PJ, which is 6% of the overall Dutch energy use. With a conservative estimate that there is potential for energy conservation of 30 – 40% this sums up to 60 PJ [6]. On the positive side is that there are good examples with new developments where renewable energy and energy conservation are basic boundary conditions to fulfill when a company considers to settle in that area. These boundary conditions are set by local governments.
Three examples are:

- 15 ha Kolksluis near Zijpe where heat pumps combined with a collective ATES are the main technologies
- Ecofactorij near Apeldoorn which is discussed in a factsheet under chapter 4
- Trompet near Heemskerk

In the development of a new area it is of importance to develop the planning process at a very early stage and to attract companies by giving bonuses and over a long period never to depart from the goals of the planning for the area.
For existing industrial areas, it is part of the renovation process which is challenging and with some small successes. Examples are give in some factsheets under chapter 4.

12.2.5 | Agriculture

Agriculture in the Netherlands covers a large area, from mushroom growth, bulb farming, pig and chicken farms, dairy farming, cheese making and greenhouses. The major energy user in this segment are the greenhouses. Even for low energy growths, heat pumps can give primary energy savings up to 35% [7]. In the period 2003-2013 approximately 40 growers of various crops have implemented heat pumps in their greenhouses. They comprise the following crops a.o.:

- Roses (2x)
- Tomatoes (3x);
- Orchids (Phalaenopsis) (8x);
- Freesia (2x);
- Anthurium (2x)

Recently the experience have been analysed [8], showing considerable difference with the well established market of commercial buildings. The already installed heat pumps are ‘traditional’ applications. As in the Paper & Pulp industry the greenhouse sector has in the past decades massively invested in cogeneration, which now gets into economic problems due to negative spark spread.

By combining electric drive heat pumps with cogeneration, more heat is generated and less electricity is produced for the power grid. This increases the flexibility in operational management of the energy system. Heat storage as well as co-producing for neighboring greenhouses and prediction of weather can lead to efficiency in management. A system is described in a factsheet.

Dairy Farmers
As an average Dairy Farms use 5.000 m3 gas and 35.000 kWh of electricity. If all 17.500 Dairy Frams in Netherlands would adopt the ECO 200 system with heat pumps using the heat extracted from the milk storage it would save up to 2PJ’s. Campina Melkunie, the large Dairy industry focuses strongly on these possibilities in order to get the complete chain from cow to end user of milk and cheese at a level of energy neutral. In all individual chains heat pumps are a key technology. of t

1.3 | Manufacturers and suppliers in the Netherlands

The market for industrial heat pumps is for an important part derived and developed from the market of industrial cooling and refrigeration. These manufacturers and suppliers are gradually ‘discovering’ the market of heating in industrial processes, but also in other markets. With their profound knowledge of thermodynamics they are developing and applying new innovative products in a fast growing market.
Compressor technology is the core of the technology, with one main well established manufacturer, Grasso from Den Bosch, part of GEA. The other manufacturers and suppliers in the Netherlands use components from Grasso and other suppliers to create and build innovative and outstanding products. Some of the products are standardised and some of the suppliers make tailor made solutions. Many of these have applications in all different sectors ranging from industry to greenhouses, skating rings and commercial office buildings.

Fig 1.5 Grasso FX P heat pump

Grasso Grenco (www.grasso.nl), is an old established company and manufacturer of screw and piston compressors of different sizes. With factories in Den Bosch (NL) and Berlin (D). The GEA group also active in several industrial sectors with MVR compressors. The Dutch division is typically a department derived from refrigeration, having developed the add-on heat pump for which they got the NVKL-Award in 2012, with an example project at Wiseman Dairies in UK.

IBK-Refrigeration (www.ibkgroep.nl) from Houten, as the name suggests, are specialists in refrigeration but at the same time supplying innovative heat pump concepts. IBK Refrigeration is part of the IBK-group. The first add-on heat pump was built at Unilever in Rotterdam (factsheet NL 08). Another interesting application is in ice skating rinks (factsheet NL 29). In a further development IBK is now involved in a pilot of a high temperature heat pump in the paper and pulp industry, for which they got the NVKL-Award 2014.

Fig 1.6 NVKL-Trofee 2014

Energie Totaal Projecten (ETP – www.etp.tv) from Dordrecht is a company delivering overall projects from engineering, design, financing, servicing and maintenance including performance guarantees for all sectors with larger systems. Their main markets are in

commercial buildings and greenhouses. Based upon a chiller from international high standard they have developed a standardized high performance compact heat pump which is skid built. Heat pumps are standardized in sizes from 85kW to 3.8MW's. Several patents are pending on new break through technologies. Example projects are under Greenhouses (NL-27).

Fig 1.7 ETP HWD-3800 skid

KODI (www.kodi.nl) from Heerhugowaard started just like ETP as a consultancy and installer firm in commercial buildings and agriculture. Not happy with the products on the market, KODI developed with a subsidy from Novem a high performance heat pump concept for greenhouses (see factsheet NL 27d). Standardized compression heat pumps based upon Grasso technology are now installed in several smaller industrial areas. KODI is also involved in projects like the Kolksluis industrial area. Their website shows a long list of reference projects.

Fig. 1.8 Typical KODI heat pump in Greenhouse

Reduses (www.reduses.nl) from Nijkerk is part of a group of companies delivering all services, from consultancy to installing, maintenace and monitoring. Installect, GeoComfort and Insted are the partners, where Installect is responsible for installation and design,

GeoComfort for the ground source (innovative concept of mono-source) and Insted for the monitoring and maintenace (inovative concept where monitoring is used as benchamarking between companies and as tool for maintenance). Reduses is a manufacturer of gas engine driven heat pumps up to 250 kW. The gas engine is from Volkswagen. Reduses have their own certified lab to do performance tests.

Fig 1.9 Reduses gas engine heat pump

De Kleijn Energy Consultants & Engineers (www.industrialheatpumps.nl) is a consulting company in Druten with a focus on industrial projects and tailor made innovative solutions (factsheet NL 11). Their focus on industrial heat pumps is clear with their website and the recent visit by NEDO in 2014. For RVO, Kleijn is executing a communication strategy on heat pump technologies.

NRG-TEQ (www.nrgteq.nl) from Rosmalen is a manufacturer of heatpumps in the range from 4 – 400 kW's. Until recently, NRG-TEQ was only active in domestic and comercial buildings.

It is of importance to notice that next to these Dutch companies other large companies are active in this market, where the local office often developes innovative applications with components from their 'mother'. Carrier from Hazerswoude, together with their French office, is such an example. Their heat pumps are rather populair in greenhouses and commercial buildings.

TASK 2

MODELLING IN THE NETHERLANDS

2. MODELING IN NETHERLANDS- TASK 2

Between 1992 and 1996, the IEA HPP Annex 21 generated an overview of potential industrial heat pump applications and also developed an “Industrial Heat Pump Screening Program” to determine how industrial heat pumps could be used in different applications [8]. The computer program should assist potential users in assessing the opportunities to integrate industrial heat pumps (IHP) into different types of industrial processes. The program has also been designed to determine the economics of heat pumps, at least on a preliminary basis. The computer program has been developed based on pinch technology concepts. It aims to identify IHP opportunities that are consistent with fully optimized plant heat exchange systems to provide the most economic IHP designs and the lowest possible plant-wide energy consumption.
The screening program contains data on more than 100 industrial processes in five main industries: food, chemicals, petroleum refining, pulp and paper, and textiles. These data can be used directly, or modified by the user as needed, to assess site-specific IHP opportunities. The computer program also contains data on more than 50 types of IHPs. Recent analyses by the Operating Agent of Annex 13/35 concluded that an update of the screening program is not advisable as since 1997 no further work has been done on the program and the software seems to be outdated. An analysis by the Operating Agent of existing software process optimization models shows that the difference between ‘pure’ pinch models and sophisticated mathematical optimization models has been bridged in modern software tools. Independent of any software tools, approaches and optimizations, a general heat pump data base should come more into the focus. Such a data base is needed for many purposes. Typical information to the database are not only source and sink temperature as well as size of heat pump etc. but also further details of the selected hot and cold streams to which the heat pump is selected, because this would allow to select a specific heat pump type.
Several of these specific heat pump models and databases have become available in the Netherlands during the work on the Annex. In order to integrate a heat pump properly in an industrial process, a good knowledge of the process is necessary. In this respect, pinch analysis is a very powerful tool. Although broadly introduced into the market in the nineties in the Netherlands, the use of models for process integration (i.e. pinch) and general process optimization is still limited to a fairly small number of research groups and highly specialized groups within large companies.

2.1 | Industrial heat proces optimization

Many tools are available to optimize industrial processes. Depending on the situation there is no univocal answer to the question which tool is the best to use. It is important to be aware of the fact that the costs of measures for energy conservation are often higher when they are further from the core of the process. Still it is amazing that under the past decade of Multi-Year Agreements in The Netherlands often cogeneration was installed as an energy conservation measure, which in the end has to do with the fact that interfering with the core of the process is often considered as ‘dangerous and risky’ and with the fact that the Multi-Year Agreements within the policy of participating companies was a responsibility of the energy manager of the company, i.e. the utility manager, and not of the process manager.

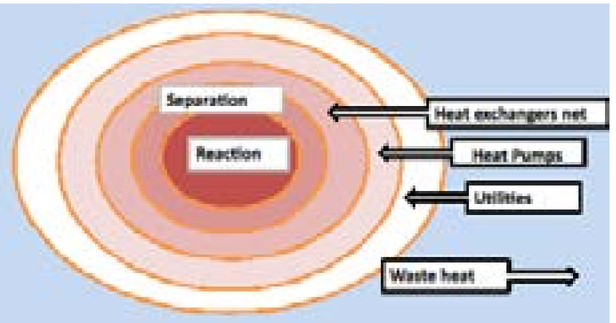


Fig. 2.1 Onion model for process approach

A systematic approach in improving the energy efficiency of industrial processes is the onion-model a translation of the TRIAS-Energetica where the pre-assumption is that one should first save on energy by optimising the process and then go into thinking about the way in which the energy is exchanged within the process and then generated at the outside of the process.
The model is explained for a chemical distillation process where in the first shell the processes occurring in reactors and separators (Process) are optimized. In practice this is done by an economic optimization in which energy and other operating cost are balanced with annualized investment cost for the equipment. In distillation “Process” refers to molecular improvements such as extractive distillation as well as optimization of internals, trays and column compartments. Energy consumption can be reduced further by heat integration using heat exchangers (HEX). As heat exchangers need a driving force there is a limit to what can be achieved by heat integration. Optimization of the heat exchanger networks is done using pinch technology leading to the rule of thumb: “Do not transfer heat across the pinch temperature”. In addition, the “grand composite curve” (enthalpy flow rate versus temperature) provides the minimum total cooling and heating power required for the plant. Now the temperature difference at the pinch temperature, ΔTpinch, is optimized by the economy: a higher value leads to smaller investment costs in the heat exchanger area but also to increased utility cost. After heat integration has been optimized, further reduction of energy consumption can be achieved in the third shell: the heat pump (HP).
Process integration, modeling and optimization problems in chemical engineering are generally complex tasks of a considerable scale and comprehensive interactions. The application of information technology (IT) and computer software tools is essential for providing fast and, as much as possible, accurate solutions with a user-friendly interface. General purpose optimization and modeling tools overviews have been available through the years. A number of computer-based systems have been developed to support process engineers in the energy and mass balance calculations. However, due to the substantial ongoing funding needed for the continuous development, only a limited number of these systems have remained on the market. They have only been secured by a substantial number of continuous sales.

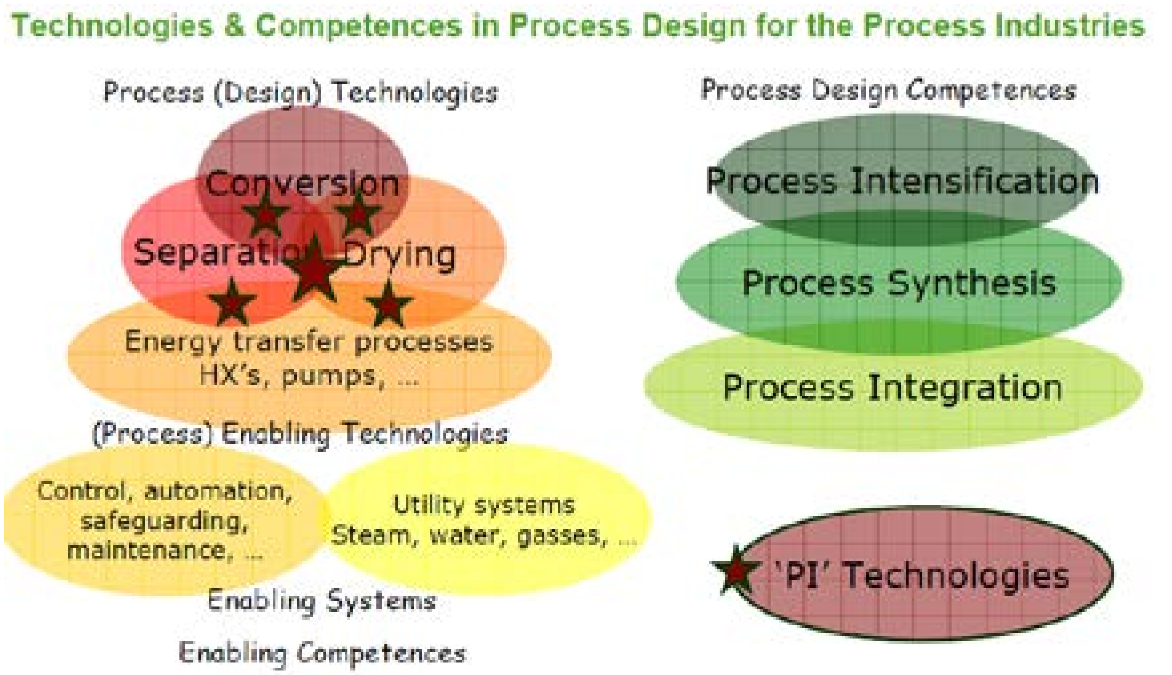


fig 2.2 Technologies for process design in chemical industry (source TKI)

A variety of efficient tools is available. Each provider mainly stresses their advantages. Klemeš et all presented a comprehensive list of software tools that are available for the simulation of material and energy balances of chemical processing plants, which includes: (1) Aspen HYSYS (2) CHEMCAD; (3) GAMS; (4) gPROMS; (5) HEXTRAN; (6) OpenModelica; (7) PNS Solutions and S-Graph Studio; (8) PRO/II; (9) SPRINT STAR, WORK and WATER; (10) SuperTarget and (11) UniSim Design.
Computers have been changed substantially the practice of chemical engineering, allowing large advances in process modeling and simulation. The chemical engineering community has generated a rich literature about rigorous unit operation models and efficient algorithms to solve them, employing rising computational resources. Several problems, which in the past demanded a considerable occupation of engineering manpower, now can be solved by a single engineer in a fast and accurate way. Simultaneously, plant automation developments can provide a large amount of information about the process behavior in real time.
Two factors; the availability of plant data and the capacity to handle these using adequate models, have opened a large field of improvements in process engineering. In a globalized world, characterized by an intensive business competition, these opportunities assume a special importance.

2.2 | Available tools [10]

Tools for complex industrial processes are developed to visualize and analyse heat flows in processes to support consultants in their advice on process improvements. Many of the available tools are based on graphs, diagrams and figures to ease the process of design and/or communication between experts and client

2.2.1 | Consultancy tools

Under the now long running policy of Multi-Year Agreements between industrial sectors and the Ministry of Economic Affairs, companies are benchmarked on an Energy Efficiency Index and have to make an Energy Efficiency Plan (EEP), done by an external consultant, every three years. Based upon Environmental Legislation, companies that do not participate in the program of Multi-Year Agreements, have to invest in energy efficiency measures with pay back times shorter than 5 years.
In this approach for energy conservation in industry, the Netherlands Enterprise Agency (and its predecessors) have developed and used tools to facilitate the consultancy and to increase the impact by translating difficult process decisions into clearly understandable reports on management level. Some of these are:

- Energy screening
- Energy Potential Scan
- Proces integration analyses and thermal audit (Einstein)
- Renewable energy scan

Energy analyses

An Energy Analyses which is part of the EEP consists of an energy balance, proposed measures, costs and economy and a consultancy report for decisions and an Energy Efficiency Plan for three years.
In a good Energy Analyses, the heat flows and waste heat flows are mapped, not only the chimneys but also the locations in the process where the products are cooled and heated. Important to notify is the location of cooling towers and or condensors in the process. These two technologies are easily detected.

Energy Potential Scan

Energy Potential Scan is a form of a participative model. Unlike the traditional energy audit approach, in EPS company and energy consultants work together to detect the possibility to conserve energy. This method has been developed by Philips in Eindhoven, together with Novem. There are two keys in EPS: quality and acceptance.

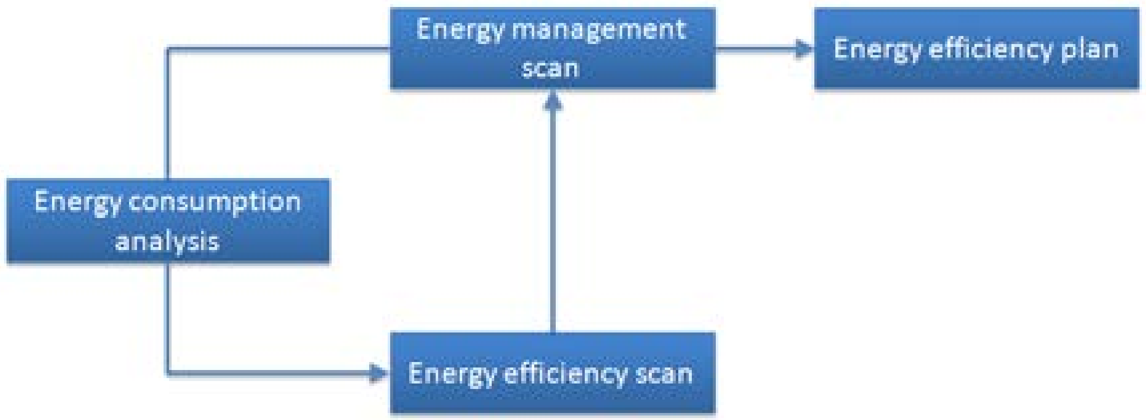


Fig. 2.3 Energy Potential Scan

A key word is Acceptance, which is created by something different from traditional energy audit where in the phase of the Energy Efficiency Scan (after the process analyses) it involves brain storming, thinking about the ideas to improve efficiency, and possible application both financially and technically. This creates commitment from management and participation of key personnel of the company.
From this very structured approach a large number of ideas are listed and discussed. The options for energy conservation are a preferably developed by the company itself in an Energy Efficiency Plan.

Processintegration analyses

In a Process integration analyses approach all heat flows for a process are mapped. For simple processes with a maximum of 20 heat flows a simple spreadsheet and pinch visualization are sufficient to develop an arrow and block diagram to engineer a heat exchanger network. For larger processes like in chemicals, specialized software is needed to be able to optimize energy and economy at the same time. Based upon distances in the process between coordinates for heat, costs data and data for materials the software can propose a set of technical choices. Next to the right fit for heat exchangers the right fit for a heat pump can be calculated if the data for heat pumps are available to the program. This last boundary condition seems at this moment to be the largest problem for heat pumping technologies.
At a European level it was noticed that a lot of software available for process integration analyses was not used for smaller processes as the software is often too complex or too expensive for small consultancies. Even worse is the fact that although the Dutch Government thinks that process integration broadly introduced in the nineties is an accepted tool, this is not the case anymore for the larger part of industry, with exception of course for the chemical industry.
In a European project a simple to use thermal audit has been developed under the name of “Einstein”. It is a freeware software tool with a report generator in Open Office. Companies with relatively simple processes can be scanned in a few days on the potential heat integration, the internal use of waste heat, heat pumps, cogeneration and renewables like solar heat and bio-energy. The Einstein tool is still fully under development and needs as well as other software tools the right and objective information on heat pumping technologies.

Renewable Energy Scan

The Renewable Energy Scan has been developed by the Netherlands Enterprise Agency (and its predecessors) to make companies aware of the potential for applying renewable energy. This methodology is especially of interest for companies that do not have large process heat flows and can be found on many mixed industrial areas in the Netherlands.

2.2.2 | Methods for Visualisation & analyse

For optimizing heat flows and to get process integration with heat exchangers and heat pumps in the first two levels of the onion, the available waste heat flows should be charted. If no data are available or if the design of the process is dated, it is advised to execute when possible an extensive monitoring on the process over a certain period of time, since it is the experience (often painful) that no process runs optimally according to the design. Several methods are available for visualization of (waste) heat flows.

- Sankey diagram
- Arrows diagram
- Block diagram
- Pinch diagram
- Grassmann diagram

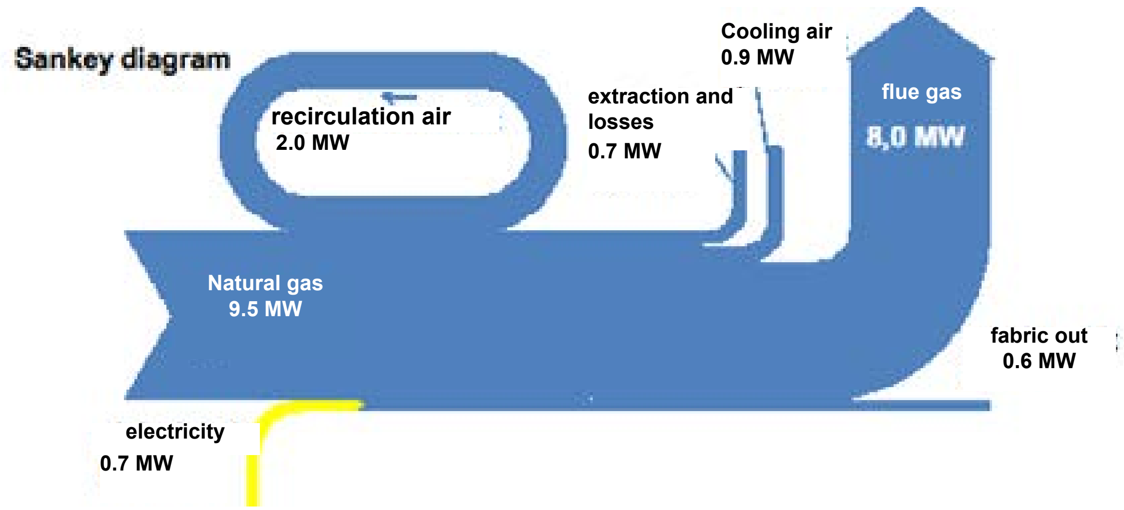


Fig. 2.4 Sankey diagram

A Sankey diagram can give insight in the energy balance on parts of the process or the complete process. The width of the arrows is a measure of the capacity of the energy flow

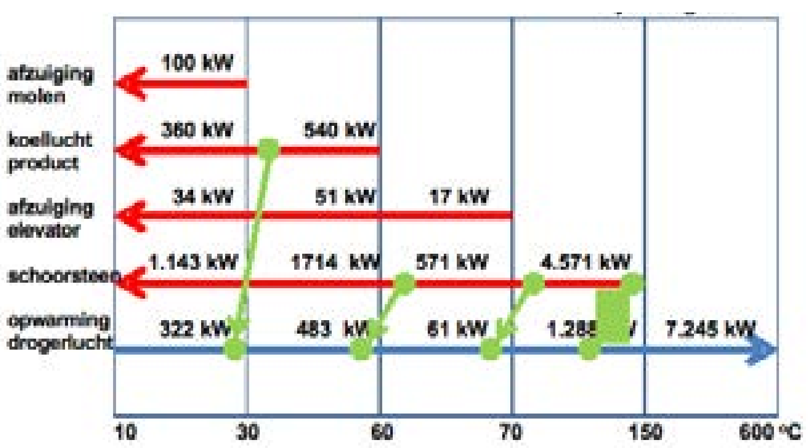


Fig. 2.5 Arrows diagram

An Arrows diagram gives the heat flows at with the temperature levels. Together with the heat capacity of the flow in not too complex processes the right position for heat exchangers can be proposed. The green arrows give the potential heat exchanger between red (=hot) and cold (=blue) to be heated flows.

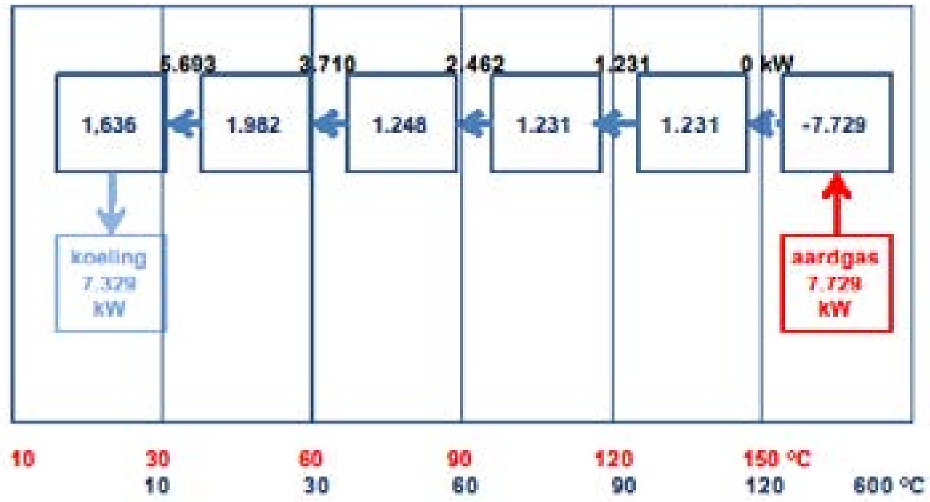


Fig.2.6 Block diagram

A block diagram is a tool to give the optimal lay out of a system of heat exchangers in a simple process. With this tool, the capacity of heating and cooling can in theory be calculated. The figures in the blocks give the amount of heat residue which is available in the given temperature segment. These segments have to be placed in order to make the exchange of heat possible. The flows to be heated (blue) have to have a lower temperature than the waste heat flows (red). The block in the lowest temperature segment has to be cooled by external energy. In this example only heat has to be supplied in the highest temperature segment.

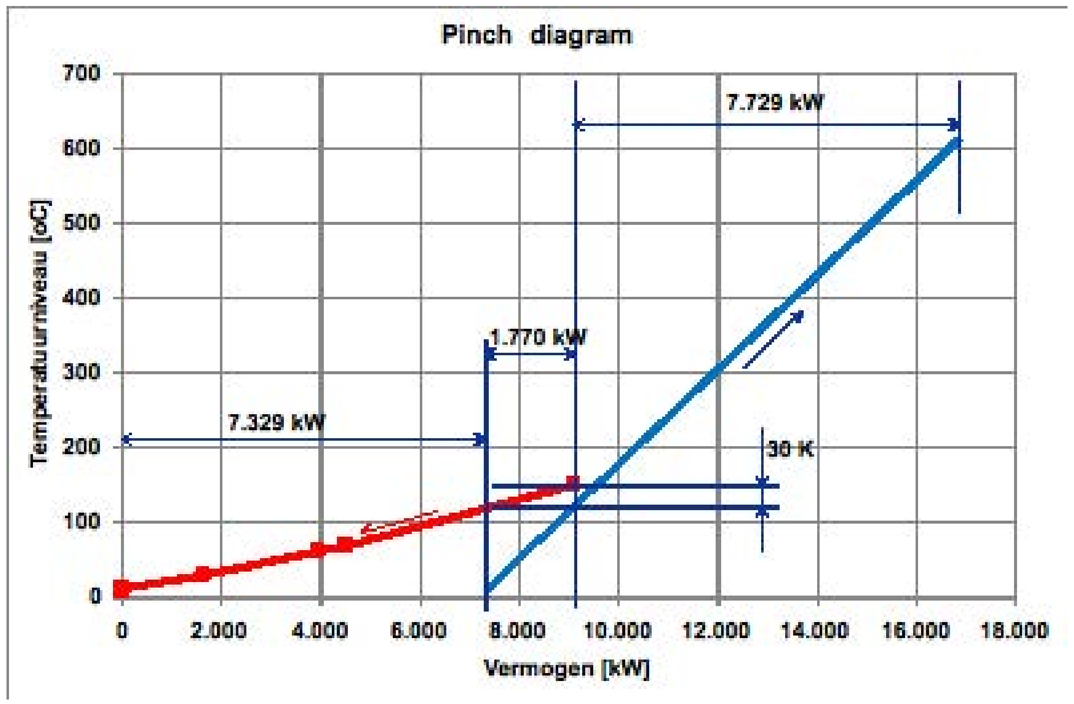


Fig. 2.7 Pinch diagram

A pinch diagram gives capacities and temperatures. The process data are converted into a hot and cold composite curve. The hot composite curve gives all the process streams to be cooled including waste heat and the cold composite curve gives the stream to be heated. The art of engineering the process is to combine these streams in order to reduce the final heating and cooling demand of the overall process. Where the curves are closest together, i.e. the smallest temperature difference, is the so called ‘pinch’. A heat pump is only functional if the heat pump crosses this pinch. In the given example, in the diagram a theoretical minimum heat is required of 7,729 kW’s and cooling of 7,329 kW’s, while 1,770 kW’s of waste heat can be re-used in the process.

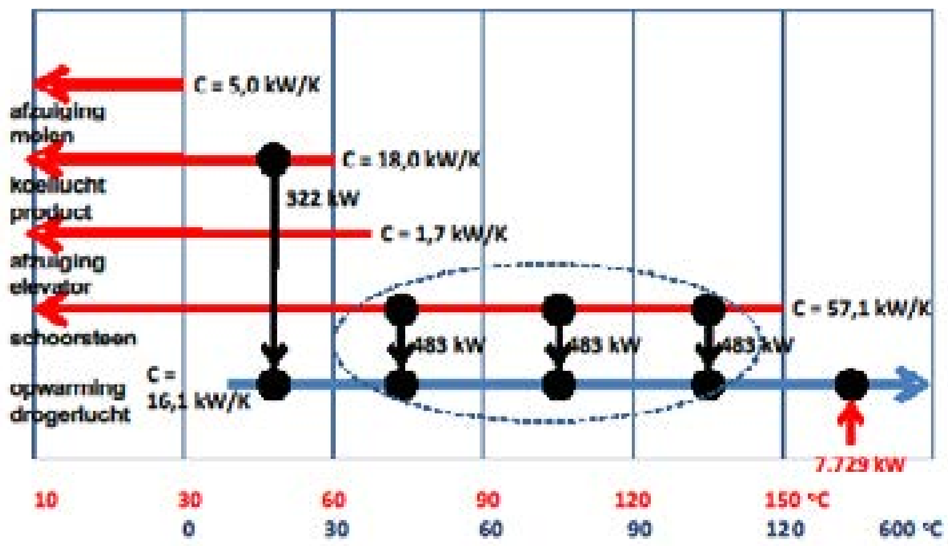


Fig 2.8 Heat exchanger Network

If the pinch temperature is known, a heat exchanger plan can be engineered. For complex processes software is available to design this. For simple processes an arrows diagram can be configure the basic design of the network.

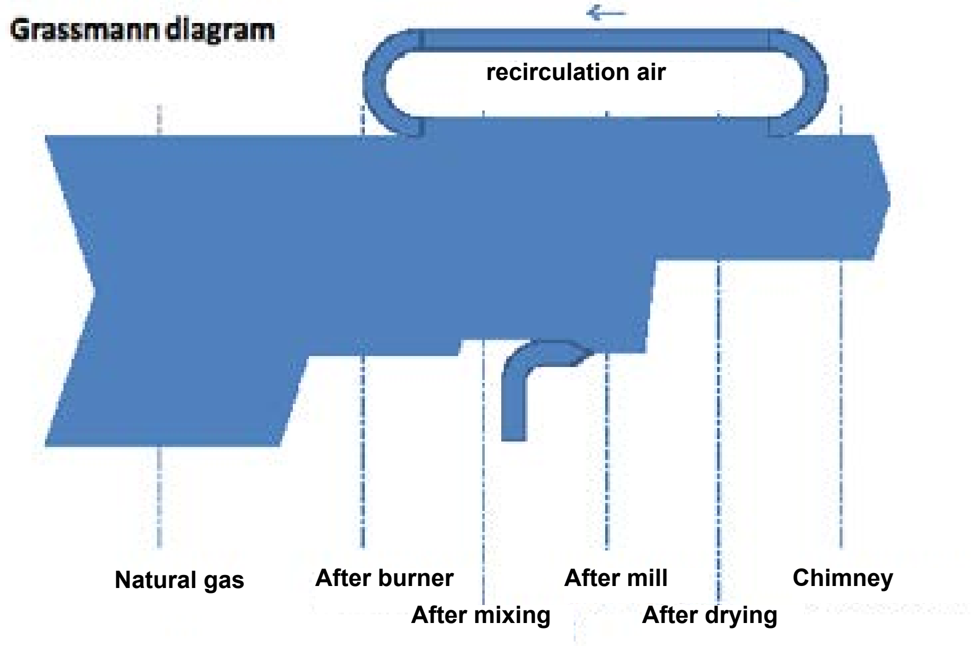


Fig 2.9 Grassman diagram

A Grassman diagram shows the exergy flows in the process. The exergy of a heat flow is a standard for the quality (temperature level) of the energy flow and a benchmark for the amount of electricity which can be generated from the flow. This is often used to analyze the optimal use of cogeneration.

2.3 | Which tool fits best?

Many tools are available to optimize industrial processes where depending on the situation there is no univocal answer to the question which tool is the best to use. Several approaches for process optimisation in industry can be met with based upon the onion model as in figure 2.1. In order of ranking:

- Process optimisation
- Process integration
- Optimisation of Utlities
- Heat exchange with surrounding energy users

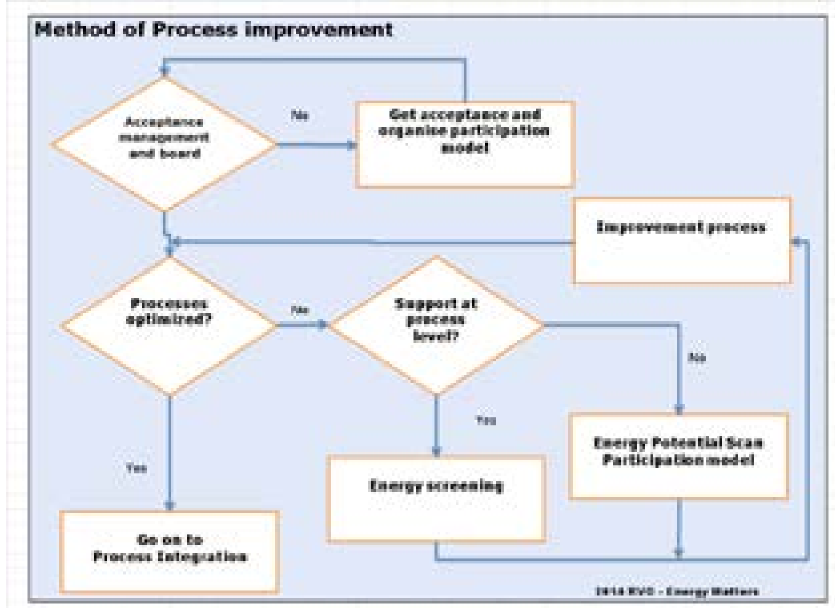


Fig 2.10 Flow diagram Improvement Process

Projects for reducing the energy use through process optimisation go beyond the responsibility of the energy or utilty manager alone and often have to have additional profits than only energy, like a better product or a higher yield of the production. If the project only gives reduced energy costs, the profitability is often lower than competing investments. In these kinds of projects it is of importance to create support and trust with the decision making management first, before even considering starting the project. The first phase of the project will have to focus on process mapping an improvements of the process as it is. From the core of the original process questions can be raised as:

- Are the setpoints optimally adjusted?
- Is heat recovery already installed and optimal according to the pinch principles?
- Can temperatures be used at lower levels? Often for the easiness of installation and transport cheap steam systems are installed where only low grade heat is needed.
- Can drying processes be used by mechanical drying?
- Are heat flows mixed with degradation of heat?

Often the process (as mentioned earlier) does not run according to the original design due to changes and small improvements over the years. (an interesting example is given in the factsheet on the Lips project with Doorgeest NL-18). Monitoring of the process can

often already lead to large costs savings before even starting the more complex task of process integration. When it is assured that the process is optimized, the task of process integration can start.
The flow diagram of the improvement process makes it clear that support and acceptance start at management level. If the challenge can be translated to the management and board in clear and simple to understand messages, the project can start. The next phase is to get participation at the operational level. The Energy Potential Scan is an excellent methodology to get that result.
When the process has been basically optimized, the potential for process integration can be analysed. When not all data of the process are not already gathered in the first phase of the project, the task of data gathering must be undertaken. Monitoring of the process getting to know all mass balances, temperature levels, enthalpy levels seems to be a costly effort in time and money but will be worth every penny in the end result. The next step is to translate the data into energy balance with costs attached (Sanky) and analyse the complexity of the process.

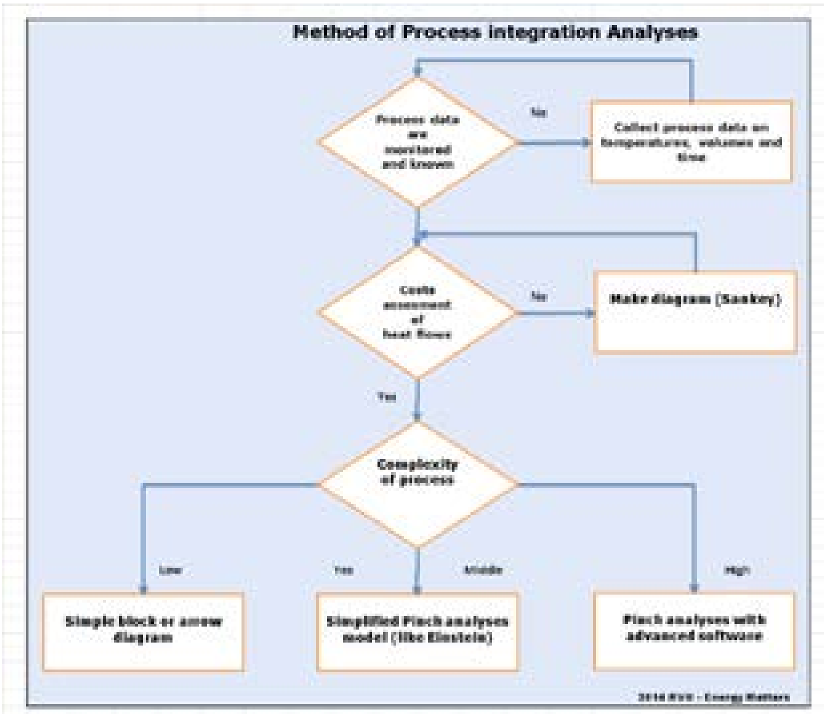


Fig 2.11 Flow diagram Integration Process

The question then raised is: how many processes are suitable for process integration? In day to day practice often installers in medium sized industries often are responsable for a part of the project. For cooling a refrigeration engineer is asked for. This misconception has for a long time been dominant in industry. However there are of course still a lot of smaller industrial companies can be supported with a simple block or arrow diagram. The flow diagram makes this distinction betwee simple and complex processes. For more complex situations Pinch software is needed to bale to calculate and design the optimal process integration. As mentioned before, process integration has been broadly introduced in the nineties as a tool, however it is not broadly used anymore in the larger part of industry, with exception of course for chemical industry. Therefore RVO has started togethet with the Federation of Energy Consultants (FEDEC) a series of training courses with the pinch model of 'Einstein' (see paragraph 2.4). In more complex processes a specialized consultant with advanced software steps in.
When all rational heat exchangers within the first inner circles of the process are established, the next step is to optimize the utilties and to find a useful application for the waste heat of the process. A heat pump can be used to upgrade the waste heat over the pinch to supply a part of the heat demand of the process. With newly developoed heat pump technologies the temperature rise can be larger than originally was the case. Other possible use can be steam expansion or absorption cooling, both for the heat and cold demand of the original process. Eventually an ORC can make electricity from the wast heat if the temperature is at an acceptable level.

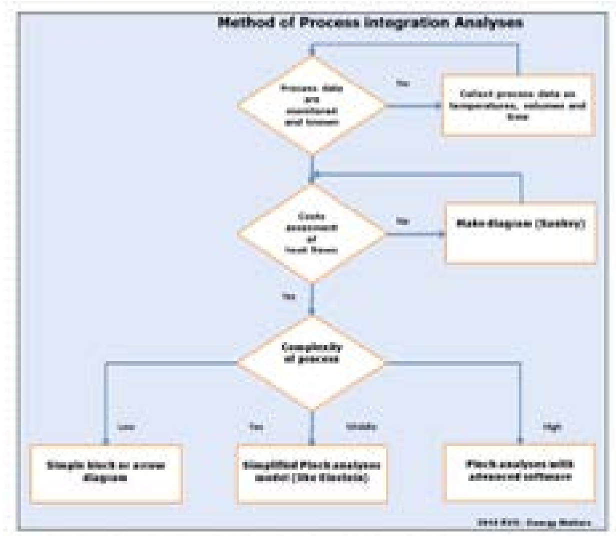


Fig 2.12 Utility Flow diagram

When there is still a constant and fair amount of heat needed for a larger part of the year, cogeneration can be a serious option. However at the moment of writing the spark spread is negative, thus cogen will in almost all cases be no economical option. Renewable energy options are decided on at the level where the Renewable Energy Scan as has been developed by RVO can be used. Cogeneration can also be based upon bio-energy.
When still waste heat is still available a survey can be done on possible users of heat in the neighboring area, where it must be closely watched that heat is not transported over too long distances with too high temperatures and transported to a heat demand with a stable demand over the year, especially in summer periods when process cooling is at its most critical. The best exergetic option for waste heat is to generate electricity with an ORC. This can be put into the grid.

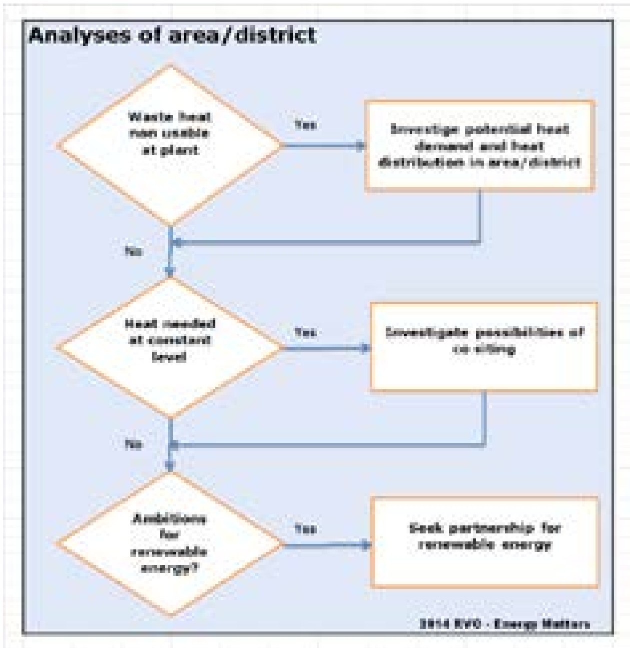


Fig 2.13 Flow diagram for area survey

2.4 | EINSTEIN

The EINSTEIN methodology for thermal energy audit has been developed in the framework of the European Intelligent Energy Europe (IEE).
In the follow up under EINSTEIN-II project aims to contribute to a widespread implementation of integrated energy-efficient solutions for thermal energy supply in industrial companies with a high fraction of low and medium temperature heat demand and for non-industrial users of similar demand profiles, such as hospitals, commercial centres, large office buildings, district heating and cooling networks, etc. To further optimise thermal energy supply, a holistic integral approach is required that includes the possibilities of

demand reduction by heat recovery and process integration, and by an intelligent combination of existing affordable heat (and cold) supply technologies, under the given economic constraints. The follow up builds on the EINSTEIN tool kit for thermal energy auditing. This tool kit, based on an expert system software tool, guides the user through the whole procedure, from auditing (preparation of visit and data acquisition) to data processing, to the elaboration, design and quantitative (energetic and economic) evaluation of alternative solutions. The tool kit, together with complementary databases, has been developed as a free and open source software project available in all the IEE project partners' languages. It uses pinch analyses as the basis is open-source software and provides the possibility for thermal energy efficiency improvements and the implementation of renewable energy within industrial processes, in different industry sectors.

The Einstein website and information (www.einstein-energy.net) claim that the methodology and Software Tool has proven in Auditing Practice (72 energy audits) that:

- The EINSTEIN methodology and tool has been successfully consolidated within the project. It has been proven that it can be applied in a great variety of different applications.
- The application of EINSTEIN compared to conventional auditing offers a great deal of support for the auditor for organising information in a systematic and structured way and in carrying out fast feasibility analysis for a large number of possible alternatives.

Large Potential for Energy Efficiency

An average primary energy saving potential of close to 20 %, and in some companies up to more than 60 % has been detected even under the constraint that has been applied in most audits that pay-back times should not be longer than 4 years (although this limit varied from company to company, from below 2 year up to 8 years in some specific cases). At many companies there was a positive take-up of the proposals presented (at the end of the project out of 72 companies 20 had initiated some further detail planning steps and out of them 5 already had implemented (some of) the proposed measures). The development and presentation of an attractive proposal to the company was in many other cases in-sufficient for triggering action towards a further development of detailed technical issues with the objective of a real implementation of the measures.

Einstein Approach in Netherlands

In the Netherlands well as in in Europe it is noticable that although process integration based upon pinch analyses was broadly introduced in the nineties and should be an accepted tool, that this is not the case anymore for the larger part of industry, with exception for the chemical industry. Consultants as well as energy managers within companies should therefore be trained and educated in process analyses based upon the approach described in paragraph 2,3 starting with an Energy Potential Scan and further worked out as described in the flow diagrams in fig. 2.11.
Dependent on the complexity of the process, a tool like Einstein is used or more complex tools are used. RVO has ordered Energy Matters after their study on which tools to use [10] to develop a training program together with FEDEC (Federation of Energy Consultants in Industry) based upon Einstein. The focus is to improve the availability of skilled energy auditors and energy managers and the diffusion of energy management systems and best practices. A next step will be to develop instruments to ensure availability of updated, comprehensive and usable information on energy efficiency relevant for industries. Heat pumps is one of the key technologies in this approach, with models developed and described under the next paragraph.
During the process of training with Einstein, bugs and small problems were discovered and are now discussed with the developers of the Einstein tool kit.

2.5 | Process tools and heat pumping technology

Most of the tools discussed are focusing on heat integration and with these tools the right position and choice for a heat pump can be made. In general, experienced process designers working with pinch software can easily detect from the grand composite curves where heat pumps can be applied, also from the 'nose' of the curve they in general know which type of heat pump. The main problem is that it is difficult to select the right size and brand of heat pump as there is scarce information that can be directly be used. A lot of information can be found on the Internet but a consultant (often highly paid) doesn't have the time available to sort out this information.
Independent of any software tools, approaches and optimizations, a general heat pump data base should come more into the focus. Such a data base is needed for many purposes. Typical information for the database contains not only source and sink temperature as well as size of heat pump etc. but also further details of the selected hot and cold streams to which the heat pump is selected, because this would allow to select a specific heat pump type.
For a heat pump to be effective there is a number of issues to be considered:

- The pinch temperature and the flexibility of the plant
- The thermodynamic cycle and the heat pump efficiency
- The temperature lift required
- The enthalpy balance
- The selection and constraints of heat pump equipment
- The configuration of the system
- The available utilities
- The economy or the annualized capital cost versus the utility cost

As the target group for heat pumps consists of a large variety of industrial sectors several heat pump selection models have been developed and are becoming available. Three of these are discussed in the next paragraphs.

2.5.1 | Mastering Heat Pumps Selection for Energy Efficient Distillation1 [12]

In Appendix 2 of this report an overview is given on application criteria for practical systems [13].
Distillation still remains the most popular separation technology, in spite of claiming about 40% of the operational costs from chemical and refining plants. Distillation has a relative low thermodynamic efficiency, requiring the input of high quality energy in the reboiler to perform the separation task. At the same time, a similar amount of heat at a lower temperature is rejected in the condenser. Several heat pump concepts have been proposed to upgrade that discharged energy and reduce the consumption of valuable utilities. For example, vapor compression (VC) uses work to increase the temperature of a fluid heat transfer media in a closed loop. Mechanical or thermal vapor recompression (MVR or TVR) use the top product as working fluid in an open cycle, reducing further the investment costs. Similarly, the structure of an internally heat integrated distillation column (HIDiC) lowers the required temperature lift, reducing the compressor work. Meanwhile, compression-resorption heat pumps (CRHP) use absorption processes to enhance the heat transfer, allowing higher efficiency and a wider applicability range. Average energy savings when using any of the heat pump systems in distillation range from 20 to 50%.

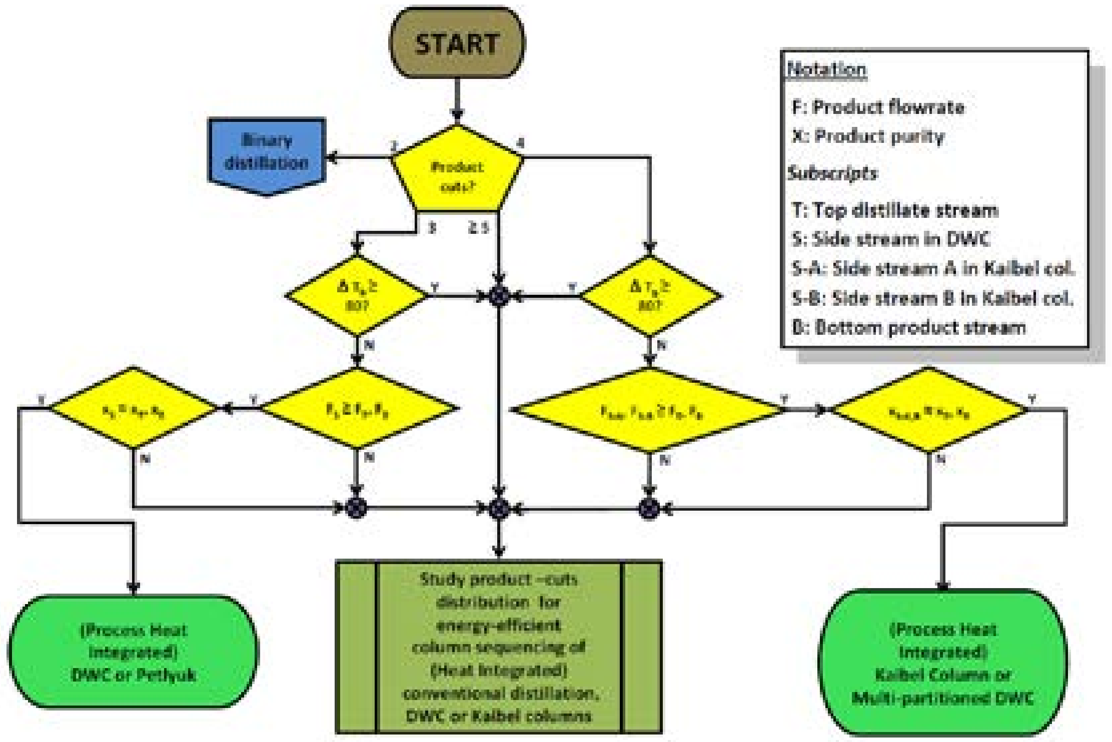


Fig 2.14

However, the energy efficient systems described in literature were evaluated for different separation tasks. Thus, their performance comparison is difficult, complicating the technology selection for other applications. To solve this problem, we developed a practical selection scheme of energy efficient distillation technologies, with a special focus on heat pumps.
Only the most promising technologies in terms of actual implementation were selected for this study: vapor compression, mechanical or thermal vapor recompression, compression-resorption and thermo-acoustic (TAHP) heat pumps, heat integrated distillation column (HIDiC), cyclic distillation (CyDist), dividing-wall column (DWC) and Kaibel distillation column. The selection criteria include the type of separation tasks, the products flow and purity specifications, the boiling point differences (ΔTb), the reboiler duty (Qreb) and its temperature level (Treb).

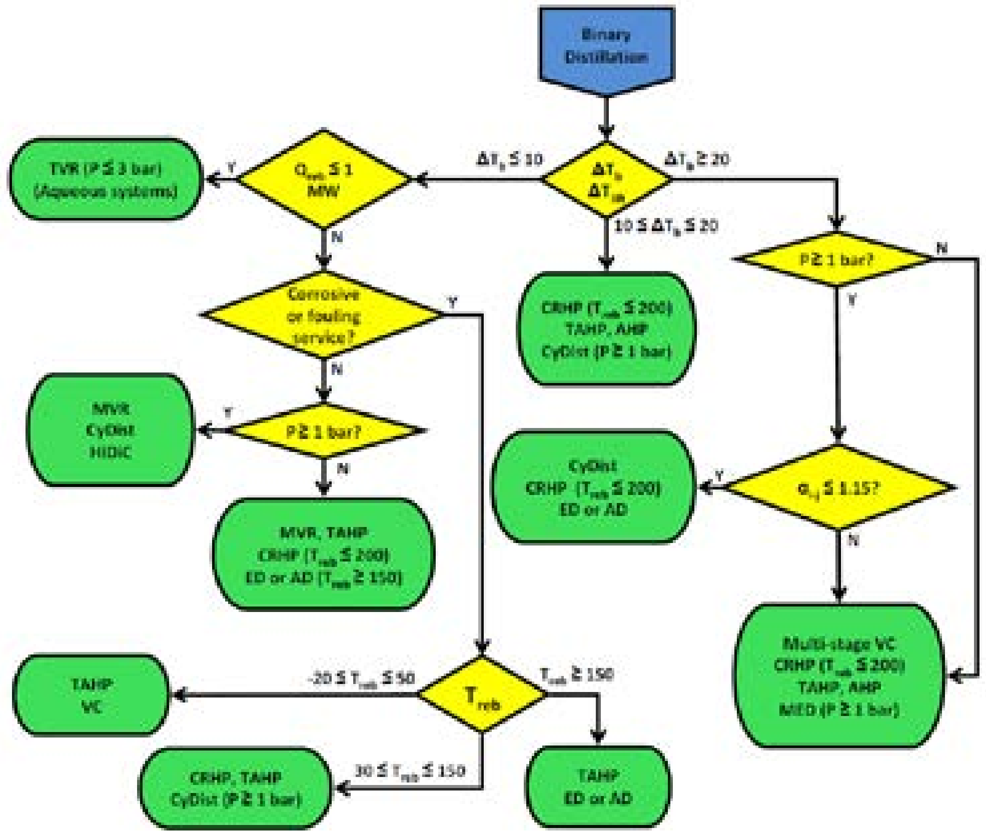


Fig 2.15

The straight-forward selection scheme presented in this work allows the quick selection of the most suitable technology for any distillation task. Thus, the application of the proposed scheme allows considerable savings in time and resources allocated for the selection of eco-efficient separation technologies. The ultimate goal of this work is to facilitate significantly the design of energy efficient chemical processes, thus becoming a valuable tool for enhancing the sustainability of the chemical industry.

2.5.2 | Heat pump models

A more general model that can be used has been developed under the Task 2 of the Annex by KWA for RVO. The challenges arose during the meetings on Annex 35 with the Dutch market, consisting of consultants and institutes. The main consultants for process industries advised not to focus on process integration tools but to develop a model that could be used as an add-on to existing tools. Integrating this basic heat pump model into software models would make this model dependent on the tools. No specific new process analyses tool was deemed necessary.
The heat pump model based upon Excel would idealy 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. 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.
In a step by step approach, the user is lead through the process, filling in data from his own process.

- Find source heat with a high as possible temperature, below the pinch-temperature in the process. Determine the amount of heat available with corresponding temperature. Find out what will be the impact on the process and the existing heat integration. Determine whether it is possible to adapt the process to increase the amount and/or temperature of the source heat.
- Find process heat with a low as possible temperature but higher than the pinch-tem-

perature. Determine the amount of process heat and temperature required.

- Determine which type of heat pump fits the process conditions that are investigated in step 1 and step 2. Heat source and heat sink temperature, power and type of process medium should be considered.
- To determine the feasibility of a heat pump, the performance of the heat pump at given process conditions should be calculated.
- When the performance of the heat pump is calculated, an indicative calculation of energy and cost savings can be performed

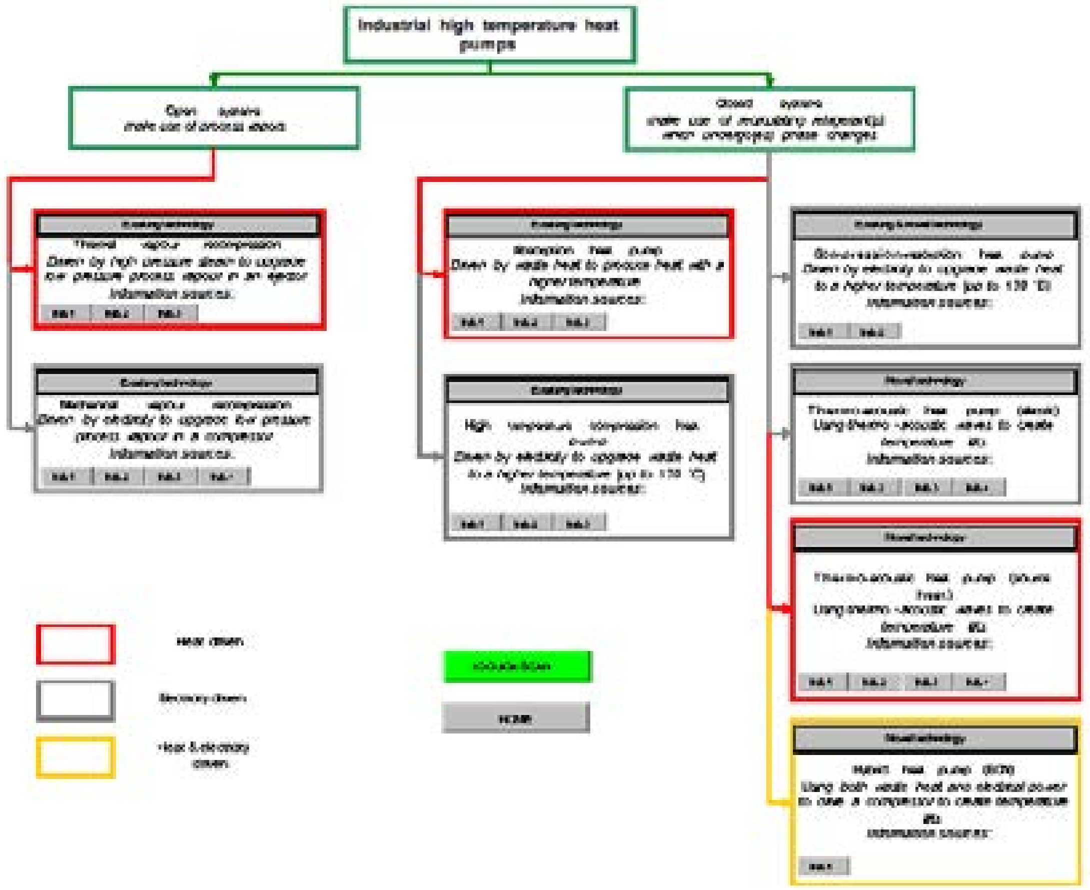


Fig 2.16 RVO - Heat pump model selection screen

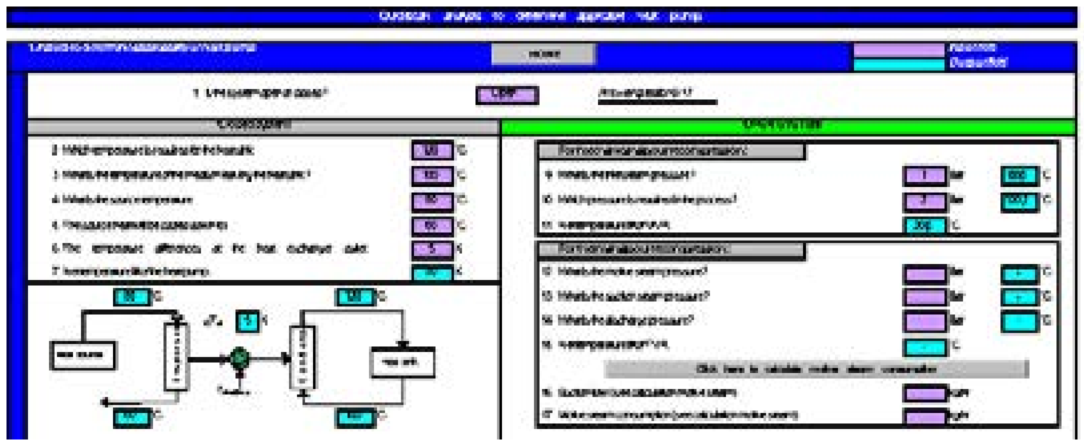


Fig 2.17

The further development of this model will be taken up in 2014 – 2015, under a new Task 2.

2.5.3 | Heat Pump Check

The Heat Pump Check is another online calculation tool which is developed by De Kleijn Energy Consultants & Engineers from Druten (www.industrialheatpumps.nl). The tool can help industrial companies to determine the feasibility of heat pumps for their processes. it gives a global indication of the applicability and feasibility of a heat pump. The result is a good starting point to determine whether further investigation, for example by an external consultant, is useful.

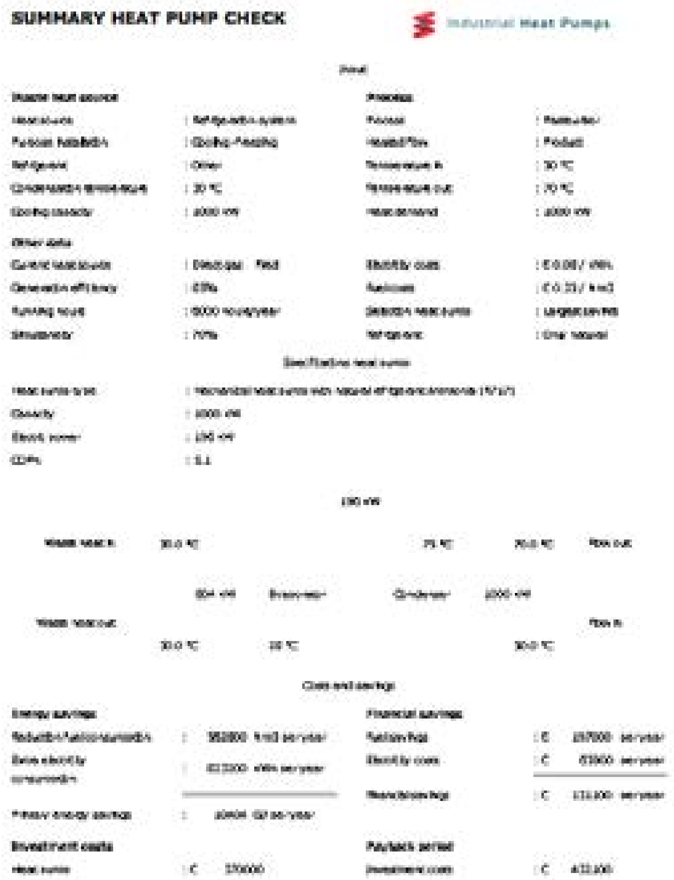


Fig 2.18 Report generated by Heat Pump Check

TASK 3
RESEARCH AND DEVELOPMENT

3. RESEARCH AND DEVELOPMENT - TASK 3

R&D in the Netherlands on industrial process innovation is for a large part supported by the Ministry of Economic Affairs through the ISPT Innovation Program. Major players in this programm are the Dutch process industry, TU-Delft and ECN. The focus on heat pump technology as one of the key technologies is logical and has a long track record starting with basic research now reaching the pilot phase.
More than 80% of the total energy use within the Dutch industry consists of heat demand, in the form of steam at different pressure levels and for firing furnaces. The total industrial heat use (530 PJ/year) together with exothermic heat from chemical reactions is eventually released to the ambient atmosphere through cooling water, cooling towers, flue gasses, and other heat losses. We call this heat loss 'Industrial waste heat'. A first, most logical, solution to this waste heat problem is to reuse the heat within the same process through process integration or at the same site. In an ideal process that will be within the process unit otherwise technology will have to be applied to transform the heat coming out of the process to a common carrier. This being high pressure steam or electricity generated by a high temperature heat pump or an ORC.
European R&D and the goals set are defined by the European Technology Platform on Renewable Heating and Cooling (RHC-Platform) in their recent Strategic Research and Innovation Agenda for Renewable Heating and Cooling. Industrial heat pumps are an important part in that strategy. The report is presented to the European Commission as advice on which technology to support.
In this chapter, ISPT and RCH are discussed followed by a general description of research and development projects. Please note that for confidentiality reasons, exact details of the process and the control and design alternatives for these projects are not provided and only described in general terms.

3.1 | TKI- ISPT Innovation Program

Mid 2012, ISPT founded its Topconsortium Knowledge and Innovation for Processing (TKI-ISPT). This TKI connects the chemistry, agriculture and food, energy, and biobased economy sectors.
The TKI Processing takes care of the innovation contracts for:

Topsector energy	Energy reduction in the industry (EBI) and Biorefinery
Topsector chemistry	Process Technology
AgriFood	Sustainable Manufacturing
BioBased Economy	TKI-ISPT executes the biorefinery part for the innovation contracts of the topsectors

DSTI (Dutch Separation Technology Institute) is a partnership in which industry, universities and knowledge institutes work closely together to develop breakthrough technologies for application in different sectors of the process industry. "Together we can take bigger steps, have more impact, and share the risks".
So far, 45 companies from the Food, Pharmaceutical, Oil and Gas, Chemical and Process Water Industries and 8 knowledge centers have joined DSTI. The estimated budget is EUR 65 million for the next 5 years. The research program covers all aspects from (fundamental) knowledge generation to technology implementation.
The program contributes to the process industry's sustainability objectives in terms of product value, efficiency, energy savings, and the reduction of emissions through the generation and application of new knowledge in collaborative development and demonstration programs.

TKI-ISPT has been working on translating the plans of the innovation contracts into a coherent set of activities. These activities are executed within 14 cross-sectoral clusters, of which of interest for heat pumps:
- Energy Efficient Bulk Liquid Separation
- Drying and Dewatering
- Utilities & Optimal Use of Heat
- Process Intensification
- Sustainable Business Models
- Maintenance

From PPP-ISPT and the TKI Action-program 2012 several projects are running which will be finalized leading to pilot projects 2014/2015, with the focus on the aplication of newly developed prototype heat pumps in chemical industry and paper and pulp.
- Utilities and optimal use of heat

This cluster aims to:
- reduce (fossil) energy use for the production and use of industrial heat;
- improve competitiveness of stakeholders by reduction of energy costs;
- create new market possibilities for equipment manufacturers;
- improve the energy efficiency of industrial processes.

The estimated energy saving potential equals 100 PJ/year. The use of heat within industry is responsible for more than 80% of the final energetic energy use. Heat is used for heating feedstock, enable reactions, and to drive separation processes. The required temperature level spans a broad range, depending on the specific process. At the same time, large quantities of waste heat are released to the ambient atmosphere that cannot be reused in an economical way.

- Reuse of waste heat:

The recovery and reuse of industrial waste heat is hindered by technological and economic barriers. Several possible paths can be envisioned that start from economical heat recovery of waste heat. Next, waste heat can be converted into process heat, process cold or power. Finally, heat storage and distribution can be realized.
All activities carried out within this cluster are related to:
- Technology scouting
- Feasibility studies
- Research & Development
- Dissemination

The main bulk separation processes within chemical and refining industry are distillation, absorption/desorption, and crystallization. The thermodynamic efficiency of these processes is usually very low (<10%). Environmental implications and increasing energy costs demand improvement of energy efficiencies. Significant reductions in energy consumption are expected by using innovative heat pump concepts for removal and supply of heat from/to a separation process. The efficiency of e.g. distillation systems can be increased by heat integration of reboiler and condenser using high lift high temperature heat pump concepts.

3.2 | European Technology Platform on Renewable Heating and Cooling (RHC-Platform)

RHC-Platform has produced the present Strategic Research and Innovation Agenda for Renewable Heating and Cooling [13],

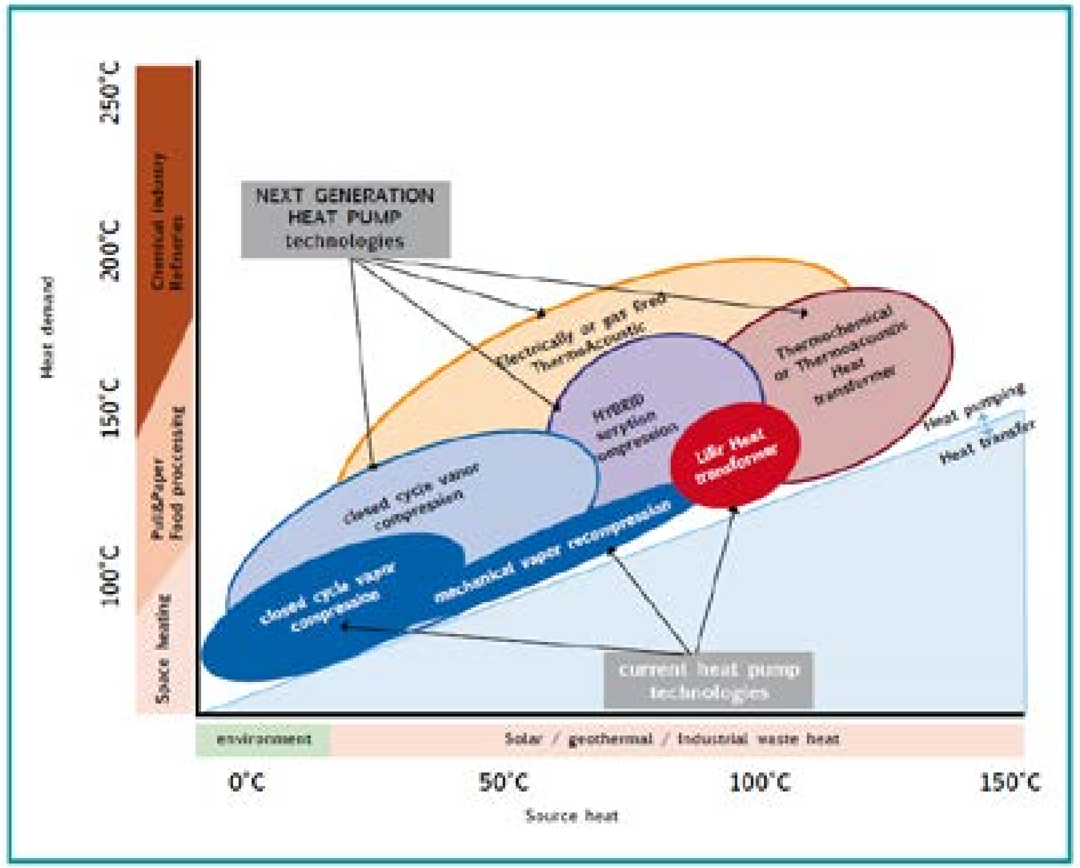


Fig 3.1 Heat pump technologies and their operating temperatures.

Figure 3.1 plots the driving temperature ("source heat") against the delivered temperature ("heat demand") for various heat pump technologies. Current vapour compression systems deliver heat at a maximum temperature of ~80°C. New vapour compression systems should use low GWP synthetic refrigerants or natural refrigerants (such as butane or water) to reach temperatures of up to 150°C. Components and materials should be developed to achieve temperature lifts of up to 70 K. The use of water as the working medium allows the heat pump to be integrated into industrial heating processes. Alternative concepts such as heat transformers are interesting when a heat source of more than 90°C is available. Current systems use thermally-driven compression to upgrade waste heat from 100°C to 140°C. Reversible solid sorption reactions, such as the reaction of salts and ammonia are applicable for heat transformation at temperature levels up to 250°C. Similarly, thermoacoustic systems can accept a range of driving temperatures and output heat also in a wide temperature range. A hybrid system can be created by adding mechanical compression as the driving input to a heat transformer, allowing for use of low temperature waste heat and still generating temperature lifts of up to 100 K.
A broader range of operating temperatures and higher temperature lifts are needed to increase the application potential and the energy saving potential that heat pumps offer. The end users' demands extend beyond the required temperature and cost of the system to topics such as the toxicity & flammability of the working medium and the reliability of the system. No single heat pump technology can cover this entire range of demands, which means that different heat pump technologies should be developed in parallel. The main objective is the exploration of alternative thermodynamic cycles for heat-pumping and heat transforming for different industrial applications, with the goal to increase the operating window of industrial heat pumps, so that they can deliver heat at medium pressure steam levels (app. 200°C).
Not only will these improvements allow larger energy savings, but they will also unlock the benefits of economies of scale for the European heat pump industry.

Figure 3.1 above shows four types of technology that can potentially overcome the aforementioned limitations in terms of temperature range and lift. Not only these improvements will allow larger energy savings, but simultaneously they will unlock the benefits of economies of scale for the European heat pump industry. Apart from their operating temperatures, these technologies have different levels of maturity. They form a chain of new heat pump technologies in which the mechanical vapour compression systems with new working fluids are the next generation to be tested at a small scale in real applications for higher delivery temperatures. The salt-ammonia sorption and thermoacoustic heat transformers are in the development stage of laboratory prototypes, proofing the concept of the system. The hybrid sorption-compression systems and gas fired thermoacoustic heat pumps are in the stage of proofing the principle.
Conventional heat pumps provide limited temperature lift. Therefore, heat pumps are required which can operate at the temperature levels of the column and provide the desired temperature lift between condenser and reboiler. These heat pumps are presently not commercially available and therefore need to be developed. The project covers the theoretical and experimental verification of the performance of innovative heat pumps integrated in a separation process. Presently three innovative heat pumps are identified, but early on in the project an assessment is made to find out whether additional systems should be considered. The three heat pump concepts to be covered in the program and their main technological challenges are the following:

1. Thermo-acoustic heat pumps: achieve the required efficiency with a design integrated within a separation process.
2. Thermo-chemical heat pumps: identify the proper solid/vapor combination and ensure stability and continuous heat supply.
3. Compression-resorption heat pumps: manufacture compressors that can operate under "wet" conditions. The project is setup in two phases: Phase 1: Feasibility and heat pump selection. Phase 2: Testing model heat-pump systems under reference operation conditions.

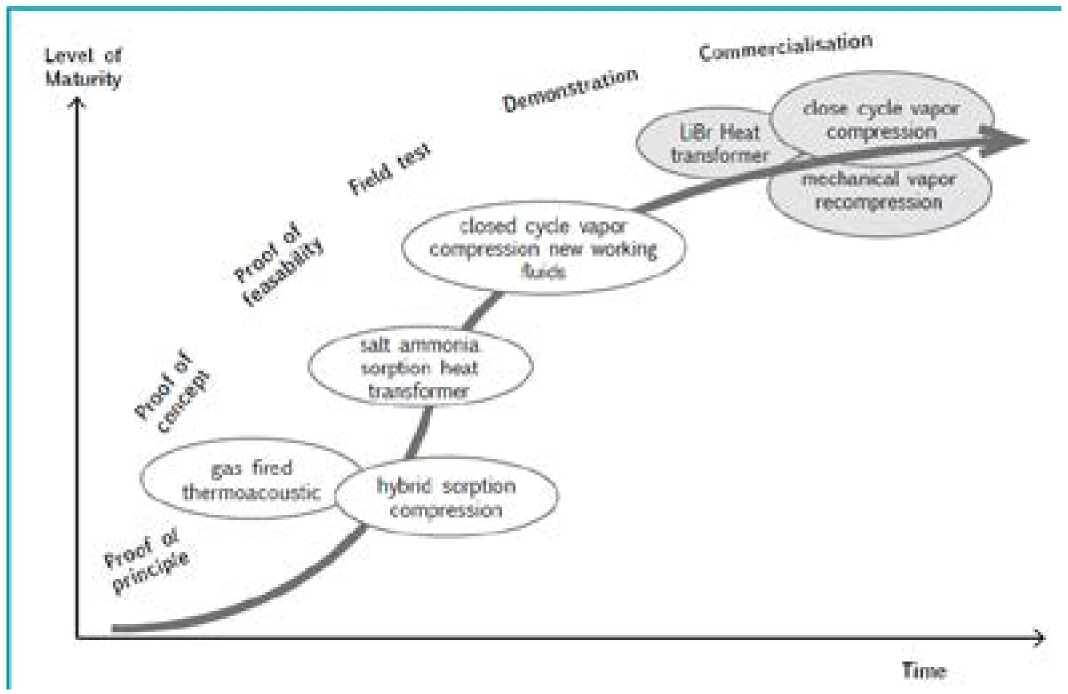


Fig 3.2 Development stages of new concepts for industrial heat pumps(source RHC-Platform).

In their advise to the Commission the RHC Platform [14] have proposed:

	Research and Innovation Priorities	Predominant type of activity	Impact
CCT.12	Enhanced industrial compression heat pumps	Development	By 2020
CCT.13	Process integration, optimisation and control of industrial heat pumps	Demonstration	By 2020
CCT.14	Improvements in Underground Thermal Energy Storage (UTES)	Demonstration	By 2020
CCT.15	Improvement of sorption cooling from renewable energy sources	Development	By 2025
CCT.16	New concepts for industrial heat pumps	Research	By 2030

CCT.12	Enhanced industrial compression heat pumps
Objective	Development of advanced compression refrigeration cycles based on novel working fluids for use in medium temperature industrial applications (condensation temperatures up to 150 °C and evaporation temperatures up to 100 °C). Applications of these novel heat pumps include process heat generation as well as waste heat recovery in industrial processes yielding substantial increases in energy efficiency. R&D topics to be addressed in this context comprise: · new working media (low GWP, non-inflammable) or natural refrigerants (water), · improved compressors and lubrication methods for high evaporating temperatures (up to 100°C), · heat exchangers with improved design for direct using of condensing gases (flue gas, exhaust air, drying processes, etc.).
State-of-the-art	Current vapour compression systems deliver heat at a maximum temperature of ~80 °C
Targets	· Carnot efficiency of at least 0.35 · At least 2 demonstration projects should be realised by 2020. · Condensation temperatures up to 150°C · Temperature lift up to 60 K · Energy saving up to 30% · Cost target heat pump unit: 200 to 300 Euro/kW
Type of activity	20% Research / 60% Development / 20% Demonstration

CCT.13	Process integration, optimisation and control of industrial heat pumps
Objective	Development and demonstration of electrically and thermally driven heat pumps in individual industrial applications as well as in combination with district heating and cooling networks including thermal energy storage. R&D topics to be addressed comprise: · classification of processes (temperature levels, time-based energy demand, etc.), · process integration of industrial heat pumps (control and hydraulic design), · impact of heat pumps on existing process (dynamic behaviour), · selection of components (refrigerant, compressor, heat exchangers etc.) for the process identified,
State-of-the-art	First prototypes of compression heat pumps with evaporation temperatures of up to 40°C and condensation temperatures of up to 80°C are available but still need to be demonstrated. First prototypes of absorption heat pumps using new working pairs without crystallisation effects are available, but not demonstrated yet in real-life operating conditions.
Targets	· 5 lighthouse projects with a capacity of minimum 1 MWth implemented by 2020 · Compression heat pump: minim sCOP of 5, energy savings of at least 30% · Absorption heat pump: minimum sCOP of 1.5; energy savings of at least 50% · Cost target on system level for electrically driven heat pumps (unit plus installation): 400 to 500 Euro/kW
Type of activity	30% Development / 70% Demonstration

CCT.16	New concepts for industrial heat pumps
Objective	A broader range of operating temperatures and higher temperature lifts are needed to increase the application potential and the energy saving potential that heat pumps offer. The end users' demands extend beyond the required temperature and cost of the system to topics such as the toxicity & flammability of the working medium and the reliability of the system. No single heat pump technology can cover this entire range of demands, meaning different heat pump technologies should be developed in parallel. The main objective is the exploration of alternative thermodynamic cycles for heat-pumping and heat transforming for different industrial applications, with the goal to increase the operating window of industrial heat pumps so that they can deliver heat at medium pressure steam levels (app. 200°C). Not only will these improvements allow larger energy savings, but they will also unlock the benefits of economies of scale for the European heat pump industry.
State-of-the-art	The efficiency of any heat pump system increases as the temperature difference, or "lift", decreases between heat source and destination. Efficiently providing heat for industry at temperatures higher than 90°C with heat pumps is difficult. Industrial heat pumps (for heating purposes) currently consist of closed cycle vapour compression, open cycle mechanical vapour recompression and Lithium Bromide (LiBr) heat transformers.
Targets	· Delivery temperature up to 200°C · Temperature lift ≥ 70 K · Energy output compared to current technology ≥ 20%
Type of activity	70% Research / 30% Development

3.3 | Technological developments

Before 2005, heat pumps were merely refrigeration plants where pressures are increased to deliver condensing heat at temperatures of 35°C up to 50°C. This operation range also depends on the evaporation temperature, efficiency and pressure ratio. The refrigeration compressors have a design pressure of 25 bar. This is also a limit for higher condensing temperatures. The large manufacturers of industrial refrigeration in the Netherlands, i.e. GEA Grenco with its seat in Den Bosch and IBK from Houten, have discovered this new market of high temperature applications and already executed projects (see factsheets in chapter 4). A large application potential of industrial heat pumps is still not used because of these 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 [15].

3.3.1 | CO_2 – Heat Pump

Since 2000 the refrigeration industry has been introducing CO_2 again as refrigerant and secondary refrigerant. CO_2 is a natural refrigerant without ozone depletion potential and with a low global warming potential. It is therefore a sustainable alternative for the synthetic refrigerants such as the HFC types.
Since CO_2 is a high pressure refrigerant, the refrigeration industry had to develop equipment with design pressures up to 45 bar. It is this development that has led to the construction of 50 bar industrial compressors. Using these compressors with ammonia or HFC like R134a as refrigerant, high temperature heat pumps (HT heat pumps) can be produced for industrial purposes. Condensation heat at temperatures up to 80°C can be delivered in a large variation of capacities with good efficiency.
HT heat pumps are also executed with CO_2 as refrigerant in a transcritical cycle. Larger units for water heating from 10° up to 70°C are available in a range up to 120 kW running with any heat source, and can even produce cooled water (8°C). Essential is that the CO_2 at condensing pressure can be strongly cooled in order to maintain a sufficient efficiency. This is possible by a process flow that starts to heat up at e.g. 15°C. The COP of CO_2 can be higher than ammonia in case of high temperatures differences. Compressor sizes for these high pressures are however limited available.

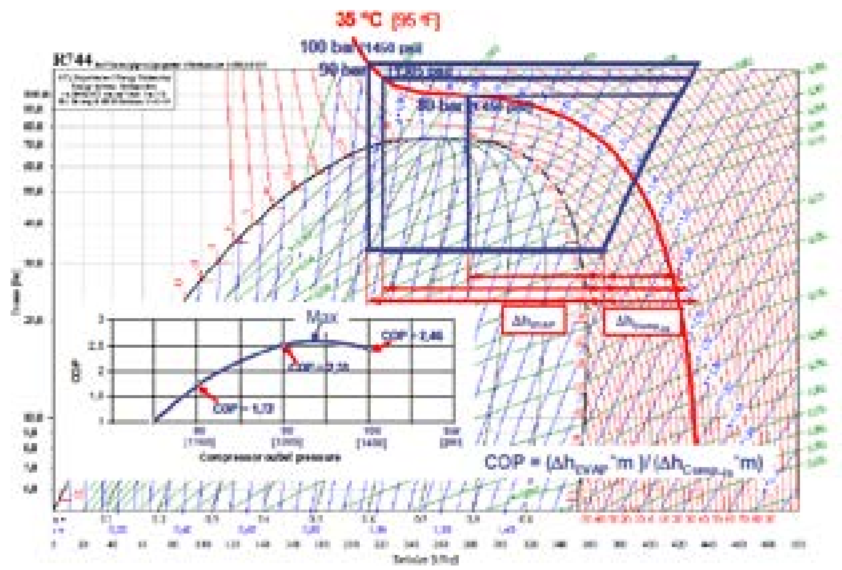


Fig. 3.3 - Efficiency of the CO_2 heat pump cycle, depending upon the discharge pressure [source HPC]

3.3.2 | n-Butane heat pump

With the search for natural refrigerants for heat pumps, the refrigerant n-butane is regarded as a proper medium in high temperature heat pumps with condensing temperatures up to 120°C. These temperatures can be reached in standard 25 bar compressors. This type of HT heat pump is based on conventional, reliable refrigeration design with special safety attention and features for safety. Several feasibility studies have been carried out in industry and refrigeration contractors nowadays offer the HT heat pumps.
The feasibility studies show the technical and economical implications that arise when integrating the n-butane heat pump in an existing installation. To integrate a heat pump, it is necessary to redesign the original process and thus the equipment (heat exchangers, process layout). This should clearly be a task for manufacturers and suppliers of process equipment.

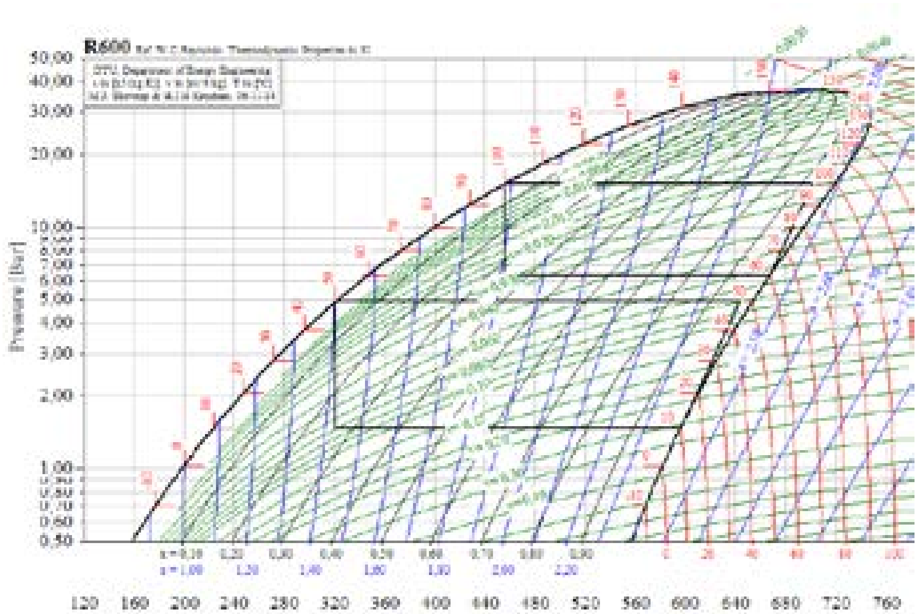


Fig 3.4 - n-Butane heat pump cycle (at 60/100°C: COP=7,1 and at10/50°C: COP=6,8) (source GEA-Grenco)

As can be seen in figure 3, the n-butane gas is compressed in the gas-liquid area of the n-butane Mollier (log p-h) diagram. Therefore it is necessary to preheat the suction gasses before they enter the compressor. This can be executed in heat exchangers that simultaneously heat up the suction gas and cool down the liquid after condensation. This is a regular design aspect in refrigeration installations.

3.3.3 | New refrigerants

An interesting paper is presented at the 11th Heat Pump Conference in Montreal 2014 [14], where it is stated that an ideal working fluid should be non-flammable, non-toxic and should have a low GWP, no ODP and a high critical temperature. Four ideal working fluids are identified: LG6, MF2, R1233zd and R1336mzz.

Working fluid	T_{crit} [°C]	Flammable or toxic	ODP	GWP
R1233zd	166	no	0.0003	6
R1336mzz	171	no	0	9
LG6	>165	no	0	1
MF2	>145	no	0	<10

Table 3.2: Properties of ideal working fluids for high temperature use [14]

Important producers of these new working fluids with high condensation temperatures and low GWP are Honeywell, Siemens en Dupont. First pilots are reported of.
Interesting is the development of LG6 by Siemens, showing a temperature lift of 50K with an experimental COP of 4.8.

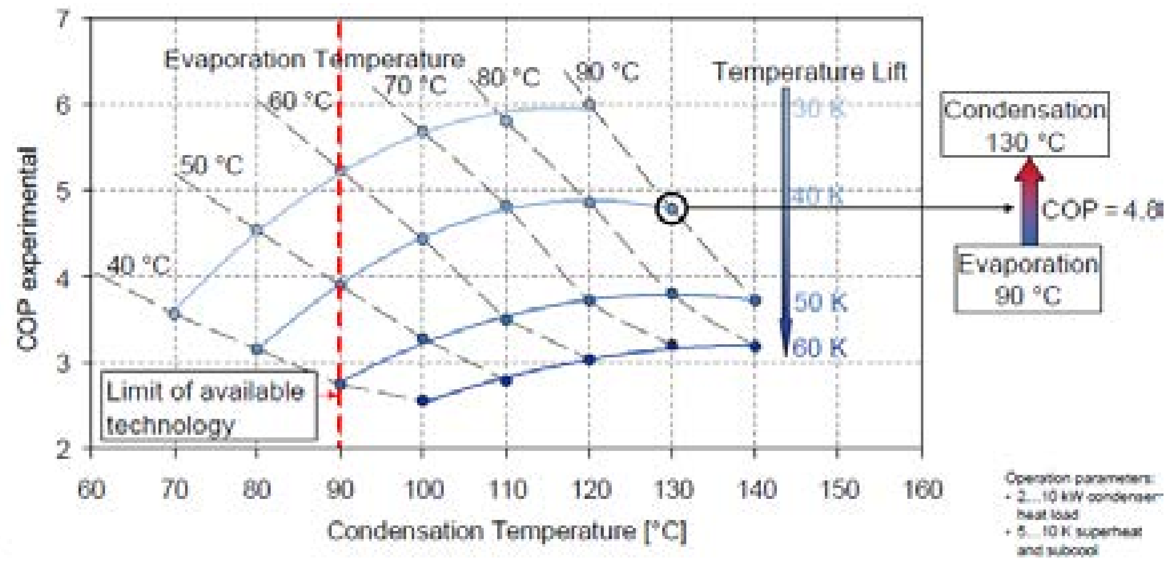


Fig. 3.5 LG6 Siemens

DR-2 of Dupont even claims better results

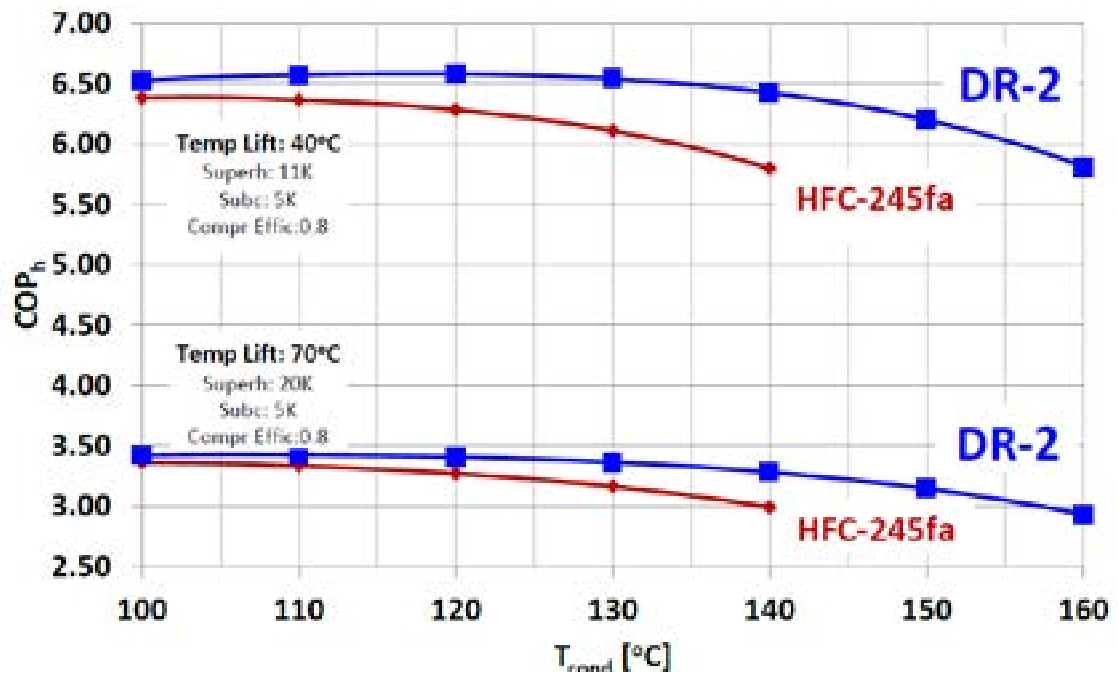


Fig. 3.6 DR-2 Dupont

Solstice™ L41 from Honeywel is based upon R32 as an alternative for R410a and has already been used by several heat pump manufacturers, the largest application being by Friotherm in the district heating heat pump in Drammen (Oslo). R1234yf wiil be applied by ETP in Netherlands.

R-410A Alternatives

Refrigerant Supplier	Designation	Composition	(Mass%)	GWP	ASHRAE Class	Thermo Performance* Capacity	Thermo Performance* Efficiency
Arkema	ARM-70a	R-32/R-134a/R-1234yf	(50/10/40)	482	A2L	-15%	3%
Daikin	D2Y-60	R-32/R-1234yf	(40/60)	272	A2L	-20%	2%
DuPont	DR-5	R-32/R-1234yf	(72.5/27.5)	490	A2L	0%	1%
Honeywell	L-41a	R-32/R-1234yf/R-1234ze(E)	(73/15/12)	494	A2L	-6%	2%
Honeywell	L-41b	R-32/R-1234ze(E)	(73/27)	494	A2L	-9%	2%
Mexichem	HPR1D	R-32/R-744/R-1234ze(E)	(60/6/34)	407	A2L	-1%	0%
Daikin/National	R-32	R-32	(100)	675	A2L	8%	1%
National	R-32/R-134a	R-32/R-134a	(95/5)	713	A2L	5%	1%
National	R-32/R-152a	R-32/R-152a	(95/5)	647	A2L	3%	1%

* Relative to R-410A 4C ET / 38C CT

3.4 | Running R&D Projects

An analysis was made of distillation heat pump potential in the Netherlands, leaving out columns that do not cross the pinch and oil refinery columns. The data show that the total heat pump potential is in the order of 2.4 GW and that the average temperature lift over the column is 59^{0}C.
Conventional heat pump cycles are driven by compressors or blowers depending on the required volumetric capacity and pressure ratio or temperature lift. The economic range for the VRC configuration driven by a compression heat pump is limited to columns with a temperature difference of about 30^{0}C. The heat pump that has to meet this requirements has to operate in a temperature window of 100 to 250ºC. The required temperature lift should be in the order of 50-100ºC. The heat pumps that are available nowadays are not able to fulfill both requirements.
New developments in distillation heat pump technology are therefore aimed at novel heat pumps with a higher economic range and at new heat integrated configurations. In the Netherlands these developments are:

- Thermo Acoustic Heat Pump at ECN
- Compression Resorption Heat Pump at TU Delft
- Adsorption Heat Pump
- Heat Integrated Distillation Columns at TU Delft

3.4.1 | Thermo Acoustic Heat Pump

In order to upgrade waste heat to process heat, a heat pump is required that can generate a temperature lift of 50-100ºC. A thermoacoustic (TA) system is capable of doing this.
A very powerful acoustic wave is needed in order to drive a TA-heat pump. The required acoustic energy can be generated in several ways. ECN is concentrating on TA-engines that use a heat source to create the acoustic wave. Two situations can be distinguished:
The waste heat temperature is high enough to drive a TA-engine.

- The required temperature is at least 120ºC.
- The TA-engine is driven by a high temperature source like an electrical heater or a burner

An electrically driven Thermo Accoustic (TA) heat pump consists of a linear motor that generates an acoustic wave, a resonator that together with the working gas (usually helium) determines the resonance frequency and houses all equipment and two heat exchangers on both sides of the porous regenerator.

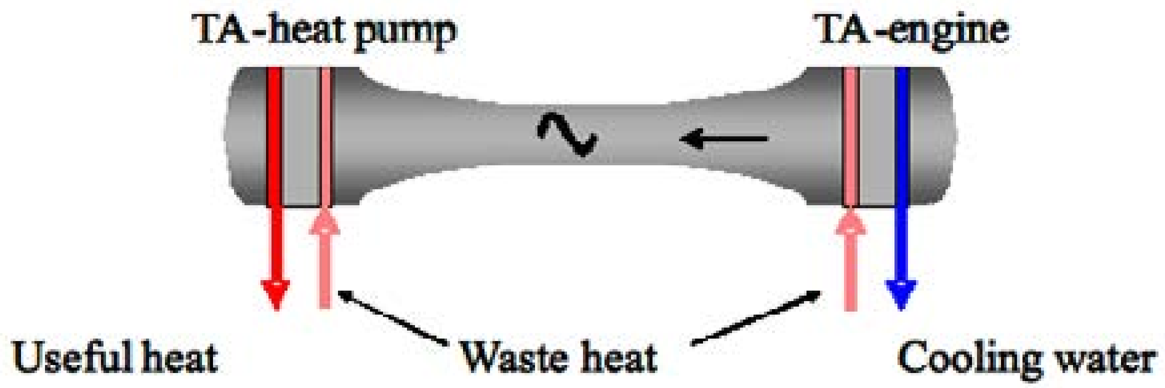


Fig. 3.7 TA principle

The acoustic energy is subsequently being used in a TA-heat pump to upgrade waste heat to usable process heat at the required temperature. The TA-engine is located at the right side and generates acoustic power from a stream of waste heat stream at a temperature of 140ºC. The acoustic power flows through the resonator to the TA-heat pump. Waste heat of 140ºC is upgraded to 180ºC in this component. The total system can be generally applied into the existing utility system at an industrial site.
The goal of the ECN activities is to develop this technology in order to upgrade industrial waste heat to usable process heat in a cost effective way. The objective is to upgrade about 20% of the waste heat that is presently being released to the ambient atmosphere. The energy saving potential using this technology within the Netherlands amounts to about 5 PJ.
The present activities are carried out on a scale of 1-5 kW. In the longer term the expected size will be about 1 MW. The picture below gives an impression of such a system.
TA-systems use sound waves to pump heat. These systems are very flexible with respect to operating temperature compared to conventional systems. In addition, high temperature lifts can be generated. TA-heat pumps are developed that can upgrade a wide variety of waste heat sources to useable process heat.
Currently, the following applications are envisaged and are part of this program:

- Waste heat driven thermoacoustic heat transformer

This system consists of a waste heat driven thermoacoustic engine, operating between waste heat temperature and ambient temperature, generating acoustic power for a ther-

moacoustic heat pump, operating between waste heat temperature and process heat temperature.
The final requirements for this application are:
- Driven by waste heat in the temperature range 100 - 200°C;
- Delivering process heat in the temperature range 150 - 250°C, with process heat temperature at least 50°C higher than the waste heat temperature;
- System efficiency (process heat out/waste heat in) in the order of 20%, depending on operating temperatures;

Lab-scale experiments and modeling have proven that the required conversion efficiencies can be achieved. ECN reached a world record efficiency on the conversion of heat into acoustic power. Business cases in cooperation with end users industrial end-users from the chemical & refining industry showed positive results. Up scaling to bench-scale level is now taking place in cooperation with two Dutch equipment manufacturers.

Fig. 3.8 High-temperature heat driven thermoacoustic heat pump

This system consists of a high-temperature driven thermoacoustic engine, operating between a burner or high-temperature flue gasses and process heat temperature, generating acoustic power for a thermoacoustic heat pump, operating between waste heat temperature and process heat temperature.

The final requirements for this application are:
- Driven by high-temperature heat in the temperature range (> 200°C);
- Being able to deliver process heat at a temperature level at least 50°C higher than the waste heat temperature;
- Coefficient of Performance (COP) (process heat out/high-temperature heat in) in the order of 1.4, depending on operating temperatures

Fig. 3.9 Linear motor driven thermoacoustic heat pump

This system consists of an electrically driven linear motor that generates acoustic power for a thermoacoustic heat pump, operating between waste heat temperature and process heat temperature.
The final requirements for this application are:
- Efficient linear motor (> 85%) for the conversion of electrical power into acoustic power;
- Being able to deliver process heat at a temperature level at least 50°C higher than the waste heat temperature;
- Coefficient of Performance (COP) (process heat out/electrical power in) in the order of 3.5, depending on operating temperatures.

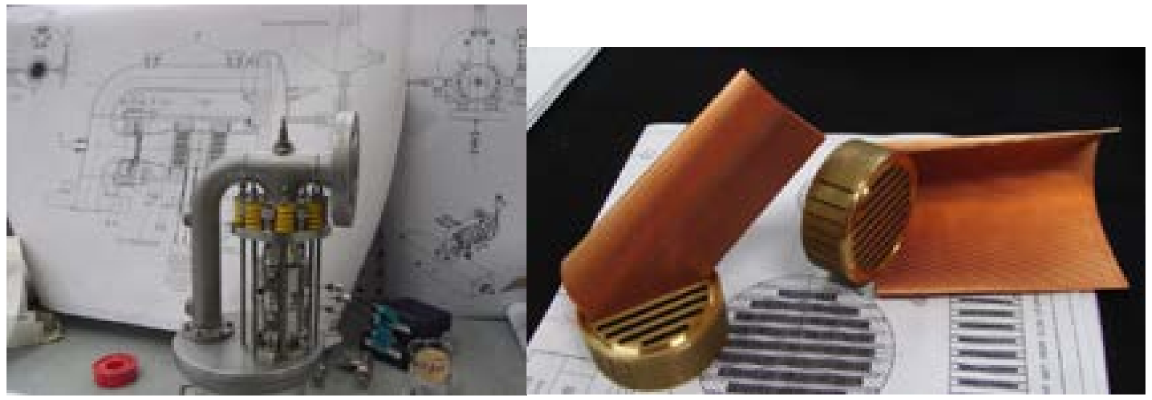


Fig. 3.10 Component design

3.4.2 | Upgrading industrial waste heat with a thermochemical heat pump

A heat pump with a temperature lift of 50-100ºC is necessary in order to upgrade industrial waste heat. A thermochemical heat pump is theoretically able to do this. There are two applications in this field.
- Generic upgrading of industrial waste heat to a general utility like medium pressure steam.
- Process specific upgrading of waste heat across the pinch temperature.

The system operates at three temperature levels for both applications. These temperature levels are the waste heat temperature, the ambient temperature and the temperature of the upgraded heat. The system consists of two reactors, each containing a different salt. For this specific system lithium chloride is used as low temperature salt (LTS) and magnesium chloride as high temperature salt (HTS). Ammonia vapour is exchanged between these two salts. Industrial waste heat is used to free the ammonia from the LTS. The ammonia flows, driven by the pressure difference between the two reactors, to the HTS and reacts with the HTS. This exothermic reaction delivers heat at high temperature. During

the regeneration step, the ambient temperature cools the LTS and the waste heat heats the HTS. The ammonia vapour flows back to the LTS under these conditions. The scheme below shows the implementation of such a system in an industrial process. Both the LTS and HTS reactor vessel are build in twofold in order to achieve a continuous system. A switching control system determines whether the above pair of reactor vessels are loading (regenerating) or discharging. The other vessels are running in the reverse process.
The goal of the present activities is to obtain the most efficient thermo-chemical reactions by increasing our knowledge on the thermodynamics and kinetics of the individual reactions as well as optimisation of heat and mass transfer in the salt/vapour reactors. In the first few years' period, the technical performance of a system with a thermal power of 1-5 kW will be proven, after which it will be scaled up to about 100 kW. On the long term, field tests with a 1 MW system are foreseen.

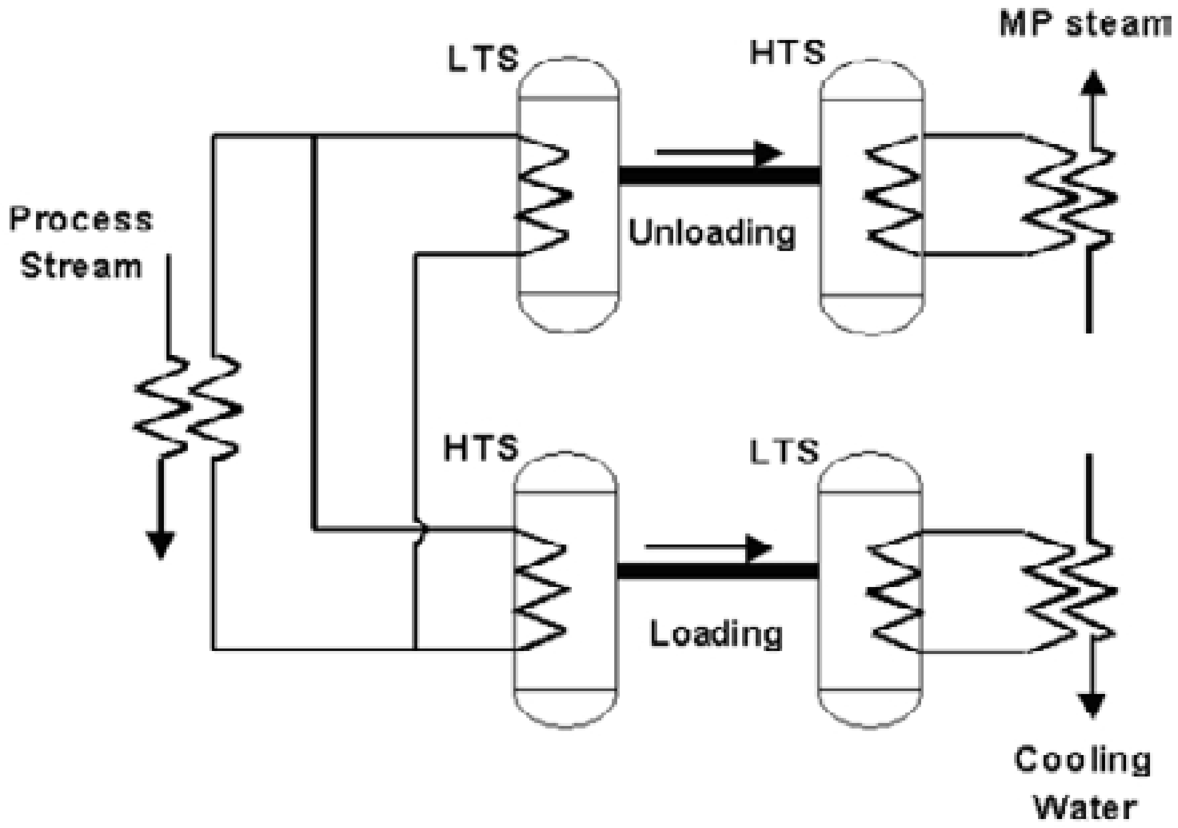


Fig. 3.11 Thermochemical heat pump system

TC-systems are based on solid-vapour reactions and are able to operate at higher temperatures and provide higher temperature lifts than conventional systems. In addition, they offer intrinsic heat storage capabilities. TC-heat pumps are developed that use (industrial) waste heat (80-140°C) to generate either process heat or cooling. In addition, compact long-term TC heat storage technology is developed.

- Waste heat driven thermochemical heat pump

This system consists of two reactors containing different ammonia salts. One reactor operates between waste heat temperature and ambient temperature and generates the driving force for the other reactor, operating between waste heat temperature and process heat temperature.

The final requirements for this application are:

- Driven by waste heat in the temperature range 100 - 200°C;
- Delivering process heat in the temperature range 150 - 250°C, with process heat temperature at least 50°C higher than the waste heat temperature;
- System efficiency (process heat out/waste heat in) in the order of 25%, depending on operating temperatures.

Fig. 3.12 Thermochemical heat pump component testing

In the early stages of development, cooperation with universities was established to develop and characterize TC materials. Nowadays, the focus is on reactor & system development in cooperation with Dutch equipment manufacturers. Lab-scale experiments have shown that the required operating temperature and temperature lift can be achieved. Business cases have been evaluated with industrial end-users from the chemical & refining industry, which show positive economic results. An important requirement is the power density, which is the main challenge.

- Hybrid thermochemical-compression heat pump

This system is an extension of a regular thermochemical heat pump. The extension consists of a compressor that adds flexibility to the system with respect to operating temperatures, and more important, enables to use of lower temperature waste heat than the system without compressor.
The final requirements for this application are:

- Driven by a compressor and waste heat in the temperature range 50 - 150°C;
- Delivering process heat in the temperature range up to 250°C, with process heat temperature at least 50°C higher than the waste heat temperature;
- System efficiency (process heat out/waste heat in) >25%, depending on operating temperatures, (average) Electrical COP > 5.

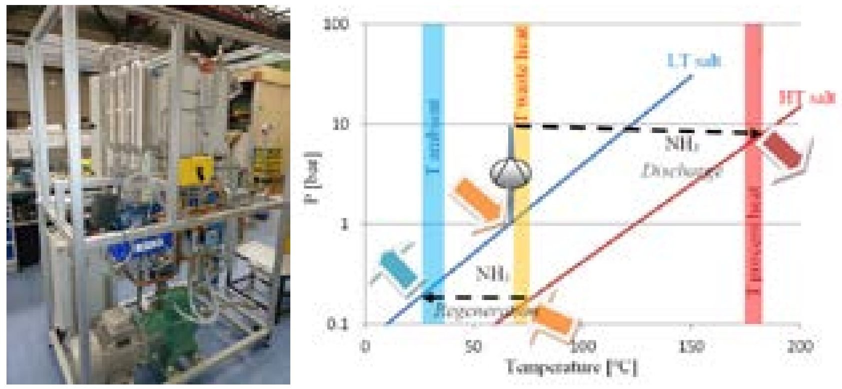


Fig. 3.13 Hybrid Thermochemical-compression heat pump testing

3.4.3 | Compression Resorption Heat Pump

Compression Resorption heat pumps have the potential to add significant contributions to the improvement of the energy performance of heating processes. Specifically for industrial heating processes, they allow for energy performance gains of more than 20% when compared with vapor compression heat pumps. Ammonia-water high temperature heat pumps that are used to upgrade industrial waste heat show a number of advantages. ¨ High temperature operation is possible at relatively low operating pressures.
The R&D on this project is executed at the Technical University of Delft.
Until now the top and bottom product were considered as pure compounds with fixed condensation temperatures at the operating pressure. In reality, one or both products are often mixtures with a condensation trajectory between dew and bubble point; the glide. The temperature difference over the glide leads to an extra exergy loss over the heat exchanger, unless the working fluid has the same glide.

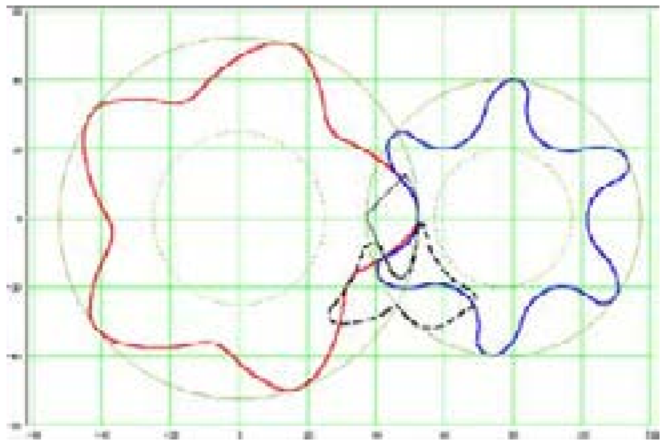


Fig. 3.14

This principle is applied in the Compression Resorption (CR) heat pump. In the CR heat pump, the working fluid is a zeotropic mixture, usually ammonia-water. The composition of this mixture is adjusted until the glide of the working fluid optimally matches the glide at the condenser or the reboiler. The cycle can be designed to show a temperature glide in the resorber that corresponds the temperature glide of the industrial waste flow that has to be heated. For specific operating conditions the cycle performance is significantly better than for the vapor compression cycle. The main problem of the cycle is the compressor that has to be suitable for oil-free wet compression and still show acceptable isentropic efficiencies. These compressors must be suitable for high compression ratios and for simultaneously compress vapor and increase the liquid pressure. Besides, the compressor should not be sensible to liquid carry over.
The main goal is the development of a compressor that is suitable for operation in compression resorption heat pumps. For high temperature industrial heat pumps, a gain of about 20% in comparison with “conventional” vapor compressor heat pumps can be attained if this type of cycle is used. Limitation of this cycle is the wet compressor need. To reach this goal both theoretical and experimental works have to be developed.

Fig. 3.15

3.4.4 | Adsorption Heat Pump

In an adsorption heat pump, waste heat is upgraded in a cycle based on adsorption and desorption of a working fluid onto a low-temperature salt (LTS) and a high-temperature salt (HTS).
The adsorption heat pump is essentially a heat transformer with four adsorption columns where waste heat is upgraded to the temperature above the pinch required for the reboiler by adsorption of NH^3 onto the high-temperature salt $MgCl^2.2NH^3$.
The heat balance shows that for most distillation columns an adsorption heat pump will need an additional heat source.

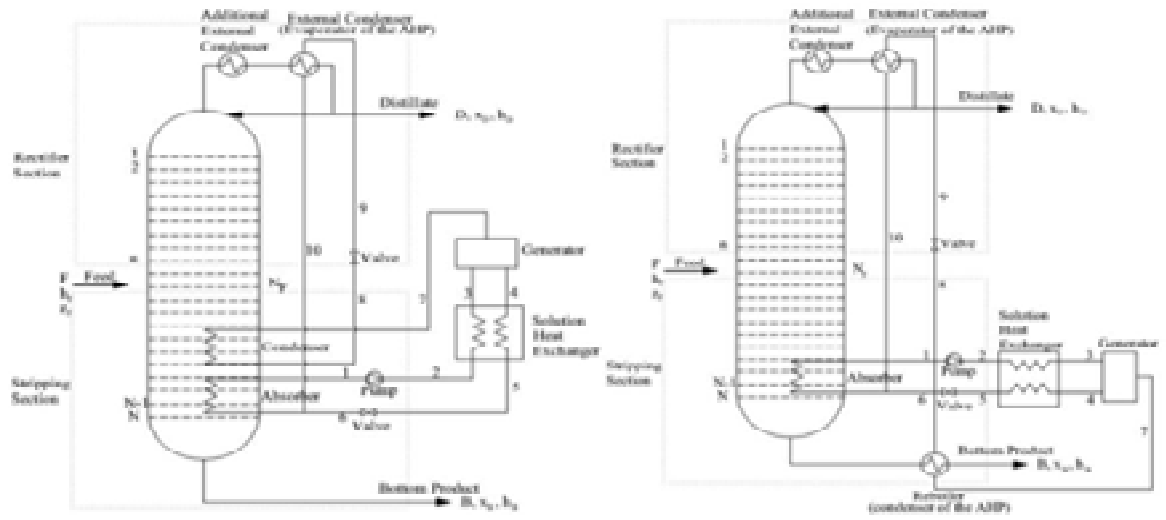


Fig. 3.16

3.4.5 | Minichannel heat exchangers for compression resorption heat pumps

Current separation processes within chemical and refining industry consume large amounts of energy. Increasing rising energy costs demand improvement of energy efficiencies. Significant reductions in energy consumption are expected by using innovative heat pump concepts for removal and supply of heat from/to a separation process. The research should lead to a fully integrated system consisting of traditional distillation and novel heat pump technology.

The amount of heat transferred will be determined by measuring mass flow, temperature and pressure at in- and outlets of a mini channel test section. From this data and the use of a fluid properties library, heat and mass transfer coefficients can be determined. Also the pressure drop can be measured.
Goals of the project are achieving high heat transfer rates and large surface area to volume ratios. This should lead to reduced investment cost and an optimized heat pump system.

Fig. 3.17 Mini channel test setup 4 diameters from 0.5 to 2mm, 5 lengths each one 6mm tube as a reference

3.5 |

Heat Integrated Distillation Columns

A large part of the work is undertaken by TU Delft and partially published in a paper for the 10th Heat Pump Conference in Tokyo. It concerns the integration of heat pump technology in a distillation column.

In certain cases it is possible to split the process into two parts. An example is a distillation column where the rectifier and stripping section can be split from each other and exchange heat. In order to exchange heat the rectification section has to work at a higher temperature and therefore higher pressure than the stripping section. This is reached by placing a compressor between the top of the stripping section and an expansion valve at the bottom of the rectification section. Possible advantage compared to compression-resorption heat pumps is the lack of one temperature driving force. The operating principle of a HIDiC is shown in figure 3.18.

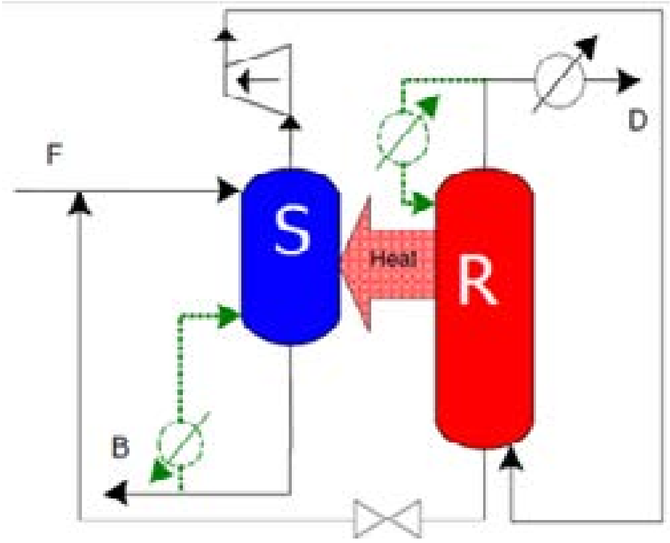


Fig. 3.18

Vapour from the top of the stripping section is compressed and directed to the rectifier. In the rectifier the vapour condenses, creating an internal reflux that is returned to the top of the stripper. The heat of condensation is used to evaporate the liquid at the stripper side. Usually the reboiler duty can be close to zero and a small external reflux is required at the top of the rectifier, in order to produce the required distillate purity.

Optimization of the pressure ratio for a constant separation task is based on the balance between the compressor power cost and investment cost for the compressor and HIDiC column. The HIDiC configuration can reduce the utility cost compared with the VRC with an additional 25-35% and the total annualized cost with 10-20%.

Future developments

A simulation study on the existing plant was undertaken by the Delft University of Technology [34] focusing on enhancing thermodynamic efficiency of energy intensive distillation columns by internal heat integration. In the simulation study, taking propylene/propane splitter as base case, an internally heat integrated distillation column (HIDiC) offers significant potential for energy saving compared to energy requirements associated with the operation of conventional and heat-pump assisted distillation columns. The rectification section, of a propylene/propane splitter contains usually two times more stages than the stripping section, implying a number of heat coupling possibilities, which appears to be strongly influencing the thermal efficiency of the HIDiC. The configuration with the stripping section stages thermally interconnected with the same number of stages in the upper part of the rectification section emerged as the most efficient configuration, allowing a reduction in energy use in the range 30 to 40 % compared with a state of the art heat-pump assisted column, depending on the trade-off between the operating compression ratio and the heat transfer area requirement, the latter one being the key limiting factor.

In general, a distinctive feature of HIDiC is the fact that it combines advantages of direct vapour recompression and adiabatic operation at a significantly reduced total column height and therefore may be considered as an example of a most compact, and with respect to thermal energy conservation potential, an ultimate design of a distillation column.

TASK 4

EXAMPLE PROJECTS AND CASE STUDIES

4. EXAMPLE PROJECTS AND CASE STUDIES – TASK 4

4.1 | Example projects in Netherlands

Developing and dissemination of knowledge is important for a successful growth of the application of heat pumps. To stimulate the application of heat pumps, it is useful to analyze heat pumps which have been placed in the past and analyse how they operate in practice. In this study the operation of these “older” heat pumps is analyzed. The research has been performed through contacts by phone and e-mail. In this study an inventory was made about the experiences of the companies, whether there has been any changes of the design over time, whether operating & maintenance of the installation is difficult (high level of knowledge, complexity, etc.), whether promised energy savings have been achieved and whether there are remarks that can be defined as lessons learned.

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

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

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

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

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

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

When the heat pumps are still in use, the companies lack insight into the reasons for which there ever was chosen for the heat pump, given the long period since the investment decision. The heat pumps which are still in use are generally still running in their original design. They are running relatively many hours a year (5000-8000), usually at full load. In several cases the maintenance is outsourced for reasons of complexity, high operating hours and capacity problems in the technical department. Operating the installation is generally regarded as a relatively simple. The installations have few problems and / or malfunctions. Companies have no insight on whether the system achieves its efficiency, or whether the intended energy savings have been obtained. They have no reference, given the initial situation is so far in the past. Below are a couple of remarks which have emerged from this study. They should be taken into account for the application of heat pump technologies.

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

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

4.1.1 | Chemical industry

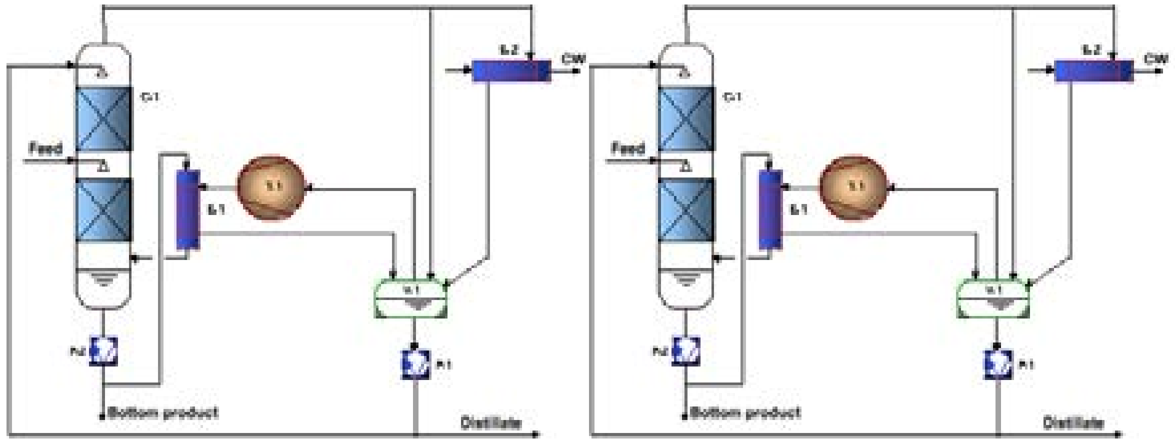
Distillation is by far the most widely practised technique for separating mixtures in the chemical and petrochemical industry. Distillation columns are in many chemical plants the largest energy consumers. In a conventionally operated distillation plant, energy is used to heat in the reboiler and about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

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

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

boiler house can be avoided.
Heat pump systems can be implemented for new distillation units, as well as for revamp of existing plants.
In the process of direct vapor recompression (see Fig.1) the pressure of the vapor leaving at the top of column (C-1) is elevated in a compressor (T-1). This raises the dew point of the vapor, after which it can be condensed in the reboiler (E-1). There are, however, applications where the medium in the column, and thus the vapor from the column top, is not suitable for compression (due to, for example, polymerization and corrosion). In these cases an additional, separate working fluid like water can be selected (see Fig.2). The water is evaporated in the condenser (E-2) of the column (C-1), the generated steam will be compressed in a compressor (T1) and condensed in the reboiler (E-3). The water condensate is circulated back through a throttle valve into the condenser, where it will be evaporated again.

Fig. 1. Typical scheme of distillation with direct vapor recompression. Fig. 2. Typical scheme of distillation with an indirect heat pump.



Practical application criteria are given in Appendix 2, where also six cases are described [16].
Three example projects are discussed. A fourth large example project which was already published in a paper in 1995 did not get the allowance to be published as according to the new mangement there was too much confidential and competitive process information in the sheet.

NL-01 - MVR for chemical process at PP-splitter for Shell in Pernis
At Shell Nederland Chemie on the location at Pernis (NL) products such as cleansers, solvents, fibres, resins and polymers are produced. These products are manufactured from raw materials produced in the refinery on the same site. Propylene is a key material in the production of a number of chemical products, including polypropylene (PP) and solvents. It is obtained by distillation separation of propylene and propane in a so called PP-splitter column. In a conventional distillation the reboiler is heated by low pressure steam and the overheated vapours are cooled with cooling water.
In 1995, as a part of the modernisation of the complete propylene distribution system within the Shell site at Pernis, a new propylene-propane distillation column was built with the application of mechanical vapour recompression (MVR), built by Mannesmann Demag AG. This was done to save energy, reduce the use of cooling water and increase the yield of the distillation.
The heat pump as described is still running in line with the original design, at 8650 hours per year at fixed speed. Maintenance is done by an external party as specific knowledge is required.

NL-02 - Croda in Gouda
Croda is produces special oleochemicals and derivates for a broad market of applications. In the separtion process for oleïne and stearine, an MVR heat pump is used since 1994. The heat pump as decribed in the factsheet is still running to the design at 90% full load for 8000 hours/year.
Maintenance and service is contracted as a high level of expertise, not present at Croda, is needed. Once a year the process is stopped for that overhaul. At most of these occassions, only cleaning of the system is needed and no parts are broken down or have to be replaced.

NL-03 Hoechst Vlissingen
Since 1982 three steam recompression systems have been in operation at the Hoechst production plant in Vlissingen. The heat pumps are a part of the process for the production of dimethyl-terephthalate (DMT). With the application of steam recompression, steam pressure is increased from 1.14 bara to 3 bara, which can be used in the low pressure steam system. The main goals for the application have been cost reduction and the possibility to work with a smaller steam production plant. Due to the recline in the PMT market worldwide, the Hoechst plant was closed in 2007.

4.1.2 | Food industry

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

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

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

NL-04 Campina in Veghel
FrieslandCampina DMV in Veghel installed an energy-efficient evaporator that is unique in its kind. It evaporates water from whey, allowing the lactose to crystallise spontaneously. By using smart technology, the current combination of mechanical and thermal evaporati-

on techniques can be replaced by a single mechanical technique to cut energy consumption by an additional 60%. The heat released using this new technique is used so efficiently that cooling water is no longer needed. The discharged condensate is cooled until it reaches a temperature of 15°C. Approximately 35 technicians work on the installation. The new evaporator has become fully operational in October 2013. The construction and installation of the new evaporator is part of an extensive capital expenditure programme at Veghel, in which FrieslandCampina invests over 60 million euros. The knowledge gained in developing this evaporator will also be put to use in future projects where there are similar cost savings can be achieved.

NL-05 De Graafstroom
In Bleskensgraaf, the Cheese & Butter group produces and sells semi-hard Gouda cheeses in a number of varieties (Campina Holland Cheese) which is produced in Bleskensgraaf. Since 1992, Campina has supported the Dutch Long-Term Energy Efficiency Agreements for Industry (LTA-1 and LTA 2) covenants between the private sector and the government to realise the goals of (inter)national climate policy.

NL-06 McCain

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

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

UK-01 Wiseman Dairies
The company of Robert Wiseman in the UK was confronted by the choice of replacing the refrigerant R22 by a more environmentally friendly solution, or of investing in a completely new plant based on ammonia as refrigerant. Although planning revealed that an ammonia plant would operate more efficiently, the customer initially did not accept this solution due to the long amortization period. Yet, in the end, GEA Refrigeration Technologies made an investment so attractive by an add-on, in the form of a heat pump, that Wiseman could not resist. The new system allows using the heat emitted by the refrigeration plant to be used for pasteurization of the milk – and the entire plant will now amortize itself in less than two years (Source Grenco).

NL-08 Blue Band margarine factory Unilever Rotterdam

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

NL-09 Thermal vapour recompression heat pump at Heineken Den Bosch
Heineken Den Bosch has installed a heat pump in the wort boiling house during a renovation. The heat pump is a thermal vapour recompression (TVR) type placed on the wort boilers. The TVR is used to reduce the energy consumption of the wort boiling process. The heat pump started operation early 2005. The savings on gas consumption and CO_2 emission are considerable.

NL-11 Export Slachterij Apeldoorn (Slaughterhouse)
The slaughterhouse at ESA for veal requires large amounts of hot water for room and machinery cleaning and for removing hair from veal skin, and a smaller amount for sterile water (90°C). The heat pump has been installed in a slaughter house at a moment that the steam boiler had to be replaced. This created the opportunity to improve the hot water system efficiency. The heat pump is a 45 bar reciprocating compressor coupled to the high pressure side of a refrigeration plant with ammonia as refrigerant (see figure 1). The heat pump condenser heats up water up to 62,5°C. The installation is running more than one year now, with great satisfaction and reliability.

NL-12 GPS (Gecombineerde Pluimvee Slachterijen)
GPS in Nunspeet is a slaughterhous for poultry. The condensor heat from cooling and refrigeration is used for process and space heating. The heat pump as described is running

since 1994 with 3750 hours/year of operation, often in 65% partial load. Running the heat pump is simple, but maintenance is more complex and contracted out. There are no data available on the energy savings as there are no reference data.

NL-14 AVEBE Ter Apelkanaal
AVEBE is one of the largest potato starch producers in Europe, with a yearly output of 500,000 tons of starch. The waste water stream from the production process is evaporated to the stage of protamylasse. An overall of 2,475,000 tons of water is evaporated in the process per year. In this part of the process AVEBE already in 1990 invested in energy efficiency measures, where a mechanical vapour recompression heat pump was installed in the first phase of a three phase evaporator. The heat pump runs 5000 – 6000 hours/year largely in partial load of 65%.
Running is simple but servicing is contracted out. AVEBE estimates that the expected savings are largely achieved.

4.1.3 | Misceleneous

Under this heading, several industries are clustered that use various types of processes. Berendsen Textiel in Apeldoorn is an industrial washing plant for industrial cleaning cloths. The evaporation of watery sludge streams is done through a process of mechanical vapour recompression and has replaced a process of water treatment with reversed osmosis. The heat pump as described in the original factsheet and in its original design is stil in use and makes 6000 running hours per year. It is running at 50 – 100% partial load.

NL-15 Sophus Berendsen Textiel
Every week the heat pump is stopped to be able to clean the heat exchangers while once a year the heat exchangers are replaced by new ones. Maintenance is done by in-house technical service department, with the main attention at the heat exchangers and the composition of the waste water.

NL-18 SCM-TDC in Kampen
SCM was founded by the Van der Sluis family and was the first company of what has become the ITM Group . For most of its history, SCM traded in second-hand cigar machines. TDC originated in Switzerland and was taken over by the ITM Group in 1997. All activities of TDC were moved to ITM's home town of Kampen. SCM and TDC together have 60 employees. SCM and TDC share the same building in Kampen together with ITM Group's headquarter. The same building is home to the ITM spare parts centre . SCM maintains their stock of over 1000 used cigar manufacturing machines at GTS/SCM, S.A in the Dominican Republic. Through its long history in trading and upgrading cigar machines, SCM has vast experience with virtually any type of cigar manufacturing machine on the planet. Apart from trading in used and refurbished cigar machinery, SCM also develops its own high-speed cigar manufacturing production lines, for which parts are being built in various sites within the ITM Group. TDC builds machinery for roll-your-own and make-your-own products, as well as snuss and molasse. Being one of the pioneers in its field, TDC has established itself as a leading expert on tobacco products that do not fit in the cigar and cigarette domains.

NL-19 Brinks Metaalwaren
Brinks is specialist in drilling, milling, thermal deburring and cleaning in serial batches ranging from 500 to 200,000 units. Maximum unit weight is 20 Kgs. In the chain of production Brinks performs the role of process-supplier, with the specialism of multispindle CNC processing, thermal deburring (TEM) and the specifically custom-made cleansing of products.

NL-20 Icerink in Enschede
In October 2008 a new indoor skating rink was opened in the city of Enschede. The refrigeration plant for this skating rink was designed, delivered and installed by IBK. CO_2 was chosen as the secondary refrigerant. CO_2 is easily detectable, sustainable and - above all - very energy efficient, since less pumping energy is required and pipes with a smaller diameter can be used. The residual heat of the refrigeration plant is used for the Zamboni, for the CH block and for the unique floor heating system, which is located under the skating rink.

4.1.4 | Industrial areas

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

NL-23 Ecofactorij industrial area
Ecofactorij in Apeldoorn is an industrial business area south of the City of Apeldoorn. The local authorities have the policy to develop this area as sustainable as possibly by creating the right boundary conditions for settling new companies. This has been described in the “Kwaliteitsplan Ecofactorij” (Qualityplan Ecofactorij). By investing in sustainability and renewables, points are given with which rebates were given on the price of land.
Energy is within this sustainability approach an important topic as almost 40% of the point could be gained by investing in these. This has resulted in the fact that 80% of the companies and buildings are equiped with heat pumps and 20% with bio-pellet heating. As the business area is near the trafic junction A1/A50 in the middle of the country, logistic service providers like Sandds, Sils, Harbers and Grolleman Cold Store are settled at the Ecofactorij.

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

NL-24 Bakker Barendrecht – freezing store
A large distribution centre for fruit and vegetables requires a cooling capacity to maintain temperatures at 2ºC and 12ºC during the year. At the same time heat is required for ripening of bananas, defrosting of air coolers and water heating. Industrial heat pumps have been installed for cooling and simultaneously heating. The heat pumps increase the energy efficiency of the total plant and have reduced the investment costs for electricity supply equipment and heating installations.

NL-25 Bovendeert Shoes
The warehouse and headquarters of shoe store chain Bovendeert in Boxtel, contains, besides thousands of colourful shoeboxes and shoes, also an installation with highlighted technical features. Besides the accompaniment of an international automation standard type KNX to link an innovative and energy saving heat pump installation from LG Electronics on an advanced controlled electrical installation, a durable and comfortable installation concept arose.

4.1.5 | Agriculture

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

NL-27 Greenhouses

Since 1998, when the first idea were reported on the 'closed greenhouse' concept, several projects and experiments have been started. Some failed as there are different crops which have to be handled differently, but in the end the concept is now broadly accepted for most of the types of crops. All these applications are feasable because of the broad experience built up with ATES systems. Under NL-27 five examples are generally described. In the period 2003-2013, in Dutch horticulture approximately 40 growers of various crops have implemented heat pumps in their greenhouses. In the following, we present 5 fact-sheets concerning the application of heat pumps in Dutch horticulture for the production of roses, tomatoes and orchids.

4.2 | Integrated heat pump technologies

A very important part of the market is where suppliers of turn key unit operations integrate heat pumping technologies into their products to make them more energy efficient. GEA-Grenco is one of the best examples. They have there drying processes almost always equiped with MVR type of heat pumps [4]. Sulzer Chemtec from Winterthur does the same for their distillation columns.

Smaller companies in the Netherlands less prominent in the market do the same. Examples are Reinders Droogtech, applying heat pumping technologies integrated in many of their dryers, and Rhima integrate heat pumps in their crate wash units.

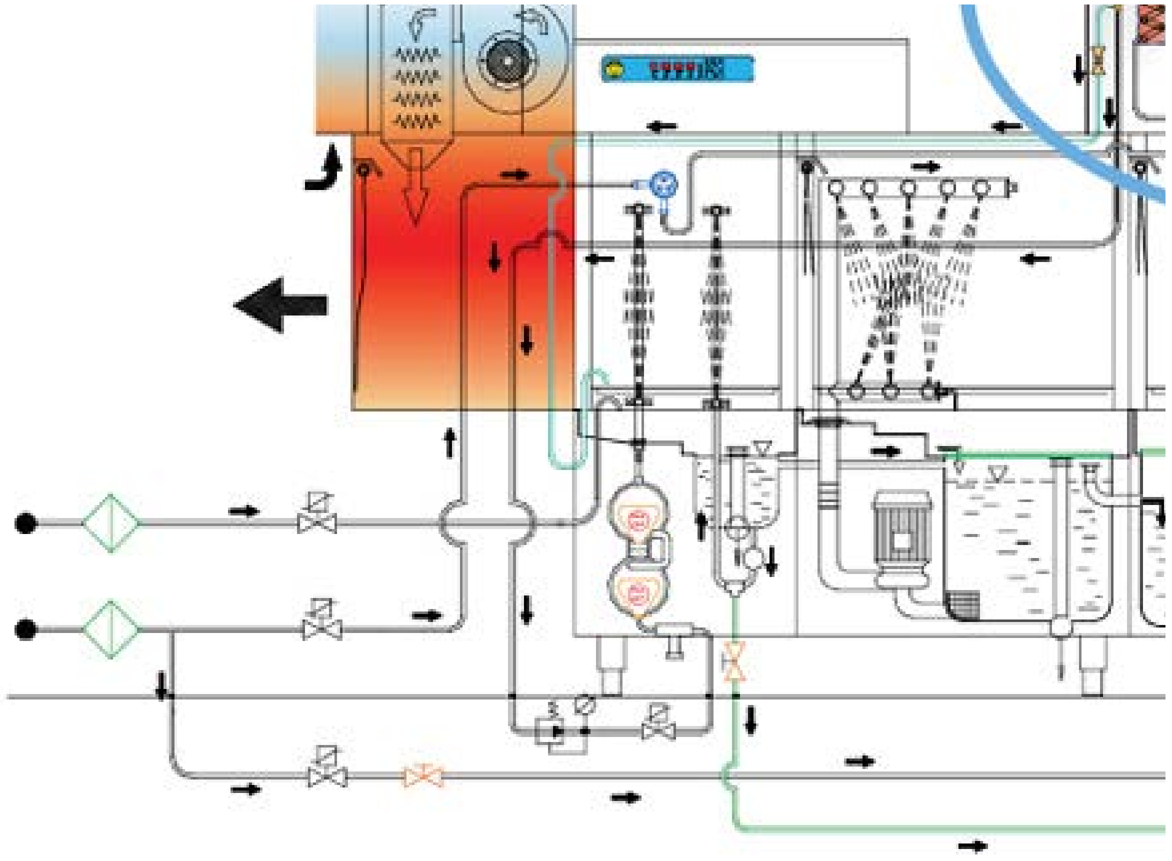


Fig Rhima crate washer

Due to competitive markets, details of the two applications are not given.
Information at:
www.droogtech.nl (Reinders Industrial; Plesmanweg 17; 7602 PD Almelo)
www.rhima.nl (RHIMA Nederland; Energieweg 4-6; 3762ET Soest)

4.3 | What happened with projects on older factsheets?

In this part we inform about some older projects that were published on factsheet in de mid nineties.

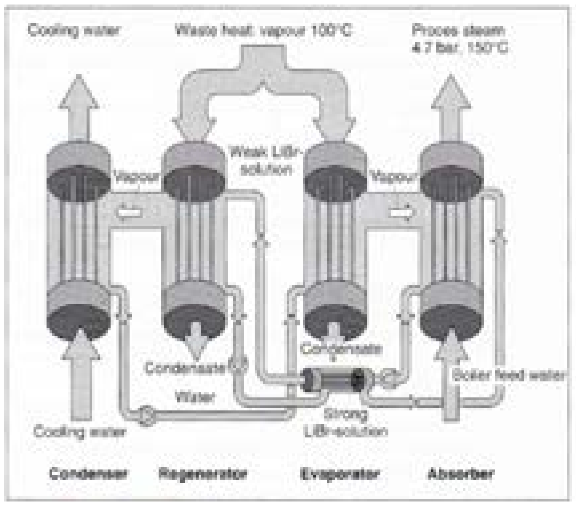
4.3.1 | Efficient cooling system with heat recovery for Tofu production

At the Lin Tahoe plant, tofu is produced by allowing soya bean milk to curdle at a temperature of 95°C. The process takes place in open vessels, which are checked visually. During the curdling process, a considerable amount of water vapour is released, which tends to condense inside the production hall. After the curdling, the product is pressed into blocks and cooled, initially from about 60°C to 14°C by pouring cold water over it, and then to 5°C in a cold storage chamber.

Stricter demands from the health authorities mean that the product now has to be cooled to 7°C in one single stage, and that condensate from the production hall can no longer come into contact with the product. To meet these demands, a new, energy-efficient cooling system has been installed. A heat pump prevents condensation forming on the factory walls on cold days.
The cooling installation in the main production line consists of two parallel cooling vessels containing circulating cold water, through which blocks of tofu are passed by a conveyor belt. It takes about three hours to cool the blocks from their production temperature of about 60°C to their maximum storage temperature of 7°C. The water in the vessels is kept at a temperature between 2°C and 4°C by cold glycol flowing through the double wall of the steel cooling vessels.
The glycol in turn is cooled in an external cooling unit to a temperature of -2°C. In the cold season, the heat from the condenser of this cooler is used to heat the ventilation air of the factory hall. Apart from the improvement in the indoor climate of the factory, the enhanced temperature prevents the condensation of evaporated water. This condensate could otherwise make contact with the product and cause contamination.
The total investment for this project was USD 200,000 (1992), of which 60% is attributed to the new cooling system. Compared to the previous situation, the cooler saves 140 MWh/year and the heat pump 235 MWh/year. At an electricity price of USD 0.1/kWh, the investment resulted in a payback period of 5.5 years.
The heat pump was installed in 1991. The Lin Tahoe plant has since then been sold to Alpro Soja, which in the end stopped production at the site.

4.3.2 | Absorption Heat Pump, Type II Heat transformer in the chemical industry

The heat transformer was in operation with Dealmine in Delfzijl in an ethylene amine plant. It produced 11 tonnes of saturated steam at 145°C and 4.6 bar at full load, and used saturated steam at 100°C to drive the system. The measured heating capacity was 6.7 MW at 11 tonnes of steam per hour, whilst 13.7 MW of waste heat was needed to drive the unit. The measured COP of was 0.49. The total power needed for circulating pumps etc. is 53 kW (less than 1% of the output). At the time the system was installed (1985) the payback period was two years.
Prior to filling the system, the equipment was cleaned and tested for air leakage. Chromate-hydroxide was used as inhibitor in the LiBr circuit. The equipment operated for six months without problems, before interruptions occurred due to corrosion. Corrosion was first noticed in the heat-recovery heat exchanger, circulation pumps and steel tubes. Later, corrosion problems developed in the other heat exchangers. Due to the corrosion, performance and heat output decreased. The lower output was due to clogging of passages by corrosion products.



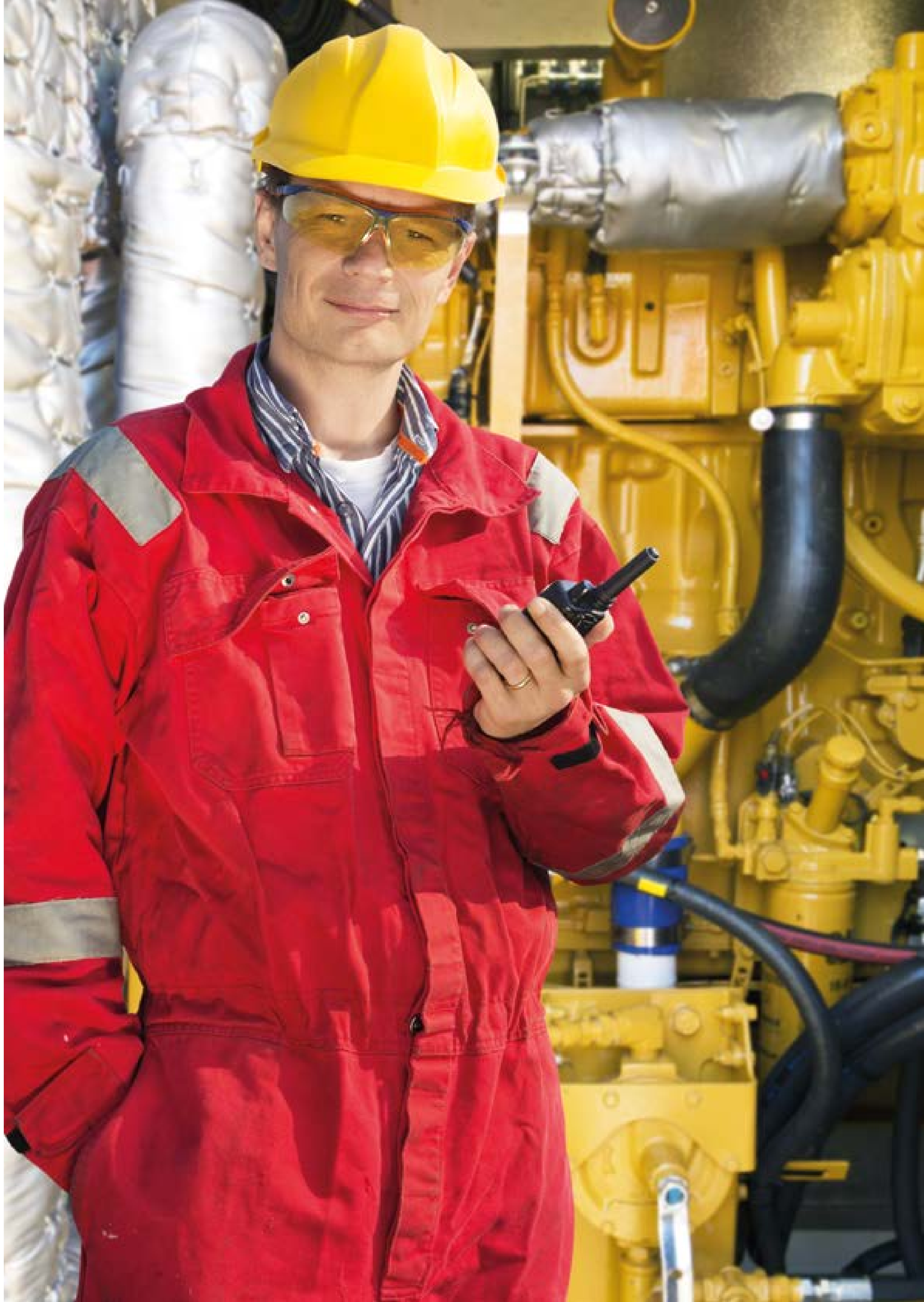
The heat-recovery heat exchanger is of the plate type, with titanium plates and ethylene propylene diene methylene gaskets. In the heat exchanger, crack corrosion occurred in the structure housing the gasket.
When the leakage became too large, a new heat exchanger with Ti/Pd plates was installed. That heat exchanger corroded after only a few hours of operation, due to flow-induced vibration causing stress corrosion.
A new heat exchanger with Ti plates and safeguards to eliminate the plate vibration was later installed. During operation, clogging of the heat exchanger occurred due to the settling of corrosion particles. To reduce the extent of corrosion particles in the system, two filters have been installed. However, corrosion and fouling continues, and plates have to be replaced twice a year. The principal corrosion type is deposit attack. This causes the plate material to become brittle locally, and extremely sensitive to cracking.
In the evaporator, after seven months of operation, four stainless steel tubes were found to be leaking, and other tubes had suffered from pit corrosion. A new evaporator equipped with Ti tubes and CuNi-clad inner shell was then installed to tackle the problem. Inspection of the absorber showed that all unalloyed steel parts which were in contact with LiBr were covered with crusty corrosion products. Carbon steel parts, such as the shell, had suffered from galvanic effects. The absorber was again replaced, and carbon steel piping, which was in direct contact with the LiBr solution, was replaced with CuNi.
The canned weak solution pump had to be replaced after five months of operation. Stainless steel parts such as the inducer had broken, and the adjustment ring had cracked. The inducer had probably suffered from cavitation during operation, which led to stress corrosion. The same type of corrosion occurs in the pump as in the heat-recovery heat exchanger, i.e. deposit attack.
The heat transformer at the Hoogovens site was the second one installed in the Netherlands. The first one, at Delamine Delfzijl is definitively taken out of operation due to serious internal corrosion problems caused by the LiBr-solution and air-leakage. This corrosion phenomenon was studied extensively under a European project and has led to the following measures adapted in the Hoogovens design:

- minimize number of materials; exclusively CuNi, carbon steel and, for the plate heat exchanger, titanium are used.
- regular testing for high air tightness.
- flange connections are avoided to a maximum.
- continuous measuring of the oxygen content in the condensate (may not exceed 5 ppb).
- regular control of the composition of the working fluid and corrosion inhibitors
- continuous measuring of corrosion rates
- continuous filtering of LiBr-solution and condensate
- only N_2 is permitted to fill up the vacumized part of the installation.

The heat transformer consists of four vertical shell and tube heat exchangers which are open connected in pairs (evaporator + absorber, regenerator + condenser). A rich LiBr-solution (63%) is mixed with water vapour in the absorber. The released heat is used to produce steam (2.7 bar, 130 °C) from boiling feed water (110 °C). The water vapour used in the absorber is produced in the evaporator at a pressure of 0.05 bar with waste heat of 90 °C. The lean LiBr-solution (60%) from the absorber is sent to the regenerator at a pressure of 0.5 bar to create a rich solution by evaporating water with waste heat of 90 °C. The rich LiBr-solution is directed to the absorber. The water vapour is condensed in a fourth heat exchanger with cooling water and pumped back to the evaporator. As well as the four large shell and tube heat exchangers, a compact plate heat exchanger is used to exchange heat between the rich and lean solution. The efficiency of the heat transformer is determined by the temperatures of cooling

water, waste heat and steam.
At the Hoogovens site, large quantities of waste heat are released in the hot rolling strip mill. The furnaces are cooled with water of which the temperature is increased to 90 °C. Since 1991, the duty of this cooling water is no longer cooled in a cooling tower but is partly used in a heat transformer. Therefore transportation of cooling water takes place through pipelines to the heat transformer at 800 metres distance. The heat transformer cools the water from 90 down to 85 °C and produces steam at 130 °C and 2.7 bar. With 1700 tonnes per hour waste water it is possible to generate 6.5 tonnes low pressure steam per hour. The saturated steam is superheated to 136 °C with middle pressure steam from the existing boiler and used in several processes at the cold rolling strip mill. The heat transformer is supplied by Rinheat OY from Finland. This company has great experience with this type of heat exchangers used for the heat transformer.
Economics: The heat transformer takes up 9 MWth from the waste heat from the hot rolling strip mill. The produced steam is equal to 4.1 MWth. The other part is cooled by cooling water (4.9 MWth) of which the temperature increases from 20 to 26 °C. The power consumption of the several pumps is only 60 kWe. The energy savings are 4.8 million m3 natural gas when assuming an annual operation time of 8000 hours.
The total investment was approximately 3.4 million euros, of which 60% was spent on the heat transformer. The transportation system for 90 °C cooling water and adaptations in the existing steam system were 25 and 15% respectively. The European Union and Novem have sponsored the project.
The heat transformer has only been in operation for several years, as the high maintenance costs and the low availability and reliability made further operation in-economic. Due to process changes where the temperature of the cooling water for the furnace was lowered, the heat transformer did not run optimally.

TASK 5
COMMUNICATION



5. COMMUNICATION – TASK 5

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

Give input for training courses in relation to existing organizations
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 analyses 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.

5.1 | 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 have 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.

5.2 | 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.

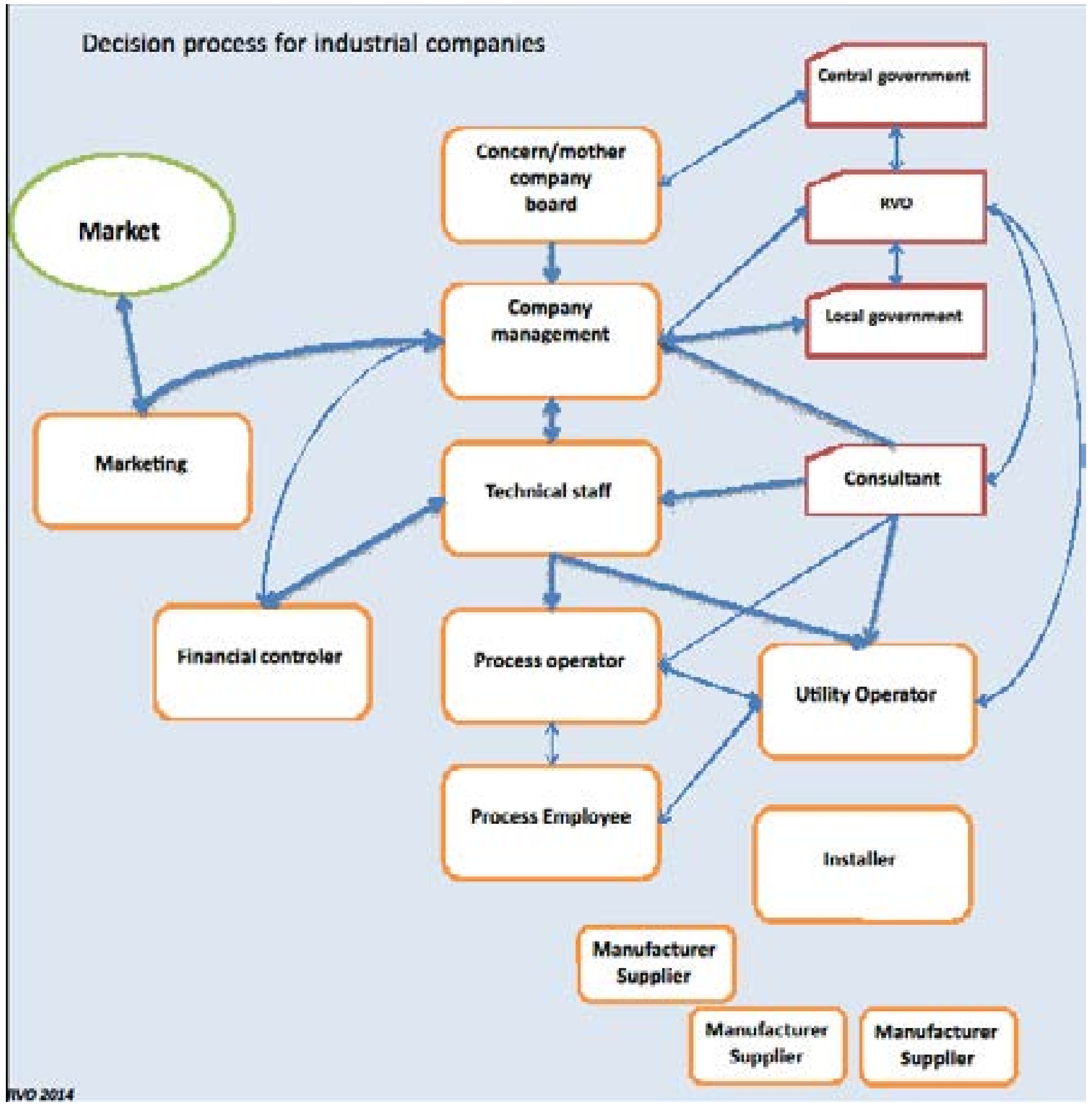


Fig 5.1 Communication network in industry

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.

5.3 | 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 condensor 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 1000C 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 1200C 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 2500C.
- 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

5.4 | 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 an 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 has 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 exist 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 TRIAS-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.

This 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.

TASK 6
CONCLUSIONS

6. CONCLUSIONS

In the Netherlands heat pumps of different types can be applied in all levels of industry ranging from bulk distillation in chemical industry to the level of milk processing at the farm or growing tomatoes in greenhouses and steamproduction in paper and pulp. The potential with industrial heat pumps for energy conservation and reduction of CO2-emissions in the Netherlands is enormous being between 60 – 90 PJ's and at this moment not naturally a part of policy papers nor for a large part under the attention of industry itself. The huge potential is often underestimated by policy makers, hence there are no structural and sufficient support mechanisms for this key technology. On the other hand there is a lot of attention for the use of industrial waste heat in the Rotterdam area and the province of Zuid Holland for district heating systems. A first, most logical, solution however to this waste heat problem is to reuse the heat within the same process through process integration or at the same site. In an ideal process that will be within the process unit, otherwise technology will have to be applied to transform the heat coming out of the process to a common carrier. This being high pressure steam or electricity generated by a high temperature heat pump or an ORC.

This attention for waste heat for district heating should therefore better be devoted to reduce the energy use and waste heat within industries itself.

It is advised to engage into a new IEA Annex on Industrial Heat Pumps phase 2 in which a communication structure is the main focus, firstly to inform and engage policy makers, but secondly and as important to inform end users in industry and decision makers at all different levels.

Heat pumping technologies, the main focus of this Annex, but also other energy conservation technologies are widely available, where in some sectors there is ample experience as these are well on the road to an energy neutral supply chain. The number of applications of heat pumps in industrial sectors in the Netherlands is rapidly growing since the last 4 – 6 years, with some exiting innovative examples, created by the supply industry. Dutch Manufacturers and suppliers have high standards of innovation and next to that Research and Development in the Netherlands are on the brink of application and need further support.

The experience in the various sectors and their approach can be used in other sectors to help these on their way. Training and education and an up to date information structure is proposed at international level (EU and IEA) based upon:

Trias Energetica;

- Energy Potential Scan and participation model
- Data gathering and optimization through monitoring
- Models for process analyses and integration are available which are not widely used anymore

In order to decide which optimisation model to use to approach the industry is based upon the needs and trending topics within the company (that can be very local), within the sector (competition) or through legislation (F-gases for refrigeration) and market developments (less economic growth) or tariffs (less economic cogeneration through spark spread). But also upon the philosophy to become energy neutral for the whole supply chain (dairy industry in the Netherlands) or become frontrunner in renewables (Lidl supermarkets).

Interesting conclusion is that to promote the application of heat pumps all models ranging from simple to complex can use the same simple excel based information model that has been developed by RVO and which should be further expanded in Phase 2 of the Annex. Based upon these aspects a flexible communication strategy can be developed and the model to be used is chosen. An important starting point is getting trust within the company starting at management level (sometimes middle management). These managers need a simple decision model and prove that the effort and investment will realise sufficient results. The Energy Potential Scan developed by Philips/Novem is a participative model to start the analyses of the industrial process. Unlike traditional energy audit approaches, in EPS, company and energy consultants work together to analyse the possibility to conserve energy. This model is used in many countries worldwide to get awareness within companies to work on energy conservation. The next step in the process is to get or generate sufficient data by monitoring and measurements, then the industrial process is optimized. Without applying a heat pump optimisation can often be achieved by new valves, other setpoints in pressure and temperature and new electromotors. The approach is from inside to the outside of the process according to the onion model. If all data is known, dependent on the complexity of the process a choice is made in process optimisation models. Simple: arrow diagram; More Complex: Einstein pinch approach; Complex: Advanced modelling with expensive programs.

TASK 7
LITERATURE

7. LITERATURE

1. The state of the art of industrial heat pumps in the Netherlands, A.M.G. Pennartz M.Sc., August 2011, KWA – Amersfoort, Report number 3005660CR03
2. Ervaringen met warmtepompen in de industrie, A.M.G. Pennartz M.Sc., April 2012, KWA – Amersfoort, Report number 3102000DR01
3. Heat pumps in distillation; O.S.L. Bruinsma; S. Spoelstra, ECN report - ECN-M--10-090 – November 2011
4. Milk Powder Technology, Evaporation and Spray Drying, ed. Vagn Westergaard, 5th Edition, GEA Process Engineering
5. Ervaringen met warmtepomptechnologie in de papier en karton industrie, Laurens de Vries (KCPK), presentation of a meeting of DT-IHP, June 2012.
6. www.energiezuinigebedrijventerreinen.nl
7. Quickscan toepassing van warmtepompen voor energiebesparing bij teelten met een laag energiegebruik, J.A.F. de Ruiter (KEMA), KEMA report June 2011
8. Monitoring van (energetische) prestaties en knelpuntenanalyse WKO-systemen in de glastuinbouw, ir. C.P.J.M. Geelen en ir. K.J. Braber; Arnhem, December 2013
9. Annex 21 report Industrial Heat Pumps
10. Warmtetools industrie, Jan Grift, Allan Hart (Energy Matters), april 2011, Projectnummer: 11.450
11. Energy Potential Scan, An overview; Michiel Steerneman (Energy Experts Int. B.V); June 2010; Ministry of Economic Affairs publication.
12. Mastering heat pumps selection for energy efficient distillation, Kiss A. A., Flores Landaeta S. J. and Infante Ferreira C. A., (2012), Chemical Engineering Transactions, 29, 397-402
13. Strategic Research Priorities for Renewable Heating & Cooling, Cross-Cutting Technology European Technology Platform on Renewable Heating and Cooling; Many authors edited by Simone Landolina – European Renewable Energy Research Centres Agency, Manuscript completed in April 2012. Brussels, © European Union, 2012.
14. Strategic Research and Innovation Agenda for Renewable Heating & Cooling, European Technology Platform on Renewable Heating and Cooling, Manuscript completed in March 2013. © European Union, 2013.
15. Reissner, F., Gromoll, B., Schäfer, J., Danov, V., Karl, J., 2013a. Experimental performance evaluation of new safe and environmentally friendly working fluids for high temperature heat pumps, European Heat Pump Summit, Nürnberg, Germany
16. Kleefkens O., Industrial Heat Pumps, MVR/TVR-systems in chemical industry, Dv3.4.39 96.11 ©Novem, Utrecht 1996.
17.
18. Experimental set up for determining ammonia-salt adsorption and desorption behaviour under typical heat pump conditions: a description of the setup and experimental results; Michel van der Pala, Robert de Boera, Jakobert Veldhuisa, Simon Smedinga; Energy research Centre of the Netherlands (ECN), P.O. Box 1, 1755 ZG, Petten, Report number: ECN-M--11-030, March 2010
19. Ontwikkeling van een hoge temperatuur chemische warmtepomp. S. Spoelstra, R. de Boer, Openbare eindrapportage OPTISORP project, EOS-LT02027, Report number: ECN-E--09-066
20. Study on performance of hybrid adsorption-compression type II heat pumps based on ammonia-salt adorption, M. van der Pal, A. Wemmers, S. Smeding, K. van den Heuvel (TU Delft); Presented at the 9th International Conference on Sustainable Energy Technologies, 24-27 August 2010, Shanghai JiaoTong Uversity School of Medicine in Shanghai, China, ECN-M--10-074 September 2010.
21. Heat integrated distillation using a plate-fin heat exchanger; O.S.L. Bruinsma, S.A. Tromp, M. Strijker, A. Malhotra, M. Saric, J. Cot Gores, Z. Olujic; Presented at CHISA, 30 August – 3 September, Prague, Czech Republic; ECN-M--10-091; November 2010;
22. Energy Saving for Batch Distillation with Mechanical Heat Pumps, Gabor Modla*, Peter Lang; Budapest University of Technology and Economics; CHEMICAL ENGINEERING TRANSACTIONS; VOL. 35, 2013
23. Compression heat pumps; In touch with heat pumps for industry and commerce; GEA Refrigeration Technologies; © GEA. All rights reserved. 09/2012 – RT-001-1300-US-EU
24. Advances in process integration, energy saving and emissions reduction; Klemes, J., Friedler, F., 2010. Applied Thermal Engineering 30, 1e5.
25. Sustainability in the Process Industry: Integration and Optimization, Jirí Klemes, 2011 The McGraw-Hill Companies Inc, New York, ISBN: 9780071605540

The literature search in the Netherlands gives following results.

- *How successful are heat pumps in Dutch Process Industry applications?* C.A. Infante Ferreira, S. Spoelstra, E. Hamoen, RCC Koude en Luchtbehandeling, **102**, (2009), 15-20
- *Determination of structural, thermodynamic and phase properties in the NA2S-H2)* system for application in a chemical heat pump, R. de Boer, W.G. Haije, J.B.J. Veldhuis, Thermochimica Acta, **395**, (2003), 3–19
- *Solid/vapour sorption heat transformer: Design and performance, W.G. Haije,* J.B.J. Veldhuis, S.F. Smeding, R.J.H. Grisel, Applied Thermal Engineering, **27**, (2007), 1371–1376
- *Absorption heat transformers and an industrial application,* Ilhami Horuz, Bener Kurt, Renewable Energy, **35** (2010), 2175-2181
- *Wet Compression-Resoprtion Heat Pump Cycles: Thermodynamic Analysis and Design,* L. Itard, PhD thesis, TU Delft, (1998)
- *Development of Wet Compressor for Application in Compression-Resorption Heat Pumps*, D. Zytsev, PhD thesis, TU Delft, (2003)
- *Applications of absorption heat pumps in the pulp and paper industry for increased efficiency and reduction of greenhouse gas emissions,* A. Costa, V. Neuhann, J. Vaillancourt, J. Paris, Paptac 90th Annual Metting, (2004)
- *A review of heat pump drying: Part 1 – Systems, models and studies,* N. Colak, A. Hepbasli, Energy Cionversion and Management, **50,** (2009), 2180-2186
- *Heat sources — technology, economy and environment,* T. Berntsson, International Journal of Refrigeration, **25**, (2002) 428 - 438
- *The compression/absorption heat pump cycle - conceptual design improvements and comparisons with the compression cycle,* M. Hulte, T., International Journal of Refrigeration, **25**, (2002) 487 – 497
- *Performance of a gas engine heat pump (GEHP) using R410A for heating and cooling applications,* E. Elgendy, J. Schmidt, A. Khalil, M. Fatouh, Energy, **35**, (2010), 4941-4948
- *Nanoscale magnetic heat pumps and engines,* G.E.W. Bauer, S. Bretzel, A. Brataas, Y. Tserkovnyak, Physical review B, **81**, 024427, (2010)
- *Gaswarmtepompen, Efficiënt verwarmen en koelen met aardgas,* E. Bakker, J van der Garde, K. Jansen, R. Traversari, P. Wagener, GasTerra / Castel International Publishers, (2010)
- *ECN ontwikkelt akoestische warmtepomp voor industrie,* M. van Baal, Technisch Weekblad, (2008)
- *Large energy savings and reduction of Innovative Heat Pumps,* S. Spoelstra, NPT Procestechnologie, **5**, (2007), 14-15
- *Warmtepompen in Nederland in 2008,* O. Kleefkens, (2009)

Bruinsma O.S.L., Spoelstra S., 2010, Heat pumps in distillation, report ECN-M--10-090

Modla G., Lang P., 2013, Energy saving for batch distillation with mechanical heat pumps, Chemical
Engineering Transactions, 35, 301-306 DOI:10.3303/CET1335050

NL-01 MVR SYSTEM AT SHELL PP-SPLITTER IN PERNIS

Summary
Propylene is a key material in the production of a number of chemical products including polypropylene (PP) and solvents. It is obtained by distillation separation of propylene and propane in a so called PP-splitter column. In a conventional distillation, the reboiler is heated by low pressure steam or hot condensate and the overhead vapours are cooled with cooling water.
In 1995, as a part of the modernisation of the whole propylene distribution system within the Shell site at Pernis, a new propylene-propane distillation column was built with the application of mechanical vapour recompression (MVR), built by Mannesmann Demag AG. This was done to save energy, reduce the use of cooling water and increase the yield of the distillation.

Process description
Propylene is a key ingredient in a number of chemical products, including polypropylene and solvents. It is produced by the distillative separation of propylene and propane in a so called PP-splitter column. The splitter became into operation in October 1995 and produces polymer grade propylene with a purity of 99.5%. In a conventional distillation the reboiler is heated with low pressure steam or hot condensate and the overhead vapours are cooled with water.
With the application of MVR on the distillation column, the overhead top vapours are used to heat the column at the bottom. In the MVR, an electrically driven two stage fixed speed compressor, manufactured by Mannesmann DEMAG AG, increases the pressure of the top vapours which are then condensed in a condenser/reboiler with UOP Hi-flux double enhanced tubes to heat the bottom stream from the PP-splitter. The main part of the condensed overhead vapours is returned to the column as reflux, the remainder providing feed stock to downstream chemical plants.
Because the column can operate independently from a cooling fluid, the temperature can be reduced and thus the column pressure can be reduced, giving a better split between propylene and propane, increasing the relative volatility. The operating pressure is one of the primary process variables in optimizing the design for the separation of propylene and propane by distillation. The volatility ratio is significantly greater at pressures in the range of 3 – 10 bars, compared to the traditional values at 15 – 20 bars. The use of lower pressure prevents the use of cooling water and this problem is solved by using MVR. Because the column can operate independently of a cooling fluid, the column pressure can be reduced, resulting in a better split between propylene and propane by the increase of relative volatility. The splitter thus produces polymer grade propylene with a purity of min. 99.5 wt%.
High reliability of the system has been achieved by the advanced process control system developed by Shell (Shell Multivariable Optimization Control). The SMOC process control system adjusts several parameters periodically. It sets the variables at given targets, taking into account the steady state and dynamic interactions between the variables.
Starting up procedure is initiated by purging with nitrogen and brought up to operational pressure by feeding in with propylene vapour generated in the de-ethanizer column from propylene storage.

Energy savings

Energy Heat pump drive energy (kWh/year):	50 400 MWh/year
Fuel:	Electricity
Energy output, useful heating (kWh/year):	401 600 MWh/year
Energy output, useful cooling (kWh/year):	352 000 MWh/year
Energy cost (EUR/kWh):	136 EUR/kW demand charge

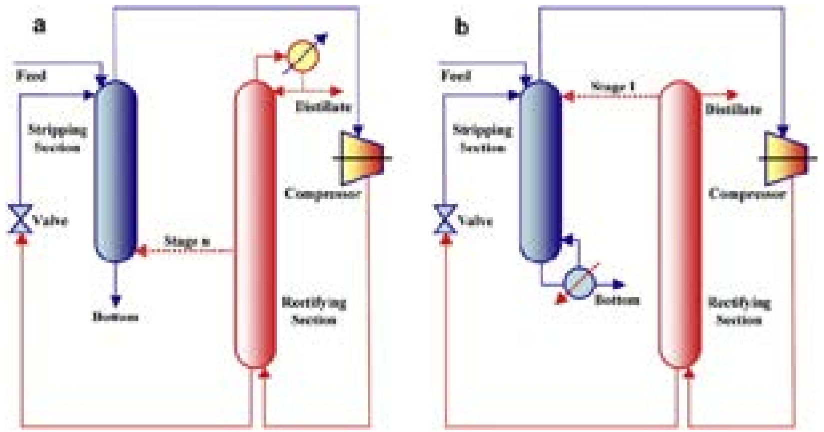
The net yearly energy savings thus are 1.2 PJ/year (equivalent to 37.8 Mill m3 of gas per year) at an operating time of over 8650 hours per year. CO_2 emissions are reducted with 67 kton/year. In this calculation, electricity is generated at an efficiency of 40% by gas-fired power plants.

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

Project summary/information

Company	Shell
Location	Pernis, Netherlands
Process application	Distillation in PP-splitter
Type of heat pump	MVR
Capacity	5.8 MW
Running hours	8650/year
Year of operation	October 1995
Primary energy savings	1.2 PJ/year
Reduction in CO2 emission	67 kton/year
Maintenance costs	
Manufacturer/supplier	Mannesmann DEMAG AG
Pay back	2 years

The system has a sophisticated level of automatic controls through the SMOC process control system. It does not require much human effort to run. The start-up procedures are due to the process requirement rather complex, but they do seldom occur.
The energy conservation can be calculated if compared to another smaller pp-splitter at the same location which is run on hot condensate feed and top cooling water. This splitter needs 2.2 GJ per ton feedstock while the MVR-equipped splitter needs only 0.5 GJ per ton, being a savings of 77%.
Maintenance problems have not occurred during the years of operation. The company has experienced the systems to have a very high reliability. Next to saving on heating, a considerable saving on cooling energy has been achieved, thus also reducing the use of surface water and disposing of waste heat on surface water.



Future developments
A simulation study on the existing plant was undertaken by Delft University of Technology [34] focusing on enhancing thermodynamic efficiency of energy intensive distillation columns by internal heat integration. In the simulation study, taking propylene/propane splitter as base case, an internally heat integrated distillation column (HIDiC) offers a significant potential for energy saving compared to energy requirements associated with the operation of conventional and heat-pump assisted distillation columns. The rectification section of a propylene/propane splitter contains usually two times more stages than the stripping section, implying a number of heat coupling possibilities, which appears to be strongly influencing the thermal efficiency of the HIDiC. The configuration with the stripping section stages thermally interconnected with the same number of stages in the upper part of the rectification section emerged as the most efficient configuration, allowing a reduction in energy use in the range of 30 to 40 % compared with a state of the art heat-pump assisted column, depending on the trade-off between the operating compression ratio and the heat transfer area requirement, the latter one being the key limiting factor.

In general, a distinctive feature of HIDiC is the fact that it combines advantages of direct vapour recompression and adiabatic operation at a significantly reduced total column height and therefore may be considered as an example of a most compact, and with respect to thermal energy conservation potential, an ultimate design of a distillation column.

NL-02 MVR SYSTEM AT LYONDELL – BOTLEK

Summary
Since 1983 a mechanical vapour recompression has been in operation at the isomerasation plant of Lyondell in the Botlek plant. The application of MVR at the plant leads to savings in steam consumption and in cooling of 20MWth with an increase in power consumption of 3MWe. Furthermore a better seperation of components can be achieved due to the lower operating prssure and thus an increase in relative volatality.

Process description
At the Botlek location the primary products made by Lyondell are propylene oxyide (PO) and tertiary butyl alcohol (TBA) being the largest producer of propylene oxyide. The Botlek plant has an annual production capacity of 245,000 tonnes of PO and 560,000 tonnes of TBA. The raw materials for the plant are butane, propylene and methanol where the first step in the manufacturing process is isomerisation. Most of the n-butane is converted into isobutane. The non-converted part is sperated from the isobutane in a de-isobutanizer. The purified isbutane is oxidized with oxygen toward tertiary butyl hydro peroxide (TBHP). In the epoxidation, proylene and TBHP are converted into tertiary butyl alcohol (TBA) and propylene oxide. After dehydration of TBA, isobutylene and methanol react to form methyl tertiary butyl ether (MTBA).
In the PO/TBA process applied at LyondellBasell's Botlek location isobutane is oxidised with industrial oxygen to tert-butyl hydroperoxide (TBHP).

The applied raw materials are supplied by third parties:
- The oxygen is produced by an over the fence conventional cryogenic air separation plant and supplied by pipeline.
- Propylene is purchased from steam cracking installations and supplied by pipeline and by ship.
- The isobutane is primarily purchased from natural gas processing plants and refineries and is supplied by ship and pipeline.

The produced tert-butyl hydroperoxide is next mixed with a catalyst solution to react with propylene, giving propylene oxide and TBA during this process step.

The produced propylene oxide and tert-butyl alcohol (TBA) are separated by distillation after which:
- The TBA is dehydrated into iso-butylene, which is subsequently converted into ETBE by addition of ethanol or to MTBE by addition of methanol. The ETBE or MTBE is supplied to oil companies for blending into gasoline.
- The propylene oxide is partly supplied to external consumers and partly processed on site into a range of chemicals, including ethers and glycols.

Undesired by-products are isolated as liquid and gaseous fuels. These are either:
- applied on site for firing furnaces;
- sold to nearby CHP units which supply steam and power to LyondellBasell Botlek;
- or sold to cement industry as a secondary fuel.

Process steam and power for the different processes are supplied by nearby gas fired STAG-CHP plants and a natural gas and residual fired CHP steam boiler with back pressure steam turbine.

Mechanical Vapour Recompression
As is widely known isobutane and n-butane have close atmospheric boiling points, respectively -11.7 and -0.5oC. This will normally result in a very large distillation column to seperate the mixture into pure components in combination with large reflux ratios. The large reflux ratios ask for large reboiler and condensor duties (hot and cold utility consumption). The two main reasons for Lyondell to invest in the MVR-system for this distillation process were:
- Limitation of cooling capacity. When designing the de-isobtanizer according to conventional distillation, a very large condensor duty would be needed for the condensation of the top reflux stream. Thus a large plot area for installation of air coolers would be required to deliver the cooling duty.
- Two very large distillation columns. From conventional design rules for the seperation of the butane mixture two very large columns would have to be used because of the very large vapour streams. From operating viewpoint this would be very complex.

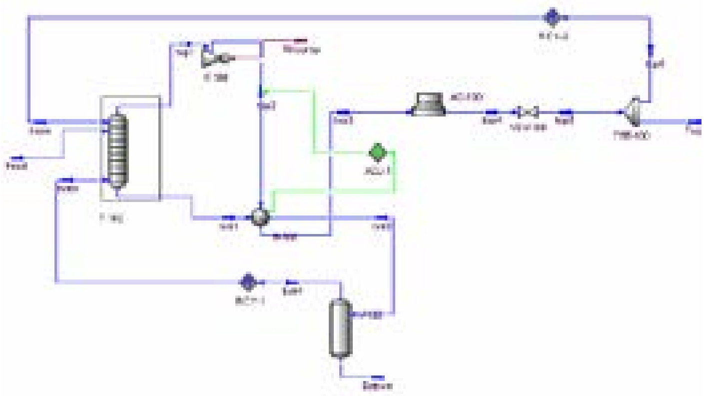
Project summary/information

Company	Lyondell
Location	Botlek, Netherlands
Process application	Distillation isobutane
Type of heat pump	MVR
Capacity	9.600 kW
Running hours	8650/year
Year of operation	1983
Primary energy savings	TJ/year
Reduction in CO_2 emission	kton/year
Maintenance costs	
Manufacturer/supplier	Borsig
Pay back	years

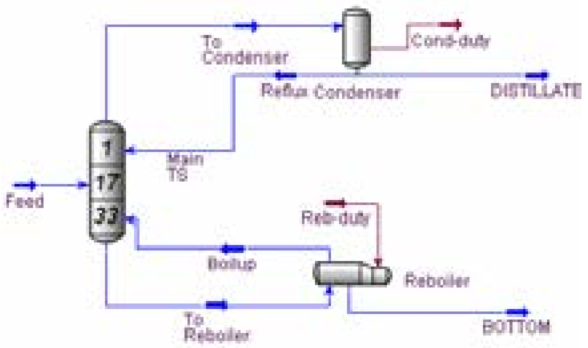
The solution was to use mechanical vapour recompression of the top vapour stream. The almost pure isobutane top stream is compressed from 3.8 to 9.5 bar and condensed by a side stream in the so called side-reboiler. This was installed because of the concentration and temperature profile within the column. Between the side-reboiler and the condensor, there is stripping to yield a pure isobutane top stream.

	with	without
Ptop (bar	3.8	7.2
Ttop (°C)	28	52
reflux ratio	2.95	5.1
Energy (MW)	9.6	26.9

The main figures with and without MVR on the distillation process are given in the table.
The Bosig compressor is driven by a Siemens turbine (64 – 12 bar) with a consumption of 40 tonnes of steam per hour. By this not only the steam consumption is reduced by 70% but also the cooling duty by the same amount.
Another advantage is the independency of the coolin temperature in the condensor. In conventional distillation the temperature and therwith the column pressure is determined by the temperature of the cooling medium. In the new MVR-situation this is no longer limited by the cooling medium. Cosequently the column can be operated at a lower pressure resulting in a better seperation efficiency (improving relative volatility), leading to a decrease in the number of trays and lower reflux ratios (smaller column diameter) and nhence a lower energy consumption.



HYSYS Process Flow diagram for the vapour recompression heat pump



HYSYS Process Flow Diagram for the conventional column

NL-02 MVR SYSTEM AT CRODA EMERSOL-PROCESS IN GOUDA

Summary

For seperating oleine and stearine Unichema, now Croda, in Gouda uses the Emersol-process, using ethanol as a solvent. Recompression of methanol-vapours with help of a vapour-recompressor gives an energy saving of about 119 TJ, which is 3.4 million nm3 gas a year.
Unichema Chemie Gouda emerged out of the Stearine Kaarsfabriek ‘Gouda’ (candlemaking-factory), which started in 1858. It became part of Unilever, that worked under the name of Unichema International for all their oleo-chemical products. Animal and vegetable oils and fats are the starting point for producing destilled and fractioned fatty acids, stearine, oleine, glycerin and high value chemicals like esters, amides, dimere fatty acids and soap granules. The products made by Unichema have a broad scope, for instance in cosmetics, rubbers, textile, leather, paper and lubricants.

Process description

For seperating oleine and stearine, Unichema uses the so called Emersol-process. Seperating the two is being done by using the difference in solubility in methanol of unsaturated and saturated fats. To get there, the fatty acids are being mixed with methanol at 30^{0}C, a temperature where the fatty acids dissolve totally.
By cooling this mix to about -8^{0}C there will be an almost complete seperation of the two: stearine crystallises at this temperature and the oleine will remain dissolved in the methanol. The stearine-crystals are being separated mechanically by using a rotating filter.
The filter cake containing 40 to 60 percent of methanol is being collected in a collecting basin. By heating this basin again, the stearine-methanol-mix will become liquid again. Originally this mix was transported to a destillation tower, where the methanol was being seperated again. This was a very energy-consuming process, where 90 percent of all the condensators were being destroyed. By adding a mechanical evaporator the use of energy was greatly reduced.
There is a mechanical evaporator in the oleine-sludge as well as in the stearine-sludge. The methanol-vapours from both evaporators are being compressed (raising temperature and pressure) and led back to the vaporizers. Here the mix cools down (vaporising the methanol) and condensates. Capacities for vaporising are 8.200 kg/hour. At the same time, 800 kg/hour of water is being diverted. The total of thermic power of both vaporisers is 3 MW.

Project summary/information

Company	Unichema (part of Unilever)
Location	Gouda, Netherlands
Process application	Seperating oleine and stearine
Type of heat pump	MVR
Capacity	23 MW
Running hours	8650/year
Year of operation	1995
Primary energy savings	119 TJ/year
Reduction in CO2 emission	
Maintenance costs	
Manufacturer/supplier	Wiegand Amsterdam
Pay back	

Energy savings

The net yearly energy savings are 119 J/year (equivalent to 3.4 Mill m3 of gas per year) at an operating time of over 8650 hours per year. The COP turned out higher than expected: 15.5 instead of 13.

NL-03 MVR AT HOECHST CHEMICALS VLISSINGEN

Summary
Since 1982, three steam recompression systems have been in operation at the Hoechst production plant in Vlissingen. The heat pumps are a part of the process for the production of dimethyl-terephthalate (DMT). With the application of steam recompression, steam pressure is increased from 1.14 bar to 3 bar, which can be used in the low pressure steam system. The main goals for the application have been cost reduction and the possibility to work with a smaller steam production plant. Production at the DMT-factory in East Vlissingen has been limited lately, because of lowering demand in the DMT-market. DMT is basic material for the chemical industry.

Industry/process
The base chemical for the production of polyester is paraxylene (“PX”). Through an oxidation process, PX is transformed into pure terephthalic acid (“PTA”) or dimethyl terephthalate (“DMT”), two forms of terephthalic acid. An amorphous polyester polymer (“APP”) is then created by reacting either PTA or DMT with a di functional alcohol, most often mono-ethylene glycol (“MEG”). APP is used to generate a variety of end products, which can be segmented into six general categories:

- polyester packaging resin (“PPR”)
- industrial fibres
- textile fibres
- non-wovens
- PET film
- engineering plastics

DMT and PTA are terephthalates derived from PX. For nearly all end-uses, DMT and PTA are interchangeable. DMT is easier to recover and to purify but PTA needs lower capital and operating costs (less of raw material and by-product handling). Thus, DMT and PTA should be considered together in any relevant market assessment. Hoechst is active in the production of DMT only. Its share of the total terephthalate market (DMT and PTA taken together) was approximately <10%. Even if one would consider a separate market for DMT, the share of Hoechst of the 1997 Western European merchant market for DMT was only between 10% and 20%. In 1997 Hoechst took over Invista and changed its name, and in 2007 production came to an end.

Project summary/information

Company	Hoechst
Location	Vlissingen
Process application	production of dimethyl-terephthalate (DMT).
Type of heat pump	
MVR	
Capacity	
Running hours	
Year of operation	
1982	
Primary energy savings	
Reduction in CO_2 emission	
Maintenance costs	
Manufacturer/supplier	
Pay back	

Description of the process
In the production of dimethyl-terephthalate (DMT), the first step is the oxidation of para-xylene C6H4(CH3)2 with air. The second step is the esterification of the oxidation product (paratoluic acid) with methanol, towards para-toluic acid, methyl ester. This intermediate is oxidised and esterified once again to the resulting DMT (second and third steps). To produce a product with a purity of 99.96%, the DMT is partly purified by distillation. The remaining impurities are removed by crystallisation. In the condenser of the methanol distillation column, steam is generated at 1.14 bar by condensation of the methanol reflux (15 tons/h, 106ºC, 4.2 bar). The generated steam is compressed to 3 bar in a two-stage centrifugal compressor (Linde GT040T2K1, 760 kWe) and supplied to the low pressure steam system. Interstage cooling between the two stages takes place and additional condensate is injected after the second stage of the compressor. A total of 7 tons/h of steam is delivered to the 3 bar steam system. The two-stage compressor is directly driven by a radial centripetal expansion turbine (Atlas Copco, ET410NS). Exhaust gases (19,000 Nm^3/h) from the oxidation section of the DMT reactor (mainly N_2 and CO_2) are expanded from 5.5 bar to 1.25 bar. The outlet temperature is controlled by a by-pass over the expander. Besides this steam compression system, another system is in operation. Steam generated in two oxidators (4.2 and 3.9 bara) is compressed to 5 bar in two electric-driven centrifugal compressors (Atlas Copco GT026T1K, 131kWe and 132kWe). A total of 20 tons/h of steam is produced at 5 bara (=163ºC), which is delivered to the steam grid.

Energy savings
Savings have been calculated roughly from the following: Steam driven system: investments EUR 295 000 with cost savings of approximately EUR 270 000 per year. The second system (two compressors): investment EUR 155 000 with cost savings of EUR 725 000 per year. These systems were newly built, so the investment costs are calculated on extra costs compared with traditional systems in a new plant.
CO_2 emissions reductions are 5.3 and 14.2 kton/year. These figures are calculated at assumed efficiencies for the steam boiler of 90%, gas fuelled power generation of 52% and at a running time of 8 000 hours. Energy savings are for the steam driven heat pump calculated at 3 million m^3/year of gas equivalent and for the two electric driven systems at 8 million m^3/year.

Operational experience and other comments
The systems are considered as very reliable. Although heat pumps in general are seen as difficult and not very reliable, the heat pumps at Hoechst were not really recognised as such because maintenance costs are extremely low. There have been no operational problems. Extremely short payback times can be achieved by installing heat pumps at new-built plants from the beginning. Heat pumps should in the case of MVR systems be marketed as compressors, integrated in systems.

NL-04 CAMPINA AIRY IN VEGHEL

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

Project characteristics and process design of installed system
Prior to the drying, the whey is preconcentrated, which removes about 90% of the water. This is carried out in a multi-effect falling film evaporator with vapour recompression in order to save steam. Apart from the actual evaporating calandrias the evaporator is equipped with preheaters for

Project information

Company	Campina
Location	Veghel, The Netherlands
Process application	Evaporating water from whey
Type of heat pump	MVR
Capacity	Not known yet
Running hours	Not known yet
Year of operation	October 2013
Primary energy savings	17,00%
Reduction in CO2 emission	Not known yet
Maintenance costs	Not known yet
Manufacturer/supplier	GEA Happel
Pay back	Not known yet

heating the whey by means of vapour before it is finally pasteurized by means of live steam, either direct or indirect. The evaporated whey is pumped either to crystallization tanks or directly to the spray dryer by a pump with variable speed. The spray dryer may be with either pneumatic conveying or fluid beds for after-drying and cooling.
The pretreatment prior to evaporation is as follows: The raw fresh whey should be cooled to 5-10ºC immediately after it is drained off the cheese vat, in order to avoid bacterial decomposition with a troublesome drying as a result.
Following the closure of the cheese production plant in Niedermörmter (Germany), the evaporator, a machine for concentrating whey, didn’t stand idle for long. The entire installation, which stands around 20 metres high, was soon relocated to the cheese production plant in Tilburg (the Netherlands). For this purpose a new building had to be constructed. Project leader Henk Miedema, head of production Eldert Bruinink, team leader Rob Bekkers and operating engineer Cees van Roestel spent considerable time preparing the evaporator for its new role, to produce thicker (more concentrated) whey. Converting the evaporator means that approximately 520 fewer lorries now drive between the plants in Tilburg and Veghel. ‘We’ve substantially reduced our energy costs,’ plant manager Jolanda ten Wolde proudly reported. ‘The new mechanical evaporator runs on electricity, whereas the old thermal model was steam (gas) powered. This has cut our total energy bill by an impressive 17%.’

Lessons learned and challenges
Efforts to reduce energy consumption are not always given the priority they deserve. Low energy versions of new filling lines, evaporators, steam boilers and a range of other equipment leads to major long-term efficiency gains (see the box in this section). Lower energy consumption reduces CO2 emissions and cuts energy bills. There is also the likelihood of a further rise in energy prices over the next few years. So extra attention for more energy-efficient installations is a two-edged sword. Do we take quick decisions which appear to be cost-effective in the short term? Or do we wait for a more energy-efficient design which delivers progressive long-term benefits? So far, the first option seems to be the most common. But Campina prefers to opt for long-term sustainability. The second option will therefore inevitably play a bigger role in efforts to reduce energy consumption. Campina will therefore be fostering a debate on sustainable enterprise within all disciplines, from marketing to production. Suppliers will be challenged to come up with energyefficient solutions that are also cost-effective. A working group has been set up with support from SenterNovem (currently: RVO, the innovation and sustainable development agency of the Ministry of Economic Affairs) to encourage suppliers to incorporate energy conservation into their designs. This will in turn ensure that the need to reduce our energy consumption is increasingly discussed throughout the company as a whole.

NL-06 CAMPINA HOLLAND CHEESE BLESKENSGRAAF

Summary
Campina is an international dairy cooperative. With a turnover of € 3.6 billion, Campina is one of Europe's leading dairy companies and a prominent global player. The organisation employs more than 6,300 people and is active from London to Moscow and from Japan to the United States. Campina's commercial activities are operated by three groups, which are responsible for the production and sale of dairy products and dairy ingredients in each of the countries in which Campina is active. The Cheese & Butter group produces and sells semi-hard Gouda cheeses in a number of varieties (Campina Holland Cheese) which are produced in Bleskensgraaf. Since 1992, Campina has supported the Dutch Long-Term Energy Efficiency Agreements for Industry (LTA-1 and LTA 2) covenants between the private sector and the government to realise the goals of (inter)national climate policy. In the Netherlands, energy consumption in 2006 totalled 4.65 PJ.

Project information

Company	Campina
Location	
Process application	
Type of heat pump	
Capacity	
Running hours	
Year of operation	1993
Primary energy savings	77 TJ
Reduction in CO2 emission	3962 tons
Maintenance costs	
Manufacturer/supplier	Schiele Turbomaschinen;
	Stork Friesland
Pay back	

Project characteristics and process design of installed system
The production of cheese releases whey. Before it leaves the production plant, this whey is evaporated to leave a 25 to 30% whey solid. Reducing the volume of whey saves on transport costs, but the evaporation process itself consumes energy. The evaporator is built up as a multi pass evaporator each equiped with a Schiel turbocompressor. In the first evaporator two passes and the second five are constructed with a total of seven. The processflow is heated by the condensate from 32.6 to 58ºC, while the product is cooled from 64 to 35ºC. The 'oningetrokken'product then goes to the pasteurisation step and is heated with low pressure steam to 70ºC. This low pressure steam is generated from the vapour and fresh steam of 7.5 bar. The used amount of fresh steam is 0.0116 ton per ton evaporated water. A standard evoporator without MVR uses 0.12 tons.
The water released by the process is re-used wherever possible. In addition to the environmental load caused, the production of cheese also involves the emission of chlorides when the brine is discharged.

Running experience, savings and economics
With the application of the mechanical vapour recompression on the multi pass evaporators an energy consumption of 120MJ per ton whey is realised. Standard evaporators without MVR use 360MJ per ton. With a production capacity of 34,000 tons of cheese at the design stage there will be an overall savings of 77TJ/year. Besides energy conservation there are smaller capacities needed for the hot and cold utilities, resulting in a decreased use of cooling water by 640,000 m3/year.

NL-06 DRYING FRENCH FRIES AT MCCAIN IN LELYSTAD (NL)

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

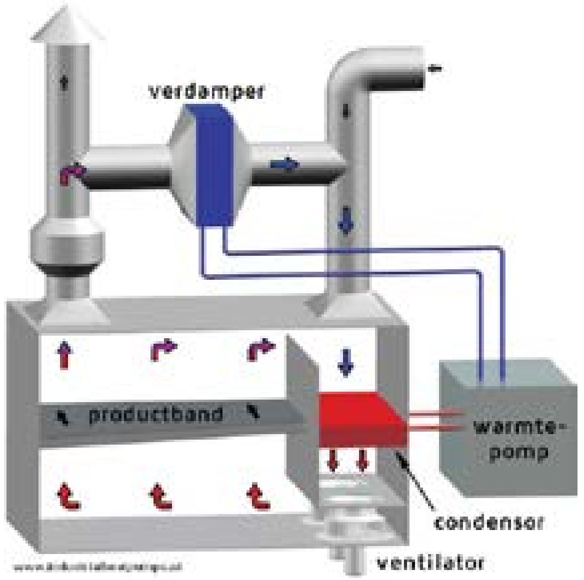
Process design of installed system
The principle of operation for drying in conventional dryers can be divided in two parts. The first step concerns fresh outdoor air that is being brought inside the dryer and getting heated. Secondly, the air is circulated over the wet product. During this circulation it picks up moisture from the wet product due to which its humidity increases and its temperature decreases. The energy contained in this humid air flow may make it a useful heat source. Standard procedure is to exhaust this used air or dehumidify it. Most of the humid and cold air is recirculated when the innovative heat pump is applied. The air is cooled below condensation point and thus dehumidified at the evaporator of the heat pump. The pressure and temperature of the refrigerant are increased with the use of a compressor. This energy is released into the dryer air, at the condenser site. Due to the application of a heat pump, large energy savings can be obtained. Furthermore, the drying process is less influenced by outdoor air conditions. A more stable drying process increases the quality of the French fries.
The heat pump uses Ammonia as its refrigerant. This is a natural refrigerant with which high efficiencies can be obtained. Another advantage is the fact that considerable knowledge about this refrigerant is present in the food industry: Ammonia is very commonly applied there.
Two reciprocating compressors are used; a Grasso 45 HP and a Grasso 65 HP. These compressors have a continuous capacity control. Their COP in this process depends on the drying conditions and varies between 5 to 8.
The heat pump dryer is designed as an ammonia pump system. In the engine room, compressors, separator and pumps are situated. Evaporators are situated on the roof and connect the ducting for exhaust and fresh air with each other. Condensers are installed inside the dryer.

Running experience, savings and economics
The heat pump is designed to condensate 1,500 kg of water per hour. If this quota is reached an annual energy saving of 800,000 Nm³ of natural gas is obtained. The payback time is than 4 years. This particular project has a shorter payback time since financial support is given by the so called SBIR program of AgentschapNL (the Dutch government).

Project information

Company	McCain Foods
Location	Lelystad
Process application	Dying of patatoes
Type of heat pump	Compression Heat Pump
Capacity	880kW
Running hours	4000
Year of operation	2012
Primary energy savings	
Reduction in CO2 emission	
Maintenance costs	
Manufacturer/supplier	Kleijn/Gea Grenco
Pay back	4 years

The heat pump performance is better than expected. Intensive monitoring shows there is a 67% saving on primary energy use at the dryer, due tot the high COP (Coefficient of Performance) that has been realised - with an average value of 7.9. A COP of 7.9 means that every kW of electrical energy used by the heat pump results in the release of 7.9 kW of heat in the dryer. With enough operational time and a sufficient load, the payback time of the installation will be less than 4 years.
At least as important as high efficiency is the fact that the heat pump can easily obtain the desired drying conditions. Experience has shown that it's even possible to get the dryer operational from start within 5 minutes without adding external heat. The heat pump has been installed at the existing dryer at McCain. The conventional internal steam heater has been replaced by the condensors of the heat pump.
Contamination of the heat exchangers has been an important point. However, even after using the installation for half a year without any cleaning, contamination proved to be insignificant.



Picture: Funnels at the roof, and the three recirculation section with evaporators.

Some important figures regarding the heat pump installation at McCain:
- The total heat capacity of the heat pump is 880kW;
- The maximum air temperature in the dryer is 70°C
- In the heat pump, two reciprocating compressors with speed control have been applied
- The installation is filled with the natural refrigerant Ammonia
- A great deal of attention has been given to the safety and reliability of the installation
- The average (monitored) COP of the heat pump is 7.9

NL-07 HT-HEAT PUMP AT THE BLUE BAND FACTORY IN ROTTERDAM

Summary

The Blue Band factory from Unilever at the Nassaukade in Rotterdam is over 120 years old and at the moment the world largest factory for margarine, with an output of more than 200,000 tonnes of margarine and 10,000 tonnes of peanut butter. Over that period of 120 years many changes in building, expansion and machinery have been done and a large overhaul of the complete production and building has never been undertaken, which results in a complex situation. When in 2009 the boiler-room was going to be renovated, the 40 years old steam boiler had to be replaced. Of the installed capacity more than 40% was not used because the new production lines have a lower energy use. As production had to go on, a new boiler-house was designed near the old existing one.

Project characteristics and process design of installed system

The production line for margarine and peanut butter uses various heat and cold streams for the process:

- Hot water at several temperature levels
- Steam
- Warm water for space heating
- Ice water
- Freezing from an ammonia system at -23°C

All of the hot water and steam is generated by the old steam boiler on which the heat demanding processes run independent from each other and can run on partial load. The complete energy demand of the existing factory has been mapped and simulation and pinch models were used to design the new heat generating process. The basic thought is to make the plant as energy friendly as possible and robust for the next decade with a focus to use as much waste heat when occurring as possible. The heat demand could be split into low temperature heat (<70°C) and high temperature heat (>90°C).

For the low temperature heat the condenser heat from the NH3 chiller is used in a Grenco add-on heat pump to generate temperatures up to 80°C.

This construction is called an add on heat pump. It is a mechanical heat pump that uses the refrigerant of an existing refrigeration system, in this case Ammonia. With the use of an add on heat pump, the pressure of the gaseous Ammonia is increased. This causes the refrigerant to condensate at a higher temperature. In this case the add on heat pump is used to heat a water circuit up to 65 °C. Application of a heat pump enables several processes to benefit from the waste heat of the refrigeration system. Therefore energy savings can be realized as well as a reduction in CO2 emission.

In this project a COP (coefficient of performance) of 5 is realized, or: every kW that is used by the compressor delivers 5 kW of useful heat. An additional advantage of the add-on heat pump is that the load of the existing condenser is reduced.

The installation has the following specifications:

- Heat capacity: 1400 kW at a temperature of 65 °C of the heated water
- Heating COP: 5,5
- Annual hours of operation: 6.000
- Annual energy savings: € 220.000
- Annual reduction of CO2 emission: 1.600.000 kg
- Pay back time: ca. 2 years

De Energy Enhancer add-on heat pump is a GEA Grenco innovation. They won the NVKL cooling award 2012 with this innovation. The system is especially designed to be integrated in existing cooling or refrigeration systems with Ammonia as a refrigerant. At this moment the condensation temperature can be increased to a maximum of 90 °C with the use of a heat pump. Through a heat

Project information

Company	Unilever
Location	Rotterdam; Netherlands
Process application	
Type of heat pump	Compression add on heat pump
Capacity	1400 kW
Running hours	5000
Year of operation	2011
Primary energy savings	
Reduction in CO2 emission	1,600,000 kg
Maintenance costs	
Manufacturer/supplier	Grenco
Pay back	2 years

exchanger this energy is delivered to the medium that requires it.

For the high temperature heat a cogeneration gas engine is used with a steam boiler as back up. In partial load situations heat can be exchanged between the two systems

By means of a cogeneration system of Caterpiller, 1.6 MW electric power and 2 MW thermal power is generated. The heat is being used to provide the factory with process water of 90 C.

For additional heat or to provide heat in a case of emergency, a steam boiler has been installed, which can deliver 6.5 tons of steam per hour, at an atmosphere of 12 bar.

Office building De Brug, of Unilever, Rotterdam

The office building ‘De Brug’ of Unilever Bestfoods in Rotterdam, the Netherlands is well-known in Holland for its remarkable architecture and because it is prominently present at the shore of the river Maas. However, not too many people know that this building is a classic example of the application of ‘low temperature heating’ (LTH, by Low-H2O technics) in combination with radiators. What is even more: no wall – or underfloor heating is getting used here. Merely the combination of low temperature heating radiators of Jaga with ceiling cooling is sufficient to create a comfortable temperature.

Already in 2001, at an early stage of development of this building, it was decided that sustainability should be one of the key factors, regarding heating and cooling as well. This was not an easy task, given the fact that the steel construction containing four levels with 15.000 square meter of office space in total, had a façade which almost solely consisted of (double pane) windows. As a solution for this challenge, low temperature heating radiators were applied to counteract the downdraft of cold air. The low temperature radiators as well as the cooling system in the ceiling use river water as a source. The temperature of this water is uplifted by a heat pump.

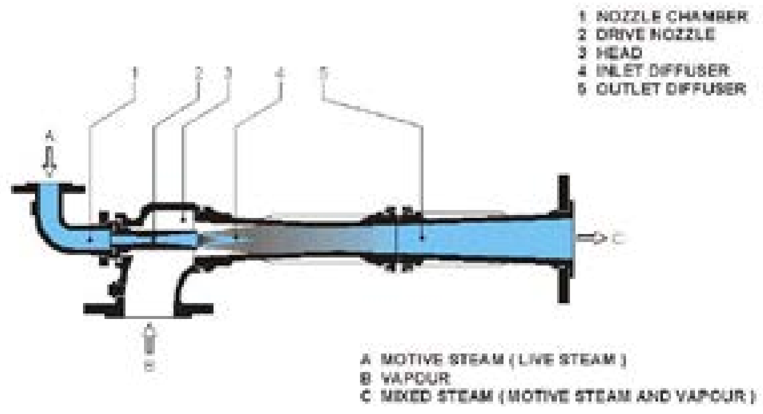
Running experience, savings and economics

The overall steam demand is reduced by 80%. To reduce efficiency losses in heat generation hot water storage tanks were installed.

The heat pump, chp and steam boiler are running since 2010 getting into a 25% energy conservation. This is exactly according to the design of the system.

NL-09 THERMAL VAPOUR RECOMPRESSION HEAT PUMP AT HEINEKEN DEN BOSCH

Summary
Heineken Den Bosch has installed a heat pump in the wort boiling house during a renovation. The heat pump is a thermal vapour recompression (TVR) type placed on the wort boilers. The TVR is used to reduce the energy consumption of the wort boiling process. The heat pump started operating early 2005. The savings on gas consumption and CO_2-emission are considerable.



Thermal vapour recompression (TVR) heat pump, working principle

Industry/process
The thermal vapour recompression (TVR) jet pump is integrated in the new built wort boiler system. In the process of brewing beer, wort boiling is an important and highly energy consuming process step. The wort is boiled to obtain an evaporation rate of 5% to 6% depending upon the brewers recipe. A TVR is an ejector type of compressor. Fresh steam of 11 bar is the driving force to recover 65% to 75% of the water vapour of the wort boiler kettle by returning this amount of mass and energy into the process. The principle of the TVR is to extract the atmospheric vapour from the wort boiler and compress it to a temperature that is 8K higher than the wort boiling temperature. The compressed vapour is heating the wort boiler by means of an external boiler heat exchanger.
The remaining part of the vapour flow from the wort boiler is not extracted by the TVR but is condensed by a heat exchanger to heat up the process water up to 95°C for storage in a stratification tank and to preheat process water for the mashing process. The condensate is then disposed at a temperature of 30°C after recovering all its heat. The heat cycle of the brewhouse is almost closed. The TVR is an open loop heat pump since the process flow (water vapour from the wort kettle) is the mass flow absorbed by the jet compressor. The design efficiency of the TVR is 5 units of fresh steam, recovering 4 units vapour from the wort kettle, hence delivering 9 units of steam to the external boiler.

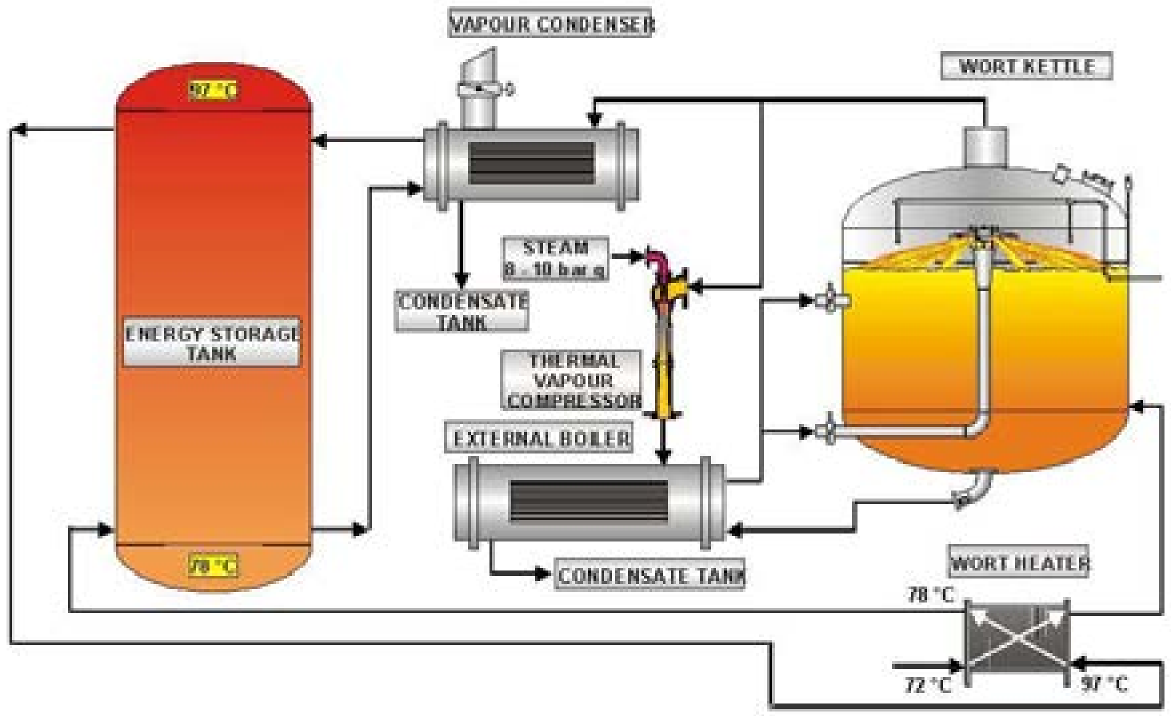
Heineken produces approximately 6 million hectolitres per year in two brewhouses. The larger brewhouse runs at a capacity of approximately 75 brews per week of 1000 hl. The TVR is operating in this brewhouse. The energy saving is 18.5 MJ/hl on a total average specific value for thermal energy of 95 MJ/hl.

A new to build brewhouse is the most favorable condition to implement a heat pump. The feasibility of the TVR is high in such circumstances. Nevertheless, a TVR can be an option in existing plants as well. Each brew house size and operation needs its own analysis and feasibility for energy optimization by heat pumps and heat exchanger network. A heat pump that is process integrated (open loop), such as the TVR, has a high feasibility. For reasons of proper control, reliability and reduced complexity, each wort kettle of the new brew house has been executed with a TVR and vapour condenser.
It is difficult in a brewery to match the energy balance with the water balance. Since water is also the heat transport medium, breweries appear to have hot water surplus. A TVR reduces this surplus

Project summary/information

Company	Heineken
Location	Den Bosch
Process application	Thermal vapour recompression
Type of heat pump	TVR
Capacity	
Running hours	
Year of operation	2005
Primary energy savings	18.5 MJ/hl by TVR and heat recovery from condensation and optimized heat exchanger network. In total 100 TJ annually, equivalent to 3.5 million Nm3 gas consumption of steam boilers.
Reduction in CO_2 emission	6,200 ton CO_2 annually
Maintenance costs	Low - regular
Manufacturer/supplier	
Pay back	2-3 year

in comparison with a single vapour condenser system. A mechanical vapour compression system (MVR) is the competitor of the TVR. It has a higher efficiency and may provide a better water balance. Its investment and maintenance costs are however much higher.
The TVR reduces the emission of odours to the environment since all the vapour from the wort boiling is condensed. The TVR heat pump with Heineken operates satisfactorily and fulfills the expected energy savings.



Lay-out of the thermal vapour recompression heat pump with vapour condenser on a wort boiler kettle

NL-11 SLAUGHTERHOUSE FOR VEAL, THE NETHERLANDS

Summary
Export Slachterij Apeldoorn, part of the Alpuro Group, produces a broad selection of veal products for the retail business worldwide. This production needs large amounts of hot water for the cleaning of production rooms and machinery and for removing hair from veal skin, and a smaller amount for sterile water (90°C). The heat pump has been installed in a slaughter house at a moment that the steam boiler had to be replaced. This created the opportunity to improve the hot water system efficiency.
The heat pump is a 45 bar reciprocating compressor coupled to the high pressure side of a refrigeration plant with ammonia as refrigerant (see figure 1). The heat pump condenser heats up water up to 62,5°C. The installation is running more than one year with great satisfaction and reliability.

Project design
A new system was designed with three smaller warm water boilers and a high temperature heat pump on top of the refrigeration plant operating at -10°C refrigerating temperature.
This refrigerating plant has a cooling capacity of 1200 kW, at a condensing temperature of 23°C, which is the suction pressure of the high temperature heat pump. The condensing temperature of this heat pump is 65°C, producing hot water at 62,5°C. The COP on heating appeared to be approximately 6,7. The heat pump compressor is a 6 cylinders piston type compressor, frequency controlled, extracting only part of the discharge gasses. The heat produced at 65°C amounts to 500 kW. This heating capacity heats up a water flow from 15°C up to 62,5°C.
The superheated discharge gasses of the regular refrigerating installation have to be cooled down to almost saturation at 23°C in order to avoid extreme discharge temperatures of the heat pump. This gas desuperheater (= heat pump suction gas cooler) is cooled by high pressure ammonia liquid (23°C) from the condensers of the regular refrigeration plant (see figure 2 upper left vessel). The discharge gas of the heat pump is cooled by heat pump condensate (65°C) in vessel V22. The municipal water intake is heated up from 15°C to 62,5°C in two stages, first by a liquid subcooler E25 and compressor head cooler E70 and secondly by the condenser E24. The water is stored in a 100 m3 insulated water tank.

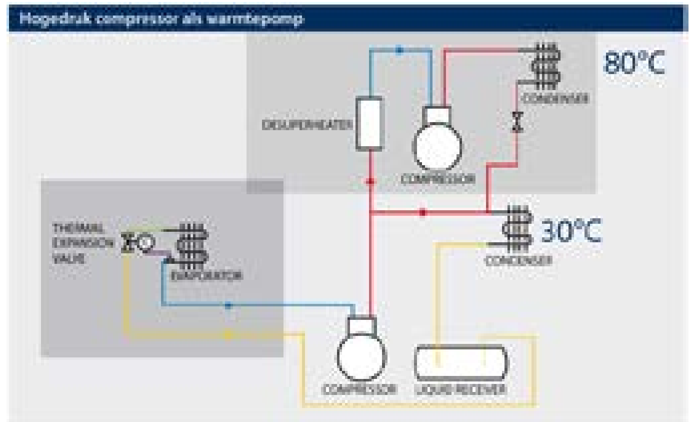


Figure 1: Principle of a high temperature heat pump on top of a refrigeration plant for process heating

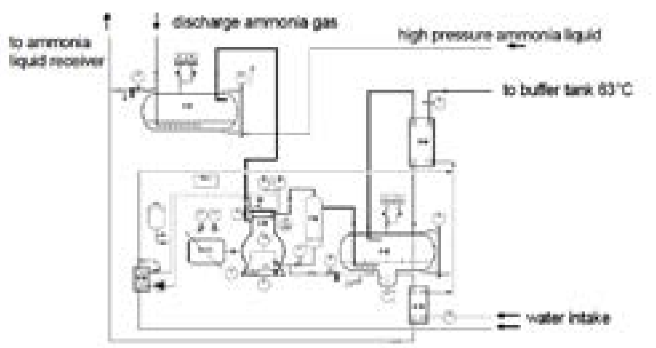


Figure 2: Heat pump layout in practice, ammonia high temperature compression and water flow from intake to buffer tank.

The slaughter house requires a hot water flow for dehairing and cleaning of the production areas at the end of the day. The water demand varies a lot during the day. The storage hot water tank is sufficiently large to cope with the variations.
Hot water boilers are connected to the water system of the heat pump as back up system and to heat the water up to 90°C for sterilization water for knives cleaning.
The water flow circulating in the boilers however is separated by a plate heat exchanger from the water flow running through the heat pump. This heat exchanger appears to be required since the warm water boilers became damaged by severe calcification.
The heat of the heat pump is released into a water cooled condenser. The discharge temperatures are above 90°C causing severe calcification of the heat exchanger surfaces. This is prevented by

Project summary/information

Company	Export Slachterij
Location	Apeldoorn, Netherlands
Process application	Slaughterhouse for veal
Type of heat pump	Electrical compression heat pump
Capacity	440 kW
Running hours	
Year of operation	September 2009
Primary energy savings	/year
Reduction in CO2 emission	/year
Maintenance costs	
Manufacturer/supplier	IBK Koudetechniek
Pay back	years

the use of the desuperheater heat exchanger cooled by the condensed ammonia liquid at 65°C. This heat exchanger has been installed in the discharge line of the heat pump.
The heat pump started operation in September 2009 and is running 16 hours per day, approximately 4000 hours per year at almost 100% capacity. By comparing gas consumption figures during the last years, it showed that the gas consumption was reduced by 50%.
On theoretical basis the energy saving by the heat pump is 65% compared with a hot water boiler for this field application as shown in table 2. The electrical energy consumption of the heat pump is included in this calculation. The CO2 emission is reduced by 50%.

Heat production options		Heat pump 23°C/65°C	Hot water boiler
Heat demand	kW	500	500
COP heat pump		6,7	
Boiler efficiency	%		90
Operating hours	hours/y	4.000	4.000
Primary energy use	MJ/y	2.686.600	8.000.000
CO_2 emission	kg/y	200.150	450.000

Table 1: MJ primary energy and CO2 emission reduction by the heat pump in comparison with a hot water boiler

The electricity consumption is increased by the operation of the heat pump but the condensing temperature of the refrigeration plant is reduced by 4K, resulting in a better efficiency and energy savings of the refrigeration plant. In addition, the heat pump reduces the load on the evaporative condenser of the refrigeration plant. This creates a saving in water and chemical water treatment costs of approximately euro 6.000,-- per year.

Organization
The project is implemented by IBK Koudetechniek B.V. (IBK Refrigeration) in Apeldoorn.

Financially
The simple pay back time is approximately 4 to 5 years. The project is subsidized by reduction of companies taxes according to a Dutch energy efficiency investment program.

Lessons learned
The three boilers were initially integrated in the hot water system of the heat pump. Severe calcification took place in these boilers, causing break downs. For this reason the boiler water loop and the fresh water loop through the heat pump were separated by a plate heat exchanger. Water quality have to be checked to be able to control calcification of heat exchangers during heating.

NL-14 AVEBE STARCH

Summary

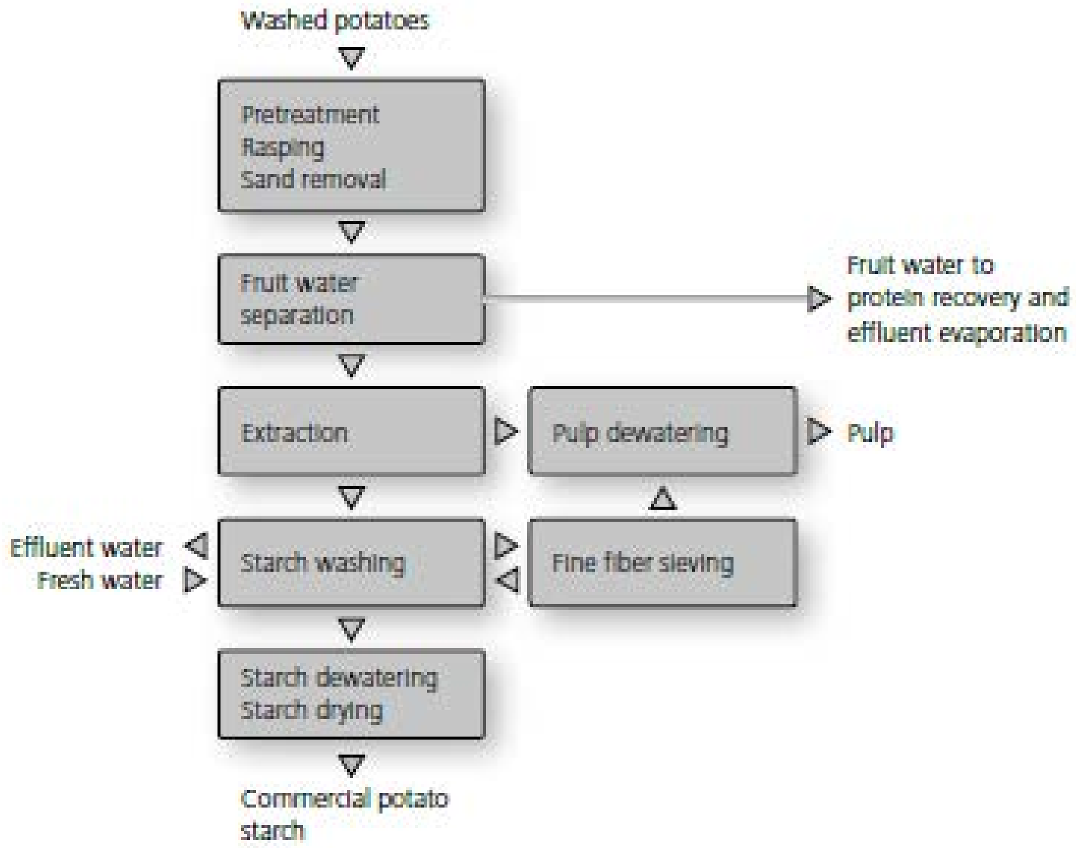
AVEBE, founded in 1919, was at first a marketing and sales organisation for several independent Dutch potato starch co-operatives. The word AVEBE is an abbreviation of Aardappelmeel Verkoop Bureau (Potato Starch Sales Office). As a modern international co-operative, AVEBE translates the concept of integrated chain management into practice with direct management of its members/ suppliers.

Potato starch is used everywhere. Worldwide. Potato starch products are indispensable in the food, paper and textile industries. It is impossible to imagine life without them in the adhesives and animal feed sectors. There are also many other less well-known applications for potato starch, such as in building materials for example.

The mission of AVEBE is to maintain a sustainable operation for our shareholders, which is in compliance with the standards in the process industry. Finally, for the Dutch locations, the following main topics have to be mentioned:

- AVEBE has signed the longterm Energy Agreement to become one of the world's most power-economical companies.
- There is also a Benchmarking Energy Efficiency Agreement, in order to become one of the world's most energy-economical companies.The studies arising from this also have an international tint.
- AVEBE has set up and maintain a certified management system for reduction and control of CO2 emission.

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



Project information

Company	AVEBE
Location	Ter Apelkanaal
Process application	
Type of heat pump	MVR
Capacity	2.7 MW
Running hours	4500
Year of operation	1990
Primary energy savings	5.6 million m3 gas
Reduction in CO2 emission	10,092 tonnes of CO2
Maintenance costs	
Manufacturer/supplier	A.Pillar from Osterode, Germany
Pay back	

Project characteristics and process design of installed system

Once the potatoes have been broken up and the sand removed, the fruit water is separated by a decanter. The starch is then extracted followed by washing. The washing line consists of 3-phase nozzle separators in three stages working on the counter-current principle, fresh water only having to be supplied to the last stage. The separators separate the starch milk into the fractions starch, fine fibers and water.

In this process, use of 3-phase technology ensures a high starch yield in top-class quality.

After the last washing stage, the starch arrives for dewatering via a buffer tank. The fine fibers leave washing in the first stage for fine fiber screening.

The washed and concentrated starch milk is dewatered and then dried by decanters. The fine fibers and the pulp from the extraction screens are dewatered by a decanter. The dewatered pulp can either be dried or extracted from the process and used as a feed immediately downstream of the decanter.

Evaporation plant for the concentration of potato fruit water, consisting of two identical lines; each line with a single-effect falling film evaporator as pre-evaporator, heated by a mechanical vapour recompressor, as well as a 3-effect falling film forced circulation finisher, heated by a thermal vapour recompressor (Brochure GEA-WIEGAND)

NL-15 MVR FOR SLUDGE DRYING AT SOPHUS BERENDSEN TEXTIEL IN APELDOORN (NL)

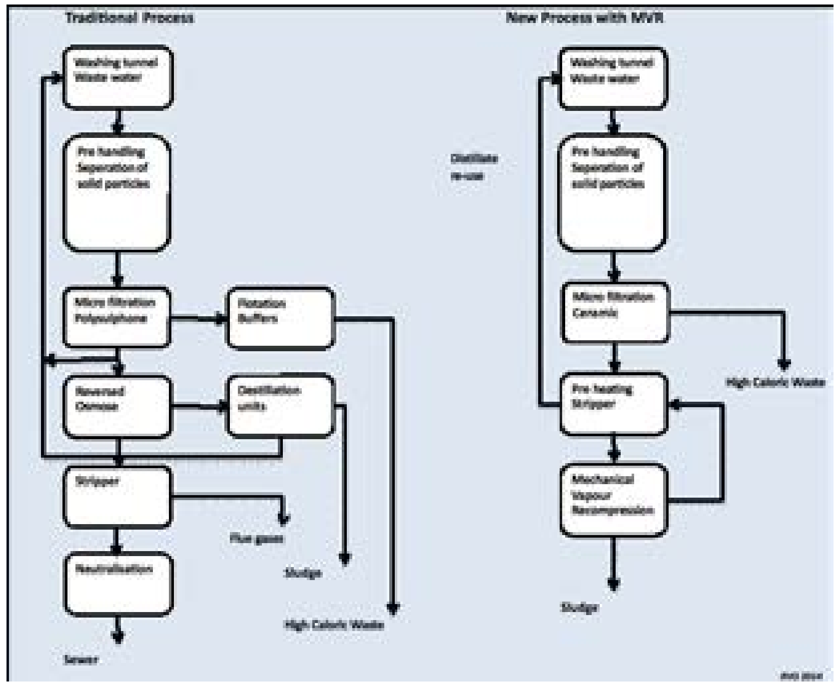
Summary
Berendsen Textiel in Apeldoorn is an industrial washing plant for industrial cleaning cloths. The evaporation of watery sludge streams is done through a process of mechanical vapour recompression and has replaced a process of water treatment with reversed osmosis.
Berendsen handles 200.000 cleaning cloths per day. The processes are ISO 9001:2000 and ISO 14001 certified and the company has been awarded the FTN energy award and the MVO innovation award.

Process description
At the moment of renovation the company was looking at expansion from 1200 tonnes to 3000 tonnes of cloth handling with technologies that could increase the economy by reducing operational and energy costs with a special focus on the waste water streams.
At the industrial washing process waste water streams are released containing heavy metals, hydrocarbons and other polutants, like chemicals. These waste water streams are purified first by pre-cleaning units consisting of polysulphone micro-filtration and reversed osmose untill the needed effluent quality is achieved. The sludge concentrate from the reversed osmose, with a 33% concentrate, was further condensed by a steam driven evaporator. Per m3 of effluent about 1 ton of steam is needed. The the waste water from the osmose stage is drained to the local sewer system. This original process was state of the art in the nineties, but was energy intensive and highly sensitive and costly on maintenance, especially on the cleaning of the membrane section. The overall energy use at a capacity of 1200 tonnes cloths handled was 586.000 m3 of gas (20TJ).
In the new process the polysulphone micro filtration is replaced by ceramic filtration which gives considerable reduction in maintenance. Next to that the steam driven evaporator is replaced by an evaporator with mechanical vapour recompression. The condensate from the MVR is used as pre-heating for the washing process. The new process saves 90% on the use of water and 1.162.000 m3 of gas, being 86%.
The total investements in the project

Project summary/information

Company	Sophus Berendsen
Location	Apeldoorn, Netherlands
Process application	Sludge drying process for cleaning cloths
Type of heat pump	MVR
Capacity	
Running hours	8650/year
Year of operation	October 1998
Primary energy savings	40T/year
Reduction in CO2 emission	kton/year
Maintenance costs	
Manufacturer/supplier	
Pay back	2 years

for extension of the process were € 1.434.250, whereas the additional investments for the MVR was € 454.550. The savings on energy are € 221.150 and on operational costs € 172.750. Additional gain is the lesser use of cleansing agents in the process.
Technical development by USF Waterbehandeling Zoetermeer and MVH Partners in Pollution Control at Uden.



Evaluation of heat pump
The heat pump as described in the original factsheet and in its original design is stil in use and makes 6000 running hours per year. It is running at 50 – 100% partial load.
Every week the heat pump is stopped to be able to clean the heat exchangers while once a year the heat exchanger are replaced by new ones.
Maintenance is done by in-house technical service department with the main attention at the heat exchangers and the composition of the waste water.
The company does not have figures on the running efficiency of the heat pump.
In the start up the main problems were with the fouling of the heat exchangers

NL-18 CIGAR FACTORY AT SCM-TDC IN KAMPEN

Summary
SCM was founded by the Van der Sluis family and was the first company of what has become the ITM Group. For most of its history, SCM traded in second-hand cigar machines. TDC originated in Switzerland and was taken over by the ITM Group in 1997. All activities of TDC were moved to ITM's home town of Kampen. SCM and TDC together have 60 employees.
SCM and TDC share the same building in Kampen together with ITM Group's headquarter. The same building is home to the ITM spare parts centre. SCM maintains their stock of over 1000 used cigar manufacturing machines at GTS/SCM, S.A in the Dominican Republic.
Through its long history in trading and upgrading cigar machines, SCM has vast experience with virtually any type of cigar manufacturing machine on the planet. Apart from trading in used and refurbished cigar machinery, SCM also develops its own high-speed cigar manufacturing production lines, for which parts are being built in various sites within the ITM Group.
TDC builds machinery for roll-your-own and make-your-own products, as well as snuss and molasse. Being one of the pioneers in its field, TDC has established itself as a leading expert on tobacco products that do not fit in the cigar and cigarette domains.
Being true to our historical roots, the ITM Group still owns the "Olifant", the only remaining cigar factory in Kampen (where there once were at least 100). Here, the tradition of cigar making is maintained with old machinery in an old building in the center of and old town. The site is also used to train new operators and mechanical engineers on the basics of the cigar manufacturing trade.

Project information

Company	SCM-TDC
Location	Kampen
Process application	Process (clean room) nand space
heating	
Type of heat pump	Electric compression heat pump
Capacity	2 x 60kW
Running hours	3000
Year of operation	2013
Primary energy savings	
Reduction in CO2 emission	
Maintenance costs	
Manufacturer/supplier	Viessmann
Pay back	

Project characteristics and process design of installed system
In the renovation project for the manufacturing location in Kampen the goals were to be as sustainable as possible based upon economic principles. The first option was to build a completely new manufacturing hall but in the end it was decided te renovate the existing premises. In the original halls a capacity of 1.4MW gasheaters were installed with a high temperature hydronic heating system.

In the renovation of the building and the process energy use the measures taken were:
- Insulation of existing halls and roofs
- Internal lighting by LED
- Split in high temperature heating where needed and low temperature distribution system
- Heating and cooling of different sections simultanious
- Installation of clean room as test facility with high humidity for cigars fed by two air handling units

Extension of office space with new front building
For the energy systems were installed:
- Wood pellet heater of 200 kW for the higher temperatures by Estava Hargassner
- Two electric compression ground source heat pumps of each 60 kW by Viessmann with an open aquifer ground source ATES system
- Gas boiler of 400 kW
- Solar pv 2000m^2 and 80 kW
- Energy storage tank of 5m^3

The high temperature distribution is fed by the gasboiler of the wood pellet burner, where it is also possible to feed the low temperature system by the heat generators.
The energy installation is completely monitored as random spot check on line by the installer Doorgeest Koeltechniek from Heino. SCM-TDC itself run the installation on the basis of best costs by monitoring on line the energy costs of the different heat generators. The generator with the lowest costs is preferred. An online costs overview on the day of our visit showed:
- Gasboiler € 14.80/GJ
- Wood pellet burner € 8.19/GJ
- Heat pump € 5.84/GJ

The costs for the wood pellets are monitored at the feed of the burner where the net heating value is determined.

NL-02 COMPRESSION HEAT PUMP FOR BRINKS - VRIEZENVEEN

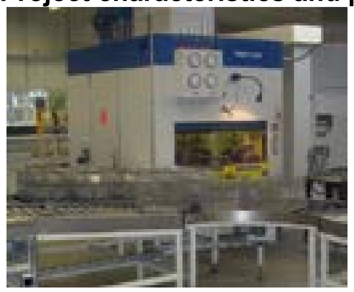
Summary

Brinks Metaalbewerking BV. is one of the leading European suppliers of hydraulic valve blocks and components to meet the needs of the:

- Automotive Industry
- Agricultural Industry
- Machine and Engine Construction
- Renewable Energy

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

Project characteristics and process design of installed system



The thermal deburring method (TEM) guarantees the removal of burrs both internally and externally. Burrs are removed from components manufactured by metal removal machines, but also from injection moulded components. The components to be deburred are placed in a high-pressure chamber. In the closed chamber a mixture of oxygen and gas is ignited and the heating temporarily applied causes all the burrs to burn.

Within these processes of deburring the ignition gives high temperature heat up to 3000oC which in the original process was actively cooled down bij a chiller placed on top of the high-pressure chamber. This conventional chiller had R22 as a refrigerant.

In the first meetings between the Teunis Industrietechniek, the comapny servicing and mainteaining the utilities of Brinks, and Dutch Heatpump Solutions, the discussion was about reducing the high maintenance costs and the removal of R22 at the spot.

On the three burr machines were cooling appliances of 7.5 kW and the piller machine was mounted 30 kW cooling capacity, with an average COP of 2.2.

The focus widened to integrating the heat and cold demand of all processes with a heat demand very close to the deburring in the pickling process. Pickling is a metal surface treatment used to remove impurities, such as stains, inorganic contaminants, rust or scale from ferrous metals, copper, and aluminum alloys.[1] A solution called pickle liquor, which contains strong acids, is used to remove the surface impurities. It is commonly used to descale or clean steel in various steelmaking processes. The pickling baths need temperatures of 70oC while also the heating of the factory building (shop floor) in wintertime is Soon thoughts were on a design where a heat pump refrigerant circuit can feed Brinks TEM-machines for cooling. At the same time, it can upgrade the heat from the same heat pumps from the returntemperature of the cooling system to heat the pickling. At these processes much heat is released, which requires an active cooling of the machines. Elsewhere in the factory special pickling must be warmed up properly.

The solution to the cooling process consisted of removal of the individual chillers. In its place, came the construction of a cooling circuit by which the burr machines can be provided and kept at the right temperature. The cooling circuit was based on two Ochsner water/water heat pumps of 25 kW each. They are cooled indirectly through a tank of thousand liters, from which the cooling circuit is powered, that a constant temperature of 16 to 18 º C can be maintained. At the same time , on the other hand, the heat from the return pipe of the cooling circuit is also discharged in a tank of 1000 liters. This warm water has a temperature of about 50 to 55 º C. The design calculations showed that when the cooling process is based on that 20º C, the heat should be about 50º C.

This temperature is not high enough for the pickling baths, where a temperature of 70º C is needed. But to achieve the highest possible return on the cooling process there is chosen not to further

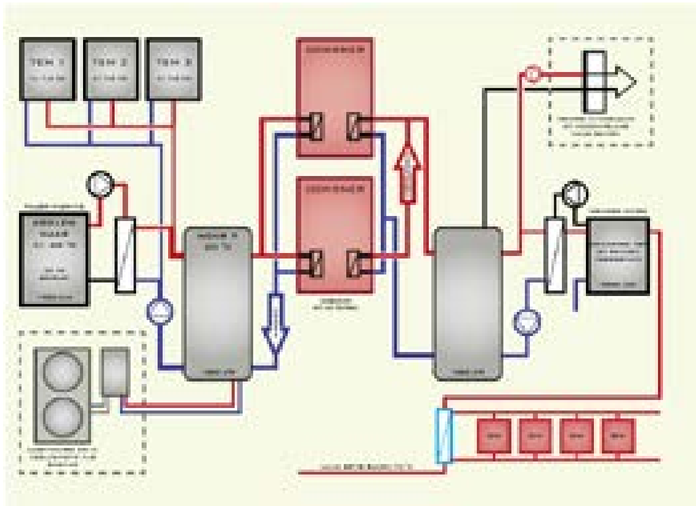
Project summary/information

Company	Brinks Metaalbewerking
Location	Vriezenveen
Process application	Heating pickling water from the cooling function of the thermal deburring process
Type of heat pump	Compression heat pump
Capacity	2 x 25 kW
Running hours	
Year of operation	2013
Primary energy savings	
Reduction in CO2 emission	
Maintenance costs	
Manufacturer/supplier	Dutch Heat Pump Solutions
Pay back	

increase the output on the heat-side. Therefore, the water of 50° C from the heat buffer goes first to a vessel with osmosis water, which is then reheated to the required 70º C by boilers. This requires considerably less energy than heating the osmosis water with only boilers. Until recently seven osmosis water boilers have been finished, each with an output of 30 kW. Now the use of these boilers can sometimes be reduced to two devices.

The heat of Ochsner heat pumps have in normal use in a ‘normal’ climate control a COP of 4. With the higher source temperature, the COP in this application is 4.5 to 5. With energy rates of 5 cents per kWh and 50 cents for one m3 of gas costs for conventional cooling, the total amount will be about 45 kWh € 9.000/year at 8600 operating hours. Assuming that the heat pumps are installed for heating the pickling and the cooling of the deburring is residual.

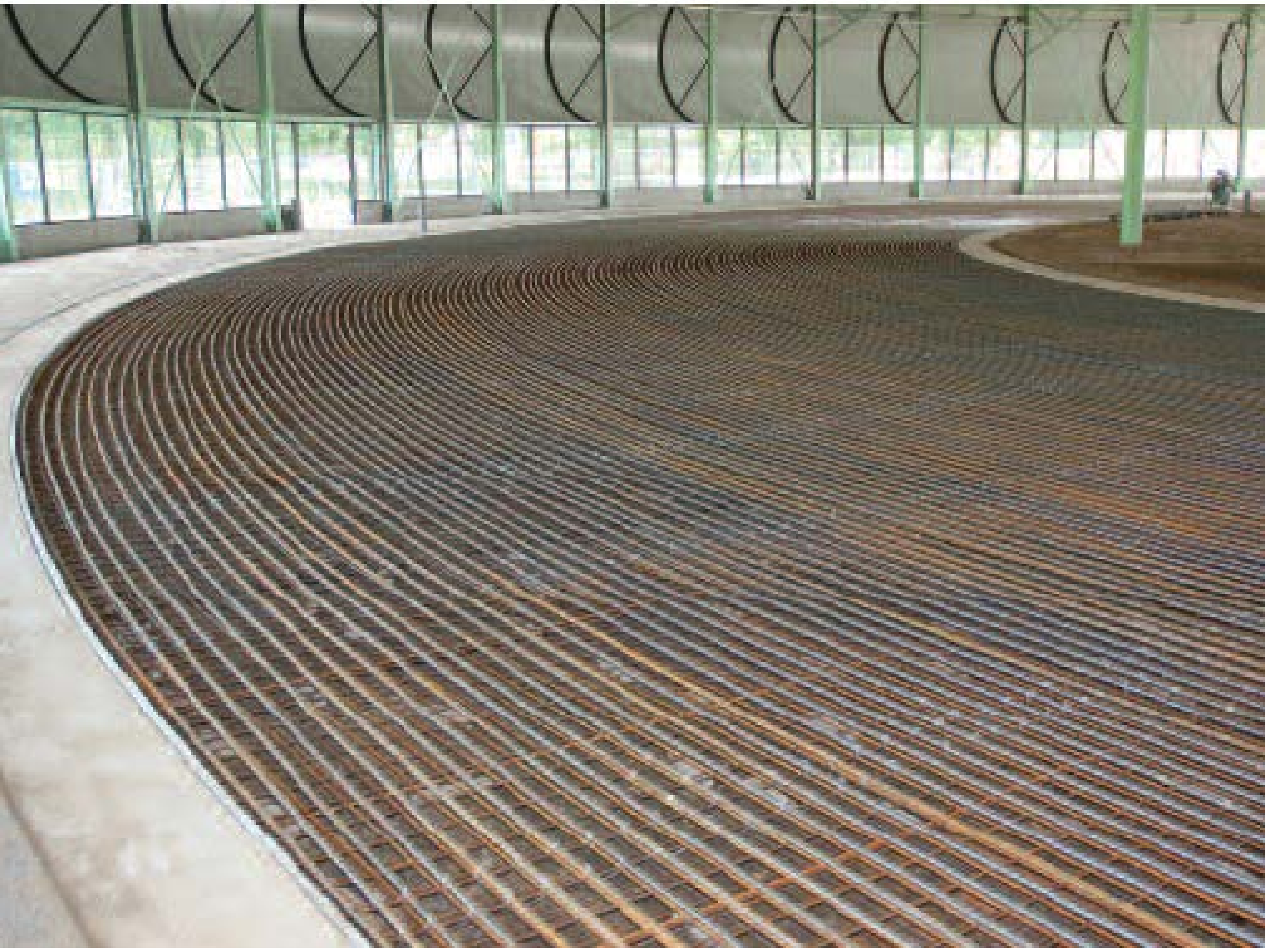
Also on the side of the heater, there is a saving. Assuming a gas price of 50 cents per cubic meter, converted one sits at a price of 8 cents a kWh of heat from gas. And because the COP of the heat pump in this configuration in the most conservative case is 4, the hot water for pickling heated at a price of 5 cents divided by 4 is 1.25 cents per kWh. Thus, heating the water through the heat, in this case a capacity of 50 kW, is six and a half times as cheap as with gas-fired boilers. The calculations have been made, it appears that the company, because it is in a constant process instead of boilers, also saves about 6,000 euros per year on the gas bill. If the cooling and the heating power of the ‘heat - recovery process ‘ is added together and divided by the input power, the system returns will be 8- to 10-fold. These savings are an investment in the conversion and optimization of the cooling and heating system. Besides the heat, there were also two buffer tanks and a cooling pipe work. Outside on the roof a split unit Mitsubishi Electric has been installed set that is associated with the Hydro Module Dutch Heatpump Solutions in the technical area. The air/water heat pump system can deliver 25 kW cooling capacity and thus act as backup when the primary heat from Ochsner fails or temporarily is out of service for maintenance. Then there is also created the possibility for the primary heat pump system to supply heat to a heater in the warehouse. This was an industrial building that previously had no space. Especially in the winter it was uncomfortably cold in this hall . Now the client can choose to also heat it. This heating unit is a good ‘exhaust’, should there be no heat required for the pickling process and the buffers are full. And to ensure that the heat pump can also lose its heat on hot days when the warehouse needs no heating, it is using the same heating unit achieved by a fan outlet to the roof. A simple thermostat determines whether the heating unit heats the warehouse or if he discharges the heat to the outside air.



NL-20 ICE SKATING RINK IN ENSCHEDE

Summary

In October 2008 a new indoor skating rink was opened in the city of Enschede. The refrigeration plant for this skating rink was designed, delivered and installed by IBK. CO_2 was chosen as the secondary refrigerant. CO_2 is easily detectable, sustainable and - above all -very energy efficient, since less pumping energy is required and pipes with a smaller diameter can be used. The residual heat of the refrigeration plant is used for the Zamboni, for the CH block and for the unique floor heating system, which is located under the skating rink.



Project characteristics and process design of installed system

Systabo as projectdeveloper has decided to install a large cooling capacity of 1.9 MW. In the engine room two NH3 screw compressors were installed both with 350kW electric motors. This large capacity is only needed in the fall when the ice floor of the skating rink is made. As soon as the 3 cm ice floor is made and the first skaters are welcomed only one compressor can maintain the quality of the ice floor. The frequency controlled chillers can easily run in partial loads. Ammonia was chosen as refrigerant because alternatives like R507 and R410a have an energetic bad performance and a high GWP factor.

Looking at other ice rinks a glycol or salt/water mixture is obvious as a secondary refrigerant. Gradually when the building arose, however, the idea to use in the secondary circuit emerged: use CO2 as refrigerant. This had some great advantages. The steel pipes under the ice functioning as an evaporator, causing the temperature in the whole ice surface, would remain intact. In addition, the pumping of natural carbon dioxide takes much less pumping energy, while pipe sizes may even be smaller. Due to the high pressure (30 bar) plastic pipes are taboo; these shall be of steel.

Project information

Company	IJsbaan
Location	Enschede - Netherland
Process application	
Type of heat pump	Compression ad on
Capacity	350 kW
Running hours	
Year of operation	
Primary energy savings	
Reduction in CO2 emission	
Maintenance costs	
Manufacturer/supplier	IBK
Pay back	

The mechanics had as many as 6,000 welds to choose to connect. The steel pipes of 12 meters formed a total of 66 kilometers. Ammonia (-15 ° C) from the primary circuit absorbs the heat from three cascadecondensors of the CO2 in the secondary circuit. The pressure is between 28 bar (-7° C) and 30 bar (-4 ° C.

Utilization of waste heat is the second part of the cooling system. Immediately after the oil separator there is a compressed gas cooler, when the heat is at a high temperature from the refrigerant ammonia. With this heat filtered source water is heated to about +50° C. The water is needed for the mop machine, regularly scraping the ice and warm water sprays on the ice so that there will be a nice smooth skating rink created. It is also fully utilized. Two wells will scrape the ice thawed by heat from the refrigeration system, and then used as makeup water for the evaporative condenser. Heat from the oil cooler (max. 235 kW) of the screw compressors and heat (up to 175 kW with ammonia as refrigerant) is used for heating the heating block in the air handling unit (45.000m3 / h) on the ice rink. By post-heating, the temperature of the hall can be maintained at a comfortable value of about +8° C to +10° C. If the chillers do not provide heating power in the low season when there is no ice surface, the heat is extracted from the outside air.

The Ice Rink Twente is also unique in another respect, for there is underfloor heating beneath the ice. This is necessary in order to prevent freezing. The expanding water can cause damage to the building structure. “Especially when the ice for more than six consecutive months is,” says Kremers. The heat for the heating comes from the oil cooler.

Design and installation process

In consultation with the client Systabo it was decided to install some 1.9 MW relatively large cooling installations. The cooling plant had two NH3 screw compressors, both with an electric motor of 315 kW. That great power is still only required when creating the ice in the autumn. Once the 3 cm thick ice floor is beautiful and there in the first skaters their laps, a compressor can handle it. Even in part load, for by frequency controlled motors is possible. The choice of refrigerant was quickly made. “Ammonia” says Kremers without hesitation. “Alternatives such as R507 or R410a are energetically worse and also have a high GWP-value.”

NL-22 SIMULTANEOUS COOLING AND HEAT GENERATION BY HEAT PUMPS IN A DISTRIBUTION CENTRE FOR FRUIT AND VEGETABLES

Project characteristic

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

Project description

Bakker Beheer Barendrecht BV has built a distribution centre for fruit and vegetables including a new office in 2001. The distribution centre measures 100.000 m2 in floor surface with two temperature zones of 2ºC and 12ºC. The distribution activities are loading, unloading trucks, short term storage, repacking, bananas storage and ripening in chambers.

The total cooling capacity is 3000 kW. Roughly 2000 kW is installed for the 12ºC zones and 1000 kW for the 2ºC. Two ammonia screw compressor units produce cooling capacity, one for a glycol flow at 4 ºC at an evaporating temperature of 0 ºC, the other for a glycol flow at -6 ºC at an evaporating temperature of -9ºC. The two glycol systems transport the cooling capacity to more than 60 air coolers. The use of two evaporating temperatures increases the total energy efficiency. Each compressor unit is provided with two plate heat exchangers as condensers. One is cooled by a cooling tower; the other is cooled by a glycol flow, heating up this glycol flow up to 45ºC. The principle of the lay out is shown in figure 1.

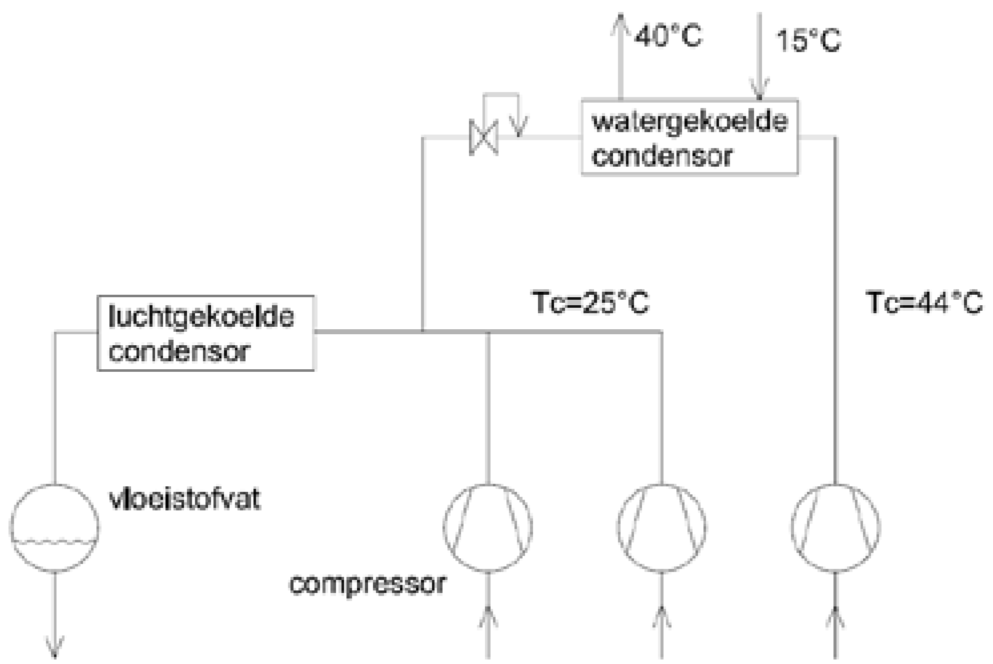


Figure 1 Combined condenser system of heat pump (upper right) and refrigeration installation.

In case heat is required the right side compressor goes into heat pump mode generating the heat for the glycol flow by increasing the condensing pressure. The other compressor remains running at a low condensing pressure, running as efficient as possible. This system produces 500 kW of heat in total. This is much more than can be delivered by the discharge heat from the compressors. Moreover, the cooling capacity of a distribution centre is very much depending on ambient conditions. In part load the amount of discharge heat only (approximately 15% of the condensing heat) is insufficient. The condensing capacity is therefore required.

The glycol heat is used for defrosting the 2ºC air coolers, heating up water, centre area and office heating and is used for ripening the bananas in 46 ripening chambers. The ripening capacity is high. Each ripening chamber would normally be heated by electric elements of approximately 12 kW or in an alternative design by hot water from boilers. The use of condensing heat generated by the heat pump is much more efficient than electrical heating or heating by boilers, despite the limited extra absorbed power increase due to the higher condensing temperature of the heat pump compressor. Not only the energy costs of 36 x 12 kW of electricity or boiler heat is avoided but also the lower investment costs for electrical equipment (power supply, transformers) or boilers.

The 3000 kW is generated with an extremely low ammonia charge of only 200 kg due to the use of plate heat exchangers for evaporators and condensers. See figure 2.

Organization

The system is designed by KWA Business Consultant B.V and built by the refrigeration contractor Koeltechniek Dorenbosch in Vries.

Financially

Since there are savings in electricity and gas, all savings are converted to gas equivalents. The equivalent energy saving is approximately 200.000 m3 natural gas per year. There is hardly any gas consumption left. The extra investment costs for the heat pump function and warm glycol system are € 140.000,-- not taking into account the avoided investment costs in electricity installations. The simple pay back time is therefore 2,3 years. The energy efficiency increase with the heat pump for the total distribution centre is 15%. The project is subsidized by reduction of company taxes according to a Dutch energy efficiency investment program.

Lessons learned

The heat pump was a relatively new application in the fruit and vegetable sector. After analysis of feasibility and a brief process of convincing in the early beginning of the project, the end users, engineers and all parties that were involved became enthusiastic. They start contributing with ideas that save extra energy and reduce investment costs. Without all parties with one focus, the final result would not be as efficient and effective.

Splitting of compressors and condensers and using part of the refrigeration installation as heat pump is not common engineering within the refrigeration industry, despite the fact that all equipment and knowledge is available. The reason is that refrigeration contractors are not familiar with the heat demand and installations for heating in industry.

Heat pumps have the best feasibility in new built plants. Each new project should take a heat pump into account, always in competition with other techniques of course.

Figure 2: Industrial cooling/heat pump installation Bakker Barendrecht

Project summary/information

NL-23 INDUSTRIAL BUSINESS AREA ECOFACTORIJ APELDOORN

Ecofactorij in Apeldoorn is an industrial business area south of the City of Apeldoorn. The local authorities have the policy to develop this area as sustainable as possibly by creating the right boundary conditions for settling new companies. This has been described in the “Kwaliteitsplan Ecofactorij” (Qualityplan Ecofactorij). By investing in sustainability and renewables points are given with which rebates were given on the price of land.
Energy is within this sustainability approach an important topic as almost 40% of the point could be gained by investing in these. This has resulted in the fact that 80% of the companies and buildings are equiped with heat pumps and 20% with bio-pellet heating. As the business area is near the traffic junction A1/A50 in the middle of the country, logistic service providers like Sandds, Sils, Harbers and Grolleman Cold Store are settled at the Ecofactorij.
Some of the conditions are mandatory conditions like using green electricity and….
Initially the idea was to cluster companies on connecting to a common infrastructure of heat, waste heat and annual thermal energy storage with heat pumps. In the end the slower than expected developmemt of the area and the larger than expected attraction for logistic distribution centres changed into an approach to individual sustainable and renewable solutions.
In the Netherlands other industrial areas are getting more and more sustainable. Information can be found on: www.energiezuinigebedrijventerreinen.nl.

Process descriptions
Underneath some of the companies are described not in detail but more as a general impression.
Information Centre Ecofactorij. This information Centre run by the consultancy of Sparkling Projects has many technical innnovations in its building.

The main heating and cooling demand is covered by Phase Change Materials integrated in the floor heating system and the walls. A wood pallet burner is used for extra capacity. For 1.000m2, the yearly consumption is about 8 tons pellets. For additional cooling a dew point cooling system has been installed. 6.000 m3/h per hour is cooled by indirect evaporation of water. The air is cooled to the dew point. In the Netherlands, the dew point is always below 19°C, so the air is cooled to 19,5°C. The yearly water consumption is 50 to 60 m3.. Several companies working on renewables, innovation and sustainabilty are accomodated in the building, which also gives ample space for special meetings. Amongst these companies is **Energiebedrijf deA (Apeldoorn) BV** (www.de-a.nl) The main activities for the local Energy Company deA are the production, distribution and trading renewable electricity. Another one is Stedendriehoek Innoveert (www.stedendriehoekinnoveert.nl), the local sustainability and innovation centre for enterprises, and also Maas en Hagoort, (www.maashagoort.nl), supplier of lighting systems. .
Harbers Volvo Trucks Apeldoorn has a new premises at the Ecofactorij.
A garage for commercial Volvo trucks and vans of 4400m2 has six large gates and has been expanded with a semi-trailer and body work department of Thermoking. The complete building is heated and cooled with a set of ground source heat pumps supported for peak loads by a gas boiler.

The capacity of the heat pump is 87 kW. The maximum heat ing demand is 237 kW. The heat pump covers about 80% of the heat load. Gas boilers deliver the extra heating at temperatures below 0.

Project summary/information

Company	Bedrijventerrein Ecofactorij
Location	Apeldoorn
Process application	Various companies
Type of heat pump	Compression heat pumps
Capacity	560 kW offices/logistics (8 systemen) 300 kW process water 590 kW heat recovery cooling installation
Running hours	About 2.500 hours for heating/year and 2.500 hours for cooling/year. In processing about 6.000 hours/year
Year of operation	2002
Primary energy savings	Offices/logistics: 40% in heating and 70% in cooling. Equals 150.000m3 gas/year Process: 400.000 m3 gas eq/year
Reductions in CO2-emissions	About 1.000 tons/year
Maintenance costs	
Manufacturer/supplier	Diverse
Pay back	Between 5 and 10 years

Huisman van de Scheur Logistiek
After the merger of the transport companies Huisman and Van de Scheur into HSL Logistiek is the existing logistics centre erected in 2008 enlarged with a Crossdock and Warehouse. A second independent Crossdock will be built.

The building now has 770m2 of office space, 10.000m2 crossdock and 50 docklevellers and gates. The building has a living room, movie theatre and dormatories for stop over truck drivers.
Sustainability is realised by automatic sun shading. thermal storage in the building mass. Heating and cooling is with ground source heat pumps and ATES system. De heat in the first building (2007) is delivered by a heat pump. This Clivet 22 has a heating capacity of 75 kW and a cooling capacity of 62 kW. The maximal capacity of the source is 9,9 m3/h. Next to the heat pump, there are two gas-fired boilers present. Heating is being done by a combination of floor heating and vents. Only the server room has a separate air conditioning installed.
At the second building (2011) heat is supplied by a Clivet WRH242 heat pump with a heat output of 94 kW. The power consumption at full load is 18.2 kW. The heat pump is connected to a source with a maximum capacity of 9.9 m3 / h. The heat pump provides the entire heating. Heating is provided by a combination of heating and a fan. An HR boiler acts as a back up for the heat and jumps as necessary on cold days at.

ITB-Kwadraat Apeldoorn, Ecofactorij
ITB2 Data centers have their data center at industrial Ecofactorij opened a few months ago. The carrier-neutral data center occupies 1500 (3x500) m2 net floor area colocation and is built according to the company’s energy - efficient and environmentally friendly attitude (with a calculated energy efficient PUE of 1.08 , using wind energy and renewable materials).
ITB-Kwadraat is the 1st data center in the Netherlands that was built without using compression cooling. Linthorst implements adiabatic cooling in combination with a redundant pipe that runs from the air conditioning units to the watermeter space. To ensure 99.999 % reliability the cooling of a data center requires additional backup. If the pressure in the public water supply is cut off, there is always water buffers to ensure the continuation.
An open source system (HCS) and heat pump heats the offices in the winter and cools the spaces in the summer. Release of the energy is carried by underfloor heating and fan coil units (cooling). A

high efficiency (HR) heat recovery ensures that the office will be ventilated. The offices are suited with sustainable LED lighting .

Sustainable technologies
- Heat and cold storage (TES)
- Heat recovery unit (HRU)
- Heat pump
- LED lighting and presence detectors

VDL Weweler

On Friday, 29 November 2013, suspension systems manufacturer VDL Weweler opened their new building at the Ecofactorij industrial estate in Apeldoorn (NL). This expansion was necessary due to the tremendous growth the company has undergone in recent years and anticipated future growth. The new VDL Weweler premises, which cover some 22,000 m², are also fitted with a completely new production line.

After nearly 50 years of operation on the Kayersdijk in Apeldoorn, VDL Weweler has found a new home at the Ecofactorij, an industrial estate that maintains strict sustainability standards. The new building consists of eight halls, each approximately 2,500 m². Production of the suspension systems and axles will take place in four of these halls, while the other areas will be used for assembly, shipping and offices. Residual heat from the production process will be used to heat the floors in the shipping area, and a ground source heat pump will heat and cool the offices.

New production line

VDL Weweler designed the new production line and carried out all the automation work themselves. The new system integrates various processes, previously performed separately due to space limitations, to form a single line. Now that the springs will be hot-formed (rolled and bent) and then tempered (hardened in an oven) in a continuous process, the residual heat from the first step can be reused in the second. This will cut energy requirements by 35% and significantly reduce production time. Another important benefit of the new production line is the ability to perform 3D forming, making it possible to build a suspension system with fewer parts that is both lighter and easier to assemble.

The office is heated with a CIAT DYNACIAT LG / LGP 300V R410A. It has an energy efficiency of 5.33 measured according to EN 14511. The source has a cooling capacity of 230 kW. The heating capacity of the heat pump is 81 kW. The additional heat is supplied as waste heat in the production process.

Grolleman Coldstore Apeldoorn, Ecofactorij

In 2004, Cofely realized a concept for Grolleman Cold Store on sustainable industrial Ecofactorij in Apeldoorn. This freezing house has no gas and operates entirely on the heat released from the freezing process. Besides Cofely the installer Linthorst took care for all mechanical installations. Rainwater is collected and used as process water with water from a drilled well. This water is stored after treatment in huge storage tanks where it is heated by the energy released from the freezing process continuously. In 2011, IBK Refrigeration received contract for the extension. Grolleman makes with residual heat from the refrigeration cleaning hot water. One of the NH3-piston compressors may be placed in a heat pump mode. Than a portion condenses at about 50°C and heats the water. Phase 1 consisted of 180 kW and 220 kW heat pump. Phase 2 is expanded to 390 kW extra heat. Total capacity is now 570 kW and 220 kW waste heat pump.

Sandd Head Office and central Sorting Hall

Sandd was in July 2008 the first postal company in the world that fully operates climate neutral. The total CO2 emissions caused by the Sandd is fully compensated and reduced where possible in cooperation with Green Balance. Green Balance advises in the area of sustainability and helps organizations create carbon neutral CO2 emissions. Climate neutrality is achieved through energy reduction, energy efficiency , use of renewable energy and offsetting unavoidable CO2-emissions. Compensation takes place through the use of CO2 credits arising from the production of renewable

energy. All CO2 reduction projects meet stringent quality standards, with a measurable contribution to the climate.
Sandd is located at the industrial Ecofactorij Apeldoorn. This industrial park is centrally located at the intersection of two major highways, the A1 and the A50. Ecofactorij is part of the policy of the municipality of Apeldoorn to make sustainability more work.
Within this policy, the guidelines to design and environmental responsibility and build. According to Ir. Ed Euser , director Artec Architects & Engineers, those guidelines include the reason for the “lifting “ of the office segment. This is the same surface area that will also provide room for parking. On the roof is an AHU (Air Handling cabinet) that has been fitted with heat recovery. Fresh outside air is filtered and warmed with a heating coil or cooled via a cooling engine for a given primary temperature and thus to the induction units on the wards transported.

SILS
Far beyond the borders of Apeldoorn people know the name ‘Streng’. It began with transporting tourists around on the Veluwe, a natural parc at the end of the 19th century. From here, a big logistics and transportation company emerged. The transportation-part had been sold in the early nineties. Also the logistic activities changed hands and formed the base of a new company: SILS, Streng Integrated Logistic Services (SILS). As customers increasingly focus on their own “core” in production or sales, they created the need for a logistics partner like SILS.
The activities are carried out since January 1, 2008 from the new logistics center Ecofactorij. In developing the distribution is acted in line with the commitments of SILS to as environmentally friendly possible to work. The development and realization is accompanied by IJsseldelta Vastgoed from Zwolle. The architecture is Buro Duck turned from Deventer.

The building of SILS consists of:
1 . The office with a floor area of approximately 583m2
2 . Central expedition of 1,650 m2
3 . A repackaging area of 600 m2
4 . 6 pallet warehouses of 1,000 m2

Heating and cooling is provided by two Viessmann heat pumps WW 254 with a capacity of 2 x 73 kW heating and 2 x 60 kW of cooling. The same heat pumps also provide heat and cold for the storage- and shipping-departments. It is an arrangement that demand from the office is leading. This is because the comfort requirements of the office are significantly higher than the requirements in the expedition-hall.
SILS is completely cooled and heated by the heat pump. There is no additional air conditioning or heating. The property does not have a gas connection. The province has issued a permit for a cold water storage of 25,200 m3 per quarter.

Breustedt Chemie
It’s an extraordinary sensation: a chemical transshipment in a sustainable environment. The construction of Breustedt chemistry is carried out in a building team, consisting Hesch Support

Courage architects , Breustedt Chemistry and contractor at the Stegge Twello. The new location of

Breustedt Chemistry consists of an office, shipping/storage, a production and a paved outdoor area with the required infrastructure.
When the construction of a chemical company building mainly revolves around the processing plants. For Breustedt Chemicals these are the facilities for the storage and distribution of chemical products. Hammer Installation develops and implements these plants, as well as cooling, heating, electricity and plumbing.
After an intensive preparatory Hammer developed in collaboration with Weber, the process plant. The liquids are deposited ‘freefall’ in storage tanks. From there they are transported to six dosing packages and also deposited ‘freefall’ in smaller packages. Subsequently, these packages go to the dispatch hall, in order to be distributed. The process plant is entirely in plastic. The bases and acids which are transported through the plant, must be kept separate. To this end, separate bins and sewer systems is realized.
Partly due to the sustainable location of Breustedt Chemie, Ecofactorij, Hammer electrical and mechanical installations worked as sustainable as possible. There is a heat pump system with source available. In the shipping room and offices is a system with heat recovery. Furthermore, there is presence-controlled LED lighting. All systems are controlled by a building management system, which again is linked to the access control. “Is there no one there , then the lights and heater.
Heat is supplied by a water/water heat pump with a heating capacity of 80 kW. The power consumption at full load is 20 kW. The heat pump is connected to a source with a maximum capacity of 10 m3 / h. The heat pump takes care of the entire office heating and PGS hall. The storage is heated with gasheaters. The gas consumption is less than 1,000 m3/year.

Lessons learned
Heat pumps with underfloor heating are a particularly pleasant way of cooling and heating of logistic buildings. These buildings are traditionally heated with air-heaters . Disadvantage in the standard calculations and consultancies installation is that the cooling function of the heat pump is included in the energy calculation. This while logistics centers naturally has no air conditioning and the savings thus does not apply.
The reference for heating logistic centers prepared by TNO and is 0.5 m3 of gas per year per m3. With a heat pump that decreases by at least 25%. With a concept in which the office is leading, and the production next creates a “mini smart grid”. The production area fills the overcapacity of the heat pump. With this , the additional costs are relatively low.

The choice for low temperature heating is seen less and less as a bottleneck. Requirement is that it is clear where machines or cabinets may be, without making damage to the net below.
In the savings computations consultants tend to reference on the conduct of the production halls. This differs from the practice and gives the heat pump a negative connotation. Entrepreneurs perceive this as “pushing” a technique .
In various projects at startup there have been problems commissioning. a heat pump. Commissioning in conjunction with a production hall, requires a bit more attention to the hydraulic system. To date, all the problems have been solved. It is therefore a matter of skill and workmanship if a heat pump solution works, not a matter of the heat pump itself.

At the business parc Ecofactorij there is no problem with interaction of sources, despite the relatively strong groundwater flow. When a new source is there, because of the proximity of the businesses, there is a lot of information exchange.
Currently the business parc is working on a Smart Grid application. The electrical network and fibreoptic-net belong to the companies on the parc. The heat pumps are suitable for controlling imbalance. There are several times a project submitted by NL Agency, but not approved. This causes a much slower pace.
In the development of industrial Ecofactorij in the second half of the nineties, the spatial vision was set. The main aim was to develop a high quality durable and large-scale industrial area, which is characterized by a spatial and environmental quality with a high feeling of quality by the user and future value, while maintaining and enhancing the quality of the current planning area as a link between the green wedge of Zonnehoeve/Groot Schuilenburg/Woudhuis/Bussloo on one hand and rural areas on the other. The vision is translated into a number of topics, which are mentioned in section 3.2.
Meanwhile, the development of Ecofactorij is largely completed , so the focus shifts to managing the business area. This has created an agenda to review the issues and to determine whether adjustment of the spatial vision is desirable .
Companies established on Ecofactorij meet the sustainability requirements. The intended reuse between companies of waste heat has so far only made a very limited contribution to the achievement. This proved difficult to implement. Reliance on conventional energy supplies stayed.

NL-25 BOVENDEERT WAREHOUSE IN BOXTEL NETHERLANDS

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

Process description
The applied LG Electronics Multi V Heat Recovery system plays an important role in the concept. It is a three -pipe heat-recovery heat pump system that can simultaneously cool and heat different rooms. The heat extracted in the cooling mode, is directly used for indoor spaces with a heating requirement. In total 4 LG Multi V outdoor units are situated on the roof and all connected as one system.
The outdoor unit is connected to 23 ceiling concealed duct units, which are connected to tailor made discharge jets. The system is also connected to 4 LG Hydro kits that are located indoor in the technical area of the property. The Hydro units provide warm water to feed the low temperature underfloor heating system. In this way the total climate system and the warm water preparation for the entire building is provided by the combined heat pump system and no gas is required.
Thanks to the advanced heat pump technology with inverter controlled compressors, this system with Hydro Kits saves up to 77 % energy compared to conventional heating systems. Due to hydro kits a 50%reduction of CO_2 emission is made. In order to ventilate the building efficient and effective, Elin Installations also installed 7 pieces of 1000 m3/h CO_2-controlled LG ECO-V heat recovery ventilation units.

The logical choice for the Multi V Heat Recovery system was done keeping in mind the heat and cooling demand of the warehouse as per the offices, loads may vary. Thus, this system can make the offices warm and comfortable and at the same time keep the shoes in the warehouse at a lower temperature and minimum humidity because they thrive better at it.

It was decided to optimize the control and operation of the units and climate system to be integrated into a building management system that is based on the globally standardized KNX protocol. The link between the heat pump system, underfloor heating and KNX has not previously been achieved in Europe. All system's parts are working together to optimize comfort, control and energy savings. For example, the ventilation units are controlled by KNX controlled CO_2 sensors. Presence and motion detection controls both the lighting and the climate, for each room or area individually. If there is no one in for an hour, the climate system is switched off or the heating system is switched to "low settings".

Project summary/information

Company	Bovendeert Shoes
Location	Boxtel
Process application	Warehouse
Type of heat pump	Air Source compression
Capacity	224 kW Cooling 252 kW Heating
Running hours	8650/year
Year of operation	2013
Primary energy savings	n/a yet
Reduction in CO2 emission	n/a yet
Maintenance costs	n/a yet
Manufacturer/supplier	LG – Centercon B.V. – Elin Installations
Pay back	Less than 5 years when compared to conventional installation with gas boiler and cooling only air-conditioner

In the evening the "all off" function switches the system to "Night mode", the lights and the air conditioning off and the alarm is triggered. In the morning, intelligent cooperation between systems provides an achievement of the desired temperature at the desired start time. When the underfloor heating system will not get to the desired value at the right time, the concealed duct units will support to reach the required temperature settings. System integrator Elin also created separate summer and winter settings in the system. In the summer the system does not heat, but the air conditioning cools all rooms. Such integrated smart control strategy is even more energy -saving than the also energy saving control strategy of LG Electronics Heat Pump system it selves.

Specifications of heat pump

Description	Heat Pump	Back up
Type		
Heating capacity	252 kW (Outside Air 7°C Inside Air 20°C)	
Cooling capacity	224 kW	
Power consumption	63 kW	
Heat source	Outside air minimal -25°C - Temp °C	
Refrigerant	R410a	
Compressor type	Hermetic Inverter Scroll 12pcs	
COP	4,18	
Operation hours	24hrs a day	
Storage water tank	1 m3 - 35 Temp °C	
Manufacturer of heat pump	LG Electronics, Korea	
Supplier/consultant	Centercon B.V. Rotterdam, Elin Boxtel	

Project characteristics and process design of installed system
- New build warehouse and office.
- Ability to fully exchange heat inside the building. Cooling offices and heating warehouse and vice versa.

NL-27 HEAT PUMPS IN GREENHOUSES

Summary
In the period 2003-2013, in Dutch horticulture approximately 40 growers of various crops have implemented heat pumps (most of them in combination with ATES – Aquifer Thermal Energy Storage) in their greenhouses. They comprise the following crops a.o.:

- Roses (2x)
- Tomatoes (3x)
- Orchids (Phalaenopsis) (8x)
- Freesia (2x)
- Anthurium (2x)

In the following, we present a factsheets concerning the application of heat pumps in Dutch horticulture in the production of tomatoes.
In the evening the "all off" function switches the system to "Night mode", the lights and the air conditioning off and the alarm is triggered. In the morning, intelligent cooperation between systems provides an achievement of the desired temperature at the desired start time. When the underfloor heating system will not get to the desired value at the right time, the concealed duct units will support to reach the required temperature settings. System integrator Elin also created separate summer and winter settings in the system. In the summer the system does not heat, but the air conditioning cools all rooms. Such integrated smart control strategy is even more energy -saving than the also energy saving control strategy of LG Electronics Heat Pump system it selves.

Project characteristics and process design of installed system

- New build warehouse and office.
- Ability to fully exchange heat inside the building. Cooling offices and heating warehouse and vice versa.

A Heat pump application at a commercial nursery for tomatoes
Project summary/information

Company name *)	Commercial nursery for tomatoes
Location / production area	Berkel & Rodenrijs; 54.000 m2
Process / Application	Growing tomatoes
Type of Heat Pump	30HXC285 Carrier
Capacity	1250 kW-th per heat pump, 3x HP in total
Operational hours	15000 hours = average of 5000
	per heat pump; 3 heat pumps operating
Year of commissioning	2003
Energy savings	29%
CO2 emission reduction	40-60%
Maintenance costs **)	N/A
Manufacturer / supplier	Innogrow
Simple Pay Back Time **)	14,9 years

**) Companies cooperated in this project on the basis of anonymity*
***) if such data are available*

Specifications of the heat pump

Type		water-cooled, condenserless chillers using screw compressors	
Heating capacity (total)		1250x3=3750	kW/unit (3 units)
Cooling capacity (total)		1100x3=3300	kW/unit (3 units)
Power consumption		240x3=720	kW/unit (3 units)
Heat Source	Temperature	20 °C	
	Flow	240 m3/h	
Supply		Temperature	42-50 °C
Refrigerant		R134a	
Compressor type		twin-screw compressor	
COP		5,2	
Buffer tanks		1800 m3 (3x 600 m3) at 55 °C (maximum)	

Specifications of back up system
Gas fired boilers are used to provide additional heat when the capacity of the other systems (ATES) is insufficient. It is also used to provide backup in the event of any breakdown. Two gas engines (CHP's of 650 and 300 kWe respectively) were used to generate electricity to power the heat pump and fans. The relative high temperature water produced by the CHP was used to heat the conventional (open) part of the greenhouses. However, due to market conditions in The Netherlands (low electricity prices / feed in tariffs) the CHP is used less and less.

Project characteristics of the company

- Description of the existing situation

Until 2003 this horticulturist grew his tomatoes in a traditional ('open') greenhouse using a combination of a gas fired boilers and CHP to generate the required heat. The total area of this greenhouse was 54.000 m2. No lighting is applied during the production, so the electricity consumption is relatively low.

- Description of the implementation of the heat pump

Cultivation of tomatoes in the new situation takes place in a (semi-)closed greenhouse, using a heat pump and ATES. This new concept is applied on 14.000 m2 of the total area of 54.000 m2 (40.000 m2 remaining as it was). By the end of 2003 this horticulturist –as the first grower in The Netherlands!- began to operate his ATES-system. The heat sink/source used at this company is an aquifer. Air humidity and temperature are controlled by a ducted ATU (Air Treatment Unit, see picture), using low temperature heat exchanger/heaters.

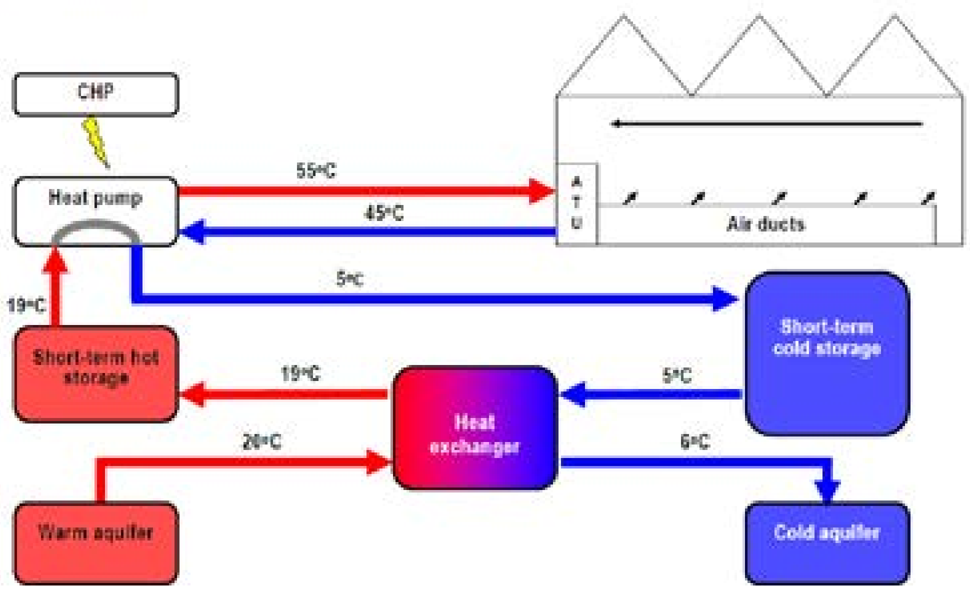

The company originally utilized the closed greenhouse (Gesloten Kas®) concept that was developed by the Dutch environmental/engineering consultancy Innogrow B.V.. The concept utilizes the fact that during the summer a greenhouse vents off more heat (solar gain) than it requires in the form of fossil fuel heat during the winter. Therefore, if the summer heat can be captured and stored until it is required during the winter significant reductions in fossil fuel use can be achieved. In the

summer cold water (6˚C) is drawn from a borehole and passed through water-to-air heat exchangers in the greenhouse. The recovered warm water (around 20˚C), is returned to the aquifer via a second 'warm' borehole. When heat is required during the winter a heat pump recovers the heat from the warm aquifer water boosting it to 45-55˚C. This in turn leads to the production of cold water (6˚C) that is stored in the aquifer and used the following summer for cooling. The concepts results in a heat excess in the closed section of the greenhouses which –after seasonal storage- is used in the other (open) sections of the greenhouse and is partially supplied to an adjacent greenhouse farmer (from October to April).
An important benefit of cooling in this way is that the vents do not open in the summer and CO2-levels can therefore be maintained at higher levels than would normally be possible. A significant yield (17%) increase results. A reduction in pest and disease incidence is also claimed due to reduced pest invasion (no venting) and more reliable, accurate and uniform temperature and humidity control.

- Graph (simple schematic of the installation)

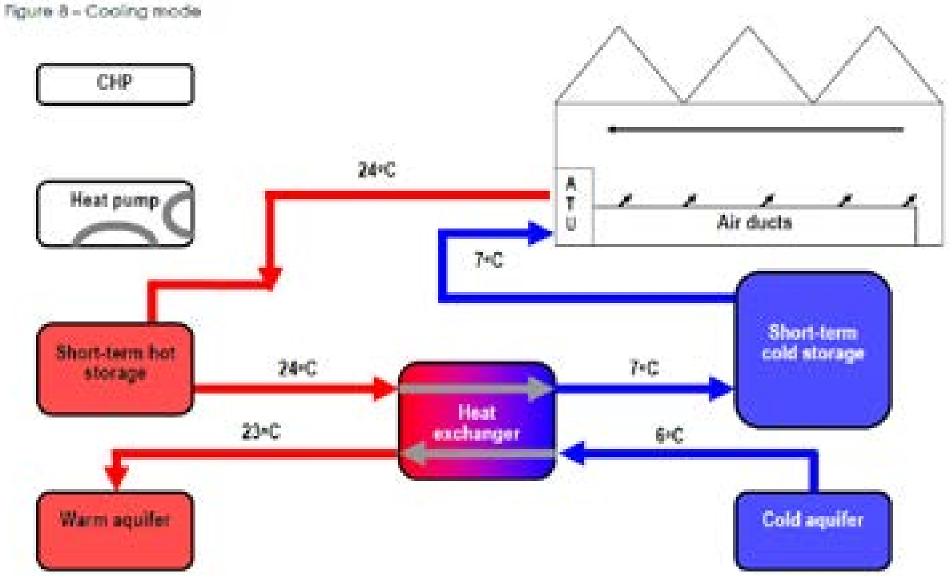
Installation at heating mode (during winter)

Figure 7 – Heating mode



Installation at cooling mode (during summer)

Figure 8 – Cooling mode



Running experience, savings and economics

- Energy cost savings: approximately 29%
- Energy savings: approximately 30-40%
- Reduction of CO2 emissions: approximately 40-60%

ITEM	
Investment costs	EURO/m2
CHP & aquifer	
ATU & heat storage	75
Total investment costs	40
Operating costs	115
EURO/m2 per annum	
Energy saving – 200 kWh/m2 (36% for entire nursery)	5,00
Increased yield (9% for entire nursery)	3,50
Minus extra annual costs (entire nursery)	6,50
Net gain	2,00

- Other savings i.e. less use of water, higher performance or yield of the system

The closed greenhouse concept results in better temperature and humidity control of the cultivation process and hence in an improved crop management. It also enables higher CO2-concentrations inside the greenhouses, which in turn results in higher crop yields (17% increase) and better crop quality. This also results in a 80% reduction of pesticide use, reduced pest and disease incidents.

Lessons learned

- Overall view of owner/user of the system: are they happy, would they do it again?
- In the next project the horticulturist would refrain from all unnecessary technology which makes the project needlessly complicated . For example, an additional "TSA" (heat exchanger) that allows him to add condenser excess heat to the warm side of the aquifer would not be installed in a next project.
- Essential to the success of the project is the quality of the aquifer and boreholes. Therefore, it is important to select an experienced and trustworthy "manufacturer" of boreholes.
- The application of an (ducted) ATU (for heating, cooling and dehumidification) instead of the traditional rail heating system enables the horticulturist to generate more air movement inside his greenhouse. These increased dynamics result in a more homogeneous climate in the greenhouse and especially a different micro-climate (relative humidity; RH!) at the micro-level of the plants themselves. The measured RH in the (bulk of the) closed greenhouse can therefore be maintained at a higher level than in traditional greenhouses: in this 'static' situation the plant itself experiences a higher RH than measured. Due to this the productivity can be increased by higher CO2-concentration, higher temperature and controlling towards maximum photosynthesis.
- The 'trick' of crop production in a (semi-)closed greenhouse is that it requires a totally different way of operating and production philosophy than in a traditional greenhouse: the horticulturist needs to learn to grow all over again.
- Cultivation with a few % "over pressure" in the greenhouse (especially in winter) reduces the 'drop of coldness' from the glass and contributes to a more homogeneous climate as well. Also, it is more difficult for insects and pests to enter the greenhouse.
- All in all this horticulturist is very satisfied with his ATES-heat pump system, because –on top of the resulting energy savings (29%) and increases in crop yield (17%) ánd quality- it gives him much more flexibility to deal with the dynamic energy markets.
- For a new project, this horticulturist would certainly apply ATES and heat pumps again in his greenhouse .

Do's and don'ts, attention for pit holes, etc.

- It is important for any horticulturist who's new to these type of systems to invest serious time -starting with the first days of operation- to thoroughly learn to operate the system and the new settings of the climate computer in close cooperation with the supplier/installer of the ATES-system. Only then, the horticulturist will learn to understand the consequences and possibilities of cultivation under higher temperatures, CO2-concentrations and relative humidity. This will enable him to understand the complex interactions between crop/plants and greenhouse climate and allows him to truly optimize and control his production and crops.

- It is important to select an installer/system supplier (and/or a consultant) who has his roots in the horticultural sector and not just some installer only with experience with heat pumps, CHP and other energy systems.

Literature & sources

Interview with Theo Ammerlaan by Krijn Braber & Charles Geelen (Infinitus Energy Solutions)

Raaphorst M., (2005) Optimale teelt in de gesloten kas – Teeltkundig verslag van de gesloten kas bij Themato in 2004
http://www.hdc.org.uk/sites/default/files/research_papers/PC%20256%20final%20report%202007.pdf

B Heat pump application at a commercial nursery for orchids

Project description

Company name *)	Commercial nursery for orchids
Location;	Ter Aar; 15.000 m2
Process / Application	Growing orchids
Type of Heat Pump	Reciprocating compressor/ammonia: 1x Grasso 612; 600-1100 rpm 1x Grasso 810; fixed at 1470 rpm
Capacity	1500 kW-th at ΔT +6 ˚C /+50 ˚C
Operational hours	
Year of commissioning	2006/7
Energy savings	40-50%
CO2 emission reduction	
Maintenance costs **)	N/A
Manufacturer / supplier	Grasso installed by Frans van Zaal
Simple Pay Back Time **)	Years

**) Companies cooperated in this project on the basis of anonymity*
***) if such data are available*

Specifications of the heat pump

Type		reciprocating compressor
Heating capacity (total)		1500 kW (in 2 units)
Cooling capacity (total)		1500 kW (in 2 units)
Power consumption (total)		225 kW (in 2 units)
Heat Source	Temperature	°C
	Flow	180 m3/h
Supply Temperature		50 °C
Coolant		NH3
Compressor type		reciprocating compressor
COP		6,7 (NH3 Heat Pump of Grasso)
Specifications of back up system		NONE, only emergency electric back up boiler
Buffertank		2x 200 m3 Temperature °C
6x wells (3x warm/3x cold); well depth 100 m		

Project characteristics

A new 100.000 m2 greenhouse was built by Anthura in 2009 to produce the small Anthurium plants that are supplied to growers all over the world. 30% of the greenhouse consists of a climate controlled ‘closed greenhouse’ environment where the young plants are subjected to a temperature treatment in order to promote the formation of leaves and flower butts. During this critical phase a tight control of humidity levels is required to achieve optimal quality and minimum process time. The heat pumps have been developed for high efficiency, using frequency controlled compressors and economisers to achieve a 20% higher efficiency than standard available units.

The ATES system consists of 3 cold wells and 3 warm wells. The water is pumped back and forth between the warm and the cold wells, with each well providing 90 m3/h of ground water.
For heating, cooling and dehumidification of the air in the greenhouse, 120 custom built air treatment units where fitted in the 30.000 m2 closed greenhouse with heating and cooling coils and frequency controlled fans with air streamers.

Energy Total Projects (ETP) designed the heat pump system and the aquifer thermal energy system along with the air treatment units and supplied this as an entire operational system.
Compared to the conventional alternative with chillers and a gas fired boiler, 60% energy is conserved while increasing production and quality of the plants.

Supplier characteristics

ETP is a systems supplier of specialised heat pump technology for several applications in buildings, industry and agriculture. The heat pumps are supplied with a variety of heat source modules, ranging from aquifer systems and deep geothermal wells to exhaust gasses and surface water. In the last 10 years, ETP has fitted their special developed heat pumps and source modules in almost 200 projects with a total capacity of ca. 100 MWth.

C Greenhouse for breeding and propagating Anthuria

Summary

The installation consists of a heat pump and an aquifer thermal energy system and is applied to provide heating and cooling to create a temperature and humidity controlled environment for the critical stage in the propagation of Anthuria.

Project description

Company	Anthura
Location	Bleiswijk
Process application	Climatisation of pot plants in greenhouse
Type of heat pump	Ground source compression heat pump with Aquifer Thermal Energy Storage (ATES)
Capacity	2x1300 kW heating 4 MW total cooling capacity with ATES system
Running hours	6000 hrs/yr heat pump heating 4000 hrs/yr ATES cooling
Year of operation	2009
Primary energy savings	30 TJ/yr
Reduction in CO2 emission	1600 ton/yr
Maintenance costs	40.000 euro/yr total guarantee
Manufacturer/supplier	Energy Total Projects b.v. (ETP)
Pay back period	4 years, excluding subsidies

Project characteristics

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D Greenhouse Hecostek in Biezenmortel

Summary
HECO STEKCULTURES cutting businesses is a cutting firm in Biezenmortel that has specialised in slips from plants (Tree Nursery plants) mainly shrubs, conifers and roses, this all in cutting trays (multi-trays).
The company has a surface area of 3.5 hectares of which about 2.5 hectares are mother plants and 10,000 m2 greenhouses. These greenhouses are sub-divided into 1,800 m2 green label hothouse with tunnels for striking cuttings and floor heating (Hecodek system), 1,800 m2 is equipped with a spray installation for the slips and the remaining 6,400 m2 is for continuing cultivation and overwintering of the cuttings. The greenhouse is equipped with a screen installation and hot air heating. The climate is automatically operated and monitored.
Two cold aquifer sources (ATES) keep the cuttings in optimal condition during the process. The cuttings that are produced to order can meet your specific requirements such as multiple slips per pot. There is also a stock of many types so that it is possible to supply the required cutting very quickly. Because of the scale of Hecostek (more than 6 million items annually) they are capable of handling large quantities in a short time.
Hecostek considers it important to produce in a sustainable and responsible manner, and partly for this reason have taken part in the QualiTree quality programme and were certified for this in 2001. Hecostek has the MPS qualification and in 2001 the green label hothouse with floor heating (Hecodek).

Project characteristics

Cuttings need a proper temperature at root level, for example in the summer, the demand for cooling is large; to prevent loss of cuttings at high greenhouse temperatures and to ensure the controllability of temperature for a better and more even crop. almost the entire coverage of the growing bed is being heated.
The cutting greenhouse was renovated in 2001 and converted into a green label hothouse equipped with tunnels for cuttings and floor heating. The cutting is ventilated regularly so that a complete control and maintenance can be performed. When the roots are sufficiently grown, the sprigs go to the hardening greenhouse where they can further acclimatise and remain until it is time for delivery
By using ground and solar heat and a heating/cooling installation that covers 99 percent of all soil, an optimal and controlable temperature control on a plant-level can be reached.
Used materials:

1. EnergyDak on the building
2. R&R heat exchangers for about 1800 m² soil in the greenhouse
3. CIAT heat pump
4. A well for heat and for cold

200 m² EnergyDak® is used for the regenaration of the ATES source.
Overall investments were €83.000. The energy use before the new installed system was 100.000 m³ gas/year in the new process it is reduced to less than 30.000 m³/year. An additional advantage is a better control of the growth and a better quality of the products.

E Greenhouse project Entius Heerhugowaard

Summary

The company started on 01-03-1969 to Plaetmanstraat 4 Heerhugowaard North.
There was a company built greenhouse of 7000 square meters.
Mr. J. Entius began in the cold vegetables and after a few years later in the cucumbers. After some try, my father proceeded slowly in the flowers of carnations and tulips to irises that have grown for several years. This change happened around 1975.
Irises and tulips years we have grown about 1.8 miljoen tulips we broeiden per year irises and a few million per year. In 1985 there was 5000 square meter greenhouse to build and we moved slowly to the lilies and we started to grow lily Connecticut King and later lily Enchantmentthere. A year later we were in speciosum rubrum as the No. 10 and Uchida. It also came when the first sons in business Adri and Piet. Then there were 5 people on the horticultural business.
In 1990 we started a new company (behind the old company) at around 5 hectares of land with an in and out to the Middle Way in the North. There was 13,000 square meter greenhouse built with a large processing room with 2 cooling cells there was a large boiler built and an Total Energy System Installation ready for the future with a facility for cultivation of the lilys.

After 9 years we are back to tickle the cash to build a lot changed there then.
It was 7000 square meter greenhouse to build a potting soil and potting shed with 2 bunkers for storage and 1 bunker before the steaming of the soil. The heating boiler from the old boilerhouse is moved to the new boilerhouse and steam boiler is fixed. The cash was put into use in 1999 was also a 1200 KW transformer house built our current facility. In 2004, the company is located Middenweg to a belt system. This belt system is installed above the concrete pad and be hung on the partaalspanden and each 6.40 meters down and the cutting unit are presented, the lilies are transported to the processing. (This happened with picking rails where we lay flowers and wooden mats.) Also, a heat pump in heat source where the gas in third drops. End 2006 is back in 7000 square meter greenhouse constructed so that the total fund size has grown to 39,000 square meters. The company is still room for 7000 square meter building is built with the following still an opportunity to work space to build.
The company is the oldest in 7000 square meters are not exposed or fired.

Project description

Company	Fa. J. Entius & Zn.
Location	Heerhugowaard
Process application	Climatisation of freesia in greenhouse
Type of heat pump	High temperature compression
Capacity	480 kW heating and 370 kW Cooling
Running hours	
Year of operation	2003
Primary energy savings	
Reduction in CO2 emission	
Maintenance costs	
Manufacturer/supplier	KODI Heerhugowaard
Pay back	4.7 years

Project characteristics
At this company there is an existing plant with gas-fired boilers and CHP with electric compression heat pump which an aquifer used as a source system. This is possible through the proper use of a heating curve. In fact, it is a bivalent system realized by which 65% of the total heat demand will be covered.
Inside the greenhouse project (Fa. J. Entius & Zn . Te Heerhugowaard / lily cultivation), the existing energy infrastructure consisting of a delivery system with a conventional upper and ondernet, gas-fired boilers and cogeneration plant has been expanded with a heat pump installation with an aquifer system source system. This is possible by making use of the part of the curve (with lower release temperature), which allows a useful implementation and clever use of a heat pump. Because the site only hass the business heat, and the sustainable use of an aquifer system requires a thermal balance, the aquifer is regenerated by the palpable cooling the greenhouse, using the excess heat from the cogeneration lamps, and excess heat from the cooling cells.
The basis for the concept grew out of the desire to combine renewable energy technologies in such a way that maximum energy savings could be achieved.
The gardener had already had good experience with an air/air heat pump system which is used for the preservation and storage of products in cells. Before the start of the project there were several options; the most sensible option covers the heat 65% of the annual heat demand is and takes care of 27% primary energy savings, and 95 tons/year of CO2-reduction and € 27.500,- /year energy cost savings at a payback time of 4.6 years (including grants). The total net investment compared to traditional scenario amounts to € 109,240 .
In technical terms, the risks are very limited due to the bivalent nature of the installation; if the heat pump system unexpectedly fails or perform less, than the company can shift to the existing installation. In cultivation the risks are very limited.

E Greenhouse for Freesia G. en G. Ermstrang

Summary
In freesia grower Ermstrang Brakel underground thermal storage was built, in combination with electrically driven compression heat pumps in early 2004. In summer, cold spring water used to cool the heat from greenhouses and greenhouses stored in underground storage. If the temperature of the cold spring water is too high, the heat pump is switched on as a chiller.
In winter, the system is reversed and heat pumps extract heat from the ground to take this heat the greenhouses. The heat pumps are connected in cascade, so there is always a spring into action when a greater capacity is desired. The system is also equipped with a back-up in the form of chillers and boilers. The latter are also used for the production of CO2, which is used in order to promote growth of crops.
Energy in combination with heat pumps is an excellent alternative for both heating in winter and cooling demand in summer. Besides freesia, they grow include amaryllis and alstroemeria. The system described is energy efficient, takes relatively little technical risks with it and pays for itself - by the much lower energy costs - within eight years back. A license is relatively easy to obtain, in contrast to conventional cooling systems.
The construction of the special energy to flower grower Ermstrang was a demonstration project under the Renewable Energy program in the Netherlands. Other growers can learn from the experience .

Project information

Company	Mts. G. en G. Ermstrang
Location	Brakel, Netherlands
Process application	Heating and cooling of 2,65 hectares Greenhouse for growing fresia
Type of heat pump	Electric open ground source compression
Capacity	3 x 100 kW heating 250 kW cooling
Running hours	
Year of operation	
Primary energy savings	
Reduction in CO2 emission	
Maintenance costs	
Manufacturer/supplier	Carrier
Pay back	7 years

Project characteristics
The maximum heating capacity is 300 KW. The three heat pumps of each 100kW are cascaded and dependent on the need they run to full capacity.
Traditionally freesias need to be cooled, but still a large part of the time heating is needed at temperature levels of 30 - 40oC. The open ground source (ATES) has a depth of 50 metres and 40 m3/h for heating at 16 oC as source for the heat pump and 60 m3/h for passive cooling at 8 oC. In the period of high summer the heat pump will assist the passive cooling when the temperature of the ground source gets higher than 9 oC.
Important effect of this energy system is better control of the temperatures. In the traditional greenhouse energy systems the heating was at high temperatures 70 - 90 oC. Also the cooling temperatures wer over 11 oC. In the end the product quality and the yield of the greenhouse increases.


Koudeopslag in de freesiateelt (DEN)
Gijsbert Ermstrang, freesiateler te Brakel:
Ingebouwde warmtepompinstallatie
verwey
"Voor de freesiateelt is in de zomer grondkoeling
en in de winter kasverwarming nodig. Wij zochten een
goed alternatief voor koeling met bronwater.
We maken nu gebruik van koudeopslag in een aquifer in
combinatie met een warmtepomp. Een duurzaam
en energiebesparend alternatief voor conventionele koeling."
Freesia's

[Disclaimer]

This book is work in progress. Names change, techniques alter, people move. Leading is the digital version. The latest digital version can be requested at RVO, by sending an e-mail to Onno Kleefkens (onno.kleefkens@rvo.nl). We have done our best to deliver a flawless document. If, however errors or inaccuracies in this document occur, we will try to correct this as soon as possible.

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