Heat Pumping Technologies MAGAZINE

A HEAT PUMP CENTRE PRODUCT

Low GWP Refrigerants - System Solutions and Components

Christoph Reichl, Austria, OA of Annex 51

”ACOUSTIC SIGNATURES OF HEAT PUMPS ARE CURRENTLY RECORDED IN THE PARTICIPATING LABORATORIES, WITH PSYCHO-ACOUSTIC LISTENING TESTS PLANNED TO COME.”

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In this issue

Climate change is going on around us, across the world. There is no doubt that we, mankind, is the reason behind this development – and there is also no doubt that we need to tackle it. The deployment of heat pumping technologies is one way to do this, leading to energy efficiency and reduction of CO_2 emissions. Unfortunately, the refrigerants currently used in heat pumps have a high global warming potential (GWP) and are thus themselves potent climate gases. But it doesn't have to be like that. There are also refrigerants with significantly lower GWP, both such that have been known for a long time and more recently developed ones. Some of these come with another challenge: they are flammable to different degree, which needs to be dealt with.

This issue of HPT Magazine focuses on low GWP refrigerants, their system solutions and the systems' components. The importance of the shift is underlined in the Foreword, and is further discussed in the Column, also giving some background regarding the situation in the EU. The News in focus gives an overview of an unwanted consequence of the EU F-gas regulation: illegal refrigerant sales.

The three topical articles shed light on different aspects of low GWP refrigerants: the situation in forerunner Japan, development of centrifugal chillers, and also challenges due to the flammability. The non-topical article describes new combinations of heat pumps and district heating systems.

Enjoy your reading!

Johan Berg, Editor

Heat Pump Centre

- the central communication activity of Technology Collaboration Programme on Heat Pumping Technologies (HPT TCP)

Topical Articles

Non-topical Article

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SWEDEN
Tel: +46-10-516 55 12
hpc@heatpumpcentre.org

www.heatpumpingtechnologies.org

Editor in chief: Monica Axell
Technical editors: Tommy Walfridson, Markus Lindahl - RISE Research Institutes of Sweden. Caroline Haglund Stignor, Tommy Walfridson, Johan Berg, Ulrica Örnemar, Kerstin Rubenson, Louise Quistgaard - Heat Pump Centre.

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FOREWORD

Low GWP refrigerants – system solutions and components

We are seriously experiencing harsh climate change and hearing news on more rapidly melting glaciers in many parts of the world. During the past summer, most extreme weather and record heat hit countries in Europe and Asia, which adds more weight to the concerns regarding the acceleration of climate change – since increase in use of air-conditioning, and thus consuming more energy, is an obvious result of increasing temperatures. Under these circumstances, the most important task of thermal engineers is providing thermal and food safety to all, but at a much reduced environmental burden.

While improving energy efficiency would greatly contribute to this emission reduction effort, reducing the global warming potential (GWP) of refrigerants used in air-conditioning and refrigeration systems is also important for the goal of minimizing total environmental impact. Therefore, in achieving this environmental goal, we need to consider both improving energy efficiency and reducing refrigerants' GWP as our bi-objectives in the multi-objective optimization field, which tells us that there are many Pareto solutions with various GWP values for different applications. Along with this effort, the International Institute of Refrigeration proposed to use the Life Cycle Climate Performance (LCCP) as an environmental metric and in 2016 published the guidelines for LCCPs of all types of stationary air conditioning, heat pumping and refrigeration systems.

As scientists noted that the ozone layer was being depleted, and also saw the subsequent global warming trends in 1970s, the search for more environmentally-friendly refrigerants began. This effort includes not only developing new fluids, but also utilizing more natural refrigerants safely and economically as they have an ultra-low GWP value merit. In addition to an exhaustive search for better combination of molecules by using modern computing power, practical experimental evaluations of potential fluids were jointly conducted by the Air-Conditioning, Heating, and Refrigeration Institute (AHRI) and the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE). These efforts helped to identify leading candidate refrigerants with ultra-low, very low, and moderate GWP values. In this context, I would like to suggest classifying GWP value ranges as follows: 0 to 10 as "ultra-low", 10 to 100 as "very low" and 100 to 1000 as "moderate".

Since natural refrigerants and newly-identified synthetic refrigerants have different thermodynamic and heat transfer characteristics from currently used refrigerants, transitioning to ultra-low to moderate GWP refrigerants requires a whole-system approach. With this point in mind, the IEA Technology Collaboration Programme on Heat Pumping Technologies, HPT TCP, is aiming to start a new annex called "Heat Pump Systems with Low GWP Refrigerants." This annex aims at promoting low GWP refrigerant application to accelerate phase-down of high-GWP HFCs by developing design guidelines of optimized heat pump components and systems for low GWP refrigerants.

The competition between our efforts to minimize the total environmental impact from new air-conditioning and refrigeration systems to be used and the consequences of our past environmental engineering recklessness has already begun. Our success in this competition stems from our awareness of the seriousness of permanent environmental damage from our short-term viewed engineering goals, and depends on our urgency for fast conversion to low GWP refrigerants. It is now time for us to dance with low GWP refrigerants.

YUNHO HWANG
Research professor, Associate director
Center for Environmental Energy Engineering, USA

Fighting climate change is a rocky road - but it's the right one

Heat pumps is one of the few technologies that has the potential of providing 100 % emission-free heating. However, heat pumps need refrigerants to function and currently this usually means HFCs – the most common type of F-gas.

For the last decade, the possibilities of reducing CO_2 emissions and limiting the impact of climate-damaging gases have been the focus of attention. Since the Montreal Protocol in 1989 and the Kigali Amendment and the Paris Climate Change Agreement two years ago, the combat against global climate change has spread throughout the world. The EU F-gas Regulation is one of the most important drivers to combat climate change in Europe. The main objective is to push the industry towards low GWP and natural refrigerants, as well as to encourage the recycling and reuse of existing HFCs through a phase-down and quota system that gradually and significantly reduce HFCs – to end up at no more than 21 % of 2015 sales by 2030. But with this comes certain challenges.

The industry is now facing a comprehensive transition that calls for competences to deal with the many challenges. Some of the refrigerants most currently used by heat pump manufacturers are R410A, R407 and R32, as well as R134a in larger heat pumps. As some of these have high or medium-high GWP, they are affected by the phase-down.

Marketing quotas are introduced to limit the volume and the circulation of HFCs, and, due to this, prices are rising rapidly at all levels of the supply chain. Some refrigerants have increased by several hundred percent in recent months. Thus, refrigerant suppliers are producing less to respond to the limits of the quota system creating yet another challenge: immediate shortage or even unavailability of certain high-GWP HFCs. In the coming years, we will experience further massive cuts in the available quantities of HFCs in the EU. Some analyses even indicate that it might be difficult to get sufficient amounts of refrigerant for servicing existing systems.

The phase-down and the GWP limit of 2,500 do not leave much choice other than to stop using HFCs and instead turn to the low-GWP and natural alternatives, such as pure HFOs, CO_2, ammonia, and hydrocarbons, including reclaimed or recycled HFCs, which are not affected by the phase-down. Initiatives to extend the use of HFCs until solutions with alternatives are found have been made, but such extensions have not been granted. Therefore, an increase in the use of natural and low GWP refrigerants is expected, and opportunities have increased as new products come to fruition. The uptake of heat pumps on the European market will in part depend on the industry's ability to make the switch to low GWP and natural refrigerants.

The Ecodesign Directive not only sets the framework for common requirements for environmentally friendly products, it also contributes to the protection of the environment. The two Ecodesign regulations that apply to heat pumps are currently under review. The new requirements will be approved in 2019, and it is expected that they will more or less continue in their current form – maybe with more strict requirements on energy efficiency.

Denmark has introduced special provisions for artificial refrigerants, stating that the maximum charge of HFCs in a heat pump must not exceed 10 kg. HFOs with a GWP below 5 can now be used in charges larger than 10 kilos. The 10 kg-limit is currently up for debate and it is expected to be raised to 50 kilos for heat pumps.

For the heat pump industry, the combat for global climate change means a rocky road full of challenges to ensure the move towards low GWP and natural refrigerants, as well as recycling and reusing existing HFCs.

JANNIE GULDMANN WÜRTZ
Consultant
Refrigeration and Heat Pump Technology Energy and Climate
Danish Technological Institute, Denmark
jgw@teknologisk.dk

Welcome to the IEA Heat Pump Conference in 2020

13th IEA
HEAT
PUMP
CONFERENCE
2020 | JEJU KOREA

The 13th IEA Heat Pump Conference will be held in Jeju Island from Monday, May 11th through Thursday, May 14th in 2020. With the theme 'Heat Pumps – Mission for the Green World', we aim to address global climate change and discuss necessary actions.

Previous Conferences

The upcoming conference will be 13th of the series of conferences held by the International Energy Agency (IEA) Heat Pumping Technologies TCP (HPT TCP). Preceding conferences were held in Austria (1984), USA (1987, 2005), Japan (1990, 2011), The Netherlands (1993, 2017), Canada (1996, 2014), Germany (1999), China (2002), and Switzerland (2008). After successful histories in Japan and China, it is the fourth Heat Pump Conference to be held in Asia, and the first to be held in the Republic of Korea.

Conference Venue

The conference venue is Ramada Plaza Hotel Jeju located in Jeju city, easily accessible from Jeju airport. Jeju Island is a famous holiday destination in Southeast Asia, with beautiful beaches, volcanic mountains, and extraordinary cuisine. Home to the natural World Heritage Site, Jeju Volcanic Island and Lava Tubes, participants and those accompanying will certainly enjoy visiting the beautiful island. In addition to sightseeing opportunities, a variety of technical tours are planned.

Conference Goal

Heat pumps, as a reliable and confirmed technology, is the key equipment for energy savings and greenhouse gas reductions with its wide range of application to various energy sources. The upcoming conference will serve as a forum to discuss the latest technologies in heat pumps, and exchange valuable knowledge in market, policy, and standards information on related technologies. Exhibitions will be held at the conference, to share products and technologies from domestic and foreign companies.

Conference Topics

Within the conference program, participants will encounter numerous cutting-edge presentations on the following issues:

- Recent Advances on Heat Pumping Technologies
- Environment-friendly Technology
- Systems and Components
- Field Demonstration and Multi-disciplined Applications
- Research and Development
- Policy, Standards, and Market
- International Activities

Conference Structure

Within the conference program, participants will encounter numerous cutting-edge presentations on the following issues:

- Keynote and Plenary lectures by renowned researchers
- Oral and poster presentations on innovative heat pump technology, applications and markets
- Exhibitions of heat pump equipment
- Workshops on collaborative projects, connected to annexes in the HPT TCP
- Technical tours
- Sight-seeing programs
- Social gatherings

Call for Paper

The abstract submission system will be opened from January, 2019. The abstracts will be screened by an appropriate Regional Coordinator and authors will be advised of acceptance. Important dates are given below.

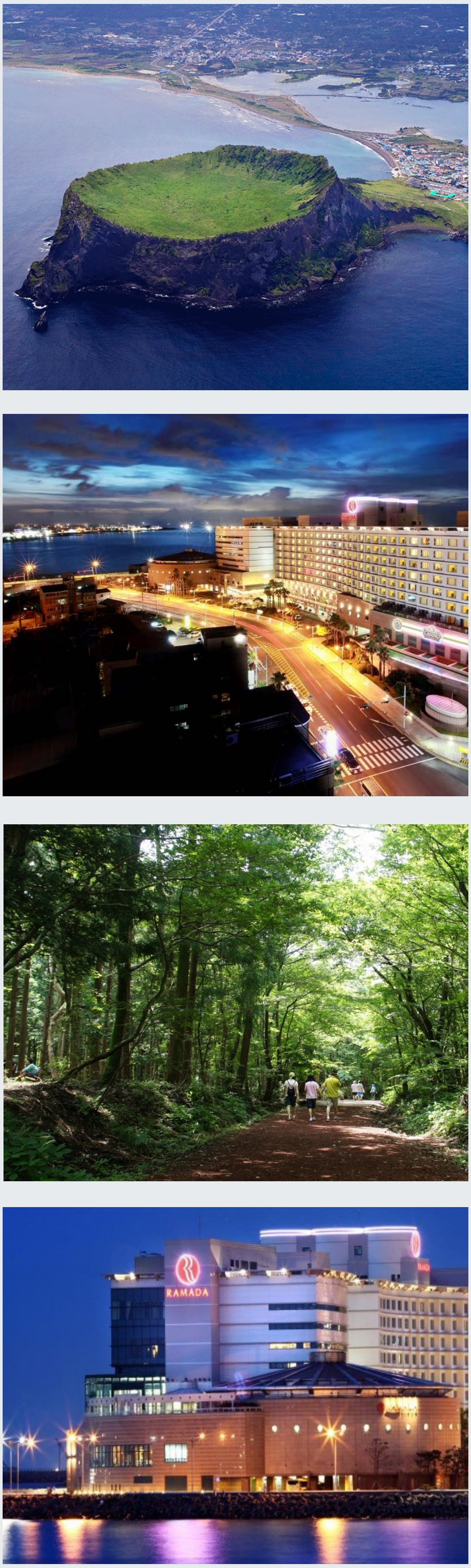
January 1 2019	**Abstract submission open**
May 15 2019	**Abstract submission due**
November 1 2019	**Full paper submission due**
February 15 2020	**Final paper submission due**

Organization

The conference is organized by the International Organizing Committee (IOC) and the National Organizing Committee (NOC) on behalf of the Executive Committee of the IEA HPT TCP.

Per Jonasson	Chairperson IOC, Swedish Refrigeration & Heat Pump Association, Sweden
Sophie Hosatte	Vice-Chairperson IOC, CanmetENERGY, Canada
Hiroshi Okumura	Vice-Chairperson IOC, HPTCJ (Heat Pump and Thermal Storage Technology Centre of Japan)
Min Soo Kim	Chairperson NOC, Seoul National University, South Korea
Minsung Kim	Conference Secretariat, Chung-Ang University, South Korea

For further information, please refer to the Conference website with the 1st announcement of the 13th IEA Heat Pump Conference. http://www.hpc2020.org/



Images of Jeju and Night view of Ramada Plaza Hotel Jeju

HPT TCP welcomes two new Annexes!

ANNEX 53

ADVANCED COOLING/REFRIGERATION TECHNOLOGIES DEVELOPMENT

Growing populations and improving economies worldwide, especially in the developing world, are projected to lead to huge increases in global demand for space cooling, dehumidification, and refrigeration. This will make reaching global energy and climate goals extremely challenging. In order to address this, what actions can the global HVAC&R community take to reduce the impact of this demand growth?

Within the recently approved HPT Annex 53, two possible technology paths are under investigation:

- *Advanced vapor compression with low or ultra-low GWP refrigerants;*
- *Non-traditional technologies (zero-GWP).*

(Source: U.S. Department of Energy Building Technologies Office, Emerging Technologies Program)

No single technology is a clear winner for air-conditioning or refrigeration in all applications. Vapor compression technology has had decades of RD&D to date, and this is continuing. It may continue to be the system of choice, especially for the near term, and possibly for the long term as well. However, vapor compression is vulnerable to further refrigerant restrictions. Non-traditional technologies generally are not subject to this challenge, since they do not rely on refrigerants in the traditional sense. On the other hand, these technologies generally need further development in order to be ready for the market.

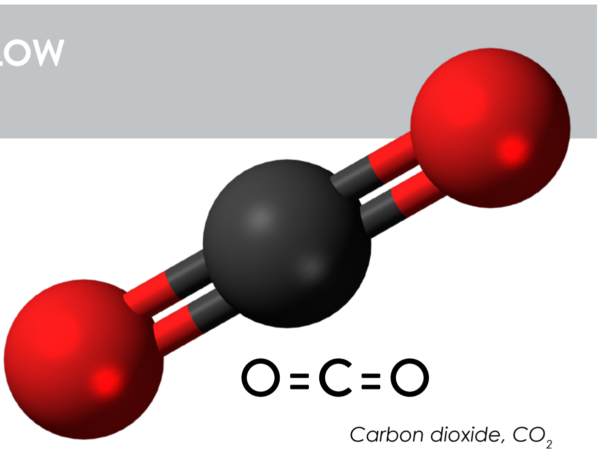
Objective
The objective of Annex 53 is to develop technology solutions for higher efficiency air-conditioning/refrigeration systems to help minimize/reduce projected energy consumption increases. The main technology focus areas are traditional vapor compression, alternative vapor compression approaches, and non-traditional cycle approaches for AC and/or refrigeration applications. The Annex scope is broad, but the challenge is also huge; it is not likely that there will be only one, or a few, "right" solutions.

ANNEX 54

HEAT PUMP SYSTEMS WITH LOW GWP REFRIGERANTS

The objectives and scope of Annex 54:
This annex aims at promoting low GWP refrigerant application to accelerate phase down of high-GWP HFCs by developing design guidelines of optimized heat pump components and system for low-GWP refrigerants through the review of available low-GWP refrigerants, their properties and applicable standards, safety and flammability of refrigerants, and safe use of flammable refrigerants:

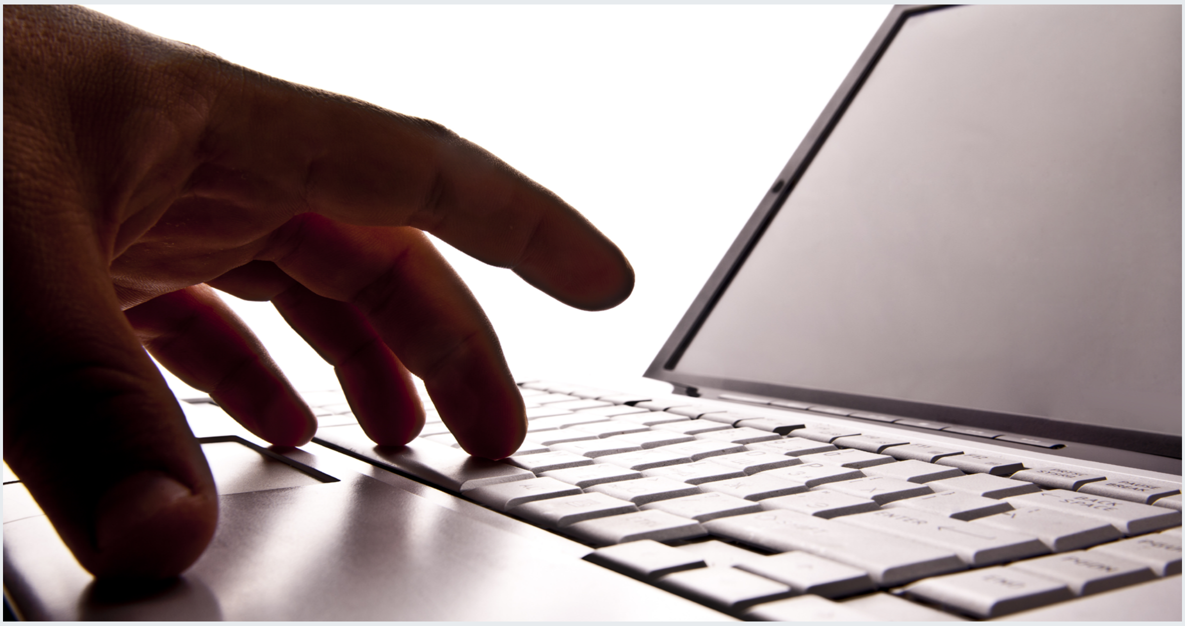
- *Optimization of heat pump components and system for low-GWP refrigerants;*
- *Analysis of the LCCP impact by the current design and optimized design with low-GWP refrigerants;*
- *Market opportunity study for heat pumps with low-GWP refrigerants and low-GWP refrigerants availability for 2030. Target applications are air-conditioning and heat pump systems for residential and commercial buildings.*



Carbon dioxide, CO_2

Annex 54 aligns with IEA's vision and mission by targeting clean, low-carbon energy systems' design and applications. It will assist IEA to achieve its strategic goals by promoting new, alternative or natural refrigerants with low-GWP for heat pumps. By engaging experts worldwide, the annex will promote environmental awareness to policy makers.

Read about all our other Annexes at: www.heatpumpingtechnologies.org/ongoing-annexes/



Illegal refrigerant sales challenge the F-gas Regulation

The European F-gas Regulation aims at reducing the amount of refrigerants with a high global warming potential, GWP. But now there are clear signs that the market has not adjusted properly, leading to illegal sales of high-GWP products. And the authorities seem nonplussed.

The F-gas regulation was updated in 2014, including an approach where HFC refrigerants will be phased out successively. Between 2015 and 2030 the amount of HFCs placed on the market should be reduced by 79 %, through a quota system. To replace them, low-GWP refrigerants are expected to be developed and put into use. Even though this is definitely happening, the strengthened F-gas regulation seems to have had also other effects: there is evidence that various refrigerants are sold illegally online, and even in illegal containers.

Simple searches on common online purchasing platforms carried out by Cooling Post suggest that it is relatively easy to buy HFCs outside the quota system. This system is constructed so that actors on the market are given certain quotas of HFCs that they are allowed to put on the market, based on the GWP for each specific HFC. Also, buyers need to have an F-gas certification. But some online vendors don't ask their customer for this certificate, which is a clear violation to the regulation.

This is now taken to court in Italy. The online retailer Amazon is accused of selling HFCs without asking buyers for their certificate. As of October, 2018, the lawsuit is still ongoing and there is no verdict yet. The plaintiffs are 18 Italian companies, claiming unfair competition. They are backed by the CNA, the Italian National Confederation of Crafts and Small and Medium Enterprises, pointing at the risk that parallel markets will be created, where scrupulous sellers and buyers can meet on an illegal market where the risk of being revealed is low. On this illegal market it could be easy to sell amounts above the stipulated quotas.

Unfortunately, the high-GWP HFCs are not the only refrigerants being sold illegally via internet. This trade also includes substances from the ozone layer-depleting groups HCFC and CFC. The consumption and production of these refrigerants is regulated under the Montreal Protocol from 1987, where a phasing out was decided on globally. As of 1996, CFCs are banned, but HCFCs are still allowed to some extent.

Then there is the container issue. Since 2007, it is not allowed to use disposable cylinders to store the refrigerants. All HFC refrigerants should be sold in refillable containers, but not all vendors act according to this. Again, the Cooling Post searches show that the disposable ones are openly sold online.

The updated F-gas directive from 2014 has not yet been widely implemented by national governments throughout the European Union. France and Germany are examples of countries where the process has come a long way, but e.g. Belgium and Italy are lagging behind. Better national transposition of the directive into national laws could help curb the illegal sales.

Source:
https://www.coolingpost.com/world-news/amazon-in-court-over-illegal-f-gas-sales/

https://www.epeeglobal.org/refrigerants/

Ongoing Annexes in HPT TCP

The projects within the HPT TCP are known as Annexes. Participation in an Annex is an efficient way of increasing national knowledge, both regarding the specific project objective, but also by international information exchange. Annexes operate for a limited period of time, and the objectives may vary from research to implementation of new technology.

FUEL-DRIVEN SORPTION HEAT PUMPS	43	AT, **DE**, FR, IT, KR, SE, UK, US
HYBRID HEAT PUMPS	45	CA, DE, FR, **NL**, UK
DOMESTIC HOT WATER HEAT PUMPS	46	CA, CH, FR, JP, **NL**, KR, UK, US
HEAT PUMPS IN DISTRICT HEATING AND COOLING SYSTEMS	47	AT, CH, **DK**, SE, UK
INDUSTRIAL HEAT PUMPS, SECOND PHASE	48	AT, CH, **DE***, DK, FR, JP, UK
DESIGN AND INTEGRATION OF HEAT PUMPS FOR nZEB	49	AT, BE, **CH**, DE, NO, SE, UK, US
HEAT PUMPS IN MULTI-FAMILY BUILDINGS FOR SPACE HEATING AND DHW	50	AT, **DE**, FR, NL, IT
ACOUSTIC SIGNATURE OF HEAT PUMPS	51	**AT**, DE, DK, FR, IT, SE, DE
LONG-TERM MEASUREMENTS OF GSHP SYSTEMS PERFORMANCE IN COMMERCIAL, INSTITUTIONAL AND MULTI-FAMILY BUILDINGS	52	BE, NL, **SE**, US, UK, FI

◖ FINALIZED ◖ NEW

*) Operating Agent from Germany, but no other parties from the country participate.

The Technology Collaboration Programme on Heat Pumping Technologies participating countries are:
Austria (AT), Belgium (BE), Canada (CA), Denmark (DK), Finland (FI), France (FR), Germany (DE), Italy (IT), Japan (JP), the Netherlands (NL), Norway (NO), South Korea (KR), Sweden (SE), Switzerland (CH), the United Kingdom (UK), and the United States (US).

Bold, red text indicates Operating Agent (Project Leader).

ANNEX 49

DESIGN AND INTEGRATION OF HEAT PUMPS FOR nZEB

Less than two months to go for the introduction of the requirement that all new public buildings shall comply with a Nearly Zero Energy Buildings (nZEB) in the EU member states. Two years later, the requirements will be extended to all new buildings. Also on other continents, like in the USA, Canada and Japan, Net Zero Energy Buildings are the next step for the high performance buildings of the future. However, what is understood by an nZEB and how ambitious an nZEB is compared to the state-of-the-art, will vary among the EU member states, which makes it difficult for manufacturers to develop performance standardized system solutions for the application in nZEB.

The Annex 49 is thus to evaluate the operation of heat pumps in nZEB, which are a promising technology due to the low load and low temperatures that can be realized in nZEB, thereby yielding a high performance. Moreover, the heat pump enables higher self-consumption rates of the installed on-site PV generation in nZEB, which can make the PV installation more economic in times of decreasing feed-in tariffs.

The work of Annex 49 is scheduled into four tasks: ***Task 1*** summarizes the state-of-the-art of heat pumps in nZEB and is currently continuing to evaluate a methodology to determine the ambition levels in different countries in order to overcome the problem mentioned above.

Task 2 covers integration options for heat pumps in nZEB, on the source side as well as for storage integration to extend the energy flexibility. In Task 3 various monitoring projects have started in the participating countries, and interim results are partly available.

Task 3 also covers the testing and further development of nZEB components.

Task 4, on the design and control of heat pumps for nZEB application, is interlinked with Task 2 on the integration options, e.g., concerning the design of the source and the sink systems as well as regarding the development of advanced heat pump control to enhance energy flexibility and demand response.

Interim result of the Annex Tasks 2-4 were presented and discussed at an Annex 49 meeting at SINTEF Building Research and NTNU in Trondheim on June 7-8, 2018.

In Task 2 the integration of solar thermal absorbers as heat source for a heat pump and sink for the building summer cooling loads has been simulated for residential buildings in Switzerland, and in Germany the integration of thermal and electric storage is investigated by simulations of a neighbourhood with 8 houses, which will also be subsequently monitored. The evaluation of thermal and electric storage integration for higher self-consumption and demand response is linked to other monitoring projects which are ongoing. In Belgium the integration of the sewage water as heat source for larger buildings is investigated, linked to a monitoring plant.

The interim results of the work in Task 3 comprise results of these ongoing monitoring projects. Norway has several projects which have been started or are starting in 2018/19, also in larger non-residential buildings such as kindergartens, hospitals and supermarkets.

In Austria and Germany, monitoring is accompanied by simulations studies in order to evaluate which performance data are possible by optimized operation, and subsequently applying the optimization potentials in the monitored systems. In Sweden two identical houses, called twin houses, of which one is inhabited and one is equipped with tunable loads, have been monitored and compared regarding the operational behavior of the different heating systems floor heating and radiators, as well as different controls of the heat pumps in on-off control and capacity control by inverter. Moreover, a free-cooling operation with borehole-to-air heat exchanger has been evaluated. In the USA different air heating systems have been extensively tested and evaluated at the NIST NZE Residential Testing Facility regarding performance, and achieved thermal comfort. Moreover, different system variants for cost- effective NZE technology has been evaluated.

In Task 4, correlations between the system design of the PV and battery and the self-consumption indicators have been evaluated for electric storage integration in connection to monitoring results in Germany. In Norway, different control strategies including rule-based and model predictive control are evaluated on the background of demand response capability of the building and system technology, which is also a topic in IEA EBC TCP Annex 67.

A presentation and discussion of upcoming results in the different Annex 49 Tasks has taken place at the recent Annex 49 meeting, at the National Institute of Standards and Technologies (NIST) in Gaithersburg near Washington DC, USA on November 7-9.

Annex website

http://heatpumpingtechnologies.org/annex49/

Contact

Operating Agent is Carsten Wemhoener, for SFOE, Switzerland. carsten.wemhoener@hsr.ch

Fig. 1: Twin houses in Sweden used for the evaluation of different heating system characteristics and the evaluation of different heat pump control.

ANNEX 51

ACOUSTIC SIGNATURE OF HEAT PUMPS

Introduction

I order to further increase the acceptance of heat pumps, reduction of acoustic emissions is important. To minimize noise annoyance, more focus must be put on the acoustics emissions at steady state and on the transient behaviour of acoustic signatures during different operating conditions. In particular air to water heat pumps provide a convenient and effective way to exploit potential energy savings, and are often used in retrofit installations, making acoustic improvements crucial for both the new and retrofit markets.

In the framework of Task 2, where three heat pumps have been selected for testing, the first measurement campaigns have been carried out. An Exhaust air Heat Pump Water Heater (HPWH) unit has been tested at CETIAT double reverberant rooms (see figure 1). An Air-to-water Heat Pump has been tested both at the Acoustic Center Austria (ACA; Stetten, Austria) and at the Austrian Institute of Technology (AIT; Vienna, Austria) transient acoustic signals have been recorded with more than 60 microphones surrounding the heat pump in the climate chamber (see Figure 2). These tests have been performed at various operating points, including the critical icing and de-icing cycles. In addition, traditional scanning techniques have been applied using sound intensity probes for calculating the sound power level. The heat pump has been transferred to the Danish Technological Institute (DTI, Denmark), in July.

Fifteen attendees from the participating institutes joined the two-days 3rd working meeting hosted by RISE in June 2018 in Borås, Sweden (see figure 3). During the two-day meeting the focus was on reviewing documents on Introductions to Acoustic, Measurement Techniques and Regulations, which have been prepared under the task led by Politecnico di Milano, Italy. Furthermore, psycho-acoustic tests, which will be performed through listening tests in Sweden and Austria, have been discussed. They are crucial for correlating available mathematical sound characterisation methods to the human perception. Thus, the Annex will contribute to guidance and future standards in this field in the short and long term, to help in harmonizing the different local approaches for the benefit of all involved stakeholders.

Participants of the Annex are now working hard in all tasks and are contributing by presenting and discussing the results of their heat pump-related acoustic research projects. Related national projects supporting Annex 51 are running at full speed.

Objectives

- Further increase the acceptance of heat pumps for comfort purpose with respect to noise and vibration emissions;
- Increasing knowledge and expertise at different levels (manufacturers, acoustic consultants, installers, legislators);
- Input to national and international standardization;

Fig. 1: Exhaust Air Heat Pump Water Heater unit installed in CETIAT's double reverberant room. [Source: CETIAT, France]

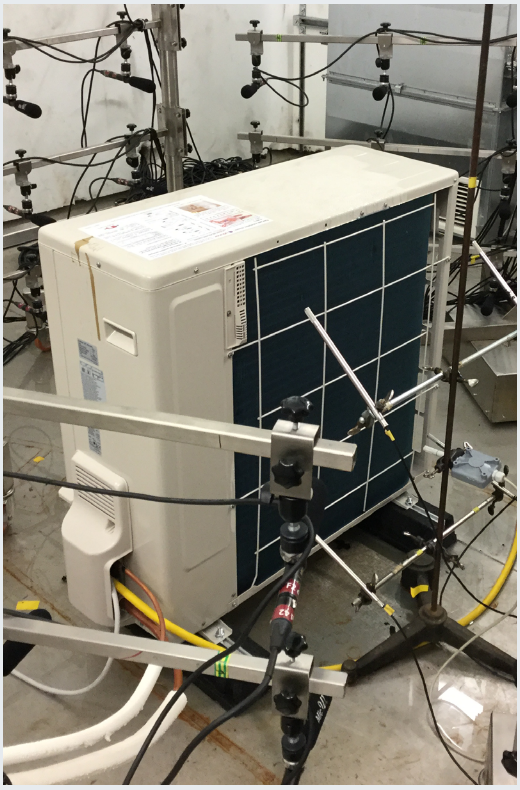


Fig. 2: Air-to-Water Heat Pump surrounded by the acoustic dome with more than 60 microphones installed in the climate chamber of AIT. [Source: AIT, Austria]

- Preparation of six Annex meetings on acoustics in the participating countries; three meetings held (Austria Vienna 06-2017, France Lyon 01-2018, Sweden, Borås, 06-2018), one planned (Denmark Aarhus 01-2019);
- Organization of a concluding international workshop and compilation of proceedings; planned at Mostra Convegno, Italy, in 2020;
- Worldwide dissemination of conclusions to heat pump manufacturers via already available dissemination media;
- Generation and distribution of Acoustic Guidelines for the different levels (Component Level, Unit Level, Application Level).

Overview of Tasks

Task 1: Legislation and standards – Gathering and comparison of acoustic regulations and standards, measurement techniques and certification schemes.

Task 2: Definition of heat pump units to be covered by the study – Compilation of a list of representative products to be used in the Annex.

Task 3: Identification of noise, at component and unit levels, and noise control techniques – Generation of an overview on component and unit noise, as well as design and control strategies.

Task 4: Analysis of the effect of operating conditions of heat pumps on acoustic behaviour.

Task 5: Heat pump installation and effects on surrounding environment - Focussing on acoustic perception, heat pump installation and its environmental effects will be investigated.

Task 6: Improved measuring and description of the acoustic performance – Discussion on future options for more detailed and relevant acoustic performance figures.

Task 7: Diffusion, dissemination – Preparation of Guidelines, recommendations and educational material on heat pump acoustics.

Key data
Project duration: April 2017 – March 2020

Operating Agent: Christoph Reichl, AIT Austrian Institute of Technology, christoph.reichl@ait.ac.at

Participating countries: France, Sweden, Austria, Italy, Germany and Denmark

Further information: http://heatpumpingtechnologies.org/annex51/ and Research Gate https://www.researchgate.net/project/IEA-HPT-Annex-51-Acoustic-Signatures-of-Heat-Pumps

Annex website
http://heatpumpingtechnologies.org/annex51/

Contact
Operating Agent is Christoph Reichl, christoph.reichl@ait.ac.at, AIT Austrian Institute of Technology in Austria.

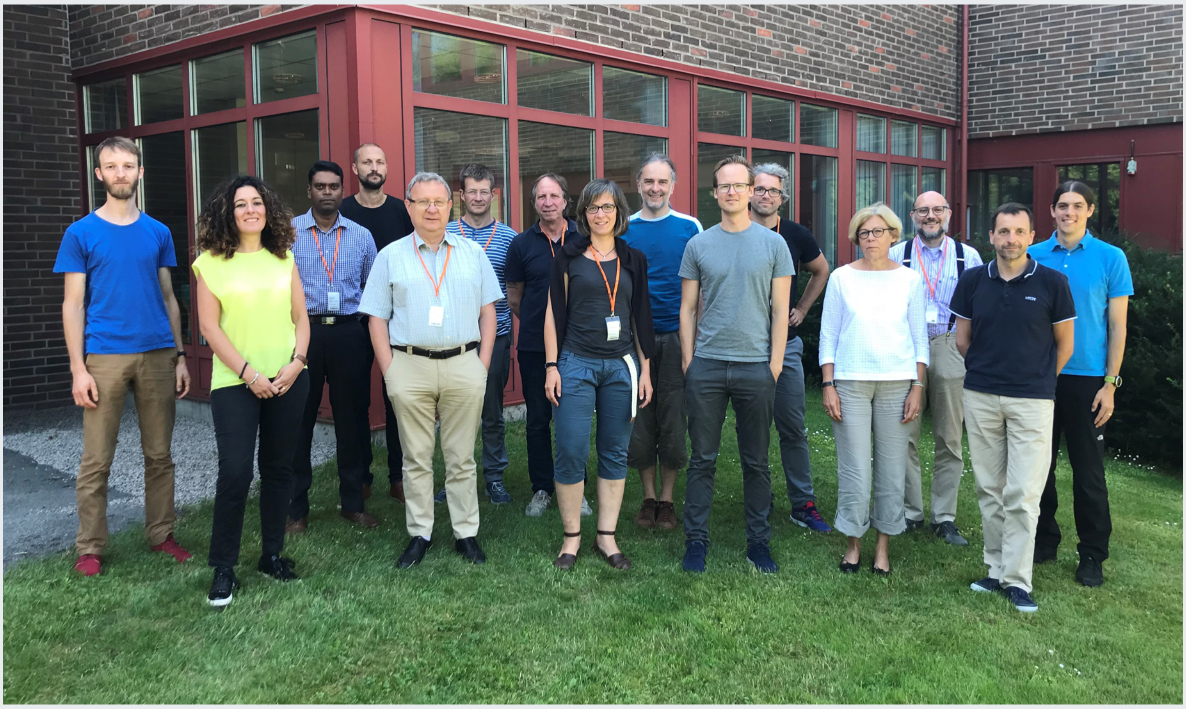


Fig. 3: The IEA HPT TCP Annex 51 team at the 3rd working meeting at RISE in Borås, Sweden [Source: The IEA HPT TCP Annex 51 team]

Heat pump market report for Italy

Maurizio Pieve and Raniero Trinchieri, ENEA, Italy

This paper presents an overview of the Italian heat pump market over the past 10 years. It provides a brief explanation of the statistical methodology used for accounting for air-source heat pumps in order to correctly filter out those units installed as auxiliary systems only. It also analyses the position of the Italian market in a European context, followed by a breakdown by type with relevant remarks. Finally, a brief outline is given of the current potential of the heat pump market, including incentives and barriers to further deployment.

Introduction

Heat pump systems used for space heating and cooling and for domestic hot water production are today increasingly playing a leading role in European policies on energy efficiency, both in buildings and in end-use technologies, as well as in the fight against atmospheric pollution. Such trends are confirmed by more and more encouraging sales trends that are currently pushing towards greater electrification of end uses. Compared with combustion systems, heat pump technologies can offer many advantages in this context – as recently summarized by Fernando Pettorossi, coordinator of the Italian association Assoclima [1]. These can be divided into environmental benefits, techno-economic benefits and safety benefits.

The first include a reduction in fossil fuel consumption, an increase in the use of renewable sources and an absence of local emissions or particulates in the environment. The second set of benefits comes from using a unique system in the building for heating, domestic hot water and cooling, with just one electricity bill for all these uses and lower maintenance costs. Finally, no more combustion in the building means no risk of fire or explosion, as well as no need for a chimney.

The Italian heat pump market has great potential for improvement in both qualitative and quantitative terms. It is currently dominated by reversible air-source heat pumps (ASHPs), mainly used for summertime cooling. However, the Italian climate – especially in central to southern areas – could allow the use of ASHPs as the only heating system, for both space heating and domestic hot water production. Opportunities for this would be even greater if the technological development of hybrid heat pumps (i.e., solar HP systems) and low-temperature ASHPs was completed. Moreover, the ASHPs on the market in recent years have meant that as long ago as 2014 Italy had already succeeded in achieving and even surpassing the share of energy from renewable sour-

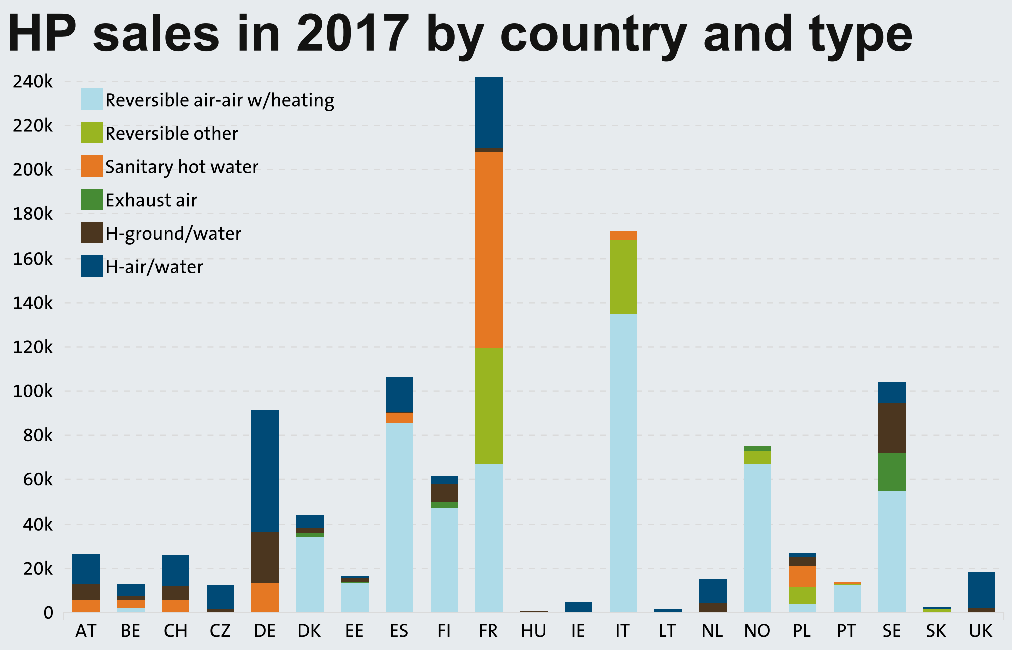


Fig. 1: Heat pump market in the EU-21 by type and by country in 2017 [5]

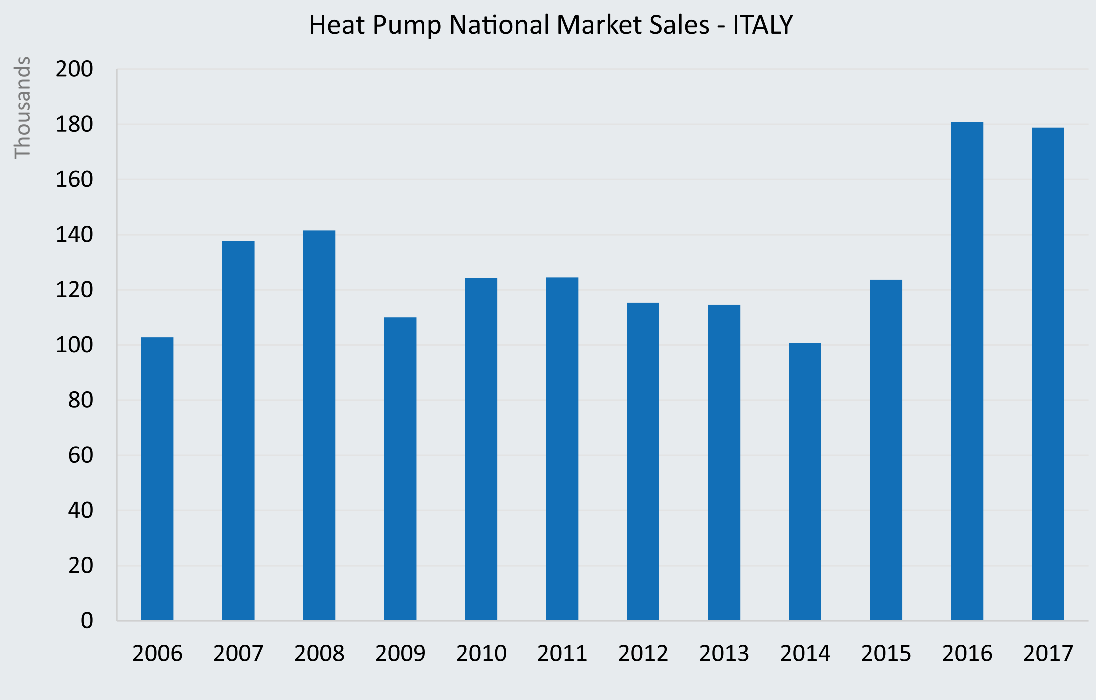


Fig. 2: Heat pump market in Italy, 2006–2017 [3,5]

ces planned by the National Action Plan for Renewable Energy (PAN) for the year 2020 [2].

Statistical issues

In the case of heat pumps used for space heating, some clarification is needed concerning the accounting methods used for reversible ASHPs. In Italy, Technical Annex VIII to Ministerial Decree DM 14 January 2012 lays down the methodology to be used when reporting heat pump use in the system used for national energy statistics. The achievement of national targets, measured as the RES share for heating and cooling of final energy consumption, fulfils the requirements of Legislative Decree D.Lgs.28/2011, which adopts EU Directive 2009/28/EC on the promotion of the use of energy from renewable sources. Annex VIII is based on a technical study of the Italian market that experts deem to be representative for the rest of the Mediterranean region as well.

Where the share of cooling-only air-to-air units cannot be determined, as in the Italian case, only a small fraction of the air-to-air units (about 9.5 %) are included in the statistics and the calculation. More specifically, to reduce any risk of over-estimation in the national RES contribution statistics, reversible air-to-air systems with a capacity of less than 17 kW – usually known as “monosplit” and “multisplit” systems – were accounted for at a level of initially 9.5 % of global sales, subsequently revised to 10.2 % as of 2012, since only this fraction is intended to be used as the main heating system.

The same principle is expressed in European Commission Decision 2013/114, where it is remarked that reversible heat pumps in warm and, to some extent, average climates are often installed for the purpose of cooling the indoor environment, even though they are also used to provide heating during the winter. Since the cooling demand in the summer is higher than the heating demand in the winter, the rated capacity reflects the cooling demand rather than the need for heating. As the installed capacity is used as an indicator of heating demand, it implies that the statistics on installed capacity will not reflect the capacity installed for heating purposes. Therefore a conservative reduction to 10 % is adopted for a warm climate, in terms of annual equivalent heat pump hours (HHP) – which are the assumed annual number of hours a heat pump has to provide heat at rated capacity. Indeed, in support of this, the EU Decision mentions the same Italian study.

The statistical methodologies described above are reflected in heat pump sales statistics. For instance, the European Heat Pump Association (EHPA) – which represents the majority of the European heat pump industry – follows the approach set out in the EU Directive, as previously detailed. Its sales data may therefore differ significantly from other sources, which include all equipment that is in any way comparable to a heat pump regardless of its main use (cooling mode, back-up heating mode, heating as unique system, etc.). In this regard, a comparison has been made between data from the EHPA and the Heat Pump Barometer EurObserv’ER [3] (a European monitoring project which measures the progress made by renewable energies in many sectors in the EU), with the 9.5 % correction applied to the air-to-air share. Good agreement was achieved between the two sources, so the EHPA reference will be adopted in the following.

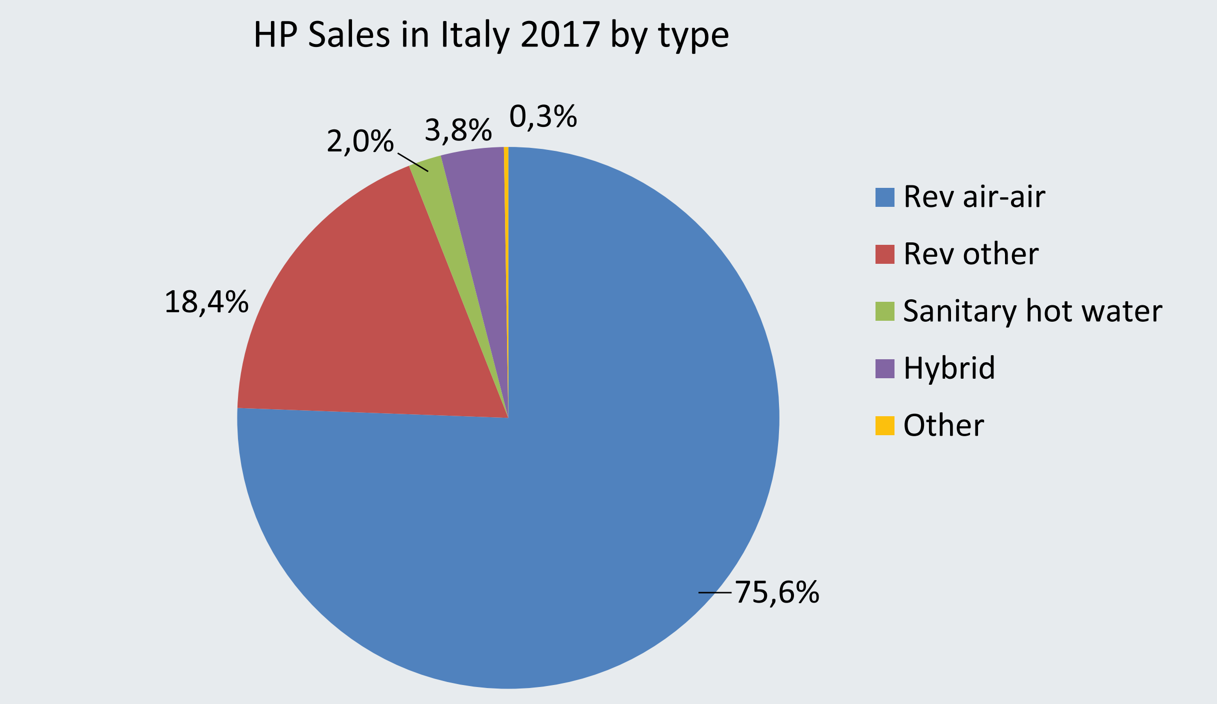


Fig. 3: Breakdown of the Italian heat pump market in 2017 [5,6]

The Italian heat pump market

In a European context, the Italian heat pump market is one of the largest: in the last 10 years it has been always the second largest market, with a share of between 13 % and 18 %. Figure 1 [5] shows the most recent (2017) composition by country (EU-21) and by type according to the EHPA. It is worth noting that, as expected, the market in Italy is composed largely of reversible air-sourced applications.

Over the last 10 years average annual sales of heat pumps in Italy were around 130,000, peaking in the last two years up to about 180,000 units. In 2015 and 2016 overall sales increased by 23 % and 46 % respectively compared with the previous year, as shown in Figure 2 [3,5]. The market was boosted by the introduction in 2014 of a special tariff that was available only to residential consumers using a heat pump as their main heating system, and also by other incentive mechanisms, although this tariff is not currently applicable to new applications. The increase in those years is also attributable to the weather conditions in recent summers.

The breakdown of heat pump sales in Italy shows a great prevalence of air-to-air split systems, as Figure 3 shows for the 2017 market, for the reasons detailed previously. In terms of the primary energy source, air covers almost all the market and accounts for around 97 %, followed by ground with almost 3 % and a negligible contribution by water [7]. Among heat pumps categorised as Reversible other in Figure 3, most are of the air/water type – i.e., with air as the source and water as the heat sink. Their sales volumes have almost tripled in the past 10 years (Figure 4), being close to 33,000 in 2017 [5,6] with an average yearly increase of more than 27 % between 2014 and 2017. It is worth bearing in mind that currently their market share is a quarter of the figure for air-to-air machines. As well as the matter of cost, such a low share of global heat pump sales may also be due to the practical infeasibility of retrofitting a space heating system without replacing radiators, which account for more than 90 % of current domestic equipment in households.

A positive trend can be seen for hybrid systems which combine a gas boiler and a traditional heat pump (smaller than usual) in a unique integrated system that guarantees best performance relative to climatic conditions. Although this is a recent technology, the increase in its spread is promising, with sales doubling in 2017 compared with 2015. Otherwise, domestic hot water production by means of a heat pump is still not a widespread technology, presumably for cost reasons: currently, a heat pump for domestic hot water production can be as much as eight times more expensive than a traditional electric boiler, depending on size and specific features. Finally, the market for ground-source heat pumps has been largely flat over the last 10 years, with average annual sales of less than 1,000 units [4] – despite the fact that Italy is in the top 10 countries in the world when it comes to exploiting geothermal heat for electricity and is one of the top in the EU for direct heat consumption from geothermal energy.

Potential and barriers

The sales rate per 1,000 households is a typical index used to measure the market penetration of a technology and its as yet unexpressed potential. In Italy, this index was almost 7 in 2017 [5] – a value comparable with a small group of mostly nearby countries. Compared to the countries of Northern Europe, however, it is 4–5 times lower, suggesting good potential for growth. The main barriers include energy prices, policy measures and incentives, and developments in the building sector, both in the construction of new buildings and in building renovations. In the last three years the Italian electricity-to-gas price ratio (the ratio between the price of electricity and the price for 1 kWh of useful heating energy delivered by natural gas) fluctuated between 2.3 and 3.3, with an average value of around 3 [8]. It should be recalled that a heat pump system has a comparative cost advantage over competing technologies whenever the seasonal performance factor (SPF) is higher than the energy price ratio.

In recent years Italy has increased incentives using three different mechanisms. One is what are known as "white certificates", which provide a grant proportional to the energy saving, depending on the final use (heating, cooling, DHW) and sector (industrial, civil). Another incentive, available only to private individuals, guarantees a tax rebate (up to 65 % of the investment) for replacing an old heating system or electric heater for DHW. Finally, the newest mechanism is called "Conto termico 2.0" (Thermal Account 2.0) and is aimed at public administrations, small enterprises, and private individuals, providing a cash grant for the installation of heat pumps that replace an old heating system. Heat pump installation meets the requirements for all three mechanisms described above, so the choice of the most appropriate will depend on the specific intervention.

A further barrier that has not yet been mentioned is lack of knowledge in the supply chain; for instance, the installer may not know the advantages of the technology or may not promote it adequately. Indeed, the technology requires an initial investment cost that is not negligible and which should be carefully explained to end-users so that they are aware of all the functionalities of a heat pump that can be exploited. When used for space heating and cooling and for domestic hot water production, heat pumps are the most efficient method from a primary energy standpoint – and their payback period can be cut to just a few years.

Conclusions

The Italian heat pump market is currently one of the most important in Europe, having grown from nothing 10 years ago to some 180,000 units sold last year. Potentially, further deployment can be expected since the penetration index is considerably lower than in the best-performing countries. After some years of relatively stable sales volumes, the Italian heat pump market recently experienced a substantial upturn – with annual increases of 23 % and 46 % respectively in 2015 and 2016. The leading sector remains air-to-air reversible domestic applications, which historically caught on as summer cooling machines, particular in view of Italy's warm climatic conditions in recent years. A promising trend can be seen for systems that are not air-to-air machines, with sales volumes having tripled over the last 10 years. Nevertheless, the current market share of these heat pumps is too small, essentially due to their high investment costs – even though the incentive rules introduced by the government have played a relevant role. In addition, the market could be boosted by players in the supply chain; particularly installers, who should act to increase end-users' awareness – so that they fully understand the benefits of choosing heat pumps, both in terms of environmental compliance and economic sustainability. heat pumps offer many advantages that will make them highly popular in France for some years. However, it remains difficult to predict exactly which applications that will develop, and at what speed.

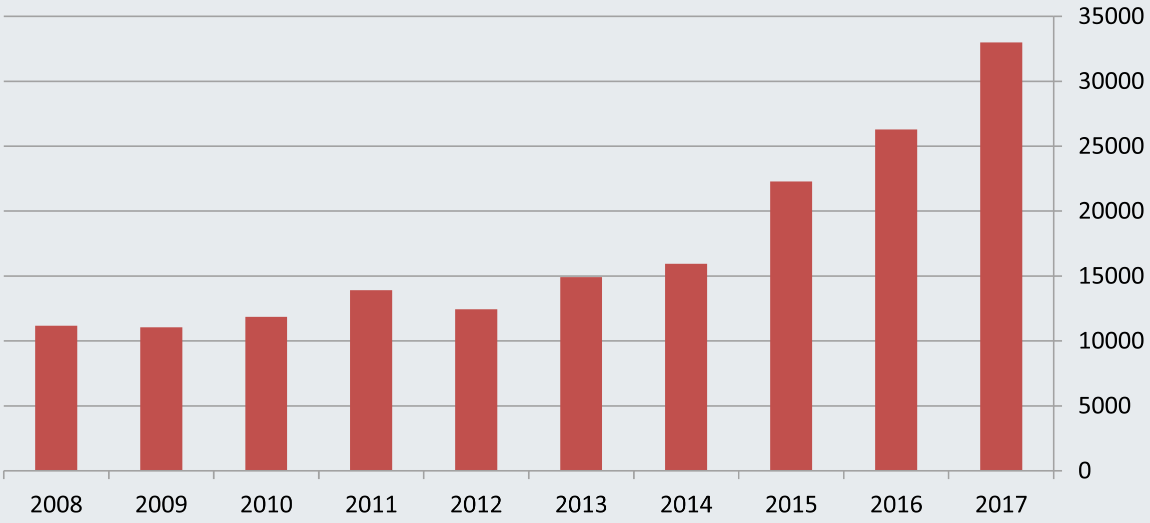


Fig. 4: Breakdown of the Italian heat pump market in 2017 [3,5,6]

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MAURIZIO PIEVE
Ph.D.
ENEA (National Italian Agency for New Technologies, Energy and Sustainable Economic Development)
Italy
maurizio.pieve@enea.it

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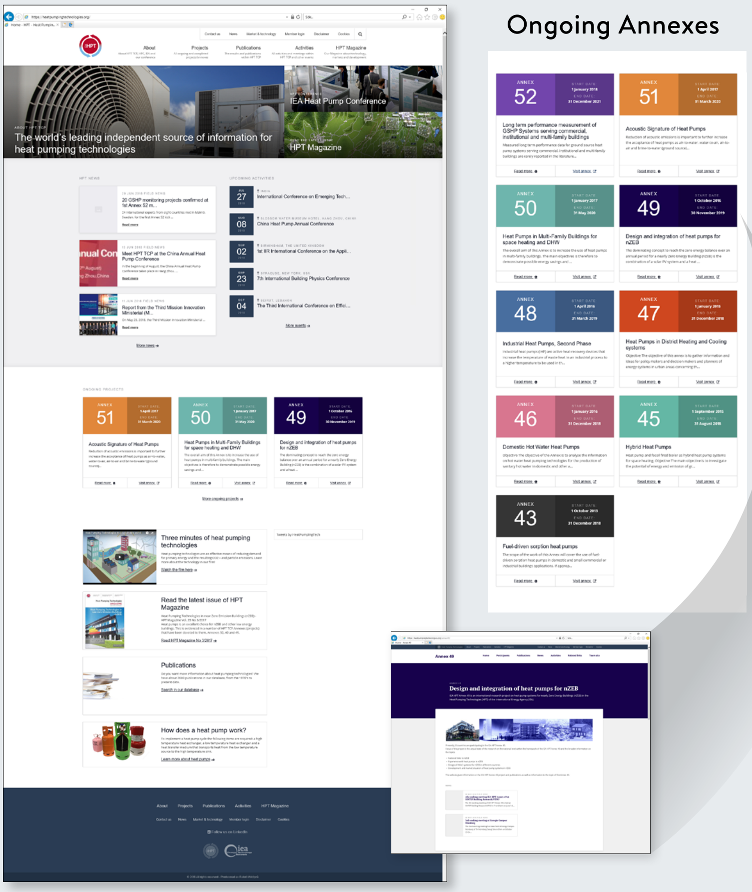
INFORMATION



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Seven burning questions about mildly-flammable refrigerants

Peter B. Sunderland – Univ. of Maryland, USA

Concerns about global warming are strong motivation to adopt new, lower global warming potential (GWP) halogen refrigerants that break down quickly in the atmosphere. This reactivity can present new hazards if these mildly-flammable refrigerants leak into residences where ignition sources are present. Seven questions about these refrigerants are addressed to offer insight into flammability test methods, ignition source viability, leak detectors, and hydrogen fluoride (HF) hazards.

Introduction

Since the phase-out of chlorofluorocarbon (CFC) and hydrochlorofluorocarbon (HCFC) refrigerants, beginning in 1987, most new heat pumps have used non-flammable hydrofluorocarbons (HFCs) as the working fluid. Unfortunately, these have high GWPs. The environmental impact is tremendous: on average, residential air conditioning systems leak 8.5 % of their charge annually into the atmosphere [1].

There are four safety classes of refrigerant flammability: 1, 2L, 2, and 3, in order of increasing flammability per standards ANSI/ASHRAE 34 [2] and ISO 817 [3]. Refrigerant charge limits generally decrease with increasing flammability class. During the next decade it is expected that most new residential heat pumps will transition to Subclass 2L halogen refrigerants, which are mildly flammable. These include R-32, R-143a, R-1234yf, R-1234ze, and many blends. Their fire hazards are the primary impediment to their adoption.

Subclass 2L refrigerants must meet three flammability requirements: a lower heating value (LHV) below 19 kJ/g; a lower flammability limit (LFL) above 100 g/m^3 or 3.5 %; and a laminar burning velocity below 10 cm/s [2-4]. All three requirements are determined by small-scale combustion tests. Tests at large scale indicate that 2L refrigerants are difficult to ignite and unlikely to produce strong blasts upon burning.

Seven Burning Questions

1. How are lower flammability limits (LFLs) measured?

The standard method for measuring refrigerant LFLs is ASTM E681. Results from ASTM E681 are tied not only to refrigerant classifications, but also to charge limits that are based on the LFL and the room size. Furthermore, it is the only test that can qualify a refrigerant as Class 1 (non-flammable).

ASTM E681 makes visual observations of premixed flames propagating in a 12 L glass vessel. The LFL is defined as producing flames that burn upward and outward along a 90° cone. Unfortunately, ASTM E681 suffers from relatively poor accuracy and disparate LFL determinations [5]. For example, the LFL for R-32 has been reported between 13.5 – 14.8 %.

Our research [5] has recommended five relatively simple changes to ASTM E681 that, if adopted, are expected to significantly improve the test's accuracy. For example, the vessel material should be transparent polycarbonate to avoid etching, venting should not be allowed during the measurement period, and the electrodes should be horizontal. The vessel assembly shown in Fig. 1 incorporates these changes.

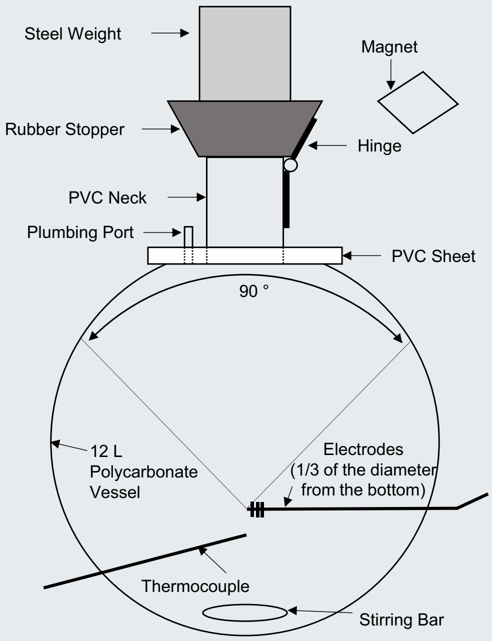

Fig. 1: Schematic of the proposed polycarbonate vessel assembly, reproduced from Ref. [5]. The 90° cone shown represents the location of a flame at the LFL.

Representative images of halogen refrigerant flames near their LFLs are shown in Fig. 2. Vertical electrodes (required by the existing standard) are seen to create a large hole in the top of the flame. Horizontal electrodes, facilitated by the design of Fig. 1, eliminate such holes and thus improve accuracy.

2.Can non-flammable refrigerants burn?

At room temperature they cannot, but there are two key scenarios where sufficient external heat is applied that Class 1 halogen refrigerants will burn exothermically and emit a large amount of hydrogen fluoride (HF). Many refrigerant leaks are accompanied by aerosolized lubricating oil. In the presence of a viable ignition source, this oil can ignite the surrounding Class 1 halogen refrigerant in a fireball.

If an external fire impinges on a refrigeration system with a Class 1 halogen refrigerant, this can weaken the containment and/or increase the internal pressure, resulting in a loss of containment. The resulting refrigerant jet will ignite if it encounters the flames.

3. Is it hard to ignite a Subclass 2L refrigerant?

Subclass 2L refrigerants are much harder to ignite than Class 3 refrigerants (such as propane and butane). This is principally because they have large quenching distances – on the order of 8 – 25 mm [5]. The minimum ignition energy for a typical 2L halogen is 10 J, compared to 3×10^{-4} J for methane. Between these energies, a typical static electric discharge releases 0.1 J. Thus, although 2L refrigerants can be ignited by open flames or unenclosed yellow-hot heating wires, they cannot be ignited by typical motors, electrical switches, or resistive heating devices such as toasters, hair dryers, and space heaters [6].

4. Can Subclass 2L refrigerants suppress some flames?

Yes. Testing in our lab has identified several scenarios where 2L halogen refrigerants suppress flames [6]. For example, when a smoldering cigarette is introduced into a stoichiometric 2L/air mixture, the cigarette quickly extinguishes. When a 2L halogen fills a chamber with good mixing, this extinguishes a candle flame before the LFL is reached (see Fig. 3). These observations are consistent with the findings of Ref. [7], which showed halogens can act as either fuels or suppressants depending on the conditions.

5. What can we learn from past experience with ammonia fires?

As discussed by Ref. [7], ammonia is a 2L refrigerant with flammability characteristics similar to 2L halogen refrigerants. Ammonia is too toxic for most heat pump applications. However, its flammability is well understood, and its historical safety record offers a wealth of information for future risk analyses of 2L halogen refrigerant systems. For example, large ammonia leaks have ignited and resulted in blasts powerful enough to cause structural damage. Ammonia may be a good surrogate for 2L halogen refrigerants in research tests because its products of combustion are far less toxic.

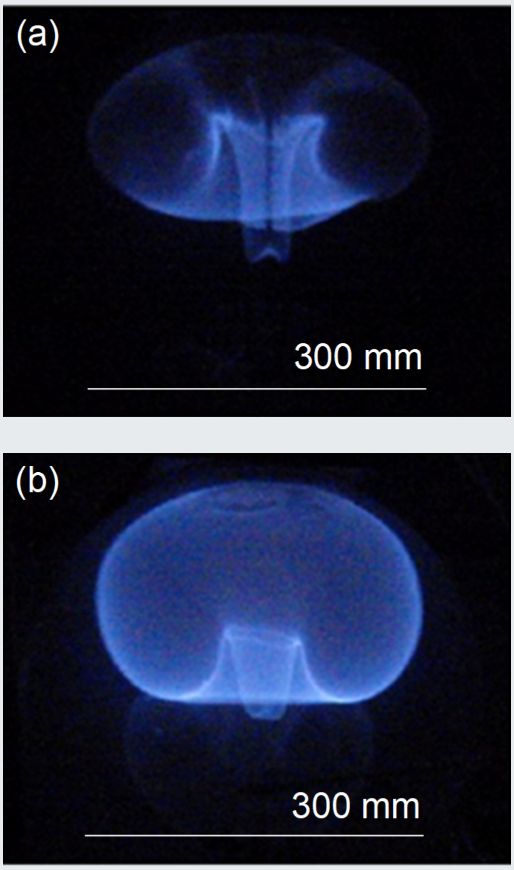

Fig. 2: Effect of electrode orientation on R-32/air flames near their flammability limit. Images (a) and (b) are for vertical and horizontal electrodes, respectively. Reproduced from Ref. [5].

Fig. 3: A candle flame undergoing extinguishment when R-32 is introduced with good mixing.

6. Do reliable area monitoring leak detectors exist?

Many technologies exist for detecting 2L halogen leaks [8]. These are normally optimized for either leak pinpointing or area monitoring. Pinpointing detectors are commonly used in servicing, where they are powered up for only a few minutes at a time. Reliable and affordable pinpointing detectors exist for 2L halogens.

Area monitoring detectors will be required for many future heat pump systems that use 2L refrigerants. These detectors will operate continuously, preferably without service for many years. Standards are being drafted that will require these detectors to have a 15 s (or shorter) response time to any concentration of 20 % (or higher) of the LFL [8]. Inexpensive detectors that meet these requirements do not yet exist. This gap may delay the release of these standards.

7. Is HF a major hazard?

Yes! For residential heat pump systems it could be a greater hazard than the other three flame hazards combined: secondary ignition of furnishings, blasts, and thermal injuries. HF volume fractions can be up to 50 % following a 2L halogen refrigerant fire. HF can be produced upon heating even with no flame present.

Two employees of a major research laboratory recently suffered HF injuries following test burns of 2L halogens. In one case an employee entered the burn room briefly during a test and without the required personal protective equipment. He later collapsed, presumably owing to cardiac arrest, and required hospitalization.

In another incident, an employee touched a wall interior to the burn room and immediately felt a burning sensation in his hand. There had been dozens of air changes, but a high concentration of HF persisted. This is surprising because no liquid water was present and HF has a boiling point of just 19.5 °C.

Subclass 2L fire hazards were discussed recently at a meeting of fire chiefs and fire marshals attended by the author. These experts expressed far more concern about the HF hazards than the other fire hazards associated with 2L halogen refrigerants. First responders, fire investigators, and remediation personnel will require specialized training and medical supplies when responding to fires involving 2L refrigerant leaks.

HF can also be produced when Class 1 halogen refrigerants encounter flames or heat. The key difference is that 2L refrigerants can ignite and burn on their own when there is a viable ignition source. An untrained resident or first responder may fully extinguish the fire with an extinguisher, only to perish later from contacting and/or inhaling the HF fumes.

Conclusions

Mildly-flammable halogen refrigerants are already being adopted owing to environmental concerns. These refrigerants present several new hazards, and further research is needed to address these. For example, the flammability limit test standard should be improved and new detectors should be developed. Perhaps their greatest hazard is the generation of toxic HF when these refrigerants burn.

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PETER B. SUNDERLAND
Professor
University of Maryland
USA
pbs@umd.edu
https://doi.org/10.23697/gfdx-3b69

Low GWP refrigerants for refrigeration and air conditioning systems in Japan

Kenji Matsuda, The Japan Refrigeration and Air Conditioning Industry Association (JRAIA), Japan

The type of refrigerants used for air conditioning and refrigeration purposes have changed significantly over the years, for environmental reasons. In Japan, this conversion started early. There, legislation dealing with global warming has been in place since 1988, also affecting regulation on refrigerants, since they historically have a high global warming potential. Currently, the step is taken toward refrigerants with low global warming potential. Unfortunately, these types of refrigerants present a new kind of challenge: they are often flammable and combustible. This safety risk can be handled for some applications, but for others, more expertise and analysis are needed.

Introduction

Measures to counter global warming are needed to preserve the ozone layer and protect the global environment. As a result, the chlorofluorocarbons used as refrigerants in refrigeration and air-conditioning systems have changed significantly. Chlorine, identified as a substance that destroys the ozone layer, is found in certain chlorofluorocarbons (CFCs) such as refrigerants R11, R12, and R502 and in the hydrochlorofluorocarbon (HCFC) refrigerants R22, R123, etc. These refrigerants have therefore been replaced by for instance hydrofluorocarbon (HFC) refrigerants R410A, R404A, R134a, etc., none of which contain chlorine. These are now gradually being replaced by products with a low global warming potential (low-GWP products).

Except in the case of ammonia refrigerants, past refrigerant conversions – from CFC to HCFC, then to HFC – did not raise concerns regarding flammability. However, moving to even lower-GWP refrigerants tends to weaken the chemical bonds between the atoms, increasing instability, which results in flammability. Finding ways to be able to use combustible refrigerants safely, while maintaining and improving energy-saving performance, is one of the largest challenges faced when converting refrigerants to combat global warming.

In Japan, the characteristics of flammable refrigerants have been clarified and risk assessments have been carried out for their use, in order to enact safety standards. In addition, the High Pressure Gas Safety Act which regulates safety standards for refrigeration and air-conditioning systems has been relaxed. International regulations such as ISO 5149, IEC 60336-2-40, and IEC 60336-2-89 have also been significantly revised. The movement to lower-GWP refrigerants in Japan to protect the global environment, the revisions to related laws and the current status of refrigerant conversion by product are detailed in Fig. 1.

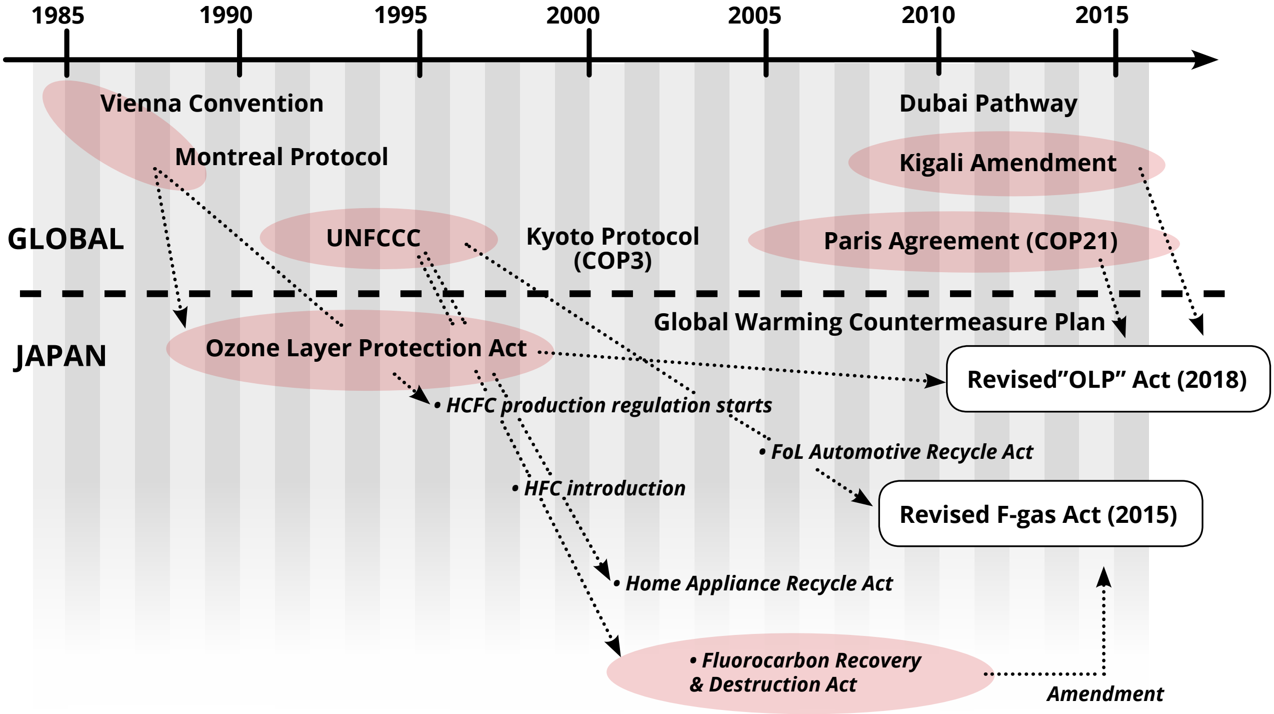

Fig.1. Timeline of regulations and protocols (relationship between global and Japanese acts)

Refrigeration and air-conditioning refrigerant policy in Japan and worldwide – current status

The regulation of chlorofluorocarbons originated from the publication of an article by American researchers Rowland et al. in Nature in 1974 [1], which described the ozone depletion phenomenon caused by specified chlorofluorocarbons. Further efforts to control the use of chlorofluorocarbons in refrigeration and air-conditioning systems began with the Montreal Protocol of 1987 and continued with the enactment of global warming countermeasures based on the Kyoto Protocol of 1997.

Japan subsequently launched the Promotion of Measures to Cope with Global Warming in 1998. In 1999, the Energy Saving Law was revised and the Top Runner Program was enforced by this law. To encourage the recovery and destruction of refrigerants, the Fluorocarbon Recovery and Destruction Act and the Home Appliance Recycling Act were enacted in 2001, followed by the Automobile Recycling Act in 2002.

The control of chlorofluorocarbon refrigerants that was set out in a series of international agreements and protocols has thus been accompanied by improved Japanese laws and early refrigerant conversion (Fig. 1).

In April 2015, the Fluorocarbon Recovery and Destruction Act was renamed the Act on Rational Use and Proper Management of fluorocarbons (fluorocarbon Reduction Act), clarifying the shared responsibility for managing refrigerants throughout their life cycle. This includes the production, use, management, reuse and destruction of refrigerants. The Act required manufacturers of refrigeration and air-conditioning systems to market products suitable for refrigerants with an average GWP within the limits set for specific products (Table 1). Products specified in the fluorocarbon Reduction Act (products which use fluorocarbons with stipulated target values and target years) must be produced by refrigeration and air-conditioning manufacturers as low GWP equipment. The GWP of these products is to be reduced with a view to energy saving, safety and economic efficiency. Target values and target years were therefore determined through discussions and approved by a national deliberative council.

In the international arena, the United Nations Climate Change Conference COP21 was held in Paris, France in December 2015. The resulting Paris Agreement set out an equitable and effective legal framework, effective from 2020 for all participating countries.

In response to the adoption of the Paris Agreement, Japan's Global Warming Prevention Headquarters drafted the Global Warming Countermeasures Plan. After being completed at the March 15, 2016 session of the Global Warming Prevention Headquarters, the Plan was adopted by the Cabinet on May 13, 2016. The Plan sets out a process for achieving a 26 % reduction in greenhouse gases by 2030 compared with fiscal year 2013, at the same time setting a goal of an 80 % reduction in greenhouse gas emissions by 2050.

The Kigali Amendment to the Montreal Protocol, adopted on October 14, 2016, introduced staged reductions (by CO_2 conversion) in the quantities of hydrofluorocarbons (HFC) produced and consumed. This will come into force on January 1, 2019 if it is approved by at least 20 countries. Through the Ozone Layer Protection Act amended on July 4, 2018, Japan has given a legal guarantee that it will regulate (allot) the production and consumption of ozone-depleting and global warming substances, which include specified fluorocarbons.

Noteworthy low-GWP refrigerants

Refrigerant conversion as a global warming countermeasure (rather than retrofitting or switching to refrigeration and air conditioning equipment newly designed and built for low GWP refrigerants) is a policy intended to minimize the GWP of fluorocarbons.

Low-GWP refrigerants include R32, R1234yf, and R1234ze(E), which are mildly flammable refrigerants (A2L: burning velocity of 10 cm/s or slower, a flammability

Designated Products	Target GWP (Weighted Average GWP)	Target year
Residential A/Cs (mini-Split)	750	2018
Commercial A/Cs (Split/smaller than 6HP)	750	2020
Larger Commercial A/Cs (Split/exclude VRF)	750	2023
Centrifugal (Turbo) Chillers	100	2025
Mobile A/Cs	150	2023
Condensing unit & refrigerating unit	1500	2025
Cold storage warehouses	100	2019
Urethane foam	100	2020
Dust blowers	10	2019

Two product categories will be added in April 2019

Table1. Regulations relating to F-gases in Japan

Refrigerant number	Safety class	Chemical formula or nominal composition of blends (mass-%)
R-12	A1	CCl_2F_2
R- 22	A1	$CHClF_2$
R-123	A1	$C_2HCl_2F_3$
R-13 I1	A1	CF_3 I (trifluoroiodomethane)
R-32	A2L	CH_2F_2
R-125	A1	CHF_2CF_3
R-134a	A1	CH_2FCF_3
R-143a	A2L	CH_3CF_3
R-245fa	B1	$CHF_2CH_2CF_3$
R-404A	A1	R-125(44.0%) / R-143a(52.0%) / R-134a(4.0%)
R-407C	A1	R-32(23.0%) / R-125(25.0%) / R-134a(52.0%)
R-407H	A1	R-32(32.5%) / R-125(15.0%) / R-134a(52.5%)
R-407I	A1	R-32(19.5%) / R-125(8.5%) / R-134a(72.0%)
R-410A	A1	R-32(50.0%) / R-125(50.0%)
R-417A	A1	R-600(3.4%) / R-125(46.6%) / R-134a(50.0%)
R-422D	A1	R-600a(3.4%) / R-125(65.1%) / R-134a(31.5%)
R-427B	A1/A1	R-32(20.6%) / R-125(25.6%) / R-143a(19.0%) / R-134a(34.8%)
R-444A	A2 L	R-32(12%) / R-125(5%) / R-1234ze(E)(83%)
R-445A	A2 L	R-744(6%) / R-134a(9%) / R-1234ze(E)(85%)
R-446A	A2 L	R-32(68%) / R-1234ze(E)(29%) / R-600(3%)
R-447A	A2 L	R-32(68%) / R-125(3.5%) / R-1234ze(E)(28.5%)
R-447B	A2 L	R-32(68%) / R-125(8%) / R-1234ze(E)(24%)
R-448A	A1	R-32(26.0%) / R-125(26.0%) / R-134a(21.0%) / R-1234ze(E)(7.0%) / R-1234yf(20.0%)
R-449A	A1	R-32(24.3%) / R-125(24.7%) / R-134a(25.7%) / R-1234yf(25.3%)
R-451A	A2L	R-1234yf(89.80%) / R-134a(10.20%)
R-451B	A2L	R-1234yf(88.80%) / R-134a(11.2%)
R-452A	A1	R-32(11.0%) / R-125(59.0%) / R-1234yf(30.0%)
R-452B	A2 L	R-32(67.0%) / R-125(7.0%) / R-1234yf(26.0%)
R-454A	A2 L	R-32(35%) / R-1234yf(65%)
R-454B	A2 L	R-32(68.9%) / R-1234yf(31.1%)
R-454C	A2 L	R-32(21.5%) / R-1234yf(78.5%)
R-455A	A2 L	R-744(3.0%) / R-32(21.5%) / R-1234yf(75.5%)
R-457A	A2 L	R-32(18%) / R-1234yf(70%) / R-152a(12%)
R-459A	A2 L	R-32(68.0%) / R-1234yf(26.0%) / R-1234ze(E)(6.0%)
R-459B	A2 L	R-32(21.0%) / R-1234yf(69.0%) / R-1234ze(E)(10.0%)
R-460A	A1	R-32(12.0%) / R-125(52.0%) / R-134a(14.0%) / R-1234ze(E)(22.0%)
R-460B	A1	R-32(28.0%) / R-125(25.0%) / R-134a(20.0%) / R-1234ze(E)(27.0%)
R-463A	A1	R-744(6.0%) / R-32(36.0%) / R-125(30.0%) / R-1234yf(14.0%) / R-134a(14.0%)
R-466A	A1	R-32(49.0%) / R-125(11.5%) / R-13I1(39.5%)
R-514A	B1	R-1336mzz(Z)(74.7%) / R-1130(25.3%)
R-516A	A2L	R-1234yf(77.5%) / R-134a(8.5%) / R-152a(14.0%)
R-1224yd(Z)	A1	cis-CHCl=CFCF3
R-1233zd	A1	$C_3H_2ClF_3$
R-1233zd(E)	A1	
R-1234yf	A2L	CF_3 CF= CH_2
R-1234ze(E)	A2 L	CF_3 CH= CHF
R-1336mzz(E)	A1	trans-CF3 CH= CHCF3
R-290	A3	CH_3 CH_2 CH_3
R-600a	A3	$CH(CH_3)_2 CH_3$
R-744	A1	CO_2

Table 2. List of conventional and alternative refrigerants

limit over 3.5 vol-% (or 0.10kg/m^3) and heat of combustion lower than 19 MJ/kg). These, and many other refrigerants that are mixtures of these, are listed in ASHRAE Standard 34 (Table 2).

The listed refrigerants are composed of a mixture of R134a, R125, R152a, R290 (propane), R600 (isobutane), R744 (carbon dioxide), etc., based on R32, R1234yf, and R1234ze(E). Many refrigerants in refrigeration and air-conditioning systems, such as R410A, R134a, R404A, and others considered to be non-flammable, were classified in safety category A1 in ISO 817. If low-GWP refrigerants are to be used highly efficiently and safely in the future, it is imperative to evaluate mixed refrigerants that have been classified as A2L, A2, etc.

Introduction to lower-GWP products

Table 3 shows the status of refrigerant conversion for the major product categories in Japan. To the left of the arrows are refrigerants that are currently being used or that have been used previously. To the right of the arrow are refrigerants that have been introduced in order to lower GWP. A question mark (?) to the right of the arrow means that although a lower-GWP refrigerant is being sought, at this stage either there is no appropriate refrigerant or so many challenges still exist that it is impossible to specify an alternative.

For the most part, residential air-conditioners have been converted to R32. Small commercial air- conditioners are also being converted to R32. However, for VRF and other machines that require large quantities of refrigerant, the use of a low-GWP refrigerant that is flammable is not appropriate. Enacting and publicizing control standards to ensure safety is expected to take a significant timeframe to complete. For this reason, low-GWP machines of this type have made little headway in the market.

Residential water heaters, which are machines with a low water-heating capacity, have appeared on the market as R32 models, but residential-use heat pump-type water heaters known as "eco water heaters" use a carbon dioxide refrigerant. Commercial water heaters, on the other hand, use R410A and a carbon dioxide refrigerant. Systems requiring high-capacity water heating and systems that recover, reheat, and reuse hot water use R410A for the sake of system efficiency. Machines that use R454C (with a low GWP of 149) as an alternative refrigerant to replace R410A have also been launched. The reaction of the market will determine whether R454C becomes more mainstream.

For turbo chillers, low-pressure refrigerants (R1233ze(E), R1224yd(Z), R514A) and high-pressure refrigerants (R1234ze(E), R1234yf) have appeared and are already available on the market. Even after refrigerant conversion, there is only a slight decline in performance and no extensive changes to the design of the machines are required. It is assumed that conversion to these refrigerants will continue in the foreseeable future.

Chillers, on the other hand, are used over a wide range of temperatures and are equipped with many types of compressors. A variety of refrigerants match these specifications, making it impossible to select and evaluate appropriate products.

As for refrigeration and cold storage equipment, products that use natural refrigerants such as carbon dioxide or isobutane are on the market, but only in extremely small numbers. For condensing units, machines using carbon dioxide refrigerant have been put on the market, but they do not ensure sufficient energy-saving performance in all usage ranges. They are often used in new systems because existing pipes cannot be used. For these reasons, many condensing units use fluorocarbon refrigerants; machines that use R448A, R449A, R407H, R463A, and other A1 refrigerants (i.e., refrigerants with a GWP of 1,500 or lower) have been released. However, no refrigerants with a GWP of less than 1,000 have appeared on the market. Refrigerants R448A and R449A have begun to be used as retrofit refrigerants in Europe, for example, but in Japan they are used in newly designed machines.

Refrigerants for automobile air-conditioners have been converted from R134a to R1234yf, but the spread of hybrid and electric automobiles has been accompanied by a reduction in the heat source used for heating, making it necessary to convert automobile air-conditioners to the heat pump model. As a result, automobile air-conditioners using carbon dioxide refrigerant are beginning to be used in some automobile models. Automobile air-conditioners could potentially be refrigerant-converted not only to fight global warming, but as a side effect of the trend towards the use of this kind of heat pump.

Domestic refrigerators and vending machines have already been converted to low-GWP refrigerants (R600a, carbon dioxide, R1234yf, etc.).

Outlook

Global warming countermeasures present huge challenges both within Japan and beyond. Improving energy-saving performance, converting to lower-GWP refrigerants and taking steps to prevent the leakage of refrigerants from equipment are all important areas for the refrigeration and air-conditioning industry to address.

The Paris Agreement and the Kigali Amendment require the use of HFCs to be reduced. Mildly flammable refrigerants that are slightly combustible (i.e., R32, R1234yf, R1234ze(E), and refrigerants that are mixtures of these) and carbon dioxide refrigerants that are higher pressure than fluorocarbons will often be used. Hydrocarbon refrigerants in the refrigeration and cold storage field will also be desirable as next-generation refrigerants. There are advantages and disadvantages to both that need to be considered. The number of refrigerants that must be handled more carefully than in the past, specifically to ensure safety, is rising.

For the refrigeration and air-conditioning industry to safely use flammable refrigerants with which it has little past experience, the safety risk must be evaluated and any dangers analyzed and mitigated. It is imperative that

Product Category	**Number of Units** In fiscal year 2017 (x1,000)	**Conventional Refrigerants → Alternatives**
Residential A/Cs	9,054.6	R410A → R32 → ?
Commercial A/Cs	827.1	R410A → R32 (for small single split models) → ?
Gas engine-driven A/Cs	28.7	R410A → ?
Residential H/P Water heaters	446.7	CO_2 (R744) / R32
Commercial H/P Water heaters		R410A → CO_2 (R744) / R454C
Water Chilling Units	12.2	R410A / R407C / R404A /R134a →?
Centrifugal (Turbo) Chillers	0.266	LP: R245fa → R1233zd(E) / R1224yd(Z) / R514A HP: R134a → R1234ze(E) / R1234yf
Commercial Built-in Ref. Cabinets	184.8	R404A / R410A /R134a → ? R600a / CO_2 (R744)
Commercial Ref. Cabinets/split	128.0	R404A →R410A →R448A / R449A / R407H / R463A → ? CO_2 (R744)
Condensing Units	93.4	
Refrigeration Units	28.3	R404A / R410A / R134a → ?
Automobile A/Cs	(4,700)	R134a → R1234yf (CO_2 (R744))
Vending Machines	(320)	R404A / R134a → R600a / CO_2 (R744) / R1234yf
Domestic Refrigerators	(4,400)	R600a

Table 3 Low-GWP alternatives and products

the industry collaborates with academic experts and regulatory authorities that are highly specialized and already possess this knowledge.

Using evaluation and analysis technologies to risk-assess mildly flammable refrigerants, along with safety evaluations and analyses carried out through industry/government/academic cooperation in Japan, could be a powerful force driving the conversion to low-GWP refrigerants. This is one way to counter global warming, which has now become a worldwide challenge.

KENJI MATSUDA
Senior Manager
The Japan Refrigeration and Air Conditioning Industry Association (JRAIA)
Japan
matsuda@jraia.or.jp
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Performance of centrifugal chiller and development of heat pump using a low-GWP refrigerant

Ryosuke Suemitsu, Mitsubishi Heavy Industries Thermal Systems, Japan

The manufacture of HFCs has been restricted by increasingly stringent regulations, with the aim of reducing global warming. Low-GWP refrigerants are needed for air-conditioning and refrigeration equipment. We have developed and commercialized centrifugal chillers using the low-GWP refrigerant R-1234ze(E) for capacities from 1055 to 17581 kW, and using R-1233zd(E) for capacities from 527 to 2461 kW. We have also developed a centrifugal heat pump system that is capable of using a low-GWP refrigerant to produce pressurized hot water at 200 °C, with a coefficient of performance (COP) of 3.5.

Introduction

In December 2015, the 21st Session of the Conference of the Parties to the United Nations (UN) Framework Convention on Climate Change (COP 21) adopted the Paris Agreement, according to which every country is to update and submit its own reduction target every five years. Furthermore, in October 2016, the Kigali Amendment to the Montreal Protocol was ratified, obliging signatory countries to curb the production of hydrofluorocarbons (HFC) and gradually reduce their consumption. For refrigeration and air-conditioning equipment, Regulation (EU) No 517/2014 on fluorinated greenhouse gases (the F-gas Regulation) in Europe, and the Act for Rationalized Use and Proper Management of CFCs and HFCs in Japan, were designed to reduce the environmental impact of these gases.

HFC refrigerants with a high GWP, such as R-134a, R-245fa, etc., have been replaced by new types of low-GWP refrigerants. We use R-134a as the refrigerant of centrifugal chillers and heat pumps, so there is a need to switch to low GWP refrigerants in air-conditioning and refrigeration equipment. In order to investigate whether the low GWP refrigerants are suitable for the refrigeration and air conditioning equipment, we must verify several aspects such as their physical properties, stability, toxicity, flammability, and availability. The choice of refrigerant depends on the capacity, compressor type, operating temperature, and other conditions of the refrigeration and air-conditioning equipment, and the alternative refrigerant must have the following characteristics:

- Environmental factors: Non-ozone depleting substance, GWP ≤ 100.
- Physical properties: Cycle efficiency equivalent to that of HFC refrigerants. Design pressure should not be excessively high.
- Low toxicity, and no or mild flammability.
- Availability: Low-GWP refrigerants have applications other than refrigeration and air-conditioning equipment, so there must be an adequate level of production and cost-effectiveness .

A range of double-bond olefin refrigerants was considered. Table 1 shows a comparison of HFC and olefin refrigerants. The GWPs of the olefin refrigerants range from 0 to 2, and their cycle efficiencies are equivalent to those of HFC refrigerants.

Design of centrifugal chiller using low GWP refrigerant

Currently, R-134a is used as refrigerant for centrifugal chillers. Refrigerant R-1234ze(E) is mildly flammable, R-1233zd(E) is non-flammable, and both are of low toxicity. R-1234ze(E) and R-1233zd(E) can be used as a foaming agent and an aerosol, so these offer availability and cost-effectiveness, and the physical properties of R-1234ze(E) are similar to those of R-134a. We therefore selected R-1234ze(E) as the refrigerant for the large-capacity systems from 1055 to 17581 kW.

R-1233zd(E) has a better cycle performance than R-134a and other olefins in Table 1, and its physical properties are similar to those of R-245fa. However, the gas specific volume is about five times that of R-134a – requiring increased volume to accommodate the compressor, evaporator, and condenser. A more advanced and compact chiller design would allow its replacement with R-1233zd(E) centrifugal chillers.

Centrifugal compressor

To minimize the compressor volume, the compressor was designed for a large gas flow rate. A large gas flow rate tends to lower the adiabatic efficiency. The optimal shape of the leading/trailing edge of the impeller blade, the blade angle distribution, the shape of the flow path of the impeller inlet portion, and the shape of the inlet guide vane were therefore optimally determined by a Computational Fluid Dynamics (CFD) analysis. As a result, the adiabatic efficiency was equal to or higher than that of R-134a, and the gas flow rate could be increased by about 30 % with the same impeller diameter.

Refrigerant	HFCs		Olefins			
	R-134a	**R-245fa**	**R-1234yf**	**R-1234ze(E)**	**R-1233zd(E)**	**R-1336mzz(Z)**
Global warming potential (GWP)[*1]	1300	858	<1	<1	<1	2
Ozone depleting substance[*2]	no	no	no	no	no	no
Safety class[*3]	A1	B1	A2L	A2L	A1	A1
Standard boiling point [°C][*4]	-26.1	15.0	-29.5	-19.0	18.3	33.5
Critical point [°C]	101.1	153.9	94.7	109.4	166.5	171.4
Saturated pressure (@6 °C)[*4][kPa(G)]	260.7	-314.8	283.9	167.3	-39.1	-68.5
Saturated pressure (@38 °C)[*4][kPa(G)]	861.9	133.2	866.4	624.3	100.8	18.0
Saturated vapor specific volume (@6 °C) [m^3/kg][*4]	0.0564	0.2409	0.0467	0.0694	0.2770	0.4205
Saturated vapor specific volume (@70 °C) [m^3/kg][*4]	0.0087	0.0298	0.0076	0.0109	0.0370	0.0469
Theoretical COP[*4][*5]	7.23	7.14	7.11	7.26	7.47	7.44

Table 1: Comparison of HFCs and olefins
**1: IPCC Fifth Assessment Report *2: Montreal Protocol *3: Refrigerant Safety Classification Standard ASHRAE 34*
**4: Reference Fluid Thermodynamic and Transport Properties Database (REFPROP) Version 10.0 *5: Refrigeration cycle efficiency with single-stage cycle, evaporation temperature 6 °C, condensation temperature 38 °C, supercooling 4 °C, adiabatic efficiency 90 %.*

Evaporator and condenser

We use shell-and-tube type heat exchangers, specifically the flooded type, in our evaporators. As the refrigerant gas flow rate increases, the pressure drop, performance deterioration due to dry-out in the evaporator and carry-over to the compressor should be carefully considered. We therefore conducted thermo-fluid analysis to optimize the arrangement of tube bundles, the direction of water flow, and the shell dimension. By comparing the thermo-fluid analysis at the early design stage with the verification evaluation on the prototype machine, we optimized the arrangement of tube bundles, the direction of water flow, and the shell dimension, and determined a compact shape and their combinations. As a result, the volume of the evaporator and condenser is reduced to 120 % compared with the R-134a heat exchanger, and the outside heat-transfer coefficient of the evaporator and condenser registers no more than a 10 % decrease in the rated condition (703 kW system).

Verification of centrifugal chiller

A centrifugal chiller with the component design described in the previous sections was manufactured, and a verification test was carried out. Table 2 shows the rated COPs and the installation area designed based on the verification experiment results, comparing the developed equipment and the conventional R-134a equipment. Under the rated condition (703 kW system), performance improved by about 3 % compared with the conventional system. Moreover, the refrigerant gas specific volume is about five times that of R-134a, but the installation area was possible to be kept within about 105 % of the conventional throughout the range from 527 to 2461 kW.

Comparison of rated COP and installation area

Chilled water capacity [kW]		527–879	879–1231	1407–1758	1758–2461
Chilled water temperature [°C]		12.0 → 7.0			
Cooling water temperature [°C]		32.0 → 37.0			
Starting method [-]		Inverter			
Rated capacity [kW]		703	1055	1407	2110
Rated COP [-]	Conventional	6.1	6.2	6.1	6.2
	Developed	6.3	6.3	6.3	6.2
	Developed/Conventional	103%	101%	102%	100%
Installation area [m^2]	Conventional	5.55	6.30	8.36	8.82
	Developed	5.83	6.61	8.48	9.10
	Developed/Conventional	105.0%	104.9%	101.4%	103.2%

Table 2.

Design of heat pump using low-GWP refrigerant

Heat pumps are increasingly being used to supply hot water and heating in the household sector, but awareness in the industrial sector has been slower. The demand for high-temperature heat and reuse of waste heat is comparatively strong in mechanical and chemical industries, and the adoption of exhaust heat recovery heat pumps offers great potential for improved energy efficiency and a reduction in CO_2 emissions. High temperature heat pump systems capable of producing pressurized hot water at 200 °C with COPs of 3.5 or more are part of the research and development program of Japan's New Energy and Industrial Technology Development Organization (NEDO). These naturally require low-GWP refrigerants capable of operating at high temperatures.

Refrigerant and lubricant oil

When selecting the refrigerant and lubricant oil, the operating temperature range of the heat pump must be considered. This requires the following physical properties:

- Stability at high temperature: Prevention of isomerisation and decomposition at the operating temperature of the heat pump.
- Standard boiling point: The compressor volume should not be too small for the adiabatic efficiency, and the design pressure should not be too high.
- Critical point: The critical temperature should be higher than the operating temperature to improve the efficiency of the cycle.

The lubricant oil must maintain its stability at high temperatures and have the required temperature-dependent solubility in the refrigerant, viscosity, and other factors.

As a first step, we investigated an exhaust heat recovery heat pump which can heat pressurized water to 160 °C using a low-GWP refrigerant. The vapor specific volume of R-1234ze(E) is small and the stability of R-1233zd(E) is poor at 175 °C. Refrigerant R-1336mzz(Z) has a larger vapor specific volume than other olefins in Table 1 and good stability at up to 250 °C, so R-1336mzz(Z) was selected for the 160 °C application.

The lubricant oil was also selected as for the heat pump using R-1336mzz(Z). Synthetic oil is commonly used with non-chlorine refrigerants such as HFCs. The polyol ester (POE) oil was therefore selected because of the stability of R-1336mzz(Z). Table 3 shows the results of accelerated thermal stability testing for the 160 °C application, demonstrating stability at 220 °C. We estimated the replacement period of the lubricant oil, but this is not long enough for 200 °C applications. Moreover, the kinetic viscosity and solubility are 175 % and 167 % compared with the requirements for bearings in applications of up to 160 °C.

We intend to develop heat pumps targeting an outlet temperature of 200 °C. R-1336mzz(Z) does not have a large enough vapor specific volume at that temperature to use with the centrifugal compressor. For higher temperatures, we will take appropriate refrigerants and lubricant oils from among the refrigerant candidates, evaluate their stability, safety and physical properties in parallel, and select the best refrigerants.

Equipment design

A two-stage compression economizer cycle is used to produce water at 90 °C in existing heat pump designs. However, a high temperature heat pump using the two-stage economizer cycle cannot achieve the target COP of 3.5. A two-stage compression bleed cycle shown in Fig. 1 was adopted to achieve the target COP. The bleed cycle is highly efficient as it uses some of the refrigerant gas discharged from the low-stage compressor for intermediate heating. The compressors were designed for a high head and large volume flow rate, to reduce the number and volume of the compressors. CFD analysis was used to optimize the

Accelerated thermal stability testing for 160 °C applications

Test condition				Result
R-1336mzz(Z):Oil	Temperature [°C]	Duration [h]	Air/Moisture [ppm]	Acid Value [g KOH/kg]
50:50	200	168	0 / 0	0.01
50:50	200	168	100 / 1000	0.01
50:50	220	168	0 / 0	0.01
50:50	220	168	100 / 1000	0.01
50:50	220	336	0 / 0	0.25
50:50	220	336	100 / 1000	0.23
50:50	220	672	0 / 0	0.55
50:50	220	672	100 / 1000	0.45
50:50	250	168	0 / 0	1.37
50:50	250	168	100 / 1000	2.25

Table 3.

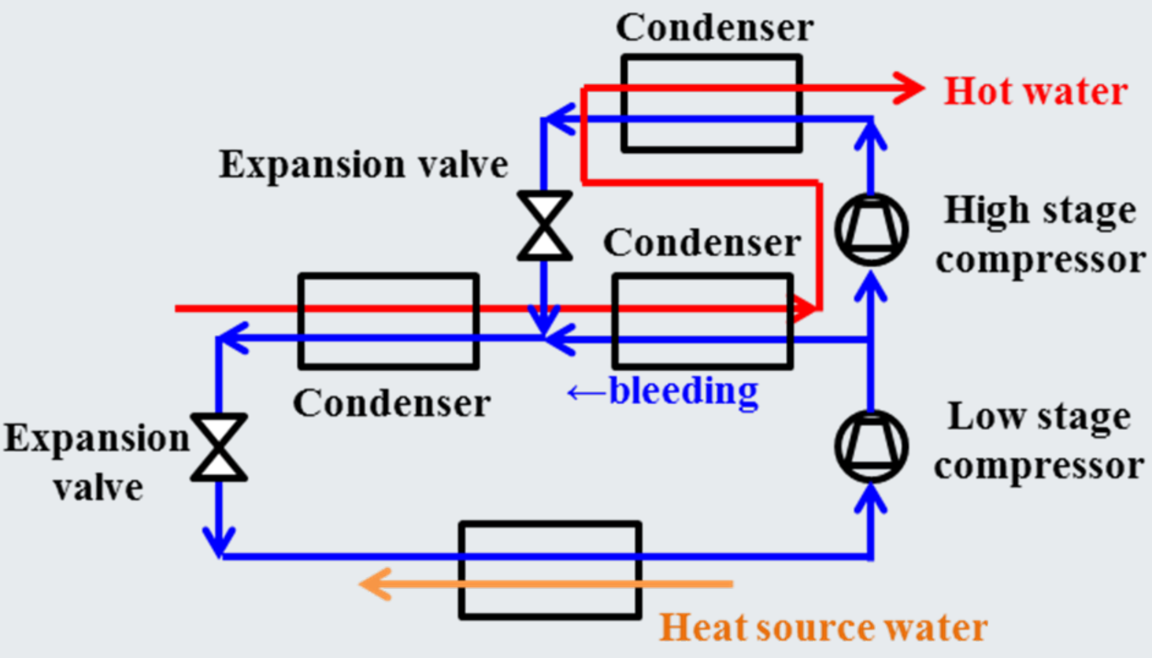

Fig. 1: Two-stage compression bleed cycle

leading-edge position of the splitter and the blade angle distribution. The flow rate is 39 % greater, and the adiabatic efficiency is improved by 3.5 %, for the same impeller diameter.

Conclusions

It is essential that low-GWP refrigerants are developed for use with cooling and heating equipment.

Centrifugal chillers using low-GWP refrigerants have been developed. Refrigerant R-1234ze(E) can be used from 1055 to 17581 kW, and refrigerant R-1233zd(E) from 527 to 2461 kW.

Centrifugal heat pumps using low-GWP refrigerants are in development. R-1336mzz(Z) was selected for a heat pump capable of heating pressurized water to 160 °C. Preparations are in progress to manufacture this and to develop the 160 °C application further, with a final goal of operating at 200 °C.

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RYOSUKE SUEMITSU
Mitsubushi Heavy Industries Thermal Systems
Japan
ryosuke_suemitsu@mth.mhi.co.jp
https://doi.org/10.23697/2asr-yp72

New ways of combining Heat Pumps and District Heating

Markus Lindahl, RISE, Sweden

In the Swedish research project Heat Pumps in District Heating Systems new combinations of heat pumps and district heating systems have been investigated. The project group has looked into three different way to combine heat pumps and district heating. Firstly, focusing on the combination of heat pumps and district heating in the manufacturing industry, secondly, hybrid heat pumps with the possibility to alternate between a heat pump and district heating depending on the energy prices, and thirdly, the combination of low temperature district heating and heat pumps for production of domestic hot water.

Introduction

Heat Pumps in District Heating Systems has been a Swedish national research project founded by the Swedish Energy Agency through the research program Effsys Expand. The project has also had an exchange of knowledge with IEA HPT TCP Annex 47, Heat Pumps in District Heating and Cooling Systems. The project has run for three years and was completed this summer.

The overall aim of the project was to investigate new combinations for heat pumps integrated in district heating systems. In three sub-projects, new possibilities have been explored for combining heat pumps and district heating. We have looked into the combination of heat pumps and district heating in the manufacturing industry, hybrid heat pumps that can alternate between heat pumps and district heating depending on the energy prices, and the combination of low temperature district heating and heat pumps for production of domestic hot water (DHW).

RISE Research Institutes of Sweden has been the coordinator, and the project was conducted together with five project partners from the industry: the heat pump manufacturers Nibe, Bosch Thermoteknik and Thermia, the district heating company Borås Energy and Environment, and the manufacturing company Volvo Cars.

Heat pumps in Swedish district heating grids today

Traditionally in Sweden there is a strong competition between the heat pump and district heating industries. By finding new applications, the two industries both can benefit from coexisting. Today, four heating technologies dominate the Swedish heating market: district heating, heat pumps, electrical heating and biofuel boilers. District heating covers over half of the total heating demand, while heat pumps and electrical heaters together have one third of the market. District heating is dominating for multi-family houses and premises, while heat pumps dominate for single-family houses [1].

District heating is well developed in Sweden and there are district heating grids in 285 of the county's 290 municipalities [2]. Also, no other country has the same or a larger amount of heat pumps installed in their district heating grids. 2013 the total installed heat pump capacity was 1.2 GW, and 4.5 TWh heat was produced with heat pumps for production of district heating in 2016 [3, 4]. This represents 7 % of the total heat delivered to the Swedish district heating grids. The main part of the energy is supplied to a few grids. The five largest producers of district heating via heat pumps deliver 85 % of the total amount of heat produced via heat pumps in the Swedish district heating grids [5].

Heat pumps in the manufacturing industry

One part of the project has focused on heat pumps combined with district heating in the manufacturing industry. Volvo Cars in Gothenburg, Sweden, uses heat pumps to recover heat from process cooling water. The heat pumps are used in combination with district heating for space heating and production of DHW. During winter, when the heating system requires high supply temperatures, the heat pump capacity is not enough and a district heating boost is required to reach a sufficiently high supply temperature. Since cooling water, of about 25 °C, can be used as heat source for the heat pumps, the COP is relatively high over the year, and a Seasonal Performance Factor (SPF) of 5.2 has been achieved.

The building where the heat pumps are installed is primarily used for development within Volvo Cars, which means that the building includes offices as well as test rigs. The two heat pumps installed have been running since 2011, and deliver around 10 GWh/year; in the same time the use of district heating is about 13 GWh/year.

Current connection of the heat pumps and district heating substation is made with heating in series. The return flow of the secondary heating system is first heated by the heat pump, then by district heating. The heat pump constitutes a base load during the heating

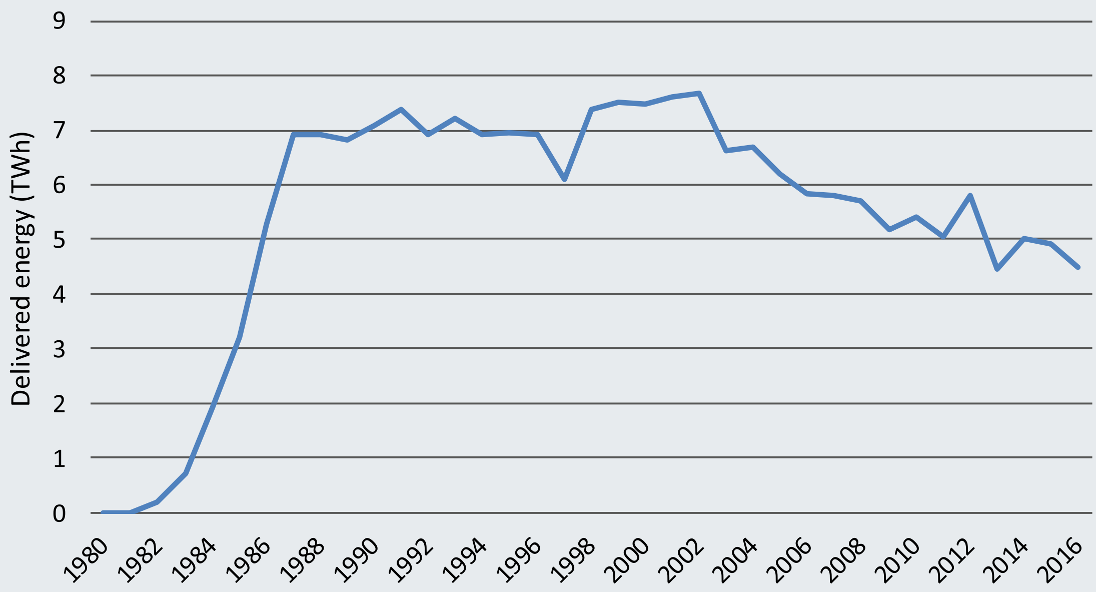

Fig. 1: Delivered heat from heat pumps to the Swedish district heat grids.

season, and district heating covers the peaks. During the summer, when the heating demand is lower, the heat pumps are shut off and all heating is produced by district heating. This is mainly due to seasonal variations in the district heating price, giving low energy prices during the summer. In the same time Volvo Cars evaluates the environmental burden from the district heating to be low during summer when the mix mainly consist of industrial excess heat and waste incineration.

The evaluation of the heat pumps at Volvo Cars shows that the best compromise for combining heat pumps and district heating is to make the connection in parallel instead of in series, since this gives a high COP for the heat pump and a low return temperature for district heating. The drawback is that the control strategy will be more complex compared to a series connection.

Hybrid heat pumps

Another part of the project has studied hybrid heat pumps with the possibility to alternate between heat pump and district heating for production of space heating and domestic hot water. In facilities and multi-family houses in Sweden with an installed heat pump there are often, for historical reasons, also a connection to district heating, and when needed district heating is often used as auxiliary heat. For the house owner it would be a benefit if it was possible to alternate between the two alternatives of heating depending on the lowest cost. This could also be used to reduce greenhouse gas emissions by using electricity or district heating when the share of renewables is high in each grid.

In a future smart grid, it would be a benefit to have the possibility to alter the technology for the heat production based on the demand and supply for electricity and district heating at the moment. Here a hybrid heat pump

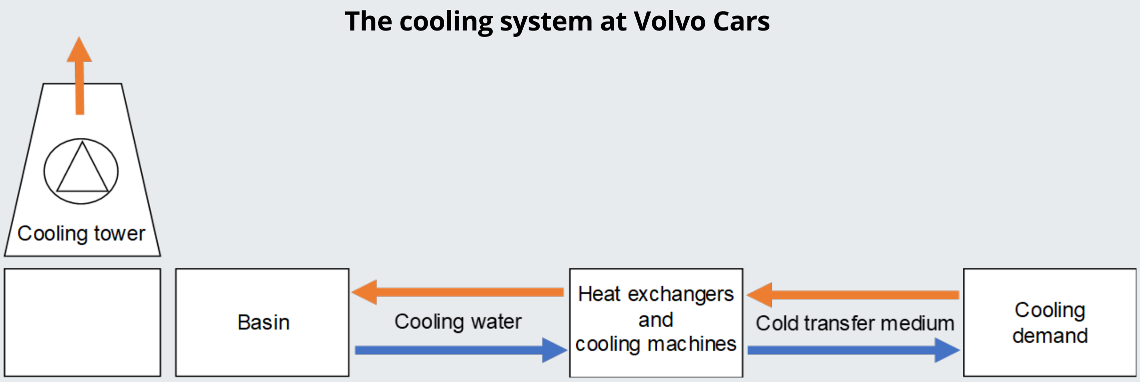

Fig. 2: The cooling system at Volvo Cars. Source: Volvo Cars

increases the flexibility. Today there are already existing hybrid heat pumps on the European market, but with a possibility to alter between a gas or oil boiler and a heat pump.

An algorithm was developed within the project, calculating the variable cost related to the choice of heat pump or district heating, depending on current operating conditions and energy prices, as well as selecting the energy production with the lowest hourly cost.

The algorithm has been tested in a case study based on a multi-family house in Linköping with both district heating and an exhaust air heat pump installed. Based on electricity and district heating prices in Linköping in 2015 [6, 7], the algorithm will mainly choose the heat pump during the autumn, winter and spring, while district heating dominates in the summer. The main reason is the seasonal energy prices for district heating in Linköping, with low prices during the summer month and higher during the rest of the year. Figure 3 shows the calculated variable cost for heating the model house in the case study.

In table 1, it is shown how the energy demand of space heating and DHW will be distributed when the hybrid heat pump in the case study makes an active choice based on the lowest variable cost for the model house in the case study. Since the heat pump cannot cover the total heating demand of the building during a large part of the year auxiliary heat, based on district heating, will be needed. With the heat pump used in the study it is possible to make an active choice for approximately 60 % of the energy demand.

In order to evaluate the financial conditions for using double systems, including both variable and fixed costs for heating, the life cycle costs were calculated using the net present value method. Based on the case study, the result shows that with a payback time of five years, depending on the energy prices, the investment of a hybrid heat pump can be 4,000-9,500 Euro higher than a traditional installed heat pump, cover as much as possible of the heating demand, and still have the same payback time (discount rate of 6 %/year). With a payback time of 10 years, the investment can be 7,000-17,000 Euro higher.

Heat Pumps for DHW production

For the future, low temperature district heating grids in combination with heat pumps can be an interesting solution. Using a low temperature in the grid has several benefits, such as lower losses to the surroundings and possibilities to use excess heat of lower temperatures as a heat source. Depending on the temperature in the grid, heat pumps will be needed primarily for production of DHW. The same approach can be used for using the district heating return flow as a heat source. The temperature in the return flow is often high enough for space heating, but for production of DHW a heat pump is needed to increase the temperature.

The project has studied how a heat pump solution for production of DHW should be designed, using district heating return flow as a heat source. One challenge with using the return flow as a heat source is the temperature variations, which affect the working conditions for the heat pump. One can also see that due to the temperature levels of the return flow, the use of the heat source for space heating directly requires floor heating in order to work. Thus, for multi-family houses in Sweden, this is

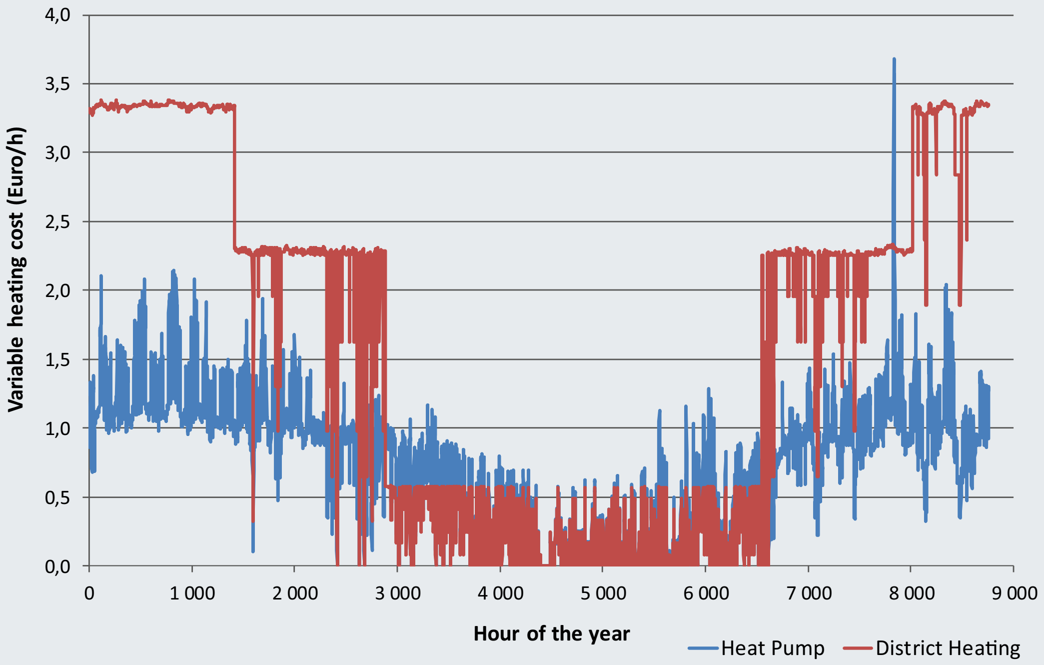

Fig. 3: Variable cost for space heating for the model house heated with exhaust air heat pump and district heating. Based on data for 2015. Costs for auxiliary heating excluded.

	Space Heating (MWh/year)	**DHW** (MWh/year)	**Total** (MWh/year)
Heat Pump (lowest variable cost)	378	10	388
District Heating (lowest variable cost)	116	63	179
District Heating (auxiliary heating)	316	117	433
Total heating demand	810	190	1 000

Table 1: Energy demand of the model house based on data for 2015, divided into heat pump and district heating

only applicable in new built houses, since more or less all existing multi-family houses today have radiators. The higher price for installing floor heating requires low energy prices of the return flow to make the alternative economically interesting.

The study has also shown that a storage tank for DHW is required for individual apartments or villas; direct heating of DHW without a tank requires a high power output from the heat pump and the Swedish building regulation (BBR) will not be fulfilled. It has also been shown that, for multi-family houses, a centrally placed heat pump is preferable compared to small heat pumps for each apartment, even though it leads to larger heat losses from the DHW circulation.

Acknowledgement

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MARKUS LINDAHL
Researcher
RISE Research Institutes of Sweden
Sweden
markus.lindahl@ri.se
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Events 2018/2020

2018

19-21 November
ATMOsphere Europe 2018
Lago de Garda, Italy
http://r744.com/events/view/atmosphere_europe_2018

5-7 December
49th International HVAC&R Congress and Exhibition
Belgrade, Serbia
http://kgh-kongres.rs/index.php/en/

6-7 December
The 13th International Symposium on New Refrigerants and Environmental Technology 2018 (Kobe symposium)
Kobe, Japan
https://www.jraia.or.jp/english/symposium/index.html

2019

12-16 January
ASHRAE Winter Conference
Atlanta, Georgia
https://www.ashrae.org/conferences/winter-conference

12 February
ATMOsphere Japan 2019
Tokyo, Japan
http://www.atmo.org/events.details.php?eventid=74

20-22 February
AiCARR 51st International Conference - The human dimension of building energy performance
Venice, Italy
https://www.ashrae.org/conferences/ashrae-endorsed-conferences/51st-aicarr-international-conference-the-human-dimension-of-building-energy-performance

11-13 April
Ammonia and CO_2 Refrigeration Technologies
Ohrid, Republic of Macedonia
https://www.mf.edu.mk/web_ohrid2019/ohrid-2019.html

26-29 May
13th REHVA World Congress CLIMA 2019
Bucharest, Romania
https://www.ashrae.org/conferences/ashrae-endorsed-conferences/13th-rehva-world-congress-clima-2019

22-26 June
ASHRAE Annual Conference
Kansas City, Missouri
https://www.ashrae.org/conferences/ashrae-conferences

24-30 August
25th IIR International Congress of Refrigeration
Montreal, Canada
http://icr2019.org/

28-29 August
5th International HVAC/R Congress
Atlantico, Colombia
https://www.ashrae.org/conferences/ashrae-endorsed-conferences/5th-international-hvac-r-congress

9-11 September
11th International Conference on Compressors and their Systems
London, UK
https://www.city.ac.uk/compressors-conference

25-27 September
2019 ASHRAE Building Performance Analysis Conference
Denver, Colorado, USA
https://www.ashrae.org/conferences/topical-conferences/2019-ashrae-building-performance-analysis-conference

9-12 December
2019 Buildings XIV International Conference
Clearwater Beach, Florida, USA
https://www.ashrae.org/conferences/topical-conferences/2019-buildings-xiv-international-conference

2020

1-5 February
ASHRAE Winter Conference
Orlando, Florida
https://www.ashrae.org/conferences/ashrae-conferences

15-17 April
6th IIR Conference on Sustainability and the Cold Chain (ICCC 2020)
Nantes, France
http://www.iifiir.org

11-14 May
13th IEA Heat Pump Conference 2020
Jeju, South Korea
https://hpc2017.org/next-iea-heat-pump-conference-2020/

7-10 June
9th International Conference on Caloric Cooling and Applications of Caloric Materials (Thermag IX)
College Park, Maryland, USA
http://www.iifiir.org

27 June – 1 July
ASHRAE Annual Conference
Austin, Texas, USA
https://www.ashrae.org/conferences/ashrae-conferences

13-16 July
Purdue International Compressor Engineering, Refrigeration & AC, High Performance Buildings Conferences
West Lafayette, Indiana, USA

6-9 December
14th IIR-Gustav Lorentzen Conference on Natural Refrigerants (GL 2020)
Kyoto, Japan
http://www.iifiir.org

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National Team
CONTACTS

AUSTRIA
Mr. Thomas Fleckl
Austrian institut of Technology
Tel: +43 50550-6616
thomas.fleckl@ait.ac.at

BELGIUM
Ms. Jozefien Vanbecelaere
Beleidsmedewerker PVen
Warmtepompen
Tel: +32 2 218 87 47
jozefien.vanbecelaere@ode.be

CANADA
Dr. Sophie Hosatte Ducassy
CanmetENERGY
Natural Resources Canada
Tel: +1 450 652 5331
sophie.hosatte-ducassy@canada.ca

DENMARK
Mr. Svend Pedersen
Danish Technological Institute
Tel: +45 72 20 12 71
svp@teknologisk.dk

FINLAND
Mr. Jussi Hirvonen
Finnish Heat Pump Association
Tel: +35 8 50 500 2751
jussi.hirvonen@sulpu.fi

FRANCE
Mr. Paul Kaaijk
ADEME
Tel: +33 4 93 95 79 14
paul.kaaijk@ademe.fr

GERMANY
Dr.-Ing. Rainer M. Jakobs
Informationszentrum Wärmepumpen
und Kältetechnik - IZW e.V
Tel. +49 61 63 57 17
email@izw-online.de

ITALY
Dr Maurizio Pieve
ENEA, Energy Technologies Dept.
Tel. +39 050 621 36 14
maurizio.pieve@enea.it

JAPAN
Mr. Tetsushiro Iwatsubo
New Energy and Industrial Technology Development Organization
Tel +81-44-520-5281
iwatsubotts@nedo.gojp

Mr. Hiroshi Okumura
Heat Pump and Thermal Storage
Technology Center of Japan (HPTCJ)
Tel: +81 3 5643 2404
okumura.hiroshi@ptcj.or.jp

NETHERLANDS
Mr. Tomas Olejniczak
Netherlands Enterprise Agency (RVO)
Tel: +31 88 60 233 17
tomas.olejniczak@rvo.nl

NORWAY
Mr. Rolf Iver Mytting Hagemoen
NOVAP
Tel. +47 22 80 50 30
river@novap.no

SOUTH KOREA
Mr. Hyun-choon Cho
KETEP
Tel: +82 2 3469 8872
energykorea@ketep.re.kr

SWEDEN
Dr. Emina Pasic
Swedish Energy Agency
Tel: +46 16 544 2189
emina.pasic@energimyndigheten.se

SWITZERLAND
Mr. Stephan Renz
Beratung Renz Consulting
Tel: +41 61 271 76 36
renz.btr@swissonline.ch

UNITED KINGDOM
Mr. Oliver Sutton
Department for Business, Energy &
Industrial Strategy
Tel: +44 300 068 6825
oliver.sutton@beis.gov.uk

THE UNITED STATES
Mr. Van Baxter – Team Leader
Building Equipment Research
Building Technologies Research &
Integration Center
Tel: +1 865 574 2104
baxtervd@ornl.gov

Ms. Melissa Voss Lapsa – Coordinator
Whole-Building and Community
Integration Building Technologies
Research & Integration Center
Tel: +1 865 576 8620
lapsamv@ornl.gov

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Heat pumping technologies play a vital role in achieving the ambitions for a secure, affordable, high-efficiency and low-carbon energy system for heating, cooling and refrigeration across multiple applications and contexts.

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Heat Pump Centre
c/o RISE Research Institutes of Sweden
P.O. Box 857
SE-501 15 Borås
Sweden
Tel: +46 10 516 55 12
hpc@heatpumpcentre.org

www.heatpumpingtechnologies.org