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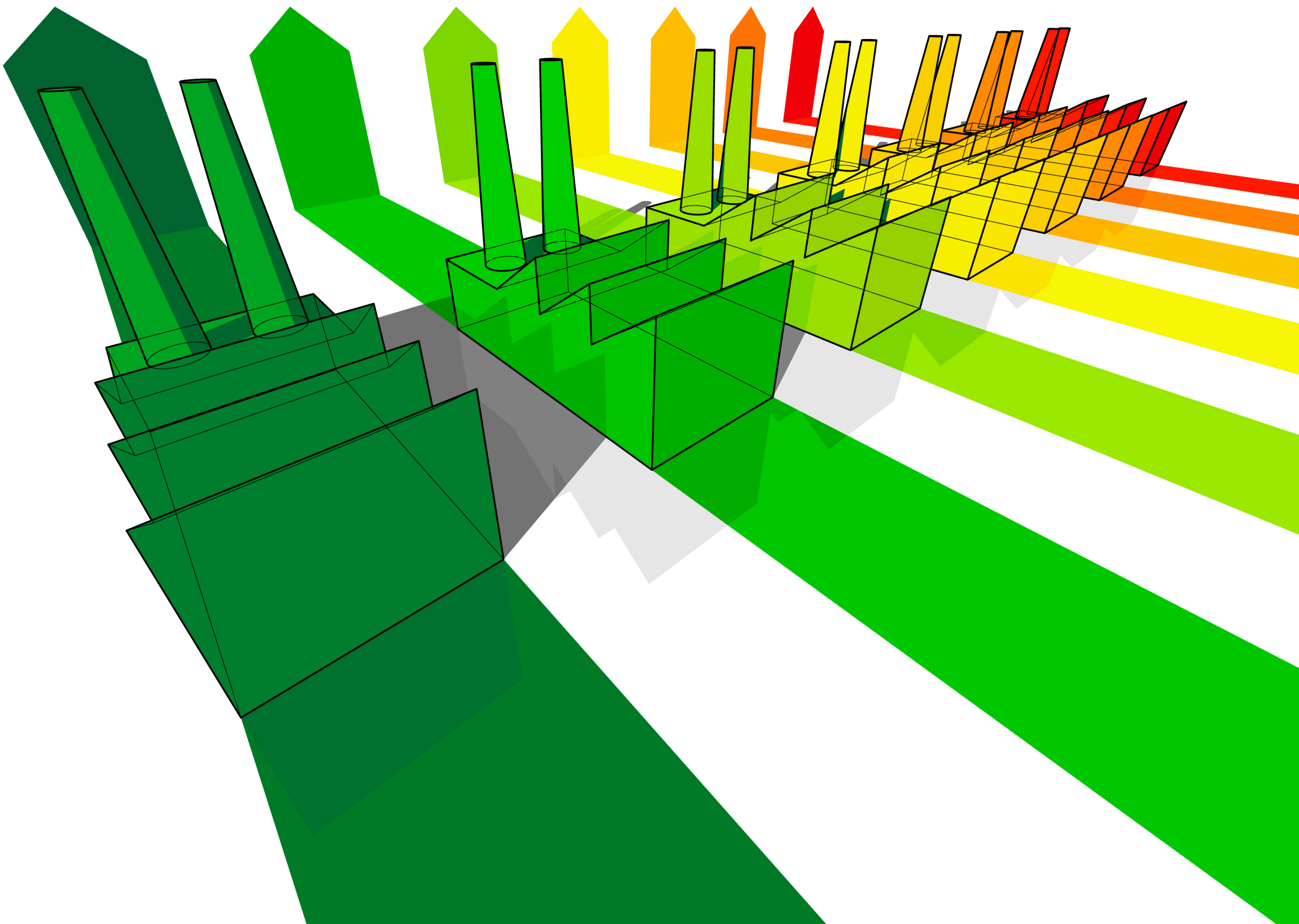
IEA HEAT PUMP CENTRE

NEWSLETTER
VOL. 30
NO. 1/2012

Heat Pumps - The Solution for a Low-Carbon World

Industrial heat pumps



HPs in sawmills, a campus, and a natural gas plant

High temperature HPs with natural refrigerants

Market report: The Netherlands

IEA **Heat Pump** CENTRE
NEWSLETTER

Volume 30 - No. 1/2012

In this issue

Heat Pump Centre Newsletter, 1/2012
Industrial and other large heat pumps is the topic of this issue. Examples of applications are presented. Further, overviews of natural refrigerants, and of trends in Japan, regarding industrial heat pumps are provided.

There is also a summary of industrial heat pumps applications, from the Heat Pump Summit in Nürnberg, and an account of the heat pump market in the Netherlands.

We also want to announce and highly recommend the Heat Pump Programme Open Conference, which will take place in conjuction with the Chillventa, on Monday October 8, in Nürnberg, Germany. Read more on page 10.

Enjoy your reading!

Johan Berg
Editor

Heat pump news

Regulars

Topical articles

COLOPHON

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Foreword

Industrial Heat Pumps

Laurent Levacher,
Director of ECLEER,
European Center & Labs for Energy Efficiency Research,
EDF R&D

In December 2008, the European Parliament gave its backing to the EU's climate change package, known as "20-20-20". The main objective of this package is to achieve the following climate targets by 2020: a 20 % reduction in greenhouse gas emissions, a 20 % improvement in energy efficiency, and a 20 % share for renewables in the EU energy mix. In the EU 27, the industry sector accounts for 28 % of final energy consumption and 21 % of greenhouse gas emissions. So it must be considered in this legal framework.

The ODEX indicator shows that energy efficiency in industry in the EU-15 has improved by 1–1.5 % per year from 1990 to 2002. Analyses of CO_2 emissions from the industry sector by the European Environment Agency, and the ODEX indicator, show that the decrease of 69 Mt of direct CO_2 emissions by the EU-15 industry sector is due to fuel switching and efficiency improvement.

Although the energy efficiency of the industrial sector has improved over the past years, there still remains vast energy-saving potentials. IEA estimates that manufacturing industries in the OECD countries can improve their energy efficiency by between 18 % and 26 % (compared with 2004) in terms of primary energy, by the adoption of best practice commercial technologies. It also estimates that manufacturing industry can reduce its CO_2 emissions by between 19 % and 32 %.

In addition, other factors make these energy and CO_2 saving potentials achievable:
1. Industrial processes and fuel combustion of manufacturing industries and construction.
2. ODEX is based for the industry sector on unit consumption expressed in terms of energy used per unit of physical output and production index.
- the behaviour of those involved in industry is more rational than in other sectors, and energy efficiency contributes directly to the competitiveness of a company.
- the equipment renewal rate is high in industry (5 to 10 % per annum), with modernisation integrating technological progress and consequently energy efficiency.

In Europe, the energy savings potential in industry by using Best Available Technologies (BATs) are estimated at 20 % (savings: 31 % furnaces and dryers, 26 % heat recovery, 14 % boilers, 13 % industrial buildings) of the baseline energy consumption.

Over the last few years, only short-term solutions have been implemented. Now, new breakthrough solutions are required for industrial processes.
- Process analysis by new methods of energy integration, including exergy analysis (quality of the energy used), for sectors which have never been explored before must be applied and can lead to re-conceptions of parts of processes.
- Electrical BATs become more and more relevant (especially in the case of low CO_2 electricity), so that investments deliver better quality and productivity with profitable payback times.
- Systems to recover and quantify the value of energy losses and energy in waste and co-products greatly increase potential energy savings. In particular, the feasibility and the use of MVR (Mechanical Vapour Recompression) and high-temperature heat pumps is emphasised.

The re-use of waste heat, with its substantial energy-saving potential, is a key point.

Industrial heat pumps can deliver substantial benefits. However, it is necessary to focus on the right process, with the right technology, after having analysed the entire system by efficient methodologies. This issue presents the main contributions in this domain.

Column

Industrial heat pumps - where are they?

Per-Åke Franck,
CIT Industriell Energi AB,
Sweden

Industrial heat pumps can upgrade excess (waste) heat to useful heat and reduce energy costs. However, raising the temperature requires a primary energy input, which is associated with a cost. In industrial applications, the key issue is to utilise excess heat to reduce the total use of primary energy and thus reduce overall operational costs, assuming that the capital cost of the necessary installation does not exceed the profit from energy savings.

About 15 to 20 years ago, several reports (e.g. Industrial Heat Pumps – Experience, Potential and Global Environmental Benefits, IEA Heat Pump Centre) pointed out the advantages of industrial heat pumps and quoted the technical and economical performances of various types. Disadvantages and obstacles for applications were also identified:

- lack of knowledge of the potential benefits of IHPs;
- lack of experience in different types of industries;
- lack of hardware for some types of potential applications;
- lack of combined process and heat pump technology knowledge.

It seems to me that the same arguments apply today! The ongoing joint Annex between HPC and IETS (Industrial Energy-Related Technologies and Systems) and the activities around this Annex are therefore essential and will hopefully help to overcome some of the barriers.
However, the situation for heat pumps in industry is not as bad as you might think. The explanation lies partly in how a heat pump is defined. According to the common definition, a vapour compressor is a heat pump, but it is not necessarily seen as one on an industrial site. There, it could just be listed as "the compressor", and no one at the site regards it as a heat pump. Another case, although not as common as "the compressor" case, is the utilisation of heat from refrigeration systems for water pre-heating. This is an excellent example where the heat flows of both sides of the machine are useful.

The last obstacle listed above - lack of combined process and heat pump technology knowledge - could alternatively be formulated as lack of understanding of process integration. This is clearly shown when the use of excess heat from a process is discussed. The temperature level of the excess heat is determined by process fundamentals and process equipment design, and is thus, for an existing plant, fixed. However, the temperature level at which the excess heat is discharged and can be used is determined by the design of the utility systems, i.e. cooling water and air, and is therefore often at a much lower temperature. This essential difference is often overlooked when discussing excess heat utilisation. The amount and temperature level of the excess heat can be determined by process integration methods, e.g. pinch analyses. These methods are powerful tools and give an overall picture of the situation at the plant, including the possibilities for internal use of the heat.

Energy efficiency improvement is one of the most cost-effective ways of reducing greenhouse gas emissions, and I am convinced that heat pumps will contribute significantly to efficient use of energy in industry.

General

EU member states want fewer public buildings to be renovated

The Danish presidency received its much-awaited mandate to start negotiations with the European Parliament on the draft energy efficiency directive, after a "tough" discussion between member state representatives. However, the Danes were left with a mandate described as "weak" and "vague" by activists.

Member states have watered down the main provisions of the bill, which had been hailed as the most important energy efficiency law to date and was to serve as the EU's main tool in reaching its aspirational 20% energy savings target for 2020.

Source: http://www.euractiv.com

A quarter of Europe's energy-related GHG emissions come from homes

A European Environmental Agency (EEA) report, *End-user GHG emissions from energy: Reallocation of emissions from energy industries to end users 2005-2009*, has used an analytical method of redistributing 'indirect' emissions, mostly from oil refineries and plants generating electricity and heat, in order to calculate the overall emissions linked to each sector.

The EU number-crunchers found that while homes in the EU only emitted 12 % of energy emissions directly, that figure rose to 25% when related emissions from power plants and district heating were taken into account.

Monica Frassoni, president of the non-profit European Alliance to Save Energy, said that the report findings underlined the "pressing need" for the EU to step up its regulatory efforts.

"The EU has an opportunity to do this through the proposals for the Energy Efficiency Directive," she said. Frassoni was a Green member of the European Parliament for northwest Italy until 2009.

Source: http://www.euractiv.com

AHRI publishes industry standard for variable frequency drives

The US Air-Conditioning, Heating, and Refrigeration Institute (AHRI) today announced the publication of an industry-first standard for Variable Frequency Drives (VFDs). As with all AHRI Standards, 1210 (I-P)-2011 & 1211 (SI)-2011, Performance Rating of Variable Frequency Drives, are available free of charge on AHRI's website.

Once considered a "high tech" option for only the most elaborate HVACR systems, VFDs have been in the mainstream for several years, providing better efficiency with improved reliability. VFDs produce fast-rising, high frequency pulses of electrical energy to control and power motors.

Source: http://www.ahrinet.org

Reefer industry gets to grips with contaminated refrigerant

Vietnam is said to have imposed strict controls over the supply of R134a following the contaminated refrigerant scare which caused a number of explosions and three deaths in the refrigerated container industry last year. It is now known that a total of 1,181 units were serviced in Vietnam in 2011 in terminals identified as using contaminated refrigerant. All these units have been isolated and are being tested.

Two units showing chloride contamination which had no connection to Vietnam have recently found in New Zealand and some contaminated boxes in the USA were found to contain R12/R22 with no trace of methyl chloride.

This latest information was revealed at the recent Forum on Contaminated Refrigeration Systems, in Singapore. Organised by the Container Owners Association, the forum focused on the challenges to the container industry caused by the contamination of container refrigeration machinery with counterfeit refrigerant gases. Those involved in the forum included representatives from 19 shipping lines, nine leasing companies, 18 container depots together, five inspection companies, together with the four major reefer machinery manufacturers.

Source: http://www.acr-news.com

University begins final phase of largest GDHP project in US

Ball State University has started the second and final phase of converting the university to a geothermal ground-source heat pump (GSHP) system. It is reportedly the largest project of its kind in the United States. The conversion, started in 2009 to replace coal boilers, provides heating and cooling to nearly half the campus. The first phase of the project will be dedicated in March. For the second phase, Ball State is installing a vertical, closed-loop district system that uses only fresh water. It will include a district energy station containing two 2,500-ton (8800 kW) heat pump chillers and a hot water loop around the south portion of campus. The system will connect to all 47 buildings on campus, spanning 5.5 million ft2 (511 000 m2). When the system is complete in 2014, the shift to a renewable energy source will reduce the university's carbon footprint by nearly half while saving $2 million a year in operating costs.

Source: http://www.ashrae.org

EHPA breakfast debate: stakeholders recognize the power of heat pumps

More than 50 people joined the EHPA breakfast debate on March 6th, which focused on the currently discussed Energy Efficiency Directive (EED), in particular on the role of heat pumps. The participants comprised representatives and experts of the European energy industry, as well as Members of the European Parliament and the European Commission. It ended up being a lively debate in which many interesting points came to the fore.

One significant point of remark concerned the Primary Energy Factor (i.e. primary energy input needed to produce 1 kWh of electricity), which is fixed in the EED. Both EHPA and EURELECTRIC called for a variable Primary Energy Factor, as in the Renewable Energy Directive. This is necessary in order to show the efficiency of the heat pump technology in comparison to other technologies.

Although it is recognized that the heat pump technology is a valuable instrument in achieving the EU targets of energy efficiency and GHG emission reductions, there can still much be done to get the acknowledgement it deserves.

Source: http://www.ehpa.org

Policy

Building energy codes in China: impressive improvements, says report

In recent years, China has been adding 1.6 to 2.0 billion square meters of new residential and commercial buildings each year, making it the largest market for new construction in the world. Though the enforcement of China's building energy codes has been widely viewed as fraught with challenges, in recent years China has seemingly achieved unusual progress in improving its compliance rate at both design and construction stages. According to China's annual national inspection of building energy efficiency in urban areas, the compliance rates with building energy codes at both design and construction stages in urban areas have improved from 53% (design) and 21% (construction) in 2005 to 99.5% and 95.4%, respectively, in 2010.

What is the definition of the compliance rate in China's enforcement of building energy codes? If the improvement data are accurate, how is it that China has been able to bring about such impressive improvements in only five years? This report will try to answer the above questions, with a focus on the role of third parties in the implementation of building energy codes. The report concludes that strong governmental support and effective employment of third parties coupled with strict quality control and supervision are the key factors for China's impressive improvement of compliance with building energy codes.

Source: http://aceee.org

Europe's Energy Roadmap 2050: Neither Hot nor Cool

With more than 40 %, heating and cooling represents by far the largest share of final energy consumption in Europe. Although this sector is not only huge in size, but also as regards low and no-carbon solutions available already today, it is largely overlooked in all scenarios presented in the EU Energy Roadmap 2050.

A large group of stakeholders, including EHPA, call on the European Institutions and the Member States to set and to swiftly execute an ambitious European heating and cooling policy.

Source: http://www.ehpa.org

Standard and labeling symposium held in Tokyo

On February 10, a symposium on standard and labeling (S&L) policy development assistance was held in Tokyo. IEE Japan, together with the Collaborative Labeling and Appliance Standards Program (CLASP), a U.S. NPO, has been conducting a project since 2006 to establish energy-efficiency standard and labeling systems in Asian countries like China, Vietnam, India, Indonesia, and Thailand. This year's symposium focused on an initiative to deploy superefficient equipment and appliances, an update on the 4E (Efficient Electrical End-use Equipment) program from the Institute of Applied Energy (IAE), and a status report on assistance from Japan in the S&L field. Following these sessions, country reports were given by China, Vietnam, Thailand, Indonesia, and India. The symposium ended with a question-and-answer session where participants could ask questions directly to panelists. The symposium was sponsored by the Ministry of Economy, Trade and Industry (METI), the Agency for Natural Resources and Energy, and the Institute of Energy Economics, Japan (IEE Japan).

Source: http://www.ejarn.com

Eco directive could hit refrigeration companies

Commercial refrigeration equipment manufacturers have warned that the proposed EU Eco De-

sign Directive could place significant costs on refrigeration companies and discourage them from developing new technologies. The Catering Equipment Suppliers Association (CESA) reports that the new directive would require all models to be tested - a costly undertaking for manufacturers and suppliers in the foodservice sector where customisation and non-standard equipment is increasingly demanded. EFCEM (the European Federation of Catering Equipment Manufacturers), of which CESA is a member, recently met with the EU Commission at a consultation forum to discuss the future development of catering equipment, focusing particularly on refrigerated cabinets, blast chillers and walk-in cold rooms. A key issue of the forum was the Eco Design Directive.
Source: http://www.acr-news.com

US energy department announces $5.2 million to advance heating and cooling systems

As part of the Obama Administration's blueprint for an American economy built to last, Energy Secretary Steven Chu has announced the availability of up to $5.2 million in fiscal year 2012 to develop improved building efficiency technologies, including advanced heating and cooling systems and high efficiency insulation, windows and roofs.
Homes and commercial buildings consume approximately 40% of the energy used in the United States, costing American consumers more than $400 billion, and nearly a third of that energy is used for heating, ventilation, and air conditioning (HVAC). Advancing HVAC building technologies and improving the design and materials that make up a building's "envelope," or air seal, will significantly reduce the cost of heating and cooling residential and commercial buildings, while providing a tremendous opportunity to cut carbon emissions and reduce the nation's reliance on fossil fuels. This effort supports the department's commitment to an all-out, all-of-the-above approach to American energy, which includes saving businesses and families money by saving energy.
Source: http://apps1.eere.energy.gov

Working fluids

EPA approves three hydrocarbon alternatives

The US Environmental Protection Agency (EPA) has added isobutane (R600a), propane (R290) and the R-441A blend (of ethane, propane, butane and isobutane) as acceptable hydrocarbon alternatives in household and small commercial refrigerators and freezers.
The newly-approved refrigerants can be used to replace ozone-depleting chlorofluorocarbon (CFC)-12 and hydrochlorofluorocarbon (HCFC)-22 in household refrigerators, freezers, combination refrigerator-freezers, and commercial stand-alone units.
The EPA took action after requests from Ben and Jerry's and General Electric, as well as A.S. Trust & Holdings, and True Manufacturing to use ozone layer-protective hydrocarbon refrigerants in order to facilitate hydrocarbon substitutes being widely used in the United States.
Source: http://www.acr-news.com

BRC calls for natural refrigeration incentives

A new British Retail Consortium (BRC) report - *A Better Retailing Climate: Towards Sustainable Retail* - reveals that in their commitment to reduce greenhouse gas emissions by 50% in 2013 (relative to floor space), compared to 2005, the retailers have so far achieved reductions of 37% per m2 (25% in absolute terms).
The retail sector is said to be directly responsible for around 3.5% of UK greenhouse gas emissions. Refrigeration accounts for up to 50% of energy costs of supermarkets and is estimated to contribute 15-30% of grocery retailers' total carbon footprint. The major source of emissions is leakage of HFC refrigerant gases but the BRC argues that all leading UK grocery retailers have made long term com-

mitments to address the impacts of refrigeration and some have committed to eliminating HFC systems altogether.
Source: http://www.acr-news.com

EPEE specifies its F-gas position

The European Partnership for Energy and the Environment (EPEE) has said that to meet the EU target of a low-carbon economy by 2050 further steps are needed to achieve more reductions of up to 60%.
EPEE has said that full implementation of the F-gas regulation is key to creating a low carbon economy and has made additional emissions reduction suggestions, which includes extending the regulations to all transport refrigeration and air-conditioning (currently only car AC is included) and ensuring that distributors and wholesalers are only allowed to sell refrigerant to certified companies.
Any company or person (not only operators) who assign work to a third party on a refrigerant circuit should also need to make sure that this third party is properly certified, says EPEE.
EPEE also suggests that the European Commission should continue with its infringement procedures for Member States which are not yet compliant with the F-gas rules.
Source: http://www.acr-news.com

AREA calls for compulsory training on low GWP refrigerants

With the EC taking measures towards decreasing the use of HFCs, the European contractors body AREA has called for compulsory training on the use of low GWP refrigerants. A new survey by AREA bears out previously reported end-user concerns of a lack of knowledge and training in the use of natural refrigerants. It reveals that out of all the air conditioning, refrigeration and heat pump contractors active in the 14 countries that replied, 6% are trained with CO2, 11% with HCs and 12% with ammonia. Some training facilities exist in Western Europe but - except in some countries such as Denmark or the Netherlands - they are generally insufficiently equipped, thus focusing on theory rather than practical training. Training is scarce in Eastern Europe. Training schemes are usually set up by the private sector.
Source: http://www.acr-news.com

Climate Center to stock HFO blends

Climate Center is the first company to announce it will be stocking Honeywell's new range of HFO blends and other low GWP refrigerants.
The company reports particular interest in Genetron Performax LT (R407F), a replacement for R404A with half the GWP and greater energy efficiency. An HFC-blend based on R32, R125 and R134a, it has the lowest GWP of all commonly used blends and is classified as non-toxic and non-flammable.
The new generation of Honeywell's Solstice HFO blends offers a choice of reduced or low GWP replacements for many common HFC refrigerants with high GWPs high GWPs, such as R404A, R22, R134a and R410A. In the case of R404A (GWP of 3922), alternatives with a GWP below 300 have been identified.
Source: http://www.acr-news.com

Danfoss Turbocor releases HFO1234ze prototypes

Danfoss has announced the availability to OEM:s of prototype versions of its oil-less Turbocor compressor to run on the new refrigerant HFO1234ze.
The prototype, named TG310, is said to be suitable for outdoor, air-cooled chiller applications and is being offered to chiller manufacturers for shipment in April.
Source: http://www.acr-news.com

Technology

Shimizu testing high-efficiency geothermal heat pump system

In November, a Japanese general contractor Shimizu and Shinshu University started demonstration tests of a high efficiency heat pump air conditioning system that uses underground water as its heat source. This project was selected as part of 'Research and Development of Next-generation Heat Pump Systems' by the New Energy and Industrial Technology Development Organization (NEDO), and a test plant was subsequently installed within the Faculty of Engineering of Shinshu University in Nagano City. The developers intend to confirm the new system's efficiency by February 2013 and aim to realize more than 50% higher efficiency than existing building air conditioning systems.
Source: http://www.ejarn.com

New pipe connection system introduced

A new aluminium tube connection system has been introduced by Reflok.
The brainchild of Gloucestershire-based air conditioning and refrigeration manufacturers JSC, the connector is made of steel and uses aerospace technology to connect and seal aluminium pipe. More importantly, the connector needs no hot works, using a special high pressure hydraulic tool.
The connection will withstand pressures up to 100 bar, needs no purging and there is no risk of system contamination.
Source: http://www.acr-news.com

The aluminium alternative

The ever rising prices for copper and its increasing shortage on the world market are leading to a resurgence of alternatives for the refrigeration

industry. Foremost among these is aluminum, a widely available material which costs less than half that of copper. UK manufacturer Eco Refrigerant Aluminium Pipe has developed a range which they say matches copper in terms of strength and workability. The piping is supplied in 50m-long coils in sizes from 0.25 to 0.75 inches and can work with pressures up to 2,400 psi (about 160 bar). Workability is similar to that of copper in terms of bending, flaring and swaging but special rods are needed for brazing and the process is said to be four times faster than with copper.
Source: http://www.ejarn.com

Development of mechanical seals for high-pressure CO_2 applications

A mechanical HVAC seal usually rotates at 1800 rpm. However, in Brazil a high-pressure mechanical seal suitable for every phase of CO_2 (gas, liquid, and supercritical), for dynamic rotation of 3600 rpm, and for pressures up to 500 bar has been developed.
High pressure CO_2 offers unique design challenges for HVAC&R system development, particularly with regard to seals. This recent development in the field of mechanical seals suitable for high-pressure CO_2 applications is used to minimise leaks from pumps and compressors.
The innovative high-pressure mechanical seal technology is suitable for every phase of CO_2 -gas, liquid, and supercritical. It was originally designed for the enhanced oil recovery industry, but could provide lessons for the HVAC&R industry.
Source: http://www.r744.com

Cool new material that responds under pressure

A team at Barcelona University has identified a new material that exhibits what has been described as an inverse barocaloric effect at room temperature, which means that it cools when pressure is applied, unlike most other materials. In studies the team found a material which exhibits a substantial change at moderate pressures: its temperature drops by 1ºC for each additional 1 kbar of pressure.
The material, a compound of lanthanum, iron, silicon and cobalt, also changes temperature when an external magnetic field is applied. This group of materials is considered to be the most promising for potential refrigeration systems. The fact that it responds to two types of external stimulus - magnetic fields and pressure - would allow for the design of devices that apply these stimuli simultaneously to obtain higher levels of performance.
Source: http://www.acr-news.com

Happy birthday psychrometrics!

The formula which underpins the relationship between temperature, humidity and dew point - the basis of all air conditioning calculations - marks its 100th anniversary today.
It was on this day in 1911, less than a decade after the invention of air conditioning, Dr Willis Carrier's Rationale Psychrometric Formulae finally cracked the precise correlation between temperature and humidity to create a year-round comfortable environment.
Carrier presented the psychrometric formulae on December 8, 1911 at the annual meeting of the American Society of Mechanical Engineers and initiated the field of scientific air-conditioning design. His invitation to the meeting recognized air conditioning as a formal branch of engineering.
The formula still stands today as the basis in all fundamental calculations for the air conditioning industry. Carrier said he received his 'flash of genius' while waiting for a train. It was a foggy night and he was going over in his mind the problem of temperature and humidity control. By the time the train arrived, Carrier had an understanding of the relationship between temperature, humidity and dew point.
Source: http://www.acr-news.com

Markets

French supermarkets to shut the door on open cases

French supermarkets have pledged to do away with the majority of open refrigerated cabinets by 2020 in an effort to reduce energy consumption.
The voluntary agreement by a number of major supermarkets to add doors to all cabinets could save an estimated 2.2TWh/year, or 20 % of the energy consumption of stores.
In an agreement signed this week between the French government and France's Federation of Commercial and distribution (FCD), three-quarters of the 700km of French cabinets must be equipped with doors by 2020.
Eight major retailers (Auchan, Carrefour, Casino, Cora, Francap, Monoprix, Simply Market System and U) have signed up. Intermarche, with 1800 stores in France is expected to sign in the coming days and others will be invited to join the scheme.
Source: http://www.acr-news.com

UK supermarket Waitrose installs HFO chillers in South London store

Continuing its leading role in the field of environmentally responsible refrigeration, Waitrose, an upmarket chain of supermarkets in the United Kingdom, is carrying out an energy assessment in a working store of chillers running on fourth generation low global warming potential (GWP) HFO refrigerants.
Source: http://www.ejarn.com

Report offers unique insight into UK market

The move by many major supermarkets to alternative "natural" refrigerants provided a major boost to the UK refrigeration market in 2010, according to the latest market statistics report from the British Refrigeration Association (BRA).

Despite the depressed market, sales of system components and controls for hydrocarbon and CO_2 refrigerants showed a marked upward trend. A move to electronic controls - especially required for CO_2 systems - saw a consequent decline in sales of electro-mechanical controls, although some of this was due to a decline in OEM sales.

In line with this, the market for refrigerant gas declined, partly due to the complete phase out of R22 but also due to the move towards smaller more efficient systems and lower system leakage.

As might be predicted, the decline in new build led to a marked increase in service and repair activity.

This unique annual report into the sales of refrigeration equipment and components provides an invaluable insight into market trends.

Source: http://www.acr-news.com

Daikin to build largest factory in China

Daikin is to build its largest residential and light commercial air conditioning factory in China. Production at the £120m factory is scheduled to start in April, eventually producing 1.5 million units a year. The new company Daikin Air-Conditioning (Suzhou) Co Ltd will include more in-house production to achieve cost competitiveness.

Source: http://www.acr-news.com

IEA Heat Pump Programme News

Heat Pump Programme Open Conference

In conjunction with the Chillventa, October 8, Nürnberg, Germany

In order to promote the Heat Pump Programme, we are planning to hold an Open Conference. During this Open Conference, work and visions of ongoing and planned HPP Annexes will be presented. There will also be invited speakers, with presentation of hot subjects, such as the ETP2012 (by an IEA representative), heat pumps in smart cities, and others. The programme of the Conference has not yet been finalized. Please reserve the day , and let us know your interest by sending an e-mail to johan.berg@sp.se.

Heat Pumps in The Netherlands – an overview

Peter Oostendorp, The Netherlands

As in many other countries, implementing heat pumps in the Netherlands is a sport for go-getters. It seems that the energy put into this by many during the last decades will be worthwhile in the end. We see increasing numbers of heat pumps installed, new markets entered, new products launched and concepts developed, together with an increasing number of enthusiastic and involved persons. Slightly fewer heat pumps were installed in 2010 than in 2009, but this decrease is not very large when seen in the context of the economic crisis and (virtually) the end of support by the Dutch government.

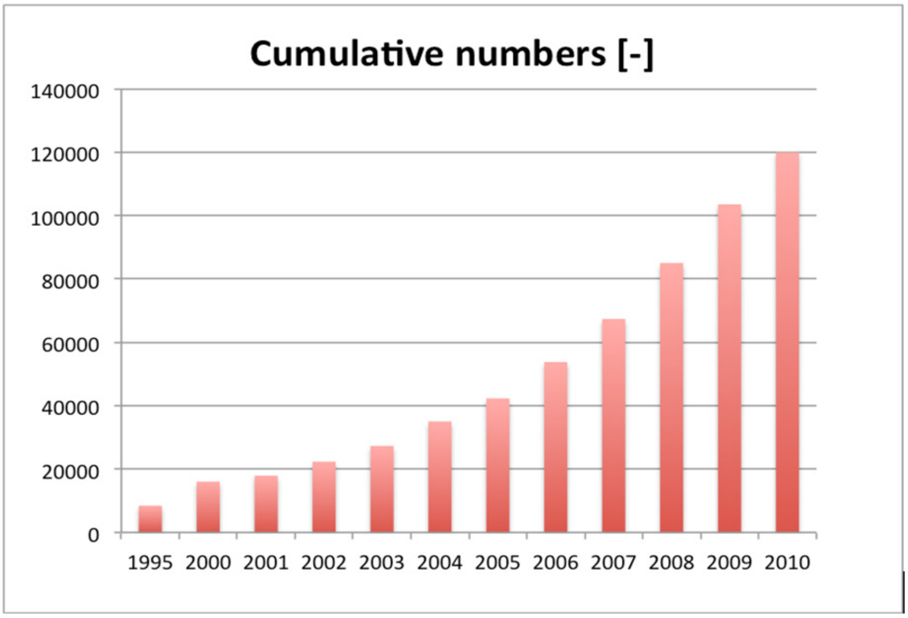

Figure 1. Number of heat pump units installed

Context

In the Netherlands, heat pumps experience fierce competition from gas-fired boilers. The modern condensing combi-boiler is capable of delivering heat for space heating and domestic hot water with a high efficiency and guaranteeing comfort across a wide range of users' demands. In addition, the changeover from gas to electricity (as needed for electric heat pumps) requires a transition to a more expensive energy carrier, so the boundary conditions for electrically driven heat pumps in particular are not very favourable.

One of the ways in which a possible solution can be found is to emphasise the fact that heat pumps are much more than heating devices: they can deliver cooling as well. In particular, free cooling - as delivered by ground-coupled heat pumps - is interesting. This category is a favourite in new buildings. Another inducement is to lower the cost of investment, which is a strong point for heat pumps that use outside air or ventilation exhaust air as a heat source. The latter are increasingly found in renovation projects.

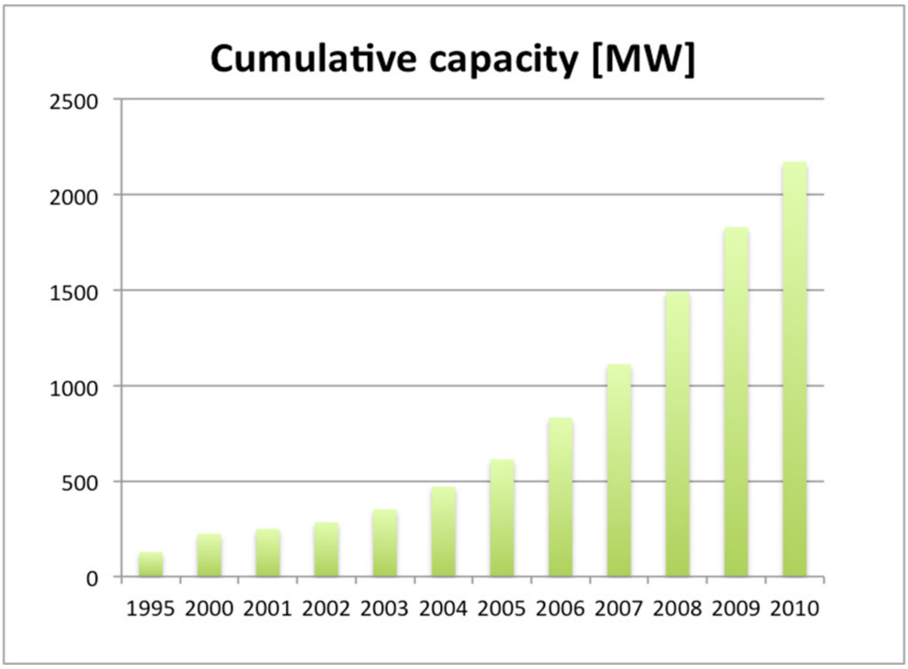

Figure 2. Total installed capacity

Another attraction is the fact that the disadvantage of the necessary low-temperature heating system is increasingly sold as an advantage: eliminating radiators that need cleaning and emphasising the high quality indoor climate provided by underfloor heating. Even in systems with conventional boilers, underfloor heating systems are becoming standard.

Numbers installed

By the end of 2010, about 120 000 heat pumps were in operation in The Netherlands in the domestic and utility sector. 2010 saw a break in the trend of yearly increasing numbers of installed heat pumps. At 16 970, new installations were less than the 18 918 of 2009. Figures 1-3 show the cumulative numbers of units installed, the cumulative installed capacity, and the cumulative CO_2 emission reduction. Figure 4 shows a breakdown of the numbers and types of heat pumps installed over the period 2006-2010. It should be noted that, in 2006 and 2007, the different types of heat-only heat pumps were not distinguished, so brine/water, water/water, air/water and exhaust air heat pumps are all grouped under the brine/water category. Reversible heat pumps are mainly used in commercial buildings, while heat-only heat pumps and heat pumps for sanitary hot water are mainly installed in domestic buildings.

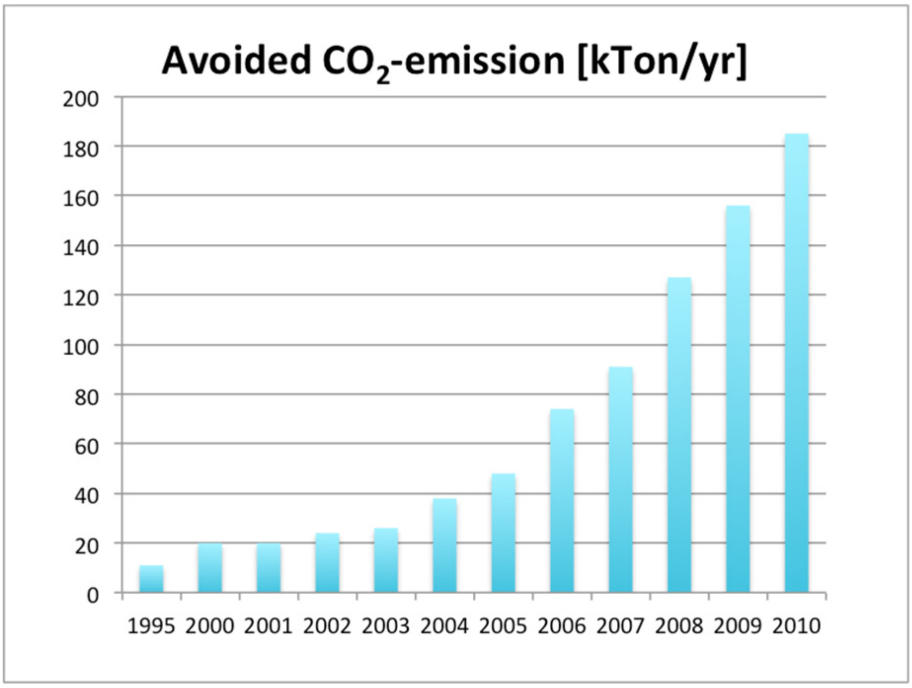

Figure 3. Annual reductions in CO2 emissions

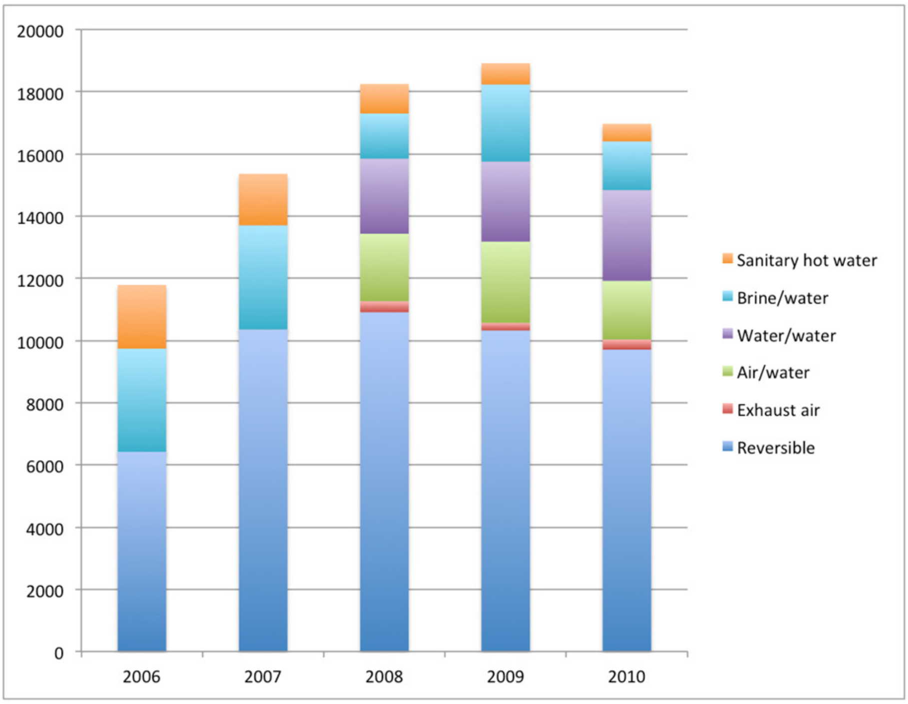

Figure 4. Numbers of units installed per year, by types

European and other regulations

In conformity with the EPBD, a new standard has been developed in The Netherlands for calculating the energy performance of buildings. NEN 7120 specifies how to define and calculate the energy performance of both existing and new residential and commercial buildings, expressing the result as a Coefficient of Energy Performance (EPC).

The Dutch EPC regulations specify a maximum permitted normalised energy use of a building, including construction and insulation, air conditioning, domestic hot water, and lighting. The calculation methodology is standardised, and the Ministry has gradually decreased the maximum EPC for residential buildings from 1.0 in 2000 to 0.8 in 2006 and 0.6 in 2011. For commercial buildings, determining the maximum energy use is more complicated. The regulations distinguish between various functions of the building, e.g. office space, hotel space, education etc. In 2009, the EPC for commercial buildings was tightened up, from 1.5 down to 1.1 for office buildings, and from 1.4 to 1.3 for schools (and so on). Heat pumps can help achieve the EPC requirements.

In 2011, the Dutch Heat Pump Association decided to join the EHPA Heat Pump Quality Scheme. It is expected that this will be operative in the course of 2012.

2012 will also see the coming into force of also the certification scheme for installers, as required in the RES Directive. In both cases, we are pleased to cooperate with our colleagues from the Belgian Heat Pump Platform, who joined the system one year earlier.

Market trends

Up till now, most heat pumps have been installed in new-build houses. However, the rate of new construction of single/two-family houses at the moment is equivalent to only 0.6 % of the existing housing stock of 7.2 million (43 200 new houses were built in 2010). If we are to achieve the European 20/20/20 objectives, existing housing stock should be seen as a very relevant market for heat pumps. For renovations, the hybrid air/exhaust air heat pump is very promising. Its heat source makes it very cost-effective. In many cases, the heat pump could be connected to the house's existing central ventilation unit. "Hybrid" refers to a bivalent system with a gas-fired back-up (peak load) boiler. The electric heat pump is small, and provides base load heating only, so it can in most cases be powered from the existing electricity supply.

Not surprisingly, (gas-driven) cogeneration is also a favourite technology in The Netherlands. Its combination with electric heat pumps is promising in areas where a heat demand-coupled local electricity production can relieve the electricity grid.

Figure 5. Cascade of six gas-fired absorption heat pumps heating a residential-care centre.

Gas-driven heat pumps are of increasing importance in The Netherlands. Specifically, gas-driven absorption heat pumps are so similar to gas-fired boilers in terms of implementation that renovation projects in the utility sector (and in the group-heated domestic sector) that gas boiler systems are increasingly being partly replaced by absorption heat pumps. Figure 5 shows a cascade of six gas-driven absorption heat pumps delivering heat to a residential-care centre. The system also includes gas boilers covering the peak load.

Figure 6 shows a schematic diagram of a very popular system for new-build houses: individual heat pumps connected to vertical ground-source heat exchangers, which deliver free cooling in summer.

Figure 6. Ground-coupled heat pumps for heating and domestic hot water. Free cooling in summer.

Figure 7 shows the outdoor part of an air-to-water heat pump, installed in an existing building (in this case, a farm that was converted to a dwelling).

Organisation

In the Netherlands, most manufacturers and suppliers of domestic heat pumps belong to the Dutch Heat Pump Association. Suppliers of reversible systems are grouped in the VERAC. The Smart Cooling Foundation is the branch organisation for suppliers and manufacturers of gas-driven heat pumps. Networking and overlaps between the three mean that cooperation is quite good.

At the moment, the DHPA is preparing a “500 000 Heat Pumps” plan. The target is to have this number of heat pumps installed in 2020, with a focus on the market of existing dwellings.

References

[1] EHPA. Outlook 2011 – European heat Pump Statistics, EHPA, 2011. See Chapter 6.12 The Netherlands

[2] www.CBS.nl. CBS stands for Central Bureau of Statistics in The Netherlands. Data for [1] are provided by CBS.

[3] www.DHPA-online.nl

[4] SEPEMO. Heat Pumps, field measurements and methods in The Netherlands. Country report

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Figure 7. Split air-to-water heat pump applied in a converted farm

Annexes, ongoing

IEA HPP /IETS Annex 35 / 13 Application of Industrial Heat Pumps

The joint HPP / IETS Annex "Application of Industrial Heat Pumps" started in April 2010 with 15 participating organisations from nine member countries of the two Implementing Agreements. The annex is focused on the reduction of energy costs, fossil energy consumption and CO_2 emissions in industrial heat generation by studying applications of industrial heat pumps.

Work in 2011 was concentrated on two Annex meetings:

- 16 June 2011 at EdF-R&D, Les Renardières, Moret-sur-Loing, France, the day before the 6th Energy Efficiency Seminar with EdF / ECLEER:
  « Energy Performances of Industrial sites: from Research to Sober Plant»

and

- 27 September 2011, at the Exhibition Centre, Nuremberg, Germany, together with the HPP / IETS Annex 35/13 Workshop "Practical Applications of Industrial Heat Pumps" on 28.09.2011 as part of the European Heat Pump Summit 2011.

At the request of the Dutch delegate, the participants redefined the definition of industrial heat pumps for the annex:
Heat pumps which are used for heat recovery and for heat upgrading or cooling/ refrigeration in industrial processes or for heating and cooling in industrial buildings

The present version of the final report of Task 1:"Heat Pump Energy Situation, Energy Use, Market Overview, Barriers for Application" (see Figure "EU 27 Industrial heat supply") has been approved under the condition of a permanent update at the end of the annex.

Several aspects of Task 2 "Modelling Calculations and Economic Models" were discussed in 2011. The key task was further specified:

a) A SWOT analysis of available software and calculation procedures for application is to be performed by SP Technical Research Institute of Sweden. Important input will be provided by the Delft University of Technology, which will perform an in-depth study of available software (organised and supervised by the Dutch participant).
b) Analysis and update of models from Annex 21. This relates basically to the Industrial Heat Pump (IHP) data base. The critical review of the Screening Program developed in Annex 21 will be part of Item a).

The SWOT analysis of available software is at present in progress. One important output of this analysis will be the state-of-the-art of principle approaches, such as pinch technology and more refined mathematical optimisation methods. Are sophisticated mathematical optimisation models already advanced enough to be used in the framework of a user-friendly software package? A step into modern optimisation methods was presented and discussed at the meeting in Les Renardières, Moret-sur-Loing, France.

A contribution to the review of the "IHP Screening Program" developed in Annex 21 has been made. The IHP Screening Program has been analysed as far as possible on the basis of the Annex 21 report on industrial heat pumps. As a by-product, the relevant program parts have been converted from the outdated Version 3 of Visual Basic to the most modern version. Proposals for improvements and further developments are given. In this connection, the relevance of the economic analysis needs special attention.

A workshop is planned for 2012 to disseminate the possibilities of the use of heat pumps in industrial processes. The workshop will be arranged on 21st June 2012 as a session of the ACHEMA Congress at the Exhibition grounds of Messe Frankfurt/ Main, Germany, Room Europe 1, entitled "Application of Industrial Heat Pumps – Improving Energy-Efficiency of Industrial Processes".

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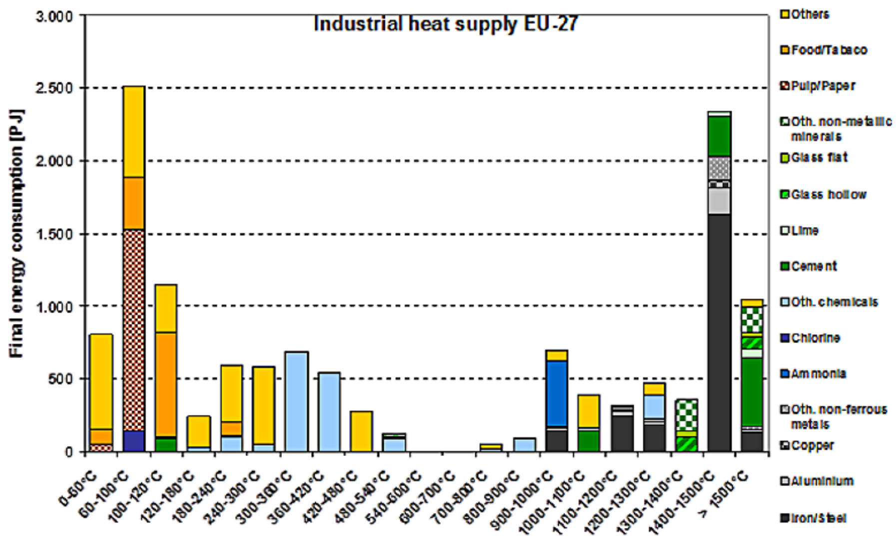
Addendum for Annex 35: Application of Industrial Heat Pumps

Improving energy efficiency is the single most important first step toward achieving the three goals of energy policy: security of supply, environmental protection and economic growth.



Source: SP Technical Research Institute of Sweden

Nearly a third of global energy demand and CO_2 emissions are attributable to industry, especially the major primary materials industries such as chemicals and petrochemicals, iron and steel, cement, paper and aluminium. Understanding how this energy is used, national and international trends and the potential for efficiency gains, is crucial.

While impressive efficiency gains have already been achieved in the past two decades, energy use and CO_2 emissions in manufacturing industries could be reduced further if best available technologies were to be applied worldwide.

Heat pumps have become increasingly important in the world as a technology to improve energy efficiency and reduce CO_2 emissions. They are presently widely used, mainly in residential buildings for space heating and domestic hot water production, and are expected to spread to the industrial sector for heat recovery and heat upgrading in industrial processes and for heating, cooling and air-conditioning in industrial buildings.
In many cases, the introduction of heat pumps in food and beverage manufacturing factories and wood drying, with operating temperature below 100 °C, is considered to be easy. However, higher temperature application still require additional R&D activities for the development of high-temperature heat pumps, integration of heat pumps into industrial processes and development of high-temperature refrigerants.

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

The Annex officially started on 1st April 2010, with 16 participating organisations from ten IETS and HPP member countries. Industrial heat pumps in this annex are defined as heat pumps which are used for heat recovery, and for heat upgrading or cooling/refrigeration in industrial processes or for heating and cooling in industrial buildings.

The main market barriers to the introduction of industrial heat pumps are expected to be lack of experience, and thus lack of market acceptance by operators, industrial partners and their supply and consulting chains.

The focus of the Annex, and also this issue of the Newsletter, should be on presenting information on heat pumping technologies for industry in such a way that it will lead to better understanding of the opportunities and using them in the right way to reduce the use of primary energy, CO_2 emissions and energy costs.

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IEA Annex 36 Quality Installation / Quality Maintenance Sensitivity Analysis

Annex 36 is evaluating how installation and/or maintenance deficiencies cause heat pumps to perform inefficiently and waste energy. The focus and work being undertaken by each participating country is given in the table below. The Annex is scheduled to run through November 2013 with future working meetings planned for September 2012 (in the U.S.) and the fall 2013 (in France).

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Annex 36 Participants	Focus Area	Work to be Undertaken
France	Space heating and water heating applications.	Field: Customer feedback survey on HP system installations, maintenance, and after-sales service. Lab: Water heating performance tests on sensitivity parameters and analysis.
Sweden	SP -Large heat pumps for multi-family and commercial buildings KTH/SVEP – Geothermal heat pumps	Field: SP – literature review of operation and maintenance for larger heat pumps. KTH/SVEP - investigations and statistical analysis of 22000 heat pump failures. Modeling/Lab: Determination of failure modes and analysis of found failures (SP) and failure statistics (KTH/SVEP).
United Kingdom	Home heating with ground-to-water, water-to-water, air-to-water, and air-to-air systems.	Field: Replace and monitor five geothermal heating systems Lab: Investigate the impact of thermostatic radiator valves on heat pump system performance.
United States (Operating Agent)	Air-to-air residential heat pumps installed in residential applications (cooling and heating).	Modeling: Examine previous work and laboratory tests to assess the impact of ranges of selected faults covered augmented by seasonal analyses modeling to include effects of different building types (slab vs. basement foundations, etc.) and climates in the assessment of various faults on heat pump performance. Lab: Cooling and heating tests with imposed faults to correlate performance to the modeling results.

IEA HPP Annex 37 Demonstration of Field Measurements on Heat Pump Systems in Buildings – Good Examples with Modern Technology

It is a pleasure to welcome Norway as a new participant in Annex 37. Austria will participate in the annex as an observer.

The aim of this project is to demonstrate and disseminate the economic, energy, and environmental potential of heat pumping technology. The focus will be on modern technology, and results from already-performed field measurements will be used to calculate energy savings and CO_2 reductions. It should be possible to predict the most suitable heat source and heat pump system for a specific application in a specific geographic region. In order to draw the right conclusions, it is most important that the quality of the measurements is guaranteed. The criteria for good and assured quality will be defined in the project. From the start, an additional goal has been to establish a database connected to the Heat Pump Centre website, where data from field measurements will be presented. Since only four countries participate in the annex, it is not economically viable to develop a database with only 15 good examples. It was therefore suggested that all other IEA HPP members should deliver new data every year after the annex finished. However, the ExCo meeting in Atlanta decided not to support this suggestion, which means that Task 5 (Establish a data base) is to be left out of the annex. Results from the measurements will be presented on the HPC website and in a brochure.
In order to achieve the objectives of the Annex, the activities have the following structure:

Task 1 (Task leader, SP, Sweden)
Prepare a common template of what should be communicated. The focus is on the template content. Cosmetics are not considered in this task.
Task 2 (Task leader, Plainair SA, Switzerland)
Define criteria for good quality of field measurements (e.g. boundaries of the measured systems, number and location of measuring points, measurement uncertainty, time increments etc.) and decide what parameters are important for assured quality.

Task 3 (All countries are responsible for their measurements)
Collection and evaluation of ongoing and concluded field measurements on heat pump systems. The focus is on the best available technology.

Task 4 (Task leader, Plainair SA, Switzerland)
Agree how to recalculate the selected annual performance measures, such as seasonal performance factor, energy savings and carbon footprints. Parameters will be compared with those for other heating systems. Annex 34's definition of SPF will be applied for thermally driven heat pumps. Regarding systems with heat pumps combined with solar thermal, the results from the work of combining the solar fraction or solar savings fraction with an SPF (which is ongoing in Task 44 of the IEA Solar Heating and Cooling Programme/ Annex 38 of the IEA Heat Pump Programme) will be considered.

Task 5 (removed from the project)
Establish a database connected to HPC website based on data from field measurements and the common template; the best examples will be documented.

Task 6 (Task leader, DECC, United Kingdom)
Information dissemination

Information to installers and manufacturers should include good examples, but it could also include bad examples with mistakes that are often made and which should be avoided. This information should support further development of training documentation (e.g. EU Certified Heat Pump Installer) and also installation manuals and regulations supplied by the manufacturers.

The work in Task 1 is completed (see HPC Newsletter no. 3, 2011)
The work in Task 2 is completed (see HPC Newsletter no. 4, 2011)
The work in Task 4 has just started, and it is planned to be finished in May 2012.

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IEA HPP ANNEX 38 Solar and heat pump systems

The objective of Annex 38 is to assess performances and relevance of combined systems using solar thermal and heat pumps, to provide a common definition of performances of such systems, and to contribute to successful market penetration of these promising new combinations of renewable technologies.

The Annex considers solar thermal systems in combination with heat pumps, for the supply of domestic hot water and space heating in family houses. It is thus concentrated on small systems in the range of 5 to 20 kW, combined with any type of solar collectors.

The Annex is a joint effort of the Solar Heating and Cooling Programme and the Heat Pump Programme. It is Task 44 for SHC and Annex 38 for HPP.

More than 100 different systems were identified during 2011. A two-page leaflet describing each solution in detail is available for more than 20 systems. A draft report bringing this material together has been issued.
Four categories of concepts have been defined: the parallel concept, where solar and heat pumps run almost independently; the serial, regenerative and the complex concepts. The so-called "Square view" scheme, developed in 2010, became

the reference tool for the work, with every system being represented in this format.

The performance of many projects is already being monitored, and results presented in 2011 will be analysed with a common format.

As far as system performances are concerned, one important question when dealing with hybrid systems, such as S+HP systems, is how to calculate the benefit of the "solar and heat pump" combination. Is the benefit to be calculated against other alternative solutions such as solar and wood or solar and gas, or against "solar-only" or "HP-only" solutions? There is still some way to go before Annex participants issue a document on this issue.

A number of institutes participating in Annex 38 are already testing S+HP total systems, or at least system components on test stands. A common test procedure that could become a standard in the future is still being discussed.

Component and system modelling activities are progressing, with the issue in 2011 of the reference framework for simulation and some new component models for solar collectors and heat pump dynamics. Validation is in progress.

A first newsletter was published at the end of October 2011, and is available on our web site www.iea-shc.org/task44

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IEA HPP Annex 39 A Common Method for Testing and Rating of Residential HP and AC Annual/ Seasonal Performance

In Annex 39, the second work meeting was held in conjunction with the ASHRAE winter meeting in Chicago, January 21. Results from this meeting include the wish for a unified nomenclature in the field of performance testing, so that performance numbers can be interpreted more easily.
There is also a need to combine methods for water heating with space heating, so that combined units can be evaluated. Many partners of the project presented national ideas for defining national standards for evaluating performance. However, this is the worst possible case from a manufacturer's perspective, since harmonization is of outmost importance in this field. There is also an issue that new hybrid systems, which existing standards do not cover, are reaching the market. In Annex 38, the same conclusion has been made considering solar + HP systems. Annex 39 therefore plans to arrange a workshop in conjunction with the Chillventa in October to get good industry feedback on systems that are under development.

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Ongoing Annexes

Bold text indicates Operating Agent. ** Participant of IEA IETS or IEA SHC

Annex 34 Thermally Driven Heat Pumps for Heating and Cooling	34	AT, CA, CH, **DE**, FR, IT, NO, UK US
Annex 35 Application of Industrial Heat Pumps (together with Task XIII of "Industrial Energy-Related Technologies and Systems" (IEA IETS))	35	AT, CA, DK**, FR, **DE**, JP, NL, KR, SE
Annex 36 Quality Installation/Quality Maintenance Sensitivity Studies	36	FR, SE, UK, **US**
Annex 37 Demonstration of field measurements of heat pump systems in buildings – Good examples with modern technology	37	CH, NO, **SE**, UK
Annex 38 Solar and Heat Pump Systems	38	AT**, BE**, CA**, **CH**, DE, DK**, ES**, FI, FR**, IT**, UK
Annex 39 A common method for testing and rating of residential HP and AC annual/ seasonal performance	39	AT, CH, DE, FI, FR, KR, **SE**, US

IEA Heat Pump Programme participating countries: Austria (AT), Canada (CA), France (FR), Finland (FI) Germany (DE), Japan (JP), The Netherlands (NL), Italy (IT), Norway (NO), South Korea (KR), Sweden (SE), Switzerland (CH), United Kingdom (UK), United States (US). All countries are members of the IEA Heat Pump Centre (HPC). Sweden is Operating Agent of the HPC.

Using industrial heat pumps in sawmills for lumber drying

Vasile Minea, Canada

Industrial heat pumps based on the vapour compression cycle and used for wood drying have advantages such as high annual utilisation factors and energy efficiency, proper control of product moisture content, reduced energy consumption and relatively short pay-back periods. On the other hand, among their limitations when compared with basic hot air convective dryers, there are higher capital and maintenance costs, more complex operation and requirement for competent operators. This article firstly presents the energy performances of a 13 m^3 dryer coupled with a 5.6 kW (compressor) low-temperature heat pump for hardwood (yellow birch, hard maple) drying. The second industrial application describes a 354 m^3 air-forced dryer equipped with two 65 kW (compressor) high-temperature drying heat pumps and steam heating coils for softwood (white spruce, balsam fir) drying.

Introduction

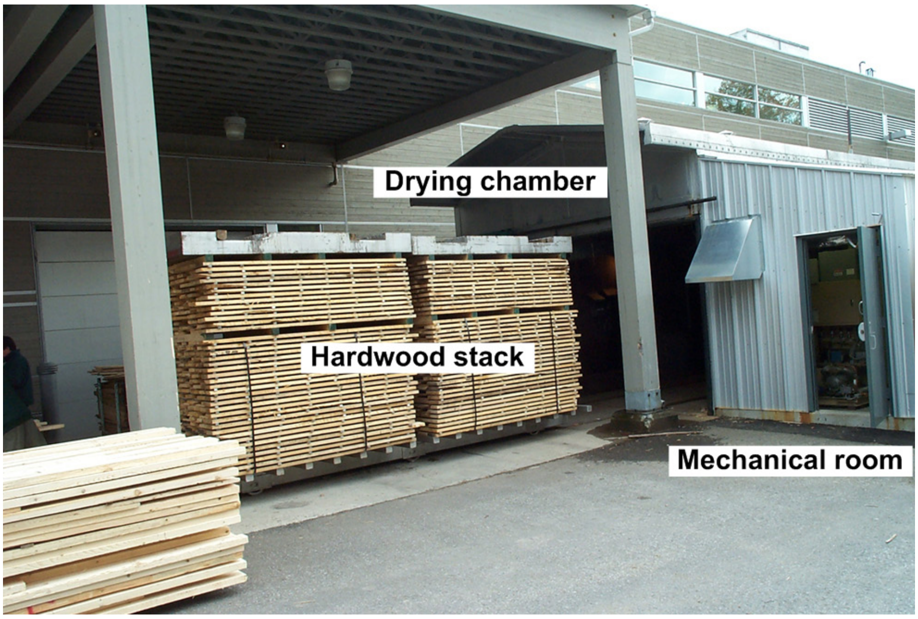
Green woods are hygroscopic materials that naturally absorb and release water, and use solar energy to continuously renew. They are cut into dimensional lumber boards in sawmills as building or furniture-making materials. Their safe moisture content, i.e. low enough to prevent organisms from growing, is recommended at around 19 % [1]. This can be achieved by drying, an energy-intensive process consuming up to 70 % of total energy used in the wood industry [2]. In recent years, sawmills emphasize increasing profits through waste minimisation and increased energy efficiency of drying processes. Wood kilns are generally air convective dryers. Most of their heat losses are due to the exhausted moist air and the poor thermal insulation of the drying enclosures. Because of energy losses, attention has focused on reducing and recovering the wasted heat, as part of the global effort to reduce global energy consumption and control greenhouse gas emissions. Among other heat recovery devices, heat pumps assisting air convective dryers have a significant potential to reduce the primary energy consumption. The heat pump drying principle (dehumidification) is based on the conservation of energy, the system being closed in terms of the overall energy envelope [3].

Drying with heat pumps

Drying of wood is a complex, highly non-linear thermodynamic process. Most conventional hardwood and softwood drying kilns use fossil fuels (oil, propane, natural gas) or biomass (bark) as primary energy sources. All of them can be coupled with heat pumps for drying by dehumidification. In this case, practically any warm air loaded with moisture is discharged into the environment. Good insulation and controls are essential to achieve the required dry-bulb and wet-bulb air temperatures, relative and absolute humidity, and air velocity. When selecting a drying heat pump and integrating it to a kiln, the first step is to identify the technical and economical feasibility of installation. The most used type is the closed vapour compression, electrical motor-driven cycle. This process includes energy conservation through re-heating and dehumidification of the drying process air. Warm dry air is led over the surface of wood boards to be dried. The low relative humidity of the drying process air helps to remove moisture from the wood. This air takes up the surface water on the wood boards. The water vapour picked up by the air condenses on the externally finned heat transfer surface of the evaporator and, finally, is heated again by passing through the heat pump condenser. Heat is thus recovered from the dryer hot and humid air by condensing the water vapour, which is then removed as liquid. The recovered sensible and latent heat is used to reheat the dehumidified air. The heat pump supplies the majority of the required heat for the drying process. However, in cold climates, additional heat input (electrical or fossil) may be supplied to overcome convective and conductive heat losses and to maintain effective drying temperatures.

Hardwood drying

Hardwoods such as sugar maple and white and yellow birch have relatively complex cell structures. In eastern Canada, their average green moisture content varies between 65 % and 72 %. For most of such species, the drying process is an essential step in the manufacturing process (furniture, etc.). If lumber is not dried according to proper procedures, improper moisture content may cause finished high-quality products to warp and split. Open-yard air drying is no longer accepted as a quality drying method for hardwood lumber [1]. Today, the most widely used method for removing moisture from hardwood is drying under controlled temperature and humidity conditions, to ensure low and constant moisture content before lumber machining, gluing and finishing. The moisture migration mechanism in hardwood during the drying process is complex and caused by a set of forces related to the affinity (attraction) that both air and wood cell walls have for moisture. The actual moisture removal occurs on the wood surface only, and is largely governed by the capacity of the surrounding air to absorb moisture. To maintain a constant drying rate, the water molecules inside the wood must absorb additional heat in order to increase their kinetic energy. The evaporation rate depends on the amount of energy supplied, the mass transfer coefficient and the air temperature and the flow rate. Air velocity on the hardwood surface must be high enough to produce rapid air changes, avoid the formation of dead zones and provide uniform drying. Hardwood is usually dried at temperatures below 55 °C. Electrically-driven low-temperature heat pumps are frequently used in combination with fossil fuels or electricity as supplementary energy sources.



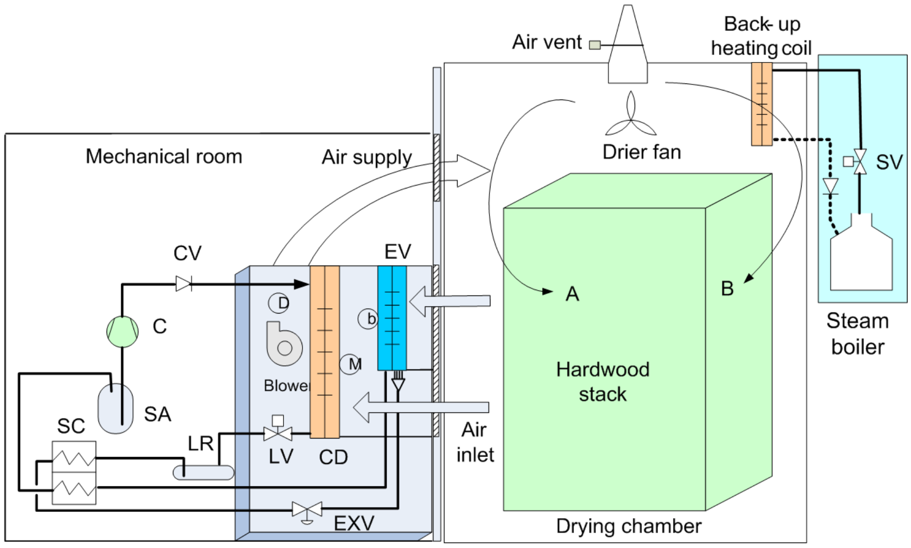


Figure 1 - Schematic and view of laboratory hardwood drying heat pump system [4, 5]
B: blower; C: compressor; CD: condenser; EXV: expansion valve; EV: evaporator; LV: liquid valve; SA: suction accumulator; SC: sub-cooler; SV: solenoid valve; VS: variable speed; A, B: air circulation direction.

Laboratory set-up

The following is a brief presentation of a typical case, in the form of a 13 m3 air-forced hardwood dryer with variable-speed fans, coupled to a 5.6 kW (compressor nominal power input) low-temperature heat pump (Figure 1). The dryer is equipped with steam and electrical backup heating coils. Steam is supplied at variable flow rates by a natural gas-fired steam boiler. The air flow rate over the surface of the lumber is maintained sufficiently high to provide a rapid exchange of air and minimise dead spots. To provide uniform heating and drying, the direction of air flow is periodically reversed. The heat pump, including compressor, blower, evaporator, condenser, sub-cooler, refrigerating piping and controls, is installed in a mechanical room beside the dryer. The drying control system contains several programmable modes, such as hardwood preheating, dehumidification with heat pump, and conventional drying with electricity or natural gas as the heating energy sources. The energy required at each step of the drying process includes the input energy to heat hardwood boards, sticks, timber sleepers, dryer enclosure, equipment, and water extracted from the wood, as well as the excess air, the water spray and the residual water after drying. Heat is also required to compensate the heat losses of the dryer walls and floor, and to overcome the water retention forces [4, 5]. The thermal energy recovered from the wood stack reduces the total energy requirement for drying, while the heat pump electrical input ends up entirely as drying energy. Few energy losses occur because the air vents are normally closed when the heat pump operates as a dehumidifier and heat recovery device.

Drying schedules and modes

The drying schedules, including the time required for each step, the dry-bulb and wet-bulb temperature

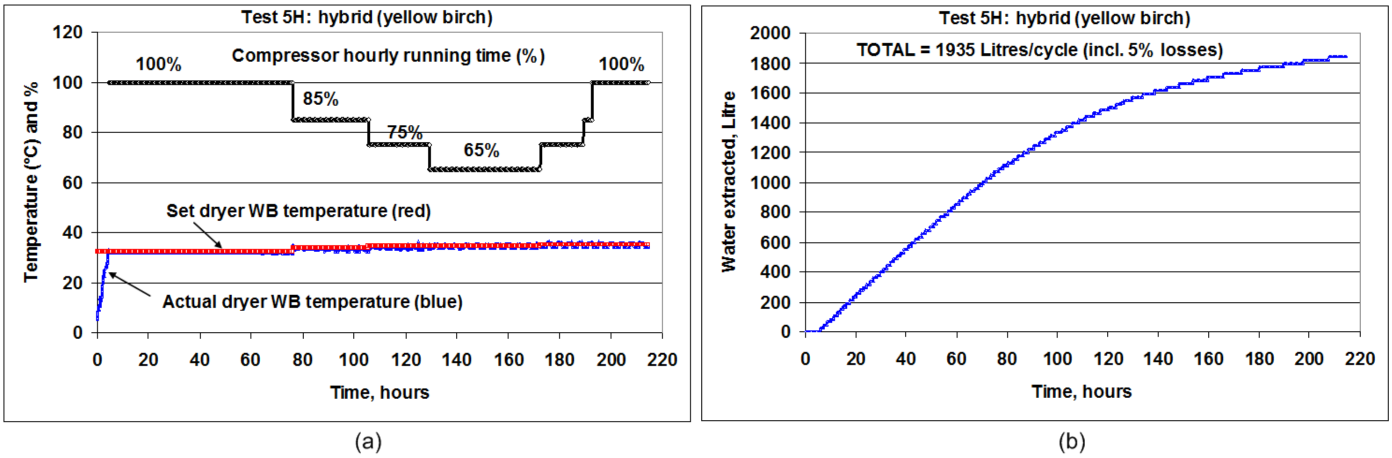


Figure 2 – (a) Compressor hourly running profile and set value and actual value of dryer wet bulb (WB) temperatures; (b) Cumulative water extracted [4, 5]

settings and/or depressions (i.e., differences between the dry- and wet-bulb temperatures), and the heat pump hourly running times, are established prior to each drying cycle. They are based on the actual average moisture content (defined as the weight of water as a percentage of the oven-dry weight of the wood fiber) of hardwood board samples within the whole drying process.

During the hardwood preheating step, the heat pump is not running. Toward the end of this step, when the air wet-bulb temperature slightly exceeds its setting point, the heat pump starts and its operating time is set in accordance with an intermittent drying schedule, as shown in Figure 2a [4, 5]. Both heating and dehumidification processes are controlled by the actual wet-bulb temperature of the air inside the drier. Under such a schedule if, for example, the compressor hourly running time is set at 60 %, it will run for 30 minutes and will shut down during the next 20 minutes. After the heat pump starts, the compressor running time is increased when the actual wet-bulb temperature is above the upper limit, and decreased when it is below the lower limit. In all-electrical and hybrid drying modes, a back-up heating source (electricity or steam) is used only when required. The amount of supplementary heating is automatically controlled according to the dryer air setting and actual wet-bulb temperatures. In addition, if the actual dryer air dry-bulb temperature is above its set point, the air vents open. However, this sequence is generally avoided by a proper design of the integrated drying system in order to reduce the energy consumption and further optimise the heat pump operation. In the conventional drying cycles, heating energy (electricity or steam) is also supplied when the actual wet-bulb temperature of the dryer air is below its set point by a preset temperature difference, and stopped when it is higher. In this operating mode, the air vents open when the air wet-bulb temperature is higher and close when it drops below the preset point.

Compressor running profile

In the intermittent dehumidification control mode, the compressor hourly running ratio was preset at 100 % at the beginning of each drying cycle. As can be seen in Figure 2a, during each drying process, it was continuously adjusted (here, between 65 % and 100 %) in order to get the actual wet-bulb and dry-bulb temperatures in the dryer practically equal to their setting points. Figure 2b shows the cumulative water extracted during the same hybrid drying test with yellow birch using the intermittent drying strategy described.

Energy consumption

All-electrical drying tests 1E and 2E (Table 1) used the electrically-driven heat pump for dehumidification and electricity as a supplementary energy source. It can be seen that the initial moisture contents (dry basis) were 29.1 % and 40.7 %, respectively. After 147 hours (with yellow birch)

Table 1 - Energy consumption of all-electrical, hybrid and conventional hardwood drying cycles [4, 5]

Test	Wood species	Moisture content (dry basis)		Cycle energy consumption				
-	-	Initial	Final	HP		Dryer		TOTAL
-	-	-	-	C	B	Fan	Back-up	-
-	-	%	%	kWh	kWh	kWh	kWh	kWh
1E	Yellow birch	29.1	7.4	747	151	229	1 828 (E)	2 955
2E	Hard maple	40.7	7.8	872	258	451	2 441 (E)	4 022
3H	Hard maple	31.1	7.5	650	129	360	2 902 (NG)	4 041
5H	Yellow birch	75.9	7.6	894	201	398	3 033 (NG)	4 526
4CONV	Hard maple	36.4	7.5	-	-	638	7 147 (NG)	7 785

B: blower; C: compressor; CONV: conventional; d.b.: dry basis; E: electric; H: hybrid; HP: heat pump; NG: natural gas

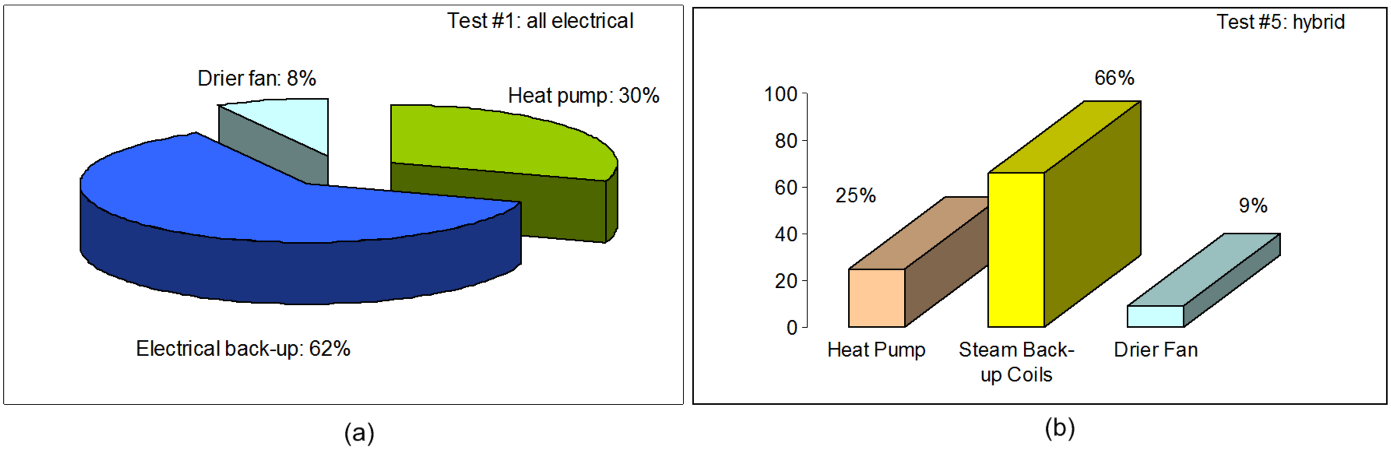


Figure 3 - Share of drying energy consumptions. (a) All-electrical drying (test 1E); (b) Hybrid drying (test 5H) [4, 5]

and 240.67 hours (with hard maple) respectively (including the preheating steps), the final moisture contents fell within the required ranges for hardwood drying (7.4 % and 7.8 %, respectively). During these all-electrical drying cycles, the heat pump (compressor and blower) used 30 %, the electrical back-up coils used 62 %, and the dryer fan used 8 % of the total energy consumption (Figure 3a). Both hybrid drying tests 3H and 5H (Table 1) were achieved with the electrically-driven heat pump and steam as backup energy. During these tests, the heat pump (compressor and blower) accounted for 25 %, the dryer fan for 9 % and the steam coils for 66 % of the total energy consumed, expressed in kWh (Figure 3b). The relatively high percentage of steam and electrical backup energy consumptions can be explained by the poor thermal insulation of the experimental dryer and its relatively high air leakage rates, a situation frequently encountered in most industrial dryers located in cold climates.

Energy performances and costs

Experimental results show that, for initial moisture contents above 41 %, the total water quantities extracted above the fiber saturation point (FSP = 25 %) were up to 2.9 times higher than those removed below the FSP. The last parameter is defined as the stage in the drying of wood at which the cells are saturated with water while the cell cavities are free of liquid water (generally, FSP=25 %). Consequently, the heat pump's dehumidification efficiency was up to three times higher above the FSP than below this value. Heat pump dehumidification efficiency is expressed in terms of the specific moisture extraction rate (SMER). This parameter represents the ratio between the mass of water extracted and the heat pump total electrical energy consumption (compressor and blower). Above this point, the SMER actually reached . On the other hand, as can be seen in Table 1, the natural gas consumption of hybrid drying test 5H decreased by 57.5 % as compared with the natural gas consumption of conventional drying test 4CONV. Compared to energy costs of the conventional drying cycle with natural gas (test 4CONV), the total energy costs (electricity plus natural gas) decreased by 20 % (test 2E – all electrical) and 23 % (test 5H - hybrid), respectively.

Softwood drying

More than 90 % of the volume of softwoods, such as pines, spruces and fir (coniferous species), is composed of vertical and horizontal fiber cells serving as mechanical support and pathways for the movement of moisture. Finished lumber is supplied in standard sizes, mostly for the construction industry. It is generally dried at relatively high temperatures, but not higher than 115 °C, and thus high-temperature heat pumps coupled with convective dryers are required.

Industrial application

The industrial application presented here includes one 354 m3 air-forced softwood dryer with steam heating coils and two high-temperature drying heat pumps (Figure 4). An oil-fired boiler supplies steam for heating. The dryer central fans provide forced circulation of the indoor air. Each heat pump includes a 65 kW (nominal power input) compressor, an evaporator, a variable speed blower and electronic controls located in an adjacent mechanical room. Both condensers are remote, installed inside the drying chamber. The refrigerant (R-236fa) is a non-toxic and non-flammable fluid, having a relatively high critical temperature compared to the highest process temperature. Expansion valves are controlled by microprocessor-based controllers that display set points and actual process temperatures.

Drying schedule

For a few days before drying by dehumidification, the softwood stacks have been outdoor air pre-dried in the sawmill yard. Several drying tests with high-temperature heat pumps were then performed (Table 2) with white spruce (tests X and Y) and balsam fir (test Z). All drying cycles included 6 to 8 hours preheating steps at average temperatures of 93.3 °C in order to destroy the micro-organisms responsible for discolouring the sapwood. The preset drying conditions of each step have been achieved based upon moisture content, type, dimensions and quality of softwood species. For white spruce, which is normally easy to dry, at initial moisture content of between 40 % and

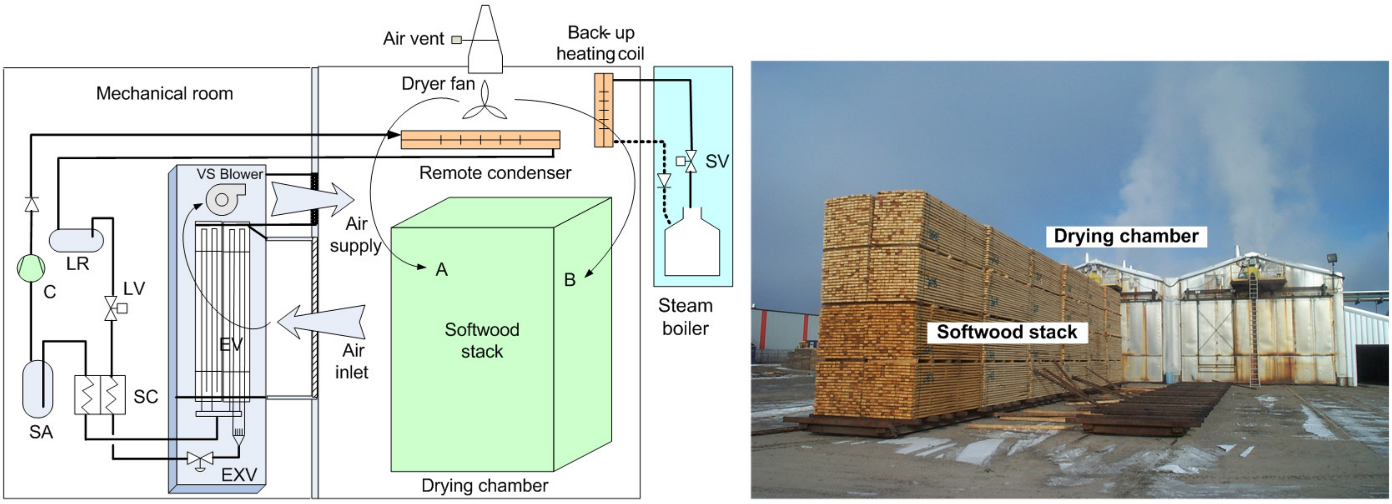
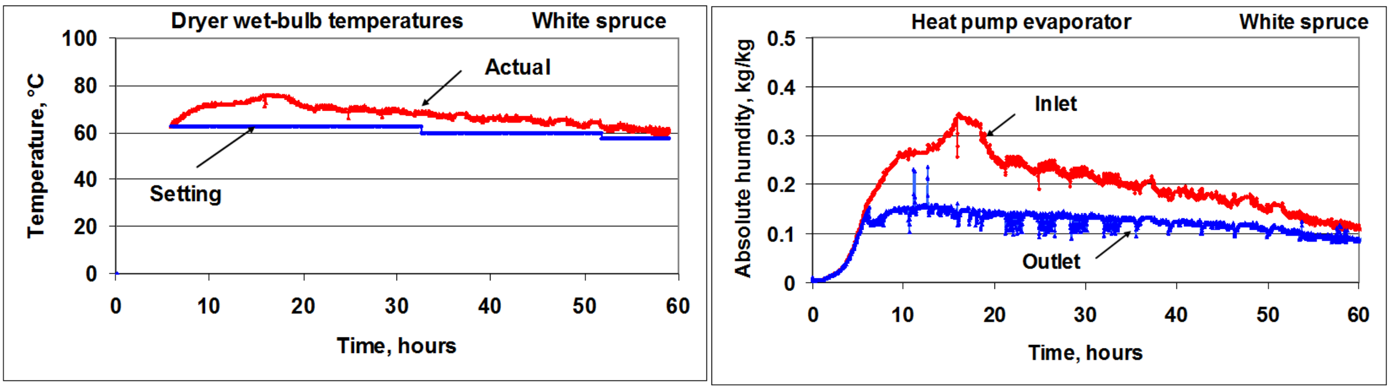


Figure 4 – Schematic and view of the industrial softwood drying heat pump system [6]
C: compressor; LV: liquid valve; SA: suction accumulator; SC: sub-cooler; EXV: expansion valve; VS: variable speed; SV: solenoid valve; A, B: direction of air circulation



(a) (b)

Figure 5 – (a) Dryer wet-bulb setting and actual temperatures; (b) Air absolute humidity entering and leaving the heat pump evaporator [6]

25 %, the dry-bulb setting temperature was between 82.2 °C and 85 °C, and the wet-bulb temperature was 62.7 °C. At a moisture content of less than 25 %, the dry-bulb temperature was generally set at 79.4 °C and the wet bulb-temperature, at 62.7 °C. With balsam fir, which is harder to dry, when the initial moisture content was above 30 %, the dry-bulb temperature was set at 82.2 °C and the wet-bulb temperature at 79.4 °C (Figure 5a).

With white spruce, the preheating steps allowed increasing the kiln's absolute humidity up to 0.35 kg/kg before the dehumidifying process start-up (Figure 5b). The maximum gradient of the absolute humidity across the heat pumps' evaporators varied from 0.214 kg/kg at the beginning, to about 0.039 kg/kg in the dehumidification process. The total drying time for white spruce and pine species was of 61.3 hours, excluding the six hours of preheating steps. The heat pump compressors ran with electrical power inputs of 65 kW, and average compression ratios of 5.5. Stable suction and discharge pressure as well as average refrigerant sub-cooling of 8 °C were achieved. The condensing temperatures varied around 105 °C and the evaporating temperatures ranged between 41 °C and 45 °C. The average relative humidity of the air entering the evaporators largely varied because of periodical changes in the rotation direction of the central fan, and also continuously decreased in time. However, the relative humidity leaving the evaporators was almost constant at between 74 % and 88 %, except at the end of the cycle when it dropped to 70 %.

Drying performances and costs

The softwood moisture content prior the drying cycle was in the range of 35 % to 45 % (dry basis). The average coefficients of performance (COP) of both heat pumps, defined as useful thermal power outputs (kW) divided by electrical power inputs (kW), varied from 4.6 at the beginning, to 3 at the end of drying cycles. As could be seen in Table 2, the heat pumps (compressors plus blowers) used 72 % and the dryer central fan 28 % of the total energy consumption of each drying cycle. The drying time to deliver white spruce with an approximate final moisture content of 18 % was about 2.5 days, while for balsam fir it averaged 6.3 days. Total quantities of water extracted from dried white spruce exceeded 19 100 kg (Figure 6) and 27 000 kg from dried balsam fir (Table 2). Consequently, relatively high water extraction rates have been achieved: 313 kg_{water}/h (test X), 263.2 kg_{water}/h (test Y) and 178.8 kg_{water}/h (test Z). These numbers do not include the venting moisture losses (on average, 90 kg_{water}/h), but account for 5 % of condensed water losses. The Specific Moisture Extraction Rate (SMER), defined as the amount of water extracted by the heat pump (kg) and the total energy input (compressors plus blowers) expressed in kWh, ranged from 1.46 kg_{water}/kWh (test Z – with balsam fir) to 2.52 kg_{water}/kWh (test X – with white spruce). These values do not include the energy consumption during the preheating steps, nor do they include allowance for the energy consumption of the kiln's central fan and the venting moisture losses. The energy consumption of the drying cycles with high-temperature heat pumps was between 27 % and 57 % lower than the energy consumption of conventional drying cycle using oil as the sole energy source. The average reduction in specific energy costs, compared to the costs of conventional softwood drying cycles, was estimated at about 35 %. For about 39 600 m^3 of dried softwood lumber, the production specific cost of the sawmill facility was of 14.75 US$/$m^3$ (2004) including kiln operation, electrical and fossil energy consumption, equipment depreciation, insurance, etc., while the energy cost averaged 6.86 US$/$m^3$.

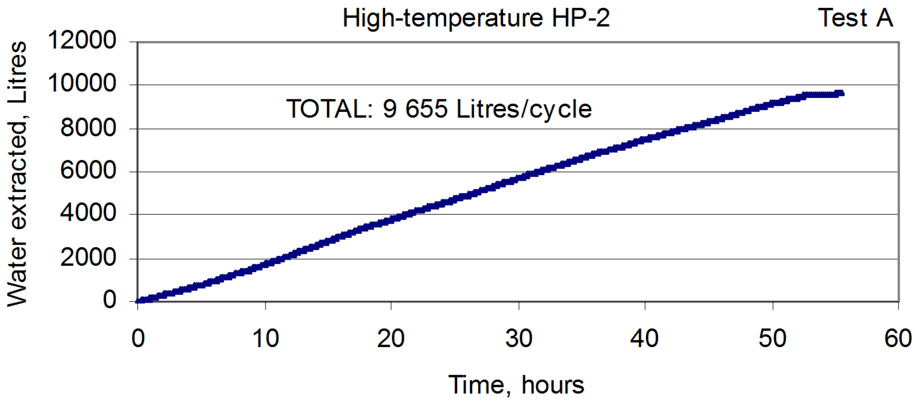


Figure 6 - Cumulative volumes of wood water extraction. HP-2: heat pump #2; L: litre [6]

Table 2 – Energy performances of softwood drying with high-temperature heat pumps

Test	-	X	Y	Z
Parameter	Heat pump	-	-	-
Softwood lumber	-	White spruce	White spruce	Balsam fir
Drying time (excluding preheating steps)(hours)	HP-1	61	61.3	151.4
	HP-2	61	61.3	151.4
Compressor power input (kW)	HP-1	65.1	63.4	61
	HP-2	62.8	58.5	57.1
Compressor energy consumption (kWh)	HP-1	3 972	3 884	9 236
	HP-2	3 830	3 586	8 651
Blower energy consumption (kWh)	HP-1	13.42	16.6	28.7
	HP-2	14.03	39.5	107.5
Water extraction (Litres)	HP-1	9 454	8 263	13 550
	HP-2	9 655	8 478	13 531
Final moisture content (%)	-	17.2	20.6	20.7
COP* (-)	HP-1	4.23	4.6	3.46
	HP-2	3.70	4.07	3.00
SMER* (kg_{water}/kWh)	HP-1	2.38	2.13	1.46
	HP-2	2.52	2.36	1.54

** Based on compressor and blower energy consumptions only; HP: heat pump*

Environmental aspects

Electrically-driven heat pumps used for lumber drying considerably reduce the fossil energy consumption (oil, propane, natural gas) and, consequently, emissions of CO_2 greenhouse gas. Despite additional electrical energy consumption for driving the heat pump compressors and blowers, using heat pumps in dehumidification dryers can substantially reduce annual CO_2 emissions in Canada compared to conventional drying systems using oil as the primary energy. For example, if the softwood drying market penetration reached 5 % in Canada over the next 5 years, the net reduction in CO_2 emissions would be 36 600 tons/year [7]. This number is based on a national annual production of more than 70 million m^3 of softwood and a national average value of around 0.3 kg CO_2/kWh. On the other hand, the water extracted from dried woods could require treatment. The volume of water extracted from softwoods dried with high-temperature heat pumps in typical 354 m^3 dryers is less than 15 m^3 per day, but this extracted water is acid (with pH generally between 3.3 and 4.3) but contains relatively low concentrations of organic loads. Problem pollutants are formaldehyde and, to a lesser degree, acetaldehyde. These substances are toxic volatile organic compounds that are harmful to trout and daphnia, but they are both fully biodegradable. Condensate treatment options may be selected taking into consideration factors as capacity to reduce the organic contaminant content in water to low concentrations and the ability of equipment to treat wastewater volumes below 15 m^3 per day. Consequently, sawmill facilities that are not connected to municipal sewer systems must use water treatment technologies in order to reduce the concentration of toxic substances to levels below the limits set by local regulations. If the kiln site is connected to a sewer system, the municipality may accept the condensate, but charge to intercept and treat the effluent. If the kiln is not served by a local sewer system, fees for collecting and transporting water to the municipal waste disposal site could be involved. Analysis based on the capacity to attain standard norms, low investment and operating costs and quick start-up capability, shows that the optimum technology would be the ultra-violet (UV) peroxidation followed by the natural mitigation. Ultra-violet peroxidation offers the advantage of significantly lower investment and operating costs. Natural mitigation is one of the most inexpensive processes in terms of investment and operating costs. The purification mechanisms combine solar UV radiation, input of atmospheric oxygen and surface algae photosynthesis, aerobic digestion at the surface, and anaerobic digestion on the bed of the basin. However, this technology is less effective in winter and requires long treatment periods and significant surface areas. For treatment capacities of 15 m^3/day, the investment costs averages 68 500 US$ for UV peroxidation and 123 000 US$ for natural mitigation. The electrical energy consumption is zero for natural mitigation and about 6.6 US$ for UV peroxidation. The annual operating costs (maintenance and labour) of such systems generally represent 5 % of the total investment costs [7].

Conclusions

This article shows that wood drying by dehumidification with heat pumps is an attractive method. As a clean energy technology compared with traditional heat-and-vent dryers, drying heat pumps offer interesting benefits for drying hardwood and softwood (resinous) lumber. They can provide high quality dried woods with relatively small capital investments and drying times similar to those of fossil fuel heated kilns. For small to medium drying capacities, heat pumps prove to be the most economical method of drying in countries where electrical tariffs are relatively low compared to conventional fossil fuel prices. Such systems provide lower energy consumption for each unit of water removed, accurate control of drying conditions, and enhanced product quality. Their limitations generally concern the need for temperature-resilient materials and fluids (refrigerants, oils), regular maintenance, the risk of refrigerant leaks and higher initial capital costs compared to conventional dryers. In the case of hardwood species, hybrid drying cycles with low-temperature heat pumps reduce the fossil energy consumption (natural gas) by up to 57.5 % and global energy costs by 21.5 %, compared to conventional drying cycles with natural gas as a single heating energy source. In the case of softwood (resinous) drying with high-temperature heat pumps, the specific moisture extraction rate varies from 1.5 kg_{water}/kWh (for balsam fir) to 2.35 kg_{water}/kWh (for white spruce), while the heat pumps' coefficients of performance range between 4.6 at the beginning and 3 toward the end of dehumidification drying cycles. On the other hand, substantial net reductions in CO_2 emissions can be achieved using drying heat pumps. Finally, for condensed water treatment, ultraviolet peroxidation and natural mitigation technologies are recommended as methods with relatively low initial investment and operating costs, and low electricity consumption.

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From Waste Heat to Cooling using Absorption Chillers: A Showcase Natural Gas Liquefaction Facility with CO_2 Capturing Plant

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Liquefied natural gas (LNG) facilities are increasing in number due to the growing demand for natural gas (NG). However, LNG facilities are energy-intensive because NG is liquefied at –160 °C. Since LNG facilities emit large quantities of CO_2, they are also suitable for CO_2 capturing. Waste heat from LNG facility power plants can be used to reduce the power consumption in the liquefaction process through the use of absorption chillers. Absorption chillers are heat-driven devices, which utilize any type of heat input. They can therefore provide useful cooling by utilizing the waste heat. This article explores the power-savings potential of using the absorption chillers in a NG liquefaction process as well as CO_2 liquefaction process for CO_2 sequestration, and inlet-air cooling to a gas turbine powering the LNG facility. The resulting power savings in a 110 MW LNG plant were found to be as much as 14 %.

Introduction

Since NG is the cleanest fossil fuel and has a higher heating value than other fossil energy resources [1], NG demand is expected to grow substantially in the coming years [2]. NG is transported either in pipelines or in LNG carriers. LNG is produced by the liquefaction of NG by cooling it from atmospheric temperature to –160 °C. An LNG plant typically requires about 10 % of the heating value contained in the NG to be consumed as fuel for the liquefaction process [3]. The high energy demand of an LNG plant produces a large amount of CO_2 at the plant site, which makes it suitable for CO_2 capture and sequestration (CCS) [4]. However, CCS also requires additional energy for CO_2 regeneration via the amine capturing method, and for CO_2 liquefaction for storage or sequestration. This additional CCS energy requirement can be as much as 15-20 %. The high energy demand in natural gas-driven LNG plants with CO_2 capture produces a large amount of waste heat (e.g. in the flue gas or in the condensed steam). The amount of waste heat in a natural gas combined cycle (NGCC) power plant is about equal to the capacity of the (NGCC) power plant (i.e. the power plant efficiency is 50 % [5]). One way to improve the efficiency of such plants is to utilize the waste heat. Several technologies exist for waste heat utilization. This article explores the power-savings potential from using absorption chillers in an LNG plant driven by an NGCC integrated with CO_2 capture.

Absorption chillers

An absorption chiller is a heat-driven device which provides cooling in the evaporator by using heat in the desorber as the primary energy source, differing from the case of vapour compression cycles (VCCs) using electricity. When waste heat is used to operate the absorption chillers, the cooling provided is essentially “free” cooling.

There are different types of absorption chillers that use either Water/LiBr or NH_3/Water as a refrigerant/absorbent pair. Typical coefficients of performance (COP) of absorption chillers vary from 0.4 to 2.0, depending on the operating temperatures and number of effects (or stages) [6]. A simple schematic diagram of a single-effect absorption chiller is shown in Figure 1. Single-effect absorption chillers can utilize waste heat with a temperature as low as 100 °C, and can achieve a COP of about 0.75. The COP of an absorption chiller is defined as the ratio of evaporator cooling output to heat input at the desorber.

Modelling of Baseline APCI LNG Plant

The APCI LNG cycle, developed by Air Products and Chemicals Inc., is the most widely used liquefaction cycle in the LNG industry [7]. It has a multi-pressure propane variable-capacity compressor (VCC) and a multi-component refrigerant (MCR) VCC that uses a mixture of CH_4, C_2H_6, C_3H_8 and N_2 as the refrigerant. The propane cycle precools the NG and subcools the MCR to about –30 °C. The MCR liquefies the NG at –160 °C. In this study, the APCI LNG plant model optimized by Alabdulkarem et al. [8] and the gas turbine model developed by Mortazvi et al. [9], were integrated with a steam cycle and a CO_2 capturing model in the HYSYS simulation platform [8]. To capture the CO_2 from the flue gas of the NGCC, a CO_2 capturing plant using an amine solution was modelled using HYSYS software. The absorbed CO_2 in the amine solution is regenerated using low-pressure steam in the stripping column. The low-pressure steam, at a temperature of 130 °C, is extracted from the steam turbine or from the steam cycle condenser having a condensing temperature of 130 °C. However, the steam condensing heat was found to be higher than the CO_2 regeneration heat. This heat is of low quality for power generation, and is considered as waste heat. The captured CO_2 is at atmospheric pressure. In order to store captured CO_2, it needs to be compressed, using either multistage-compression or liquefaction and pumping. Alabdulkarem el al. [4] compared the two approaches and reported that CO_2 liquefaction cycles consumed less power than the multi-stage-compression cycle.

A simplified schematic diagram of an APCI LNG plant integrated with NGCC and CCS is shown in Figure 2. The relevant simulation results of the APCI LNG plant integrated with the NGCC and CCS are shown in Table 1. Details of the simulation and

Table 1: Main simulation results for the APCI LNG plant integrated with NGCC and CCS.

APCI LNG plant power consumption (MW)	110.84
LNG production (kg/s)	98.89
LPG production (kg/s)	10.97
Gas turbine power production (MW)	94.7
Steam turbine power production (MW)	60.94
CO_2 regeneration heat (MW)	70.42
Available waste heat (MW)	92.33
Captured CO_2 mass flow rate (kg/s)	20.11
CO_2 liquefaction cycle and pumping power consumption (MW)	5.93

Table 2: Power savings from three options of waste heat utilization in APCI LNG plant integrated with NGCC and with CCS.

Absorption chillers application	*Waste heat used (MW)*	*Power savings (MW)*
CO_2 liquefaction	*13.35*	*1.56*
APCI LNG plant	*78.97*	*15.01*
Inlet air cooling	*92.33*	*17.44*

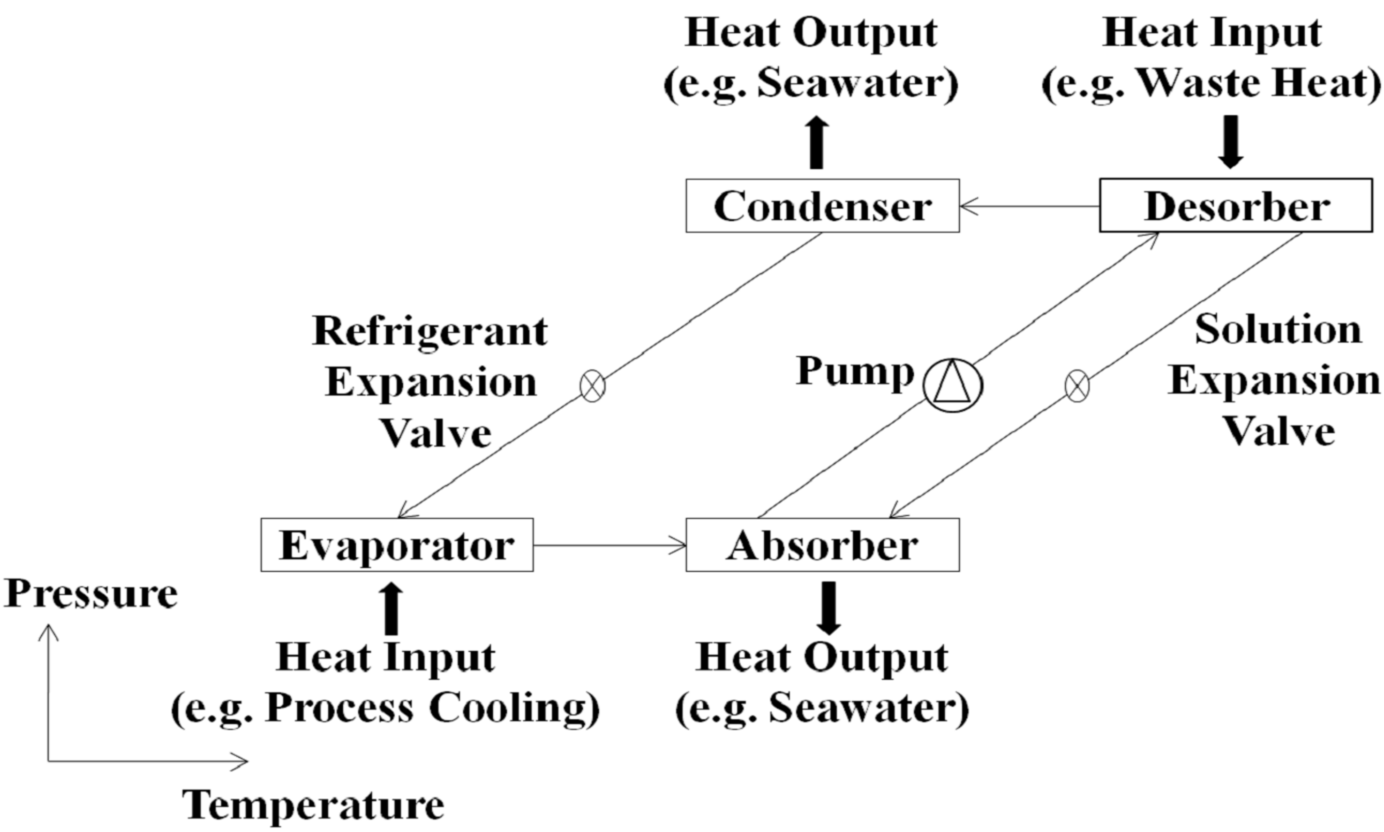

Figure 1: Schematic diagram of a single-effect absorption chiller

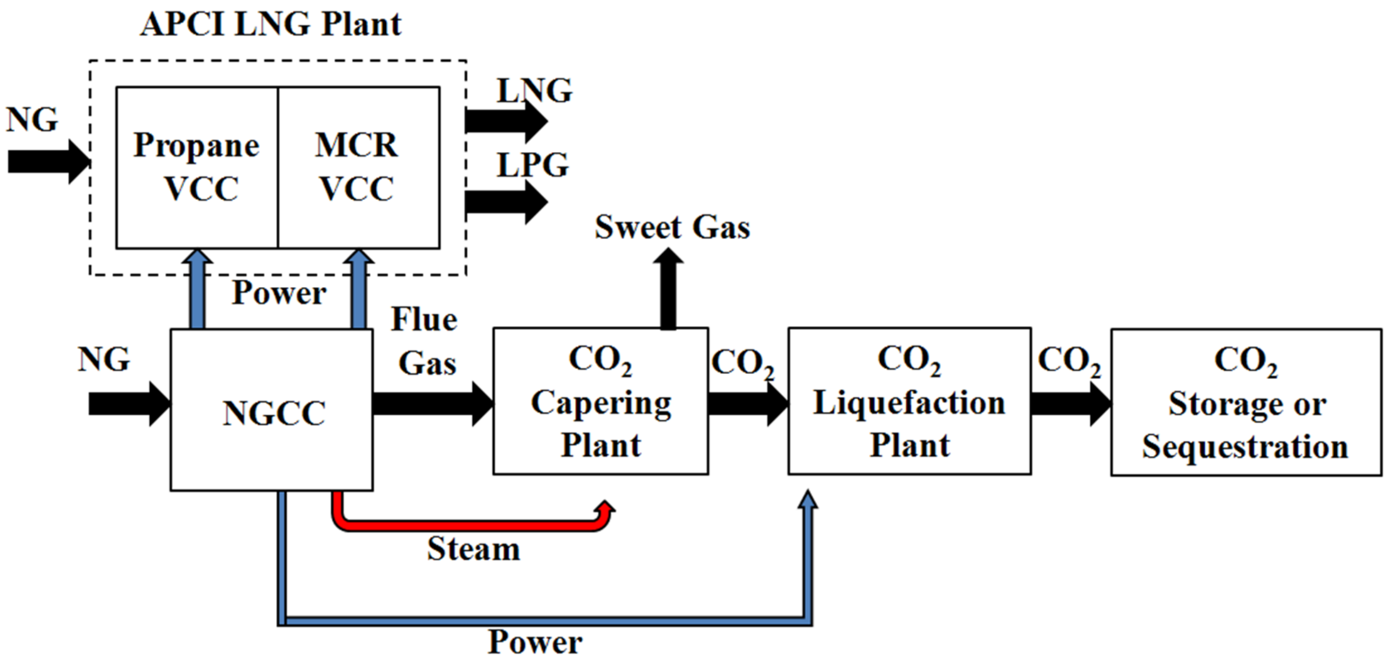

Figure 2: Schematic diagram of an APCI LNG plant integrated with NGCC and CCS

validation work can be found in [4], [8] and [9].

Waste heat utilization with absorption chillers

In order to reduce the power consumption of the integrated plants, waste heat utilization using absorption chillers was proposed. Three cooling applications using absorption chillers were investigated and modelled (Table 2). The applications use the cooling produced by absorption chillers (1) to liquefy the captured CO_2 instead of using VCCs, (2) to precool the NG and MCR, and (3) to cool the inlet air to the gas turbine.

CO_2 liquefaction

NH_3 absorption chillers can be used to liquefy CO_2. Using only 13.35 MW of waste heat from the 92.33 MW of waste heat, NH_3 absorption chillers can be used to liquefy the CO_2 at –12 °C or 25 bar liquefaction pressure. The CO_2 liquefaction load is 5.84 MW. The total power consumption, which includes the CO_2 compressors that compress the CO_2 from 1 bar to 25 bar, and pumps that raise the CO_2 pressure from 25 bar to 150 bar, is 4.37 MW. This is the lowest power consumption for preparing the captured CO_2 for injection (1.56 MW or 26.31 % power savings as compared to CO_2 liquefaction using VCCs).

NG and MCR precooling

Since the propane cycle in the APCI LNG plants requires five heat exchangers to cool the NG and the MCRs from atmospheric temperature to –30 °C, another absorption chiller application is to eliminate some of the propane cycle evaporators. reducing the liquefaction load of the APCI LNG plant or the power consumption. Detailed studies of waste heat utilization options in LNG plants can be found in [9] or [10]. For example, using 78.97 MW waste heat from the 92.33 MW waste heat resulted in 15.01 MW power savings in the APCI LNG plant by replacing some of the higher temperature evaporators (22 °C, 9 °C and part of –5 °C evaporators), and subcooling the condenser of the propane cycle (to 5 °C) with absorption chillers. The 15.01 MW power savings represents 13.54 % reduction from the APCI LNG plant power consumption.

Gas turbine inlet air cooling

Inlet air cooling reduces the air density, which allows the combustor of the gas turbine to take a higher air mass flow rate at a fixed air volume flow rate and air-fuel mass ratio. The effect of air cooling was investigated in the NGCC model. Using all of the available 92.33 MW waste heat in absorption chillers, the inlet air to the gas turbine can be cooled from 50 °C to 15 °C. As a result, the NGCC power increased by 17.44 MW, which is an 11.21 % power gain from the NGCC base case.

Conclusions

Waste heat utilization using absorption chillers provides an opportunity for significantly increasing power plant efficiency. The main barrier to implementing absorption chillers is the initial cost. Absorption chillers can be applied to different processes where cooling is needed and waste heat is to be utilized. As a show case, the application of absorption chillers was explored for an APCI LNG plant integrated with NGCC and CCS. Resulting power gains were found to be as much as 17.44 MW by utilizing 92.33 MW of waste heat to precool the inlet air supplied to the NGCC.

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Case Study: University of California, Santa Barbara Heat Pump

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The proposed University of California Santa Barbara (UCSB) Campus Hot Water Loop project, will consist of a single, electric-motor-driven, 2106 kW (600-tonne) heat pump unit that will simultaneously produce more than 10.5 million kJ (10 million British thermal units) per hour (Btuh) of heating hot water (HW) for the new campus hot water loop as well as 2106 kW (600 tonne) of chilled water (CHW) for the existing campus chilled water loop. When operational, the proposed heat pump plant is estimated to eliminate more than 12.6 million kJ (12 million Btu) per hour of local fossil fuel combustion emissions, and to save more than 84.4 million MJ (800 000 therms) per year of natural gas, which is equivalent to a reduction of approximately 6400 metric tonnes (7050 tonne) of CO_2 and nearly 12 475 kg (27 500 pounds) of NO_x per year.

Introduction

The University of California, Santa Barbara, tasked Goss Engineering Inc. (GEI), to analyze the energy savings and construction costs associated with constructing a new central heating plant and HW loop. From the results of the study, GEI has determined that the central heating plant and distribution system will save an estimated USD 339 864 per year in utility costs.

The University of California, Santa Barbara, (UCSB) commissioned Goss Engineering Inc. (GEI) to develop and evaluate the potential energy savings from constructing a new campus central plant facility, a campus hot water loop, and modification of seven existing building heating water systems for connection to the proposed hot water loop. The proposed central plant is planned to include a single, electric-motor-driven, 2106 kW (600 tonne) heat pump unit that will simultaneously produce more than 2.9 MW (10 million British thermal units) per hour (Btuh) of heating hot water (HW) for the new campus hot water loop, as well as 2106 kW (600 tonne) of chilled water (CHW) for the existing campus chilled water loop. In this case, the heat pump will act as both a chiller and as a heat source. The proposed heat pump will only operate when there is sufficient simultaneous heating and cooling load. Two HW boilers, with a total capacity of 1.76 MW (6 million Btuh) (input), will produce heating hot water when the heat pump is down for maintenance, and will also act as central plant temperature booster boilers for campus heating loads above 2.93 MW (10 million Btuh).

Equipment details

The heat pump proposed for this study was specified to have a 2106 kW (600 tonne) cooling capacity and produce more than 2.93 MW (10 million Btuh) of heating capacity simultaneously, and to have two centrifugal compressors, operating in series using a common refrigerant circuit on the chiller. Each compressor will be a single-stage centrifugal type, powered by a TEFC electric motor. Compressor castings in the low stage will be designed for a minimum 1620 kPa (235 psig) working pressure. The high stage will be designed for 1620 or 2415 kPa (235 or 350 psig), as applicable. Each compressor motor will be TEFC, squirrel cage, induction type operating at 3570 r/min.

The campus base cooling load is in excess of the 2106 kW (600 ton) output of the chiller for all but a few hours of the year. The heating load of the proposed hot water loop exceeds 1.17 MW (4 million Btuh) (which is equal to the minimum heat pump turndown output) for more than 80% of the year. It is important to note, however, that the proposed hot water loop will be expanded to include additional buildings, as well as new buildings under construction, in order to increase the heating load on the heat pump.

Since the campus base cooling load is reported to be almost always greater than 2106kW (600 tonne) (the size of the proposed heat pump cooling capacity), the proposed heat pump HP-1 will be the first campus chiller to operate (i.e. HP-1 will be the campus base load chiller). Therefore, on the cooling side of the heat pump, the proposed heat pump will almost always be fully loaded. As with any chiller, the proposed heat pump can modulate itself to meet the output chilled water temperature setpoint. Unlike a chiller, the heat pump can also modulate itself to meet the output hot water supply temperature setpoint. As the key purpose of the proposed heat pump is to provide heat, the heat pump leaving CHWS temperature setpoint can be set below that achievable by the heat pump (e.g. 2.7 °C), so that the heat pump remains fully loaded as much as possible. If the campus cooling load falls below 2106 kW (600 tonne),

Table 1: Base Case Energy Summary

Energy Summary						
Equipment	Existing		Proposed		Savings	
	Existing electricity consumption MJ (kWh)	Existing gas consumption MJ (therms)	Proposed electricity consumption MJ (kWh)	Proposed gas consumption MJ (therms)	Proposed electricity savings MJ (kWh)	Proposed gas savings MJ (therms)
Chiller	9,994,043 (2,776,123)	-	24,668,842 (6,852,456)	-	-14,674,799 (-4,076,333)	-
Boilers	-	98,195,180 (930,760)	-	13,019,228 (123,405)	-	85,175,953 (807,355)
Cooling towers	786,136 (218,371)	-	0 (0)	-	786,136 (218,371)	-
CHW distr. pump	658,916 (183,032)	-	658,916 (183,032)	-	0 (0)	-
CW / HW distr. pump	527,134 (146,426)	-	1,317,830 (366,064)	-	-790,700 (-219,639)	-
Building pumps	887,739 (246,594)	-	131,602 (36,556)	-	756,137 (210,038)	-
Total	**12,853,966 (3,570,546)**	**98,195,180 (930,760)**	**26,777,190 (7,438,108)**	**13,019,228 (123,405)**	**-13,923,226 (-3,867,563)**	**85,175,953 (807,355)**

the heat pump can unload on the cooling side, but less heat will be produced by the heat pump.

An important aspect of this project is that UCSB's campus natural gas usage is nearing a cap by the Santa Barbara Air Pollution Control District (SB-APCD) NO_x emissions limits. Boilers in new and future buildings may not be permitted by the SB-APCD. Almost all of the buildings being attached to the new hot water loop have old existing natural gas-fired hot water boilers. The addition of the proposed heat pump hot water system under this project will reduce NO_x emissions by as much as 50 % for each building connected to the loop.

The general project goals were identified as:

- To produce approximately 2.93 MW (10 million Btuh) of 68.3 °C heating hot water, sufficient to meet average heating demand of the seven campus buildings
- To maximize use of the heat pump heat output;
- To produce 2106 kW (600 tonne) of cooling, which is reportedly below the minimum campus cooling demand for almost of the year; and
- To reduce campus building boiler usage significantly for those buildings connected to the proposed HW loop.

Estimated energy savings

TRACE 700 energy modelling software was used to evaluate existing and proposed energy consumption for the seven buildings. To find the total yearly hours of operation for both the existing chiller/boiler and proposed heat pump, the heating load output from the calibrated model was analyzed. The total time during the year for which the heating load was greater than 1200 kW (4100 MBH) (40 % of peak chiller heat output of the proposed chiller) was found to be 7321 hours. The existing chiller was modelled to operate during those 7321 hours at 2106 kW (600 tonne) and 646 kJ/KW (0.632 kW/ton). The proposed chiller was modelled to operate during the same 7321 hours at 2106 kW (600 tonne) with the efficiency set at 1600 kJ/kW (1.56 kW/ton). The cooling load of the remaining 1439 hours would be met using the existing chiller capacity in both existing and proposed cases, and was therefore ignored in the calculation.

The electricity consumption of the proposed Base Case is approximately 13 932 000 MJ (3 870 MWh) more than the existing system. The reason for the increased energy consumption is due to the fact that the

Table 2: Base Case Economic Summary

Economic summary			
Equipment	Existing operating cost ($)	Proposed operating cost ($)	Proposed operating cost savings ($)
Chiller	$277,612	$685,246	-$407,633
Boilers	$837,684	$111,065	$726,620
Cooling towers	$21,837	$0	$21,837
CHW distr. pump	$18,303	$18,303	$0
CW / HW distr. pump	$14,643	$36,606	-$21,964
Building pumps	$24,659	$3,656	$21,004
Total	**$1,194,739**	**$854,875**	**$339,864**

proposed heat pump is being used to provide both cooling and heating loads, whereas the existing chiller can meet only the cooling load. The natural gas consumption saving of the proposed Base Case is more than 84.4 million MJ (800 000 therms). A summary of energy and economic results for equipment used to meet the cooling load is given in Table 1.

Spreadsheet calculations were used to determine existing and proposed operating costs of the Base Case. An average electricity rate of $0.027/MJ ($0.10/kWh) was used to calculate electricity consumption costs. The rate used for natural gas consumption cost calculation was $0.0085/MJ ($0.90/therm).

The operating cost of the Base Case is approximately $340 000 less than the existing system. A summary of economic results for equipment used to meet the cooling and heating loads is given in Table 2.

Conclusions

The implementation of a central plant heat pump can significantly reduce operating costs over the traditional chiller and boiler central plant when there are simultaneous cooling and heating loads present. While the electricity consumption will increase, the fuel consumption will decrease significantly, resulting in reduced plant emissions (from fossil fuels).

Depending on a projects emissions restriction and baseload characteristics, the use of a heat pump to produce simultaneous cooling and heating should be investigated.

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High temperature heat pumps with natural refrigerants

Andy Pearson, UK

There is a suitable technology for every section of the high temperature heat pump market, from small domestic units to commercial, industrial and district heating systems, without using fluorinated refrigerants. There is also great scope for future development of more advanced technologies, such as air systems for heating ventilated buildings, hydrocarbon systems for domestic use, higher-pressure ammonia systems to generate superheated steam and larger transcritical carbon dioxide compressors to capture a share of the industrial and district heating market.

"At long last heat pumps seem to be happening" – Prof Geoffrey Haselden, 1981.

Introduction

The development of industrial heat pumps could be considered to be the slowest "overnight success" ever known – even Professor Haselden's confident proclamation of their arrival was perhaps 25 years too early as far as industrial systems are concerned. However the economic, commercial and technical conditions now seem to be interacting in such a way as to make the recovery of heat from buildings and process outputs, or even from their surroundings, compellingly attractive, like never before.

Some of the technical requirements are quite demanding. Refrigerants which do not interact with the ozone layer or other aspects of the global climate, yet offer a high efficiency from compact and relatively inexpensive plant, are now highly desirable. In many cases requiring major investments, the environmental aspects of the specification are a prerequisite for getting the project funded. In others, particularly for private "blue-chip" clients, there may be corporate social responsibility guidelines to meet, which preclude the use of fluorinated refrigerants unless strictly necessary. This perception is particularly important in large systems. For example a system with a 10 000 kg charge of R-134a which leaks 2 % of the charge per year has a climate effect that is equivalent to driving a family saloon more than 50 000 km per week.

With these constraints the list of possible refrigerants and systems is very short. Five substances offer the most promise as working fluids in industrial heating applications: water, air, hydrocarbon, ammonia and carbon dioxide. The optimal configuration of operating system varies widely depending on the class of fluid, but they all fall within the general description of thermodynamic systems in which heat is added to a fluid by cooling the surroundings and then work is performed on the fluid to raise it to a higher pressure, at which point the heat input and the work input can jointly be extracted and usefully applied to a process, product or situation which requires to be heated. In some of these systems, notably with water, hydrocarbon and ammonia, the working fluid is evaporated and recondensed in a Perkins cycle. The air system, however, works by heating and cooling the gas without any change of phase. In the special case of carbon dioxide the heat extraction is accomplished by phase change but the heat delivery is at a pressure above the critical point and therefore there is no change of phase as the gas is cooled.

Water

Systems using water as a working fluid operate at very low pressures – the boiling point of water at atmospheric pressure at sea level is 100 °C, so for most industrial heat pumps the entire circuit would be at subatmospheric pressure. The latent heat of water is also very high, about fifteen times that of R-134a at 50 °C. These properties raise the prospect of delivering high temperatures, say 150 °C, at modest pressures compared to all other working fluid choices, but some of the other properties of water make this a challenging proposition. The swept volume required is extremely high, due to the low density of water vapour, and the pressure ratio required is also quite high, due to the low inlet pressure. For example to raise heat from 50 °C to 150 °C would require the discharge of the water vapour system to be between 4 and 5 bar gauge but the inlet would be at about 0.1 bar absolute, so the pressure ratio is between 50 and 60. Since water is a relatively simple molecule the isentropic index is quite high, at approximately 1.3 at these conditions. This makes water quite similar to ammonia in this respect, but an ammonia system operating at these pressures would evaporate at –71 °C and condense at 4 °C. Therefore, in order to keep the discharge temperature down to a tolerable level, many stages of compression are required, with interstage cooling between them.

Air

The original concept of the heat pump proposed by Lord Kelvin in 1852 was of an air cycle machine with compression and expansion cylinders on a common drive shaft burning coal to raise ambient air temperatures sufficiently to heat houses with the discharge air from the compressor. Kelvin calculated that the coefficient of performance of such a system would be 35:1 based on the shaft power when operating between temperatures of 10 °C and 27 °C, and since a "very good steam engine" converted about 10 % of the heat of combustion of the coal in its furnace to shaft power, he concluded that such a device would deliver 3.5 times more heat than could be achieved by burning the same amount of coal in a direct process. He added that if a water wheel were used to drive the compressor and expander the economy would be even more attractive. In Kelvin's preferred arrangement of this apparatus the system could be used for heating or cooling. The system had two cylinders of equal size, one passing air from the outdoor ambient to a large, thin-walled receiver and the second drawing air from the receiver and delivering it to the occupied space. A third, smaller, auxiliary cylinder was used to determine whether the system acted as a heating or cooling device. If it pressurised the air in the receiver, causing the main inlet cylinder to do work on the inlet air, then the receiver would be heated and would lose heat to the surroundings. In this case the outlet cylinder would act as an expander, cooling the air as it brought it back down to atmospheric pressure. If the auxiliary cylinder drew air from the receiver and delivered it to the destination space then the receiver would be below atmospheric pressure and would draw heat from its surroundings. The inlet cylinder would be an expander and the outlet would be the compressor, bringing the air back up to normal pressure but at higher temperature. Kelvin calculated that to deliver air at 27 °C when the outside temperature was 10 °C would require the receiver to be held at 0.82 bar absolute. In a modern version of Kelvin's system the receiver would be replaced by a finned heat exchanger and the compressor/expander device would probably be a turbocharger with a small screw or reciprocating compressor replacing the auxiliary cylinder.

Kelvin's system could be described as "closed-open". In other words the heat extraction is through a heat exchanger (the thin-walled receiver) and the heat delivery is by direct passage of the air from the system to the occupied space. This is similar to the concept used for train air-conditioners, where the system draws outside air through an expander and a heat exchanger, then compresses it to return it to atmosphere. These systems need to operate below atmospheric pressure in order to achieve the cooling and heating effects. Most modern air cycle systems, in contrast, are "open-closed" or in some cases "closed-closed". When the heat delivery process is through a heat exchanger, or "closed", then the air will be cooled during the delivery of heat. Such a system is best suited to heating through a wide temperature range because there is no phase change in the working fluid. To maximise efficiency the heat exchanger must be designed for counter-current flow, with the inlet (hot) air in contact with the outlet (heated) process fluid and the outlet (cooled) air in contact with the inlet (cold) process fluid. If a crossflow or co-current heat exchanger is used then the operating temperatures need to be much further apart than for the counter-current system and so the temperature lift is higher and the efficiency is far poorer. If high process temperatures are required then the key design challenge is to make a cost-effective counter-current heat exchanger.

Hydrocarbon

The family of short-chain hydrocarbons offers several fluids with favourable properties for high temperature heat pump systems. Butane and isobutane (methyl propane) are particularly attractive because they have high critical temperatures of 136 °C and 151 °C respectively and so can heat to extremely high temperatures if required. However the operating pressures are moderate, even at high temperatures, and therefore equipment is readily available. For example to condense at 110 °C the discharge from the compressor for butane and isobutane would be 17.3 bar g and 23.1 bar g respectively; not significantly different from the discharge pressures of R-22 and R-404A systems. However system application is constrained by safety requirements due to flammability. The quantity of working fluid in the system, also called the refrigerant charge, is used to determine permissible locations. If the system is designed under the jurisdiction of EN 378, the European Standard on refrigeration safety, then the charge of the system is limited to 150 g if it is installed in a location accessible to the general public, such as a school, a supermarket or a hospital, with some relaxation for large spaces where the charge could dissipate safely in the event of a leak. However there is an absolute upper limit of 1.5 kg charge. In supervised occupancies, such as offices and laboratories, the upper limit of charge is 2.5 kg. It is worth noting that the low molecular weight of hydrocarbons means that their liquid density is also comparatively low. It is therefore possible, on a like-for-like basis, to achieve a higher heating capacity from a given weight of refrigerant charge. For example methyl propane is only 60 % of the molecular weight of R-134a and its liquid density at 20 °C is only 46 % of that of R-134a. With propane the ratios are even lower, at 44 % and 41 % respectively.

For industrial systems it would be feasible to use much larger hydrocarbon systems with no restriction on charge but the equipment must be installed in a machinery room or outside the building in the open air, and strict precautions against explosions in the event of a leak are required. The charge in these systems can be minimised by using plate-type or plate and shell heat exchangers, but will probably still be larger than the practical limit for a typical sized machinery room due to the low value of the lower flammable limit of the hydrocarbons. The safety precautions include gas detection, ventilation and emergency lighting which must all be rated for operation in a flammable atmosphere, for example as flameproof (Exd) or increased safety (Exe). It is not normally necessary for the heat pump to be certified in this way unless it is intended to operate within a flammable atmosphere, although it will always be subject to a hazard assessment in line with the ATEX directive.

Components are generally widely available for use with hydrocarbons, although in some cases special certification is required. Compatibility of seals and O-rings should be checked, and the lubrication system may require special care because hydrocarbons are highly soluble in most lubricants. Apart from these minor considerations the hydrocarbons, especially butane and methyl propane, are relatively easy to work with, and have low discharge temperatures even over high pressure ratios.

Ammonia

Heat pumps with ammonia operate at relatively high pressures compared to almost all other options. However, as a result of ammonia's high critical temperature, it is possible to achieve excellent efficiency in high-temperature systems. Water can be heated to 90 °C taking heat from an ambient source at 8 °C with a coefficient of performance of 3.2 and if the source is from waste heat at higher temperatures then the efficiency is of course also much higher. At high temperature and pressure there are some significant challenges to overcome. Refrigerant solubility in lubricant increases, so that the viscosity of the lubricant fed to the compressor is extremely low. Seal materials which are acceptable at lower temperatures and pressures tend to shrink and harden, so alternative materials are required. The resins used in oil filters and coalescers are also affected by the high pressure and temperature which can shorten the filter life and possibly lead to failure of the filter element. Although the operating pressures are high the ratio of discharge to suction pressure is actually very low, so there are some additional challenges with screw compressors in getting the right volume ratio and keeping the compressor at optimal efficiency. Internal forces within the compressor are high due to the high pressure difference between discharge and suction. Vibration levels also tend to be high because of the high density of the discharge gas.

All of these challenges have been overcome, in some cases by selection of alternative materials and in others by redesign of the system components to ensure that the equipment is efficient and reliable. Compressors rated for 75 bar on the discharge side are now available, which in principle will allow heating to about 100 °C with allowances for high-pressure safety switch and relief valve settings.

Small to medium-sized heat pumps have also been developed for heat recovery applications, combining the benefits of ammonia and water. These systems use an ammonia/water mixture like an absorption chiller, but with a compressor to raise the gas to high pressure. They give good efficiency at lower operating pressures than the ammonia systems, and can heat to 115 °C, but it should be noted that both the heat extract and the heat delivery exchangers operate with a very wide temperature glide on the refrigerant side, as the composition of the ammonia/water mixture changes. This requires a special design of heat exchanger to ensure counterflow heat exchange. It also makes the machines unsuitable for use in water chilling applications due to the risk of freezing. These systems are therefore best suited to applications with high heat source temperatures operating across a wide temperature range, and applications heating fluid through a wide range.

Carbon dioxide

Carbon dioxide heat pumps are very common in smaller sizes, but have not been commercialised in the larger range due to the lack (to date) of a suitable compressor. Like the ammonia/water hybrid, they operate with a wide temperature glide on the high pressure side, but the low pressure side is like a traditional evaporator with phase change at a constant temperature. Operating pressures of 90 to 100 bar are required, so compressors need to be rated for about 120 bar. In the smaller sizes this has been the fastest growing segment of the market and units up to 100 kW heating capacity are now available. There have been no major technical barriers to the implementation of these systems, and no particular issues with availability of materials or components. Small systems are available for both air-source and water-source heat pumps.

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Trends in industrial heat pump technology in Japan

Choyu Watanabe, Japan

Heat pump technology is important for boosting the reduction of CO_2 emissions, reducing primary energy consumption, and increasing the amount of renewable energy used. The scope of industrial applications is also expected to expand, further enhancing these effects. Trends introduced in industrial heat pump technology in Japan include pioneering high-temperature heat pumps, such as CO_2 refrigerant transcritical cycle heat pumps for hot water and hot air supply, reverse Rankine cycle heat pumps for heating and cooling of circulating water, and steam-generating heat pumps.

Introduction

Heat pump technology is important for reducing CO_2 emissions, reducing primary energy consumption and increasing the amount of renewable energy used. The scope of industrial applications is also expected to expand, further enhancing these effects. In particular, the development and spread of high-temperature heat pumps for hot water supply, heating of circulating hot water, and hot air and steam generation must be supported. This paper describes trends in industrial heat pump technology in Japan.

Steam supply service in a factory

At a company producing cars, auto parts, electrical equipment, food, etc. as shown in Figure 1, steam is produced in the energy centre, supplied to all areas of the factory, and used in the manufacturing process. However, overall energy efficiency is generally low, due to boiler losses, heat losses from piping, steam leakage losses in traps, and drain recovery losses.

Reports suggest that total energy efficiency has improved from 26.6 % to 38.7 %. Moreover, research has been reported indicating that the most commonly used steam temperature zone is in the range 55-80 °C , and that the most commonly used steam heat load zone is less than 5 kW. In addition, many electric heaters are used for these processes for which temperature control is required.

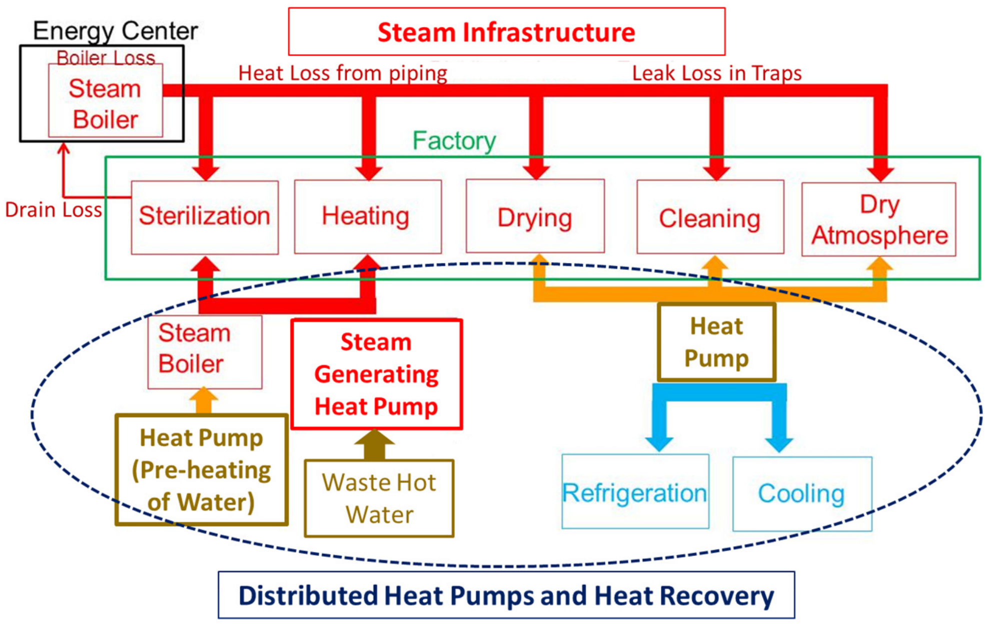


Figure 1 team infrastructure in a factory using distributed heat pumps

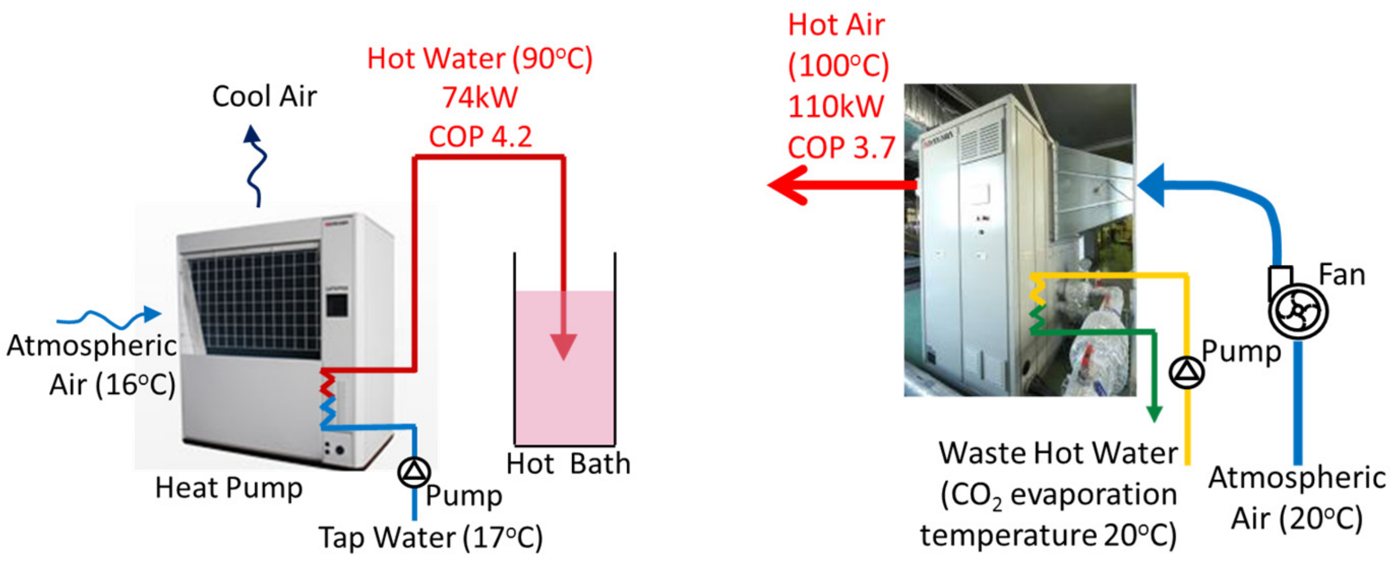
Distributed heat pumps and heat recovery

Accordingly, significant energy savings are expected by replacing some steam infrastructure and electric heaters with low energy efficiency with distributed high-temperature heat pumps for hot water or hot air supply, heating of circulating hot water and steam generation. Heat recovery – i.e. the simultaneous utilization of cooling and heating or the utilization of waste heat - should be considered as shown in Figure 1.

Hot water or hot air supply

A CO_2 refrigerant trans-critical cycle heat pump can generate hot water or hot air as required.

Figure 2a shows the general arrangement and energy flows of the CO_2 refrigerant air-source heat pump supplying hot water, delivering hot water at a temperature of 90 °C, and



(a) *Hot water supply* (b) *Hot air supply*

Figure 2 CO_2 refrigerant transcritical cycle heat pump (Mayekawa Mfg. Co., Ltd.)

with a heating capacity of 74.0 kW and COP of 4.2. The compressor is of the screw type. This heat pump has been supplied not only to Japan but also to South Korea, Taiwan, Indonesia and elsewhere.

Figure 2b shows the general arrangement and energy flows of the CO_2 refrigerant water source heat pump when used for the supply of hot air, which can generate hot air at a temperature of 100 °C, with a heating capacity of 110 kW and COP of 3.7.

Heating of circulating hot water

In many industrial processes, hot water cooled by 5 to 10 degrees is reheated and circulated. If a CO_2 transcritical cycle heat pump is applied to such processes, the COP will often fall. The reverse Rankine cycle, using HFC-134a refrigerant, is used for heating circulating hot water at 60 to 80 °C, and delivers a high COP.

Figure 3 shows a schematic of a typical application of the reverse Rankine cycle air- or water-source heat pump with HFC-134a refrigerant. While cooling water-soluble cutting oil, this heat pump heats the liquid which washes the machined parts, thus providing simultaneous cooling and heating. Three operating modes - heating mode, cooling mode and heating and cooling mode - are available, using the heat exchanger between the air and refrigerant in either direction of heat flow, as required. The total COP in heating and cooling mode reaches 5.

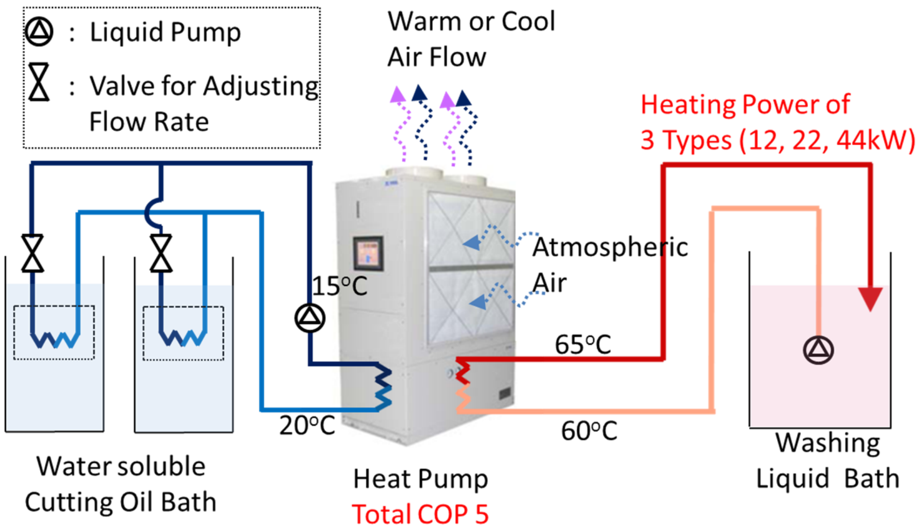


Figure 3 Heat pump for heating and cooling circulating water with HFC134a refrigerant (Zeneral Heat Pump Industry Co., Ltd.)

As an example of the effect achieved using these heat pumps, a reduction of 84 % in primary energy consumption and 80 % in CO_2 emissions compared with the conventional combination of cooling by chiller and heating by boiler steam, has been reported. At factories producing cars or auto parts, many heat pumps of this type are starting to be adopted.

Steam generation

Since an HFC-245fa refrigerant has a critical temperature exceeding 150 °C, a single-stage compression or two-stage compression heat pump can be used for re-heating circulating hot water at a temperature exceeding 80 °C, or steam generation at a temperature exceeding 100 °C. The dual cycle, which consists of an HFC-245fa cycle for the high-temperature side, and another refrigerant (HFC-134a or HFC-410A) for the low-temperature side, is also efficient.

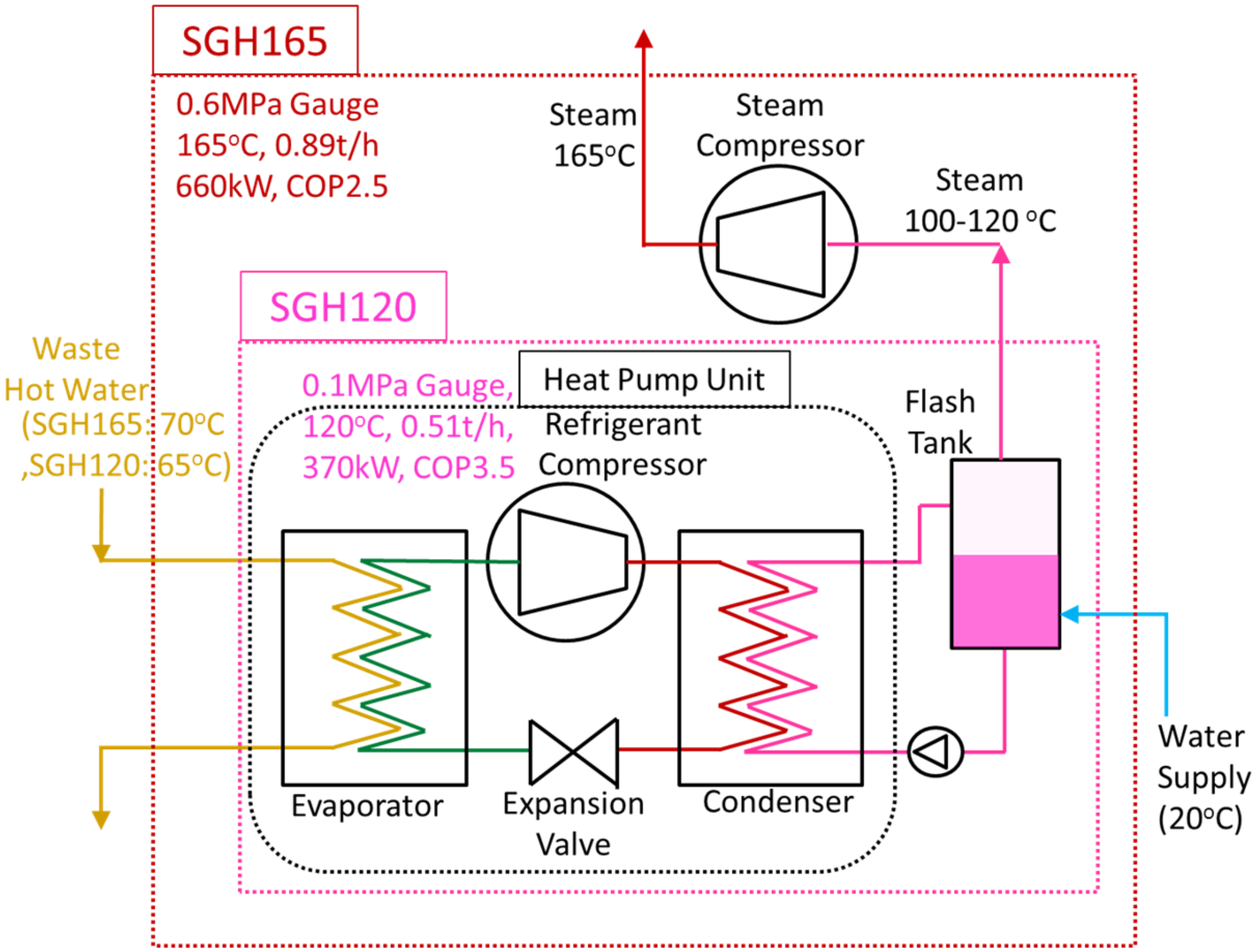


Figure 4 Steam generation heat pump with a mixture of HFC245fa and HFC134a refrigerant (Kobe Steel, Ltd.)

Figure 4 shows a schematic diagram of two models of a steam-generating heat pump. The SGH 120 version generates steam initially by heating pressurised water and evaporating it in a flash tank after leaving the heat pump unit. This model generates steam at 120 °C, with a flow rate of 0.51 t/h and a COP of 3.5 from a waste hot water input temperature of 65 °C.

The SGH165 model generates steam at 165 °C. After the heat pump unit generates steam, the steam compressor increases the steam pressure and temperature still further. The flow rate of the steam is 0.89 t/h and the COP reaches 2.5 from a waste hot water temperature of 70 °C. The SGH120 model has a two-stage compressor, and the SGH165 model has a single stage compressor. HFC-245fa is selected as the refrigerant of the SGH120 model, and a mixture of HFC-245fa and HFC-134a is selected as the refrigerant of the SGH165 model, considering the capacity per unit refrigerant flow.

Conclusions

The trend in industrial heat pump technology in Japan is towards the introduction of pioneering high-temperature heat pumps, such as CO_2 refrigerant transcritical cycle heat pumps for hot water and hot air supply, Reverse Rankine cycle heat pumps for heating and cooling of circulating water and steam generation heat pumps.

It is important, when intending to apply heat pumps for industrial applications, carefully to investigate the required final heat condition for each manufacturing process, in order to identify and quantify energy savings, economic efficiency, installation space etc. The dissemination of industrial heat pumps is more difficult than home-use air conditioners since the manufacturing process is basically a secret. It is important to provide demonstration installations that clearly show the benefits of heat pumps. It is believed that industrial heat pumps will penetrate further when the different requirements for industrial heat pumps are organized and generalised, to some extent.

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Industrial Heat Pump Applications at the HP Summit in Nürnberg

Rainer Jakobs, Germany

The second European Heat Pump Summit meeting was held in Nürnberg from 28–29 September 2011, bringing together international specialists and HP experts for an intensive exchange of views on the current political framework, technical solutions and advances in research and development. Richard Krowoza, Member of the Management Board of NürnbergMesse, was very pleased with the Summit meeting: "Heat pumps traditionally play a special role in Nürnberg. The high expectations of the participants and exhibiting companies after the successful premiere of the European Heat Pump Summit in 2009 have been topped in several ways in 2011. More visitors, more international contacts and a more comprehensive congress programme have made the European Heat Pump Summit meeting a success.

International congress programme

The European Heat Pump Summit 2011 with its internationally orientated congress programme, offered information at the highest level on the political framework in Germany and abroad, the latest research findings and technical solutions. Altogether, 83 expert presentations covered the entire spectrum of heat pumps, supplemented by workshops and panel discussions. Leading speakers impressed with their concentrated know-how and delighted the attending specialists with high-quality presentations.

Topical issues in focus

The highly professional presentations on the congress programme showed the way ahead for heat pumps and the latest state of research and development in Europe and worldwide. Highlights included positive forecasts for the use of heat pumps in the IEA Outlook until 2050, extensive presentations on refrigerants, and the highly topical assessment of the EPEE F-Gas Review.

The Industrial Heat Pump Application workshop presented by the International Energy Agency (IEA) also attracted great interest. Highlights from this workshop included:

Industrial (high-temperature) heat pumps in Germany - market situation, potentials and technological development

presented by Dipl.-Ing. Jochen Lambauer, Institut für Energiewirtschaft und Rationelle Energieanwendung (IER), Universität Stuttgart.

As a means of tackling increasing energy prices, reducing CO_2 emissions, and supporting the use of renewable energy, this research project aims to promote industrial application of heat pump technology and to support and promote the development of high-temperature heat pump technology in cooperation with heat pump manufacturers.

The presentation gave an overview of the project, which is the German contribution to the IEA HPP / IETS Annex 35/13 "Application of Industrial Heat Pumps". The first part of the presentation described the current situation of heating and cooling demand in Germany, as well as heat balances and process analyses of selected branches of industry that show high potential for the use of heat pumps. The description was followed by a detailed market analysis of current heat pump technology and an overview of existing systems. The second part of the presentation analysed and monitored selected case studies in detail, and showed initial evaluation results. Finally (in cooperation with a number of heat pump manufacturers), the presentation described innovative developments for high-temperature heat pumps (up to 140 °C), together with possible applications for such temperatures.

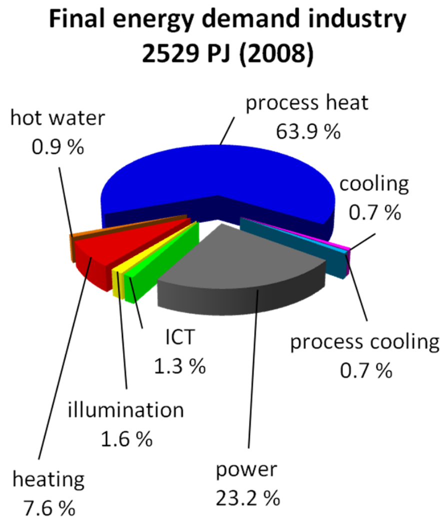

Figure 1 Heating and cooling demand in Germany

First conclusions of the project were:

- There are hardly any "real" industrial application of heat pumps.
- Potentials for improvement:
  - i. Higher COP at current temperature level (70 °C)
  - ii. Increasing output temperatures to around 140 °C
  - iii. Use of high-temperature heat sources (> 30 °C)
- Combined facilities: heating and cooling.
- Heat pump must provide a strictly defined temperature (quality reasons)
- Need for safe-to-operate and low-maintenance facilities.

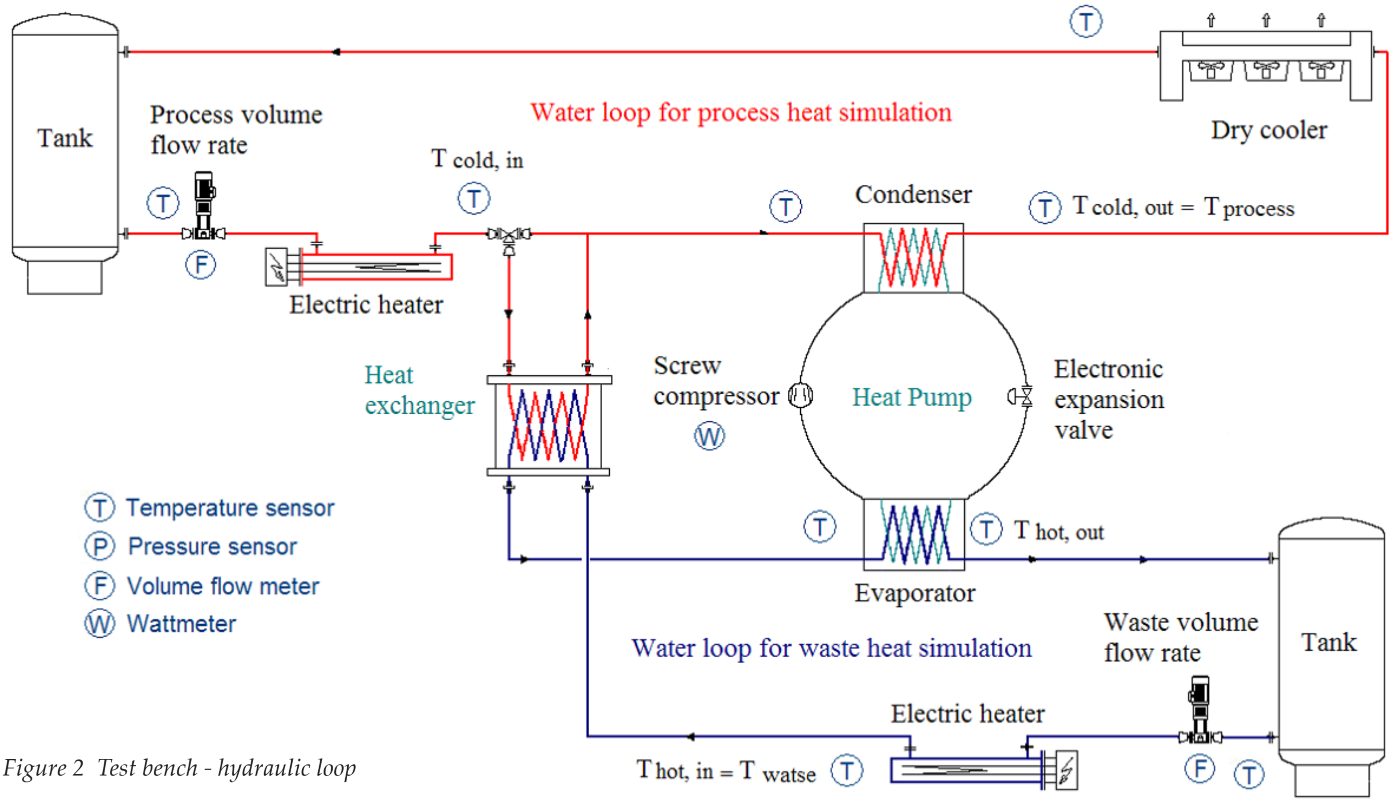

Figure 2 Test bench - hydraulic loop

Experimental investigation of a high-temperature heat pump using HFC-245fa as refrigerant for heat recovery in industry
presented by Damien BOBELIN from EDF R&D in France.

Increasing concerns about energy prices and CO_2 emissions lead industries to invest in energy efficiency. Industrial heat pumps may have a key role in this situation but, as much of industrial heat demand is at high temperatures (80/100 °C), current commercial machines cannot satisfy these needs. In this context, EDF and JCI have developed and tested a high-temperature heat pump able to produce 100 °C hot water.

This study deals with the experimental results of a test investigation of a high-temperature heat pump using R-245fa as its working fluid. The presentation described the technology choices, the test arrangement and facilities, and the test programme. The programme was divided into two parts: in the first, the aim was to evaluate the performance of the heat pump with this fluid, while the second was concerned with testing the

Figure 3 Heat pump test bench

reliability of the machine with this working fluid. The performance of the heat pumps in its operative field was described.
Conclusions:

- Substantial potential for heat pumps, especially at high temperatures
- Thanks to its thermodynamic, safety and economic properties, R-245fa was chosen as the refrigerant
- Our prototype provided by JCI demonstrates the possibility of using R-245fa on an industrial

scale.
- Reliability of the heat pump is demonstrated
- Prototype can theoretically reach a temperature of 120 °C, offering a promising field for more industrial applications
- Research into HFO refrigerants is needed.

Next-generation low-GWP refrigerant for high-temperature heat pumps
presented by Konstantinos (Kostas) Kontomaris from DuPont

This paper described a new development refrigerant, DR-2, as a potential working fluid for high-temperature centrifugal heat pumps. DR-2 is a relatively low-pressure fluid, based on hydro-fluoro-olefin technology, with an ozone depletion potential of zero and a global warming potential less than 10. Key thermo-physical properties of the new refrigerant were summarised: its thermodynamic performance under cycle conditions representative of potential applications has been evaluated by computer modelling. DR-2 is non-flammable, and has a favourable toxicity profile based on testing to date. It has a relatively high critical temperature and high thermal stability, attributes particularly attractive for upgrading low-temperature heat to high temperatures. DR-2 could enable heat pump designs that upgrade heat to higher temperatures and with higher energy efficiencies than present working fluids. In summary, the attractive environmental, safety, health and performance properties of DR-2 have the potential to enable the development of more environmentally sustainable high-temperature heat pump platforms than available today, for more widespread recovery and utilisation of low-temperature heat for commercial and industrial uses.

	HCFC-123	DR-2
Safety Class	B1	A1 (expected)
Atmospheric life time [yrs]	1.3	0.0658 (24 days)
ODP	0.02	None
$GWP_{100\ YR\ ITH}$	77	<10
Critical Temperature [ºC]	183.7	171.3
Critical Pressure [MPa]	3.7	2.9
Normal Boiling Point [ºC]	27.9	33.4
Thermal Stability	Lower	Higher

Figure 4 Comparison of R123 and DR-2

A low pressure candidate: DR-2
Summarising:
- HFOs: A substantial class of low-GWP compounds, each with each own properties; a stock of candidates tailor-made for various applications
- DR-2: A low-pressure fluid, promising potential for low-temperature heat utilisation
- Attractive safety, health and environmental properties (A1 expected, no ODP, GWP<10)
- High thermal stability, high critical temperature, low vapour pressure
- Could enable Tc up to ~155 °C with conventional equipment components and high energy efficiency

Industrial-sized, high-temperature heat pumps: technologies, barriers and implementation
presented by Lars Reinholdt from the Danish Technological Institute.

More industrial-sized compressors for higher pressures are being introduced into the market, making the implementation of industrial-sized high-temperature heat pumps more interesting. This paper describes a project to accelerate the incorporation of such heat pumps into industrial processes to recover part of the large amount of low-temperature waste heat. The project focuses on heat pump systems larger than 500 kW with outlet temperatures higher than 85 °C and up to 250 °C. Only "natural" refrigerants will be investigated.

Although many other factors besides heat pump technology influence the feasibility of this technology, these new products will, through the combination of high outlet temperatures, refrigerant type and the size of commercially available heat pumps, eliminate some of the existing barriers to their use.

Five different and suitable refrigerant technologies and unit types have been analysed:
R-717, Hybrid (combination of R-717 and R-718); R-744; R-718 and HC (R-600a or R-290).

The purpose was to determine which type of heat pump is most suitable for given conditions, based on energy efficiency.

During the process work, the heat pump system itself was considered as a black box: the focus is on implementation. Recovering waste heat from a cooling tower in order to reduce energy usage for hot water production is quite straightforward, whereas integrating heat pumps directly into a process is much more challenging. Methodologies of how to investigate the possibility and feasibility of such integration will be developed in accordance with an analysis of actual processes among the partners in the project. These processes are such as slaughterhouses, traditional dairy production facilities, large-scale industrial cheese production facilities, powdered milk production facilities, and spray dry-

ing systems in a more general view. It is expected that the feasibility studies should result in the implementation of a demonstration plant.
The summary:

- Heat demand and the amount of waste heat are huge in the process industry, making heat pumps a good alternative to fossil fuel
- New industrial compressors for higher pressures make it possible to build high-capacity heat pumps for high-temperature applications
- Heat pumps are "feel-good" products, and it is vital NOT just to sell and install a high-capacity heat pump without quite detailed energy mapping

Heat pumps in industrial cleaning applications

presented by Dipl.-Ing. Bjarke Paaske from the Danish Technological Institute.

The objective of this project is to promote the use of heat pumps in energy-intensive industrial washing applications. Energy consumption in cleaning and drying applications is vast, with an enormous amount of waste heat to be recovered and recycled in the cleaning process.

As the focus on industrial energy consumption has increased, heat pumps are interesting in more and more applications, including cleaning and drying.

Through the project, a heat pump solution has been developed and commissioned for a specific cleaning application at Grundfos. The heat pump provides heat for a single washing machine at the factory, and is simply an "ad on" concept for existing or new washing machines. Few modifications are needed, enabling easy installation and high flexibility in production facilities. The specific heat pump recovers energy internally in the washing machine by cooling moist exhaust air and recycling the energy into the washing water.

The field test showed that the overall energy consumption of the washer was reduced by about 50 % (including energy consumption of motors, pumps, fans etc.). As the washers have high running hours, the annual reduction in energy consumption is considerable and enables short payback periods.

Component	Max power [kW]	Average power [kW]	Average power HP [kW]
Heaters – soapy water	24	7.6	2.2
Heaters – clean water	18	16.7	4.7
Pump – soapy water	1.5	1.5	1.5
Pump – clean water	0.75	0.75	0.75
Blower – drying air	2.2	2.2	2.2
Heater – drying air	6	3.5	3.5
Motor	0.18	0.18	0.18
Filter mist	1.5	1.5	1.5
Total	**54.1**	**33.9**	**16.5**

Figure 5 Comparison between industrial washing applications with and without heat pumps

Heat pumps in industrial washing applications

50 % reduction in energy consumption is expected. Apart from field testing of the specific unit, the potential of heat pumps for industrial washing processes has been analysed in different applications and concepts. Grundfos has a number of washers in its production facilities, both centralised and decentralised, and in a number of different sizes. Another concept for heat pumps in washing applications is that of combined heating and cooling. Many factories have simultaneous cooling and heating demands. Heat pumps are particularly suitable in such circumstances, as it is possible to meet a cooling demand while providing hot water for a washing process. For this concept, the overall energy consumption is very small in comparison with individual cooling and heating.

To promote the use of heat pumps in new and existing applications, results from the analysis have been summarised in a software tool. The software provides energy consultants, manufacturers and end users with a quick assessment of possible HP solutions in different applications. Data such as temperature levels, heating demand, alternative heat sources and so on is entered in the program, which produces a number of possible HP solutions, together with energy consumption and savings potential. Using the program, consultants are able to make a quick first assessment of heat pump solutions, despite possibly limited knowledge of heat pump technology.

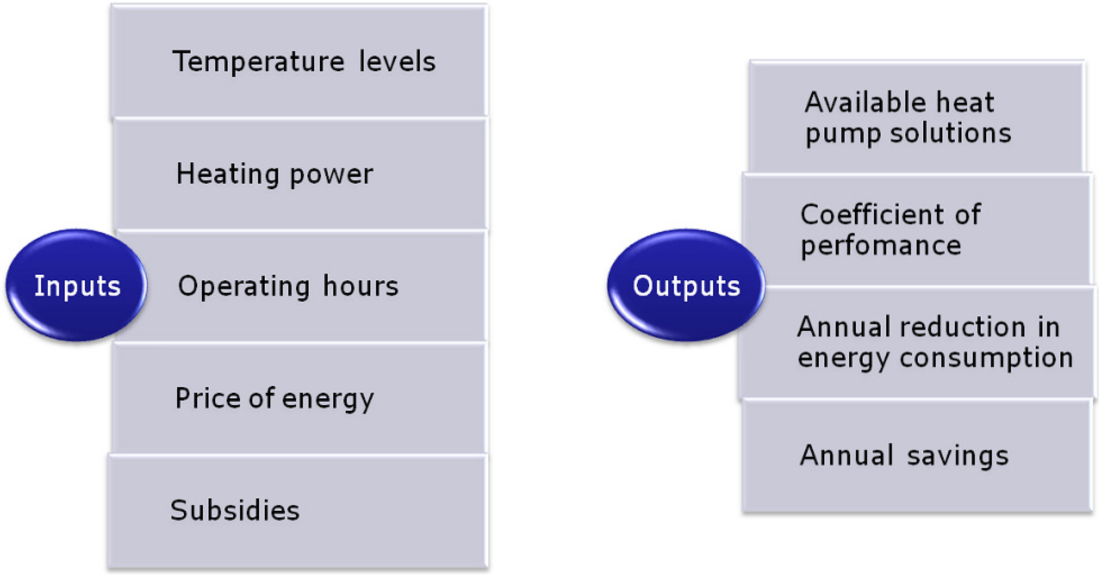

Figure 6 Software tool

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Source: European Heat Pump Summit 2011, http://www.hp-summit.de/en/

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Dipl.-Ing. Jochen Lambauer, Dr. rer.pol. Ulrich Fahl, Dr.-Ing. Markus Blesl, Dr.-Ing. Alfred Voß, Institut für Energiewirtschaft und Rationelle Energieanwendung (IER), Universität Stuttgart, 70565, Stuttgart, Germany

Experimental Investigation of a high-temperature heat pump using HFC-245fa as working fluid for heat recovery in industry
Eugenio SAPORA, Damien BOBELIN, EDF R&D, F-77818 Moret sur Loing, France

Next-generation low GWP refrigerant for high-temperature heat pumps
Konstantinos (Kostas) Kontomaris Ph.D., Principal Investigator, DuPont Fluorochemicals R&D, P.O. Box 80711, Wilmington, Delaware 19880-0711, USA

Industrial-sized, high-temperature heat pumps: technologies, barriers and implementation
Lars Reinholdt et.al.; Danish Technological Institute, DK-8000, Aarhus C, Denmark,
Heat pumps in industrial cleaning applications
Dipl.-Ing. Bjarke Paaske; Danish Technological Institute, DK-8000, Aarhus C, Denmark,

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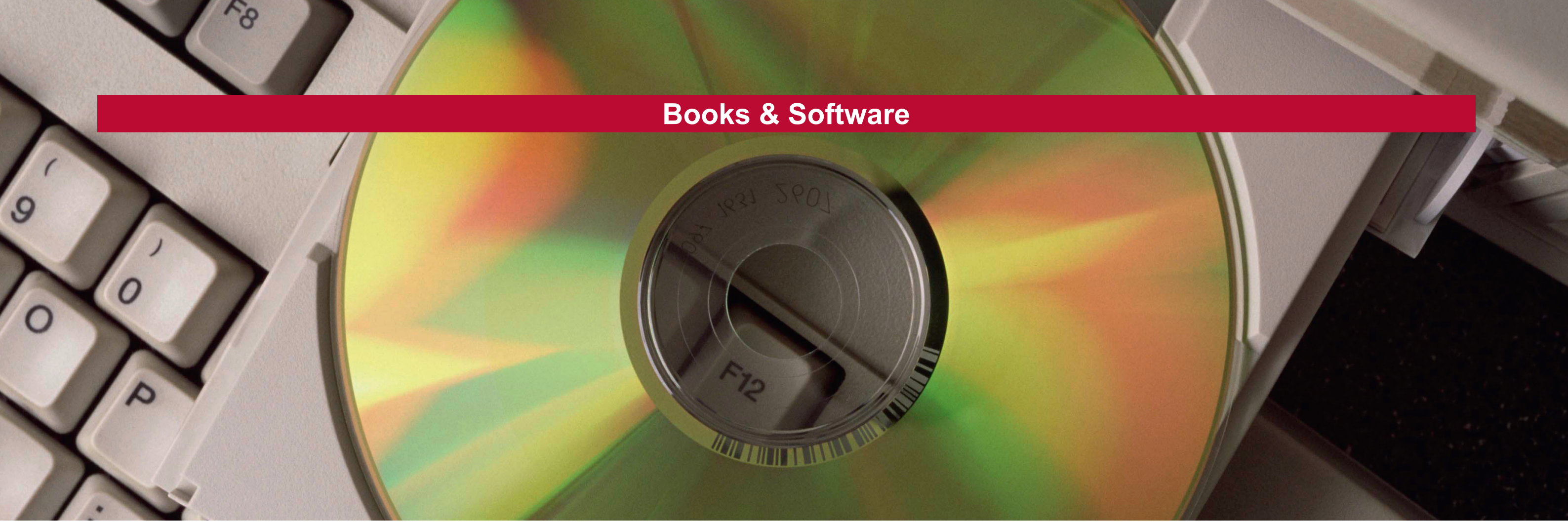

50 Percent Energy Savings for Retail Stores Now Available, No Coupon Required

Energy costs are typically the second highest operating expense for a retailer, so use of the latest 50% Advanced Energy Design Guide can help in creating a cost-effective design for medium to big box retail stores and can have a direct and significant impact on profitability.

For a discount on energy efficiency, owners, engineers, designers, architects and others on the building team are encouraged to download Advanced Energy Design Guide for Medium to Big Box Retail Buildings: Achieving 50% Energy Savings Toward a Net-Zero-Energy Building. The Guide applies to medium to big box retail buildings with gross floor areas between 20,000 and 100,000 sq. ft.; however, many of the recommendations also can be applied to smaller or larger retail buildings.

It is the third book in a series of Advanced Energy Design Guide (AEDG) publications that provides recommendations to achieve 50% energy savings when compared with the minimum code requirements of ANSI/ASHRAE/IESNA Standard 90.1-2004, Energy Standard for Buildings Except Low-Rise Residential Buildings.

“When the comfort of a customer can impact a purchase in a shopping environment it’s important for retail stores to find a balance between energy efficient measures for the building and the convenience for their customers,” Shanti Pless, chair of the AEDG project committee, said. “This guide offers guidance and tips for implementing successful energy savings strategies while enhancing the shopping experience.”

The new guide features easy-to-follow recommendations for each of the US climate zones and tips on how to implement those recommendations. Case studies and technology examples provide real-life examples of how retailers have achieved significant energy savings.

Also included is information on integrated design, including best practices as a necessary component in achieving 50% energy and the inclusion of a performance path—specifically, offering annual energy use targets to help with goal setting.

Source: http://www.ashrae.org

Natural Refrigerants - Market Growth for Europe

Under its newly established publishing arm, Shecco has launched its first in a series of easy-to-access guides for industry and policy decision makers about the global market potential of natural refrigerants. The first edition - with a focus on Europe - features market forecasts per industry sector until 2020, the end-users’ views, an industry directory, Europe’s first CO_2 transcritical supermarket map, and more.

As the first-ever approach to quantify the market potential for the natural working fluids carbon dioxide, ammonia and hydrocarbons, the “GUIDE 2012: Natural Refrigerants – Market Growth for Europe” addresses both experts and new entrants to the market for more sustainable heating, cooling and refrigeration. Building on a global industry survey among close to 1,300 HVAC&R experts, the GUIDE aims to support decision makers in industry and policy to learn about the characteristics of natural refrigerants, get familiar with their applications today and the challenges they still face, but more importantly evaluate their business potential over the coming years.

Source: http://www.shecco.com

GIZ launches publication on safe conversion of split ACs to hydrocarbons

This conversion guide is intended to assist with the safe conversion of air conditioning systems to use flammable hydrocarbon (HC) refrigerants. Converting an air conditioning system from a non-flammable to a flammable refrigerant requires special considerations, which are summarised here.

Source: http://www.giz.de

New Book Offers Guidance on Implementing Energy Savings Plan

Guidance on increasing energy efficiency in existing buildings through measuring and tracking efficiency and implementing an efficiency plan is featured in a new book from leading built environment organizations. Energy Efficiency Guide for Existing Commercial Buildings: Technical Implementation provides clear and easily understood technical guidance for energy upgrades, retrofits and renovations by which building engineers and managers can achieve at least a 30 percent improvement in energy performance relative to a range of benchmark energy utilization indexes. It features practical means and methods for planning, executing and monitoring an effective program, based on widely available techniques and technologies.

Source: http://www.ashrae.org

Events

This section lists exhibitions, workshops, conferences etc. related to heat pumping technologies. Scroll through the list to find information on upcoming events.

7 May
EHPA 2012 General Assembly
Milano, Italy
http://www.ehpa.org/milano/

8 May
5th European Heat Pump Forum
Milano, Italy
http://www.ehpa.org/milano/

13-17 May
2012 World Renewable Energy Forum
Denver, Colorado
http://ases.org/index.php?option=com_content&view=article&id=18&Itemid=147

28-31 May
5th International Building Physics Conference
Kyoto, Japan
http://rcpt.kyoto-bauc.or.jp/IBPC2012/

23-27 June
ASHRAE Annual Conference
San Antonio, Texas
http://www.ashrae.org/membership--conferences/conferences/san-antonio-conference

25-27 June
10th IIF/IIR Gustav Lorentzen Conference on Natural Refrigerants
Delft, Netherlands
http://www.gl2012.nl

8-12 July
Healthy Buildings 2012
Brisbane, Australia
http://hb2012.org

16-19 July
21st International Compressor Engineering Conference at Purdue
14th International Refrigeration and Air Conditioning Conference at Purdue
2nd International High Performance Buildings Conference at Purdue
West Lafayette, Indiana, USA
https://engineering.purdue.edu/Herrick/Events/2012Conf/index.html
http:/www.conf.purdue.edu/

29 July - 1 August
10th IIR Conference on Phase Change Materials and Slurries for Refrigeration and Air-Conditioning
Kobe, Japan
http://www2.kobe-u.ac.jp/~komoda/pcms/

1-4 August
The Second International Conference on Building Energy and Environment
Boulder, Colorado, USA
http://www.colorado.edu/cobee2012/index.html

1-3 October
Energy Modeling Conference: Tools for Designing High Performance Buildings
Atlanta, Georgia, USA
http://ashraem.confex.com/ashraem/emc12/cfp.cgihttp://www.chillventa.de/en/

8 October
Heat Pump Programme Open Conference
In conjunction with Chillventa
Nürnberg, Germany
[Please see page 10 for more info]

9-11 October
Chillventa
Nuremberg, Germany
http://www.chillventa.de/en/

25-26 October
3rd IIR Workshop on Refrigerant Charge Reduction in Refrigerating Systems
Valencia, Spain
http://www.imst.upv.es/iir-rcr2012

31 October – 2 November
35th World Energy Engineering Congress
Atlanta, Georgia, USA
http://www.energycongress.com/

8-9 November
10th International symposium on new refrigerants and environmental technology
Kobe, Japan

12-14 November
Cold Climate HVAC 2012
Calgary, Alberta, Canada
http://www.ashrae.org/membership--conferences/conferences/ashrae-conferences/Cold-Climate-HVAC-2012

3-7 December
Ecobuild America
Washington DC, USA
http://www.aececobuild.com/

2013

26-30 January
ASHRAE Winter Conference
Dallas, Texas, USA
http://ashraem.confex.com/ashraem/w13/cfp.cgi

2-4 April
2nd IIR International Conference on Sustainability and the Cold Chain
Paris, France
http://www.iccc2013.com/

In the next Issue

The role of heat pumps in smart grids and cities

Volume 30 - No. 2/2012

International Energy Agency

The International Energy Agency (IEA) was established in 1974 within the framework of the Organisation for Economic Co-operation and Development (OECD) to implement an International Energy Programme. A basic aim of the IEA is to foster co-operation among its participating countries, to increase energy security through energy conservation, development of alternative energy sources, new energy technology and research and development.

IEA Heat Pump Programme

International collaboration for energy efficient heating, refrigeration and air-conditioning

Vision

The Programme is the foremost worldwide source of independent information and expertise on environmental and energy conservation benefits of heat pumping technologies (including refrigeration and air conditioning).

The Programme conducts high value international collaborative activities to improve energy efficiency and minimise adverse environmental impact.

Mission

The Programme strives to achieve widespread deployment of appropriate high quality heat pumping technologies to obtain energy conservation and environmental benefits from these technologies. It serves policy makers, national and international energy and environmental agencies, utilities, manufacturers, designers and researchers.

IEA Heat Pump Centre

A central role within the programme is played by the IEA Heat Pump Centre (HPC). The HPC contributes to the general aim of the IEA Heat Pump Programme, through information exchange and promotion. In the member countries (see right), activities are coordinated by National Teams. For further information on HPC products and activities, or for general enquiries on heat pumps and the IEA Heat Pump Programme, contact your National Team or the address below.

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