Heat Pumping Technologies MAGAZINE

A HEAT PUMP CENTRE PRODUCT

Report from the 12th IEA Heat Pump Conference

ONNO KLEEFKENS, Chairman – National Organizing Committee (NOC), The Netherlands

"RETHINK ENERGY, ACT NOW! AND WE WANT TO SHOW THAT IT IS POSSIBLE AND URGENTLY NEEDED!"

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Heat Pumping Technologies
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In this issue

At last, it happened! The 12th IEA Heat Pump Conference took place in Rotterdam in May, very successfully! This issue of the HPT Magazine summarises some of the numerous sessions, workshops, award ceremonies, and presentations given at the conference.

In the Foreword, the Chairman of the National Organizing Committee, Onno Kleefkens, gives his view of the conference. Then, there are two different policy presentations from the plenary opening sessions with very different subjects. The workshops of the conference were centred around the HPT TCP Annexes, and six of them are summarised by their chairmen in this issue. There were four Awards at the Conference, the Ritter von Rittinger Award, the Dutch Innovation Award, the Best Poster Award, and the Daikin Best Student Award. They are all presented here. Also, three personal summary reports from conference participants are provided, each with their own selection of presentations.

In addition to the coverage of the conference, the presentation of the newly released IEA flagship publication Energy Technology Perspectives (ETP) 2017 is provided in the Strategic outlook. It outlines even more ambitious climate goals than previous editions. The Column in this issue is written by one of the HPT TCP's most highly regarded long-term members and contributors, Prof. Hermann Halozan. Two Non-Topical articles present a new view on cooling, and how heat pumps can be used in advanced thermal grids, respectively.

Enjoy your reading!

Johan Berg, Editor

Heat Pump Centre

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The 12th IEA Heat Pump Conference in Rotterdam

When I first participated in the third IEA Heat Pump Conference in 1990 in Tokyo I had already been active developing heat pumps ten years before. However, the market development in Netherlands completely blocked and failed to develop in that period. Coming to that third Conference, my eyes were opened, seeing the successful markets in Japan, Switzerland and other countries. Returning back home we set up a national expert group and in my function as policy consultant with the Ministry I advised to acknowledge heat pumps as a renewable heating technology and to get the fourth Heat Pump Conference to Maastricht in 1993 to show my country what was possible and to learn from others.

Twenty-one years later at the 11th Conference in Montréal, people asked me why all the innovations in the Netherlands in the application of heat pumping technologies were kept as a hidden gem, for internal use only. Innovative? I thought, what innovation? We are just doing it. But they were right, the innovation is not so much in the technology itself but in the way in which it is applied. So we then decided to organize the 12th Conference in the World Trade Centre in Rotterdam, the Netherlands, to show what we are doing.

For the 12th IEA Heat Pump Conference we had the theme "Rethink Energy, Act Now!" And we want to show that it is possible and urgently needed! In the host-city of Rotterdam almost all high rise buildings are heated with heat pumps. That is a real showcase.

Especially in domestic applications the governmental policy has focused on reducing the energy use by legislation with a long term tightening towards energy zero. This started off the development, primarily in newly constructed buildings. The stiff economic competition with cheap gas boilers, the extensive gas-grid and the small space available in the domestic applications triggered further innovation. The result is a number of smart solutions of the technology, with small-size equipment that are simple to install, resulting in industrialisation of the building process for new domestic buildings and for renovation of existing buildings.

Energy Cost Zero projects are becoming the next thing in the market, making the Netherlands ready for 2020 and the next decades.

The extensive gas-grid and the rather 'weak' electric infrastructure resulted in the development and application of the first hybrid heat pumps. I even installed one of the first experimental ones at my own house. Great experience.

At the first day of the Conference in Rotterdam with seven workshops, we had the challenge with the festivities for the soccer championship of Feijenoord to get in all participants in time! We succeeded with the support of the local authorities. These workshops were a really interesting interaction between experts from the different IEA TCPs generating new ideas and international collaboration. For the Conference itself we received an overwhelming number of 264 high quality papers and thus could create a Conference program with four tracks of sessions during three days. Most of the sessions were directly related to the work in past, running and future Annexes under the HPT TCP. The great challenge for the organisation is to attract participants other than authors. With over 500 participants from 34 countries we could welcome many new faces.

It has been a great honour for us to organize the 12th IEA Heat Pump Conference 2017 in Rotterdam and we thank all our sponsors, reviewers and those who supported us.

M.SC. ONNO KLEEFKENS
CHAIRMAN – NATIONAL ORGANIZING COMMITTEE (NOC)
PHETRADICO COMMUNICATION
THE NETHERLANDS

Heat pumps – the key technology for reducing CO_2 emissions in the building sector

In Europe, the building sector is responsible for 40 % of the total energy demand and for about 33 % of the CO_2 emissions. By 2050, this sector should become CO_2-free, which means the heating demand has to be reduced by improving buildings, and the remaining heating and cooling demand has to be covered by renewable energy sources.

In the European Technology Platform on Renewable Heating and Cooling, four sectors are mentioned: Solar Heating and Cooling; Geothermal divided into deep and shallow geothermal sources; Biomass; and Cross-Cutting Technologies covering District Heating and Cooling, Thermal Energy Storage, Heat Pumps, and Hybrid Renewable Energy Systems.

Solar heating systems are most commonly hybrid systems with a solar fraction of 25 %. The other system is either the conventional heating system or, for new applications, a heat pump. Large solar systems with large seasonal stores are becoming interesting for district heating networks; these systems are often combined with heat pumps to reduce the supply temperature to the solar collector and increase the solar fraction. Solar cooling is always carried out by a heat pump, which in the case of solar thermal is by an adsorption or absorption heat unit, in the case of PV by a compression unit. Presently, solar cooling is dominated by PV systems.

The majority of geothermal systems are shallow geothermal systems combined with a heat pump suitable for both heating and cooling. In the past, ground source heat pumps – for which the sources are the ground, ground water and surface water – have dominated the market. Nowadays, air source heat pumps are dominating. However, in many countries, there is a revived interest in ground source systems, even though the investment costs are higher. Advantages are higher efficiency and no problems with noise. Ground source systems enable monovalent heating operation, even in cold climates, and for utilities they are a tool for demand side management measures. In the case of large systems, the ground can be used as a store, which offers, in the case of heating and cooling operation, improved conditions at least at the beginning of both the heating and the cooling season.

However, there are some other advantages of heat pumps: they can use electricity from intermittent sources like wind and PV, and, in combination with stores, they can contribute to smart grids. They will act as the main heat generation system for district heating and cooling systems, using natural sources as well as heat recovered from industry, and they will be the key technology for making the market for heating energy efficient and CO_2-free.

DR. HERMANN HALOZAN
Graz University of Technology
Austria

European Commission: "Clean Energy for All Europeans"

Summary of my policy presentation from the plenary opening sessions.

In November 2016, the European Commission tabled a legislative package entitled "Clean Energy for All Europeans", with a focus on energy efficiency, market design and renewables. This package, which constitutes a key deliverable under the Energy Union Strategy, is designed to ensure that the EU continues to lead the clean energy transition. As the EU has committed to cut CO_2 emissions by at least 40 % by 2030, there is a clear need to continue improvements on energy efficiency and to increase the share of Renewable Energy Sources (RES) in our overall energy mix. This is also important in our efforts to modernise the EU's economy and to deliver on jobs and growth for all European citizens. The proposals that are included in the package have three main goals: putting energy efficiency first, achieving global leadership in renewable energies, and providing a fair deal for consumers.

The package builds on the existing framework, according to which the EU should reach an overall share of RES of 20 % of total final energy consumption by 2020. The vast majority of EU countries are well on track to reach their targets (See Figure 1), but all countries will have to continue their efforts to be sure to meet the targets.

As regards the heating and cooling sector, the EU as a whole is above its trajectory (See Figure 2), with an estimated renewable share of 18.1 % in 2015. Solid biomass continues to be the largest contributor to renewable heat production, but heat pumps are the second biggest source of renewable heating and cooling. Overall, heat pumps provide a 9 % contribution to the EU 2020 RES target. The contribution from heat pumps is projected to grow and have an important role in meeting the new EU 2030 RES target (See Figure 3), which is currently being negotiated by the European co-legislators, i.e., the EU Member States in the Council and the European Parliament.

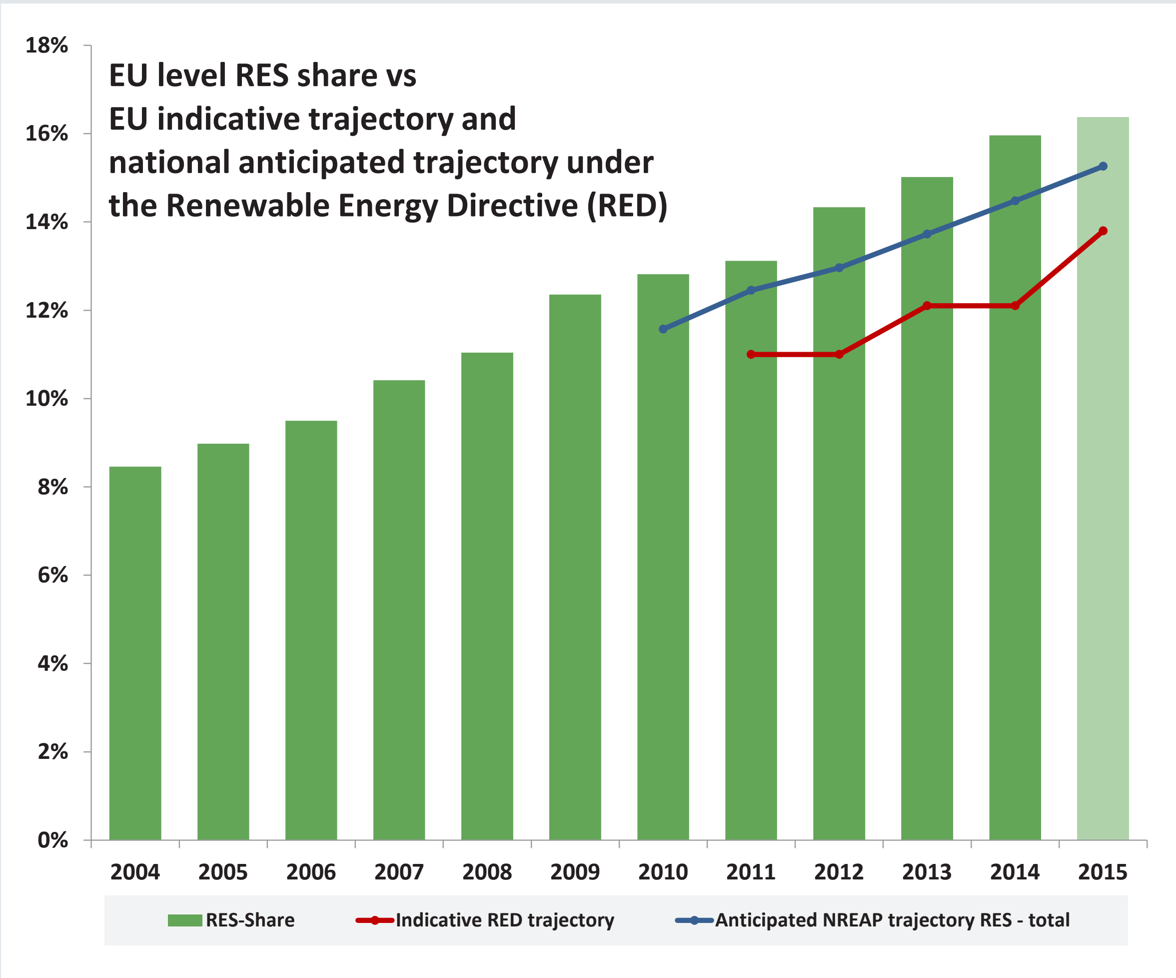

Figure 1. Progress towards the 20 % RES target by 2020.

The role and the benefits of heat pumps are fully recognised by the Commission. The Commission considers that heat pumps have a great potential to be a key element of decarbonisation and to contribute to a smooth and cost-effective energy transition. This, among other things, is due to their ability to provide flexibility in the electricity system. Heat pumps can be especially important for decarbonising buildings, which is a vision set out in the EU Heating and Cooling Strategy. Heat pumps are therefore strongly promoted in several EU instruments, i.e. the Renewable Energy Directive, the EU Eco-design and Energy Labelling framework and the Strategic Energy Technology Plan (SET Plan), which all treat heat pumps as an important technology.

The European Commission considers that the November legislative package contains proposals that will provide a strong market pull for new technologies, set the right conditions for investors, empower consumers and make energy markets work better. Once adopted, these

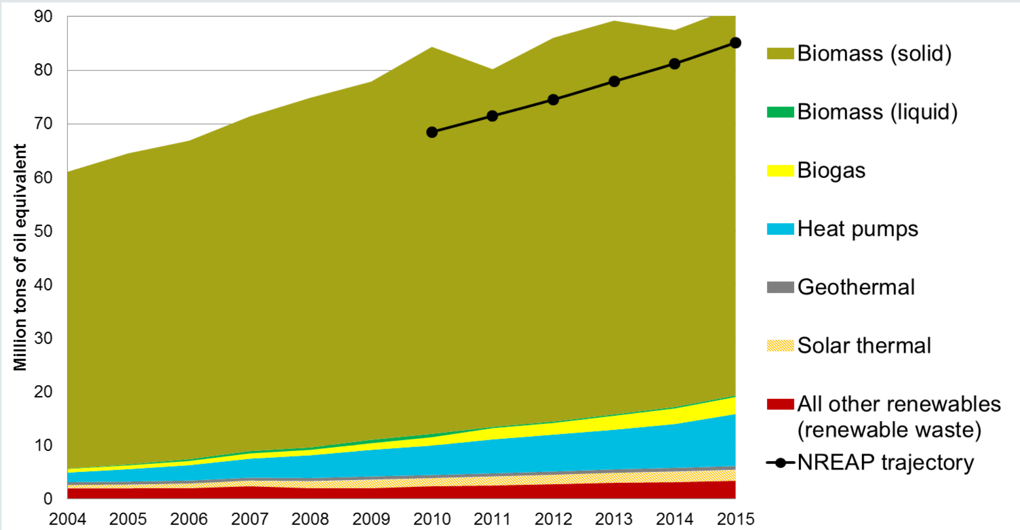

Figure 2. Renewables in heating (Mtoe, 2004-2015). EU-28 renewable heating and cooling production by source [Source: EUROSTAT, Öko-Institut]

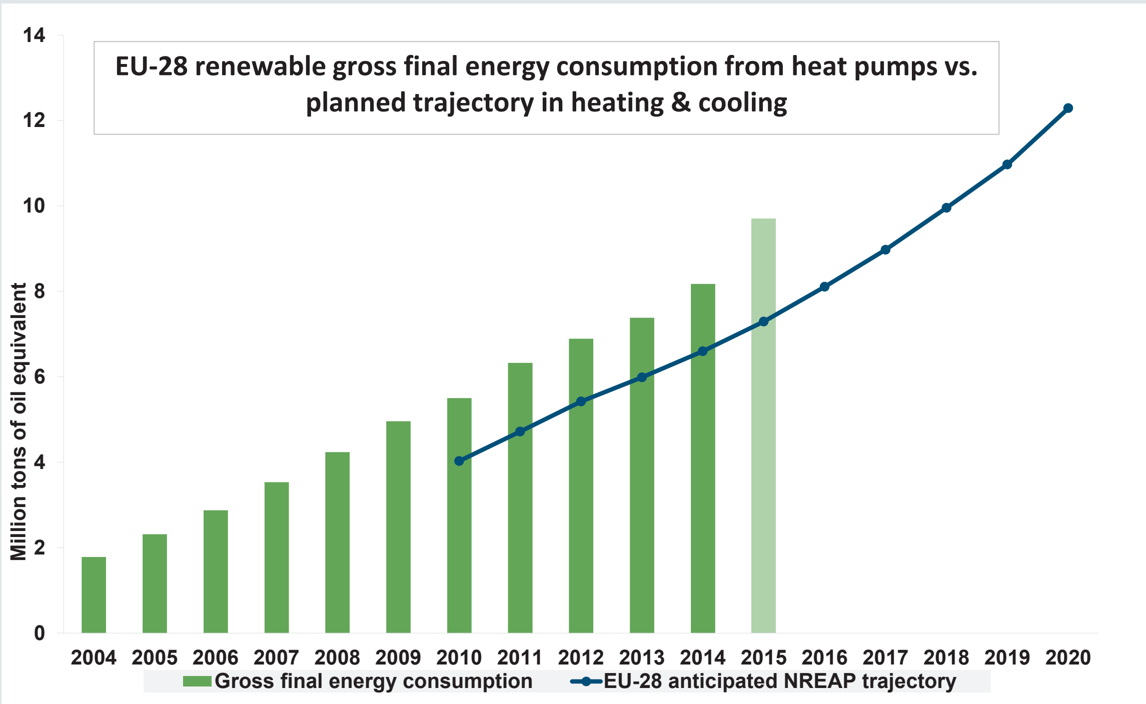

Figure 3. The contribution from heat pumps is projected to grow and have an important role in meeting the new EU 2030 RES target.

HOW WILL THE NEW PACKAGE HELP THE EU RES INDUSTRY?

- Keep renewables at the top of the EU energy agenda and secure a continued high-level of ambition in terms of renewables build-up
- Contribute to regulatory certainty beyond 2020
- Address damaging retroactivity in support schemes
- Clearly identify the key role of the consumer
- Comprehensive integrated governance

Figure 4. How will the new package help the EU RES industry?

measures will help us meet our climate targets, including by providing clarity, certainty and stability to investors, industry and consumers in Europe and beyond (See Figure 4).

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SHORT BIO

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Mr van Steen has been with the European Commission since 1989. Prior to his current assignment, he was the Head of Unit for Renewable Energy (2006 - 2013) and International Energy Relations and Enlargement (2013 - 2017).

Mr van Steen holds a Master's Degree in Political Science from the University of Århus, Denmark.

Effectively managing the transition to lower GWP refrigerants

Karim Amrane, USA

Environmental concerns raised by high global warming potential (GWP) refrigerants have triggered a series of regulatory activities around the world to curtail the use of hydrofluorocarbons (HFCs). In this article, the author reviews major regulatory drivers aimed at reducing the use of HFCs and describes efforts currently underway to update safety codes and standards so that many of the most promising alternative refrigerants could be safely used. Initiatives aimed at improving the management of refrigerants to reduce leak and service emissions, and to promote the recycling, recovery, reclaiming, and end of life destruction of refrigerants are also discussed.

Introduction

Concerns about climate change have led to worldwide efforts to reduce greenhouse gas emissions. Particular attention has been paid to hydrofluorocarbon (HFC) refrigerants because of their increased emissions in the atmosphere due to their use in air conditioning, heat pumps and refrigeration equipment. HFCs were identified in the 1990s as replacements to chlorofluorocarbons (CFCs) and hydrochlorofluorocarbons (HCFCs) which were found to destroy the ozone layer. However, while HFCs have zero ozone depleting potential (ODP), they are greenhouse gases with GWP values ranging from approximately 100 to several thousand times greater than that of carbon dioxide (CO_2). The increased amount of HFCs in the atmosphere has led to a flurry of regulatory activities around the world to curtail their use. Alternative refrigerants are being developed, but most are flammable and necessitate changes to safety codes and standards so they could be safely used. These factors as well as efforts aimed at improving the management of refrigerants are examined in this article.

Regulatory drivers

In 2014 the European commission promulgated regulations that introduced a phasedown of HFCs in addition to specific bans on high Global Warning Potential (GWP) HFCs [1]. In the U.S., President Obama announced a Climate Action Plan to cut carbon emissions [2]. Among other things, the plan directed the U.S. Environmental Protection Agency (EPA) to use its authority under the Significant New Alternative Policy (SNAP) program to identify and approve low GWP alternatives while prohibiting certain uses of high GWP refrigerants and foam blowing agents. EPA then issued two rulemakings changing the listing status of several high GWP refrigerants used in commercial refrigeration equipment, chillers and cold storage warehouses to unacceptable, effectively banning their use [3, 4]. In October 2016, a historic agreement was reached in Kigali, Rwanda, by nearly 200 countries to adopt a global phasedown of HFCs. According to the agreement as shown in Table 1, the amendment to the Montreal Protocol provides separate baselines and reduction schedules for developed

Table 1. Phasedown schedule for developed (A2) and developing (A5) countries.

	A5 GROUP 1**	A5 GROUP 2***	A2
Baseline	2020-2022	2024-2026	2011-2013
Formula	Average HFC consumption	Average HFC consumption	Average HFC consumption
HCFC	65% baseline	65% baseline	15% baseline*
Freeze	2024	2028	-
1st step	2029 – 10%	2032 – 10%	2019 – 10%
2nd step	2035 – 30%	2037 – 20%	2024 – 40%
3rd step	2040 – 50%	2042 – 30%	2029 – 70%
4th step			2034 – 80%
Plateau	2045 – 80%	2047 – 85%	2036 – 85%

* For Belarus, Russian Federation, Kazakhstan, Tajikistan, Uzbekistan 25 % HCFC component of baseline and different initial two steps (1) 5 % reduction in 2020 and (2) 35 % reduction in 2025
** Group 1: Article 5 parties not part of Group 2
*** Group 2: Bahrain, India, Iran, Iraq, Kuwait, Oman, Pakistan, Qatar, Saudi Arabia, and the United Arab Emirates.

Table 2. State of standards and codes – Global view

	Refrigerant Classification	Usage Restriction	Application		
United States	ASHRAE34 Refrigerant Designation & Safety Classification UL2182	ASHRAE15 Safety Standards for Refrigeration Systems 2015-2018	UL1995 Heating and Cooling Equipment 2014-2015	UL471 Commercial Refrigerators and Freezers 2015-2019	UL621 Ice Cream Makers 2015-2019
			UL60335-2-40 Heating and Cooling Equipment -2017	UL60335-2-89 Commercial Refrigeration -2018	
	Refrigerant Classification	**Usage Restriction**	**Application**		
International	ISO817 Refrigerant Designation & Safety Classification (2013-2014)	ISO5149 Safety and Environmental Requirements, Phase 1 Phase 2 2014-2015	IEC60335-2-40 Heating and Cooling equipment 2015-2017	IEC60335-2-89 Commercial Refrigeration 2015-2019	IEC60335-2-24 Refrigerating appliances Ice and Ice Cream Makers 2015-2019

complete | under revision

(A2) and developing (A5) countries, as well separate accommodations for certain Parties within those categories. The agreement is expected to avoid greenhouse gas emissions of at least 70 gigatons CO_2 equivalent by 2050.

Safety codes and standards

The Low-GWP Alternative Refrigerant Evaluation Program (Low-GWP AREP) conducted by AHRI [5, 6] identified viable alternative refrigerants, most of which are mildly (i.e. "2L" classification) or highly (i.e., "3" classification) flammable per ASHRAE Standard 34 [7]. However, current safety standards, such as ASHRAE 15, severely restrict the use of flammable refrigerants [8].

However, efforts are currently underway as shown in Table 2 to amend ASHRAE 15 and several international standards to include requirements on equipment using class 2L and 3 refrigerants [9, 10]. Completion is expected in 2018/2019.

Research on flammable refrigerants

The revisions of safety codes and standards to address class 2L, and to a certain extent class 3 refrigerants, identified a lack of publicly available knowledge about the safe use of flammable refrigerants. To address this challenge faced by the industry, AHRI, through its research arm AHRTI, launched a research program to identify critical needs that relevant standards and codes are depending upon for their timely inclusion of flammable refrigerants. With the support of ASHRAE, the California Air Resource Board (CARB) and the US Department of Energy (DOE), $5.6 million were allocated to conduct the following projects (leading organization undertaking the project is listed in parenthesis):

- Benchmarking risk by real life leaks and ignitions testing (AHRTI)
- Investigation of hot surface ignition temperature for A2L refrigerants (AHRTI)
- Leak detection of A2L refrigerants in HVACR equipment (AHRTI)
- Flammable refrigerants post-ignition risk assessment (ASHRAE)
- Guidelines for flammable refrigerant handling, and equipment servicing and installation (ASHRAE)
- Servicing and installing equipment using flammable refrigerants: assessment of field-made mechanical joints (ASHRAE)
- Investigation of proper basis for setting charge limits of A2L, A2, and A3 refrigerants for various types of products (Oak Ridge National Laboratory)

Most the projects listed above will be completed in the second or third quarter of 2017, on time to be considered by various safety standard committees.

Refrigerant management and technician training

The introduction of low GWP refrigerants in air conditioning, heat pumps and refrigerant equipment presents unique challenges to technicians who have very little or no experience handling flammable refrigerants. That is why education and training is critical and cannot be ignored. In 2015, AHRI teamed up with ABRAVA, the Brazilian Association, and with the Alliance for Responsible Atmospheric Policy to establish the Global Refrigerant Management Initiative (GRMI). Since then, other HVACR organizations in many different countries and regions, including Australia, China, Canada, Columbia, the EU, Japan, and Korea have joined the effort. GRMI seeks to identify and explore opportunities to educate the HVACR industry's global supply chain on ways to improve the management of refrigerants to reduce leak and service emissions, and to promote the recycling, recovery, reclaiming, and end of life destruction of refrigerants and foam blowing agents. The initial, primary purpose of GRMI is to improve global education, training and certification of the service industry associated with air conditioning and refrigeration industries. GRMI intends in the next couple of years to become a focal point for developing common approaches among national and regional actors to ensure global success.

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SHORT BIO

Dr. Karim Amrane is Senior Vice President of Regulatory and International Policy at the Air-Conditioning, Heating, and Refrigeration Institute (AHRI). He manages the industry's cooperative research program and is responsible for the development and implementation of AHRI's regulatory and international policy. Dr. Amrane is also an adjunct professor at the University of Maryland where he teaches graduate courses in mechanical engineering. Dr. Amrane has over 25 years of experience in the air conditioning and refrigeration industry.

He is a member of the American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), the International Institute of Refrigeration (IIR), and the American Society of Mechanical Engineers (ASME).

Summary reports from the Workshops of the 12th IEA Heat Pump Conference 2017 in Rotterdam

The workshops of the 2th IEA Heat Pump Conference (HPC 2017) in Rotterdam were centred around the HPT TCP Annexes, and here follows summary reports for six of them, summarised by their chairmen.

Workshop summary on "Heat pumps in nZEB, multi-family buildings and energy flexibility"

The workshop covered the application of heat pumps in buildings, mostly residential buildings. Participants of three Annexes participated in the workshop, in order to introduce the Annex work and links between the different projects within the Annexes. The Annex 49 in the IEA Technology Collaboration Programme on Heat Pumping Technologies (HPT TCP) on "Design and integration of heat pumps in nearly Zero Energy Buildings (nZEB)" has a focus on new buildings, while the Annex 50 on "Heat pumps in multi-family buildings" covers the application in multi-family buildings, also in existing buildings. The Annex 67 of the IEA Energy in Buildings and Communities Technology Collaboration Programme (EBC TCP) on "Energy flexible buildings" has the objective to define flexibility and to evaluate options, how buildings can provide energy flexibility towards the grid.

Since all three Annexes deal with heat pumps in buildings, the opportunity for a joint workshop to present the Annex work in the frame of the IEA Heat Pump Conference was utilized. The workshop included 8 presentations to introduce the Annex work. An information exchange among the three Annexes has already been established beforehand. The workshop was attended by about 80 persons. In the first part of the workshop the Annex 49 was presented in three presentations.

Carsten Wemhoener of the HSR University of Applied Sciences Rapperswil presented an introduction to nZEB with current examples from Switzerland and the current state of nZEB as well as an outline of the IEA HPT TCP Annex 49 work. Even though nZEB shall be introduced in all public buildings in the EU by the beginning of 2019, only 15 of the EU member states had a definition of an nZEB by 2015, which, however, vary both in criteria and in limits. Thus, in Task 1 of Annex 49 the current state of the art is to be evaluated. In Task 2 integration options for heat pump systems in nZEB, e.g. with electric and thermal storages or with the ground, and in groups of nZEB are covered, as well as the integration of nZEB into connected energy grids. In Task 3 technology developments and field monitorings are performed, while in Task 4 the design and control of the heat pump systems, e.g. for energy flexibility or regarding a high self-consumption of the on-site electricity generation, are investigated.

Franziska Bockelmann of the Institute of Building Services and Energy Design (IGS) of the Technische Universität Braunschweig and Christina Betzold of the Energy Campus (EnCN) of the Technische Hochschule Nuremberg Georg Simon Ohm presented projects of the German contribution to HPT TCP Annex 49. At the IGS, different field monitorings of nZEB are evaluated. A long term monitoring of a single family house equipped with different storage options was presented. The performance evaluation for four years was given, and potential for optimised storage operation were concluded. In the project HerzoBase of EnCN, 8 houses were connected by a low temperature grid and decentral heat pumps covered the domestic hot water (DHW) preparation in the houses. One objective of the research was the increase of self-consumption by capacity

Franziska Bockelmann and Christina Betzold present projects of the German contribution to HPT TCP Annex 49. [Photo: Carsten Wemhoener]

Fabian Ochs presented the results of a monitoring of two Passive Houses with low temperature heating system which are built as Net Zero Energy Buildings (NZEBs) and are equipped with HP, a solar thermal system and PV.
[Photo: Carsten Wemhoener]

controlled heat pumps. Load peaks could be reduced by 24 %. Currently, model predictive control is applied.

In the third presentation Fabian Ochs of the unit Energy Efficient Buildings of the University of Innsbruck presented the results of a monitoring of two Passive Houses with low temperature heating system which are built as Net Zero Energy Buildings (NZEBs) and are equipped with HP, a solar thermal system and PV. The two buildings comprise 26 flats for social housing. Heat loads of the buildings are in the range of 12 W/m^2. Monitoring results of the first year indicate that the expected very low energy consumption of the design could not yet be reached, due to e.g. drying of the construction moisture of the building, weather and user impact. However, projections show that with optimised operation the NZEB balance (for heating, DHW preparation and auxiliary electricity consumption) could be reached, so system optimisation measures are applied and monitoring is continued. Investigations focus on the reduction of the so-called winter gap (i.e. the grid electricity consumption in winter).

In the second part of the Workshop, the HPT TCP Annex 50 on "Heat pumps in multi-family houses" was presented. Marek Miara of the Fraunhofer Institute of Solar Energy Systems (FhG-ISE) as operating agent gave an outline of the Annex work. The objective is to increase the installation of heat pumps in multi-family buildings, which show lower installation rates in many countries than heat pumps below 20 kW heating capacity. In Task 1 of the Annex 50, the state-of-the-art, barriers and systems configurations are compiled. In Task 2 system modelling is to be performed, in Task 3, technologies shall be developed and system assessment shall be performed, while in Task 4, monitoring and demonstration projects will be performed. Different types of heat pumps, including thermally-driven heat pumps, are under investigation.

As member of Annex 50, Fabrice Rognon of the Engineering Company CSD presented three case studies from Switzerland. Air-source heat pumps are chosen due to the availability of the source for three retrofitting projects. Typical problems encountered in the retrofitting are the placement of the outdoor air heat pumps, since for some buildings the roof stability is an issue as well as a deformation of the roof due to the weight of the heat pumps. Further limitations are acoustics, maintenance and requirements of the authorities, e.g. regarding historical buildings. Moreover, for economic reasons access to cheap electricity is important. Results of the projects will be disseminated as a handbook covering building static, noise and acoustic, hydronic integration and control.

In the third part of the workshop, the Annex 67 in the EBS TCP was presented with three presentations. John Clauß from the Norwegian University of Science and Technology (NTNU) in Trondheim presented an outline of the EBC Annex 67. Due to higher shares of renewable energies in the electricity grids, high fluctuations of the electricity production result, which requires flexibilities on the demand site, e.g. by demand response strategies. The objectives of Annex 67 are to improve the knowledge on energy flexibility, to investigate how much flexibility can be provided by different building types and to identify the bottlenecks and feasible solutions to cope with energy flexibility. Currently, there is a lack of knowledge how flexibility should be defined and how much flexibility can be offered to the electricity grid by adapted building operation. As Norwegian contribution, a Solar Decathlon Building, which is operated as a Living Laboratory on the campus of the NTNU, is used to develop control strategies for a flexible operation of the Living Lab.

Thibault Péan of the Catalonia Institute of Energy Research IREC of the Technical University of Barcelona presented control strategies to unlock flexibility potentials of heat pump operation. Control strategies can be differentiated between rule-based control and model predictive control. The control is a combination of supervisory control which communicates with a local controller of the heat pump. An applied example is a residential building in Catalonia, which modifies heating set-points depending on the electricity price by rule-based control. Flexibility could be increased, while the impact on thermal comfort is only limited. Even though electricity consumption is increased by about 7 % due to storage operation, the electricity cost is decreased by shifting loads to low price periods.

Christian Finck presented a contribution of the University of Eindhoven on flexibility potentials of thermal energy storage in buildings by respective control. The work is carried out by simulation and an experimental investigation. A case study of the short-term flexibility of sensible, latent and thermo-chemical storage with optimal control was presented. The flexibility potentials of sensible and latent storages is higher than that of thermo-chemical storages. Current work is dedicated to an experimental study on model predictive control of the heating buffer and DHW storage in a residential building in the Netherlands.

Concluding, nZEB offer market opportunities for heat pumps, even though in the first step definitions among European member states will vary, which affects building technology applied in these buildings. Moreover, nZEB are a favourable candidate to offer flexibility to the grid by demand response and the integrated on-site electricity production. The extension of heat pump application in multi-family buildings can further increase the market shares of heat pumps. For future grid operation, heat pumps can additionally provide flexibility options in combination with installed thermal storage and the building thermal mass, which is assessed in EBC Annex 67.

Thus, both in new and existing buildings heat pumps will support a sustainable energy systems based on larger shares of renewable energy. The three Annexes presented in the workshop contribute to this target, and collaboration within and among the Annexes is beneficial to focus on the different aspects of heat pump integration in buildings and energy grids.

CARSTEN WEMHOENER
Operating Agent for HPT TCP Annex 49
IET Institut für Energietechnik
Switzerland

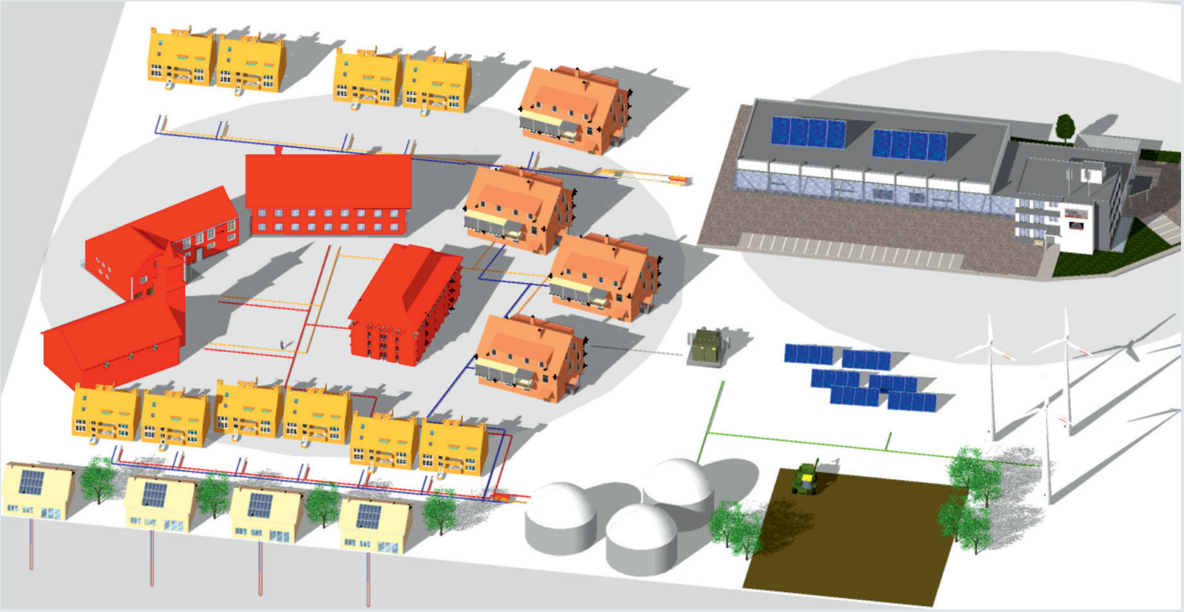
Workshop summary on "Rethink energy in urban areas": Community energy supply systems and district heating

The building is part of the so called "Alte Giesserei", which is located in Winterthur, Switzerland. This is a pilot-project for intergenerational living, built in highest Swiss standard for eco-passive houses, including 200 kWp PV.
[Photo: SIR, Helmut Strasser]

In this Workshop the future role of community energy supply systems has been intensively discussed. In particular, community energy systems need energy planning at the community scale, with strong links to urban planning processes in order to be successfully implemented. On the other hand, so-called low-exergy systems can provide additional supply options of community energy systems and thus contribute to decarbonisation of heat supply.

"Community scale methods" is one of the five high priority themes within the Energy in Buildings and Communities Technology Collaboration Programme (EBC TCP), one of the Technology Collaboration Programmes (TCPs) of the International Energy Agency (IEA). Actually, eighteen research projects, so-called Annexes, are ongoing in EBC TCP. Three of them have a strong focus on communities and their energy infrastructure.

While it is commonly agreed that "cities are at the heart of the decarbonisation effort" (ETP 2016: Towards



Example of a community with heat and electric grids. The community includes low-energy buildings, of different size, and an industry.
[Photo: Fraunhofer IWES]

Sustainable Urban Energy Systems, IEA) it is rather unclear, how cities can fulfil their role. Analyses of planning processes within the EBC TCP Annex 63 have shown that energy planning and urban planning often are separated tasks. Thus, in this Annex, experts from 11 participating countries have developed 9 strategic measures, including several feedback loops with 22 involved cities. These measures include strategic activities at a city-scale as well as action-oriented activities when it comes to project development and implementation at the community scale.

Andreas Koch (EIFER, Germany) and Jens Freudenberg (Deutscher Verband für Wohnungswesen, Städtebau und Raumordnung, Germany) presented a practical view on energy and urban planning process. The example of Quartiers Anciens de Mulhouse in France, which was built between 1850 and 1910 and modernized and renovated within the last decade, highlighted the use of different instruments at different scale in the whole planning and implementation process. In case of decentralised energy supply in urban quarters, involvement of stakeholders is essential. Cooperation is seen as an opportunity (e.g. for

Photo of some of the audience at the workshop
[Photo: SIR, Helmut Strasser]

implementation of cost-effective solutions), but needs an equalization of interests by creating win:win:win-solutions for all of the involved parties.

In addition to the planning issues there is a need of further development of the heat and energy supply structures in our cities, since more than one third of the energy is used in buildings/cities. A group of experts from eight countries is focusing the work in Annex 64 on the demonstration of the potential of low exergy thinking at the community level as energy and cost efficient solutions in achieving 100 % renewable and GHG emission-free energy systems. The central focus of all considerations is thermal energy at different exergy levels. Electricity from a renewable fluctuating supply is discussed as a contribution to the heat and cold supply of a community if it is thermally stored (e.g. storage tanks or usage of the building mass) and used for heating or cooling purposes (e.g. heat pumps). Central challenges in achieving the objectives are the identification of the most promising and efficient technical solutions for practical implementation and aspects of future network management and business models for distribution and operation. So Sabine Jansen (Technical University Delft, Belgium) and Forrest Meggers (Princeton University, USA) presented the central approach of the application of exergy assessments in the built environment, whereas Anna Kallert (Fraunhofer Institute for Wind Energy and Energy System Technology, Germany) and Isabelle Best (University of Kassel, Germany) gave some practical insights from the implementation project, a development of a housing area where about 140 houses are getting their heat from a central group-coupled heat pump with a solar thermal backup and a low temperature district heating grid.

During the following discussion it turned out that there is a common agreement in the potential of optimized community energy systems, especially considering the cost efficient fulfilment of the set climate goals. But the implementation of community systems is challenging. In particular it has to be clarified who is the person/organization organizing and coordinating this process. Municipalities could play an important role. But due to reasons such as limited resources or lack of specific knowledge it is not evident that each municipality takes this role. Here a close cooperation with other local actors, such as utility companies, is needed. Additionally, (federal) governments play a key-role, e.g. in fulfilling a motivation - or facilitating - role, as well as in giving guarantees. Examples show that accompanying programs highly contribute to strengthen the role of municipalities and stakeholder-involvement. In addition to the public bodies, cooperation with companies is essential, since a large amount of investments are covered by them.

Everybody agreed that the support of the implementation process on a large scale is an important topic for future research. Within EBC TCP Annex 63, several planning processes and case studies have been analysed. As an important outcome there will be a self-assessment tool which guides municipalities through the relevant strategic measures. In EBC TCP Annex 64 innovative heat supply strategies are assessed and further developed based on the so-called low exergy approach. Case studies and examples show the practical application of this.

For more information about EBC TCP Annex 63:
www.annex63.org

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www.annex64.org

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Workshop summary on "Heat pumps in smart grids in smart cities"

Introduction to the subject and context for the workshop

Flexibility in the power grid and more smart use of the remaining gas grid is essential for the sustainability of our energy system. The term flexibility here indicates the degree to which producers, consumers and prosumers are able to react to the fluctuating supply on the electricity market so that the problem of shortages and surpluses of electricity can be handled appropriately. In the long run, grid expansions may remain necessary, but even reduced expansions offer considerable savings to the grid owner plus its grid-using customers, who always finally have to pay the bill.

Heat pumps and thermal storage (sometimes up to days of storage) offer a solution to the asynchronicity between sustainable energy production and the energy demand.

The heat pump is, after electric vehicles, the largest energy user in an urban area and thereby the device with the greatest impact if it is managed 'smartly'. In smart grid test projects, much attention is sometimes paid to managing all kinds of household devices in a 'smart' way, but their impact is much, much smaller. In Figure 1 you see how the three major electrical perspectives more and more become integrally entwined in functionalities.

By combining heat pumps with thermal storage, a relatively large user of electricity in the building can be applied as a regulatory instrument for the intermittent supply of energy.

If heat pumps are installed on a large scale in existing buildings, there is a potential grid load peak to be managed, especially in countries / regions that currently rely on natural gas as the sole energy carrier for heat and domestic hot water. The electricity grid in those areas has never been designed for the extra amount of power that is needed for operating heat pumps (here, hybrid heat pumps may be important, see IEA HPT TCP Annex 45). Those heat pumps need to be managed in a smart way, since they will have a large coincidence factor as well (when it is cold, they all switch on simultaneously). For example, if existing housing is refurbished down to Near Zero Energy Building (nZEB) level, the increase in grid loads are considerable.

Workshop summary

The workshop, within the context explained above, focused on five items:

1. Influence of NZEB in existing housing using a Low Voltage (LV) grid *(Liander)*
2. Heat pumps in smart grids, or smart heat pumps in grids? *(BDH)*
3. Using big data to plan green energy districts *(OverMorgen)*

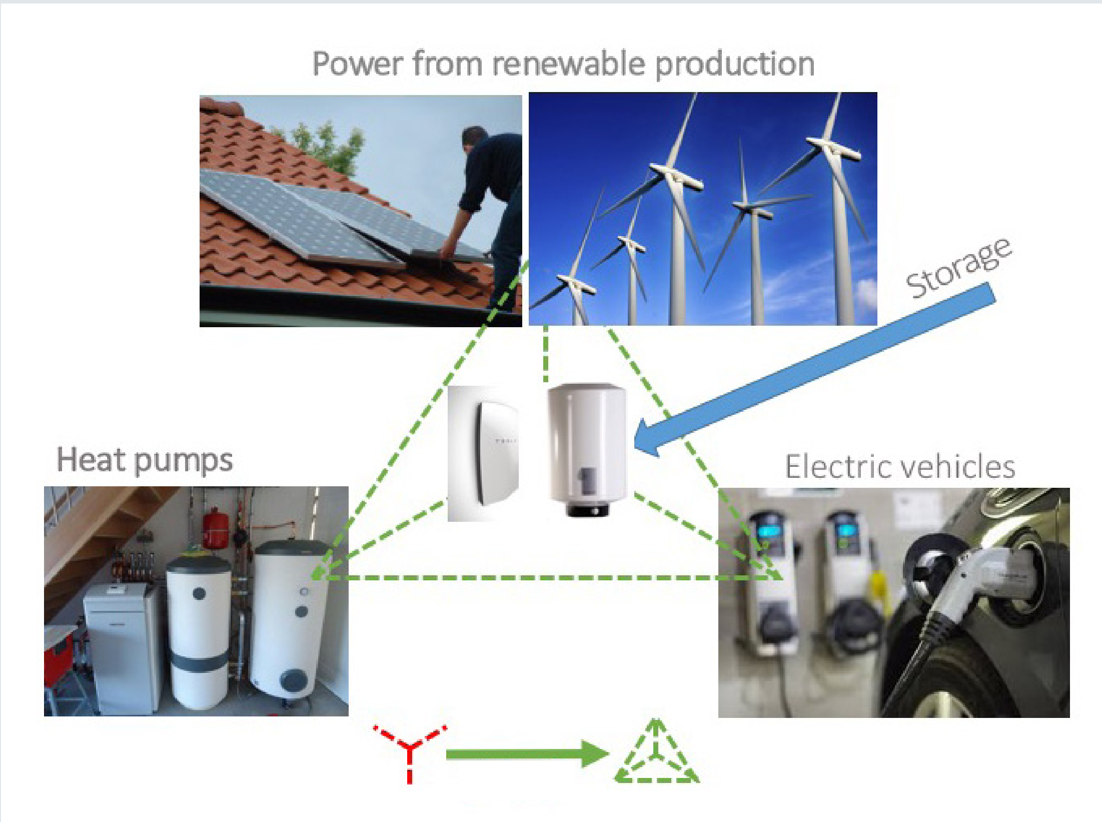
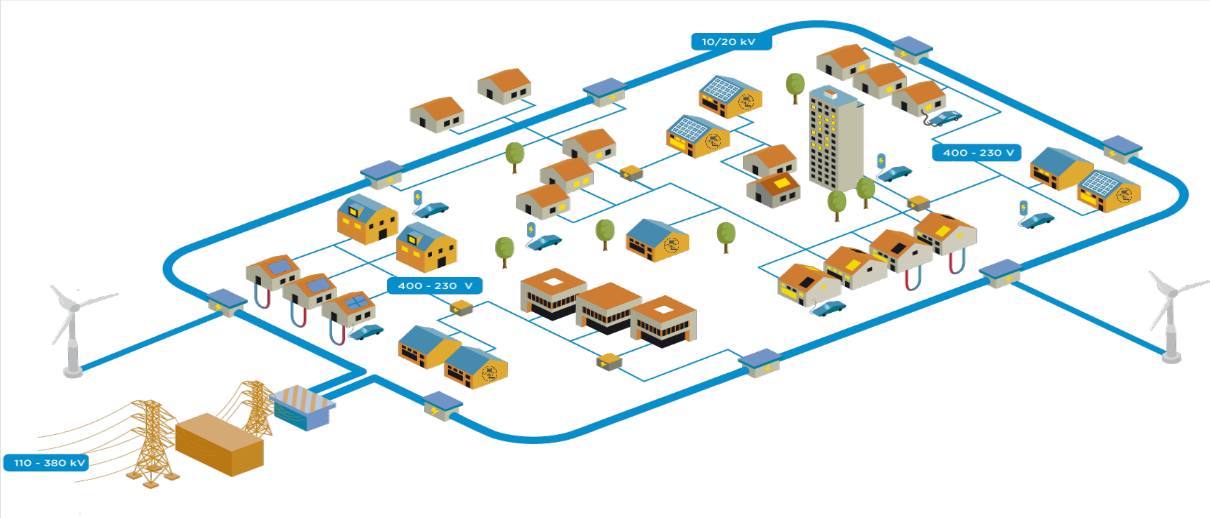


Figure 1. Integral approach of energy in smart grids.



The impact of nearly zero energy housing on the low voltage grid: Many new demands have impact on the electrical grid. [Source: Liander]

4. Flexibility with pooling of heat pumps *(Fraunhofer ISE)*
5. Hybrid HPs: a key appliance for a low carbon residential heat supply *(Dutch Gasunie)*

For each item a short and powerful presentation was made by one of the five speakers. After the presentations, five round table discussions were organised for the next hour, with one of the above-mentioned subjects for each table. The experience that the team of BDH made with the IEA HPT TCP Annex 42 expert panel meeting in October 2016 in Utrecht was recognised also here. We had lively, sometimes even enthusiastic and fierce, discussions about the subjects at each table, which was great.

We would like to share the outcome of this successful session briefly, item by item:

1. ***'Influence of NZEB in existing housing on LV-grid', by Jina Bhagwandas - Liander***
   The successful interaction between heat pumps and grids requires more of heat pumps than to be designed straightforwardly for connection to the grid. Grids need more intelligence from controls of the heat pump. But combined with the heat pumps, cooking peaks are also relevant. Distribution System Operators (DSOs) are sometimes in a somewhat more complicated position, and need to stay flexible in their option, because future developments are hard to predict.
2. ***'Heat pumps in smart grids, or smart heat pumps in grid?', by Peter Wagener - BDH***
   The increasing smartness of heat pump controls might answer the requirements of DSOs, but primarily the requirements of their customers. Will these controls act 'directly' or 'in-directly'? And which remuneration will become materialised for the heat pump user? And will we see autonomous controls or not? And at which value of flexibility, who will be paying for it?
3. ***'Using big data to plan green energy districts' by Gerwin Hop – Overmorgen***
   Our experience is not longer sufficient to foresee the impact of technology developments and innovation on energy transition. Interactive tools are required for scenarios and provision of facts and insights. Get a view on upscaling of renewables, but also ask yourself three questions if you apply for monitoring: what, for whom are you doing this, and why? All the models in the world cannot eliminate uncertainties, they are a constant factor in our context.
4. ***'Flexibility with pooling of heat pumps' by Danny Günther – Fraunhofer ISE***
   In the group of grid users, each party plays a different role. The DSO has strong responsibility in terms of grid stability and plays a conservative role. For example, the DSO owns the grid. But there is also the aggregator (a new market actor) whose business case consists of commercializing load flexibility, as a virtual business model, which can grow to ÜBER-like dimensions the moment the installed base of heat pumps reaches the critical mass. What kind of dimensions can pooling reach? And how will the end-user behave in this totally new setting? Does the grid stay 'un-smart', and is the intelligence with the aggregators and heat pump owners?
5. ***'Hybrid HP's: a key appliance for a low carbon residential heat supply?' - Nicolien van der Sar, Dutch GasUnie***
   Hybrid heat pumps, in countries with significant gas grids, are recognised as an important tool,

because they disconnect the use of renewable energy from deep renovation or heavy insulation. Consider it as a 'starter kit for renewables'. Also, the realistic pace of installing renewable energy solutions in domestic housing with all-electric options only is too slow to make us reach the climate change-combatting targets. So we need to use every available option which uses renewable energy. In addition, the roll-out of hybrid heat pumps gives installers and end-users in general some time to adapt to the use of this step in technology.

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Workshop summary on "The future of air conditioning"

On Monday afternoon May 15, 2017, a large group of participants from key global air conditioning regions gathered for a workshop entitled "The Future of Air Conditioning."

The objectives of the workshop were to:

- Discuss global perspectives on Air Conditioning (A/C) technologies;
- Understand the current status of global R&D efforts;
- Gauge interest in developing an IEA HPT TCP Annex on advanced A/C technologies;
- Suggest content and focus of potential Annex efforts - both technology gaps and programmatic vision.

The workshop began with a historical perspective on the evolution of air conditioning technologies and an introduction to the 2016 report published by the U.S. Department of Energy (DOE), entitled "The Future of Air Conditioning in Buildings" *. The report was used as a reference in international negotiations that led to the landmark 2016 Kigali Agreement to phase down the production and use of hydrofluorocarbon refrigerants.

Statistics were then presented which demonstrated the global importance of air conditioning and its environmental impacts, noting that stationary A/C systems account for nearly 700 million metric tons of direct and indirect CO_2-equivalent emissions annually. It is particularly noteworthy that energy consumption for space cooling is projected by the IEA to grow 4.4 times in non-OECD countries over the period from 2013 to 2050 versus 1.5 times in OECD countries. Clearly, rising incomes and greater access to A/C equipment in many developing nations, particularly in hot climates, will drive dramatic expansion of A/C use in the coming years, leading to substantial environmental consequences.

The attendees then discussed two potential pathways for the future of A/C. The first involves advanced vapor compression technologies with ultra-low global warming potential (GWP) refrigerants. An alternative path is to develop non-traditional, sometimes called "not-in-kind", cooling technologies.

The next portion of the workshop included presentations from key air conditioning regions around the world. The first one was an overview of non-traditional technologies, categorized into solid-state, heat-activated, gaseous, liquid-vapor, and miscellaneous technologies. Experts from Japan, China, Korea, the EU and the U.S. then presented summaries of the market trends, refrigerant policies, energy efficiency regulations, technology trends, and long term vision for air conditioning in each region.

* https://www.energy.gov/eere/buildings/downloads/future-air-conditioning-buildings-report

The speaker in the photo is Dr. Reinhard Radermacher (University of Maryland).
[Photo: Antonio Bouza]

These presentations were very valuable for participants in educating them about the diverse market conditions, regulations and technologies present in different regions.

The attendees then began discussions regarding the importance of advanced A/C technologies in addressing global energy and climate challenges. According to the electronic voting platform that was used during the workshop, approximately 90 % of the attendees feel that advanced air conditioning solutions are essential or very important to achieving global energy and climate goals and that air conditioning is an essential or very important topic in the context of other IEA initiatives. Approximately, the same number of participants supported the establishment of a new Annex on air conditioning technologies.

The participants then divided into smaller roundtable breakout sessions, where they discussed the status of research in their regions and developed key topics that should be considered in a new Annex. Potential topics include:

- Pre-competitive technology development partnerships to advance the technology readiness level (TRL) of non-traditional cooling technologies (e.g. magnetocaloric, thermoionic, thermoelastic, electrochemical compression, etc.) to the point that forward-thinking manufacturer partners could be encouraged to partner in bringing them to market;
- Better integration with nZEB or other "low energy" buildings, including system integration incorporating waste heat recovery for hot water or other concurrent heating needs;
- Independent control of latent and sensible cooling and tailoring systems for different climates (e.g. hot dry or hot humid).

Annex participants could focus on either advanced vapor compression cycle approaches with natural or ultra-low GWP refrigerants or on non-traditional cycle approaches.

It was agreed that international collaboration to advance A/C technology research is very valuable for improving the effectiveness and efficiency of R&D activities. The key next step recommended was to prepare a proposal for a new annex on advanced air conditioning technologies to be presented to the ExCo of HPT TCP for approval.

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USA

Workshop summary on "Ground source heat pump systems"

The workshop on GSHP (Ground Source Heat Pump) systems, arranged in conjunction with the Heat Pump Conference 2017 in Rotterdam on May 15th, had a special emphasis on “what we can learn from long-term performance monitoring”. The workshop's theme was aimed especially at providing direction to a new proposed HPT TCP Annex “Long-term performance measurement of GSHP systems serving commercial and institutional buildings.”

The workshop started with five short presentations by three researchers, one contractor and one real estate owner. Dr Signhild Gehlin of the Swedish Center for Geoenergy and Professor Jeffrey D Spitler spoke on two specific examples of monitoring projects in Sweden and in the USA. Both projects – one with a centralized GSHP system and the other with a distributed GSHP system – have COPs with unexpectedly high sensitivity to part load fraction. One of the systems also had a COP with high sensitivity to one single control setting, and had a heat pump reversing valve that was stuck for several months without being noticed. This was a system with a highly knowledgeable owner and maintenance staff and it had been commissioned by an expert team a few years before.

Dr Xiaobing Liu of Oak Ridge National Laboratory spoke on the monitoring of ten GSHP systems at buildings around the USA. He showed primary energy savings and reduced CO_2 emissions on the order of 1/3 to 2/3, and also showed that he had found ample opportunities for additional savings with improved design and controls.

Professor Jeffrey D Spitler (presenter in the image) and Dr Signhild Gehlin spoke on two specific examples of monitoring projects in Sweden and in the USA. [Photo: Signhild Gehlin]

Dr Henk Witte of Groenholland in Amsterdam spoke on the Dutch market for GSHP and pointed out that long-term performance monitoring is needed to help counter overly-conservative assumptions that limit the implementation of GSHP systems. Bjorn Kouwenhoven of the Dutch Railway System pointed out the need to be able to accurately quantify the investment economics before one can expect to succeed in installing large ATES (Aquifer Thermal Energy Storage) systems.

After the presentations the workshop attendants split into five groups to discuss questions that were mostly related to performance monitoring. The main points of the group discussions were that if further research and development can lead to lower costs, performance monitoring, and automated analysis, the following benefits can be foreseen:

- Identification of best system configurations;
- Better investment decisions and lower cost systems;
- Improved design of systems and system components;
- Improved controls, commissioning and fault detection;
- More efficient systems, lower energy consumption and lower emissions.

The proposed annex “Long-term performance measurement of GSHP systems serving commercial and institutional buildings” was discussed at the HPT TCP ExCo meeting on May 19th and was well received by the ExCo delegates. The legal text of the annex is now under final revision, and the annex will – if approved by the ExCo – start in January 2018.

Interested persons are encouraged to contact Dr Signhild Gehlin (signhild@geoenergicentrum.se) or Professor Jeffrey D Spitler (spitler@okstate.edu), and your national HPT delegate regarding the annex.

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Workshop summary on "Solar assisted heat pumps"

With the motto 'Heat Pumps and Solar Energy, a win-win combination', this workshop focused on increasing the synergies of the combination of heat pumps and solar energy (thermal and photo-voltaic) in a smart environment in order to get to an optimal application in the domestic market of new nZEB and existing buildings.

Stephan Harrison (Queens University, Canada) showed examples of how solar thermal can be combined with heat pumps. This technique already exists since decades. Solar assistance alleviates the problem with cold air and increases COP. A new hybrid collector is available, a glazed solar collector with a (backside) ambient air heat exchanger.

Brian Elmegaard (DTU, Denmark) described a combination of district heating with booster heat pumps in Copenhagen. It is not obvious which is the proper (sustainable) heat source. In general there is no promising business case for the booster heat pump. The costs of traditional systems (high temperature district heating) is less, despite its lower energy efficiency! However, the required flexibility and integration of intermittent renewable electricity paves the way for heat pump solutions.

Jacob van Berkel (Entry, Netherlands) pointed out that an uncovered solar collector effectively operates as a noiseless ambient air heat exchanger. A transparent, versatile and free calculation tool for solar is developed and used for system optimization and assessment of the energy performance. nZEB houses require small systems. In this case, small is beautiful and most cost effective.

John Braakman (ZON Energie, Netherlands) runs Energy Service Companies (ESCOs), every month a new one. Has had solar as a unique selling point for years. Special attention paid to the DHW distribution system: dual feed DHW distribution system gives reduction of heat losses (5 => 2 GJ/year). The next step with solar and heat pumps is Automatic Demand Response.

Krystyne Dawson (BSRIA, UK) pointed out that the hydronic heat pump market is growing by 8 % per year, but needs stronger value proposition for the end user to become real mainstream (see Figure 1). Combined heat pump and solar installations are attractive as low energy cost systems and as a low carbon solution. She concluded with two questions: Is it enough to rely on legislation and government fiscal incentives to develop this market further? Is it possible to match consumer interests with those of energy providers?

Lukas Bermann (Delta-EE, UK) noted that heat pumps and PV is about to become a must in new buildings (see Figure 2). The regulatory landscape needs to change to enable fully flexible and collective PV-self-consumption systems. Heat pumps will only be one part of the renewable driven power system, they have to interact not only with local PV, but also other systems, like battery storage, and other consumers in the home or the PV-self-consumption community.

Nelson Sommerfeldt (KTH, Sweden) expressed that Solar Thermal Assisted Heat Pump systems must be designed for simplicity, flexibility, and costs. Defining

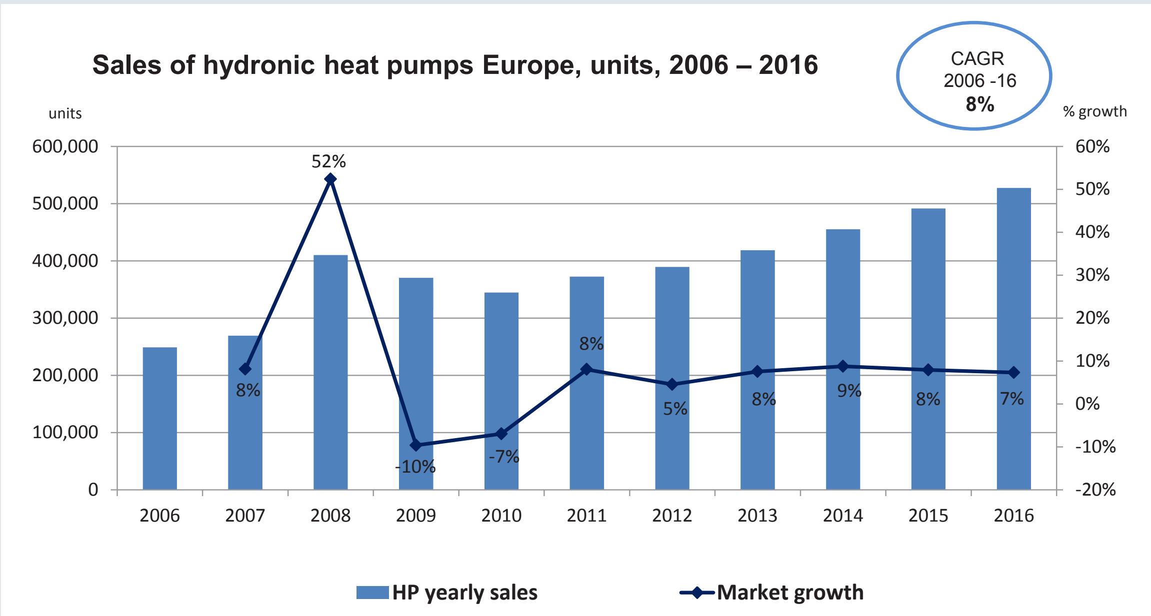

Figure 1. Sales of hydronic heat pumps in Europe during 2006-2016. Krystyne Dawson pointed out that the hydronic heat pump market is growing by 8 % per year, but needs stronger value proposition for end user to become real mainstream.
[Source: BSRIA based on data from 21 European countries]

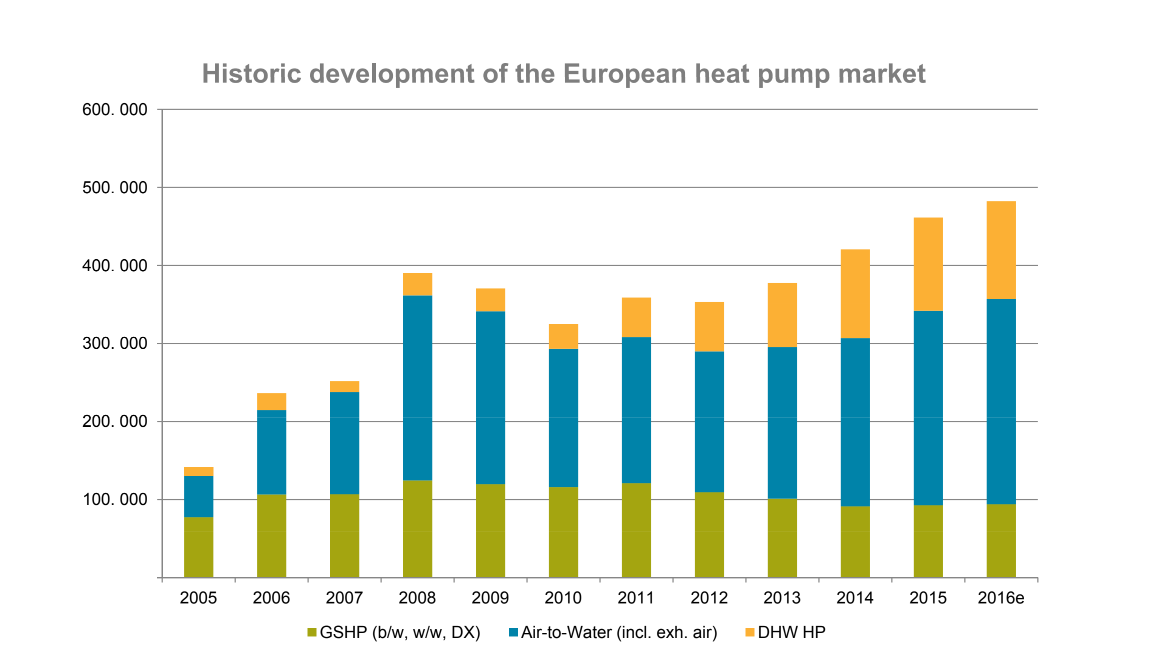

Figure 2. HP market - driven by regulations, held back by energy costs. Historic development of the European heat pump market.
[Source: EHPA]

system performance is not trivial, it depends on the boundary. For an optimising approach, Key Performance Indicators would be:

a. SPF4 (as described in the SEPEMO project);
b. Self consumption;
c. Solar fraction;
d. PVT efficiency and costs;
e. Store efficiency and costs.

In the ensuing discussions, it was concluded that:

1. The heat pump market is hindered by the increasing price of electricity;
2. Electricity market and pricing is volatile and may develop into a flat rate system;
3. There is synergy between solar and heat pumps (without heat pumps, solar thermal probably has no future);
4. The market is more interested in the PV-heat pump combination;
5. The business case for solar heat pumps very much depends on the (national) conditions, pricing, and regulations.

Solar & HP is a win-win, provided that costs decrease!

JACOB VAN BERKEL
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Summary reports from the 12th IEA Heat Pump Conference 2017 in Rotterdam

Here follows some personal summary reports of the presentations from the different focus topics during the 12th IEA Heat Pump Conference (HPC 2017) in Rotterdam.

Summary of the HPC 2017 GSHP presentations

Ground Source Heat Pumps (GSHP) are a significant part of the heat pump market around the world, and a fair number of GSHP-related papers were accepted for HPC 2017 in Rotterdam. A full GSHP track, with fifteen oral presentations, was held during the Thursday sessions. In addition to this, a handful of GSHP-related presentations appeared in other sessions. Sixteen GSHP related posters were presented in the poster exhibition area.

Quite naturally, as the conference was held in the Netherlands, one of the GSHP sessions was dedicated to aquifer thermal energy systems (ATES). The four presenters gave insights into the Dutch ATES market, regulations and development. Martin Bloemendal presented simulations of how to optimize ATES establishments in an area so that the available energy resources are shared fairly between buildings. Robert Jan Buunk described the concept of Distributed ATES (DATES), where several buildings share a common network of ATES wells, resulting in lower costs and increased flexibility for future changes in the connected buildings.

Brian Carey, from New Zealand, shared experiences from the rebuilding of Christchurch. [Photo: Signhild Gehlin]

Brian Carey, from New Zealand, shared experiences from the rebuilding of Christchurch, which is situated on top of a large aquifer. The earthquake in 2010, and the severe aftershock in 2011, left 60 % of the buildings demolished, and the cost of restoration has reached 40 billion NZD (30 billion USD). However, ATES wells were mainly unharmed following the earthquake and, in the rebuilding of Christchurch, the local government has accelerated the process for ATES system approval to facilitate the establishment of new ATES systems in the area.

The GSHP market development was discussed from different perspectives by three presenters. Burkhard Sanner illustrated the use of the ground as a source for heating and cooling, starting in Cappadocia and New Mexico several thousand years ago and ending with the newly started EU-project GeoCond, aiming to develop advanced materials and processes to improve performance and the cost-effectiveness of GSHP systems and underground thermal energy storage.

Denis Tanguay presented a somewhat discouraging view of the North American GSHP market, claiming that the market decline after 2009 was a consequence of the gas price development combined with the termination of the American subsidy program for residential GSHPs in 2012.

Denis Tanguay, from Canada, presented a somewhat discouraging view of the North American GSHP market. [Photo: Signhild Gehlin]

Thomas Nowak gave a more positive view of the European heat pump market in his talk, based on EHPA statistics. GSHP sales have been very even, with around 100 000 units sold per year during 2014-2016.

Several interesting field studies and monitoring projects were presented. Most of these studies concerned residential buildings, typically single-family size. Marek Miara's keynote presentation on ten years of monitoring of new-built and retrofitted houses clearly showed that GSHPs have higher SPFs (on average 3.3 for older buildings and 3.9 for newer buildings) than air-to-air heat pumps (average 2.6 for older buildings and 2.9 for newer buildings), and that newer GSHPs show significantly higher SPFs. His overall conclusion was that heat pumps work well in general, provided they are properly installed. Carsten Wemhoener, Hussain Kazmi and John Clauß also presented studies on single-family houses, emphasizing a combination of photovoltaics, domestic hot water production and NZEB, respectively. Moonis Ally from ORNL presented a study on system efficiency based on exergy and energy analysis of space conditioning and water heating for a single-family building.

A couple of non-residential monitoring projects were presented. Professor Jeffrey D Spitler presented results from the long-term performance monitoring of the ASHRAE Headquarters building in Atlanta, where a ground source heat pump system and an air source heat pump system were compared. The study also showed a high sensitivity in the system for single controls and stand-by energy for control boards.

Renato Lazzarin presented the performance monitoring of a school building in Italy. The building was equipped with absorption heat pumps, solar collectors and gas boilers for back-up. However, during its first year the solar system had problems, leading to the maintenance staff disconnecting the solar system, and leaving the system to run more or less entirely on gas. His conclusion was that careful monitoring, as well as education of the maintenance staff, is crucial.

Modelling and evaluation of control systems and strategies were other themes for several of the presentations, and GSHPs combined, for example, with solar collectors and photovoltaics, were the subject of some studies.

Monika Ignatowicz gave an interesting presentation on the different secondary fluids that are used in closed-loop GSHP systems across Europe, and their respective properties. The most commonly used secondary fluids used in Europe are various blends with ethyl alcohol, typically with some denaturing agents added. She showed that commercially available ethyl alcohol with denaturing agents has better properties from a heat transfer point of view than pure ethyl alcohol.

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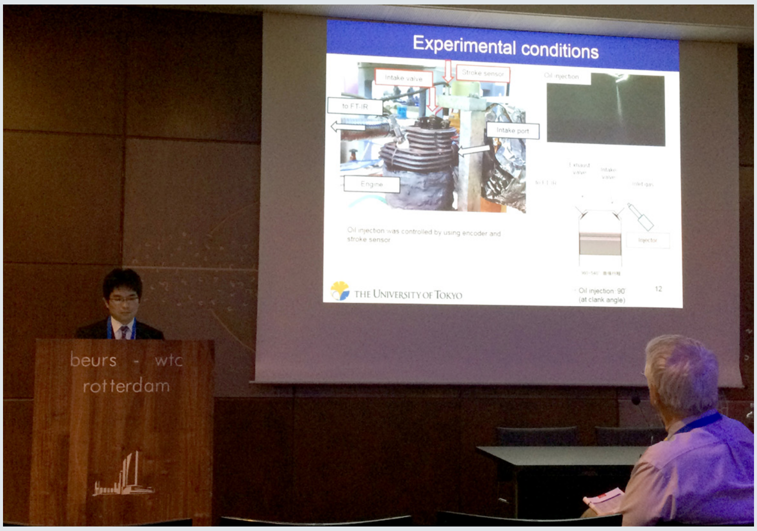
Summary of some Conference presentations

I am honoured to give my impression of the energizing days during the 12th IEA Heat Pump Conference in Rotterdam. I mainly followed the *Air Conditioning & Industry Track*, with a short deviation to the *Cold Climates* on Wednesday and the *Technology Developments* on Thursday - a wealth of very well prepared and presented contributions.

After an inspiring ***Welcome Address***, we were very positively guided into the ***topical plenary session*** with the message of the European Commission: "**Heat Pumps are part of the story!**". A study of *the future role of heat pumps* in Germany shows a domination of electrically driven heat pumps to reach the -85 % CO_2 emission target in 2050, assuming that there will be no major imports of renewable electricity. The *transition to lower GWP refrigerants* under the Montreal Protocol and U.S. Environmental Protection Agency was also presented in the introductory plenary session. The 2016 amendment (Kigali) sets a gradual phase down schedule for high-GWP HFCs. As many of the new replacement refrigerants are flammable, efforts are currently underway to amend the current safety standards for a safe and extensive use in the next years. A wide range of projects using higher efficiency heat pump systems have been initiated and implemented in Indonesia, Mongolia, Thailand and Vietnam under the Joint Crediting Mechanism (JCM) scheme, which was presented in the final plenary contribution by the University of Tokyo.

During the evaluation and development of ***air-conditioners*** using low GWP refrigerants it was shown that typical parameters, such as COP, are not enough to compare refrigerants – it is suggested that "work" equivalent to "pressure loss" is used. Furthermore, performance evaluations should be carried out at constant capacity instead of constant compressor speed. Using *machine learning algorithms*, a steady state, no-fault, reference model of heat pumps has been developed. The compressor curve method and the refrigerant enthalpy method, to estimate the performance of VRF multi-split air conditioners for commercial buildings, have been tested. A high measurement accuracy could be reached; however, simplifications are necessary to improve usability. In another contribution, the effects of piping on the heating performance have been investigated by utilizing a validated steady state model. Lengthening of the horizontal pipe will reduce the COP even under part load condition. For the use of small diameter copper tubes, there are advanced prediction correlations for simulation using different refrigerants and tube enhancements available. Furthermore, manufacturing techniques have been improved to allow for improved throughput and reliability.

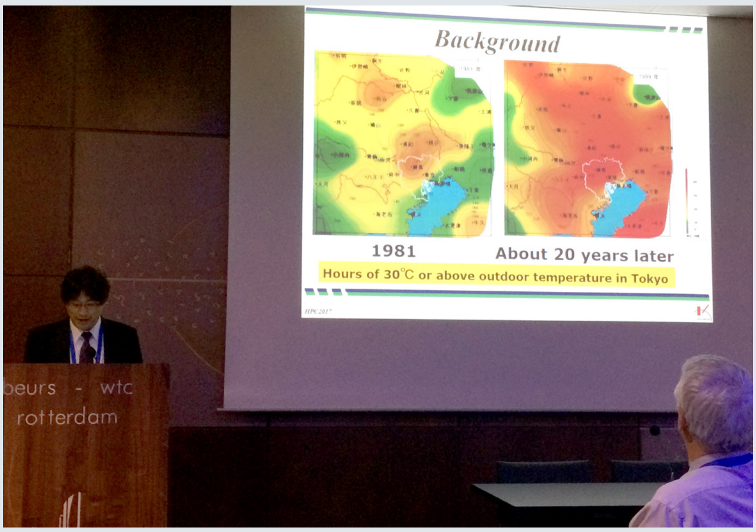
Smaller diameters help reduce the refrigerant charge, which is especially important when considering cost or flammability. *Port level maldistribution* has a significant negative impact on heat exchanger performance in microchannel heat exchangers. A variable port size profile has been suggested to improve the refrigerant flow distribution. For low ambient temperatures, an electric vehicle air conditioning using the binary mixture R-1234ze/R-32



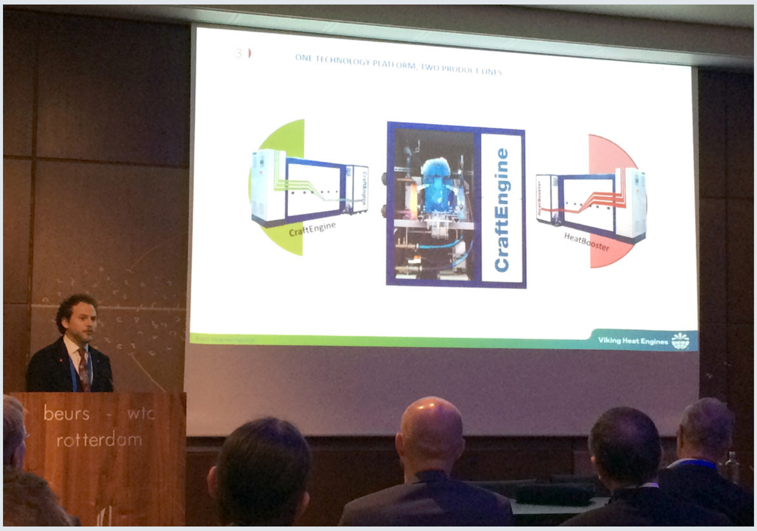
A compressor explosion accident during pump down operation was the motivation to experimentally reproduce and investigate the phenomenon of diesel combustion.
[Photo: Christoph Reichl]

has been designed. Switching from single stage to vapour injection mode, the capacity and heating COP might increase. A new component model-based steady state vapour compression system solver has been developed and validated, capable of handling arbitrary system configurations with more than 500 components and multiple (user-defined) refrigerants. A *compressor explosion accident* during pump down operation was the motivation to experimentally reproduce and investigate the phenomenon of diesel combustion. The flammable range was found to depend on both the lubricating oil used and the refrigerant. Finally, against the background of a significant increase in hours above 30 °C outdoor temperature in Tokyo in the last decades, fundamental experiments for a promising *green roof building air-conditioning system* were presented.

The performance of off-design operation of a compression-absorption heat pump based on ammonia-water started the ***session on industry***. Very high COPs using *inter-cooler heat* could be reached. *High temperature heat pumps* have been investigated using theoretical and experimental methods, showing subcritical cycles with a heating COP of 4.0. The highest COP for a single-stage compressed and two-stage compressed extraction cycle for heat recovery was attained with R-1234ze(Z). Another presentation on the performance



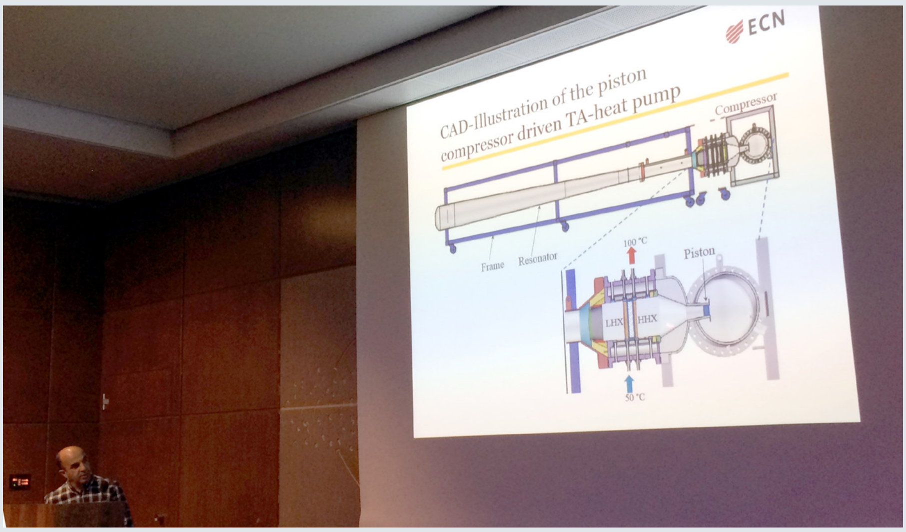
Against the background of a significant increase in hours above 30 °C outdoor temperature in Tokyo in the last decades, fundamental experiments for a promising green roof building air-conditioning system were presented.
[Photo: Christoph Reichl]



High temperature heat pumps have been investigated using theoretical and experimental methods, showing sub-critical cycles with a heating COP of 4.0. A novel working fluid, HFO-1336mzz(E), for use in waste heat recovery applications was also presented.
[Photo: Christoph Reichl]

simulation and exergy analysis for a multi-stage compression, high temperature heat pump using this refrigerant in a waste heat recovery process was given. The results indicated a three stage compression system to be the most favourable in view of exergy efficiency in this application.

A novel working fluid, HFO-1336mzz(E), for use in waste heat recovery applications was presented. The measured performance was presented in a second contribution, which also classified HFO-1336mzz(E), with a GWP of 2, as an A1 refrigerant according ASHRAE 34. A *centrifugal chiller and heat pump* based on the low GWP refrigerant R-1233zd(E) attained even better performance than its R-134a version. Twenty different cycle configurations have been investigated with different means of superheat preparation. Based on the findings, a single state, high temperature, heat pump with R-600 as refrigerant has been designed and is currently under construction. In another presentation, test results from a R-600 pilot 160 kW heat pump were shown. Furthermore, an ejector heat pump design, based on butane, was presented, increasing the COP by 25 %. Some more *exotic systems* were also presented: to recover part of the invested energy during the liquefaction of LNG, a system including an *ethylene heat pump* and a cold distribution network was proposed. A *rotational heat pump* process was presented, based on a *joule process*, which is commercially available, the next step being to increase the capacity to 2 MW. For a distillation column, the development of a *thermoacoustic*



A thermoacoustic heat pump was presented using a reciprocating piston compressor.
[Photo: Christoph Reichl]

heat pump was presented using a reciprocating piston compressor. As a summary, many qualities and a **bright future for industrial heat pumps** were emphasized, as stated in the conclusion of the second keynote lecture.

The ***cold climate session*** started with a critical review of turbocompressors for domestic heat pumps giving an overview of the current state of the art. *Dynamic gas-lubricated bearings* have been suggested as the most promising technology for small scale turbomachinery. *Frosting* was discussed in several sessions; frost layer growth was investigated under forced convection between plates with concave and convex shapes - simulation results of frost layer growth, weight, the ability of density to predict the experimental results within an error band of 10 %. The use of a *desiccant-coated heat exchanger*, to dehumidify air before entering the evaporator, has been investigated, in order to prevent air-source heat pumps and refrigerators from frosting. The performance of air source heat pumps with *variable speed compressors* has also been tested: space heating loads down to an outdoor temperature of -25 °C could be met in the laboratory by a ductless air source heat pump.

A potential analysis of heat transfer surface enlargement, by using metal wire structures, started the ***session on technology and developments***. An increase in heat transfer coefficients by a factor of ten can be reached, with low hydraulic performance, however, with accompanying high thermodynamic gain. An evaporator coil for multiple air-borne sources (ambient air and exhaust air in the case presented) has been designed with regard to optimum size, manufactured and tested. Maldistributions on the air and refrigerant sides have been included in the configuration. *Acoustic in heat pumps* was the focus of two presentations: *Transient Acoustic Signatures*, with special focus on icing and defrosting, were analysed in the GreenHP project. Flow distributions could be measured using probe and optical measurement techniques and were compared to simulation results. The horizontal heat exchanger also allowed for a local measurement of the quantity of ice. A small increase in sound pressure level and changes in the frequency content were detected during icing. In another presentation, an *improved method for measuring heat pump noise* was presented, as capacity control has a clear impact on time variant noise levels. The strong dominance of low frequency noise can be detected in some cases, suggesting separate evaluation methods for air and ground source units. In the final contribution, the seasonal performance of heat pumps was determined using a *hardware-in-the-loop test bench* setup.

I also highly recommend taking a look at the papers presented in the poster sessions during the conference, which have not been covered in this track summary due to the lack of space. Many thanks to the organizing committee for this great conference and the "on-the-spot" overarching theme: "**Rethink Energy – Act Now!**"

CHRISTOPH REICHL
AIT
Austria

Summary of the HPC 2017 presentations about heat pumps in industrial applications

Climate change and the COP21 agreement's demand for energy efficiency and CO_2 reduction, where industrial heat pumps can play a major role, were a common introduction in the industry track at HPC 2017, in Rotterdam. In particular, heat pumps can contribute to the decarbonisation of industry by upgrading low-value waste heat and replacing natural gas boilers.

The message was to hurry up and start integrating heat pumps with utilities in industry now. To achieve the successful, energy-efficient integration of heat pumps into industrial processes, pinch analysis can be used. The speakers focused on using pinch analysis, because the results show where to integrate heat pumps, i.e., across the pinch point. Pinch analysis was presented during both the initial workshop, about industrial heat pumps, and in the industry track. Furthermore, some available tools were mentioned, such as PinCH 3.0, which includes time dependent processes, such as batch processes and energy storage.

Although there is a lot of low value waste heat available, high investment costs are often mentioned as a barrier to industrial heat pumps. The industry track included presentations of technologies with Return On Investment (ROI) times in the range of 2-5 years, or even shorter. Since energy is not the core business for industrial companies, alternative business models were also proposed such as using ESCOs, avoiding the need for additional staff for heat pump operation. A specific business model was presented for the High Lift heat pump case at the TINE dairy, where the heat pump manufacturer owns the heat pump and buys both the district heating used as heat source as well as the electricity and then sells the energy via a minimum outtake per year contract.

Several industry cases as well as the industry perspective were presented during the initial workshop on future industrial heat pumps. The workshop was well-attended and its programme had many short presentations ending with a few yes/no questions to the audience and thus resulting in interesting comments or discussions. The workshop ended with discussions on alternative energy sources, where solar was accepted and the views regarding biomass were split depending on country. Regarding heat pumps, a need for greener electricity was mentioned. The conclusion was that both low and high temperature heat pumps are needed and even higher capacities are desired.

The presentations of technology development in the industry track showed many alternatives to choose from. For example, the high temperature heat pump from Viking Heat Engines was developed based on their ORC technology and works with the refrigerant HFO-1336mzz(Z). Evaluation results showed a COP of roughly 4 for delivering heat in the range 80-160 °C using waste heat in the range 30-110 °C. The development of a new, centrifugal, high temperature, heat pump by Mitsubishi, which uses R-1233zd(E), was presented as a result of industry's

[Photo: Rob Niemantsverdriet]

requirements. Their future focus is on developing a heat pump with a low GWP working fluid for heating pressurized water to 200 °C by 2023.

To speed up the process of heat pump integration in the industrial sector, good examples are also needed. A few real installations and demonstrations of high temperature heat pumps were presented, where most of the heat pumps were placed in a separate machine room or container due to space limitations or, in case of flammable working fluid, as a way to make them ATEX proof. When industry representatives gave their perspective on industrial heat pumps, several requested or presented heat pump integration for steam production.

For example, in the TINE dairy case, the heat pump from Olvondo works with a Stirling cycle and helium (R-704) and it can produce 10 bar steam from 105 °C heated water, by using district heating at 80 °C as the heat source. For a paper industry case, test results from an R-600 pilot heat pump were presented by ECN showing that the heat pump can produce steam at 1.5 bar by using 60 °C waste heat. The pilot heat pump was connected to a paper drying process at Smurfit Kappa.

Research institutes, universities and manufacturers are involved in the ongoing development of the technology for industrial heat pumps and, therefore, industrial potential studies were included in several presentations, including various system combinations and designs. One presentation included the development of high temperature heat pumps at Graz University, where calculations and simulations led to the choice of R-600 (butane) as the working fluid and a one stage cycle for prototype construction and testing in the next phase. Another presentation showed combinations of chillers and heat pumps for the energy-efficient cooling of data centres, including examples of installations in Norway. A case study focused on variations in the heating and cooling demand for a series of batch reactors at DOW, where simulations showed how the excess heat from batch processes could be utilized by adding storage and Mechanical Vapour Recompression (MVR). Another case study investigated the benefits from using humid exhaust gas as the heat pump's heat source in paper mill, laundry and production processes.

A number of presentations focused on heat pumps for drying purposes, i.e. for spray drying in the food industry and lumber drying. For example, an analysis of high temperature heat pump integration in the dairy industry for spray drying purposes, where simulations made to find a working fluid to match the process showed there was potential to preheat the drying air. Testing an MVR prototype for steam drying using water as working fluid was presented by SINTEF, where the focus was on reducing the specific energy consumption by 75 %. Taking the market conditions in Germany as the driving force in finding a cost-effective design, the ROI of the tested turbo-compressor was only 1 year.

JESSICA BENSON
RISE - Research Institutes of Sweden
Sweden

Four awardees recognized in the 2017 Ritter von Rittinger Award

[Photo: Rob Niemantsverdriet]

In a ceremony held at the conference banquet at the 12th IEA Heat Pump Conference in Rotterdam, the Netherlands, the IEA's Technology Collaboration Programme on-Heat Pumping Technologies (IEA HPT TCP) has given the prestigious Ritter von Rittinger Award to four awardees.

The Ritter von Rittinger award is presented triennially in conjunction with the international IEA Heat Pump Conference to individuals and teams who have distinguished themselves through outstanding contributions to the advancement of international collaboration in research, policy and market development and applications for energy-efficient heat pumping technologies that result in environmental benefits. The award is named after Peter Ritter von Rittinger, an Austrian engineer credited with the design and installation of the first practical heat pump system at a salt works in Upper Austria in 1856. The 2017 Rittinger awardees are Professor Eckhard A Groll, USA; Professor Alberto Cavallini, Italy; the ORNL Building Equipment Team, USA; and Professor Per Lundqvist, Sweden.

Professor Eckhard A Groll

Professor Eckhard A Groll, Reilly Professor of Mechanical Engineering at Purdue University, USA, teaches technical thermodynamics. His research focuses on the fundamental thermal sciences as applied to advanced energy conversion systems, components, compressors and their working fluids. His research efforts involve the development of experimental facilities to conduct performance testing, and the creation of detailed system or component models for analyses and optimization. Prof. Groll was recognized for his exceptional achievements and leadership in all three aspects of the faculty profession of research, teaching and service.

Professor Alberto Cavallini

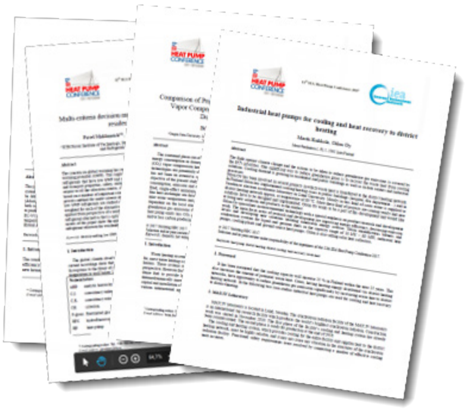
Prof. Alberto Cavallini is Professor Emeritus and former full professor of Energy Science with the Engineering School of the University of Padova, Italy. Prof. Cavallini was highlighted for his research and publications in the fields of enegy management, heat transfer (with special emphasis on boiling and condensation heat transfer with refrigerants), refrigeration and air-conditioning with particular reference to problems related with the refrigerant substitution issue. During his career, he has published more than 300 scientific and technical papers and books, and is also a member of the advisory board of the International Journal of Refrigeration, one of the European editors of the International Journal of Transport Phenomena and former associate editor of the International Journal of HVAC&R Research.

ORNL Building Equipment Team

ORNL Building Equipment Team (ORNL BERG), Oak Ridge National Laboratory, USA, was recognized for their contribution to the development of high efficiency heat pumps of all types, including electric, sorption, gas-fired, cold climate and ground-coupled for over 40 years. They have won numerous awards and been recognized for their groundbreaking research, which has included modeling (ORNL Heat Pump Design Model; used by manufacturers and academia), design, development, demonstration, and market introduction. In addition, the ORNL BERG has since the 1980's been very active in the IEA's Technology Collaboration Programme on Heat Pumping Technologies (HPT TCP).

Professor Per Lundqvist

Professor Per Lundqvist, Professor at KTH Royal Institute of Technology, Sweden was awarded for his international impact in the realm of heat pump development, which maintains a multifaceted approach to the technology's advancement, focusing both on market dynamics and technical progress. In addition, he is also co-author of the Intergovernmental Report on Climate Change (IPCC) on the influence of refrigerants on the global climate and has served as President of Commission E2 in the International Institute of Refrigeration, with focus on research, education, and international collaboration on climate issues related to refrigeration and heat pump technology.



Order Full Papers from the 12th IEA Heat Pump Conference

You can now order **all** Conference Proceedings (Full Papers) from the 12th IEA Heat Pump Conference in Rotterdam.
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Best poster at the 12th Heat Pump Conference

At the 12th Heat Pump Conference in Rotterdam, the Technology Collaboration Programme on Heat Pumping Technologies awarded ***Zuo Cheng, Wenxing Shi, and Baolong Wang*** for the best poster entitled "*Vapor injected heat pump using non-azeotropic mixture R32/R1234ze(E) for low temperature ambient*".

The authors represent Beijing Key Laboratory of Indoor Air Quality Evaluation and Control, Department of Building Science, Tsinghua University in Beijing, China.

You can read the paper - see page 40 - the source to this poster and short information about the authors on page 49.

BEST POSTER
HPC 2017

Marion Bakker, Vice-Chair National Organizing Committee (NOC), and Per Jonasson, Chairman International Organizing Committee (IOC) presenting the best poster. [Photo: Rob Niemantsverdriet]

Winner of the Best Student Award

On Wednesday, May 16, there was an afternoon session on the Daikin Best Student Award at the 12th IEA Heat Pump Conference 2017 in Rotterdam. In this session, organized by Daikin Europe, the five students who were the nominated candidates for the award gave short presentations of their heat pump-related projects and their research achievements.

Five speakers from five different universities were nominated candidates for the Daikin Best Student award:

- Mounier Violette from the École Polytechnique Fédérale de Lausanne in Switzerland presented "*ORC driven HP running with gas supported turbo-machinery – potential and optimization*" (O.4.7.2);
- Yaodong Tu from the Shanghai Jiao Tong University in China presented "*Comfortable and high-efficient desiccant-enhanced direct expansion heat pump*" (O.1.4.3);
- Monica Ignatowicz from the KTH Royal Institute of Technology in Sweden presented "*Different ethyl alcohol based secondary fluids for GSHP in Europe*" (O.4.1.1);
- Benjamin Zühlsdorf from the DTU Mechanical Engineering Technical University of Denmark in Denmark presented "*Heat Pumps using zeotropic working fluids mixtures*" (O.3.9.3); and
- Tuomo Niemelä from the Aalto University in Finland presented "*Comparison of energy performance of simulated and measured heat pump systems in existing multi-family residential buildings*" (O.1.5.4).

After the five presentations had been given, the audience and the jury voted for the best heat pump related project. The winners of the Daikin Best Student Award were announced at the Conference dinner on the Wednesday evening in the Laurens Church.

First prize – the honour and €500 - was awarded to ***Yaodong Tu***, from the Shanghai Jiao Tong University in China, who presented a desiccant-enhanced, direct expansion heat pump (DDX HP) based on a water-sorbing heat exchanger by means of a desiccant coating, which exhibits an ultra-high COP value of more than 6, without sacrificing any comfort and compactness. The efficiency is double when compared to current standard room air conditioners. This new approach opens up the possibility of designing a zero energy building (ZEB) with a DDX heat pump powered by solar PV.

Second prize – the honour and €250 - was awarded to ***Monica Ignatowicz***, from the KTH Royal Institute of Technology in Sweden, who presented an investigation into the performance of commercially available alcohol blends used for ground source heat pumps (GSHP) in Europe, in terms of pressure drop and heat transfer in the borehole heat exchangers (BHE). The results show that the most commonly used product in Sweden (EA18+PA1.6+BA0.4) has the best characteristics, in terms of higher heat transfer (up to 10 %) and lower pressure drop (up to 2.7 %), among the different commercial products used in Europe.

Second prize awardee Monica Ignatowicz to the left of Patrick Crombez (General Manager Heating and Renewables, Daikin Europe) and first prize awardee Yaodong Tu to the right.
[Photo: Rob Niemantsverdriet]

TripleAqua winner of the Dutch Innovation Award

Menno van der Hoff, Manager Research & Development HVAC at Uniechemie, was very proud to receive the Dutch Innovation Award for the Dutch innovation TripleAqua.
[Photo: Rob Niemantsverdriet]

There are many Dutch companies developing, testing and launching products and services in the field of heat pump technology. The Netherlands are being innovative with this technology in different fields: building houses, offices, horticulture and industry. The Eneco company supports the companies creating these innovations and shows its appreciation by awarding the Dutch Innovation Award.

Three promising nominated candidates – OSH, Klimaatgarant, and TripleAqua – pitched their innovations during the Wednesday lunch break, May 16, in the main Conference Exhibition Hall at the 12th IEA Heat Pump Conference 2017 in Rotterdam. An international jury selected the Dutch innovation that has had the largest impact, and the winner - TripleAqua – of the Dutch Innovation Award was announced at the Conference dinner on the Wednesday evening in the Laurens Church. Menno van der Hoff, Manager Research & Development HVAC at Uniechemie, was very proud to receive the prestigious award for TripleAqua.

The Dutch innovation TripleAqua, fully developed in the Netherlands by the Beijer Ref Dutch subsidiary, Uniechemie, is a patented three-pipe water heat pump that can store surplus heat or cold internally for reuse later. TripleAqua, designed for external installation, works with the natural refrigerant propane (R-443A), and works both in cooling and/or heating mode, always in the efficient counter-current operating mode. The fully water-based system can be combined with all types of sustainable energy and can have significant effects for reducing energy and emissions in new and existing buildings, such as hospitals, schools, hotels, offices, supermarkets, etc.

More information: www.tripleaqua.com

Next IEA Heat Pump Conference

Jeju Island [Photo: Republic of Korea]

The 13th International Energy Agency Heat Pump Conference – HPC2020 – will be held on May 11-14, 2020, at the Ramada Plaza Hotel Jeju on the Jeju Island, South Korea. The theme for the conference will be "Heat Pumps – Mission for the Green World" showing the potential countermeasures against global warming.

The organizing committee for the conference will be The Society of Air-conditioning and Refrigerating Engineers of Korea (SAREK) and Prof. Min Soo KIM (Seoul National University).

All participants are welcome to share a series of up-to-date presentations on technology, recent developments, and market and policy-making strategies on heat pumps. First announcement and Call for papers is coming soon.

Jeju Island is worldwide famous for its beauty and uniqueness of nature. You will also enjoy a vast variety of sightseeing tours in the midst of enchanting environment of the World Natural Heritage.

Jeju Island [Photo: Republic of Korea]

Catalysing energy technology transformations

John Dulac, France

The global energy system is moving closer to a historic transformation, driven by technological progress and evolving political, economic and environmental issues. Energy technology progress continues to modify the outlook for the energy sector, driving changes in business models, energy demand and supply patterns as well as regulatory approaches. Yet, the current trajectory falls short of meeting long-term ambitions for a sustainable energy system. Today's critical challenge is to ensure the positive momentum of the energy sector transformation and speed up its progress.

For the first time, the International Energy Agency (IEA) looks at how far clean energy technologies could move the energy sector towards new climate change ambitions if technological innovations were pushed to their maximum practical limits. This year's ***Energy Technology Perspectives 2017*** (ETP 2017) analysis shows that while needing policy support beyond anything seen to date, this could result in greenhouse gas emission levels that are consistent with the mid-point of the target temperature range of the global Paris Agreement on climate change.

ETP 2017 also indicates that regardless of the pathway chosen for the energy sector transformation, policy action is needed to ensure that multiple economic, security and other benefits to the accelerated deployment of clean energy technologies are realised through a systematic and co-ordinated approach.

Accelerated deployment of clean energy technologies could step up the low-carbon transition beyond an already very challenging 2 °C pathway, with potential for energy sector carbon dioxide (CO_2) emissions to be reduced to net zero by 2060. However, the shift to a below 2 °C pathway would require a fundamental and immediate shift in the current level of energy and climate policy action across both energy supply and demand sectors.

The ETP 2017 beyond 2 °C scenario (B2DS) considers how an ambitious energy sector transformation could be achieved, confirming that early and co-ordinated action is critical to meeting long-term energy and climate policy objectives at affordable costs. Among the immediate policy responses important in avoiding the lock-in of CO_2 emissions are: the phase-out of fossil fuel subsidies; measures to actively discourage or ban new subcritical coal-fired power generation while rapidly phasing out inefficient coal generation; and promoting investment in best available technologies and energy efficiency measures across all end-use sectors.

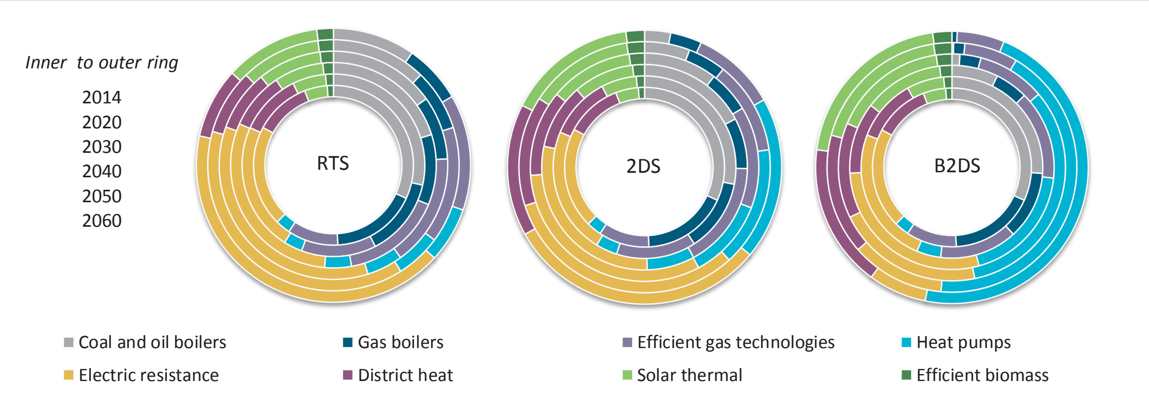
Energy Technology Perspectives 2017 (ETP 2017), available online at www.iea.org/etp2017. [Source: IEA]

In parallel, supporting development and deployment of low-emissions technology options, including the integration of variable renewable energy options, is needed to ensure that growing energy demand is met in an environmentally sustainable way.

Heat Pump Technologies for a Beyond 2 °C Pathway

The energy efficiency potential of the global energy sector still remains largely untapped. The good news is that high-efficiency and low-carbon energy technology solutions (e.g. heat pump and solar thermal technologies) already exist in most markets. Significant improvements can be achieved if existing energy policies and regulations are implemented and strengthened across all countries to cover the vast majority of energy technologies and end-uses.

The ***ETP 2017*** B2DS analysis confirms that heat pumping technologies can play a major role in the global energy transition. For instance, over one-third (35 %) of final energy consumption in the global buildings sector



Evolution of heating equipment in buildings to 2060.
Notes: RTS refers to the Reference Technology Scenario; 2DS refers to the 2 °C Scenario; B2DS refers to the beyond 2 °C Scenario. For more information on the ETP 2017 energy technology policy scenarios, please visit www.iea.org/etp.
[Source: IEA]

in 2014 was from direct fossil fuel use, where three-quarters of that was for heating purposes. If average operating efficiencies (e.g. 80 % to 90 % for gas boilers) are taken into account, this means that roughly 60 % of heating equipment in the global buildings stock today is fed by coal, oil or natural gas.

Under the B2DS, fossil fuel use in buildings effectively decreases to around 10 % of total final energy demand for heating purposes (or around 5 % of installed equipment) by 2060. By contrast, high-performance technologies, including in particular heat pumps, increase considerably, accounting for more than half of the global buildings heating stock in 2060. At the same time, the average energy performance of heat pumps in buildings, with typical coefficients of performance of around 2 to 2.5 today, doubles to 4 or greater by 2060.

Achieving B2DS deployment of high-performance and low-carbon equipment for heating and cooling in buildings would require swift and assertive policy measures, going beyond the already aggressive deployment of clean energy technologies already outlined in the 2 °C scenario (2DS). Innovation is also needed to bring forward higher performance and more affordable clean energy technology solutions.

Capturing the potential for a beyond 2 °C pathway would also require investment in technology innovation across a portfolio of clean energy technologies and energy efficiency measures. A "race to the moon" for high-performance and low-carbon technologies would help to bring forward more efficient products and technology solutions, in the same way that past research and development programmes and market incentives helped to bring to market current best available technologies.

The ETP 2017 analysis highlights that many important areas for action, including heat pumping technologies, are currently being overlooked, particularly outside the power sector. Rapid and aggressive deployment of a portfolio of clean energy technologies could put the world on a pathway to a carbon-neutral energy system by 2060. However, the gap between this pathway and current efforts is immense and is unlikely to be bridged without an unprecedented acceleration of action on a global level.

Clean energy technology investment under the B2DS, while requiring highly ambitious and possibly unprecedented policy actions, would deliver a broad range of benefits. These include lower electricity and fuel expenses for businesses and households, greater reliability in meeting energy demand without costly infrastructure and vulnerability to grid disruption, and reductions in energy sector emissions and other pollutants that pose a threat to human health.

For further information on ETP 2017, please visit www.iea.org/etp.

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Report from Decarb Heat Forum in Brussels

The Decarb Heat Forum, organized by EHPA (European Heat Pump Association, took place in Brussels in the BEL building on May 11-12. It gathered more than 220 participants, including the major players of the heating and cooling industry from all around Europe as well as relevant policy-makers at the European, national, regional and local level. Caroline Haglund Stignor from the Heat Pump Centre participated as a representative from the HPT TCP at the Decarb Heat 2017. During the forum, relatively short presentations were followed by moderated panel discussions with the presenters of the different sessions, which broadened the insight on the presenters' perspectives on different issues. Regular surveys of the opinion of the audience on different matters were also carried out and presented live on the screen.

The European heating and cooling sector comprises 51 % of the energy consumption in Europe and contributes to 27 % of Europe's overall carbon emissions. To decarbonise this sector, industry will be essential in Europe's transition to a carbon emission-free society by the middle of this century. Yet, the EU is far from being on track. The heating and cooling industry is conscious of its responsibilities, and therefore the DeCarb heat initiative (http://decarbheat.eu/) has been launched, which aims to turn the vision of a 100 % carbon-free, efficient renewable heating and cooling sector in Europe by 2050 into reality. The initiative consists of an Industry Pledge, showing the willingness of the thermal industry to take a leading role in the energy transition, as well as a Declaration of support open to all stakeholders willing to support the Decarb Heat vision, and to act.

The Decarb Heat Forum took place in Brussels, Belgium, in the BEL building.
[Photo: Caroline Haglund Stignor]

The first day of the conference focused on the policies towards the decarbonisation of cities and industry and the speakers represented both industry and policy makers. It included the DecarbHeat Ceremony in which the representatives of the industry and other major

The day before the Decarb Heat Forum the members of EHPA met at the General Assembly. The image shows Martin Forsén, President of EHPA, presenting the Activity report for previous year.
[Photo: Caroline Haglund Stignor]

During a panel discussion on the topic "Decarb Heat from vision to reality" the panellists seemed to have a common view: in order to Decarb the heating sector, there must be a combination of energy efficiency measures and replacement of fossil fuel with renewable energy sources.
[Photo: Caroline Haglund Stignor]

stakeholders had the opportunity to formally sign both the Industry Pledge and the Declaration of Support. By signing it, they show their willingness to make the vision of a 100 % decarbonised European heating and cooling system a reality.

The day was introduced by Harry Verhaar from Philips Lighting. He told a successful decarbonisation story, the case of the LED lighting revolution, to give some inspiration about what heating industry can learn from lighting. One example is that over the course of only a few years, industry went from selling analogue, "dumb" standalone products, to a large extent for replacement, to selling digital, smart lighting solutions and systems. They went from selling many small products to now selling large-scale projects. To reach something similar for heating, a mission, vision and strategy is needed, as well as both internal and external lobbying and a dialogue with policy makers. A balanced approach between the company, the (lighting/heating) sector and the (energy efficiency) domain is also necessary.

During a panel discussion on the topic "DeCarb Heat from vision to reality" the panellists seemed to have a common view: in order to DeCarb the heating sector, there must be a combination of energy efficiency measures and replacement of fossil fuel with renewable energy sources. Also, a combination of technologies, such as heat pumping technology, solar energy, wind energy, bioenergy, district heating, and waste heat recovery is necessary.

Claude Turmes of the Green Party in the European Parliament gave some advice to the heat pump industry, including joining with architects in order to get a good fossil-free energy solution in new buildings from the beginning. However, since 80 % of the building stock of 2050 is already standing and a large fraction of that is not energy efficient, heat pumps should be promoted together with energy efficiency measures for the building envelope. Otherwise there is a risk that a market disaster is created, that will hit back on the heat pump industry. He also thought that there will be a big market for large heat pumps for district heating, and that a greater partnership with other renewable technologies, such as solar, wind, bio, and geothermal is needed. In addition, he argued that we need a higher target for renewable electricity and that it is important to make a link between renewable electricity and heat pumps. He concluded his presentation by stating that we need to get the oil and gas industry to pay for their pollution – otherwise there will be no deep renovation regarding energy efficiency!

Dominique Ristori, Director General for Energy at the European Commission, said that modernisation and integration of renewable energy must go hand in hand. Heating and cooling must be at the centre of our attention. For this, communication is the key. In addition, he stated that decarbonisation of the heating sector will be profitable for both society and the people. Decarb Heat is not only for Europe but for the whole world. However, we should start by focusing on Europe, according to him. He also gave the advice to the industry associations to base their lobbying on facts, to be successful.

Dolf Gielen, Director of Innovation and Technology at IRENA, gave his perspectives on the energy transition. He stated that business as usual is not an alternative. To reach the climatic ambitions, we need to increase number of installations of heat pumps in the world tenfold, which is both a challenge and a business opportunity. He also presented a study of costs for heat pumps that his organisation was working with. They made comparisons of cost per installation, per product and per installed heating capacity and had so far come to the conclusion that there is a great spread!

The theme for the second day of the forum was the impact of digitalisation on heating and cooling and how we should use demand side flexibility to shape the energy system. The first session was moderated by Patricia Arsene from DG Connect at the European Commission. She said that the silo approach for technology development must not exist anymore, encouraged collaboration between the ICT sector and the energy sector, and advised the audience to study the ICT part of the Horizon 2020 programme, since there would be many calls relevant for energy there.

Dr Oliver Grün, CEO Grün Software, talked about the digital revolution and claimed that for most innovations 70 % of the innovation is connected to IT. He advised the heating industry that they should first of all collect data, but also use it! For example, it can be used for predictive maintenance. He asked the industry why they do not simply sell a temperature, since this would give the costumers a new value, because this is what is important for them. He advised that in order to find and create new business models, the industry must extend their scope along their value chain and cooperate with new partners. He argued that we do not need one data cloud for each company; instead it should be an open data market and sectors have to talk to each other.

On the theme Digitalization: threat or challenge for electricity utilities, Daniele Agostini, Head of Low Carbon and European Energy Policies at the Enel Group, spoke about new ways for consumers to experience energy and that digitalization is the catalyst to go from traditional offers to innovative solutions. Consumers have gone from being passive (regulated tariffs), to free (open market), to active (prosumers start acting) and in the future they will be empowered since they as prosumers can be fully active in the market.

During the panel discussion on the theme ”impact of digitalisation on heating and cooling” the panellists seemed to agree on the fact that the future energy management system will require coupling of systems, buildings, power production and shifting of loads. In order to obtain that, more open cooperation and platforms are needed. For example, standardisation and infrastructure development are important! It was also mentioned that we need to use the heat pumps as power plants.

Dr Christian Hille, P3 Group, talked about our way to an all-electric society. With a large share of heat pumps and electric cars in private homes, the power will probably exceed the limits of the Low Voltage (LV) grid, and smart control is then necessary. On the way to an all electricity society, there will be a high cost for grid expansion, since in the beginning there will be a power problem, not an energy problem. Demand side control and electric storage may limit the costs for this grid expansion.

Scott Kessler, Io3energy, gave a presentation about the benefits of micro grids for load shaping and grid extension. A utility is a platform that needs to find the revenue in its business model. There will always be a need to own and operate infrastructure to transport electrons, but the products and services for different locations, and which business models that are suitable, might differ! New business models can empower both people and utilities.

The second day of the DeCarb Forum was concluded by a summary made by Ruben Baetens from 3E, ”a youth ambassador”. To look into the future of the heating sector he made a comparison to the mobile phone sector. To start with you paid for every minute of the conversation. After that, you just paid a subscription fee. Now it is possible to get both the subscription and the phone for free. But he reminded the audience by saying "if something is free, you are the product". He concluded by stating that "digitizing heat is not the end. Digitize comfort, and (its impact on) productivity!"

CAROLINE HAGLUND STIGNOR
IEA Heat Pump Centre
c/o RISE - Research Institutes of Sweden
Sweden

Van Baxter appointed director-at-large for ASHRAE

Van D. Baxter, a researcher at the US Department of Energy's Oak Ridge National Laboratory (ORNL), has been appointed director-at-large for ASHRAE (American Society of Heating, Refrigerating and Air-Conditioning Engineers).

Baxter, a senior research and development engineer in the Energy and Transportation Science Division, is a fellow and life member of the 50 000-member organization. He works in the Building Equipment Research group focusing on heating, ventilation, air-conditioning, and refrigeration technology and water heating systems.

For the HPT TCP, Van Baxter is well-known, very active in the US National Team, as well as a regular and valuable participant at the annual HPT TCP National Teams' meetings. Regarding the future chores within ASHRAE, he comments "It is a very great honor to be asked to serve on ASHRAE's Board of Directors. To be sure it will involve a lot of work and new responsibilities but I am looking forward to the challenge and to continued association with the HPT."

UT-Battelle manages ORNL for the DOE's Office of Science. The Office of Science is the single largest supporter of basic research in the physical sciences in the United States, and is working to address some of the most pressing challenges of our time.

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Flammable limits threaten HFC phase down

As the world battles to reduce HFC emissions, AHRI president Stephen Yurek has called for changes to the barriers that restrict the use of flammable refrigerants. Speaking at the XVII European Conference on refrigeration at the Politecnico of Milan, Yurek, president and CEO of the US manufacturers' group, said that restrictions in most international, US and European building and safety codes are one of the biggest obstacles to meeting the HFC phase down aspirations of the Kigali agreement.

"We have to work together to change the regulatory safety barriers that are currently in place that restrict the use of 2L and A3 refrigerants," he said. He pointed out that currently most building and safety codes do not recognise A2L refrigerants and at the same time "severely restrict the use of any flammable refrigerants in the occupied space". "Those codes need to be changed," he said.

"We need the safety standards to tell you about charge sizes and how these refrigerants can be used in equipment. Then, when those are complete, we need to modify the building codes – the residential building codes, the commercial building codes – to reflect those new safety standards that will allow the use of 2L and A3 refrigerants.

The AHRI president and CEO revealed that the first report into A2L "mildly flammable" refrigerants from the $5m-plus research programme funded by AHRI, ASHRAE, the US Department of Energy and the state of California, was about to be published. With the first report completed, he admitted that they now needed to do more work on A3 refrigerants and to look at different types of leak scenarios. Stephen Yurek also suggested that more sensors and better sensor technology were needed and saw education and training as being "critically important".

Earlier, Stephen Yurek had again sought to allay fears that the Kigali agreement to include HFC phase downs under the Montreal Protocol might go the same way as the USA's rejection of the Paris climate deal. Maintaining that the two deals were very different, he reaffirmed the US industry's support for the Kigali agreement and was hopeful that it would be ratified by the Senate. While Republicans currently hold the majority in the Senate, the 67 votes (out of 100) needed will require a substantial mix of both democrats and republicans to ensure ratification.

Source: www.coolingpost.com

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12th IEA Heat Pump Conference 2017

Vapor injected heat pump using non-azeotropic mixture R32/R1234ze(E) for low temperature ambient

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Abstract

The traditional refrigerants such as CFCs or HCFCs has been phased out for ODP and many HFCs is being phased down for their relatively high GWP. Among all the substitutions, the mixture has become much attractive because it can reach a balance between thermodynamic performance and environmental effects. R32/R1234ze(E) is one of them. At the same time, the technology of vapor injected technology is widely applied in heat pump under low temperature ambient for its great performance improvement. In this paper, the vapor injected heat pump model with R32/R1234ze(E) is established, the injection ratio, heating capacity and COP performance with variable concentrations is analyzed and compared with that of single-stage compression system.

Keywords: R32/R1234ze(E) non-azeotropic refrigerants vapor injected heat pump

1. Introduction

Influenced by ozone depletion and global warming crisis, CFCs and HCFCs refrigerants with great thermodynamic performance are being phased out and many HFCs refrigerants are accelerated to be phased down owing to their high GWP. Considering the contradiction of environmental effects and thermodynamic performance of current pure refrigerant, the use of mixed refrigerants are promoted to provide much flexibility in searching new environment-friendly alternatives. Among recent studies [1,2], R32/R1234ze(E) refrigerant mixtures have attracted great attention for their splendid properties of this two pure refrigerant. In fact, R32 has gained increasing attraction for its large latent heat and zero ODP and middle GWP, especially in the field of air source heat pump. At the same time, R1234ze(E) is regarded as excellent environmental refrigerant for air conditioning and heat pump system in new generation.

On the other hand, with the outdoor ambient temperature decreasing, air source heat pump (ASHP) suffers from low seasonal energy efficiency ratio and encounters heavily heating capacity degradation. Refrigerant injection systems provide a promising option for its applicability in large pressure ratio (low ambient temperature) operating conditions [3~5].

Rare literatures concentrate on vapor injected heat pump system with non-zeotropic refrigerants [6~8], the system performance of vapor injected heat pump with non-azeotropic mixture R32R1234ze(E) for low temperature ambient is researched in this study.

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2. Methodology

2.1. System description

The object of this study is the vapor injected heat pump system (Fig.1). Process 1-9 is the basic vapor injected compression cycle, the dotted line represents the heat transfer process of refrigerant and air at the evaporator and the condenser. the air flows from point 10 to point 11 at evaporator and flows from point 12 to point 13 at condenser.

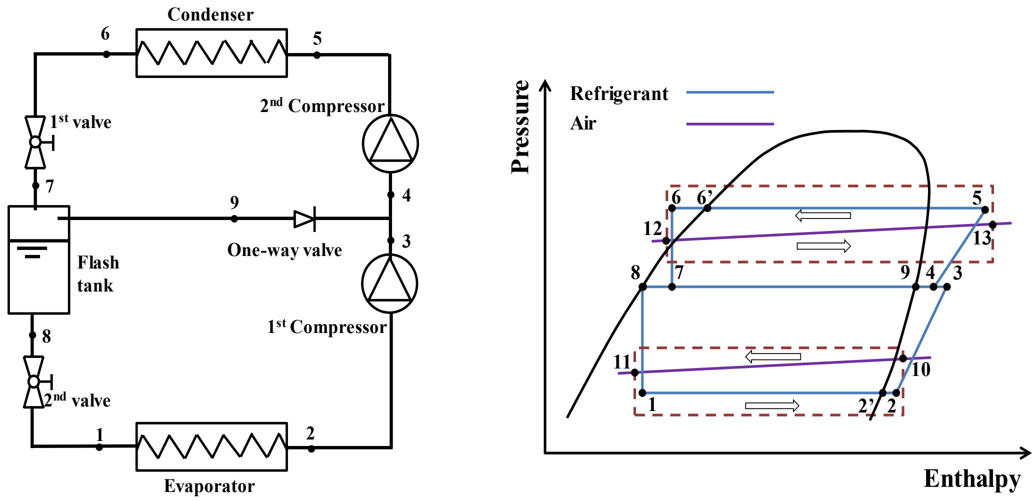

Fig. 1. Schematic of the vapor injected cycle and p-h diagram

2.2. Modeling

A detailed air source vapor injected system simulation is presented in this section. This model focus mainly on the effect to system performance of refrigerants, for which the configuration of heat exchangers and inlet air temperature on heat exchangers are fixed for different refrigerants simulation of various concentration. In order to simplify the simulation properly, the following assumptions are made:

- The superheated degree at the outlet of the evaporator is 5°C and the subcooled degree at the outlet of the condenser is 3°C;
- The pressure drop in evaporator, condenser and connecting tube are ignorable;
- The heat losses are ignorable;
- The difference of charged composition and circulation composition is neglected;
- The heat transfer area of intermediate heat exchanger is large enough.

2.2.1 Heat exchanger model

The similar configuration is adopted on both evaporator and condenser, Fig.2 presents the configuration of heat exchangers, Table.1 shows the specific configuration and size parameters of evaporator and condenser, among which P_t is the distance between tubes perpendicular to the air flow direction, P_l is the distance between tubes parallel to the air flow direction, F_p is the distance between fins, D_i is the internal diameter of tube and D_o is the external diameter of tube.

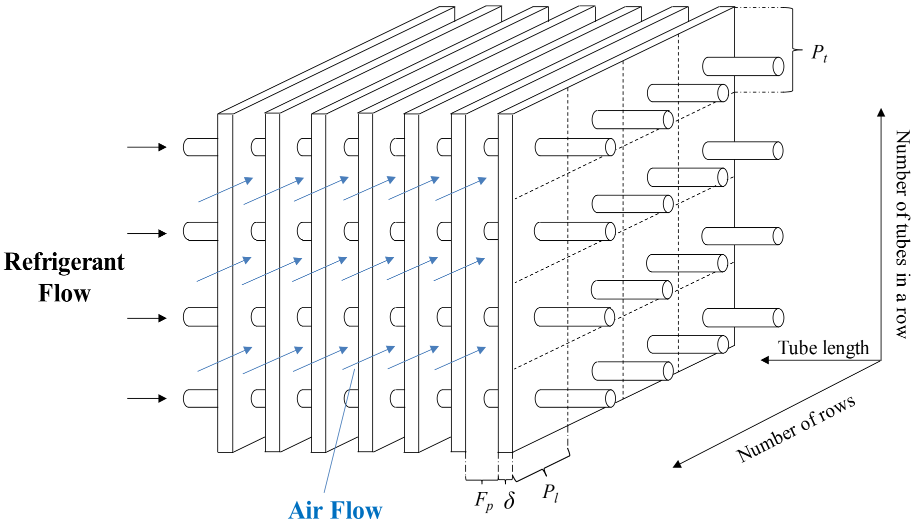

Fig. 2. Configuration of heat exchangers

Table 1. Heat exchanger designed parameters

	Number of flow paths (-)	Number of rows (-)	Number of tubes in a row (-)	Tube length (mm)
Evaporator	2	2	12	450
Condenser	2	3	8	450

	d_i (mm)	d_o (mm)	P_t (mm)	P_l (mm)	F_p (mm)	δ(mm)
Evaporator	6.35	7	16.3	20	1.8	0.115
Condenser	6.35	7	16.3	20	1.8	0.115

2.2.2 Compressor model

An isentropic efficiency model gained from a curve fitting of a practical compressor tested data is used in this study, the isentropic efficiency varies with the pressure ratio (Fig.3). The trend is that the isentropic efficiency increases in a high rate of speed between the pressure ration of two and three, the isentropic efficiency reaches the highest point in about pressure ratio of three and then decreases with the pressure ratio increasing, meanwhile the rate of rise slow down with the pressure ratio continuously increasing. The isentropic efficiency is defined as follows:

$$\eta = w_{isentropic} / w_{actual} \tag{1}$$

Where $w_{isntropic}$ is the power consumption when the compression process is isentropic, w_{actual} is the actual power consumption.

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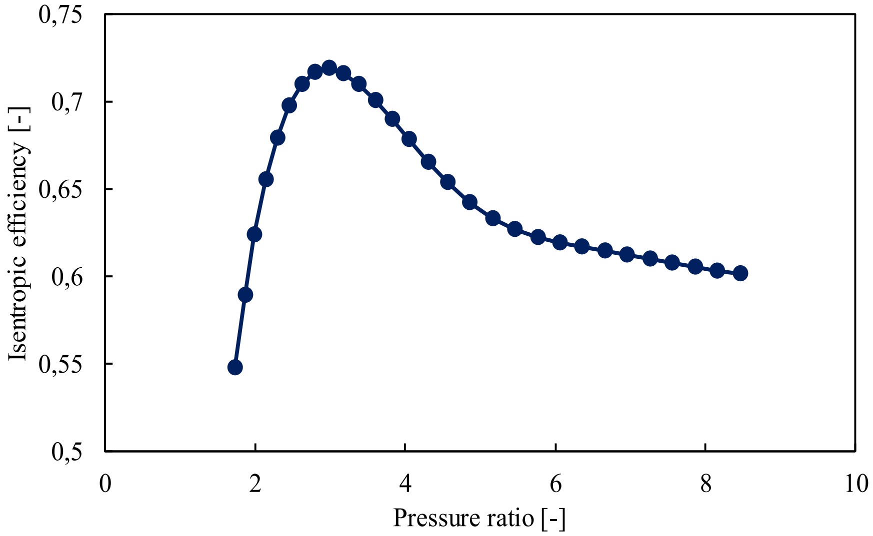

Fig. 3. Isentropic efficiency of compressor versus the pressure ratio

3. Solving procedure

Based on above-mentioned model of each component, a complete air source heat pump model with non-azeotropic refrigerants is presented. The method of inverse calculation is applied in evaporator and condenser because the iterations can be reduced when calculated from refrigerant outlet side and the assumption of the air outlet side temperature in every section is avoided.

The code is developed in the Matlab language. The REFPROP program subroutines [9] are linked to the present code to calculate the thermodynamic properties of the refrigerants and the air.

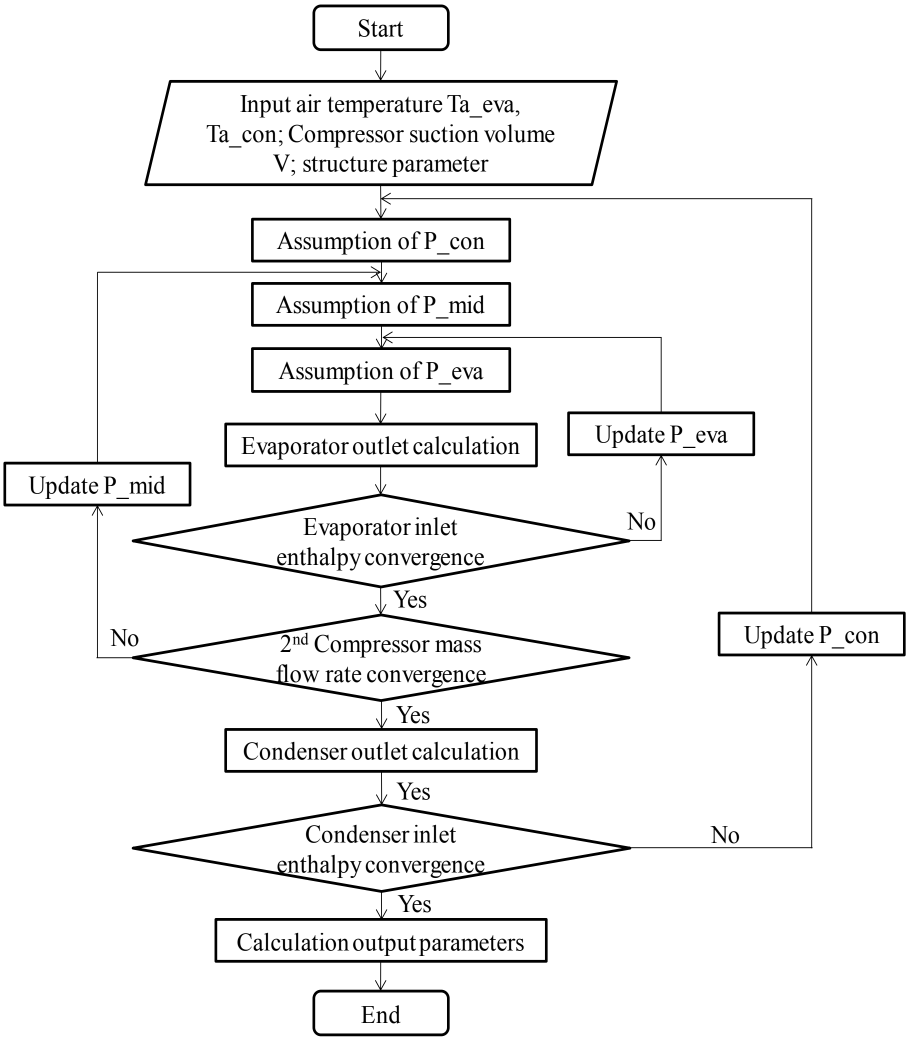

Fig. 3. Isentropic efficiency of compressor versus the pressure ratio

4. Results and discussions

Performance of vapor injected system with non-azeotropic refrigerant R32/R1234ze(E) mixtures is studied in this section. The influence of composition of refrigerant mixtures and ambient temperature to system performance are taken into account. Injection ratio, heating capacity and COP are both analyzed, where by, the normal vapor compression system (VCS) is presented and compared with the vapor injected system (VIS).

4.1. Injection ratio analysis

The injection ratio is defined as follows:

$$\alpha = m_{inject} / m_{con} \qquad (2)$$

Where m_{inject} is the injection mass flowrate and m_{con} is mass flowrate through the condenser.

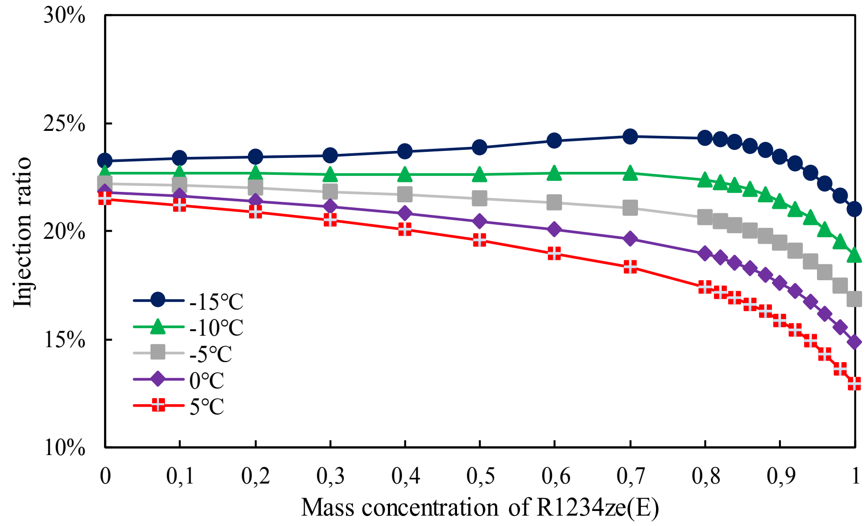

Fig. 4. Injection ratio under different outdoor ambient temperature versus composition

Fig.4 presents the injection ratio under different outdoor ambient temperature utilizing refrigerant mixtures with different compositions. It can be shown that the injection ratio increases with the outdoor ambient temperature decreasing, and it almost drops with the increase of the mass concentration of R1234ze(E) except for the case of -15°C outdoor ambient temperature. With the increase of the mass concentration of R1234ze(E), the condensing pressure will decrease obviously, which can result in the drop of injection ratio due to the decrease of the injection pressure.

4.2. Heating capacity analysis

The effects of outdoor ambient temperature on VCS and VIS are presented in Figure. 5. As a result, the changing trend of VIS and VCS versus the composition variation is similar, they both decrease with the mass concentration increasing, which is mainly caused by obvious decrease of the condensing latent heat and the dramatic decrease of the suction density with the increase of the mass concentration of R1234ze(E).

At the same time, it can be found that the gas injection can effectively enhance the heating capacity, especially for refrigerant mixture with less R1234ze(E).

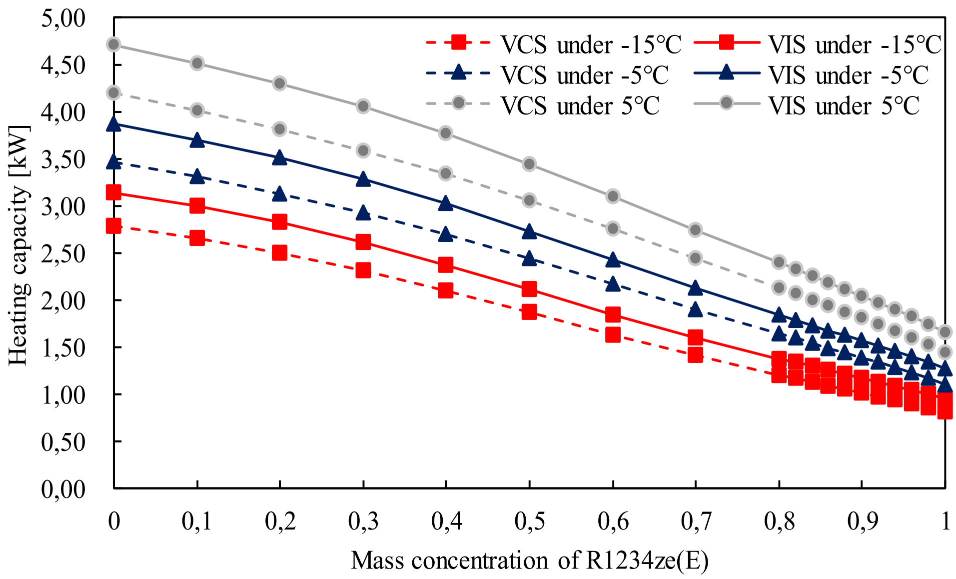

Fig. 5. Heating capacity under different outdoor ambient temperature

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4.3. COP analysis

The influence of the outdoor ambient temperature on the COP are presented in Figure.6. Firstly, it can be found that the COP of VIS increases with the increase of the mass concentration of R1234ze(E). It's coincident with previous study on VCS. This trend is closely linked with the isentropic line during compression and the temperature glide of refrigerant mixtures. The former one will become steeper with more R1234ze(E) which causes the decrease of the compression power and the increase of the COP. For the latter one, with matching better when the mass concentration of R1234ze(E) is more than 80%, the COP of both VCS and VIS increases rapidly.

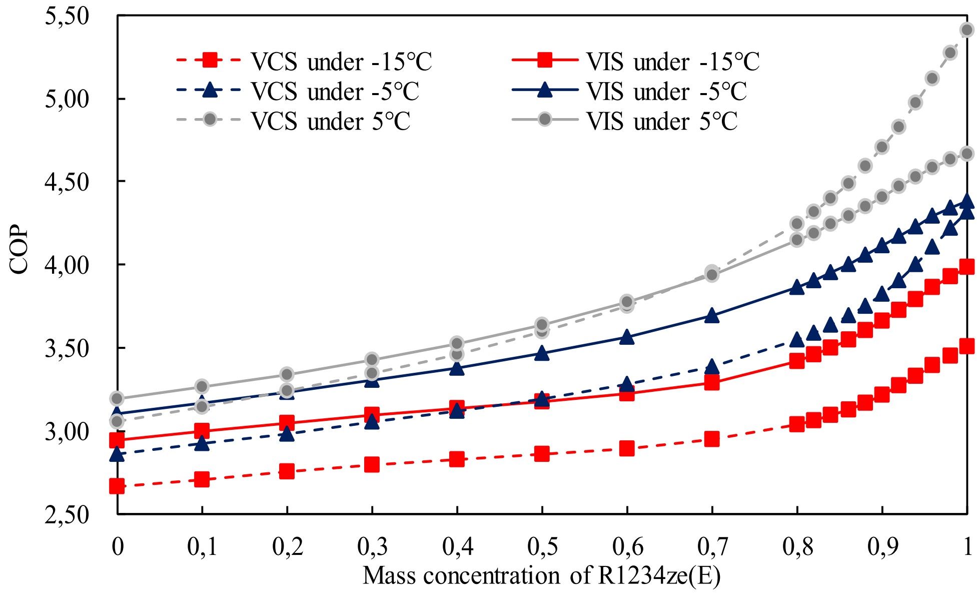

Fig. 6. COP under different outdoor ambient temperature

On the other hand, with the mass concentration of R1234ze(E) increasing, the COP difference between VIS and VCS becomes smaller and the COP of VIS even exceed that of VCS under higher outdoor ambient temperature. That is because the vapor injection is effective to system efficiency under large compression ratio, such as low ambient working conditions or refrigerant mixture with less R1234ze(E). For heat pump system with refrigerant mixtures rich in R1234ze(E) under high outdoor temperature, the system compression ratio is quite small, so the refrigerant injection will not enhance the COP but decrease it.

5. Conclusions

A detailed vapor injected heat pump model using non-azeotropic mixture R32/R1234ze(E) for low temperature ambient is developed for performance analysis. The main results are summarized as follows:

(1) With the mass concentration increasing of R1234ze(E), the injection ratio decreases except for higher outdoor ambient temperature;

(2) With the mass concentration increasing of R1234ze(E), the heating capacity of VIS decreases which is same as that of VCS. And gas injection can effectively enhance the heating capacity;

(3) The COP of VIS increases with the increase of the mass concentration of R1234ze(E). And with the mass concentration of R1234ze(E) increasing, the COP difference between VIS and VCS becomes smaller and the COP of VIS even exceed that of VCS under higher outdoor ambient temperature.

Acknowledgements

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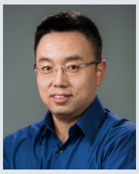

SHORT BIO

Dr. Baolong Wang is an associate professor serving the Department of Building Science of Tsinghua University in China, where he received his Ph.D degree in 2006. Dr Wang's research interest focuses on the area of efficient equipment in HVAC system, including scroll compressor, rotary compressor, low ambient temperature air source heat pump, high seasonal performance air conditioner, and low-GWP blend refrigerant.

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SHORT BIO

Dr. Wenxing Shi is a professor of Department of Building Science of Tsinghua University in China. Dr. Shi works as associate chairman of National Technical Committee 238 of China (SAC/TC238), secretary general of Committee on Continuing Education of Chinese Association of Refrigeration (CAR). He engages in refrigeration and heat pump technologies, thermal storage and renewable energy utilization, and research on performance evaluation of refrigeration and heat pump equipment.

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SHORT BIO

Zuo Cheng is a PhD candidate supervised by Dr. Baolong Wang in Department of Building Science of Tsinghua University. His research focuses on refrigerant mixtures and their application in low ambient temperature air source heat pump.

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Personal cooling and the Roving Comforter *

Anne M. Mallow and Kyle R. Gluesenkamp - USA

Today we heat and cool buildings to a single target temperature. Some problems with this conventional regime can be readily observed: first, people have differing opinions of the appropriate target temperature; and second, conditioning a whole building requires much more energy than conditioning the air immediately surrounding the occupants. In contrast to most conventional approaches to decreasing energy consumption, personal cooling offers a plug and play solution by providing localized space conditioning directly to individuals. This shift in perspective, from the room air temperature to the individual, opens new possibilities to enable more sustainable cooling architectures for energy efficient space and building design at lower cost.

Introduction

Space cooling represents a significant energy technology market in the United States, since most households (87 % in 2015 [1]) and commercial buildings (80 % in 2012 [2]) are equipped with cooling equipment. In addition to human comfort, space cooling helps to maintain safe storage temperatures for various goods, products, or equipment (data centers), while also providing comfortable working conditions to increase worker safety and productivity. Cooling large spaces to maintain desired ambient conditions necessitates significant energy and financial expenditures. Recent data suggests that space cooling accounts for 6 % of energy use in U.S. residences [3], which is reflected in homeowners spending $35 billion of their total energy-related costs on space cooling in 2010 [4]. Furthermore, 9 % of energy use in U.S. commercial buildings is attributed to this energy sector [5], or $25 billion in 2010 [6].

Improvements in space cooling technologies include tuning existing systems, reducing heat loads to minimize the burden on cooling systems, replacing older equipment with higher efficiency equipment, and adjusting to the changing demand determined by building occupancy. Although these solutions can decrease the net energy required for the same cooling demand, the general approach to space cooling is energy inefficient: maintaining a single target temperature within an entire building to satisfy small portions of occupied space.

What is the penalty paid for cooling a whole building instead of an individual person? For a sense of perspective, consider a building with 232 m^2 (2 500 ft^2) floor area and 2.4 m (8 ft) high ceilings. This represents a conditioned volume of 566 m^3 (20 000 ft^3). Compared to a typical human body volume of 0.075 m^3 (2.6 ft^3), the building is 7500 times larger! If a hypothetical monthly $75 cooling bill could be proportionally reduced, it would be $0.01. Of course, one could argue that volume correlates to stored energy, whereas area correlates to heat gain. Along these lines, assuming the building is above ground with two stories and an aspect ratio of 2:1, the external surface area would be 455 m^2 (4 900 ft^2), compared with 1.75 m^2 (18.9 ft^2) of a person. This gives a ratio of 260, and our hypothetical monthly bill would be reduced to $0.29.

The purpose of going through these simplistic comparisons is to demonstrate the huge potential of localized cooling to dramatically change the energy requirements of keeping people comfortable. Rethinking the traditional approach to space cooling and reducing energy consumption is critical to our energy infrastructure as cooling demand is only expected to increase both nationally and internationally as incomes rise and urbanization advances.

Personal Cooling

Personal cooling is the use of localized thermal management to maintain a comfortable ambient temperature to an individual without entirely relying on a centralized conditioning system. This approach to air conditioning offers numerous benefits over traditional systems. First, adapting the thermal environment around the individual rather than cooling unoccupied

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space within a building results in significant energy savings. In environments conditioned with centralized systems, such an approach allows building temperature set points to be increased to save energy, with additional cooling demand provided locally through personal cooling technologies. For example, a recent study suggested that by increasing the cooling set point of a building from 22.2 °C (72 °F) to 25 °C (77 °F), an average of 29 % of cooling energy savings can be achieved [7]. Furthermore, personal cooling offers the ability to adapt to the local surroundings and personal preference, recognizing that thermal comfort is a result of both human perception and heat transfer. The elements of heat transfer include convection to surrounding air, evaporation from the skin, and radiation with surrounding surfaces, all of which are impacted by the local environment within a building.

In addition to reducing cooling in unoccupied spaces, other benefits of personal cooling include space conditioning where centralized conditioning is infeasible, addressing barriers to entry in the market, and improving local air quality. In areas where centralized conditioning is impractical, such as in large warehouse spaces, personal cooling can condition immediate space around workers to improve safety and productivity, or in specific areas that require lower ambient conditions. Secondly, decentralized systems offer a much faster rate of market adoption as the infrastructure required for large-scale cooling systems is not required, and initial capital costs are more flexible. Furthermore, costly retrofits to entire or parts of centralized cooling systems can be delayed or reduced with the use of personal cooling devices. An additional potential benefit is improved local air quality achieved through embedding a filtering system in the conditioning device.

Recognizing the potential of personal cooling as well as the significant challenges that exist to deploy personal cooling on a large scale, ARPA-E (Advanced Research Projects Agency-Energy) developed the Delivering Efficient Local Thermal Amenities (DELTA) program. This program aims to develop technologies that adjust the physical space around the human body rather than the entire building, and that address key challenges including cost, waste heat management, operating time, and personal comfort evaluation. One such technology is the Roving Comforter, a highly efficient and mobile personal cooling device.

Roving Comforter

The Roving Comforter, or RoCo, is a portable device that provides personal thermal management for individuals in inadequately air-conditioned or even unconditioned environments. This technology is being developed through research conducted by the University of Maryland, Oak Ridge National Laboratory, and the newly formed start-up, Mobile Comfort. It incorporates the latest components for compact vapor compression, high-conductivity phase

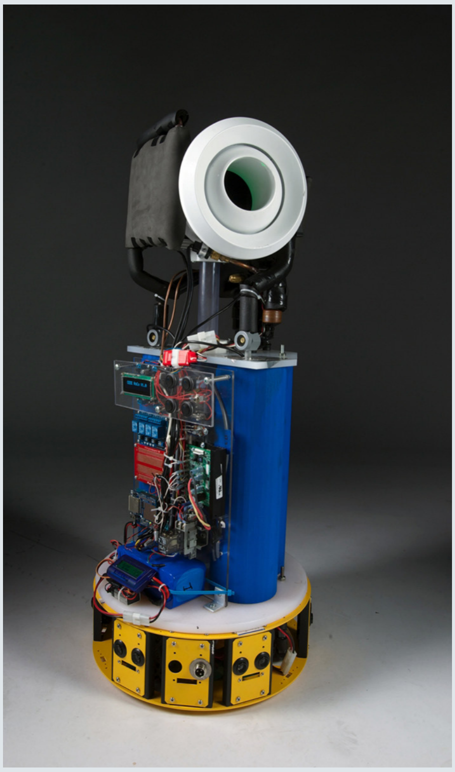

Figure 1. First RoCo prototype.
[Photo: John T. Consoli/University of Maryland]

change thermal storage, low-cost sensing and controls, battery technology, and emerging understanding and techniques regarding personal thermal comfort. As shown in Figure 1, the portable device requires no external wires or ventilation while in use.

Although many versions and features are currently being investigated to adapt to the needs of various target markets, the three main components are a movable yet stable platform, highly efficient thermal management module, and intelligent nozzles. The portable platform increases the flexibility of the cooling device to service multiple areas. The first prototype incorporated a robotic platform to enable it to follow one or several designated occupants and provide cooling as required, using technologies such as omnidirectional Wi-Fi from wearable devices.

The heart of this personal cooling device is the next generation miniature heat pump system with built-in waste heat storage. Equipped with a mini-compressor and compact air-to-refrigerant heat exchangers, the system delivers cooling with minimal power consumption. An onboard battery provides power to the compressor. Additionally, the condenser incorporates a phase change material (PCM) that stores heat removed from the refrigerant as latent heat during operation to further increase the energy efficiency of the device. Use of a PCM enables higher energy storage density with lower refrigerant condensing temperatu-

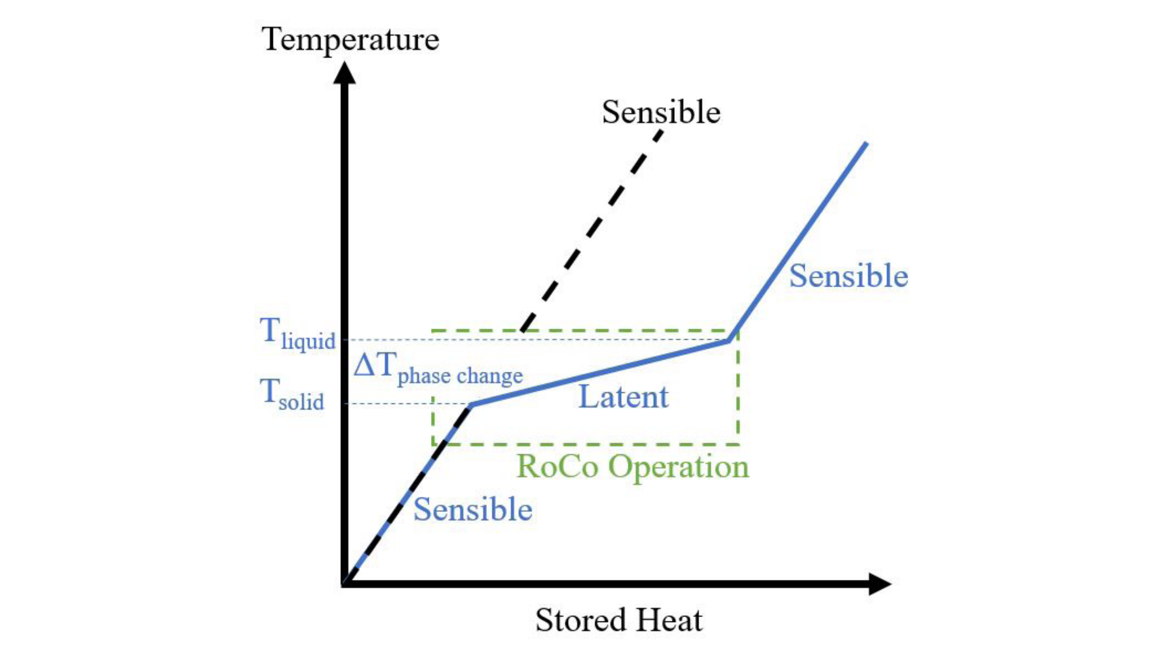

Figure 2. Comparison of stored heat to temperature for sensible and latent heat storage materials.

res due to the near isothermal PCM transition from solid to liquid as shown in Figure 2. Incorporation of high conductivity graphite foam within the PCM has been shown to increase the rate of waste heat storage and decrease the temperature gradient within the storage material.

RoCo operation ends once the PCM has fully undergone phase change as further heat storage through sensible heating would increase the temperature of the condensing refrigerant, decreasing the overall efficiency. Though the operating time determined by the application governs the required mass of PCM, the objective is to design the PCM condenser to provide cooling on demand and discharge the waste heat when conditioning is not required.

To discharge the stored heat, the RoCo functions in a thermosiphon mode of operation. Refrigerant enters the lower section of the thermosiphon loop as a liquid and absorbs heat from the PCM. The heat addition causes the refrigerant to evaporate and rise to the top where it is condensed by a heat removal mechanism. The condensed liquid flows back to the lower portion of the loop and is heated again. The cycle repeats and leads to a continuous operation until the PCM has re-solidified. During this discharge operation, the compressor and the expansion valve are bypassed to reduce pressure drops. Thermosiphons operate with relatively small temperature differences between the heat source and heat sink, and without any moving parts, making them ideal for operations where low cost, energy efficiency, and reliability are important.

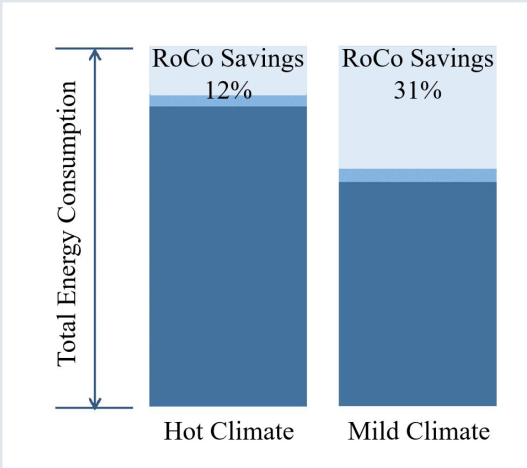

Figure 3. Personal cooling device offers significant energy savings. An example of the reduction in energy consumption for two climate scenarios is shown.

Optimally delivering the conditioned air is achieved through intelligent nozzle design. Thermal comfort studies reveal that various parts of the human body have different sensitivity levels for thermal sensation. The use of intelligent nozzles allows the RoCo to not only adjust supply air locations, but also adjust supply air conditions. Examples of advanced functionality include storing preference data such as air temperature and velocity for different human metabolic rates or tracking and adjusting nozzle location as the user moves throughout a room.

Combining these three areas of innovation results in a personal cooling device that offers significant energy savings. An example of the reduction in energy consumption for two climate scenarios is shown in Figure 3. The greatest benefit is demonstrated for mild climates, resulting from an increased building temperature set point supplemented with localized cooling to maintain the same thermal comfort level.

The first RoCo prototype was showcased at the 2016 Advanced Research Projects Agency-Energy (ARPA-E) Energy Innovation Summit. A later prototype was displayed at Maryland Day on the University of Maryland campus and was demonstrated at the 2016 Maker Faire. The most recent prototype was demonstrated at the 2017 ARPA-E Energy Innovation Summit. Ongoing research includes methods to reduce the cost through component and PCM selection, understanding operating requirements of various markets, and conducting personal comfort evaluations.

Conclusion

Innovation in space cooling is necessary for the next generation of energy efficient buildings. Air conditioning is traditionally provided by centralized systems that cool a building space to a target temperature. Personal cooling enables localized space conditioning, reducing the amount of wasted energy used to cool unoccupied building areas. One invention addressing this need is the Roving Comforter. This portable conditioning device is being developed to allow higher building temperature set points, while keeping the occupants comfortable at a lower energy consumption. Use of a movable platform, highly efficient thermal management module, and intelligent nozzles enables the Roving Comforter to provide flexible space cooling anywhere at any time.

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Fifth-generation thermal grids and heat pumps
A pilot project in Leuven, Belgium

Ir. P. Pattijn, Alex Baumans - Belgium

Belgium, the country of beer, fries and chocolate. But what energy sources are used? We have a large amount of nuclear power and a wide-spread gas network. Regarding power generation, wind power and solar power are taking up. But what are the alternatives to gas heating, considering the use of local energy sources and considering that the cooling demand will increase with respect to the heating demand? In this article we present an energy cocktail of a low temperature thermal grid of the fifth generation combined with ground sources, river energy and heat pump technology.

Introduction
Thermal grids are receiving renewed interest thanks to a number of technical developments. On the user side, the heat demand of a modern home has reduced significantly, so that one can wonder if it is still useful to place individual, gas-fired heating units in each home. On the supply side, thermal grids offer the opportunity to make use of renewable energy or waste heat. Such systems can work with far lower temperatures than traditional district heating networks. The next step is to make the thermal grids interactive, so that users can extract both heat and cold from them. In the new residential project Janseniushof in Leuven, Belgium, a pilot installation is being built with this technology.

From Hertogensite to Jansensiushof
This project is related to a large masterplan for urban renewal in the centre of Leuven. The district is called Hertogensite and is based on the renovation of the former St.-Rafaël - St.-Pieter hospital campus in the heart of Leuven. See Figure 1. Real estate developer Resiterra is building a new, sustainable, multifunctional urban development, a combination of new construction and deep renovation, on the 68 000 m^2 terrain. Since sustainability was paramount, it was decided to make use of a combination of renewable energy sources and two thermal energy networks: a local low-temperature energy grid with cold and heat storage (geothermal) in aquifers for the new buildings (heat requirement

Figure 1. Hertogensite and Jansensiushof project development at Leuven.

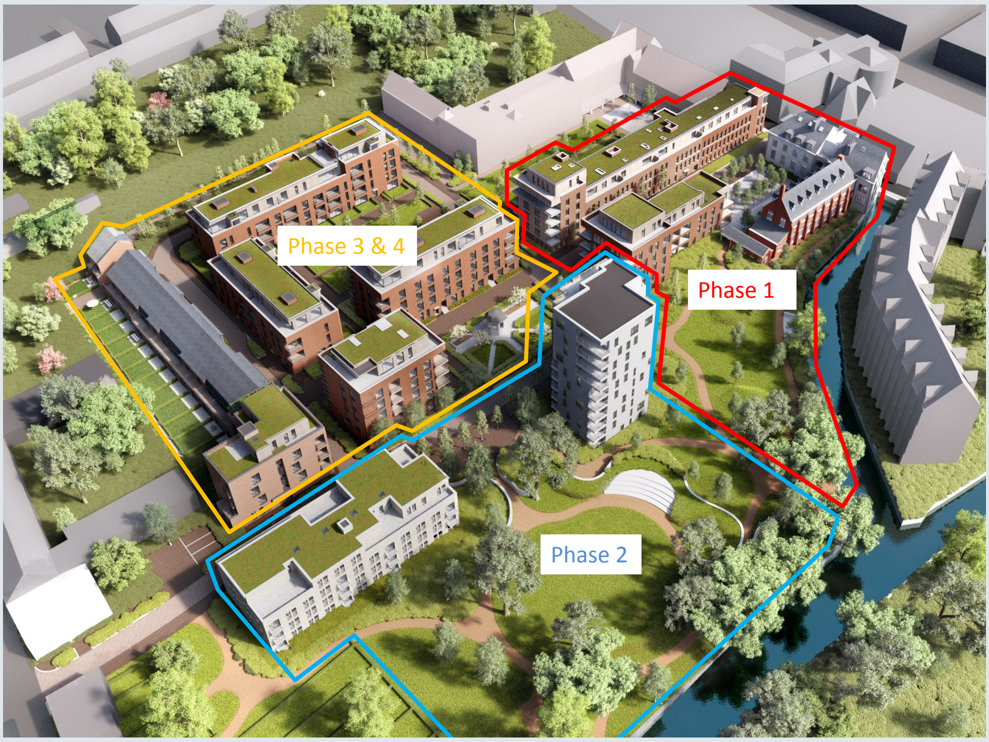

Figure 2. Jansensiushof development.

< 25 kWh/m² per annum) and a local district heating network at higher temperatures (90/70 °C) for the existing buildings (heat requirement < 70 kWh/m² per annum).

However, before the concept is applied on a large scale at the Hertogensite, it will first be put into practice in a smaller project nearby: the Janseniushof, see Figure 2. In this way, experience can be gained with a smaller project. The Janseniushof covers 25000 m² and is the redevelopment of the former car park of the hospital campus. The project comprises 206 housing units in 4 construction phases. The last two of these phases serve as the pilot for the Aquifer Thermal Energy System (ATES) and low-temperature energy network. It concerns 76 new apartments, 13 family homes and 13 service flats.

Fifth generation thermal grid

In several cities district heating has become an alternative heat supply system for gas boilers in new and existing buildings. District heating connected to homes with radiator heating have a supply temperature of 90 °C or 70 °C. They are referred to as third or fourth generation district heating grids.

However, fifth-generation thermal grids operate with low-temperature heating regimes, with a supply temperature of 40 °C or less. Depending on the application, the thermal grid can then directly supply a low-temperature delivery system, such as floor heating. The primary temperature can also be increased by means of a decentralised heat pump. The advantage of this approach is that many more diverse types of low-temperature heat sources can be connected to the thermal grid, for example solar collectors, condensers of chillers and intercoolers of combined heat and power (CHP) installations, or industrial waste heat.

For the Jansensiushof, we opted for a variant: the thermal grid is connected directly to the geothermal wells and acts as a heat source for the heat pumps in the homes. This gives the energy system an additional function: the network can also be used to cool. In summer, the homes have the possibility of free cooling via the floor heating system. This results in a pleasant indoor climate and has the additional advantage that the source can be recharged. The nearby river Dijle offers an extra possibility for recharging the source. If the source temperature drops too far at the end of the heating season, then in summer heat can be extracted from the river Dijle to recharge the heat source, see Figure 3 and Figure 4. In summer, river water at 20 °C is ideal for this. By extracting heat from the river, the urban heat island effect can locally be reduced.

In heating mode, the geothermal circuit has a supply temperature of 14 °C and a return temperature of 8 °C,

Figure 3. Janseniushof construction site and river Dijle

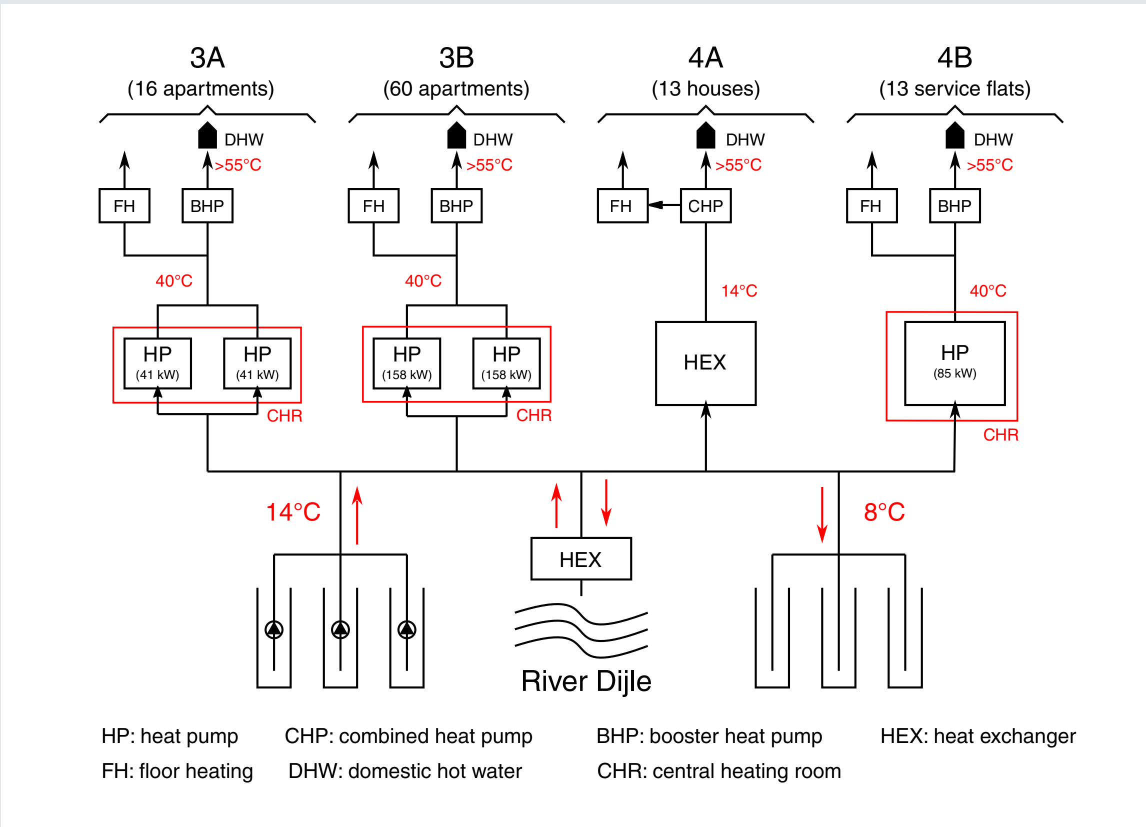

Figure 4. Overview of the thermal grid in Janseniushof.

as is shown in Figure 4. The advantage is that barely no heat is lost to the soil during transport. As a result the buried pipes do not have to be insulated. This saves a lot of time, money and effort.

Smart heat-pump system

Water to water heat pumps are applied to get the water in the primary circuit to the operating temperature. We opted for different configurations of heat pumps, depending on the type of home. See Figure 4. The apartments and service flats have a central heating room, where the heat pump heats the water to 40 °C, which is sufficient for the floor heating. For domestic hot water, each apartment has a buffer tank with a small booster heat pump that heats the water of the secondary circuit to 55 °C (with the possibility of higher temperatures depending on comfort and Legionella requirements). The central heat is produced and distributed at low temperature. This reduces the heat loss of circulating hot water and contributes to the energy efficiency of the system. The system can also react smoothly to a fluctuating demand for domestic hot water.

On the other hand, the houses each have their own combined heat pump for both space heating and domestic hot water production. A central heating room is less suitable here, for financial and practical reasons.

In summer, the flow of the geothermal system is reversed and the water of the primary circuit cools the building mass through the floor heating. There is a separate bypass installed for the bathrooms as residents do not appreciate cooling this space. In cooling mode, the water is pumped from the source at 9 °C and returned at 16 °C (not shown in the figure). As mentioned above, the return temperature can be increased further by using the river Dijle as a heat source.

Organisation and business model

An innovative technology such as a low-temperature geothermal energy network can only break through successfully with a viable business model. Such a system transcends the management of a traditional association of co-owners, and requires an energy manager. This role is taken up by the company IFTech. This company takes care of the detailed design, the execution, management, supply and the invoicing. In addition, they also take the role of investor of the low-temperature energy system. So, it functions as an Energy Service COmpany (ESCO).

The end customers pay a fixed contribution as a share in the operation of the geothermal energy system. The sharing of the individual costs depends on the configuration. In the homes which have their own heat pump installation, everything simply is paid via the electricity bill. The apartments, on the other hand, pay a share of the consumption of the central heat pump, whilst the consumption of the booster pump is for their own account. As a basic principle, the heating costs should not be higher than those of a traditional system with gas boilers. A supply contract between ESCO and end customers was defined by the legal adviser.

The option of cooling is proposed and perceived as a significant added value and a commercial strength. The cooling consumption will not be charged, but is offered as an additional free thermal summer comfort. For a balanced operation of the system, as much cooling as possible is desired, for optimum recharging of the heat source. Offering the cooling function for free encourages the residents to use it.

The geothermal system has three doublets, each consisting of two wells (as a source of heat and cold). The sources have been executed redundantly (N+1). No backup operating on gas or any other heating technology has been installed. It was a deliberate choice by Ingenium. The option to use only electricity might entail a risk with regard to the development of energy prices. On the other hand, we are convinced that a ground source energy system completely driven by heat pumps offers the most ecological advantages.

Technical specifications

The geothermal energy network supplies four heating plants (see Figure 4):

- Building 3A (16 apartments) with two 41 kW heat pumps, supplemented by booster heat pumps for domestic hot water in the individual apartments.
- Building 3B (60 apartments) with two 158 kW heat pumps, also supplemented by booster heat pumps for domestic hot water.
- Building 4A (13 homes) each with an individual 8.9 kW combined heat pump, with an electric back-up.
- Building 4B (13 service flats) with an 85 kW heat pump, supplemented by booster heat pumps.

The choice of a double heat pump in the central heating room is based on the same concern for reliability as for the geothermal sources. As described above, there is no additional backup boiler and then it is safer to spread the capacity over two devices. Another reason for double heat pumps is related to the energy-efficiency at partial-load operation. The heat demand is defined for the most unfavourable conditions, which means that the installation works in partial load mode for most part of the year.

Conclusions

We believe that low temperature thermal grids using local energy sources in combination with heat pumps are the new alternatives to be used instead of gas fired boilers. A correct design and a feasible business case and business model headed by an energy service company (ESCO) are important key elements in the final result of high energy-efficiency, low CO_2 emissions, and a win-win for all stakeholders.

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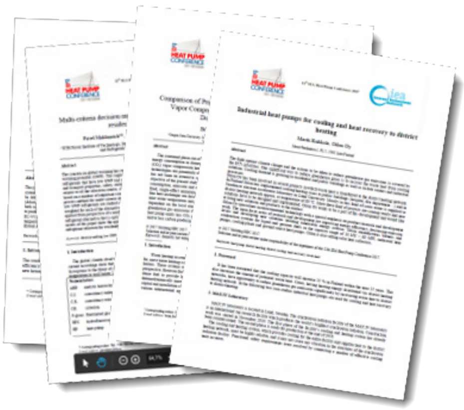

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ANNOUNCEMENT: European Heat Pump Summit 2017

Source: NürnbergMesse

The heat pump world meets in Nuremberg from 24 - 25 October 2017, where international experts discuss the European heat pump market, technology and application trends.

Product presentations at the Foyer-Expo supplement the variety of information provided by the speakers. The European Heat Pump Summit (EHPS) as a platform for specialists is intended for heat pump and component manufacturers, especially experts from science, research and development, and for planners, energy consultants, plant assemblers, and operators of local authority, commercial and industrial property.

With the two-day European Heat Pump Summit 2017, Nuremberg is offering the professional community an unique European platform for exchanging information and experiences. Now that the energy transition in Germany is being referred to all the time, the efficient utilisation of primary energy for heating and cooling is becoming more and more important. Heat pumps with innovative and impressive solutions can make a decisive contribution to sustainable energy systems here.

In the Congress during the EHPS, a number of interesting presentations are given. These include several presentations of Annexes within the HPT TCP, by their Operating Agents. In addition, the HPT TCP National Experts' meeting is being held on the day after the EHPS, Thursday, October 26.

https://www.hp-summit.de/en

Books & Software

Heat Pumps in Chemical Process Industry

Anton A. Kiss, Carlos A. Infante Ferreira
CRC Press, 2016

As the chemical process industry is among the most energy demanding sectors, chemical engineers are endeavoring to contribute towards a sustainable future. Due to the limitation of fossil fuels, the need for energy independence, as well as the environmental problem of the greenhouse gas effect, there is a large increasing interest in the research and development of chemical processes that require less capital investment and reduced operating costs and lead to high eco-efficiency. The use of heat pumps is a hot topic due to many advantages, such as low energy requirements as well as an increasing number of industrial applications. Therefore, in the current book, authors are focusing on use of heat pumps in the chemical industry, providing an overview of heat pump technology as applied in the chemical process industry, covering both theoretical and practical aspects: working principle, applied thermodynamics, theoretical background, numerical examples and case studies, as well as practical applications. The worked-out examples have been included to instruct students, engineers and process designers about how to design various heat pumps used in the industry. Reader-friendly resources such as relevant equations, diagrams, figures and references that reflect the current and upcoming heat pump technologies, will be of great help to all readers from the chemical and petrochemical industry, biorefineries and other related areas.

- Provides a comprehensive overview of heat pump technology as applied in the chemical process industry, covering both theoretical and practical aspects.
- Presents the topic in a unified and systematic manner for improving energy efficiency in the chemical industry and other energy-sensitive sectors.
- Covers working principles, applied thermodynamics, numerical examples, and case studies with practical applications.
- Includes a large range of heat pump technologies: vapor compression, mechanical / thermal vapor recompression, compression-resorption, transcritical, liquid-vapor absorption, solid-vapor adsorption, magnetic, thermo-electric, and thermo-acoustic heat pumps.
- Shows readers how to identify the need, select, design, and apply heat pumps in the chemical process industry.

www.crcpress.com/Heat-Pumps-in-Chemical-Process-Industry/Kiss-Infante-Ferreira/p/book/9781498718950

Energy Technology Perspectives 2017 - Catalysing Energy Technology Transformations

The global energy system is moving closer to a historic transformation. This year's edition of the International Energy Agency (IEA)'s comprehensive publication on energy technology focuses on the opportunities and challenges of scaling and accelerating the deployment of clean energy technologies. This includes looking at more ambitious scenarios than the IEA has produced before.

Improvements in technology continue to modify the outlook for the energy sector, driving changes in business models, energy demand and supply patterns as well as regulatory approaches. Energy security, air quality, climate change and economic competitiveness are increasingly being factored in by decision makers. Energy Technology Perspectives 2017 (ETP 2017) details these trends as well as the technological advances that will shape energy security and environmental sustainability for decades to come.

For the first time, ETP 2017 looks at how far clean energy technologies could move the energy sector towards higher climate change ambitions if technological innovations were pushed to their maximum practical limits. The analysis shows that, while policy support would be needed beyond anything seen to date, such a push could result in greenhouse gas emission levels that are consistent with the mid-point of the target temperature range of the global Paris Agreement on climate change. The analysis also indicates that regardless of the pathway chosen for the energy sector transformation, policy action is needed to ensure that multiple economic, security and other benefits to the accelerated deployment of clean energy technologies are realised through a systematic and co-ordinated approach.

ETP 2017 also features the annual IEA Tracking Clean Energy Progress 2017 report, which shows that the current progress in clean energy technology development and deployment remains sub-optimal. It highlights that progress has been substantial where policies have provided clear signals on the value of technology innovation. But many technology areas still suffer from a lack of financial and policy support.

ETP 2017 purchase includes extensive downloadable data, figures and visualisations.

www.iea.org/etp2017

Events 2017

20-22 July
8th International Conference on Compressors and Refrigeration (ICCR)
Xi'an, China
http://iccr.xjtucompressor.com/

2-4 August
China Heat Pump Alliance Annual Conference & The 6th Asian Air-Source Heat Pump Forum & 2017 China Aerothermal Energy Conference
Suzhou, China
http://heatpumpingtechnologies.org/activities/1/53067/

7-9 August
Building Simulation 2017
San Francisco, California, USA
http://www.buildingsimulation2017.org/program.html

7-10 August
International Sorption Heat Pump Conference (ISHPC 2017)
Tokyo, Japan
http://biz.knt.co.jp/tour/2017/ISH-PC2017/congress.html

6 September
ATMOsphere Asia 2017
Bangkok, Thailand
http://www.atmo.org/Asia2017

6-8 September
9th International Conference on Compressors and Coolants
Bratislava, Slovakia
https://szchkt.org/a/conf/event_dates/34?locale=en_GB

11-13 September
International Conference on Compressors and their Systems 2017
London, the United Kingdom
http://www.city.ac.uk/compressors-conference

25-27 September
ATMOsphere Europe 2017
Berlin, Germany
http://www.atmo.org/events.details.php?eventid=55

24-25 October
European Heat Pump Summit
Nuremberg, Germany
https://www.hp-summit.de/en/summit-info/exhibition-profile/exhibition-description

26 October
National Experts Meeting of the HPT TCP
Nuremberg, Germany
By invitation. If you want to be invited please let us know: johan.berg@ri.se

10-11 November
2017 Second ASHRAE Developing Economies Conference
Delhi, India
https://www.ashrae.org/membership--conferences/conferences/ashrae-conferences/2017-second-ashrae-developing-economies-conference

Events 2018

20-24 January
ASHRAE Winter Conference
Chicago, Illinois, USA
https://www.ashrae.org/membership--conferences/conferences/2018-ashrae-winter-conference

12-15 March
Cold Climate HVAC 2018 - The 9th International Cold Climate Conference
Kiruna, Sweden
http://www.cchvac2018.se/

6-8 April
5th IIR Conference on Sustainability and the Cold Chain
Beijing, China
http://iccc2018.medmeeting.org/en

25-28 April
14th International Energy Storage Conference – EnerSTOCK2018
Adana, Turkey
http://www.enerstock2018.org/

18-20 June
13th IIR Gustav Lorentzen Conference on Natural Refrigerants
Valencia, Spain
http://www.gl2018.upv.es/

9-12 July
2018 Purdue Compressor/Refrigeration and Air Conditioning and High Performance Buildings Conferences and Short Courses
West Lafayette, Indiana, USA
https://engineering.purdue.edu/Herrick/conferences

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Volume 35 - NO 3/2017

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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.

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The HPT TCP 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.

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