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IEA HEAT PUMP CENTRE

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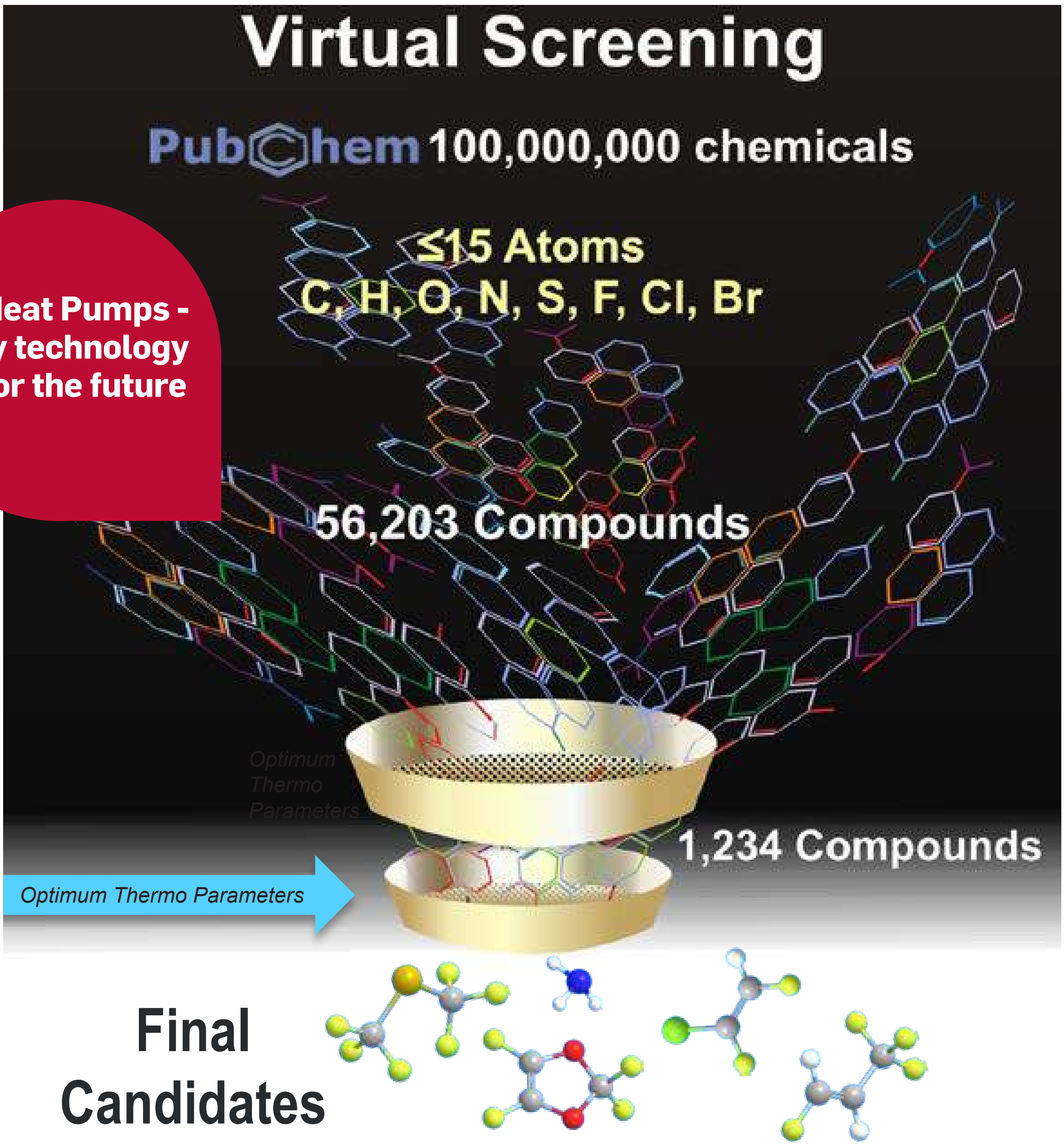
Refrigerants

Heat Pumps - A key technology for the future



IEA **Heat Pump** CENTRE
NEWSLETTER

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In this issue

Heat Pump Centre Newsletter, 1/2016
The issue of refrigerants is always hot. This is a play on words, but in the world of heat pumping technologies it is nevertheless true. The threats to the ozone layer and our climate have given rise to international and national policy, which have led to innovation of new products and re-introduction of old ones. It is also reflected by the recurrence of Refrigerants as a topic for the Heat Pump Centre Newsletter.

So, again, the topic of this issue is Refrigerants. The foreword gives an overview introduction to the five topical articles. They cover case studies of both old and new refrigerants. Refrigerants in air conditioning is highlighted, as are flammable refrigerants. The Column of this issue is divided into two, with two different views of hydrofluoroolefins (HFOs). There is also a Market report, from Norway.

Enjoy your reading!
Johan Berg, Editor

Heat pump news

Regulars

Topical articles

Front page reference: *Source: Marilyn Yetzbacher (NIST). Permission to use the image has been kindly provided by Marc McLinden (NIST) and Piotr Domanski (NIST)*

COLOPHON

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IEA OECD heat pump centre

Foreword

Martin Forsén
President, European Heat Pump Association (EHPA)

Completing the Circle

Legislators are rightfully leaving no stone unturned in their quest to fight climate change. Greenhouse gas emissions related to the use of energy and direct emission need to be given the highest priority. In this context, we need to realise that today's prevalent use of common HFC-refrigerants is questioned and subject to legislative restrictions and limitations. The search for substitutes has forced the industry to go back to the laboratory once more to look for new chemical substances as well as to reassess the use of old natural refrigerants that a long time ago were deemed unsuitable.

The search for suitable refrigerants was initiated at the beginning of the twentieth century. At that time the refrigeration industry was essentially limited to the use of ammonia, carbon dioxide, sulphur dioxide or water. None of these refrigerants were at the time viable for domestic appliances. The lack of an adequate refrigerant was seen as the most important barrier to overcome. In 1928, Thomas Midgley and his associate Albert Henne were assigned to find a non flammable and non toxic refrigerant. Being chemical engineers, Midgley and Henne went back to their laboratory to look for suitable chemical substances that would fulfil the specified requirements. Just two years later, at a meeting of the American Chemical Society, Midgley presented the new refrigerant, later known as R-12. The presentation was quite sensational as Midgley proved the desired characteristics by inhaling the refrigerant and then extinguished a candle as he exhaled. The introduction of R-12 served as the take off for the refrigeration industry and the vast use of CFCs, and later on, HCFCs. In 1973, Sherwood Rowland and Mario Molina presented the theory that CFCs deplete the ozone layer. The work of Rowland and Molina awarded them with the Nobel Prize in 1995 and led to the international agreement to phase out the use of CFCs in the Montreal Protocol 1987 and later on in the amendments to include the reduction of HCFCs.

The use of CFCs and HCFC has successfully been phased out in several countries and legislators are now aiming for the HFCs. The industry has once again been forced back to the laboratory to re-examine the opportunities. This time with a focus on limiting the global warming potential to a minimum. Extensive studies are performed on new chemical substances (HFO-1234yf, HFO-1234ze) with some of the desired characteristics. It is a tremendous challenge to find the right balance between chemical stability, flammability, toxicity, efficiency and cost. At the same time enhanced manufacturing has enabled the safe use of several natural refrigerants that for a long time seemed impossible to use in domestic appliances. There is however a great challenge to convince legislators of the need for changing the safety standards in order to allow for practical use of flammable refrigerants. We are, nonetheless, not likely to find a perfect refrigerant for all types of applications. In the future we will most likely use a portfolio of natural refrigerants and a new set of chemical blends that fulfil our needs.

Column I

Low GWP Refrigerants for Efficient Cooling, Heating and Power Generation

Konstantinos (Kostas) Kontomaris
Global Technology Leader -
Working Fluids & Foam Expansion Agents
Chemours Fluorochemicals
USA

Mounting evidence and increasing public awareness of the impacts of climate change continue to drive a transition to a new generation of refrigerants. For maximum contribution to climate protection, the new fluids must enable an early and widespread adoption of new system and retrofit options, especially for applications with high climate impact. Lower GWP fluids approximating the high performance and safety of incumbent refrigerants have been proposed to facilitate a timely and cost-effective adaptation of new and installed equipment.

In **supermarket refrigeration**, non-flammable blends containing Hydro-Fluoro-Olefin (HFO) R-1234yf, e.g. R-449A, are replacing R-404A with only minor equipment adjustments to meet European F-Gas regulations by 2020. Field experience shows that energy efficiency with R-449A can increase by over 10 % compared to R-404A.

In **cascade supermarket refrigeration**, R-513A, a non-flammable HFO-1234yf/HFC-134a blend, is commercially available as a near drop-in replacement for HFC-134a in the upper stage; CO_2 has demonstrated attractive performance in the lower stage of new cascade systems.

For systems requiring lowest discharge temperatures, including **transport and low temperature hermetic refrigeration**, R-452A, a non-flammable blend containing R-1234yf, has been commercialized to replace R-404A with minimal equipment adjustments. R-454A, a mildly flammable HFO-1234yf/HFC-32 blend, could replace R-404A to meet stricter future GWP requirements.

In **residential and light-commercial air-conditioning**, HFO/HFC blends R-452B(*) or R-454B, with GWP<700 and sufficient volumetric cooling capacity to replace R-410 with virtually equivalent performance, are mildly flammable. HFC-32 is also viable but with likely non-trivial equipment modifications (e.g. to mitigate higher compressor discharge temperatures). Evaluations continue to quantify performance, system cost and safety trade-offs while flammability standards and codes are being revised.

In **commercial air-conditioning**, R-513A, an azeotrope with virtually no temperature glide, is a near drop-in replacement for HFC-134a in centrifugal or positive displacement chillers with either direct expansion or flooded heat exchangers. R-514A*, an azeotropic, non-flammable R-1336mzz(Z) blend, is also becoming available as a design-compatible replacement for HCFC-123 in centrifugal chillers.

Climate protection, air quality and energy security are motivating the utilization of low temperature (natural or waste) heat to reduce dependence on fossil fuels. The lower GWP fluids above could replace incumbent fluids (e.g. R-410A, R-407C, R-134a) in **space- and water-heating heat pumps**.

R-1336mzz(Z) (cis-CF3CH=CHCF3) is a non-flammable HFO with a very low GWP of 2. It is surprisingly stable at high temperatures, despite its unsaturated chemical nature, possibly due to stabilization of the double bond resulting from the strong electronegativity of, and steric shielding by, the CF3 groups. It could enable **industrial heat pumps** delivering higher heating temperatures (up to or over 150 °C) and higher energy efficiency than incumbent fluids. R-1336mzz(Z) could also enable efficient **power generation** from waste heat at temperatures, potentially, up to 250 °C. It is currently under laboratory and field testing by world-class Original Equipment Manufacturers (OEMs) in advance of commercialization in 2017.

* *ASHRAE Registration pending*

Column II

Hydrofluoroolefins in Heat Pumps - Where and Why

Asbjørn Vonsild
Vonsild Consulting ApS
Denmark

The world is phasing out the refrigerants that dominate the market today. R-22 is on the way out in developing countries, and it is being negotiated to phase down the currently used HFC refrigerants due to high global warming impact (GWP).

Selection of replacement refrigerants is a complex process with many parameters, so the following will be on a very general level. With that disclaimer, I will start by announcing that the best refrigerant in small heat pumps is propane. Propane has great energy efficiency, acceptable capacity, large compressor envelope, negligible GWP and well, yes, it is highly flammable (safety class A3). Unfortunately, accor-ding to relevant safety standards, e.g. IEC 60335-2-40, most heat pumps are too big to use propane, so less flammable refrigerants are needed.

The refrigerant with the best energy and capacity performance trade-off is R-32, which is slightly higher pressure than R-410A and is classified as a lower flammability refrigerant (A2L). R-32 has a quite high discharge temperature, which may lead to redesigns impacting capacity, efficiency, and costs.

This is where HFOs comes into the game. Refrigerant producers have created A2L blends of HFO and traditional high GWP HFC's. The GWP's are typically similar to R-32. These blends have performance similar to the traditional HFC's and can often be used in the system with very small modifications. A major drawback for many of these blends is that they have significant glide, which may require a redesign of the heat exchanger. In other words, HFO blends are not fantastic but in many cases they are the best compromise.

Mixing HFO's with even more of the traditional HFC creates non-flammable A1 blends with higher GWP. These are suitable when systems become larger and even lower flammability is not allowed, or where the legislation explicitly bans flammable refrigerants. Again performance is ok, the need for redesign can be minimal, but glides are often significant.

Which sizes of heat pumps will use A1, A2L, and A3, respectively, remains to be seen. With developments of system standards, both the borders are going to shift upwards in the coming years. Generally, the higher the flammability the better the performance and GWP.

The number of HFO blends proposed is large, a UNEP/TEAP report (XXVI/9) from September 2015 mentioned 60 HFO blends, so if you chose a specific one there is a risk that it will not be available for long. The good thing is that blends from different manufacturers are very similar, so very likely you can simply choose another manufacturer.

What GWP is acceptable is unclear and environmentalist have pointed out that all the previous generations of halogenated refrigerants have had adverse effects and HFOs create highly toxic gases when burned. Although there are strong emotions embedded in these arguments, there is the risk with HFO blends that it may not be the last time refrigerants need to be replaced.

The situation is different for the larger chillers using turbo compressors. Here the low pressures of pure HFOs is desired, turbo chillers using R-1234ze(E) or R-1233zd (which is actually an HCFO, an HCFC with a double bond) have been launched on the market with very good performance, and the GWP of HFO's are negligible.

For very high temperatures, R-123 has some interesting HFO replacements, R-1336mzz(Z) and R-514 (not official number yet). Whether they will succeed remains to be seen.

A final rhetoric question: Would I recommend using HFO's? Yes, if you design a turbo chiller or want to explore new territory in the very high temperature range, and, yes, if you have evaluated other possibilities, then HFO blends are a good compromise.

IEA HPT News

12th IEA Heat Pump Conference

Have you already submitted your abstract?

That is a question we put to our network of experts. This network ranges from those experts working on heat pumps and fundamental research on fluid dynamics to experts working on smart grids for city areas combining heat pumps with other heating technologies like solar thermal, but also with solar photovoltaics and electrical storage. Experts working on stratification in storage tanks or working on sorption technologies or on ground sources, but also on cooling in supermarkets or advanced process intensification technologies for industry. The call for abstracts goes further when we approach policy makers and high level industrial management on their vision of the energy infrastructures in relation to heating and cooling and heat pumps.

The three main lines at the Conference are developed in the following parallel tracks.

- **Residential heat pumps** focusing on: Nearly Zero Energy Buildings; Technologies for Renovation; Hybrid Heat Pumps; Domestic Hot Water Heat Pumps; Multi Family Buildings
- **Non-residential heat pumps** focusing on: Industrial Heat Pumps; Waste Heat Recovery; District Heating; Commercial Buildings; Greenhouses.
- **Innovation and R&D** focusing on technology topics like: Ground sources; Advanced storage systems; Working fluids; Combination with other renewable technologies; Sorption technologies; Non vapour Compression; Smart grids/energy; Cold climate heat pumps; Air Conditioning; Gas driven heat pumps

These topics are listed in the first call for papers where authors are asked to specify their topic in detail. Each session will be opened by an invited keynote speaker.

The organisation of the Conference now enters the next stage where we invite industry and energy companies to become a sponsor or exhibitor.

Why should companies participate?

This event is the world's premier event where industry and research experts go to discuss the latest advancements in the field of heat pumps. Focused primarily on technical applications, the event provides a wide opportunity for dialogue and the establishment of business and research partnerships.

You can

- Demonstrate your company's leadership in the field of heat pumping technologies
- Reach key opinion leaders, academic, industry researchers and consultants.
- Raise your company's visibility in the field
- Exhibit and distribute your marketing and promotional materials

There is an extensive *sponsor brochure* available and already ten potential sponsors have shown interest. For companies there is a minimum of 200 m² of exhibition space available in the conference hall.

Did you already visit the website (*www.hpc2017.org*)? You can receive the regular Conference mail by subscribing to the Heat Pump Conference Newsletter on the *contact page*.

General

Europe Launches 'World's Largest Building Renovation Collaborative Project'

Green building councils across Europe have launched what is being called the world's largest collaborative project on building renovation. According to its organizers, the BUILD UPON project is a two-year project "aimed at helping European countries design and implement strong, long-term national strategies for the renovation of their existing buildings." BUILD UPON will support governments, industry and civil society to deliver "national renovation strategies"—long-term plans on how they will renovate their nation's homes and commercial buildings to high standards of energy efficiency. Such strategies are required by April 30, 2017, under EU law. The €2.35 million ($2.55 million) project is funded by the European Union's Horizon 2020 research and innovation program and led by green building councils from 13 countries.

Source: The HVAC&R industry e-Newsletter, March 3, 2016 and http://buildupon.eu/

IIR backs Euro Fridge Projects

The International Institute of Refrigeration (IIR) is providing backing for Cryohub and SuperSmart, two new EU-funded refrigeration projects.

Cryohub is researching cryogenic energy storage (CES) to examine if cooling facilities in food processing plants could be used to store renewable energy. The idea is to store energy through air liquefaction and restore it when necessary, in order to meet the cooling and heating requirements, particularly in refrigerated warehouses. It could also supply electricity back to the grid. Led by London South Bank University, the three-and-a-half-year projects was in receipt of a €7 million EU grant last year.

Supersmart is a three-year project exploring how the energy consumption of supermarkets could be reduced with better practices through education and information, as well as by using energy resources in a different manner.

The IIR has agreed to take part in disseminating the outcomes of these research works, by sharing its expertise in terms of publications, conferences and workshops.

Source: www.coolingpost.com

Policy

China: More Brands Eligible for Government Procurement

The 19th List of Eligible Energy-saving Products for government procurement was published in December 2015. Compared to the 18th Energy-saving List, air conditioning products in the 19th edition are now listed in product categories such as chillers, water-source heat pumps, lithium bromide absorption chillers, VRF heat pumps, and computer room air conditioners.

Apart from computer room air conditioners, the models of VRF heat pumps included in the list also increase, and are now the product category with the highest number of models enlisted in the 19th Energy-saving List, accounting for 37.5 % of all the air conditioning product models. During recent years, the share of VRF models in the Energy-saving List has increased steadily.

Source: JARN, February 25, 2016

A New European Heating and Cooling Strategy

The European Commission has announced a Heating and Cooling Strategy aimed at reducing energy waste. Heating and cooling currently account for 50 % of the EU's annual energy consumption. This includes 59 % of total gas consumption and 13 % of total oil consumption in Europe.

The EU is highly dependent on energy imports. Decarbonising Europe's buildings by 2050 would save around €40 billion on gas imports and €4.7 billion on oil imports per year. European buildings are old and waste energy. The current renovation rate is below 1 % per year.

The EU's Heating and Cooling strategy includes five main initiatives:

1. Making renovating buildings easier
2. Integrating electricity systems with heating and cooling systems
3. Increasing the share of renewables
4. Reusing energy waste from industries
5. Getting consumers and industries involved

These initiatives are intended to

- Help EU citizens save money
- Create jobs
- Reduce CO_2 emissions

However, this strategy is merely an EU coordination tool. It is up to member states to put it into practice.

In a comment, the European Heat Pump Association (EHPA) says 'Congratulations to the Commission for the amount of work that was put into this strategy. The wording of the document fits Europe's ambition to be leading in renewables. Executing it can make the EU a role model for a decarbonised heating and cooling sector. The request to replace fossil fuel boilers by highly efficient and renewable solutions (such as heat pumps and hybrid systems) is an important message to the industry and should help guide investment and R&I funding decisions.'

EHPA has co-signed a joint call of all renewable heating and cooling associations and representatives of local authorities, and also signed eight Key recommendations from EU Stakeholders. To view click *here* and *here*.

Source: www.euractiv.com (video), https://ec.europa.eu, and www.ehpa.org

Working Fluids

Low GWP refrigerant presentations now online

The presentations delivered at the recent US AHRI-hosted conference on the Low GWP Alternative Refrigerants Evaluation Programme (AREP) are now available online. More than 170 leading refrigerant researchers, refrigerant producers, and manufacturers attended the conference, which was held in January.

The programme began in 2011 as an industry-wide cooperative research initiative in response to environmental concerns raised by high-GWP refrigerants. It sought to identify promising low-GWP alternative refrigerants for major product categories including air conditioners, heat pumps and heat pump water heaters, dehumidifiers, chillers, ice makers and refrigeration equipment.

This, phase II of the project, was begun in January 2014 to focus on refrigerants in high-ambient conditions and others not tested in the first phase of the programme.

Source: www.ahrinet.org

Residential Refrigerator manufacturers Call for Voluntary Phase-Down of HFCs

The US Association of Home Appliance Manufacturers (AHAM) has announced a goal to voluntarily phase down the use of hydrofluorocarbon (HFC) refrigerants used in household refrigerators and freezers after 2024. The organization is seeking the support of government and safety authorities. In a release, AHAM said "A transition away from HFCs will present design and engineering challenges for manufacturers and will require significant engineering updates to refrigerators and freezers. The appliance industry, however, is willing and able to take on this task so that refrigerators continue to be a non-factor in the global emissions of greenhouse gases."

Source: www.aham.org

Selected Presentation Notes from the Recent ASHRAE Meeting

Orlando, January 2016

By Van Baxter, USA.

Edited by Johan Berg, HPC

From the seminar Improved efficiency low Global Warming Potential (GWP) commercial refrigeration systems (Seminar 61)

a. **Armin Hafner (SINTEF, Norway)** discussed application of R-744 (CO_2) with focus on improving efficiency in warmer climate locations. The system employed a multi-ejector block (6 nozzles in parallel 6-100 kW capacity, capable of pumping liquid and vapor; see International Journal of Refrigeration 57, 265 (2015)) and a flash tank supporting a parallel compressor rack (potential to recover 30 % of expansion loss). The analysis indicated potential 15-25 % savings vs. R-404A direct exchange (DX) baseline in a variety of warm climate locations. He noted that CO_2 systems in central and northern Europe have lower total cost of ownership compared to other supermarket system options.

b. **Michael Peterson (Honeywell)** focused on halogenated low GWP refrigerant options (e.g., R-448A). In his analyses, he reported that an R-448A DX system with a 16 °C (60 °F) minimum condensing temperature control beats CO_2 for outdoor temperatures >~9 °C (49 °F). He discussed a retrofit case study in a Florida supermarket, where R-448A was substituted for R-404A in the low temperature racks and R-450A for R-134a in the medium temperature racks. Case temperatures were maintained the same within about 0.5 °C (1 °F). Condensing temperatures were higher with the low GWP alternatives, but this could be fixed with optimization of controls. Despite the higher condensing temperatures, R-448A had 6-10 % lower energy use than R-404A, and R-450A energy use was about the same as R-134a. An LCCP analysis comparing R-404A DX vs R-448A DX vs CO_2 Booster systems (Buffalo, Atlanta, and Phoenix locations) indicated that R-448A had the lowest energy use in all locations, as well as lower LCCP than CO_2 in warmer locations.

c. **Sean Gouw (Southern CA Edison)** discussed beverage vending energy standards and the preferred alternate refrigerants. The average annual energy use for a vending machine is about 2000 kWh/y, and there are about 2.4 million vending machines in the US. A new DOE maximum energy use standard becomes effective in 2019. It also renders R-134a unacceptable, due to its GWP. In the future, vending machines and similar small refrigeration equipment will use hydrocarbons or CO_2 as refrigerants. Compared to R-134a data, CO_2 showed higher peak demand but lower energy use in 24 °C (75 °F) ambient. In 35 °C (95 °F) ambient, both energy use and peak demand was higher for CO_2.

Technology

US Consortium to Research Caloric Cooling Materials

Research into the development of caloric materials for refrigeration is to receive a share of $40 million of annual US government funding. Caloric materials are compounds that can generate cooling when cyclically acted upon by magnetic (magnetocaloric), electric (electrocaloric) or mechanical (elastocaloric) forces.

The US Department of Energy's Ames Laboratory in Iowa will be the home of CaloriCool, a new research consortium sponsored by the US DOE's Office of Energy Efficiency and Renewable Energy (EERE).

The CaloriCool consortium will pursue the development of alternative forms of refrigeration technologies, called caloric cooling, in partnership with the private sector and universities. CaloriCool is one of four consortia that make up DOE's Energy Materials Network (EMN). The EMN will facilitate industry access to the unique scientific and technical resources available at the national laboratories, enabling manufacturers to bring advanced materials to market more quickly.

Source: www.coolingpost.com

Markets

China to Invest RMB 1 Trillion to Promote Green Buildings

In the next five years, China will invest RMB 1 trillion (US$152 billion) to implement the Green Building Action Plan. The action plan, which was formulated by the National Development and Reform Commission and the Ministry of Housing and Urban-Rural Development, has been open for public comment for half a year, and will soon be released.

The action plan has pointed out two goals. One is to conduct energy saving retrofit for existing buildings. As planned, 570 million m^2 existing buildings will receive energy saving retrofit. Second is to build more than 1 billion m^2 of new green buildings in cities and towns and 100 million m^2 of green farmhouses during the 12th Five-year Plan, totaling 1.1 billion m^2. By this action plan, huge market opportunities may open in the fields of design, materials, and intelligence management of buildings.

Source: JARN, February 25, 2016

Ongoing Annexes

IEA HPT Annex 40 Heat Pump Concepts for Nearly Zero-Energy Buildings

IEA HPT Annex 40 has investigated heat pump applications in nearly Zero Energy Buildings (nZEB). nZEB are to be widely introduced in Europe after 2020 according to the recast of the Energy Performance of Buildings Directive (EPBD) and also in North America and Japan in the time period between 2020 and 2030. The nine countries CA, CH, DE, FI, JP, NL, NO, SE and the USA have participated in the 3.5-year Annex 40 project. Annex 40 is currently in the conclusion phase with the compilation of the final results of the Annex in reports and accompanying documents.

Summarising, the Annex 40 work confirms that heat pumps is a well-suited building technology for achieving nZEB targets both energy- and cost-efficiently in different investigated climate zones of central European and Nordic climate. In applications with cooling and dehumidification loads, the heat pump offers an integration of different building services, e.g. cooling and domestic hot water production. Field monitoring results show favourable performance in combined operation modes. Additionally, heat pumps also have good features regarding demand response, since they are often a large but flexible electricity consumer in residential buildings besides plug loads.

In conclusion, the intended broad introduction of nZEB after 2020 will be facilitated by the use of heat pumps as building technologies due to the unique characteristics:

- High seasonal performance factors, in particular in buildings with low temperature requirements
- Good integration options with other building technologies and for multiple building services
- Demand response capability

Based on these heat pump features for an nZEB application, further research issues include the integration of heat pumps in larger buildings and neighbourhoods and cost-optimal designs, since many of the current buildings are pilot and demonstration projects to test technology options regarding the fulfilment of the energy balance requirements for nZEB.

Results from national contributions to the Annex 40 will be presented in the framework of a final workshop on the 12th REHVA World Congress Clima 2016, which takes place in Aalborg, Denmark on May 22 – 25, 2016.

Final reports are currently in the review process and are expected to be published during the summer of 2016. Information on the Annex 40 can be found at the project website http://www.annex40.net.

Contact: Carsten Wemhöner, carsten.wemhoener@hsr.ch

IEA HPT Annex 41 Cold Climate Heat Pumps (CCHP)

In the past quarter, the Annex 41 participants continued to make progress on their country projects.

The 4th working meeting was held on January 22, 2016 in Orlando, FL, USA. Only the Japanese and U.S. teams were able to attend. However, all teams prepared project summaries, which will be posted to the Annex web site.

Three papers from the US Annex 41 team were presented during Conference Paper Session 12 on January 26 at the 2016 ASHRAE Winter Conference, and are published in the Conference Proceedings.

A paper from the Austrian team has been accepted for presentation and publication at the Annual ASHRAE Conference in St. Louis in June 2016.

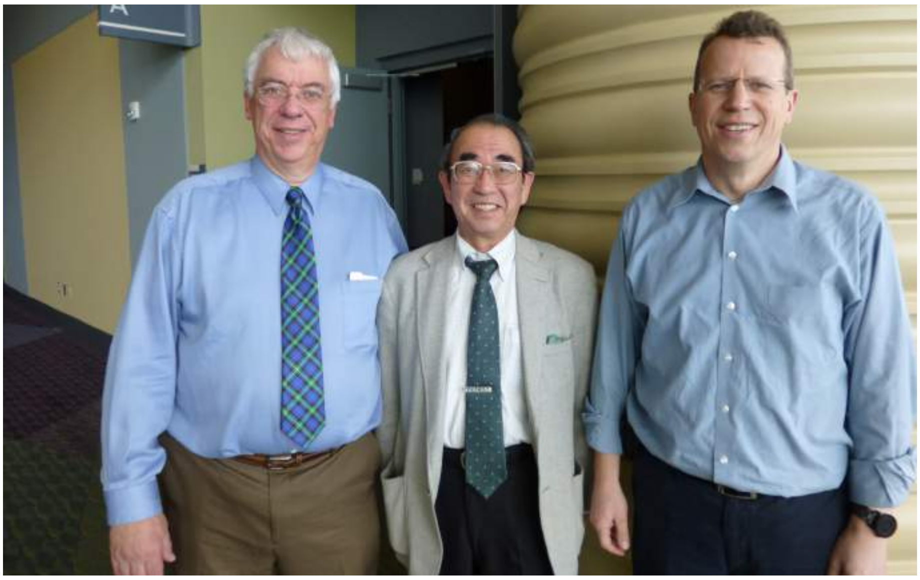
The Annex final report is planned to be submitted to the ExCo towards the end of July 2016 according to the target schedule in the table below as established at the May 2015 meeting in Vienna.

The Annex web site is http://web.ornl.gov/sci/ees/etsd/btric/usnt/QiQmAnnex/indexAnnex41.shtml

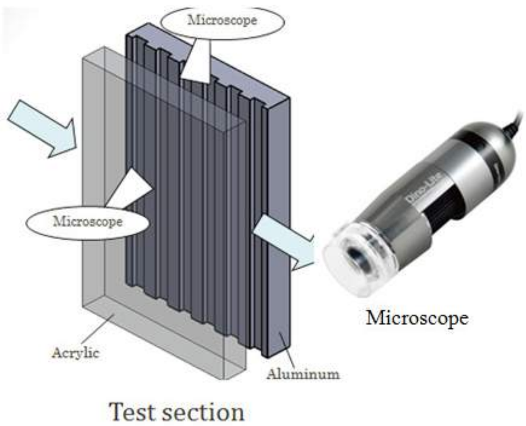
Contact: Van D. Baxter, baxtervd@ornl.gov

Table: Annex 41 – Final Report schedule

Target Date	Responsible Group	Action Item or Activity
15 April 2016	Each Annex Participant	Participants forward draft final country reports to OA
1 June 2016	Operating Agent	OA compiles draft final report & forwards to participants for review
1 July 2016	Each Annex Participant	Participants return comments on final report draft to OA
31 July 2016	Operating Agent	OA finalizes Annex report and forwards to ExCo and Heat Pump Centre for review/approval



Annex 41: Group photo of Annex 41 members - January 22, 2016, Orlando, FL, USA



Annex 41: Test section for observation of frost growth; clear acrylic cover with conductive coating to prevent fogging of surface during operation.
Image from Japanese January 22 project update, courtesy of M. Katsuta, Waseda University.

IEA HPT Annex 43 Fuel-Driven Sorption Heat Pumps

Participating countries:
Germany (operating agent), Austria, France, Italy, South Korea, United Kingdom, USA.

Recently fuel driven sorption heat pumps have gained more and more attention from research and market perspectives. At least two more companies are expected to offer products in 2016. However, they are still not widely known to customers, planners and installers and more work needs to be done to prove that they might play a significant role in the future energy system.

Objectives

The scope of the work under this annex is the use of fuel-driven sorption heat pumps in domestic and small commercial or industrial buildings and applications. If applicable, the additional possibility of supplying cooling may be considered. The main goal is to extend the use of fuel-driven heat pumps by accelerating technical development and market readiness of the technology, as well as to identify market barriers and supporting measures.

Work performed and current status

In September 2015 an international conference on sorption heat pumps with more than 100 participants from all over the word was organised by Annex 43 members in Milazzo, Sicily, Italy. The topics ranged from new working pairs for gas driven heat pumps over recent component development to field test results. Some of the most important results will be published in a Special Issue of the Journal "Renewable Energy" in 2016.

In December 2015 an annex meeting was held in Wernau, Germany, hosted by Bosch Thermotechnik with 21 participants from 7 countries to discuss new and previous results and subsequent steps. One of the

Annex 43: Annex 43 members at the last meeting in Wernau, Bosch visitor center

major decisions was to start a round robin test of gas driven heat pumps among the labs of Fraunhofer ISE, Politecnico die Milano and the Austrian Institute of technology AIT. A hybrid gas driven heat pump was chosen to test EN12309-7 for the first time and to compare results among the different labs and to measure according to the German guideline VDI-4650-2 as well as field test results. Testing began in January 2016.

As another dissemination channel, the working group for thermally driven heat pumps within the EHPA was restarted in November 2015 and an online survey regarding gas driven heat pumps was started.

The next Annex 43 meeting is planned for June in Milano/Italy hosted by Politecnico di Milano.

More information about the annex can be found at:
https://www.annex43.org/

Contact: Peter Schossig,
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IEA HPT Annex 44 Performance Indicators for Energy-Efficient Supermarket Buildings

The primary findings of the Annex, presented in August 2015 at an international conference, have now been confirmed by the Danish Annex team. These findings are that conventional technical parameters alone cannot sufficiently explain the actual annual energy consumption of a supermarket. "Non-conventional" technical parameters such as system dynamics, and non-technical parameters such as management focus, probably play an important role in the overall energy consumption. This analysis was performed in the Netherlands on a 2013 data set for 100 supermarkets, and has now been independently repeated with identical results.

Furthermore, a new data set for the Dutch supermarkets – the same supermarkets as in the original data set – has been received, covering the year 2014. This data set will be used to further substantiate the preliminary findings. New data are still expected from Denmark. In the preliminary findings, literature data on supermarket energy consumption of UK supermarkets have been found to be dubious – UK supermarkets appear to have a markedly higher energy consumption. The possibility of a data exchange with the UK exists, by which we could resolve this anomaly.

In the meantime, the efforts are now targeted on possibilities to analyse the non-conventional performance indicators for supermarket energy efficiency. There are some indications that the turnover of a supermarket does not have an impact on its energy consumption – again, quite contrary to the general idea that a higher supermarket turnover leads to a higher energy consumption.

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IEA HPT Annex 46 Heat Pumps for Domestic Hot Water

Annex 46: Group photo of Annex 46 members

After a first exploratory meeting in October 2015 in Nürnberg, the new Annex started officially in January 2016 with four participating countries, being Japan, South Korea, France and Netherlands. After a successful meeting in London on 12th January with interested parties from the United Kingdom and a meeting in Stockholm on 24th February with parties from Sweden, both countries are going to join. Germany, Switzerland, Austria and China are still working on ways to join and are invited as observers for the next start-up period.

On 10/11th February a first working meeting was staged in Soesterduinen (Netherlands), where the participating countries and some observers met the Dutch Team. Presentations on policy, state of the art technologies, developments and models were given by the Dutch participants, broader than only domestic hot water. On the second day of the meeting a new residential building site with Energy Costs Zero Houses was visited. Domestic Hot Water in these houses, being the major part of the energy use for heating, will be monitored.

The first working meeting was used to work out and discuss the planning of the first four tasks of the Annex with the four task leaders. They all presented their ideas and discussed these. The deliverables for the Annex will be:

1. An analysis of global market of systems, based upon individual country reports of participating countries and of non-participating countries when data are available.
2. Overview per participating country of the state of the market and scenarios for future market developments in a sustainable society.
3. Overview of manufacturers and brands in their supply chains in the participating countries.
4. Standardized and objective overview of individual and collective DHW systems in residential applications with boundary conditions, in order to make objective comparison possible. This overview also takes in other non heat pump DHW systems.
5. State of the art of existing modelling and simulation tools.
6. Specification file of the modelling tool, where the focus is on modelling of stratification
7. A modelling tool with validation of experimental data
8. Overview of running R&D for domestic hot water heat pumps, which does not only look into the heat pump technology, but will have an end-user and installer focus, look into water quality management technologies and focus on Smart technologies.
9. An online database about available technologies, components, materials for, and R&D on DHW heat pumps.
10. A reference guide based upon monitored example projects describing presently available domestic hot water heat pump systems with their applications; software tools, their application and users experience.
11. Two or three workshops with complete proceedings.
12. Usable input for the development of training courses for installers in the various participating countries.

The first set of deliverables will be available for the 12th IEA Heat Pump Conference in Rotterdam for the workshops on the first day and for presentations in the parallel sessions.

The next meeting will be on 20th May in Paris for developing Task 3 on modelling. A special working meeting has been organized for Asian participants on 7th June in Jeju (South Korea) and the second full working meeting for the Annex will be on 13/14th September at Ulster University in Belfast (Northern Ireland.

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Ongoing Annexes

Bold text indicates Operating Agent.

Annex 37 Demonstration of Field measurements of Heat Pump Systems in Buildings – Good examples with modern technology	37	CH, NO, **SE**, UK
Annex 39 A Common method for Testing and Rating of Residential HP and AC Annual/Seasonal Performance	39	AT, CH, DE, FI, FR, JP, KR, NL, **SE**, US
Annex 40 Heat Pump Concepts for Nearly Zero-Energy Buildings	40	CA, **CH**, DE, FI, JP, NL, NO, SE, US
Annex 41 Cold Climate Heat Pumps (Improving Low Ambient Temperature Performance of Air-Source Heat Pumps)	41	AT, CA, JP, **US**
Annex 42 Heat Pumps in Smart Grids	42	AT, CH, DE, DK, FR, KR, **NL**, UK, US
Annex 43 Fuel-Driven Sorption Heat Pumps	43	AT, **DE**, FR, IT, UK, US
Annex 44 Performance Indicators for Energy Efficient Supermarket Buildings	44	DK, **NL**, SE
Annex 45 Hybrid Heat Pumps	45	FR, **NL**, DE, UK
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Annex 47 Heat Pumps in District Heating and Cooling systems	47	**DK**
Annex 48 Industrial Heat Pumps, Second Phase	48	**DE**, JP, UK

IEA Heat Pumping Technologies participating countries: 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).
All countries are members of the IEA Heat Pump Centre (HPC). Sweden is the host country for the Heat Pump Centre.

NORWAY – Heat Pump Market Report – 2016

Rolf Iver Mytting Hagemoen and Jørn Stene, Norway

During the period 1996 to 2014 about 850,000 heat pumps have been installed in Norway. Roughly 90 % of the market has been residential air-to-air heat pumps, and more than 30 % of the single-family houses in Norway now have a heat pump. The total annual heat supply from Norwegian heat pumps is estimated at approximately 10-12 TWh/year.
In the new Norwegian building code of 2016 there is no longer any specific requirements regarding the use of renewable heat sources for heating. Consequently, low-cost electric heating systems can be applied to cover the entire heating demand in buildings.
This may hamper the future Norwegian heat pump market considerably. On the other hand, heat pump systems have attained a very strong market position in buildings of passive house standard, Zero Energy Buildings (ZEB) and BREEAM-certified buildings.

Like for many other European countries the heat pump market in Norway developed after the first oil crisis in the 1970s. In the 1980s, a government-funded prototype and demonstration programme was carried out to support the introduction of the heat pump technology, and in the early 1990s a new heat pump programme was launched. The main emphasis was on medium- and large-capacity heat pumps in non-residential (commercial) buildings, district heating systems and industrial applications. Many of these heat pumps are still working properly after many years of operations.

Due to the considerable generation of domestic hydro power, with an average production of 130 TWh/year, both residential and non-residential buildings in Norway have, to a large extent, been equipped with direct electric heating systems (base board heaters, electro boilers etc.).

In 2001 The Norwegian Government established Enova SF, a public enterprise, to support renewable energy and energy efficiency in Norway. This included, among other things, subsidy schemes for heat pumps in homes, non-residential buildings and district heating systems. These subsidies have had a considerable impact on the development of the Norwegian heat pump market, together with the increasing focus on energy efficiency and use of renewable energy in the European Union.

In 2007/2010 the new building code (TEK10) required that 40 % and

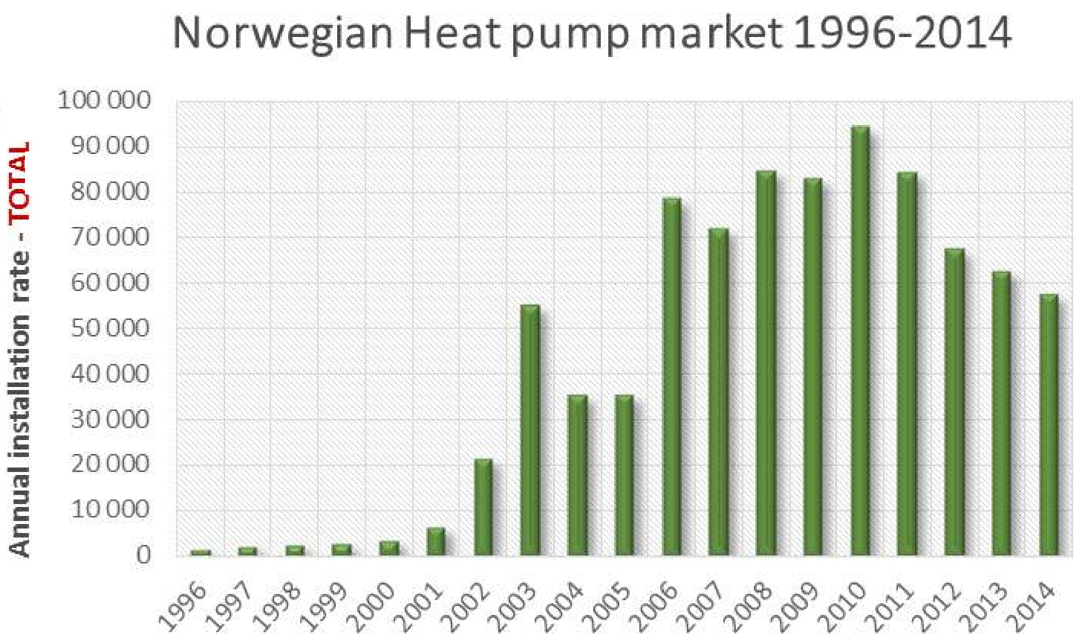

Figure 1. Total annual heat pump installation rate in Norway, 1996-2014 [NOVAP]

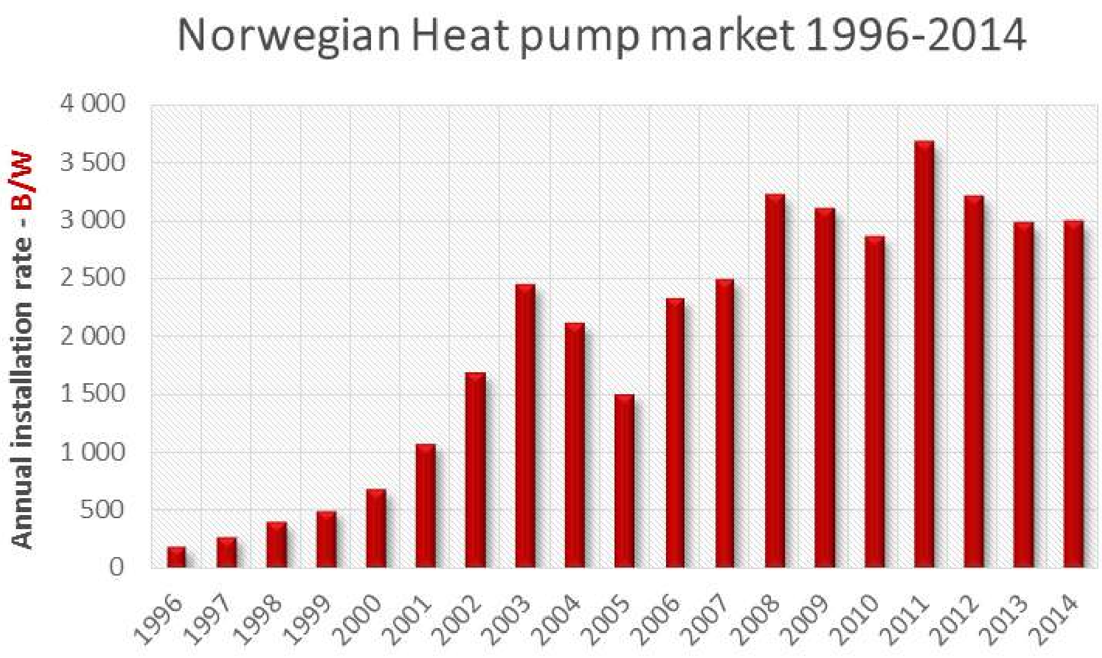

Figure 2. Annual installation rate for Brine/Water heat pumps in Norway, 1996-2014 [NOVAP]

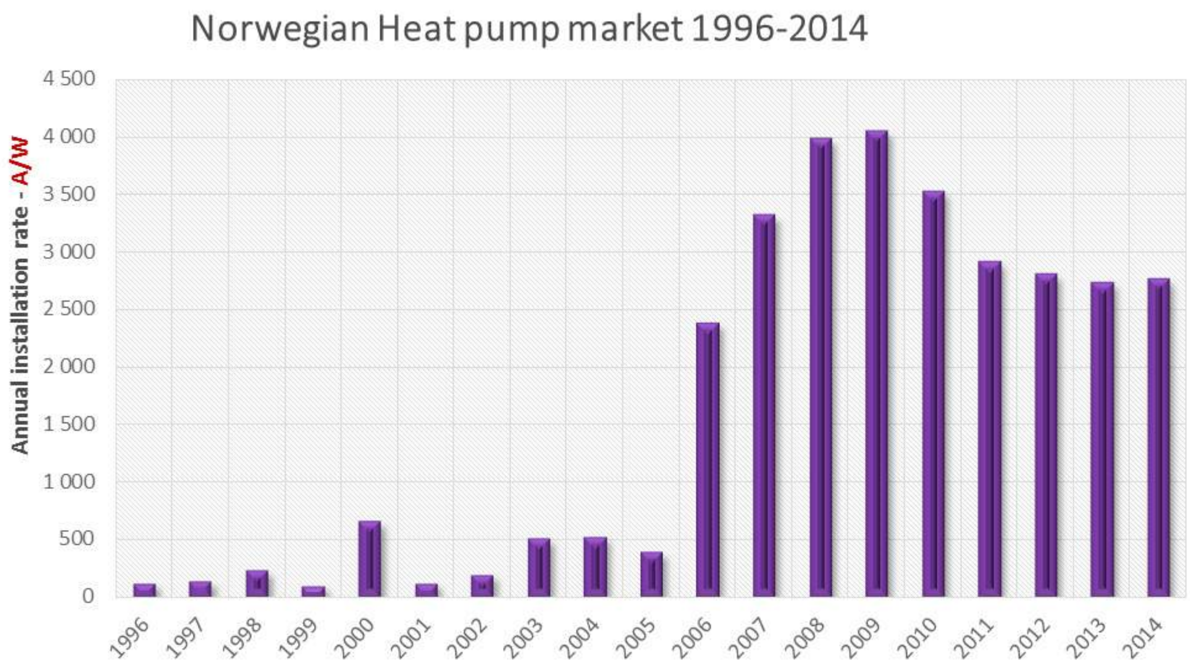

Figure 3. Annual installation rate for A/W heat pumps in Norway, 1996-2014 [NOVAP]

60 % of the annual heating demand in residential and non-residential buildings, respectively, should be covered with other sources than direct electric heating or fossil-fired boilers. The main alternatives for base heat load systems have been heat pumps, biomass-fired boilers, district heating in cities as well as solar heating systems.

Figure 1 through 3 shows the annual heat pump installation rate in Norway from 1996 to 2014.

During the period 1996 to 2014 about 850 000 heat pumps have been installed in Norway. As can be seen from the diagrams, the Air/Water and the Brine/Water heat pump sales only cover a minor amount of the total sales. The remainder is mostly residential air-to-air heat pumps, with roughly 90 % of the market. More than 30 % of single-family houses in Norway have a heat pump. The total annual heat supply from Norwegian heat pumps is estimated at approximately 10-12 TWh/year.

The new building code from 2007/10, as well as the subsidy schemes from Enova SF, have resulted in a relatively stable market for residential and non-residential A/W and B/W heat pumps. The average installation rate has been about 3000 systems per annum. The Norwegian market for ventilation air heat pumps and VRF/VRV heat pumps is still negligible.

The Norwegian heat pump market has also been strongly influenced by electricity prices and the temperature regime during the winter. The annual heat pump market was growing until the peak year of 2010, with approximately 95 000 heat pumps sold. This was a cold winter with higher electricity prices. The total market dropped moderately during the following years. There was a strong increase in the air-to-air heat pump market from 2003. Thus, many heat pumps have reached a lifetime of 12 to 15 years. The replacement market for air-to-air heat pumps will, within a few years, probably be larger than the market for new sales.

In 2015, Enova SF introduced a new support scheme, in which households receive a subsidy of 1 100 € for installation of an A/W heat pump and 2 200 € for a B/W heat pump in houses with hydronic heat distribution systems. The households also got a premium of 1 100 € for an energy metering system for the heat pump. In addition, you can receive a scrapping premium of 1 100 € for your old oil-fired boiler. There are no subsidies for A/A heat pumps. For heat pump installations in non-residential (commercial) buildings and industry, you can receive a financial support as long as the installations are not too profitable.

The dominating market for A/A heat pumps in Norway is existing houses with electric heating. The largest market for A/W heat pumps and B/W heat pumps are new houses, commercial buildings, and houses and buildings changing from oil-fired boilers to heat pumps.

The Norwegian government has, through the revised building code TEK10 (as of January 1, 2016), banned the application of oil- and gas-fired boilers in new buildings. Moreover, there are no longer any specific requirements regarding the use of renewable heat sources for heating, since the use of electricity for heating in Norway is now considered as renewable. Consequently, low-cost electric heating systems can be used to cover the entire heating demand in both residential and non-residential buildings. This may hamper the future Norwegian heat pump market considerably since many building owners and real estate development companies only focus on the investment costs, rather than the life cycle costs (LCC), the energy efficiency and the eco-friendliness of the heating systems.

During the last five years, heat pump systems have had a very strong market position in buildings of passive house standard, Zero Energy Buildings (ZEB) and BREEAM-certified buildings due to their high energy efficiency as well as the flexibility of both heating and cooling including free cooling from the heat source when using sea water, ground water or bedrock. The combination of electric heat pumps and electricity generation by PV panels is also regarded as a preferred solution in future ZEB.

Conclusion

During the period 1996-2014, Norway has had large sales of heat pumps, dominated by residential air-to-air heat pumps. More than 30 % of the single-family houses in Norway now have a heat pump. The total annual heat supply from Norwegian heat pumps is estimated at approximately 10-12 TWh/year.

In the new Norwegian building code of 2016, there is no longer any specific requirements regarding the use of renewable heat sources for heating. Consequently, low-cost electric heating systems can be applied to cover the entire heating demand in buildings.

This may hamper the future Norwegian heat pump market considerably. On the other hand, heat pump systems have attained a very strong market position in buildings of passive house standard, Zero Energy Buildings (ZEB) and BREEAM-certified buildings.

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Evaluating Alternative Refrigerants for High Ambient Temperature Environments

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To comply with the Montreal Protocol requirements, developing countries have started the phase-out of ozone depleting substances such as hydrochlorofluorocarbon (HCFC) refrigerants in 2015, and they expect them to reach 35 % reduction in 2020. This commitment to start the phase-out of HCFC refrigerants, especially R-22, in developing countries is seen as an opportunity to introduce lower Global Warming Potential (GWP) refrigerants and to leapfrog the need to go through the high-GWP hydrofluorocarbon (HFC) refrigerants. This paper summarizes an investigation of the performance of lower GWP refrigerants in mini-split air conditioning units operating at high ambient temperature environments that are typically experienced in some of the developing countries.

Introduction

This paper presents the results of a recent effort to evaluate the performance of alternative lower GWP refrigerants in two mini-split Air Conditioning (AC) units with focus on high ambient temperature environments. The first unit was designed with R-22, a popular HCFC refrigerant used in developing countries. The second unit is a more efficient unit designed with R-410A, one of the most popular alternatives to R-22. These two units and baseline refrigerants were selected as representatives of current technology in the developing countries and for potential replacement with lower GWP HFC refrigerants.

Both units had a rated cooling capacity of ~5.25 kW_{th} at the ISO 5151 [1] T1 conditions (35 °C outdoor and 27 °C indoor temperatures). The coefficient of performance (COP) at the same conditions was 2.84 for the R-22 unit and 3.52 for the R-410A unit.

We evaluated the performance of six lower GWP alternative refrigerants to R-22 and five alternative refrigerants to R-410A in their respective units. These alternative refrigerants were selected based on their thermophysical performance, to be a close match to the baseline refrigerant, and also based on high thermodynamic efficiency. Furthermore, for the R-22 unit, it was decided to include two non-flammable (A1) refrigerants to understand the potential for direct retrofit for units in the field. The units were evaluated at Oak Ridge National Laboratory's Multi-zone Environmental Chamber in Oak Ridge, Tennessee, USA. The experiments were conducted over a period of four months (May to August 2015).

The alternative refrigerants are shown in Table 1 along with their

Table 1. Baseline and Alternative Refrigerant Data

	Refrigerant	Refrigerant Manufacturer	ASHRAE Safety Class	GWP [a], AR5
R-22 unit	R-22 (Baseline) [a]		A1	1760
	N-20B [b]	Honeywell	A1	904
	DR-3 [b]	Chemours	A2L	146
	ARM-20B [b]	Arkema	A2L	251
	L-20A (R-444B) [b]	Honeywell	A2L	295
	DR-93 [b]	Chemours	A1	1153
	Propane (R-290)		A3	3
R-410A unit	R-410A (Baseline) [a]		A1	1924
	ARM-71A [b]	Arkema	A2L	461
	R-32 [a]	Daikin	A2L	677
	DR-55 [b]	Chemours	A2L	676
	L-41 (R-447A) [b]	Honeywell	A2L	572
	HPR-2A [b]	Mexichem	A2L	593

[a] Sources: IPCC AR4, 2007; IPCC AR5, 2013
[b] GWP values for refrigerant blends not included in IPCC reports are calculated as a weighted average using manufacturer-supplied compositions.

Table 2. Test Conditions

Test Condition	Outdoor Dry-Bulb Temp., °C	Dry-Bulb Temp., °C	Wet-Bulb Temp, °C
AHRI B	27.8	26.7	19.4
AHRI A	35.0	26.7	19.4
T3*	46	26.7	19
T3	46	29	19
Hot	52	29	19
Extreme	55	29	19

ASHRAE safety class and environmental characteristics. Properties of the alternative refrigerants were calculated using REFPROP [2], and the fluid and mixture interaction parameters were provided by the refrigerant manufacturers.

Both units were tested with baseline and alternative refrigerants for the six environmental conditions as shown in Table 2. These conditions represent a variety of rating conditions: ANSI/AHRI 210/240 [3] A and B conditions, ISO 5151 T3, and mixed and challenging conditions experienced in hot climates (T3*, Hot, and Extreme).

Evaluation Procedure

A comprehensive experimental setup was designed and built to comply with ANSI/AHRI Standard 210/240 and ANSI/ASHRAE Standard 37 [4]. The Air Enthalpy Method was used to evaluate the performance of the indoor unit, and the Refrigerant Enthalpy Method was used as a secondary means of evaluating the system performance to establish energy balance and assess measurement accuracy. The overall uncertainty in airside capacity was ±2.3 % for the R-22 unit and ±1.5 % for the R-410A unit. Similarly, the overall uncertainty in COP was ±2.4 % and ±1.6 % for the R-22 and R-410A units, respectively.

Figure 1 shows an overview of the setup for the condensing unit where the liquid line was diverted outside the outdoor unit housing to allow installation of the Elite Coriolis mass flow meter (CMF025), which was used to determine refrigerant-side capacity. A capillary tube header was also placed after the Coriolis mass flow meter to facilitate switching between various capillary tubes to optimize refrigerant flow. Pressure and temperature sensors were used to evaluate the refrigerant enthalpy before

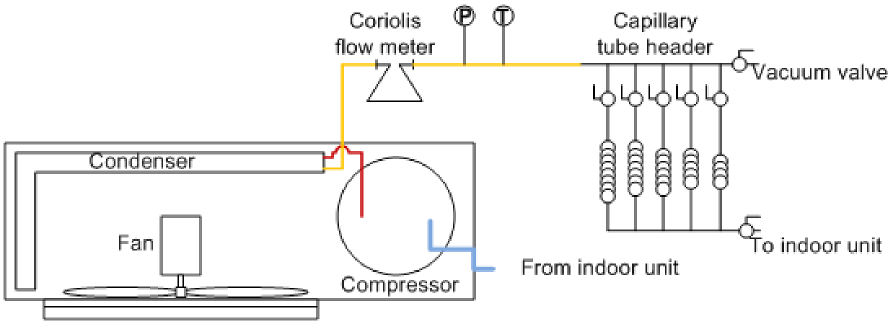

Figure 1. Outdoor unit configuration

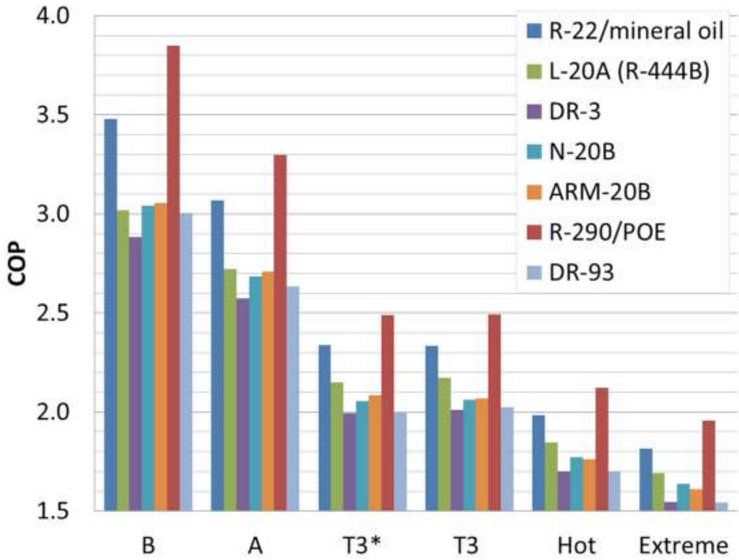

Figure 2. COP for R-22 and its alternatives at each test condition

expansion and after the evaporator coil.

System charge and capillary tube length were optimized for each of the alternative refrigerants to achieve maximum efficiency before conducting the testing at the different conditions.

COP and Cooling Capacity Performance

Figure 2 shows the COP for each R-22 alternative refrigerant at each test condition. The efficiency degradation associated with increasing ambient temperature was roughly consistent for both R-22 baseline and the alternatives; the COP degraded approximately 40 % as the ambient temperature increased from AHRI A to Extreme conditions. The system COP was the highest when using R-290 compared with all other refrigerants, including the baseline, at all test conditions. However, as shown in Figure 3, the system capacity was the highest when using the baseline refrigerant compared with all other refrigerants, including R-290. As shown in Figure 2, the system COP using the baseline refrigerant was also higher than the other alternatives at all test conditions except for R-290 which had 8 % better COP at extreme conditions.

R-444B resulted in the second highest COP of the alternative refrigerants at 7 % lower than the baseline refrigerant at Extreme test conditions. ARM-20B, N-20B, and DR-93 resulted in system efficiency similar to that of R-444B at moderate temperature conditions, but the system efficiencies for these three alternatives had larger degradation at higher ambient temperatures; the corresponding COPs were, respectively, 11, 10, and 15 % lower than the baseline under the Extreme test conditions.

ARM-20B resulted in the highest cooling capacity of all the alternatives at each test condition. At moderate temperature conditions (AHRI B and AHRI A), ARM-20B had a 3 % loss compared with the baseline, and was followed closely by DR-93 with a 6 % loss compared to the baseline. Under high ambient temperatures (Hot and Extreme), R-444B and ARM-20B yielded similar capacities (4 % and 3 % degradation compared with the baseline, respectively). DR-93 resulted in cooling capacity loss of 7 and 8 % compared with the baseline at Hot and Extreme conditions, respectively. Under the same conditions, R-290 resulted in 9 to 10 % cooling capacity loss compared with the baseline.

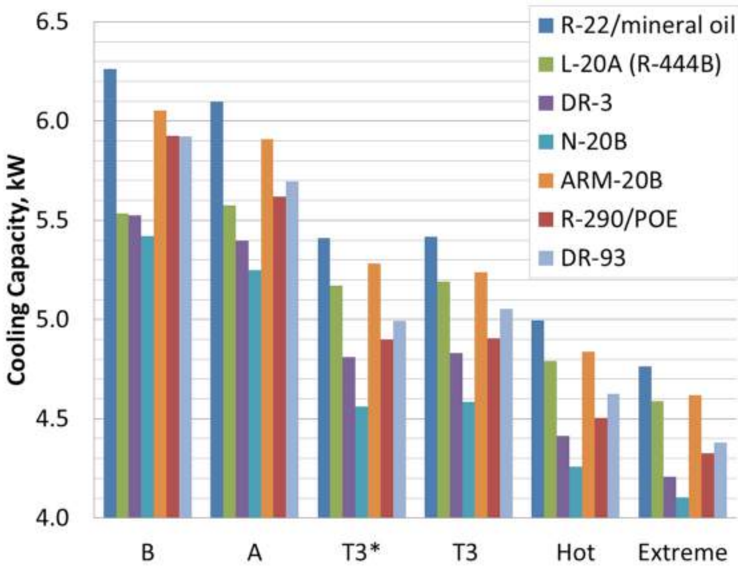

Figure 3. Cooling capacity for R-22 and its alternatives at each test condition

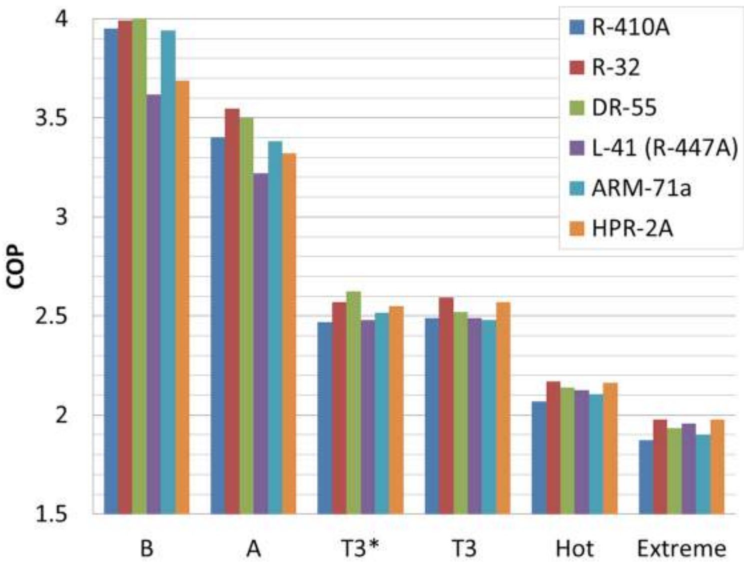

Figure 4. COP for R-410A and its alternatives at each test condition

Figure 4 shows the COP for each R-410A alternative refrigerant at each test condition. The percentage of efficiency degradation associated with increasing ambient temperature was roughly consistent across all alternative refrigerants; the COP degraded approximately 45 % as the ambient temperature increased from AHRI A to Extreme conditions. At high ambient temperatures, all five alternatives yielded higher COPs than the baseline.

R-32 and DR-55 led to higher COP than the baseline (R-410A) at all test conditions. At the Extreme Ambient condition, both R-32 and HPR-2A resulted in the highest COP (6 % higher than the baseline) followed by R-447A, DR-55, and ARM-71a at 5, 3, and 2 %, respectively.

Figure 5 shows the cooling capacity for each of the R-410A alternative refrigerants at each test condition. At moderate temperature conditions, the baseline refrigerant yielded higher cooling capacity than the alternatives, with the exception of R-32. R-32 led to 2 % higher capacity than the baseline at the lowest temperature conditions (AHRI B, 27.8 °C) and 13 % higher at the highest temperature conditions (Extreme, 55 °C). DR-55 resulted in similar capacity as the baseline, with its lowest result only 4 % below the baseline. The cooling capacities of ARM-71A, HPR-2A and R-447A all improved compared with the baseline as the temperature increased, and all three delivered within 4 % of the capacity of the baseline at the Extreme conditions.

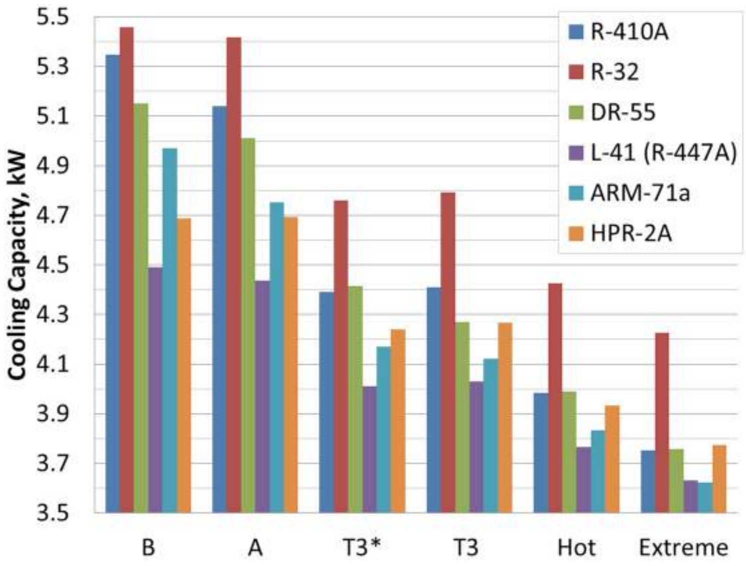

Figure 5. Cooling capacity for R-410A and its alternatives at each test condition

Discussion

This paper presents the results of an experimental study that evaluated performance of alternative lower GWP refrigerants to R-22 and R-410A in mini-split AC units specifically designed for high ambient temperature environments. The mini-split units were only optimized for capillary tube and refrigerant charge for alternative refrigerants. Some of the alternatives improved the performance of the units compared to the baseline refrigerant. In other cases, the performance of the alternatives fell within 10 % of the baseline, which suggests that parity with baseline performance would likely be possible through additional engineering design.

Of the R-22 alternatives, R-290, R-444B, and ARM-20B were the most promising. All of the R-22 alternative refrigerants except the R-290 required larger refrigerant charge. Still, the total direct GWP reduction varied from 99.9 %, for R-290, to 16 % for DR-93.

The R-410A alternative refrigerants are all in the A2L safety category. Most of them showed significant potential as replacements. All of the alternative refrigerants had optimized charge smaller than the baseline charge with an average direct GWP reduction of 74 %. R-32 was the only refrigerant that showed consistently better capacity and efficiency; however, it resulted in compressor discharge temperatures that were 12–21 °C higher than those observed for the baseline refrigerant. The highest discharge temperature of R-32 was 108 °C, which is just at the borderline for safe operating condition for most compressors [5], [6].

Conclusions

This performance evaluation shows that viable replacements exist for both R-22 and R-410A at high ambient temperatures. Multiple alternatives for R-22 performed well. Many R-410A alternatives matched or exceeded the performance of R-410A. These low-GWP alternative refrigerants may be considered as prime candidate refrigerants for high ambient temperature applications. Before commercialization, engineering optimization carried out by manufacturers can address performance loss, the increase in compressor discharge temperature that many alternatives exhibited (particularly the R-410A alternatives), and any safety concerns associated with flammable alternatives.

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Flammable Refrigerants, Trends, Legislation, and Standards for the Heat Pump Industry

Asbjørn Vonsild, Denmark

There is political pressure on the heat pump industry to find more climate friendly alternatives to the traditional HFC refrigerants, and as a consequence the majority of heat pumps will have to switch to refrigerants with some kind of flammability over the coming years. In this article we will describe this trend and discuss the implications of flammability to design, production and servicing of systems, as well as briefly touch on the challenges posed by national legislation.

Political Trends and Refrigerants

Over the next couple of years the mass market will have to find alternatives to traditional HFC refrigerants. This is driven by regulation already in place such as the EU F-gas regulation and Global Warming Potential (GWP) limits in Japan, and by the HFC phase down negotiations under the Montreal protocol. For an overview of these regulations, see Box 1. The EU regulation is probably the most far reaching regulation with a combination of a phase-down of HFC and bans on specific applications of HFC's with higher climate impact (GWP), see figure 1 for details.

This paints a picture where the political climate has shifted, so once it becomes possible to use more climate friendly refrigerants, the politicians are likely to force the industry to do so.

Box 1. Legislation pushing for a shift to low GWP refrigerants

LEGISLATION PUSHING FOR A SHIFT TO LOW GWP REFRIGERANTS

- *A global phase down of HFC's is being discussed under the Montreal protocol.*
- *In EU the F-gas regulation will phase down HFC supply, already by 2018 the supply will drop to 63 %. The regulation also contains a number of bans. A small detail which may have a profound impact is that by 2017 all pre-charged systems imported into EU need to be included in the quota system. This will require producers located outside EU to buy access to quotas, or to use refrigerants not covered by the regulation: Hydrocarbons and CO_2.*
- *In China the government intention is to replace R-22 with propane for domestic reversible A/C-heat pump units, and R-32 (an A2L flammable refrigerant) for commercial size systems.*
- *In the US the SNAP rules take a more opportunistic approach: when the EPA or the industry spots a technical opportunity to demand more climate friendly refrigerants, then the EPA can issue a new SNAP ruling, banning traditional refrigerants or allowing new refrigerants. The SNAP rule 19 allows flammable refrigerants in some types of split A/C systems.*
- *Japan has a 750 GWP limit for residential A/C systems by 2018 and for commercial systems in 2020.*

A/C and heat pump systems are often lumped together, so a ban designed for A/C system often includes a ban on heat pump systems.

When selecting refrigerants for a heat pump design, many aspects need to be considered, for instance heating capacity, energy efficiency, cost, pressures, temperature and safety. The most common refrigerants together with the refrigerants being proposed by the manufactures are listed in table 1. It is seen that there is a trade-off between capacity, GWP, and flammability. Higher capacity and lower climate impact leads to higher flammability with the notable exception of carbon dioxide, CO_2. Another outlier is ammonia, which is not in table 1 since it does not fit in with its combination of low pressure and high capacity.

In heat pumps CO_2 is operating in the transcritical phase, and it is far from being the "silver bullet" of the industry, neither is ammonia with its toxicity and lack of chemical compatibility with copper. Although both are excellent refrigerants, they are currently only useful for niches in the market. This means that there is no way around the fact that the majority of heat pumps will switch to flammable refrigerants in the coming years.

In general the higher flammability A3 refrigerants such as propane offer a better energy efficiency/heating capacity/GWP than lower flammability A2L refrigerants such as R-32, but the advantage comes with the obvious disadvantage of flammability. On top of this, the political climate in Europe seems to prefer A3 refrigerants, while the US seems to prefer A2L.

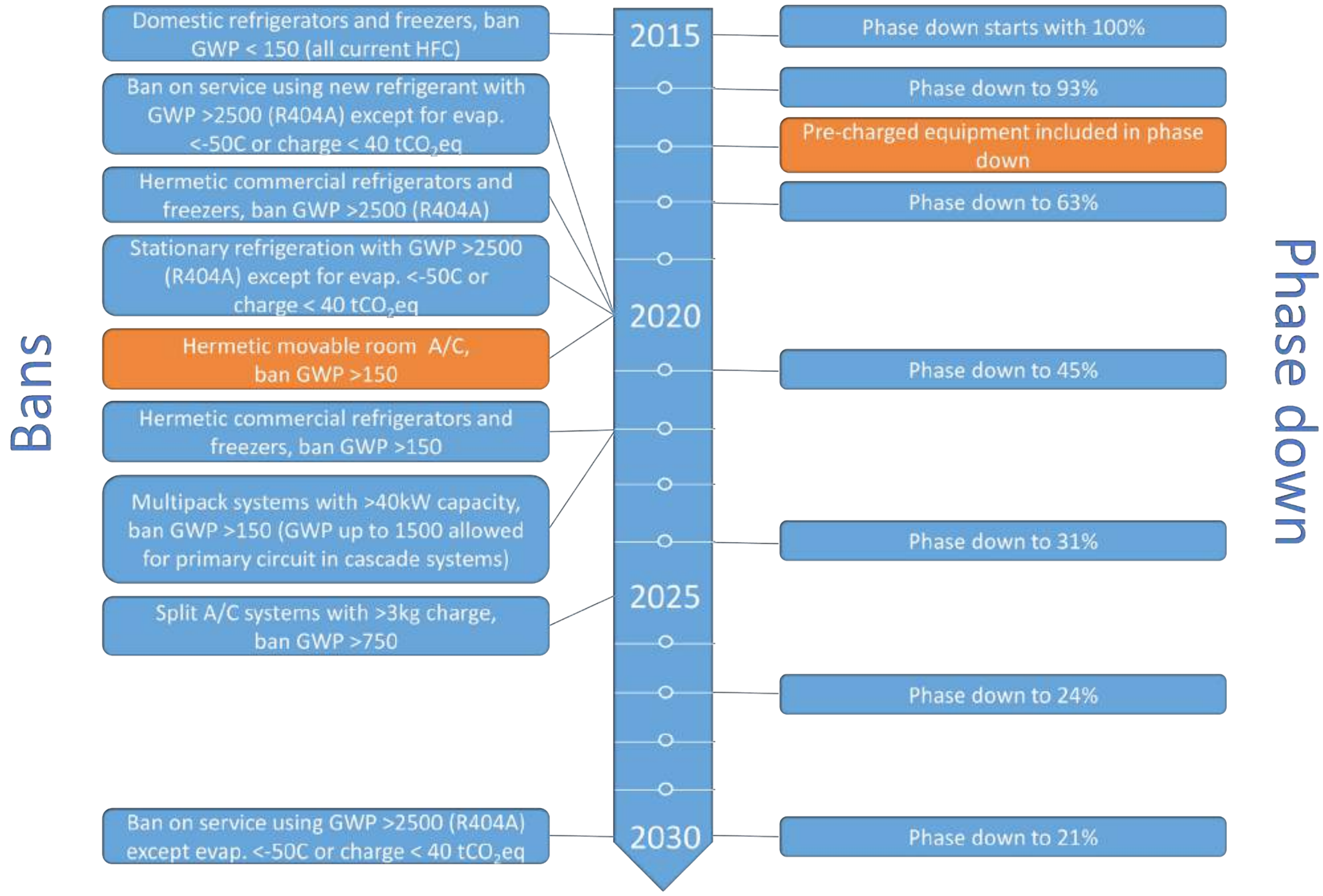

Figure 1. EU F-gas regulation [6]

Table 1. Refrigerants

GWP	Capacity/pressure level similar to				
	R123	**R134a**	**R22/R404A**	**R410A**	**R744**
< 150	∆ R601 ○ R1233zd ○ 1336mzz(Z)	∆ R600a ◊ R152a ● R1234yf ● R1234ze(E)	∆ R290		○ R744
150 — 750		○ HFO blends	● HFO blends	● R32 ● HFO blends	
750 — 1500		○ R134a	○ HFO blends		
1500 — 2500			○ R22 ○ R407	○ R410A	
> 2500			○ R404A		

○ = non flammable (A1), ● = lower flammability (A2L), ◊ = flammable (A2), and ∆ = higher flammability (A3)

System design

An important safety requirement is to avoid ignition sources where there could be refrigerant leakage. Proving that there are no ignition sources, or that the ignition sources are not where refrigerant can leak, is a different topic!

One option is to consider IEC 60079 hazardous zones for flammable gases. IEC 60079 is linked to the two EU ATEX directives, and the zones are often called ATEX zones, a term which the reader may be more familiar with. IEC 60079 is clearly "more than good enough", but professionals in the area of IEC 60079 typically consider the leak frequency of heat pumps to be too low for zone 2, which is the least restrictive zone.

There are of course exceptions. For instance, if two systems are placed in the same machine room, and one will be running while the other is serviced, then the service situation may define the systems to be in zone 1 with all components and electronic equipment being approved for this zone. As another example, a volume around the exhaust of the safety relief valve on a large system may be considered to be zone 2, just to be on the safe side.

IEC 60079 is designed for industrial settings, so although most systems do not leak frequently enough to be in zone 2 it does not mean that ignition sources can be ignored. Besides, on top of using IEC 60079, it is also good practice to do a risk assessment, and having a system causing an explosion every 20 years is not acceptable, even if it is too infrequent for zone 2 to apply.

For domestic and light commercial heat pumps the safety standard IEC 60335-2-40 includes a set of requirements for ignition sources, and a standard test to show where a leak may cause a flammable atmosphere. Likewise for larger systems, ISO 5149 includes requirements for avoiding ignition sources, but it does not yet include a test for determining where a leak may result in a flammable atmosphere. The coming version of the European standard for larger systems, the draft EN 378, includes such a test in an informative annex and it is highly likely that such an annex will also be added to ISO 5149. That said, for large systems it is important to ask whether the leak simulation test is reasonable before applying it. Simulating using a very small leak size on a very large system could give a false sense of safety.

There are other aspects than avoiding ignition sources, the most important one being the charge limits. Depending on the type of heat pump, the location, and who can access the system there will be an upper limit for the amount of charge set in the system safety standards. The amount of charge typically determines the maximum capacity a system can be designed to have, so this is an important topic, but also a complex topic worth an article on its own.

Other aspects include requirements for leak detectors for large systems, and what approvals non-permanent connections (such as flares) need to have if used indoors.

Production

The specific legislation around the production deviates from country to country; for instance in EU it is especially the ATEX directives which are relevant. However, the principles in how to approach the production set-up are universal, since it is all about how to avoid setting the refrigerant on fire.

There are in principle three steps to take:

- **Control where a release can go**: Establish barriers and ventilation, so the airflow becomes well defined and an unintended leak will be confined to a small zone. Controlling where a leak can go should also be practiced for traditional HFC's, since they are toxic at high concentrations, but with flammability it becomes even more important.
- **Move ignition sources**: There is no reason for control boxes, or equipment not related to the charging process to be in the potentially flammable zone.
- **Eliminate remaining ignition sources**: Upgrade the remaining equipment, so there are no ignition sources in the potentially flammable zone.

In general the handling of flammable gases is controlled by IEC 60079. In production, the quantity of flammable gases is much larger than in an individual heat pump. Right around the charging process there will be zone classifications, typically zone 0 (or zone 0 NE) a few cm from the charging nozzle, zone 1 right below the charging nozzle, and zone 2 in the area where the airflow can take unintended leaks.

It may be argued that A2L refrigerants do not explode, and the legislation for explosion areas therefore does not apply, but it must be kept in mind that fires and resulting decomposition products also need to be avoided, and the explosion protection legislation is the best framework for working with this risk.

Service

Accidents may happen when servicing systems, especially if the flammable refrigerant is treated as a traditional HFC. In the service situation the system may be opened and if proper procedures are not followed, then refrigerant may escape and create a flammable atmosphere to be ignited by a careless technician.

There are several actions to take to avoid accidents:

- Define a temporary IEC 60079 zone and mark off the area to avoid unauthorized people entering the zone.
- Use tools without ignition sources, especially the vacuum pump.
- Use a mobile leak detector to warn against leaks.
- Flush the system with nitrogen before doing hot work.
- Avoid static electricity.
- Etc.

But the main mitigation factor, to avoid accidents during service, is training of the service technicians. In fact the lack of training of service technicians is likely to be the biggest barrier for flammable refrigerants at the moment.

Luckily this is an area which has been recognised, and training is becoming more and more available globally. A good guide to what a refrigerant technician should know is the European standard EN 13313, which is in the process of becoming an ISO standard.

National and regional legislation

National legislation, especially building regulations, sometimes bans the use of flammable refrigerants in domestic heat pumps placed indoors. For instance in Spain and USA, and for certain types of buildings in Italy and France. The trend in the US is towards allowing A2L, but hesitating with the A3 refrigerants, while in Denmark there is a general ban on heat pumps with more than 10 kg of A2L refrigerants, not because of flammability, but because they are HFCs.

These types of national bans make life difficult for heat pump producers trying to address a global market. National differences are likely to become smaller as legislation gets adjusted to allow more environmentally friendly refrigerants, but for now national legislation adds complexity when marketing heat pumps globally.

There is also regional legislation, like the EU Pressure Equipment Directive (PED). The PED imposes extra requirements, if the internal volumes of compressors and vessels, or the diameter of pipes, are above certain limits, and for flammable refrigerants these limits apply to much smaller systems than for non-flammable refrigerants. The requirements include 3rd party approvals of designs and installation sites, and material certificates, which can sometimes be difficult to get on copper pipes and fittings. This indirectly creates a borderline between small and large systems in the EU.

Finally there are the energy regulations, where requirements are increasing steadily. These are not dependent on the choice of refrigerant, but they do put restraints on the industry: Energy efficiency has to improve with every new model. Luckily the flammable refrigerants do support high efficiency.

Conclusion

We have seen how legislation is pushing for lower GWP refrigerants, and how this leads to higher flammability.

The main implication of this is the need to avoid ignition sources throughout the lifetime of the system, including the use phase which is controlled by the system design, the production and the servicing of systems.

We have also seen that there are other additional requirements arising from the flammability, and how training of service personnel is crucial.

At the same time as the need for higher flammability becomes clear the industry is being challenged with national legislation which bans flammable refrigerants in certain applications, typically because the national legislation is simply not up to date.

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Refrigerants and the Air Conditioning Industry's Obligation

Tadafumi Mikoshi, Japan

Air conditioners currently serve a role that goes beyond simply providing comfortable environments; they have become an essential item to realise the minimum levels of wholesome and cultured living. Especially in developing countries located in tropical and subtropical regions, air conditioning can be a health issue.
On the other hand, as an energy-intensive industrial product, air conditioners can contribute to global warming. To reduce climate impacts, air conditioner energy efficiency has improved significantly with the industry also treating energy efficiency as a development issue of the highest priority. In addition, the effect on global warming of refrigerants, a key element of air conditioners to convey heat, has also become controversial in recent years.
The use of alternative refrigerants that perform well with reduced environmental impact is desirable, but it is also a fact that there are no ideal alternative substances that meet all of the requirements at present.
While presenting the current issues, this paper describes air conditioner challenges and how they are being addressed to achieve a low-carbon society.

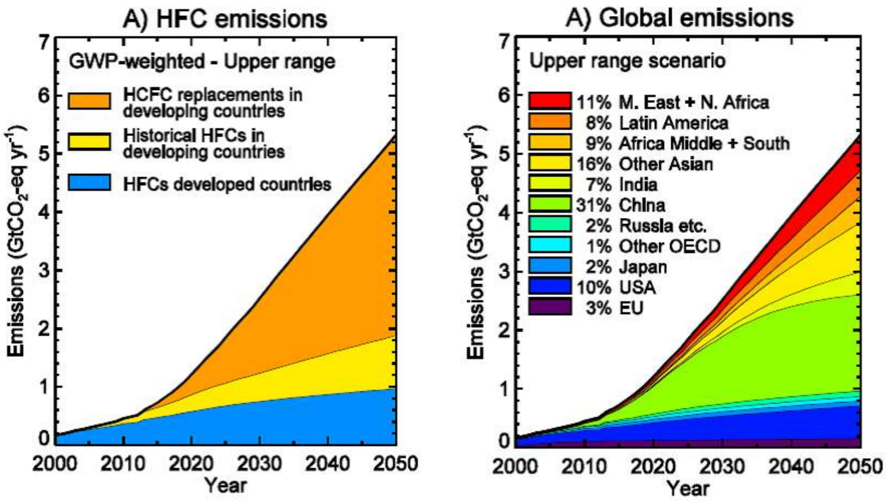


Figure 1. Future atmospheric abundances and climate forcings from scenarios of global and regional hydrofluorocarbon (HFCs) emissions [Source: Guus J.M. Velders, David W. Fahey, John S. Daniel, Stephen O. Andersen, Mack McFarland, 2015]

Refrigerants and Environmental Problems

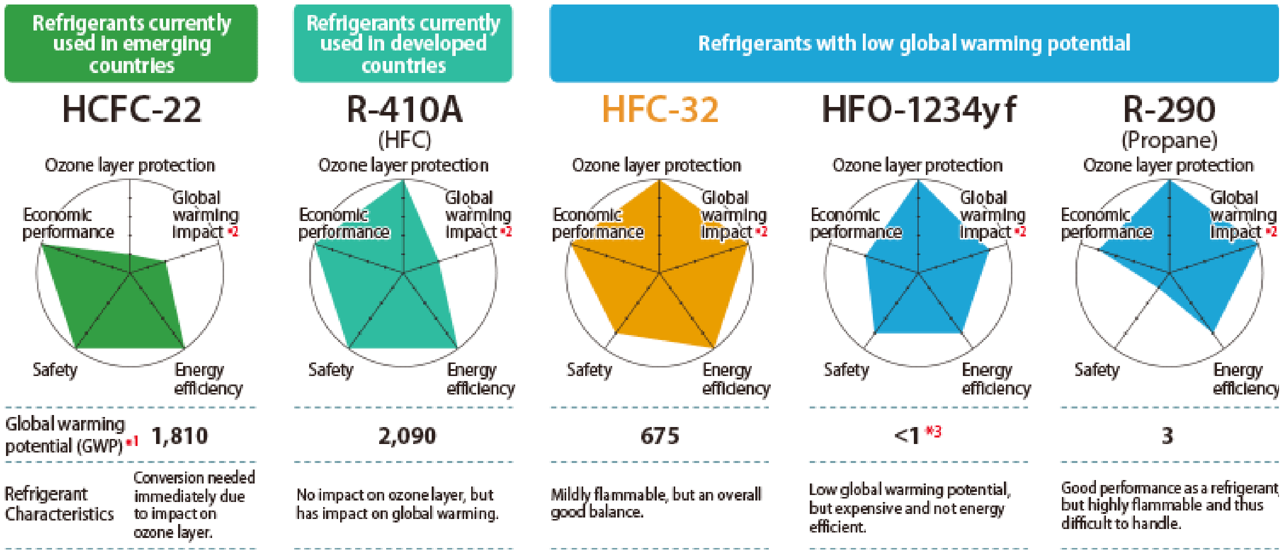
Fluorine gases are widely used as air conditioner refrigerants today. There are now many types of fluorine gases, whose development and manufacture began in the United States in the 1930s under the trade name Freon. Non-toxic, colorless, odorless, non-flammable, and chemically stable, Freon was hailed as a "dream" substance when it was released.

Subsequently in 1974, however, it was reported that fluorine gases caused destruction of the ozone layer. Ozone-depleting fluorine gases contain chlorine, and are known as CFCs (chlorofluorocarbons) and HCFCs (hydrochlorofluorocarbons).

The Vienna Convention for the Protection of the Ozone Layer was adopted in 1985, and provided the foundation for the Montreal Protocol on Substances that Deplete the Ozone Layer, which was adopted in 1987, and which phased out the use of CFCs and HCFCs. CFCs were completely phased out in developed countries in 1996 and in developing countries in 2010. Developed countries have until 2020 to completely phase out HCFCs, while developing countries have a deadline of 2030. In the beginning of the phase-out, conversion from chlorine-containing CFCs and HCFCs to HFCs (hydrofluorocarbons), which do not contain chlorine, moved forward. Later, however, concerns over global warming grew, and HFCs together with other greenhouse gas emissions were also targeted to be reduced in the Kyoto Protocol adopted in 1997.

While developed countries converted their refrigerant usage twice, from HCFCs to refrigerants with both zero ozone depletion potential (ODP) and lower global warming potential (GWP), the developing countries are encouraged to leapfrog technologies and convert only once, due to the funding mechanism of the Montreal Protocol. This is a challenge for developing countries as suitable alternatives are sometimes not yet available.

It is feared that refrigerant trends in developing countries, where refrigerant usage is expected to sharply increase, will further accelerate global warming. See Figure 1.



*1 *GWP is quoted from the Fourth Assessment Report of the IPCC.*
*2 *Global Warming Impact: Global warming impact over the entire lifecycle of the air conditioner (impact of air conditioner use and refrigerant emission).*
*3 *Quoted from the Fifth Assessment Report of the IPCC.*

Figure 2. Characteristics of possible next-generation refrigerants (for residential and commercial air conditioners)

Alternative Refrigerant Candidates

In the past, HCFC-22 was the main refrigerant in widespread use in the air conditioning field. This refrigerant shows good performance, is easy to use, and is non-flammable. The alternative refrigerants being advocated today roughly fall into the following four categories:

1. HFCs that have a lower global warming potential,
2. Non-halogen substances, commonly referred to as natural refrigerants
3. HFO (hydrofluoroolefin) refrigerants
4. Blends of the above

Many refrigerants that fall into the above categories have been proposed, but they each have their strengths and shortcomings. See Figure 2.

1. HFC refrigerants have long been used, offer good performance, and are easy to handle. Several HFC's have a lower GWP, such as HFC-32 (GWP=675) compared to R-410A (GWP 2088), and R-404A (GWP 3922).
2. Non-halogen refrigerants have long been used, but CO_2 requires very high pressure and poses energy efficiency problems in some applications. Hydrocarbon refrigerants are extremely flammable. Ammonia is highly toxic. However, these refrigerants have very low GWP in the single digits.
3. HFOs have been recently proposed as alternative refrigerants for R-134a. They have a short atmospheric lifetime and therefore low GWP, but pose challenges in terms of energy efficiency and cost effectiveness.
4. Blends combine the respective properties of their constituent refrigerants. If the constituent refrigerants have different boiling points, the temperature glide makes the blend difficult to use as refrigerant. A great many blends have been proposed, and it will take time for precise assessments of each blend to be conducted.

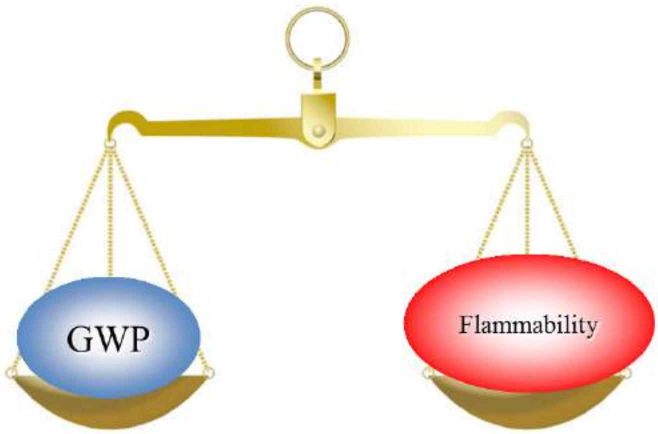


Figure 3. Lower GWP and flammability are two sides of a coin

Lower GWP and flammability are two sides of a coin. In physicochemical terms, low-GWP refrigerants will inevitably have higher flammability. See Figure 3.

As international technical standards, ISO 817:2014 provides refrigerants safety classification (See Table 1), ISO 5149:2014 provides a safety standard for refrigerating systems and heat pumps, and IEC 60335-2-40 (5th edition) covers particular requirements for electrical heat pumps, air-conditioners and dehumidifiers.

Additionally, refrigerant recycling is an important issue in preparation for future reductions in refrigerant use, and it goes without saying that a single component refrigerant is more suited to the refrigerant cycle.

Table 1. ISO 817:2014 Refrigerants -- Designation and safety classification

		Lower toxicity	Higher toxicity
Higher flammability		A3	B3
Lower flammability	Burning velocity > 10 cm/s	A2	B2
	Burning velocity ≤ 10 cm/s	A2L	B2L
No flame propagation		A1	B1

Efforts in Developed Countries

Europe

In Europe, the F-Gas Regulation has been amended and was published on May 20, 2014, in the Official Journal of the European Union. It came into force in January 2015. The EU has set the target of phasing down HFC consumption volumes by 79 % by 2030. It has also imposed GWP limits on some types of equipment. For example, a single-split air conditioner with a charge of less than 3 kg must use a refrigerant with GWP of less than 750 from 2025. The European Commission is collecting information on the codes, standards, or legislation of member states related to replacement technologies using alternatives to fluorinated greenhouse gases in refrigeration, air conditioning, and heat pump equipment and in foams. It is scheduled to publish a synthesis report by January 1, 2017.

USA

In the United States, the Clean Air Act establishes the Significant New Alternatives Policy (SNAP) program, which reviews substitutes to CFCs and HCFCs for each application and is overseen by the Environmental Protection Agency (EPA). Refrigerants not authorized in the SNAP program cannot be used in the U.S. market. In April 2015, SNAP approvals for the flammable refrigerants HFC-32 (A2L), R-290 (A3), and R-441A (A3) were published in the Federal Register. However, their use is limited to factory sealed, or self-contained, room air conditioners that fulfill requirements of UL Standard 484. In March 2011, HFO-1234yf (A2L) was authorized for use in car air conditioners. Meanwhile, use of HFC-134a, which has high GWP, will be prohibited in new vehicles from 2021.

Japan

Japan has amended its Fluorocarbons Recovery and Destruction Law, which imposes new requirements on fluorinated gas manufacturers, equipment manufacturers, managers (users), charge recovery business operators, and recycling and destruction business operators. For equipment manufacturers in particular, the target GWP and year is presented for each type of equipment. For example, residential air conditioners and store and office air conditioners have a target GWP value of 750 with target years of 2018 and 2020, respectively. Risk assessments aimed at relaxing regulations on the use of flammable refrigerants are making progress under the cooperation of industry, government, and academia, but loosening the safety requirements of the High Pressure Gas Safety Act is a matter of urgency.

In Japan, almost all leading air conditioner manufacturers have completed product conversion from R-410A to HFC-32, mainly for residential air conditioners.

Efforts in Developing Countries

Developing countries are specified as A5 countries in the Montreal Protocol and are currently being required to take immediate measures to phase out fluorine gases that deplete the ozone layer, such as HCFC-22. As previously stated, an ideal alternative substance does not exist, causing headaches for the authorities in each country.

Each developing country has drafted an HCFC Phase-out Management Plans (HPMP) and submitted it to the Multilateral Fund for the Implementation of the Montreal Protocol (MLF). After its HPMP is approved, the country can obtain assistance from the Montreal Protocol for refrigerant conversion.

Looking at the conversion plans for individual developing countries, China, the largest air conditioner producer, has announced a plan to switch its residential air conditioners to R-290 (propane) and its commercial air conditioners to R-410A and HFC-32. It has already finished converting 18 manufacturing lines to propane using MLF assistance and is beginning to deliver units to universities for testing. Thailand, another major air conditioner producer, is home to many foreign-owned manufacturers as well as local small and medium-sized air conditioner manufacturers. It has received technical support from Japan for its refrigerant conversion plan and is

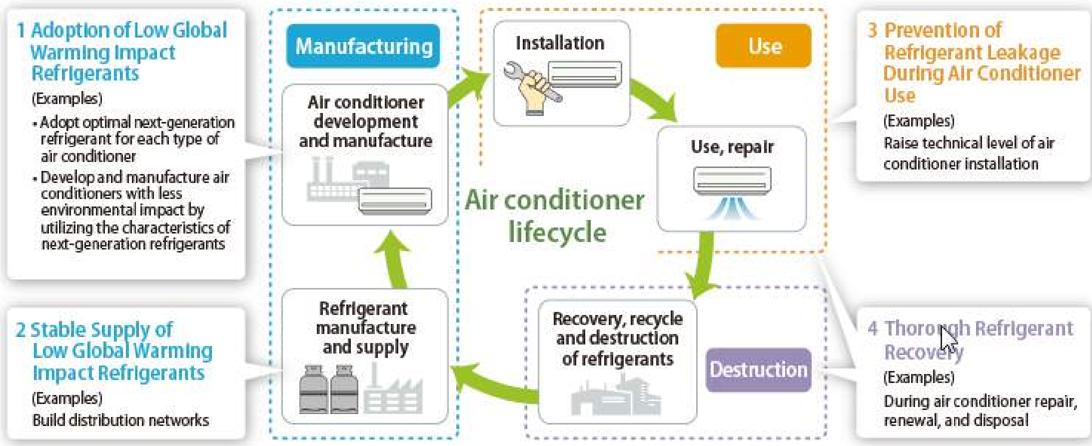


Figure 4. Air conditioner lifecycle, measures to mitigate global warming impact of refrigerants

preparing to convert mostly residential air conditioners to HFC-32. Indonesia is also moving to convert its refrigerant use mainly to HFC-32.

Developing countries are generally considering R-410A, HFC-32, R-290, and HFO blends as alternative candidates to HCFC-22. However, as R-410A has a high GWP, it is not eligible for assistance from the MLF.

HFCs, which do not deplete the ozone layer, are not gases subject to the Montreal Protocol, but a heated discussion is taking place on how the Montreal Protocol, which takes climate change into consideration, should also aim for an HFC phase-down. The discussion is also focusing on expanding assistance from developed countries to developing countries.

Air Conditioner Industry Direction

Currently, various next-generation refrigerant candidates have been proposed, mainly by air conditioner and refrigerant manufacturers in Japan, the United States, and Europe. Frequent discussions on the topic also take place at the Montreal Protocol meetings and other international conferences. Refrigerants are not simply one element of air conditioners; they are shared infrastructure across air conditioners' lifecycle through the industry and markets. Awareness of refrigerant problems, especially safety or environment issues, must be more widely achieved. See Figure 4.

In addition, as awareness of climate change grows, further demands to reduce not only refrigerants but also electricity-derived CO_2 emissions from air conditioners are expected. Various technologies have been applied to compressor operation, which accounts for the majority of air conditioner power consumption. Variable-speed (inverter) operation according to load instead of fixed-speed operation is an effective technology. Air conditioners generally referred to as inverter types have already largely penetrated markets in developed countries, while fixed-speed, non-inverter air conditioners account for most of the market in developing countries.

Using inverters is an effective way to reduce power consumption in developing countries in the future, but they will need to cost less to achieve more widespread use in developing countries.

To further reduce power consumption, air conditioners should not only be able to be individually controlled. There are expectations for the introduction of centralized controls and remote controls as well as demand response technology to control energy consumption for entire buildings and communities while monitoring air conditioner load.

Proposals

Proposals are as follows to minimize negative impact on the global environment, across the lifecycle of air conditioning products.

- Periodic maintenance to prevent refrigerant leakage from AC equipment in operation.
- With no ideal refrigerant currently available, the best option is to use a different refrigerant for each type of equipment, taking into account the properties of the various refrigerants.
- Quicker application and promotion of better refrigerant solution for the moment.
- Close collaboration and information exchange among industries, academic societies and administrative bodies.
- Review and relaxation of global and local standards and legislation to expand the use of flammable refrigerant.

The air conditioning industry, which continues to provide healthy and culturally enriched living environments on a global scale while working to mitigate the climate change, is tasked with a major challenge.

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Innovative Ammonia Heat Pump and Chiller System for Computer Cooling and High-Temperature Heat Recovery at a Norwegian Campus

Jørn Stene, Norway

Due to the accelerating use of the Internet and network-based services, large data centres have become very important. There are currently over three million data centres globally, and Information and Communications Technology (ICT) consumes up to 10 % of the world's electricity. Most computer cooling systems do not have any heat recovery system. However, there is a strong trend towards green data centres with minimum primary energy use and low greenhouse gas emissions. An excellent example of green ICT is the supercomputer centre at the Norwegian University of Science and Technology (NTNU) in Trondheim, Norway. The excess heat from the combined liquid chiller and high-temperature heat pump system is utilized in the local district heating system at the campus, thus reducing the net primary energy use to a very low level.

Introduction – Green Cooling Systems

Energy efficient and "green" cooling systems for data centres can be categorized as follows:

Type 1 – Free, renewable cooling
- Seawater, ground water, bedrock or cold ambient air

Type 2 – Cooling with low-temperature heat recovery (< 50 °C)
- Low-temperature heating systems in buildings
- Preheating of domestic hot water (DHW)

Type 3 – Cooling with high-temperature heat recovery (> 50 °C)
- High-temperature heating systems in buildings (60-80 °C)
- DHW heating (70-80 °C)
- District heating systems (70-90 °C)

When free cooling sources are unavailable, high-temperature heat recovery is the most applicable approach since the excess heat can be rejected to, for example, district heating systems or hot water systems in buildings with considerable hot water demand (hotels, hospitals, sport centres). Since standard liquid chillers have a maximum outlet water temperature of approx. 50 °C, technologies designed for high supply temperatures have to be used. This includes single-stage ammonia screw-compressor units (max. 80 °C), two-stage ammonia or R-134a/HFO units (max. 75-90 °C), cascade units (max. 90-100 °C), ammonia/water hybride units (max. 100-110 °C) and single-stage CO_2 units (70-90 °C). The different technologies have their benefits and disadvantages with regard to investment costs, seasonal COP, operational reliability, space requirement and maintenance costs.

Figure 1. The supercomputer at the Norwegian University of Science and Technology. [Photo: Bjørn Lindi]

Advanced Liquid Chiller and Heat Pump Plant

In 2014 a 800 kW combined liquid chiller and high-temperature heat pump system was installed at the Norwegian University of Science and Technology (NTNU) in Trondheim, Norway. The highly advanced chiller plant cools the supercomputer "Vilje" from Silicone Graphics Int. Corp., and the excess heat is rejected to the district heating network at the campus. See Figure 1.

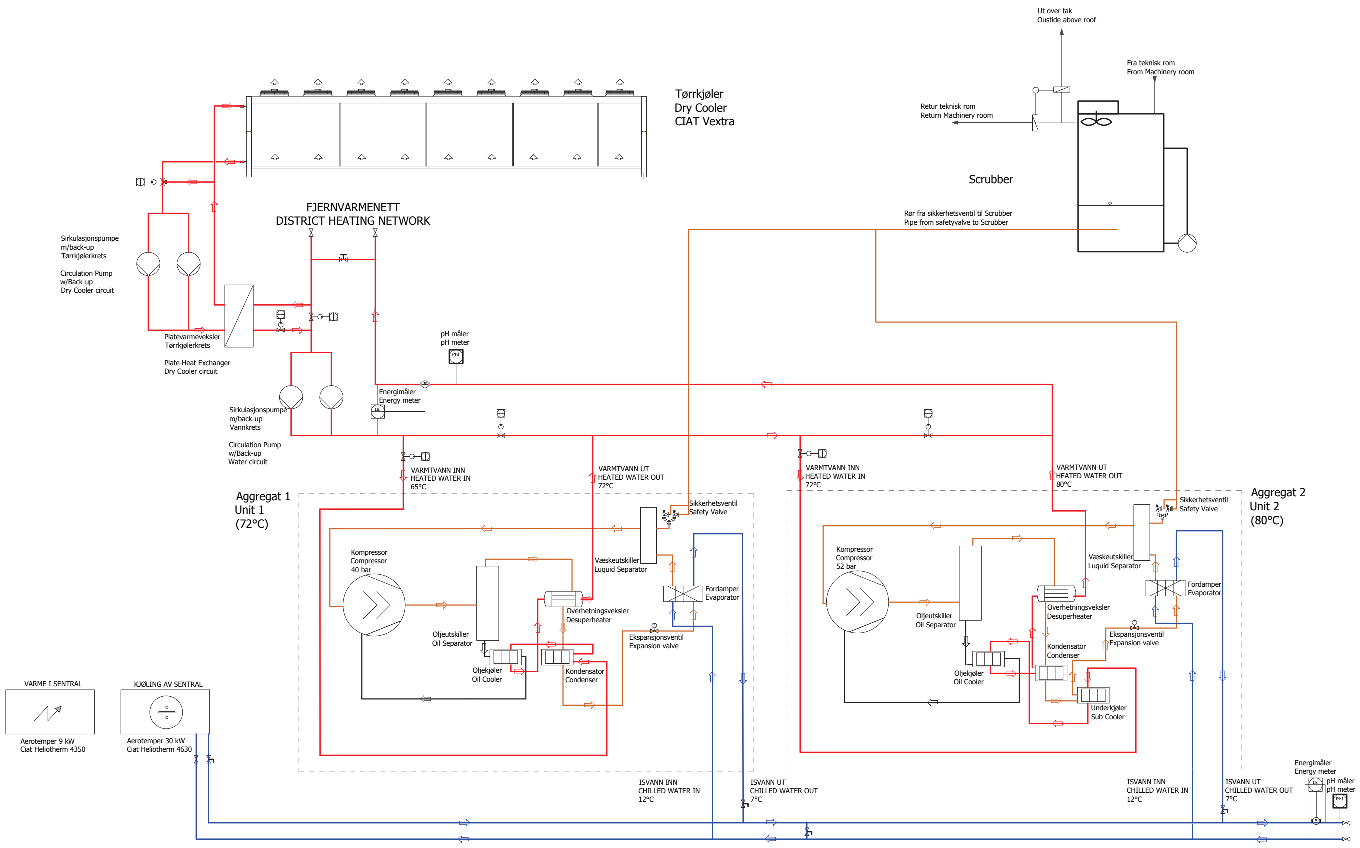

Figure 2. Principle system sketch of the liquid chiller and heat pump plant [Eptec Energi AS].

The chiller plant comprises two ammonia (NH_3, R-717) units from GEA Refrigeration Techn. GmbH, each having a 400 kW cooling capacity at 7/12 °C. The total heating capacity is approx. 1100-1200 kW, and the maximum supply temperature is 80 °C. This is about 30 °C higher than that of standard liquid chiller systems and enhances the application range considerably. At the design outdoor temperature (-20 °C) the supply/return temperature in the district heating network is 90/60 °C. The set point for the supply temperature is determined by the ambient air temperature, and this maximizes the COP for the chiller plant.

The chiller plant is located in a machinery room in the transportation zone in the basement of a building. The plant comprises tailor-made single-stage units since there was insufficient space for a two-stage plant or other space-consuming plant designs in the long and narrow machinery room. Despite the single-stage design, the plant achieves a relatively high COP even at high supply temperatures due to the use of ammonia as the working fluid, high-efficiency components and heat rejection from as many as 7 heat exchangers, all connected in series. Unit 1 is equipped with a condenser, an oil-cooler and a desuperheater while Unit 2 has a sub-cooler, an oil-cooler, a condenser and a desuperheater. The oil-coolers maximize heat recovery and lower the maximum discharge temperature to a low level (< 90 °C), the desuperheaters lower the condensation temperature for both units while the subcooler increases both the cooling and heating capacity of Unit 2. See Figure 2.

The heat exchangers are connected in series at the return pipeline in the district heating system in order to miminize the supply temperature from the chiller plant and enable full operation even during the coldest days of the year when the supply temperature in the district heating system is 90 °C. At design conditions the chiller plant heats the water from 65 to 80 °C. During summer operation the heating capacity for the chiller plant exceeds the heating demand in the district heating network, and surplus heat is rejected to the ambient by means of a dry cooler circuit.

Since the two chiller units reject heat at different temperature levels, the high-pressure sides are designed for 40 bar and 52 bar pressure rating. Unit 1 comprises a recirculation evaporator (plate heat exchanger, PHE), a high-efficiency twin-screw compressor with combined variable speed drive (50-100 %) and slide valve control (10-50 %), a condenser (shell-and-plate heat exchanger, SPHE), an oil-cooler (SPHE), and a desuperheater (tube-and-shell heat exchanger). Unit 2 has the same main components, but in addition it's equipped with a sub-cooler (SPHE). Due to the compact design and the application of PHE and SPHE, the total ammonia charge is only 220 kg, i.e. approx. 0.28/0.20 kg per kW cooling/heating capacity. See Figure 3.

The main strategy of COWI Norway is to design heat pump and refrigerating systems with working fluids that do not have any negative impact on the global environment, i.e. ammonia, CO_2 or hydrocarbons, whenever possible from a technical, economical and practical perspective. In this particular project COWI was, among other things, responsible for the analysis and the design of the ammonia liquid chiller and heat pump plant.

Ammonia as Working Fluid – Safety Measures

In contrast to the HFCs, the Global Warming Potential of ammonia is zero (GWP=0), and the fluid therefore has no impact on global warming in the event of unintentional leakage. Consequently, ammonia is not controlled by the F-gas Directive which imposes strict regulations regarding leakage testing of heat pump and chiller plants. Ammonia has excellent thermophysical properties that leads to high process COP, efficient heat transfer and high compressor efficiency. Other beneficial properties are the very small mass flow rate and the high critical temperature/pressure that enables high-temperature heat supply. Due to the low vapour density, ammonia reaches high discharge gas temperatures even at moderate pressure ratios, and it is therefore important to implement measures to keep the discharge temperature at an acceptable level.

In the European refrigeration and heat pump standard EN378, ammonia is classified in group B2, i.e. highly toxic (IDLH* 500 ppm) but moderately flammable (LEL** 15 %, AIT*** 650 °C). Ammonia has a pungent odour that eases the detection of leakage, but it may also cause panic and dangerous situations if ammonia is released in public areas where people are not accustomed with the properties of the fluid. Due to the toxicity and the pungent odour of ammonia, the university wanted the most extensive safety measures to be implemented since the plant is situated in a building located at the campus.

The machinery room is leakage proof and is able to withstand a fire for at least 60 minutes (EI60). The safety equipment is designed according to EN378, which includes, among other things, a separate fail-safe ventilation system, leak detectors for low/high/critical alarm located above the units since ammonia is lighter than air, and an alarm system. The liquid chiller units have a number of sectioning valves that are activated in case of a leakage. As an additional safety measure a scrubber system has been installed in the machinery room. The scrubber is a large water tank with a water spray system. In the event of ammonia leakage, the ventilation air is passed through the water spray for efficient absorption of the ammonia vapour. The air in the machinery room is recirculated through the scrubber several times,and the scrubber absorbs up to 98 % of the ammonia. The remaining air with a low ammonia concentration is rejected to the ambient. After

Figure 3. High-temperature liquid chiller and heat pump unit with variable speed drive twin-rew compressor [Photo: Eptec Energi AS]

* *Immediately dangerous to life or health (IDLH)*

** *Lower explosive limit (LEL)*

*** *Auto-ignition temperature (AIT)*

Figure 4. Gas-tight machinery room with separate ventilation system [Photo: Eptec Energi AS]

a leakage the ammonium water in the tank has to be treated as waste water, and the tank is recharged with fresh water. See Figure 4.

An uninterruptable power supply (UPS) has been used for the alarm system, the ventilation system and the scrubber. Since ammonia is a strong base, pH sensors have been installed in the district heating and ice water circuits in order to detect any ammonia leakage at an early stage.

Measurement Results

Students at technological universities who study heat pump and refrigeration engineering need access to high-quality demonstration plants. The liquid chiller and heat pump installation at NTNU represents one of the most energy efficient and environmentally benign technologies on the market. The plant is equipped with a large number of pressure and temperature sensors as well as thermal and electric energy meters in order to enable detailed monitoring and analysis of the plant. Some of the measurement results from the first year of operation can be summarized as follows:

- At 65 °C outlet water temperature from the chiller plant, about 60 % of the total heat supply comes from the condensers, 28 % from the oil coolers, 9 % from the subcooler and 3 % from the desuperheaters.
- The compressor efficiency is more or less constant when using VSD control, while the slide valve control leads to poor efficiency at part loads below 50 % and very low COP
- The discharge gas temperature is as low as 70-90 °C due to very efficient oil cooling
- The average heating COP is about 3.0 at 7/65 °C
- The average drop in cooling capacity and heating COP is about 1.5 % and 2.5 %, respectively, per °C rise in the return hot water temperature in the district heating network

The cooling demand for the supercomputer centre varies during the day and night with an average of about 700 kW. This corresponds to an average heating capacity of approx. 1000 kW for the chiller. During summer the minimum heating demand in the district heating network at the campus is 600-800 kW, which means that most of the rejected heat from the chiller plant is useful heat. The measured annual heat supply is about 7 to 8 GWh/year, and the annual energy saving is about 5 GWh/year. Despite the high total investment costs for the installation, the pay-off time for the chiller plant is only 4 years due to the long equivalent operating time.

Conclusion

Energy efficient and "green" cooling systems for data centres include free (renewable) cooling as well as cooling systems with low- or high-temperature heat recovery. When free cooling sources are unavailable, high-temperature heat recovery is regarded the most usable alternative. Since standard liquid chillers have a limited outlet water temperature, technologies designed for high supply temperatures have to be used. The combined liquid chiller and heat pump installation at the Norwegian University of Science and Technoogy (NTNU) is cutting-edge technology that represents an exemplary and future oriented solution for combined cooling and high-temperature heat recovery from larger computer centres.

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Evaluation of R-410A Alternative Refrigerants in a Residential Reversible Air-to-Water Heat Pump

Pierre Pardo, France

Alternative refrigerants to R-410A are under investigation for residential heat pumps and air-conditioners since R-410A has a GWP of 2088. In this paper, two promising alternative refrigerants, DR-5A (R-454B) and L41-2 (R-447A), both HFC-HFO mixtures with a GWP of 466 and 583, respectively, have been tested in a residential heat pump. The results show that R-410A replacement by L41-2 and DR-5A does not raise any particular problems and the performance obtained is, aside from some few exceptions, almost equivalent (+/-10 %) to that with R-410A. These experimental results provide better understanding and knowledge about R-410A replacement in heat pumps.

Introduction

Protocols and regulations such as the Montreal Protocol (1987), the Kyoto Protocol (1997), the European F-gas regulation (2006, revised 2014) cause a shift toward refrigerants with both zero Ozone Depletion Potential (ODP) and low Global Warming Potential (GWP) [1]. These new limitations lead to the progressive phase-out of HFC and to their replacement by the 4th generation of refrigerants based on HFO mixtures. Alternative refrigerants with low GWP are under investigation for residential heat pumps and air-conditioners as R-410A has a GWP of 2088 [2]. The objective of this work is to test two promising alternative refrigerants of R-410A, namely DR-5A (R-454B) and L41-2 (R-447A) [2–4]. The refrigerants were selected based on the results of the AHRI Low-GWP AREP program [2] (i.e., they have performance and thermodynamic behavior similar to R-410A).

In the first section of this paper the refrigerant properties are presented, then, the experimental procedure is described, and finally, the experimental results are reported and analyzed.

Table 1. Refrigerant properties [5]

Refrigerant	Composition	GWP100	Critical point	Normal boiling point	Safety class
R-410A	R-32/R-125 (50/50 % w/w)	2088	T_c = 70.2°C P_c = 47.7 bar ρ_c = 552 kg.m^{-3}	-51.6 to -51.1°C	A1
L41-2 (R-447A)	R-32/R-1234ze(E)/R-125 (68/28.5/3.5 % w/w)	583	T_c = 80.2°C P_c= 52.7 bar ρ_c = 425 kg.m^{-3}	-49.3 to -44.2°C	A2L
DR-5A (R-454B)	R-32/R-1234yf (68.9/31.1 % w/w)	466	T_c = 76.5°C P_c= 51.2 bar ρ_c = 415 kg.m^{-3}	-49.9 to -50.9°C	A2L

Table 2. Heat pump characteristics

Heating capacity at 7(6)°C-30/35°C	10 kW
Operation modes	Reversible (Four-way valve)
Type	packaged, non ducted - outdoor installation
Compressor technology	Scroll – fixed capacity
Expansion device	Calibrated orifice (Not adjustable)
Initial R-410A charge	2.35 kg

Refrigerants' Properties

Table 1 presents the principal properties of the refrigerants used in this study. The data source for these refrigerant properties is the software NIST REFPROP Version 9.1 [5].

The GWP of the alternative refrigerants are considerably lower than the GWP of R-410A. The GWP of L41-2 is 28 % of that of R-410A and for DR-5A this number is 23 %.

Both alternative mixtures are mainly composed of R-32 (~ 68 - 69 % w/w) and of an HFO (~30 % w/w). The major difference between L41-2 and DR-5A lies in the HFO used in the mixtures: R-1234ze(E) for L41-2 and R-1234yf for DR-5A. Both alternative refrigerants have a A2L safety class, which means they have a low flammability and are non-toxic.

Table 3. Rating (C) and operating limit conditions (CL) in cooling mode

	Air temperature [°C]	Inlet water temperature [°C]	Outlet water temperature [°C]
C1	35	12	7
C2	35	23	18
CL1	18	*	5
CL2	42	*	25

Table 4. Rating (H) and operating limit conditions (HL) in heating mode

	Dry air temperature (wet bulb) [°C]	Inlet water temperature [°C]	Outlet water temperature [°C]
H1	7(6)	30	35
H2	7(6)	40	45
H3	7(6)	47	55
H4	-7(-8)	*	35
H5	2(1)	*	35
H6	12(11)	*	35
HL1	-15	*	22
HL2	-10	*	42.5
HL3	24 (20)	*	54.8

Table 5. Heat pump performance with R-410A in cooling mode

	Power input [kW]	Heating capacity [kW]	COP [-]
C1	2.96	8.01	2.71
C2	3.00	8.80	2.93
CL1	2.46	9.30	3.78
CL2	3.50	8.87	2.53

Table 6. Heat pump performance with R-410A in heating mode

	Power input [kW]	Heating capacity [kW]	COP [-]
H1	2.60	10.10	3.88
H2	3.17	10.44	3.30
H3	3.73	9.95	2.67
H4	2.05	4.33	2.11
H5	2.05	6.21	3.03
H6	2.65	10.86	4.10
HL1	1.62	3.50	2.16
HL2	2.35	3.71	1.58
HL3	4.04	12.33	3.05

Table 7. Charge optimization results (at C1 rating condition)

	R-410A (baseline)	DR-5A	L41-2
Charge [kg]	2.35	2.00	1.86
Cooling capacity [kW]	8.01	8.25	7.44
Electrical power absorbed [kW]	2.96	2.78	2.63
EER [-]	2.71	2.97	2.83
Superheating [K]	9.4	4.1	6.4
Subcooling [K]	7.7	4.5	5.5

Experimental Investigation

To assess and to compare the heat pump performance when using R-410A, DR-5A and L41-2, drop-in tests were carried out on a 10 kW air-to-water reversible heat pump. The heat pump characteristics are summarized in Table 2.

For each refrigerant, the heat pump performance was assessed for 2 rating conditions and 2 operating limit conditions in the cooling mode and for 6 rating conditions and 3 operating limit conditions in the heating mode. The tests were performed according to EN 14511 standard [6]. The tests were carried out in the CETIAT climatic room, CLIM 1. The test conditions in cooling mode and in heating mode are described in Table 3 and Table 4, respectively. The operating limit conditions (in grey) were fixed by the heat pump manufacturer and they correspond to the boundary conditions of operation of the heat pump with R-410A.

In the first phase, the heat pump performance using R-410A was evaluated. Then, in phases 2 and 3, both alternative refrigerants, DR-5A and L41-2, were tested. For each, a refrigerant charge optimization was done, then the rating and operating limit condition tests were performed, and finally, a performance verification using R-410A was carried out to detect any anomaly after the use of one or the other alternatives. During all the tests, measurements allowed the determination of thermal capacities, electric energy consumptions, the efficiencies (EER or COP), as well as the pressures and discharge temperatures on the refrigerant circuit to be conducted. On account of the uncertainty of measurement on the laboratory's instrumentation, capacities were determined with a maximal uncertainty of 5 % and electric energy consumptions with a maximal uncertainty of 1 %.

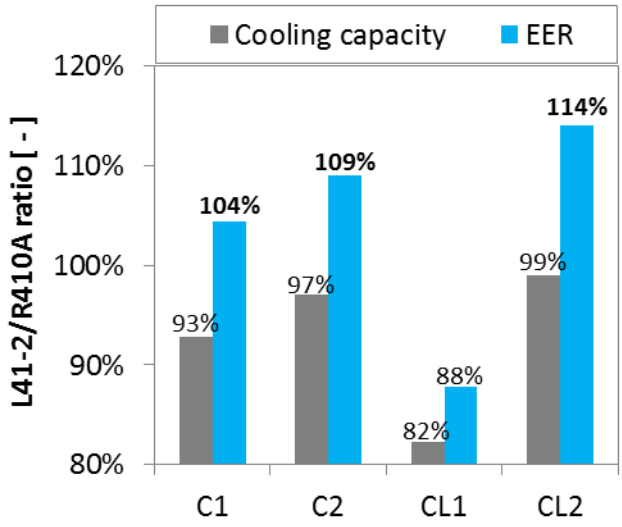
Results

Heat Pump Performance Evaluation with R-410A

Table 5 and Table 6 present the heat pump performance evaluation when using R-410A in cooling mode and in heating mode, respectively. These results are the baseline for all the performance comparisons of this study.

Alternative Refrigerant Charge Optimization

To perform charge optimization, the initial alternative refrigerant charge loaded into the heat pump was about 1.65 kg (corresponding to 70 % of the initial R-410A charge). Charge optimization was carried out at C1 rating condition (see Table 3). When the refrigerant charge was increased (~ + 50 g every 30 minutes), four parameters were followed; EER, cooling capacity, superheating and subcooling. The objective was to identify the performance curve inflexion point to determine the optimal charge. Particular attention was paid to the fact that superheating and subcooling have to be in the interval between 4 and 7 K. The charge optimization results are reported in Table 7. Both alternative refrigerant charges are lower than the R-410A charge: -15 % for DR-5A and -21 % for L41-2. These results are consistent with the literature [2 - 4].



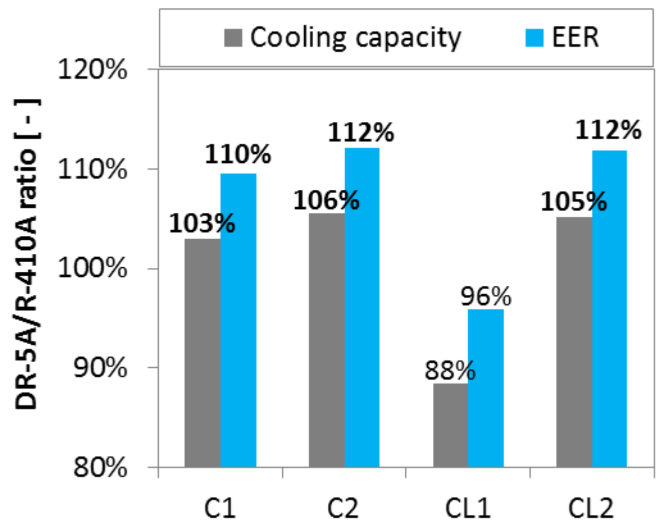


Figure 1. Heat pump performance using the alternative refrigerants in cooling mode: a) L41-2; b) DR-5A

Heat Pump Performance Evaluation Using the Alternative Refrigerants

Cooling mode

Figure 1 presents the results obtained in cooling mode as a ratio of performance (alternative refrigerant / R-410A).

For the operating conditions C1, C2 and CL2, greater performance is achieved with DR-5A than with R-410A, from +3 to +6 % for the cooling capacity and from +10 to +12 % for the EER. With L41-2, greater EER is obtained, from +4 to +14 %, but cooling capacities are slightly lower, between -1 % to -7 %, compared to those with R-410A. For both alternative refrigerants, performance at the CL1 operating limit condition is lower than that with R-410A. The discharge temperatures observed for the three refrigerants are very close (+/- 3.4 °C).

Heating mode

Figure 2 presents the results obtained in heating mode as a ratio of performance (alternative refrigerant / R-410A).

DR-5A allows an equivalent or greater COP to be reached than with R-410A, between -3 % and +13 %. DR-5A heating capacities obtained are mainly lower than those with R-410A, from -8 % to -3 %, except for H4, H5 and HL2 conditions (from +2 % to +7 %). With L41-2, COP is also equivalent or greater than that with R-410A, from -4 % to +11 %. L41-2 heating capacities are lower than those with R-410A, from -31 % to -2 %. The heating capacity at H1 rating condition is significantly lower than that with R-410A because the heat pump has carried

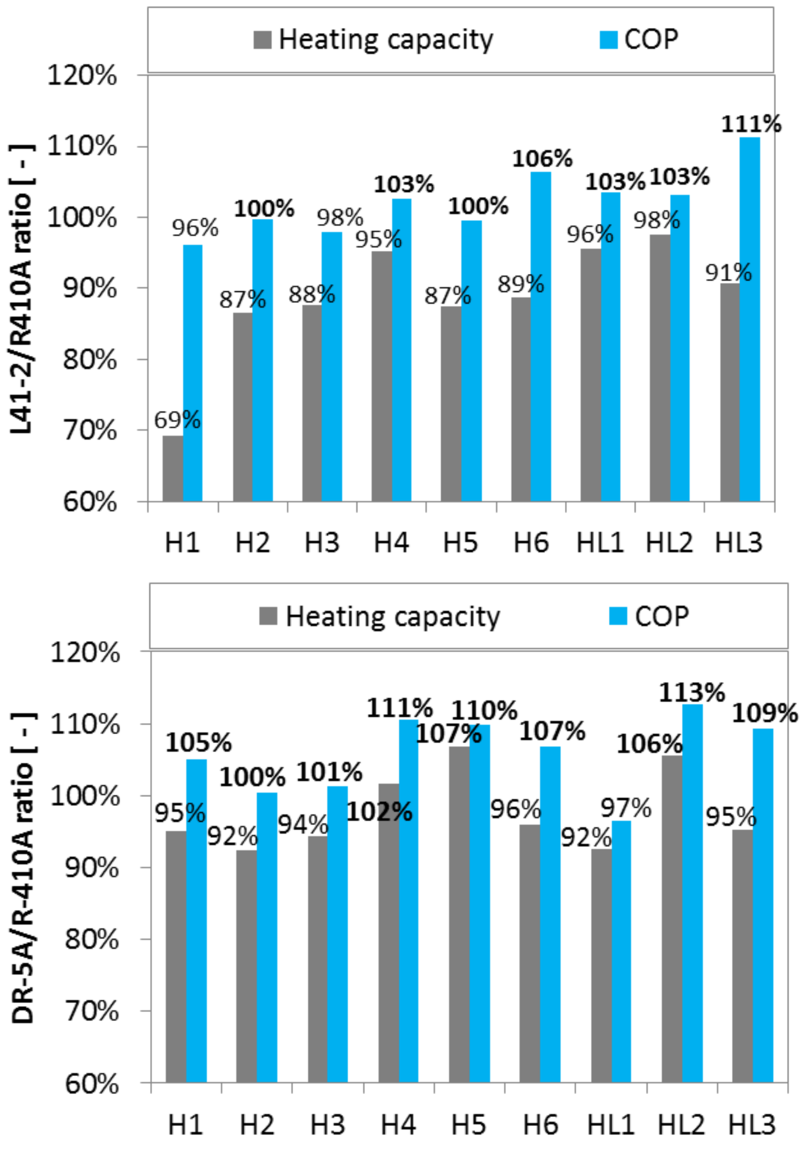


Figure 2. Heat pump performance using the alternative refrigerants in heating mode: a) L41-2; b) DR-5A

out defrosting cycles while they did not occur during the tests with DR-5A and R-410A. The discharge temperatures observed for the three refrigerants are globally the same (+/-8.5 °C), except for HL2 operating limit condition, where the discharge temperatures are +16 °C and +25.6 °C higher than that with R-410A, reaching 98.3 °C for L41-2 and 108 °C for DR-5A.

Heat Pump Performance Verification

To make sure that the use of the alternative refrigerants did not damage heat pump, tests with the initial R-410A charge (2.35 kg) have been performed after each experimental series with the alternative refrigerants. This verification allowed us to verify the heat pump performance deviation, but it did not give any answer concerning the long term use of the alternative refrigerants. The performance has been checked on the C1 and H1 rating conditions. The performance verification results are reported in Table 8. According to the results, we can conclude that there was no notable damage to the heat pump after the use of one or the other of the refrigerant alternatives as the performance gaps are quite small (from -1 % to +5 %) and within the uncertainty of measurement.

Table 8. Heat pump performance verifications

		Power input [kW] (baseline gap %)	Cooling/Heating capacity [kW] (baseline gap %)	EER/COP [-] (baseline gap %)
C1	**Baseline R-410A**	**2.96**	**8.01**	**2.71**
	R-410A tests after using DR-5A R-410A tests after using L41-2	2.97 (0 %) 3.02 (+2 %)	7.94 (-1 %) 8.31 (+4 %)	2.67 (-1 %) 2.76 (+2 %)
H1	**Baseline R-410A**	**2.60**	**10.10**	**3.88**
	R-410A tests after using DR-5A R-410A tests after using L41-2	2.62 (+1 %) 2.67 (+2 %)	10.21 (+1 %) 10.55 (+ 5%)	3.90 (+1 %) 3.96 (+2 %)

Conclusions

In this experimental study two refrigerants, DR-5A (R-454B) and L41-2 (R-447A), have been tested in a 10 kW air-to-water heat pump in order to compare their performance, as drop-in low GWP alternatives to R-410A. R-410A replacement by L41-2 and DR-5A showed no particular problem and the performance obtained is, aside from some very few exceptions, almost equivalent (+/- 10 %) to that with R-410A. Furthermore, in the operating limit conditions defined in the experimental plan, the heat pump worked normally with both alternative refrigerants. Thus, the heat pump operating map can be kept, except for the HL2 operating limit condition, because of the high discharge temperatures reached with both alternative refrigerants.

In conclusion, this work has provided results for a better understanding and knowledge about R-410A replacement in heat pumps.

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[4] T. J. Leck, J. Hughes, P. Naicker, B. Hydutsky, *Novel Reduced GWP Refrigerants for Stationary Air Conditioning*, 2014 Purdue Refrigeration Conference, July 14, 2014.
[5] *Software NIST REFPROP Version 9.1*, modified (a new file HMX. BNC has been supplied by the refrigerant suppliers to evaluate the refrigerant properties)
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Events

2016

15 – 17 May
8th Asian Conference on Refrigeration and Air Conditioning
Taipei, Taiwan
http://www.acra2016.org/index.php?po=welcome

18 – 20 May
11th IIR Conference on Phase Change Materials and Slurries for Refrigeration and Air Conditioning
Karlsruhe, Germany
http://www.hs-karlsruhe.de/pcm2016.html

18 – 20 May
EHPA Heat Pump Forum
Paris, France
http://forum.ehpa.org/

22 – 25 May
12th REHVA World Congress - CLIMA2016
Aalborg, Denmark
http://www.clima2016.org

6 June
IEA HPT IOC meeting (closed meeting designated IOC delegates)
Jeju, South Korea

7 June
IEA HPT ExCo meeting (closed meeting designated ExCo delegates)
Jeju, South Korea

8 June
IEA HPT ExCo meeting (open meeting for ExCo and observers)
Jeju, South Korea

9 June
IEA HPT Workshop and technical tour
Jeju, South Korea

9 – 10 June
IIR Korean Committee Conference
Jeju, South Korea

16 – 17 June
ATMOsphere America 2016
Chicago, USA
http://www.atmo.org/events.details.php?eventid=44

25 – 29 June
ASHRAE Annual Conference
St. Louis, USA
https://www.ashrae.org/membership--conferences/conferences/2016-ashrae-annual-conference

3 – 8 July
The 14th International Conference of Indoor Air Quality and Climate
Ghent, Belgium
http://www.indoorair2016.org/

11 – 14 July
Purdue Compressor, Refrigeration and High Performance Buildings Conferences
West Lafayette, USA
https://engineering.purdue.edu/Herrick/Events/Conferences

10 – 12 August
ASHRAE and IBPSA-USA SimBuild 2016: Building Performance Modeling Conference
Salt Lake City, USA
http://ashraem.confex.com/ashraem/ibpsa16/cfp.cgi

21 – 24 August
Gustav Lorentzen Natural Working Fluids Conference
Edinburgh, Scotland
http://www.ior.org.uk/GL2016

11 – 14 September
7th International Conference on Magnetic Refrigeration at Room Temperature
Torino, Italy
http://www.thermag2016.com/

19 – 24 September
European Geothermal Congress 2016
Strasbourg, France
http://europeangeothermalcongress.eu/

22 – 23 September
2nd International Conference Efficient Building Design: Materials and HVAC Equipment Technologies
Beirut, Lebanon
https://www.ashrae.org/membership--conferences/conferences/2016-2nd-international-conference-efficient-building-design

11 – 13 October
Chillventa
Nuremberg, Germany
http://www.chillventa.de/en/

23 – 26 October
9th International Conference on Indoor Air Quality Ventilation & Energy Conservation In Buildings
Seoul, Republic of Korea
http://iaqvec2016.org/

20 – 21 November
International Symposium on New Refrigerants and Environmental Technology
Kobe, Japan
http://www.jraia.or.jp/english/symposium/

In the next Issue

Smart Grids – heat pumps

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International Energy Agency

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

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