Heat Pumping Technologies
MAGAZINE

A HEAT PUMP CENTRE PRODUCT

Heat Pumping Technologies in
Special Applications and New Markets

BEAT WELLIG, Lucerne School of Engineering and Architecture, Switzerland

”USE OF HEAT PUMPS IN NEW APPLICATIONS WILL BECOME STANDARD, HELPING TO SAVE ENERGY AND REDUCE CO_2 EMISSIONS”

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In this issue

This new issue of the HPT Magazine has ***Special Applications and New Markets*** as the topical theme. The applications range from innovative ways to use heat pumping technologies in commercial buildings, over their use in common household appliances, to completely new ways to look at climatisation.

The Foreword provides an overview of these applications. The Topical articles in this issue show examples of the special applications. Connecting back to recent issue topics, there is one article on flammable refrigerants and one on Smart Grids. There is a summary of the recent ASHRAE Winter Conference, and an extended news about Jerry Groff, who has served the heat pump community and the HPT TCP for a very long time, and is this year's John F. James Awardee.

In this issue, **the accomplishments of the HPT TCP** (IEA's Technology Collaboration Programme on Heat Pumping Technologies) **are given some extra emphasis**. The Column, provided by the HPT TCP Chairman, provides the broad picture, and the Annex presentations have a bit more detail than normal. Finally, the programme of the upcoming HP Conference, in Rotterdam in May, is presented in some detail. With more than 400 participants and a host of renowned speakers, interesting presentations, and informal networking, this will be an event that will be long remembered!

Enjoy your reading!

Johan Berg, Editor

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

Topical Articles

Non-topical Articles

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Renovated cube houses (bottom view) in Rotterdam, Netherlands.

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New or Special Applications for Heat Pumps

Heat pumps are a proven technology today that is efficient for heating buildings and generating domestic hot water. They require relatively low investments, are easy to install and are very reliable in their operation. As a result, the use of heat pumps in buildings has grown rapidly over the recent decades. In Switzerland, for instance, the market share of newly built single and multi-family houses with heat pumps has reached over 80 % in recent years. In addition, heat pump technology for specific heating and cooling applications is widely used in the industrial and service sector, trade and commerce, households, mobility, etc.

The potential for heat pumps has not been fully exploited. On the one hand, an important foundation for expanding the use of common heat pump systems lies in the substantial increase in their efficiency. On the other hand, heat pumps are moving into many new applications and markets. Particularly interesting are heating requirements, at temperature levels suitable for heat pumps, for which electric resistance heaters are typically used. A good example of this is the water heating required in various household appliances. Although applying a heat pump for these types of processes is not very efficient, considerable amounts of electrical energy can be saved relative to the traditional electrical heater approach.

In household appliances, such as refrigerators or dryers, the use of heat pumps is the standard. In other appliances, such as dishwashers and washing machines, resistance type heaters are still used requiring a large amount of electrical energy. If the water is heated by means of an integrated heat pump, the demand for electrical energy can be halved compared to today's commercially available standard appliances. In recent years, such devices have been developed and are available on the market.

Another interesting new application is the use of heat pumps for heating electrically powered cars (e-cars) or for the thermal management of electrically powered trucks (e-trucks). Many e-cars are presently electrically heated, which reduces their range in winter by up to 50 %. The efficiency, and thus the range, of e-cars can be significantly increased by heating with a heat pump. In e-trucks, the heat pump can provide the entire thermal management such as heating and cooling of the passenger compartment, battery and power electronics and unit.

The examples above show that heat pumps in new and special applications offer the economy great opportunities for innovative products and systems enabling more energy efficiency and profitability. In doing so, R&D has to solve many new and challenging questions, whether it be the design of new heat exchangers, compressors and other components, or the development of heat pumps, or optimal control systems.

Heat pumps do a lot - but they can do even more. The use of heat pumps in new applications will become standard, helping to save energy and reduce CO_2 emissions. In this issue, several interesting examples of new and special applications are presented. Enjoy the articles.

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PROF. DR. BEAT WELLIG
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SWITZERLAND

Heat Pumps, a Key Technology to Meet the WB2DC Climate Change Targets

At the twenty-first session of the Conference of the Parties (COP21) in Paris, 197 countries approved an Agreement on climate change. The Agreement's overarching goal is limiting global average temperature rise to "well below 2°C" (WB2DC). It entered into force in November 2016. At its heart, it is an agreement about energy. Transformative change in the energy sector, the source of at least two-thirds of greenhouse-gas emissions, is essential to reach the objectives of the Agreement.

In the *World Energy Outlook 2016*, the International Energy Agency (IEA) highlights the various pathways to reach these targets. "Let's not underestimate the task ahead," said Dr Fatih Birol, the executive director of the IEA. "Limiting carbon emissions and changing our energy systems is a monumental challenge. But the IEA is working with governments around the world to help identify solutions and show how it can be done."

Heat Pumping Technologies can, and have to, contribute to this target. They can reduce CO_2 emissions in the building sector in the short term and also support transformation of the global energy system in the long-term. Heat pumps cover both of the requirements for an energy system of the future: they are highly efficient and use renewable energy.

For example, the replacement of a conventional boiler-based heating system in a building by a heat pump can locally reduce GHG emissions to zero. Even in the overall scope, including up- and downstream emissions, the GHG footprint of this technology can be nearly zero, depending on how electricity (or exergy) to run the system is generated. Newly demonstrated combinations of heat pumps with photovoltaic and solar-thermal, and thermal energy storage in dimensions up to seasonal storage, show pathways to increase the use of renewable energy. A wide range of opportunities to reduce energy demand and emissions also exist in industry. Climate change and global warming cause another effect: increasing demand for refrigeration and air-conditioning, especially in emerging countries. The challenge here is to supply cheap, reliable but nevertheless highly efficient devices.

Evaluating the challenges and opportunities for heat pumping technologies and supporting international Research, Development, Demonstration and Deployment (RDD&D) and knowledge transfer is our business. We, the **IEA's Technology Collaboration Programme on Heat Pumping Technologies**, are a part of the IEA Energy Technology Network. We are an international group of experts that enable governments and industries from sixteen countries from around the world to lead projects – called Annexes – on a wide range of Heat Pumping Technologies. Up to now we have completed 40 Annexes and published the reports on our website. Eleven Annexes are ongoing and cover upcoming challenges in the development and implementation of heat pumps. This includes Nearly Zero Energy Buildings, Industry, Smart Grids and District Heating. In upcoming annexes we will address the challenges of air-conditioning and non-vapour based technologies. The Collaboration Programme is open for other countries. If you are interested in collaborating, do not hesitate to contact us: http://heatpumpingtechnologies.org

STEPHAN RENZ
Chairman of the Executive Committee
for the Technology Collaboration Programme
on Heat Pumping Technologies

12th IEA Heat Pump Conference 2017 in Rotterdam

The 2017 IEA Heat Pump Conference will be held in the World Trade Centre in the bustling city of Rotterdam, praised for its great architecture by many. That many of these buildings, amongst them the WTC, are heated and cooled with large ground source heat pumps is unknown to many people.

On Monday May 15th, the first day of the Conference will start with a number of challenging workshops organized together with other IEA TCPs and HPT TCP Annex participants. We have selected topics where each workshop will be introduced by speakers from all continents, giving an overview of the state of the art in the market, experiences and on current research topics with challenging questions for discussion.

The topics focus on

- **Heat pumps for nearly Zero Energy Buildings (nZEB), retrofit and energy flexibility**, on aspects like how can heat pumps contribute to cost-effective nZEB, what is the effect of nZEBs with heat pumps on the grid, how can the building stock be transformed to nZEB (retrofitting) and what are the most important challenges for heat pump application in multifamily houses (MFH);
- **Rethink Energy: Community energy supply systems** is organized by EBC Annexes 63 and 64 and looks at the role of the built environment in transformation/decarbonisation of energy systems and the role and results of heat pumps in CO_2-neutral energy systems on a community scale. Additionally, the variety of contribution of cities in transformation of energy systems will be presented and discussed;
- **Smart communities**, on the results from HPT TCP Annex 42 and Annex 45, regarding the role of storage systems and hybrid heat pumps in future optimized energy systems for the built environment. During the workshop we offer a pragmatic approach on the potential of smart heat pumps in smart grids. Discussions will cover the energy storage potential and the power-to-heat-capability of heat pumps, plus the possibility of hybridising space heating and DHW (use of two energy carriers in one system). The discussion will be embedded within a smart cities perspective;

- **Industrial heat pumps, the next phase** focuses on increasing the knowledge of heat pump technologies and the way to apply these to industrial processes beyond the traditional way of approaching in order to close the production cycles and reduce the amount and level of excess heat. By using the latest technologies, working fluids and software models, we are looking into the opportunities for electrification of the energy supply;
- **Future of Air Conditioning**, has as goal to gather feedback on the value of non-traditional technologies, understand the current status of R&D efforts, and determine content and focus of potential IEA efforts (both technology gaps and programmatic vision). As a basis for the discussion, the US report by the Department on Energy on 'The Future of Air Conditioning' will be presented;
- **Ground source heat pumps and thermal energy storage systems**. The goal of this workshop is to help set future directions for performance monitoring of ground-source heat pump systems and underground thermal energy storage systems. We hope that gathering a diverse group of researchers and practitioners together will lead to a synergistic perspective regarding what is currently unknown and what can be learned from ongoing and future monitoring projects;
- **Heat Pumps and Solar Energy, a win-win combination** focuses on increasing the synergies of the combination of heat pumps and solar energy (thermal and photo-voltaic) in a smart environment in order to obtain an optimal application in the domestic market of new nZEB and existing buildings.

Renowned speakers will introduce the topics. Amongst these are Prof. Stephen Harrison from Queens University in Canada on Solar, Dr. Xiaobing Liu, Principal Investigator at Oak Ridge National Laboratories on Ground Sources, Prof. Carsten Wemhöner from HSR University of Applied Sciences, Rapperswil, Switzerland on nZEB, Antonio Bouza from Department of Energy, USA, and Helmut Strasser from the Salzburg Institute for Regional planning and housing (SIR) on the role of Smart Cities.

These workshops are organized as a mix of short presentations from the various IEA TCPs, such as Energy in Buildings and Communities (EBC), Solar Heating & Cooling Programme (SHC) and Energy Conservation through Energy Storage (ECES), and discussions with experts focusing on how the Conference theme can be set into action. Thus, after the introduction the workshops will discuss in several smaller groups questions of how to reach the potential markets, what to do and how international collaboration can support this process. Participants at the Conference will join the discussions, enriching the future work within Annexes with new ideas and market connections. The results of the workshops and conclusions will be presented at the closing plenary session on Thursday, May 18th.

Plenary opening session

In the plenary opening session on Tuesday May 16th, invited speakers from all continents will give their vision:

- **Jean-François Gagné**, Head of the Energy Technology Policy Division of the International Energy Agency, leading the strategic design of the Agency's analytical work on energy technologies, policies and strategies to promote innovation, and supporting

the IEA international collaborative work on energy technology research and development;

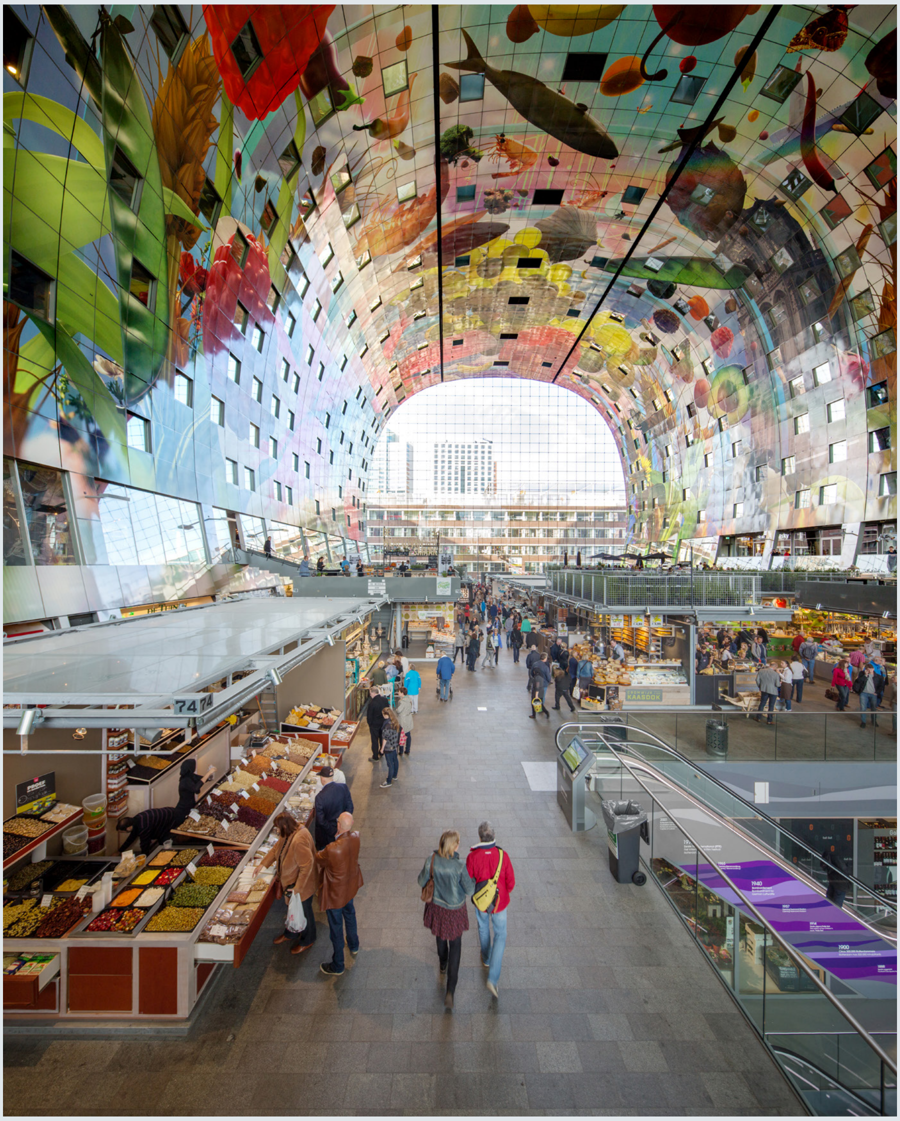
- **Mr Michael Taylor** from the International Renewable Energy Agency (IRENA) will focus on the 'Act Now' question;
- **Prof. Dr. Hans-Martin Henning**, Head of the Institute for Solar Energy systems (ISE) at Fraunhofer in Germany. In his presentation entitled 'Pathways to transform the Energy System until 2050', Prof. Henning sketches perspectives for Europe from the German example, as well as the position of heat pumps as key technology already on short term in the energy infrastructure;
- **Prof. Kensuke Fukushi** from University of Tokyo. In his presentation 'Stimulating social application of energy efficient technology for climate change mitigation', prof. Fukushi discusses the effect of Climate change on technologies needed;
- **Dr. Karim Amrane**, Ph.D., Senior Vice President, Air-Conditioning, Heating, and Refrigeration Institute (AHRI), USA. Dr. Amrane focuses in his presentation 'Effectively Managing the Transition to Lower GWP Refrigerants' on the importance of the management of refrigerants to reduce leak and service emissions, and to promote the recycling, recovery, reclaiming, and end of life destruction of refrigerants.

Four parallel tracks

After the plenary opening session the Conference will continue for three days in four parallel tracks of presentations. The final program can be found on the website http://hpc2017.org/program-at-a-glance/.

Each morning and afternoon session will be opened by a key note speaker, presenting their vision.

The very successful call for papers has generated more than 250 high quality papers. The Conference has the unique opportunity to present, in the four main conference tracks, topics directly related to the work under the IEA Technology Collaboration Programme on Heat Pumping Technologies (HPT TCP) in the now eleven running



international collaboration projects (Annexes) and two new ones under development.

There are sessions on:

- **Track 1**: Domestic and building applications, with sessions on Supermarkets, Commercial Buildings, Nearly Zero Energy Buildings, Residential buildings, Cold Climate Heat Pumps and Domestic Hot Water;
- **Track 2**: Smart Energy Communities and Ground Sources, with sessions on Markets and Policy, Combination and Hybrids, Smart Energy Systems, District Heating and Ground Sources;
- **Track 3**: Air-Conditioning & Industry, with sessions on Air Conditioning, Industrial Heat Pumps, Waste Heat and High Temperature Working Fluids;
- **Track 4**: Sorption and Working Fluids, with sessions on Working Fluids, Sorption Technologies, Gas Driven Heat Pumps and Non Traditional Technologies.

Each of these tracks will have up to 40 oral presentations and a large number of poster presentations. These poster presentations will all be in the central meeting area of the Conference hall. There will be a 'Best Poster Award' that will be handed out at the plenary closing session.

Track 1

Track 1 on Domestic and building applications will show many practical solutions for Nearly Zero Energy Buildings, with domestic hot water becoming the key factor in the overall energy demand and renovation as the main challenge. All of the Thursday sessions will be on the topic, with interesting key notes by Prof Neil Hewitt from Ulster University and Prof Stephen Harrison from Queens University (Canada). As domestic hot water is becoming more and more important, also for smart solutions, there is a running HPT TCP Annex 46 on domestic hot water heat pumps.

On Wednesday the presentations will, in addition to R&D, also show project examples, for NZEB's, for which Prof Xu Wei from the China Academy of Building Research will give a key note address on Application of GSHP system in nearly zero energy building (NZEB) in China. In the afternoon, the sessions will be on residential buildings with mainly retrofit as topic and on applications in cold climates. Dr. Marek Miara from Fraunhofer ISE will in his key note give information on long term experience in Germany with heat pumps. Also, in the first sessions of this track on Tuesday, there is a number of presentations on supermarkets from HPT TCP Annex 44 run by Sietze van der Sluis and on application in Commercial Buildings with a strong relationship to Air-Conditioning.

Track 2

Track 2 Smart Energy Communities and Ground Sources, the first session will be on markets and policy. Here we will learn from the developments, strategic outlook in the European, Japanese, Chinese and US markets; which policies and technologies are available and can be successful. In the afternoon session, hybrids and the combination with other technologies are presented and discussed.

On Wednesday the focus will be on the important link between smart grids, hybrid solutions, storage and district heating as part of an integrated community energy supply system for residential as well as commercial and industrial areas. Ranging from presentations on business models for contracting the flexibility of residential

heat pumps to a virtual energy storage network providing flexibility for the power system. But also presentations on the testing of smart heat pump controllers and hybrid heat pumps providing demand flexibility with hybrid heat pumps in combination with district heating. As for Smart Grids, storage will be the game changer. There are presentations on storage systems and domestic hot water as a solution. Important key notes are by Dr. Ammi Amarnath from the Electric Power Research Institute (USA) on the 'Next Generation Heat Pump Systems with Enhanced Smart Grid Response Capability' and by Dr. Krystyna Dawson on 'Residential PV replacements offer an opportunity that heat pumps should not miss'. All sessions on Thursday are on Ground Sources, ranging from the typical application of open source Aquifer Thermal Energy Storage (ATES) systems in Netherlands to 'Using Ground Source Heat Pumps to rebuild Christchurch in New Zealand', with a key note on a 'Fundamental Economic Analysis of Ground Source Heat Pumps Markets in North America' by Mr Denis Tanguay of the Canadian Heat Pump Association.

Track 3

Track 3 is fairly unique at this conference with the first day on Air-Conditioning and the second and third day on Industry and Waste Heat. Many interesting papers have been submitted on Air Conditioning, and the Tuesday sessions will start with a key note from Mr. Taira Shigeharu from Daikin on 'Investigation of appropriateness of next generation refrigerant for air-conditioners'. The main papers are from Asia and North America.

Wednesday and Thursday will be with sessions on Industrial Heat Pumps/Waste Heat. The interest from industry in heat pumps is growing as high temperature applications are getting into the market and industry can benefit from fluctuating electricity prices by using CHP during high rates and heat pumps and vapour recompression at low electricity rates . This hybrid energy supply leads to a robust energy supply system, whereby companies are less vulnerable to fluctuations in the electricity market. A number of presentations in the track on industrial heat pumps and the sessions on working fluids focus on these developments. Jan Grift from Energy Matters (NL) will give a key note on 'Flexible heat supply and sustainability', focusing on closing the production cycles while Dr. Sabine Jansen from TU Delft will give a key note on 'Exergetic Considerations on using Industrial Waste Heat'. In the session on emerging industrial heat pump technologies, Mr. Alexander Cohr Pachai from Johnson Controls will give his thoughts on the topic in his key note.

On Wednesday there is an afternoon session in Track 3 on the 'Daikin Best Student Award'. In this session, a number of students will give a short presentation on their heat pump related projects. An independent international jury of experts will make a selection and select the winner who will be announced at the Conference dinner on Wednesday evening in the Laurens Church.

Track 4

Track 4 focuses on Working Fluids, Sorption and Non-traditional heat pumping technologies. The key note by Mr. Xudong Wang from the US-based Air-Conditioning, Heating, and Refrigeration Institute (AHRI) stresses the importance of the research on low Global Warming Potential (GWP) refrigerants testing and risk assessment of mildly flammable refrigerants of packaged rooftop units (RTUs).

Wednesday has all day sessions on sorption technologies ranging from applications in industry and buildings to more fundamental research. Dr. Walter Mittelbach from Sortech in Germany will in his key note give an overview of the state-of-the-art of adsorption chillers and their technological developments, while Dr. Bruno Michel from IBM in Switzerland will give a key note on Sustainable Data Centres and Energy Conversion Technologies (or Breakthrough Energy Efficiency Innovations). Over 30 papers will be presented as oral and posters.

On Thursday 18th May, track 4 has three different sessions. One on Gas-driven heat pumps, one on various technology developments and one on Non-traditional technologies. Challenging topics will be presented, such as: an ORC driven Heat Pump, Metal Wire Structures as Heat Transfer Surface Area Enlargement, Transient Acoustic Signatures of the Green HP, an Ammonia Electrochemical Compressor in Vapour Compression System, a Variable Geometry Ejector and Electrochemical Compressor Driven Heat Pump Systems.

The 'Dutch Innovation Award', as sponsored by the Dutch energy company Eneco, will be presented at the Wednesday lunch break. Nominated Dutch companies will take the floor in the main Conference exhibition hall to present their innovations. An international jury will select the winner, who will be announced at the Conference dinner on Wednesday evening in the Laurens Church.

During the conference an exhibition is held in the main hall of the World Trade Centre. Suppliers and manufacturers will showcase their products. In addition, new developments will be showcased to attract experts for future developments.

This conference is the perfect forum to learn from and communicate with industry and research experts from all over the world. With more than 400 participants from over 30 countries, the event is a key event for policymakers, executives and representatives from industry, utilities and the public sector, R&D managers and technology supporters, energy managers, planners, consultants, etc. This is the place to be for all those who wish to learn about the market trends and the future applications of heat pump technologies.

Time to prepare for an extraordinary four-day meeting in Rotterdam!

Report from ASHRAE Winter Conference in Las Vegas

The Winter Conference of ASHRAE (American Society of Heating, Refrigerating and Air-conditioning Engineers) took place in Las Vegas, US, from January 28 to February 1 earlier this year. The opening session on the 28th was introduced by the ASHRAE president Tim Wentz. After this, several honors and award recipients were presented, among them Gerald C. Groff who was active in the HPT TCP for a long time and now received the John F. James International award (see page 12).

The keynote speaker of the opening session was the award-winning scientist Adam Steltzner, recognized as one of NASA's most brilliant engineers and most unique individuals. For ten years he led a team of engineers inventing, designing, testing and retesting the revolutionary ”sky crane” landing system that successfully placed the Mars Rover, Curiosity, on the Martian surface in 2012. Steltzner talked a lot about the innovation process to reach this achievement, the power of human curiosity and collaboration in his speech. Some of his quotes during the speech were ”Great works and great folly might be indistinguishable at the outset”, ”Separate the people from the ideas people hold”, ”Curiosity is in our genes” and ”Find something to love in everyone you work with”.

During the conference there were a total of 22 conference papers sessions, 7 workshops, 76 seminars, and a poster session on the programme. Many of them were about efficient and sustainable use of energy in buildings, and a number of the sessions were related to heat pumping technologies. In addition to that, 699 different meetings were held, e.g., society committee meetings and technical committee meetings. Written papers are available for purchase for the conference paper sessions and poster sessions. PowerPoint presentations with audio descriptions were posted after the sessions with presentations in the Virtual Conference, to which conference attendees have free access (and access can be purchased for others).

There were several interesting and very well attended sessions related to use of low GWP Alternative Refrigerants and their applications. It was clearly noted that many of the ASHRAE members were interested in how to reach the ambition of phasing out high-GWP refrigerants, and showed a lot of engagement in this challenge. Several of the presenters conveyed the insight that flammable refrigerants will have to be used to meet the phase-out of high GWP refrigerants, and that flammability is the greatest challenge for this phase out. The innovation of low GWP refrigerants continues, searching for new blends and new possibilities, especially for drop-in replacement of e.g. R-22 and R-410A. In the presented studies it was discussed how to handle the glide of the new blends, heat transfer and pressure drop performance of the new refrigerants, etc.

In one session an update was made on research activities towards a safe use of low GWP refrigerants within the US. As an example, it was explained that AHRTI (Air-conditioning, Heating and Refrigeration Technology Institute) conducted leak and ignition tests under realistic conditions, which will give input to ASHRAE codes. Some ASHRAE and ORNL (Oak Ridge National Laboratory) projects were initiated since current standards regarding use of flammable refrigerants are quite restrictive, and it must be thoroughly evaluated if this is motivated. According to the presenter, there is a lack of knowledge in the US on how to handle flammable refrigerants, classified as A2L, 2L, A3. However, since these are used in other countries to some extent already, the researchers investigated how others do and what has been investigated there, to develop guidelines for flammable refrigerants. At NIST (National Institute for Standards and Technology) a lot of effort has been made on developing a modelling tool for ranking of low-GWP refrigerant blends.

There was one workshop organized by the IIR (International Institute of Refrigeration) about the food cold chain for developing countries. The director of IIR, Didier Coulomb, talked about the need of a cold chain for preserving food and the challenge that in the future the food supply has to increase, at the same time as the electricity consumption must be decreased, HCFC refrigerants phased out and HFC refrigerants phased down. In addition more people will live in urban areas in the future. In the next presentation we were informed that one third of all the food that is produced is lost or wasted. This lost food consumes a fourth of the water used by agriculture and is responsible for 8 % of the global greenhouse gas emissions. At the same time, 1/9 of the global population is undernourished. As an example, in India 80 % of the households do not have a refrigerator, and especially the shelf life of fruits and vegetables would increase considerably by applying a cold chain transport. Today, in some examples 20-30 % are lost during open truck transport. It would therefore be a strong business case to invest in a cold chain, i.e. refrigerated transports.

One session about thermally driven heat pumps was organised by HPT TCP Annex 43. During this seminar results from work performed within the Annex was presented, e.g. results from field tests, existing and emerging international standards for evaluation of fuel-fired sorption heat pumps, and results from multilaboratory RoundRobin tests.

In addition to the conference there was also a large exhibition, the AHR Expo, where about 2000 vendors showed their products. Of these vendors, about 500 vendors were from outside the US.

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IEA Heat Pump Centre
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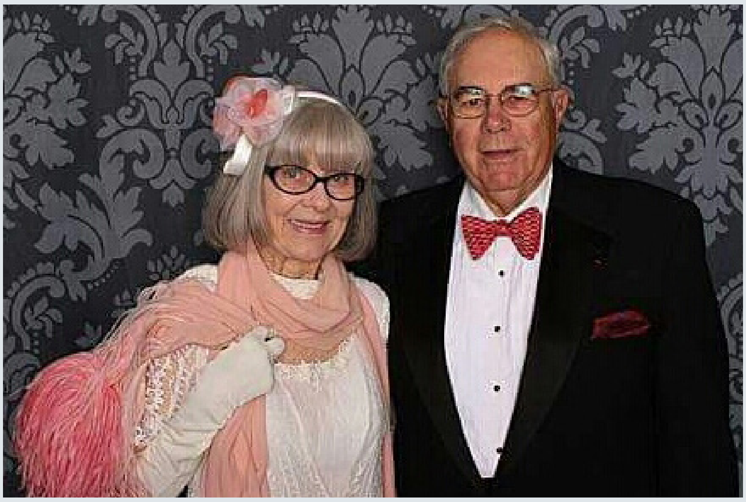
Jerry Groff Awarded with the 2017 John F. James International Award



Beth and Jerry Groff at ASHRAE's semi-annual meeting, the Winter Conference, in Las Vegas 2017.

Jerry Groff received the 2017 John F. James International Award from the American Society of Heating, Refrigerating and Air Conditioning Engineers on January 28 in Las Vegas at the ASHRAE Winter Conference. The award recognizes society members who have done the most to enhance the society's international presence.

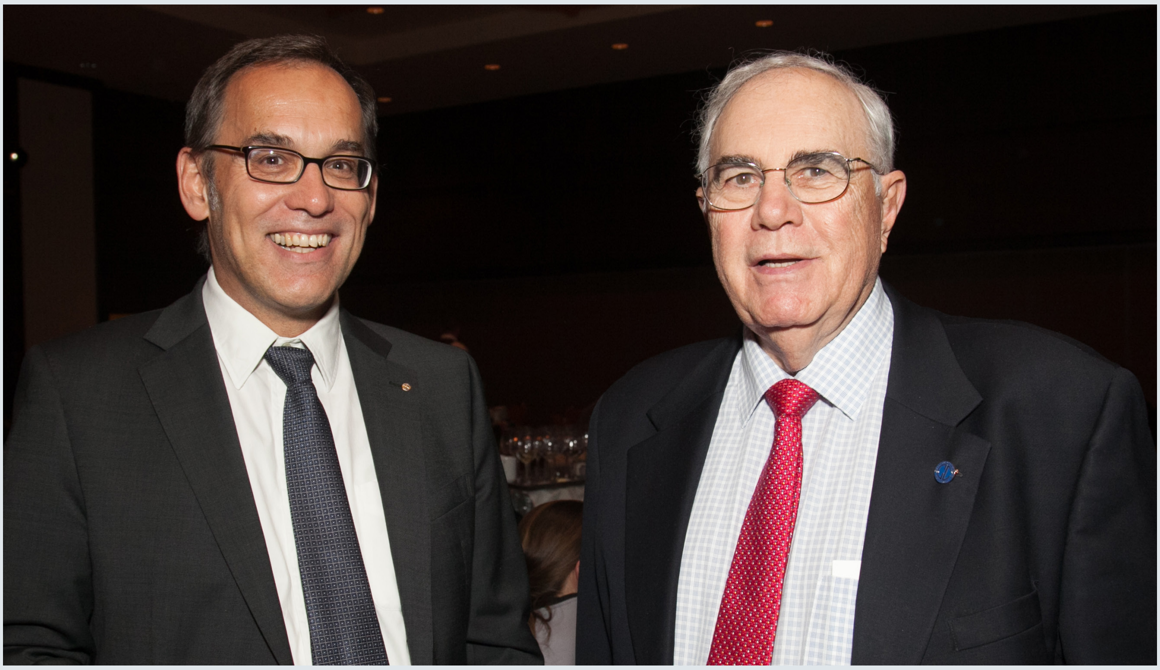
Groff is a fellow and Life Member ASHRAE and has served as chairman of the society's International Activities Committee and as chairman of the ASHRAE Associate Societies Alliance, which is responsible for coordination of ASHRAE activities with more than 55 regional and national professional associations involved with heating, refrigeration and air conditioning. Groff also served on the ASHRAE Board of Directors as a director at large. In 2010, Mr. Groff was awarded ASHRAE's F. Paul Anderson award. This award is the Society's highest award and honors members for notable achievement, outstanding work or service.

His international involvements include participation in the International Energy Agency's Advanced Heat Pump Technology program where he served as chairman of an international advisory board and as coordinator of the U.S. participation in the program on behalf of the Department of Energy and Oak Ridge National Laboratory. Jerry served as a member of U.S. National Team for the IEA Heat Pump Programme from 1989-2014 and was instrumental in formation of the team and coordination of its activities. In 2008, he was awarded the Peter Ritter von Rittinger medal, the IEA's highest international heat pump technologies award.

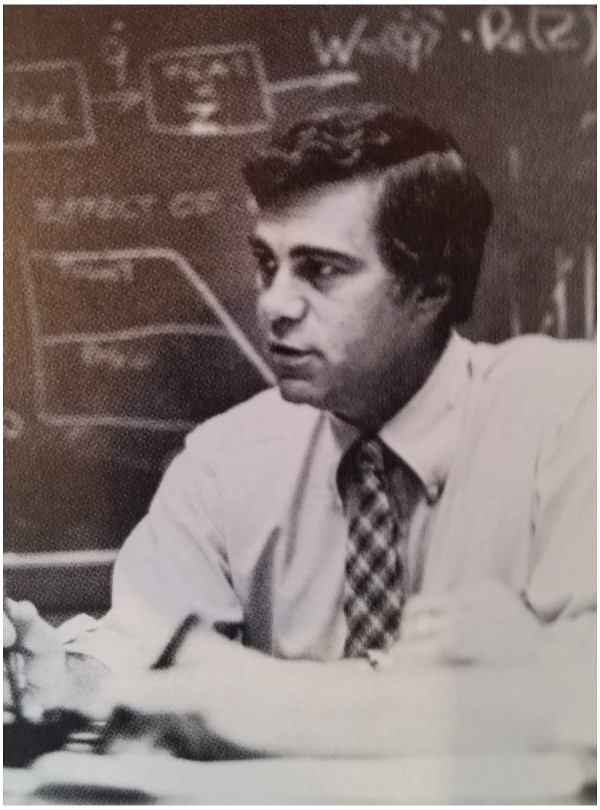
Groff also served on the Scientific and Technology Council of the International Institute of Refrigeration (IIR) as president of commissions concerned with air conditioning, heat pumps and energy recovery. He was named an honorary member of the IIR in 2007. He co-chaired the US organizing committee for the XXI IIR International Congress of Refrigeration held in Washington D.C. in 2003. He received the W. L. Pentzer Award in 1999 from the US National Committee (USNC) for the IIR in recognition of his IIR leadership activities.

Jerry Groff [Source: 1970 Carrier Research Division Report]

In addition to his technical accomplishments, Jerry has a strong record of service to his local community. He



Stephan Renz and Jerry Groff at the IEA Heat Pump Conference 2014 in Montreal, Canada.



Jerry Groff [Source: 1972 Carrier Research Division Report]

served as a Board Chairman of the Syracuse Symphony Orchestra organization from 1999-2001. Jerry was also a founding member of the Greater Cazenovia New York Area Chamber of Commerce.

He is a graduate of the University of Minnesota and received graduate degrees from Minnesota and Syracuse University.

Groff's job career began at Carrier in 1960 and included Director of Carrier Corporation Research Laboratories (1978-1984), Director of Technology Planning - Carrier Corporation (1984-1985), and Director of Technology and Product Management, Carrier ETO- headquartered in Geneva and Lyon (1985-1987), where he introduced Carrier's first heat pump product strategy for Europe. One of his activities at Carrier involved leadership of a research team in the late 1970's and early 1980's that conducted pioneering work in U.S., Canada, France, and Germany on heat pumps for northern climates

During the 1980's Mr. Groff started the first campaigns to develop common actions in many European countries that finally led to definition of European Air-conditioning standards and the agreements of European laboratories that could certify air-conditioning equipment, in a way that their performances could also be compared with those measured in accordance with the ASHRAE standards.

After leaving Carrier, he served as Director of Solar Heat Research Division, U.S. Solar Energy Research Institute (SERI), now the National Renewable "Energy Laboratory or NREL, prior to becoming President and CEO of Marquardt Switches, Inc. (North American Company of Marquardt GmbH - leading international electrical and electronic switch manufacturer) where he retired in 1999.

CHARLOTTE A. FRANCHUK,
WAYNE REEDY,
VAN D. BAXTER
USA

Ongoing Annexes in HPT TCP

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

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DESIGN AND INTEGRATION OF HEAT PUMPS FOR NZEB (CONTINUATION OF ANNEX 40)	49	BE, **CH**, DE, NO, SE, US
HEAT PUMP SYSTEMS IN MULTI-FAMILY BUILDINGS	50	AT, **DE**, FR
NEW ACOUSTIC SIGNATURE OF HEAT PUMPS	51	**AT**, FR, SE

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

ANNEX
41
COLD CLIMATE HEAT PUMPS (CCHP)

Annex 41 aims to identify and evaluate technology solutions to improve performance of heat pumps for cold climate locations. Its primary focus is on electrically driven air-source heat pumps (ASHP) but novel ground-source heat pump (GSHP) and solar assisted heat pump (SAHP) approaches are being investigated as well. The main near-term outcome of this Annex is information-sharing for use by designers/manufacturers to develop ASHPs with much better cold climate performance. In the longer term, availability of ASHPs with better low-temperature heating performance should help bring about a much stronger heat pump market presence in cold climates (loosely defined as having a significant number of hours with ambient temperatures < -7 °C). Such areas today rely predominantly on fossil fuel heating systems or, where natural gas is not readily available, on conventional electric ASHPs or even electric resistance heating systems.

Electric ASHPs generally have the lowest installation cost of all heat pump alternatives, but also the greatest performance challenges at cold outdoor temperatures. One of these is loss of heating capacity. Traditional ASHPs lose 80 % of their heating capacity at outdoor temperatures of -25 °C compared to the rated performance at 8.3 °C. This means that traditional ASHPs must use low-efficiency backup heat at lower temperatures, as noted in Figure 1. The other major issue is the loss of capacity due to frosting and defrosting of the outdoor heat exchanger (OHX) at moderate outdoor temperatures between about -5 °C to 5 °C (noted in Figure 1).

> ***Analyses and experimental work by the Annex 41 parties have shown the technical feasibility for ASHPs to achieve heating seasonal COPs in cold locations well in excess of the 2.63 target***

Annex members have focused on two primary areas to address the cold climate performance problems noted above. First, advanced Cold Climate Heat Pumps (CCHPs) with low-temperature capacity-enhancement approaches have been developed. Figure 2 shows one prototype (using two compressors) being installed for field testing in a residence in the US. Second, detailed investigations on OHX frosting have been conducted. Figure 3 illustrates a novel technique for visualization of frost growth developed by Japanese researchers using a small microscope combined with high-speed videography to observe frost crystals down to 0.02 mm size.

Objectives

1. General: Produce/share technical data/results for use by designers & manufacturers in producing ASHPs with significantly improved cold climate heating performance, achieved through technical publications and Annex presentation materials.

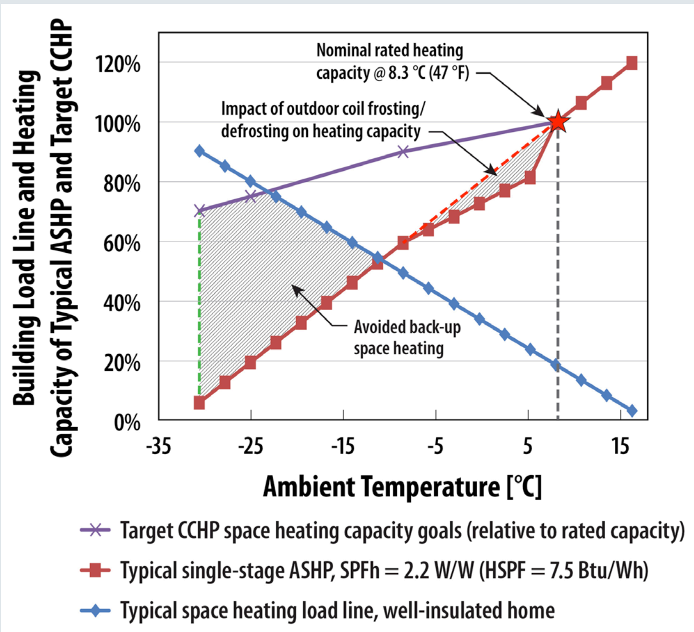

Figure 1. Space heating capacity for target CCHP vs. typical single-stage ASHP.

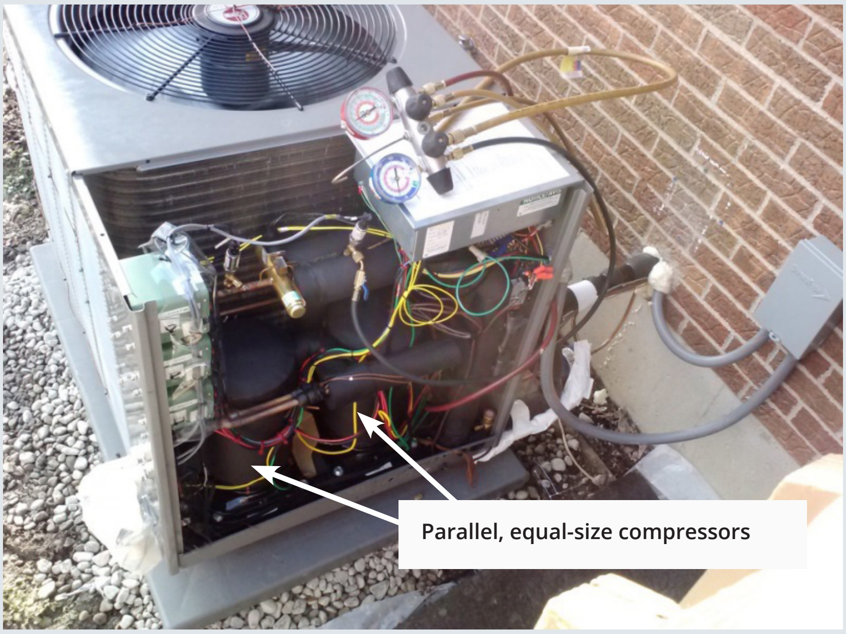

Figure 2. Two-compressor field test CCHP prototype.

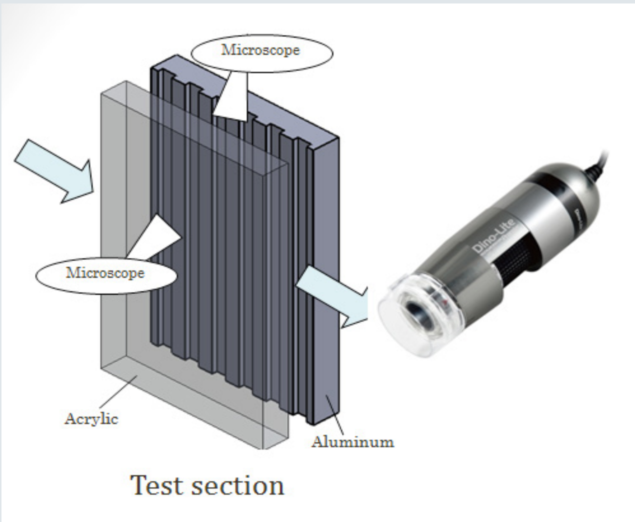

Figure 3. New frost visualization approach from Japan.

2. Achieve ASHP solutions with heating capacity at -25 °C that is ≥ 75 % of nominal rated capacity at 8.3 °C; several advanced prototypes have been developed, including some on the market.
3. Prototype cold climate ASHPs "in field" measured heating SPF > 2.63 W/W; achieved.

Progress and Results

A. Analyses and lab evaluations led to development of a prototype ASHP featuring a pair of equal size, single-speed scroll compressors (one for cooling and mild ambient heating; both for cold ambient heating). Field tests of a prototype (see Figure 2) in Ohio, U.S. in 2015 and 2016 demonstrated measured seasonal heating COPs > 2.8 and realized energy savings of more than 40 % in comparison to a conventional ASHP. Results showed that at -25 °C the unit had enough heating capacity that no backup heat was required (see Figure 4).

B. CanmetENERGY has undertaken extensive simulations and lab investigations to develop a novel SAHP (solar assisted heat pump) using ice-based thermal storage. Using validated energy models, it is estimated that such a system can reduce the energy use for space and domestic water heating in high performance homes between 61 % and 66 %, depending on the location of the building. Table 1 summarizes projected system

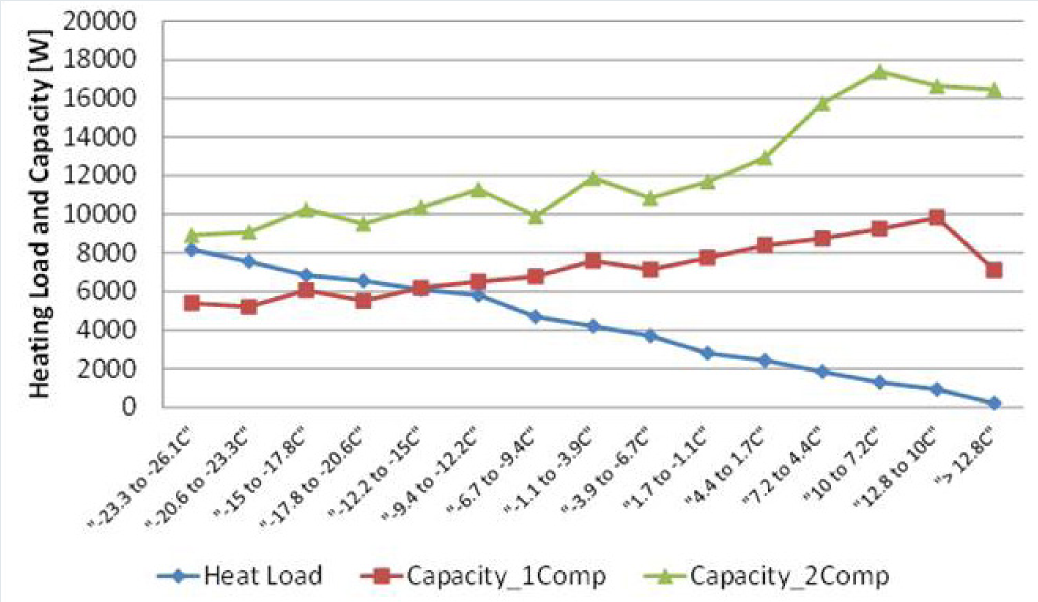

Figure 4. Two compressor CCHP prototype: measured average heating capacity (for 1 and 2 compressors) and building heat load vs. outdoor temperature

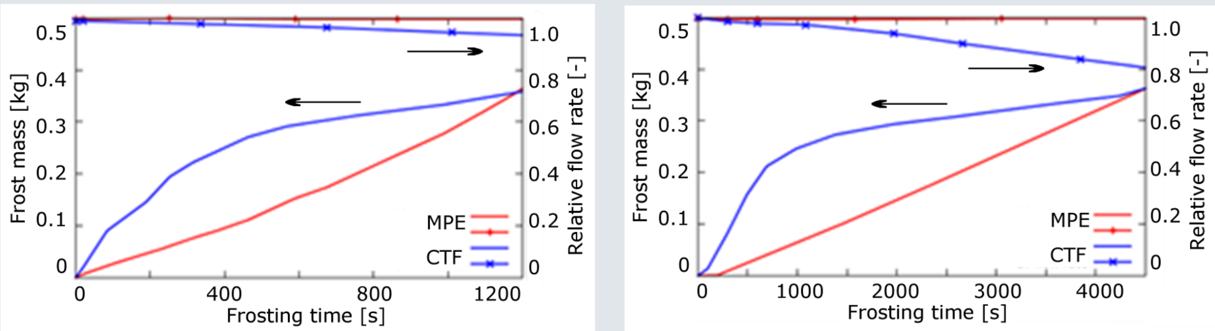

Figure 5. Frost mass growth and relative flow rate for advanced (MPE) and standard (CTF) heat exchanger configurations, at ambient temperatures 10 °C (left) and -25 °C (right).

sizing for typical existing homes in Eastern Canada. Provided that the ice generation/storage technology can be sourced at a reasonable cost, the proposed SAHP offers a cost-effective alternative to the current generation of GSHPs and is particularly interesting for retrofit applications where it may be difficult to add ground heat exchangers.

C. The research activities of the Austrian Institute of Technology (AIT) team were focused on the investigation of evaporator frosting in cold climates. Wind tunnel tests determined that advanced compact multi-port extrusion (MPE) heat exchangers have better frosting characteristics than conventional tube-and-fin (CTF) heat exchangers. This can be seen in Figure 5, which depicts evaporator frost accumulation rate vs. time, and the resulting reduction of air flow through the evaporator (relative to the maximum flow rate).

Table 1: Suggested SAHP design parameters for typical Canadian housing

PARAMETER	SUGGESTED VALUE/ RANGE
Solar Collector Area	30 m^2 to 35 m^2
Ice Storage Tank Volume	Approx. 10 m^3
Heat Pump/Ice Generator Capacity	10 kW (3 tons)

The MPE evaporator has been included in research toward developing an innovative CCHP system prototype. Shown in Figure 6 is a comparison of measured frost distribution (left side) to simulated frost distribution (right side) resulting from the refrigerant temperature variation inside the evaporator. The view is looking from above onto the horizontally mounted heat-exchanger. The heat exchanger fluid enters from the bottom of the figure. The blue bars indicate horizontal sums and vertical sums. The horizontal bars to the left show that frost builds up predominantly at the refrigerant entrance while the vertical bars indicate the extent of refrigerant fluid maldistribution. The simulation results on the right-hand side of Figure 6 are similar to the measured results on the left-hand side.

D. A number of ASHP products with improved cold climate performance have been introduced to the market by Japanese manufacturers (Mitsubishi Electric, Toshiba, Hitachi, Daikin, and others). They employ a number of heat pump cycle innovations including variable speed compressor technology, vapor injected compressors, liquid injected compressors, etc. Rated performance characteristics show capability to maintain heating capacity at 70 % to 90 % of rated capacity down to -20 °C to -25 °C outdoor temperatures. Most meet the requirements of recently released cold climate heat pump specifications by the U.S. Northeast Energy Efficiency Partnership (NEEP) - www.neep.org/sites/default/files/resources/Cold%20Climate%20Air-source%20Heat%20Pump%20Specification-Version%202.0_0.pdf. These developments demonstrate the technical feasibility to develop ASHPS with significantly improved cold climate heating performance compared to conventional ASHP products.

Publications

- Eslami Nejad, P., A. Hakkaki Fard, Z. Aidoun, and M. Ozzuane. *Assessment of Ground-Source, Air-Source, and Hybrid Heat Pumps for a Single Family Building in Cold Climates*, ASHRAE 2016 Summer Conference, St. Louis, MO, USA, 2016.
- Shen, B., O. A. Abdelaziz, C. K. Rice, and V. D. Baxter. *Cold Climate Heat Pumps Using Tandem Compressors*. ASHRAE 2016 Winter Conference, Orlando, FL, USA, January 23-27, 2016.
- Ch. Reichl, J. Emhofer, F. Lörcher, A. Strehlow, M. Popovac, P. Wimberger, C. Köfinger, A. Zottl, T. Fleckl, *Transient Acoustic Signatures of the GreenHP with special focus on icing and defrosting*, 12^{th} IEA HP Conference, May 15-18 Rotterdam, The Netherlands, 2017, accepted.

Project duration:
July 2012 - June 2017

Participating countries:
Austria, Canada, Japan, and the United States

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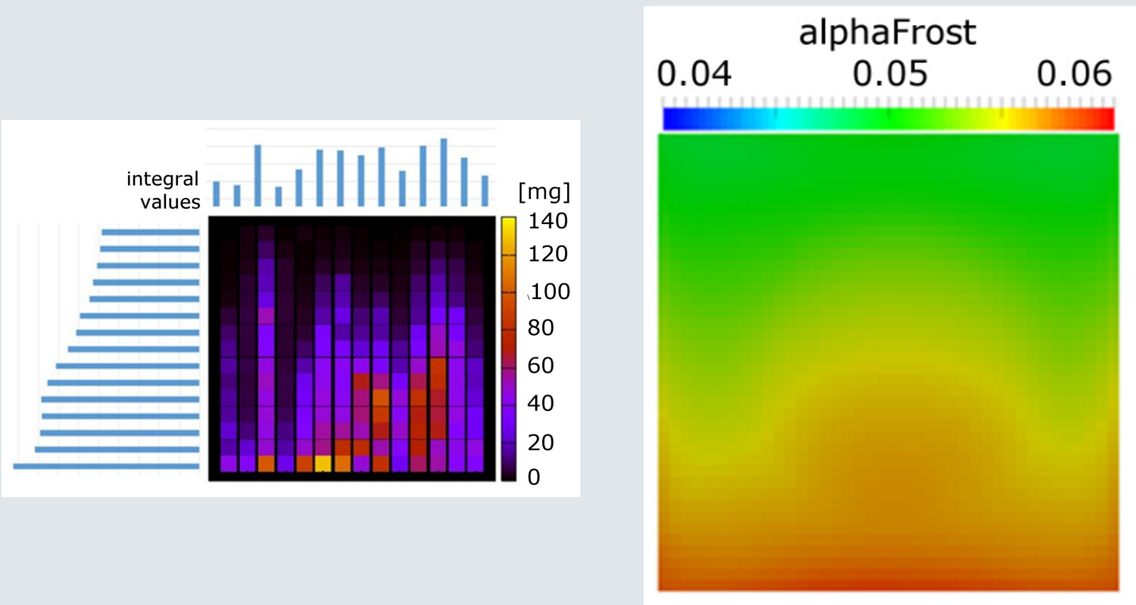

Figure 6. Measured (left) vs. predicted (right) frost distribution on MPE evaporator from CCHP system tests.

ANNEX
42
HEAT PUMPS IN SMART GRID

In our modern energy system, flexibility and smartness in the electric power grid is essential for sustainability. Here, flexibility means the degree to which producers, consumers and prosumers are able to react to the fluctuating supply on the electricity market. Particularly, if electricity from intermittent sustainable sources continues to increase, the demand will have to be geared to the supply, in some way.

Heat pumps are important components of a smart grid. They are perfect for demand management in smart grids, since they convert electrical energy into thermal energy. By combining heat pumps with thermal storage, the heat pump can be applied as a regulatory instrument. In addition, they are flexible in the sense that they can start up relatively quickly.

However, if heat pumps are installed on a large scale in existing buildings, there is a potential grid load peak that needs to be managed, especially in countries that rely on natural gas as the sole energy carrier. Furthermore, these heat pumps have to be managed in a smart way,

Smart heat pumps offer a unique bridge between power and heating, by converting renewable power to heat.

Heat pumps offer a grid management potential with huge possibilities for interaction with novel technologies, such as solar PV and electric vehicles.

since they otherwise have a large simultaneity factor: when it is cold, they all switch on at the same time.

Although smart-grid pilot projects and studies have demonstrated the advantage of smart-driven heat pumps, commercially available heat pumps are not provided with communication as a standard. Neither can the grid communicate with heat pumps. The Internet of Things is rapidly becoming the solution expected to

Figure 1. Integral approach of energy in smart grids.

bridge this dilemma, enabling smart heat pumps to interact with a standard grid.

The approach of this annex is to have each participating country consider some key questions, and then compile and discuss the answers. Key questions include the size and urgency of the country's grid problem, possible scenarios including heat pumps to solve these problems, the cost for each of these solutions, and conclusions regarding the road ahead.

The results from this Annex will make it easier to plan and implement smart grids, drawing on the advantages of heat pumps. In this way, the advantages of smart grids will be optimized: balance in the energy system, decreased energy use and greenhouse gas emissions.

Objectives

The objectives of this Annex are:

- To gather information for governmental and non-governmental policy makers and decision makers on energy systems in urban areas concerning the possibilities and barriers related to the implementation of heat pumps in smart grids;
- To develop strategic information for the heat pump industry, including its supply and consulting chain.

Further, in the long run, to contribute to the implementation of smart grids, for

- Balance between supply and demand in the energy system;
- Reductions in energy use;
- Reductions in emissions of greenhouse gases.

Results

The business model behind heat pumps in smart grids was assumed to be in flexible tariffs, which would tempt users to adjust the on/off switching of their heat pump device. One of the results from Annex 42 was that flexible tariffs may not be as effective as was anticipated, since they have limited potential to influence the end user.

The generally accepted perception in 2012 of a smart managed grid that rules and serves 'dumb' heat pumps has proven to be outdated in just four years' time. On the other hand, smart heat pumps, with their flexibility and versatility (based on the Internet of Things) aggregated by a totally new type of companies, will form an entirely new perspective on the start-up of 'heat pumps in smart grids'. This is a potentially strong instrument for managing 'smart cities'.

Publications

- M. Bongaerts - Liander and D. Mosterd, *Load management with heat pumps in domestic housing*. BDH 2015.
- B. den Ouden - Berenschot and P. Friedel, *Flex-potentieel hybride warmtepomp* (English: Flex-potential of hybrid heat pumps). BDH 2016.

Project duration:
May 2013 - April 2017

Participating countries:
Austria, Denmark, France, Germany, the Netherlands, South Korea, Switzerland, the United Kingdom, and the United States.

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ANNEX
43
FUEL-DRIVEN SORPTION HEAT PUMPS

The heat pump market is dominated by electrically driven compression technology. After a period of stagnation, thermally driven sorption technology was "rediscovered" at the end of the 20th century, mainly for thermally driven cooling. In recent years, gas fired sorption heat pumps have been identified as an efficient solution for space heating and sanitary hot water preparation, mainly in existing buildings. Consequently, a number of products have already entered the market. They are seen as a complementary technology to electrically driven heat pumps with a potential to reduce the requirements on the electric grid and to balance the overall energy consumption in the future energy mix by using different sources (e.g., biogas, power-to-gas) and existing infrastructure. The technology is efficient, especially as retrofit in existing buildings, and is often seen as the next generation of efficient condensing gas boilers with a significant usage of renewable energy. This Annex has the aim to support the technology at this early stage through cooperation between experts from industry and academia.

As the end user on the demand side, city councils and housing corporations owning large housing estates are important target groups. On the supply side, heat pump manufacturers, power companies, technical consultants as well as planners/installers will be addressed. Furthermore, political decision makers are of interest since governments set the boundary conditions for future development for a carbon emission free society.

> ***Annex 43 supports fuel driven heat pumps on their way to larger market shares by identifying most promising solutions and by generating trust in this technology with best examples.***

The Annex has produced a state of the art report on fuel driven heat pumps, cooperates on projects to develop new technologies such as adsorbers using new composite materials, e.g., coated metal fibers, to increase power density (see Figure 1). Further, the Annex is developing recommendations for lab based performance measurement standards (see Figure 2). Finally, best case examples will be compared to these results and used to generate trust in this technology (see Figure 3).

Objectives

- Widen the market acceptance of fuel driven heat pumps, increasing the market awareness for this technology;
- Identify market barriers and opportunities to allow smooth and sustainable market entrance and deployment of the technology;
- Quantify the economic, environmental and energy performance of integrated fuel driven sorption heat pumps in heating systems in a range of climates, countries and building standards;

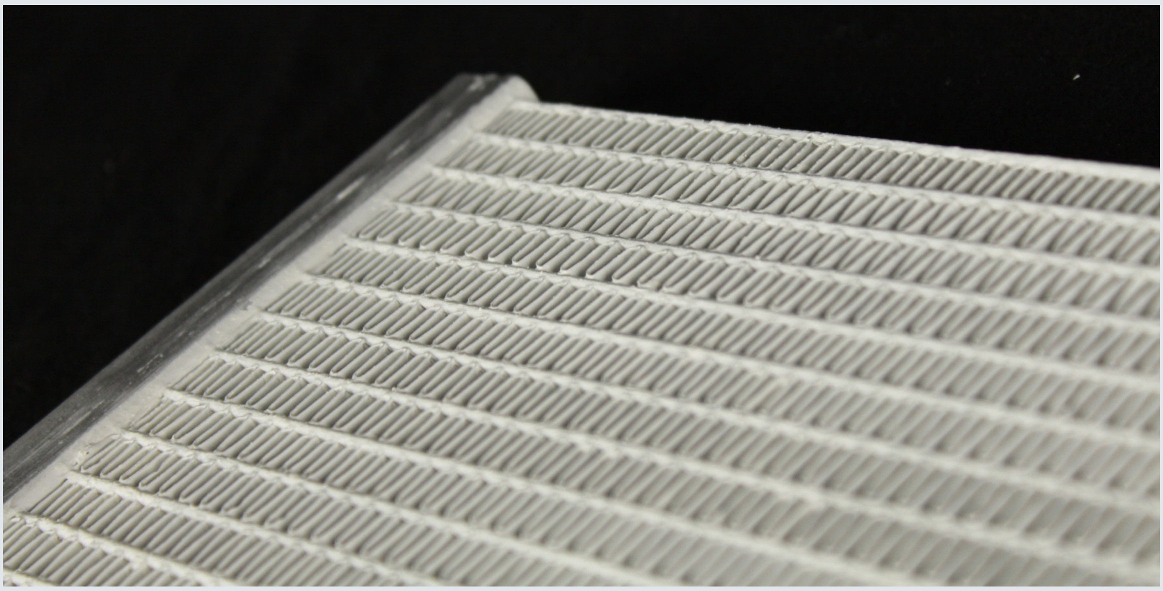

Figure 1. Heat exchangers coated with sorption materials improve heat and mass transfer and lead to significant improved power densities and thus smaller appliances and reduced costs.

- Identify the most suited system layouts and which type of fuel driven heat pump fits best to a specific building type or climate;
- Propose technical procedures to be included in future standards for determination of the performance of fuel driven heat pumps and methods to evaluate primary energy consumption of the systems within this Annex.

Progress

The Annex has made significant efforts to increase the awareness of fuel driven heat pumps, organizing several national workshops for installers and planners as well as organizing a large international conference about sorption heat pumps with more than a hundred attendees from science and industry. The best papers from this conference are published in a special issue "Sorption systems for energy efficient heating and cooling" of the renowned journal "Renewable Energy".

A second highlight is the round robin test of a hybrid sorption heat pump among four partners of the annex, comparing the performance results among the labs as well as comparing two different performance evaluation methods (VDI 4650-2 and CEN 12309) and setting up recommendations for the normative bodies.

Additionally, the cooperation between the members of the annex have led to several joint papers in reviewed journals and increased the knowledge transfer for new developments from research to industry, both new materials and new component developments.

Publications

- Marica Fumagalli, Alessandro Sivieri, Marcello Aprile, Mario Motta, Matteo Zanchi, *Monitoring of gas driven absorption heat pumps and comparing energy efficiency on primary energy*, Renewable Energy, Special Issue Sorption heating and cooling, in press.
- Stefan K. Henninger, Sebastian-Johannes Ernsta, Larisa Gordeevab, Phillip Bendix, Dominik Fröhlich, Alexandra D. Grekova, Lucio Bonaccorsi, Yuri Aristov, Jochen Jaenchen, *New materials for adsorption heat transformation and storage*, Renewable Energy, Special Issue Sorption heating and cooling, in press.
- Andrea Frazzica, Gerrit Füldner, Alessio Sapienza, Angelo Freni, Lena Schnabel, *Experimental and theoretical analysis of the kinetic performance of an adsorbent coating composition for use in adsorption chillers and heat pumps*, Applied Thermal Engineering, 73, 1022.

Project duration:
October 2013 - November 2017

Participating countries:
Austria, France, Germany, Italy, South Korea, the United Kingdom, and the United States.

Interested countries:
Sweden

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Figure 2. Different standards for performance evaluation of gas driven heat pumps are compared in a round robin test between several labs.

ANNEX
44
PERFORMANCE INDICATORS FOR ENERGY- EFFICIENT SUPERMARKET BUILDINGS

In our "information society" there is an abundance of data, but this data remains meaningless if it is not transformed into knowledge. You may have collected fuel station bills for years and years, but as long as you don't know the car's mileage you have no knowledge about the car's fuel efficiency. And even then, only you would know if this efficiency mostly reflected urban driving or long distance fuel efficiency.

The same is true in a supermarket environment. There is a clear trend for more and more monitoring systems to be installed in supermarkets, measuring, for example, temperature (typically to secure and validate food quality) and other relevant data. Measurements are taken and stored, and overall energy consumption data is available, but in many cases there is still no knowledge about the supermarket's energy efficiency compared to other supermarkets in the same chain, or to competing supermarkets.

Performance indicators are needed to transform available data into knowledge about the energy efficiency of a supermarket building. Such indicators, for example, are the size of the supermarket, the opening hours, the outdoor climate, etc. In this Annex, performance indicators will be defined that will allow evaluation of the energy efficiency of existing single supermarkets, supermarkets within one chain, supermarkets across different chains and even supermarkets in different regions or countries. (See Figure 1a, 1b, 1c).

The work in the Annex relies on measured data from the field, and not very much on theoretical and/or computer models. The results are intended for practical use in the field, and should be useful even when only a small number of performance indicators is known. Nevertheless, when more performance indicators are known, the resulting evaluation will of course be more precise.

> ***Non-conventional parameters, such as motivation of personnel and system dynamics, may play a significant role in energy efficiency.***

Objectives

The objectives of this Annex are:

- To create key performance indicators for energy efficient supermarket buildings, so that measurements and monitored data can be converted into knowledge about the energy performance of supermarket buildings.
- To create knowledge about the energy efficiency of supermarket buildings from measurements and monitored data, which is useful for decision making, benchmarking and development of energy efficiency strategies for supermarket buildings.

Supermarkets, and the supermarket sector, is the main target for the Annex. However, the methodology created in this Annex, when modified accordingly, may also be applied to other food retail establishments (e.g. hypermarkets).

Progress

Energy consumption data (for both electricity and gas) has been collected for 150 Dutch supermarkets for the years 2013 and 2014. This data contains a considerable amount of detail regarding performance indicators, such as supermarket area and the amount of refrigerating equipment, as well as the presence or absence of some 70 energy saving options.

Figure 1. When the objectives of this annex have ben fulfilled, it will become possible to identify the "weakest links in the chain" within a chain of supermarkets, from an energy efficiency viewpoint. Investments in energy efficiency can then be directed towards these weak links.

The supermarket sales area is the most relevant performance indicator for electrical energy consumption. The associated average energy intensity is 407 kWh/m² per year for the Dutch data (See Figure 2). The conventional technical performance indicators (such as size, opening hours and energy saving options) are not sufficient by themselves to give a complete view of the energy efficiency; non-conventional parameters such as motivation of personnel and system dynamics may play a significant role in energy efficiency.

Management policy can have an effect on energy efficiency. A choice to focus refurbishment and construction on the largest supermarkets in a chain, with an emphasis on energy efficiency, was clearly visible in the resulting data set (See Figure 3), with an average energy intensity of 430 kWh/m² per year for existing shops and 364 kWh/m² per year for new and refurbished shops.

Publications

- S.M. van der Sluis, U. Lindberg, A.-L. Lane and J. Arias. *Performance indicators for energy efficient supermarket buildings*. International Congress of Refrigeration, Yokohama, Japan, 2015.
- S.M. van der Sluis. *Performance indicators for energy efficient supermarket buildings*. IEA - International state of the art in urban energy. Amersfoort, the Netherlands, 2016.

Project duration:
July 2013 - June 2017

Participating countries:
Denmark, Sweden, and the Netherlands

Annex website:
http://heatpumpingtechnologies.org/annex44/

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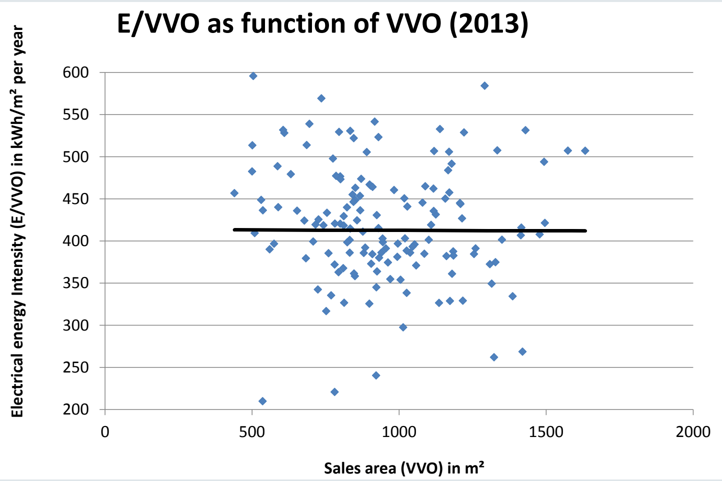

Figure 2. Electrical energy intensity versus sales area with regression line in year 2013.

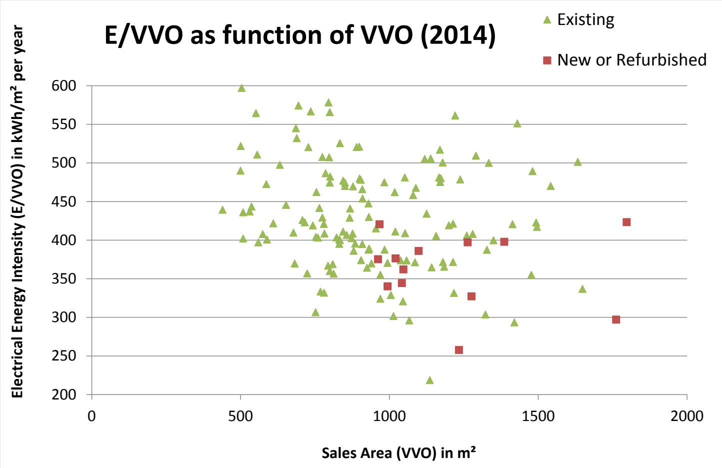

Figure 3. Electrical energy intensity versus sales area highlighting the new and refurbished supermarkets against the existing ones in year 2014.

ANNEX
45

HYBRID
HEAT PUMPS

Boiler replacement markets are the most important markets for heating and domestic hot water production in residential housing in Europe, since the technical lifespan of heating devices runs up to 15-20 years. Due to insulation measures when retrofitting buildings, a decrease in the heating supply temperature is possible. This makes such buildings interesting for an efficient implementation of heat pump technology for a substantial part of the heating season, since heat pumps function optimally at low supply temperatures. In this context, heat pump and gas boiler hybrid systems can, beside solar thermal and PV, introduce and quickly increase the usage of renewable energy in strongly conservative markets. An example of how the penetration of heat pumps, including hybrid heat pumps, may develop in a country such as the Netherlands is shown in Figure 1.

The work in the Annex relies on measured data from the field, and not very much on theoretical and/or computer models. The results are intended for practical use in the field, and should be useful even when only a small number of performance indicators is known. Nevertheless, when more performance indicators are known, the resulting evaluation will of course be more precise.

Accordingly, this offers a chance for a more rapid CO_2 emission reductions, for instance by 'hybridizing' existing installations by adding a heat pump to an existing boiler. This can help open up hidden opportunities for a far more significant usage of renewable energy in the short term. As a result of this 'hybridizing', there is currently a need for action on issues such as testing standards, definition of quality requirements, system configurations and control strategies.

> ***The potential for congestion management by means of hybrid heat pumps is in principle available whenever grid load reaches its maximum value.***

The Annex will give a perspective on the possibilities for implementation of hybrid heat pumps in potential markets. It will focus on combinations between the (electrical or gas driven) heat pump and fossil fuel driven boilers (oil or gas) in the residential sector and light commercial sector, packaged in a configuration or as an integral unit.

Objectives

The main objective of this Annex is to investigate the potential of emission reductions of greenhouse gases by the increased implementation of hybrid heat pumps, both through replacement of boilers by hybrid systems, and by means of upgrading the systems' efficiency in existing running installations. This objective will be achieved by:

- Market overview and system classification;
- Identification of market barriers and opportunities to allow sustainable market development;
- Quantification of economic, environmental and energy performance of hybrid heat pumps in heating systems in a range of climates, countries and building types and building standards;

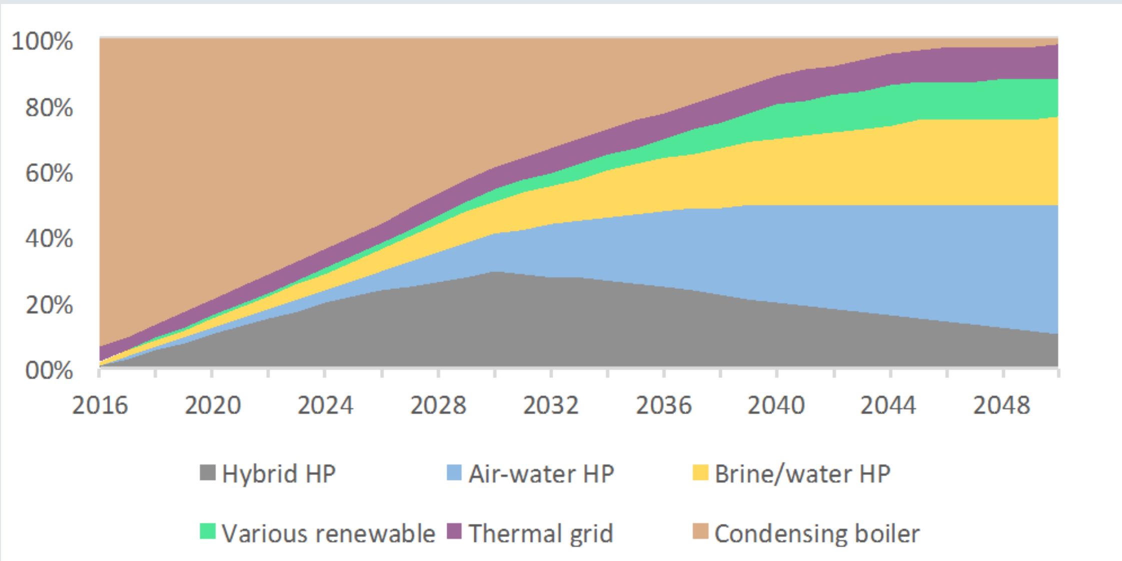

Figure 1. Spread of technologies - Annual numbers installed. Development scenario for heating devices in the Netherlands [Source: DHPA, BDH].

- Identification of best practice cases in various applications.

Results

One of the first results obtained was the matrix assembled by Fraunhofer ISE (see Figure 2, data for Germany) which sheds light on the switching point for hybrid heat pumps under the various circumstances.

At each moment, the hybrid system must make a choice whether to use the heat pump part or the boiler part to supply the necessary heat. Several operating strategies can be chosen. A simple strategy may, for instance be to always use the subsystem with the lowest marginal operating cost. The COP of the heat pump part drops (and the cost per kWh heat production rises) as the outside temperature gets lower, and ultimately a temperature level is reached below which running the boiler part is cheaper than running the heat pump part.

Depending on the choice of operating strategy, the switching point occurs at a certain heat pump COP. This COP is directly determined by the outside temperature. Above the switching temperature, the heat pump part will be supplying heat, below the switching temperature, the boiler part will be supplying heat.

In Figure 2, the switching point is shown in relation to the temperature distribution, giving direct visual insight into the contribution of the boiler and heat pump part. One of the Annex' main output goals is a comparison of hybrid systems' suitability using this type of graph.

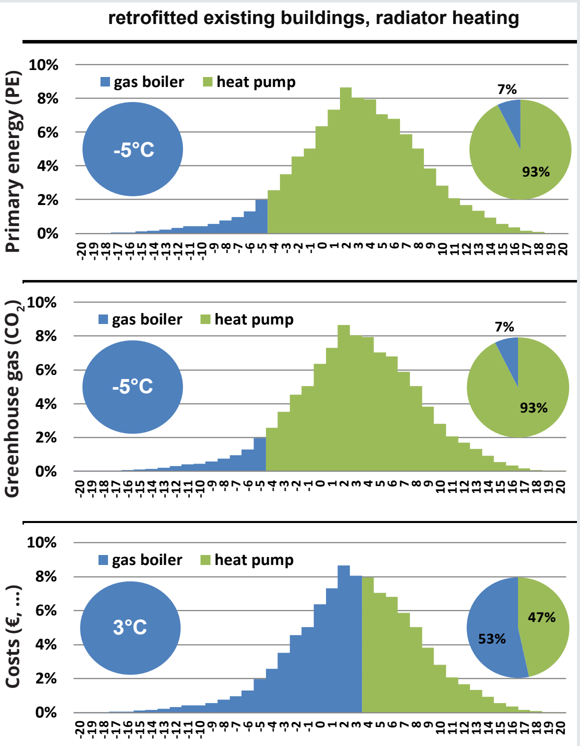

Figure 2. Switching points for hybrid heat pumps for three different control strategies.

Good examples

Island of Ameland (North Netherlands)

The Island of Ameland (1800 houses) goes 100 % renewable mainly due to hybrid heat pumps in combination with locally produced green gas. The municipality of Ameland, the local housing corporation and installers on the island are supported by Liander, TNO and GasTerra to start a joint approach to make the island independent from fossil energy in 2030. To decarbonize the houses, the primary choice is hybrid heat pumps, due to the characteristics of the housing stock.

ENECO launches exhaust air heat pump campaign

ENECO, The Netherlands' most green top five energy supplier, will offer very compact exhaust air heat pumps to its energy clients in a total package with sophisticated controls and services. The aim is to implement a significant number of installations within a few years. These systems will cover a significant part of the users' heat demand, the rest being supplied by the already present gas boiler. Thus an 'easy-entry' hybrid system can be added to existing heating installations in a potentially very diverse set of house types and sizes.

050 hybrid heat pump monitoring program

With a group of end-users in the Dutch city of Groningen (telephone pre-dial code '050'), results from hybrid heat pumps are monitored based on actual energy consumption numbers. The outcome of these field measurements should offer a better estimate on the energy performance to be expected in the daily practice from hybrid heat pumps (exhaust air and ambient air source type).

Publications

- B. den Ouden - Berenschot and P. Friedel, *Flex-potentieel hybride warmtepomp* (English: Flex-potential of hybrid heat pumps). BDH 2016.
- B. den Ouden - Berenschot, P. Friedel, *Actor analysis regarding hybrid heat pumps in the Netherlands' in cooperation with Itho Daalderop*, Daikin, Inventum, Gasunie and other stakeholders. BDH 2016.

Project duration:
September 2015 - July 2018

Participating countries:
France, Germany, the Netherlands, and the United Kingdom.

Interested countries:
Canada

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ANNEX
46

DOMESTIC HOT WATER HEAT PUMPS

Heat pump markets and the policy in many countries have focused mainly on residential heat pumps for space heating, resulting in standardized products and installations. This is not the case for Domestic Hot Water: there is still a large potential for energy optimization and thus reduction of CO_2 emissions.

Domestic Hot Water Heat Pumps (DHW HPs) deliver hot water only, for bath, shower and kitchen.

Driven by the market for electric water heater replacements and boiler upgrades, the use of DHW HPs is growing strongly (for instance, see Figure 1 for sales of DHW HPs in France) and a doubling of the European market is predicted by 2017. The same market trends can be seen in the US, Canada, Japan and China.

Other interesting applications are the replacement of collective DHW systems in apartment blocks and multifamily buildings by individual DHW HPs (Europe), combination with air-conditioning systems, where the condenser heat is used for water heating (US, Asia, Southern Europe), and combination with solar thermal systems in nZEB.

Due to strict legislation on energy performance, inherently better insulation, and higher comfort demands (e.g. rain-shower shower heads) from the end user, DHW is going to dominate the overall energy use in houses, see also Figure 2.

> ***"Great opportunities for Domestic Hot Water Heat Pumps: sustainable DHW production will become more and more important."***

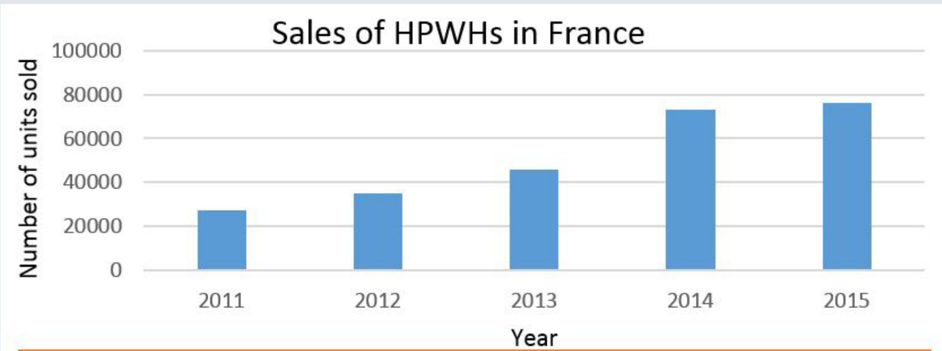
An efficient DHW system is based on a high performance heat pump. However, the overall system efficiency depends on more than the efficiency of the heat generator alone, and energy policy is concerned with the complete chain from primary (fossil) energy to the end user. The benefits of a highly efficient generation device can be nullified by poor system integration and large storage or distribution losses . Overall efficiency is a crucial point in the development of an energy neutral society with a smart energy infrastructure.

This Annex is being carried through by developing and sharing knowledge on performance optimization, high-efficiency construction and proper implementation of this specific type of heat pump.

The main actors targeted in the Annex are heat pump manufacturers, consultants, housing corporations, installers and building companies committed to the technical concept and design of equipment for high performance buildings.

Objectives

The main objective is to provide deeper insight into the possibilities for implementation and potential reduction of CO_2 emissions and energy costs using various DHW heat pump concepts and systems for new as well as existing buildings.



Year	2011	2012	2013	2014	2015
HPWH	27000	34900	45950	72949	76250
% incr.	-	+29,3%	+31,7%	+58,8%	+4,5%

Figure 1. Sales of DHW Heat Pumps in France

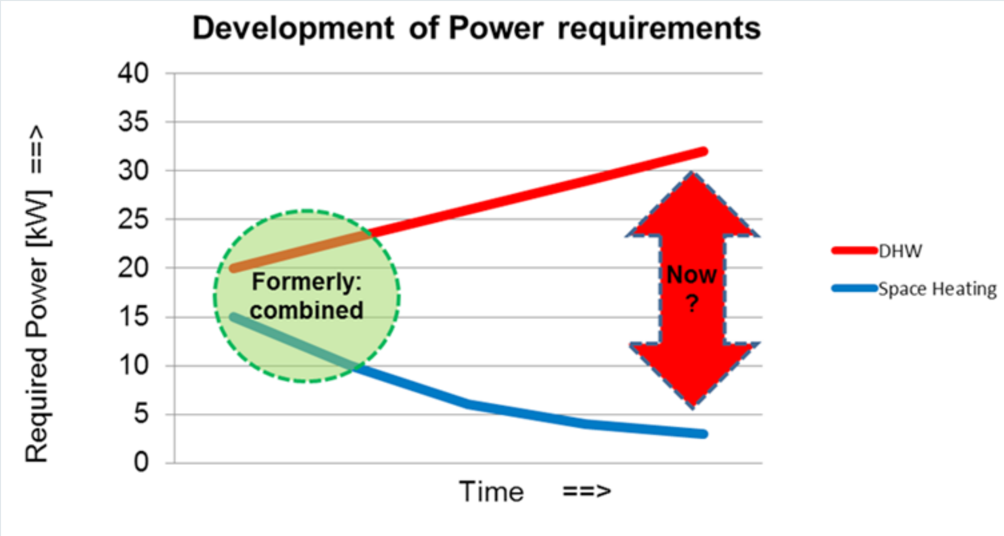


Figure 2. Trends in direct capacity demands of DHW and space heating

This will be achieved by:

- Reviewing system concepts and available DHW heat pumps;
- Gaining deeper insight into the use of DHW to create a solid basis for test and standardization procedures;
- Developing and validating a model for objective comparison of DHW heat pumping technologies and systems;
- Databasing with showcases for concepts and monitoring results;
- Creating a web-based information platform to serve participating countries by publishing information on their market approach and training courses;
- An overview of R&D on DHW heat pumps, along with the R&D still needed.

Overview of tasks

- ***Task 1 - Market overview, barriers for application***
  Combined country reports about the market situation, future expectations and specific DHW issues per country.

- ***Task 2 - Systems and concepts in comparison to alternatives***
  Overview of systems and concepts: what combinations of technologies are feasible in combination with DHW heat pumps? Where are these located in the energy infrastructure, at the building level or regional level?

- ***Task 3 - Modelling calculation and economic models***
  Finding or creating a model to calculate and compare system efficiencies in an objective way.

- ***Task 4 - R&D***
  Overview of running and still needed R&D.

- ***Task 5 - Example projects and monitoring***
  Database with showcases and monitoring results of existing projects.

- ***Task 6 - Communication and training***
  Production of a reference guide with available systems, software tool, workshops, website.

Project duration:
January 2016 - April 2019

Participating countries:
Canada, France, Japan, the Netherlands, South Korea, Switzerland, and the United Kingdom.

Interested countries:
China

Annex website:
http://heatpumpingtechnologies.org/annex46/

Contact:
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ANNEX 47 HEAT PUMPS IN DISTRICT HEATING AND COOLING SYSTEMS

> ***An interesting Annex with large perspectives, and fine synergy with the IEA DHC TCP.***

All over the world, the energy system needs to be decarbonised. As an example, the European Council has set the objective for the EU to decarbonise its energy system by 2050 to at least 80 % below the 1990 level.

Decarbonising heating and cooling of buildings requires that the use of energy becomes more efficient on both the demand and the supply side. District Heating can capture excess heat which is currently wasted, and replace the natural gas for heating in cities. Heat savings can reduce the total heat demand in Europe by 30-50 %. District Heating will grow in the future as heating supply in the cities, and it should increase from today's level of 10 % to 50 % by 2050.

Heat pumps is a technology which is expanding in district heating systems at the moment as more district heating systems are going to use excess heat and renewable energy as sources. Another reason why heat pumping technologies are interesting in combination with district heating and cooling systems is that low temperature district heating, 4^{th} generation, is implemented at the moment, and heat pumps then will be necessary for the production of Domestic Hot Water.

The goal of this Annex is to show how heat pumps can be implemented in both old and new district heating systems, but also in different sizes of district heating systems, and with different sources.

Objectives

The objective of this Annex is to gather information and ideas for policy makers and decision makers and planners of energy systems in urban areas concerning the possibilities and barriers related to the implementation of heat pumps in DHC systems.

One objective will be to suggest how heat pumps can be implemented in both new and old district heating systems in the best way. The different types of integration will be described. The differences and possibilities in integration in both central and local systems will be described.

The possibilities of increasing a larger share of renewable energy or using excess heat in the different systems by using heat pumps will be a focus area. Minimizing the system losses by using heat pumps will also be an objective.

Existing projects where heat pumps are integrated in district heating systems will be described and evaluated

for each participating country. Further, the market potential and economic opportunities will be evaluated and described for each participating country.

Overview of tasks

- ***Task 1 - Market and energy reduction potential***
  The primary objective is that each participating country draws an overview of the market potential for heat pumps district heating and district cooling and describes the potential for implementing heat pumps in these thermal grids.
- ***Task 2 - Description of existing DHC systems and demonstration and R&D projects with heat pumps***
  Here, existing DHC systems and demonstration projects are presented, where heat pumps are used for heating or cooling in DHC systems described on a country basis. The projects will be described and presented as an idea and inspiration catalogue.
- ***Task 3 - Review of the different concepts/solutions***
  Based on the work done in task 1 and 2, the different concepts will be described. The concepts will be divided between central and decentralized systems, and between options for existing DHC grids and options for new DHC grids.
- ***Task 4 - Implementation barriers, possibilities and solutions***
  Description of typical barriers regarding implementation. Different business models for different systems.
- ***Task 5 - Dissemination***
  Summary report of the project. Presentations at workshops and conferences.

Project duration:
January 2016 - June 2018

Participating countries:
Austria, Denmark, Sweden, Switzerland, and the United Kingdom

Annex website:
http://heatpumpingtechnologies.org/annex47/

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ANNEX 48 INDUSTRIAL HEAT PUMPS, SECOND PHASE

> ***Industrial heat pumps have a great potential for more efficient use of energy and reduction of greenhouse gas emissions in industrial processes.***

Securing a reliable, economic and sustainable energy supply as well as environmental and climate protection are significant global challenges of the 21st century. Using renewable energy and improving energy efficiency are the most important steps to achieve these goals of energy policy. While impressive efficiency gains have already been achieved in the past two decades, energy use and CO_2 emissions in manufacturing industries could be reduced further, if best available technologies were to be applied worldwide. In the previous completed Annex 35 “Application of Industrial heat pumps” a total of 39 examples of R & D projects and 115 case studies were collected.

The results show the successful integration of heat pumps in the industry and how to overcome barriers: short payback periods are possible (less than 2 years), high reduction of CO_2 emissions (in some cases more than 50 %), and temperatures higher than 100 °C are possible. Supply temperatures below 100 °C are standard.

Based on these results, collected information and experiences the main goal of the Annex 48 is to overcome difficulties and barriers for the market introduction of industrial heat pumps.

The collected cases studies of industrial branches with a large potential should be analysed and elaborated for a clear understanding of the benefit and advantage of the application. This will be shown in a simple table form. The goal is to develop a web-based information platform for heat pumps in industrial and commercial applications. Interested users should have the possibility to find their application with meaningful data of existing case studies from global sources.

We will arrange the information on heat pumping technologies for industry, for policymakers, industrial planners and designers, stake holders as well as heat pump manufacturers in a way that will lead to a better understanding of the opportunities. It will also lead to the use of this information for the reduction of primary energy consumption, CO_2 emissions, and energy costs of industrial processes.

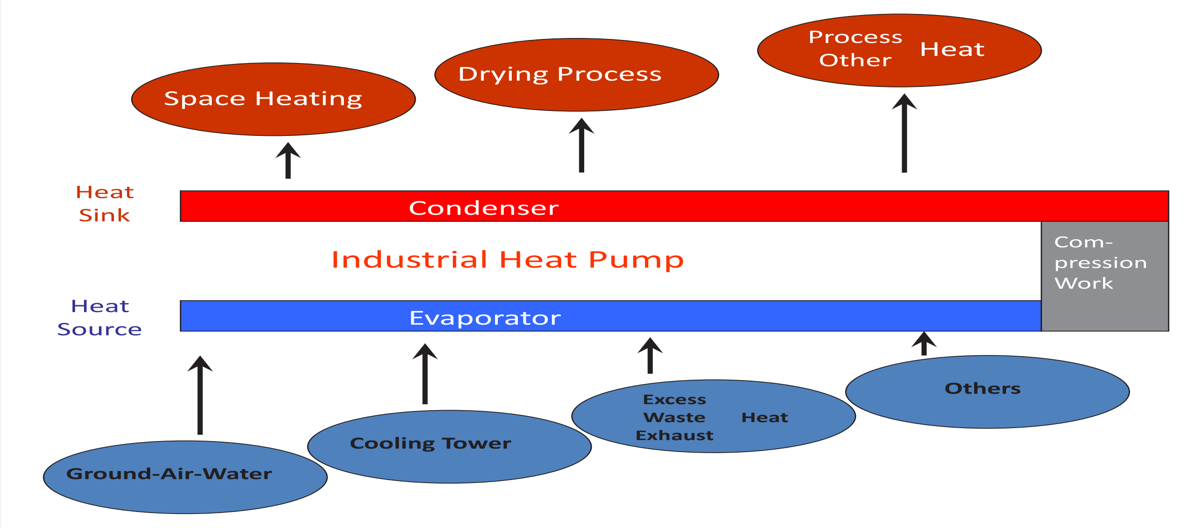

Figure 1. Possible heat sources and heat sinks for industrial heat pumps

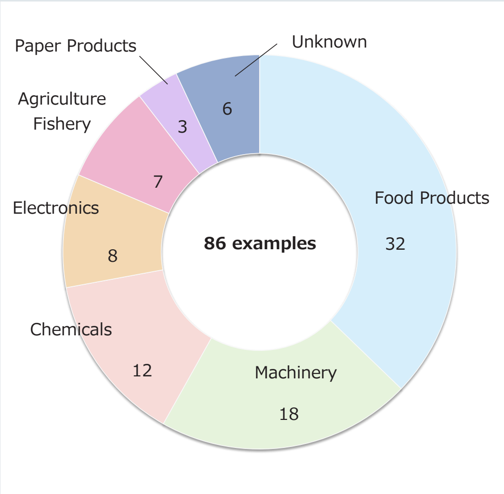

Figure 2. Japanese applications of heat pumps in different industries

Objectives

- Annex definition of Industrial Heat Pumps (IHP): Heat pumps in the medium and high power range and temperatures up to 200 °C, which can be used for heat recovery and heat upgrading in industrial processes, but also for heating, cooling and air-conditioning in commercial and industrial buildings.
- Development of a framework which structures information on IHP applications, using the existing and new case studies. Best available technologies and best practices should be selected based on the matrix (sorted by type of installation, of technology and system).
- Creating information material for IHP training courses.
- The material describing the IHP potential for more efficient use of energy and reduction of greenhouse gas emission should be accessible for policy makers.

Overview of tasks

- Task 1 - Analysis of the collected case studies and successful applications of industrial heat pumps
- Task 2 - Structuring information on industrial heat pumps and preparation of guidelines
- Task 3 - Application of existing models for the integration of a heat pump into a process
- Task 4 - Communication of the IHP potential for policy makers, designers and decision makers

Project duration:
April 2016 - April 2019

Participating countries:
Austria, France, Germany, Japan, Switzerland, and the United Kingdom.

Interested countries:
Denmark

Annex website:
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ANNEX 49 DESIGN AND INTEGRATION OF HEAT PUMPS FOR NZEB

Nearly Zero Energy Buildings (nZEB) are to be introduced by the beginning of 2019 for all new public buildings and, by the beginning of 2021, for all new buildings in Europe. Heat pumps are already a wide-spread technology in built nZEB due to their high performance, which is attained in efficient buildings with low supply temperature requirements.

However, many of the currently realized buildings are showcase and demonstration projects, and cost-effective nZEB still remain a challenge. Building companies and designers will have to fulfil new requirements for reaching a nearly zero energy balance according to the national definitions in the EU member countries. Building system manufacturers will have to provide highly efficient and adapted equipment. Besides performance and cost, the energy flexibility may also become an important criterion in the future, in order to integrate nZEB in the connected energy infrastructure and to operate renewable energy systems for on-site generation more economically. Flexibility and demand response capability are linked to the enhanced control of the building technology.

Annex 49 will therefore investigate the design and integration of heat pumps with other building technology, such as renewable energy systems in the building envelope, ground and other heat sources, and thermal and electric storage systems. The work is carried out by simulating the system integration as well as developing new technologies and the field monitoring of new and existing heat pump systems for different building uses in nZEB. Investigations will also be extended to groups of buildings connected by thermal or electrical micro-grids and smart neighbourhoods.

> ***Heat pumps are the key technology for the realization of cost-effective and energy flexible nZEB as the future standard for a sustainable built environment.***

Objectives

- Evaluate and compare definitions of nZEB across the participating countries regarding the impact on building technologies with heat pumps
- Evaluate the design of heat pump systems for different applications in residential or office buildings regarding performance, cost and demand response.
- Refine integration options for building technology with heat pumps in terms of multi-functional operation and the needs of integrated systems
- Field monitoring of buildings across different participating countries and evaluation of different concepts and technologies under different climate and market conditions
- Derive recommendations for integrated heat pump systems as well as heat pump design and control in single nZEB and groups of buildings.

Overview of tasks

- ***Task 1 - State-of-the-art of definitions and nZEB concepts***
  Task 1 will update the state of the art regarding definitions and technologies used in nZEB as a basis for the evaluation of building technologies.

- ***Task 2 - System integration options of heat pumps***
  Task 2 will investigate in more detail the

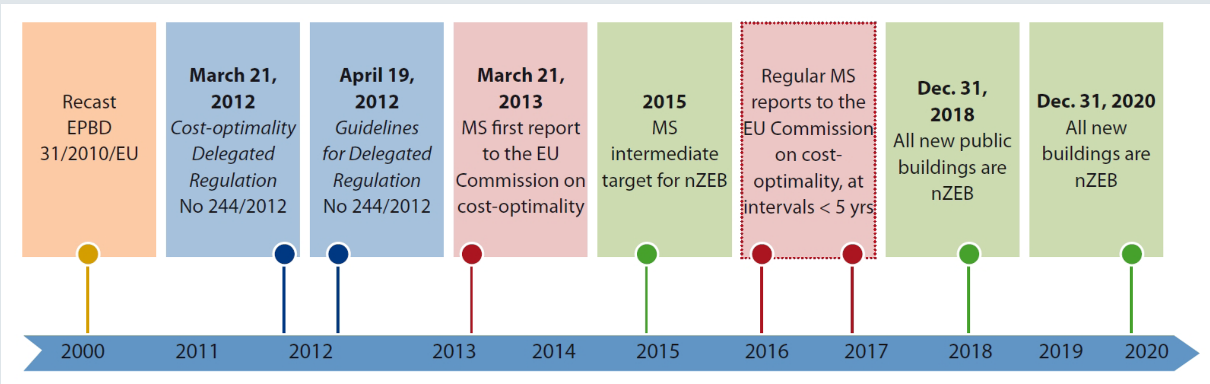

Figure 1. Timetable for the introduction of nZEB according to the EPBD recast of 2010 [Source: B. Atanasiu and I. Kouloumpi. 2013. Building Performance Institute Europe - BPIE].

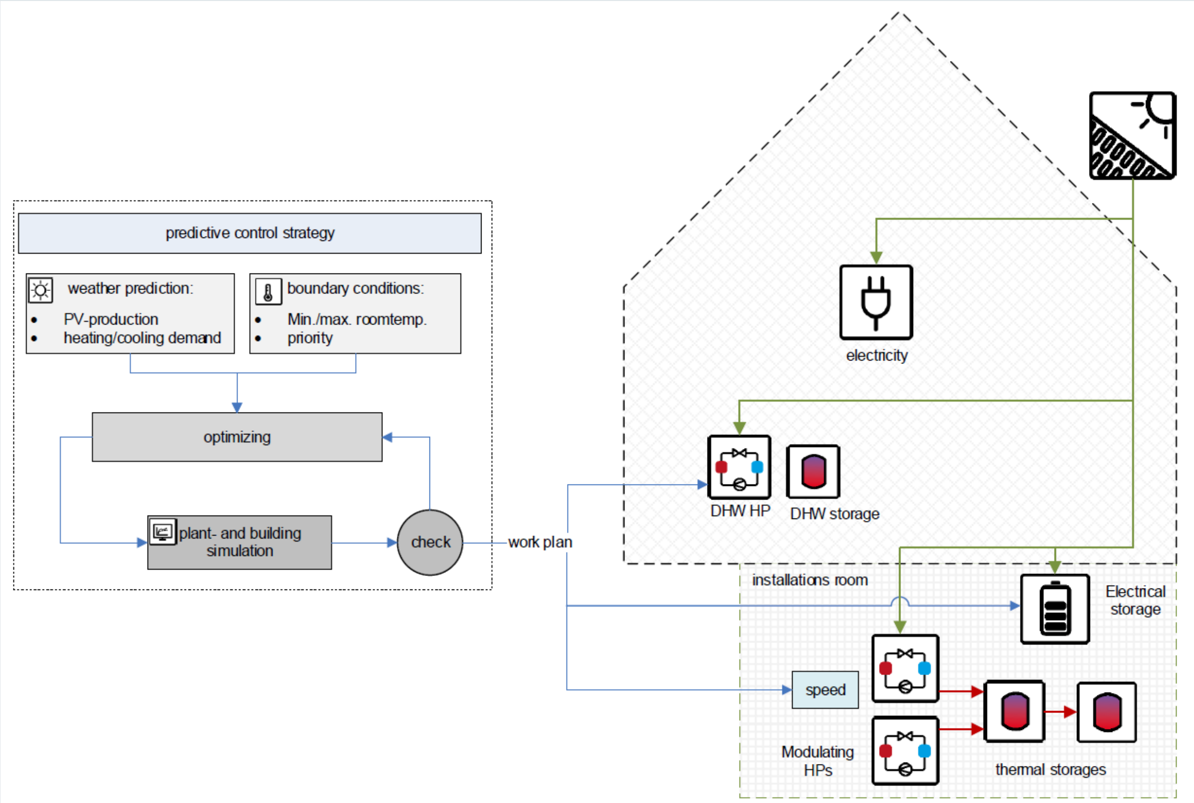

Figure 2. Building technology and control concept of project Herzo-Base as one German contribution to Annex 49 [Source: Technical University TH Nuremberg (Technische Hochschule Nürnberg)].

integration options for heat pumps with other building technologies, such as the building envelope, ground and both thermal and electric storage systems, e.g. by simulation studies.

- ***Task 3 - Technology evaluation and development/ Continued field evaluation***
  In Task 3, technology developments started in Annex 40 and new developments will be investigated by prototyping, lab-testing and field monitoring, which will also include built nZEB in operation.

- ***Task 4 - Design and control of nZEB technologies***
  Task 4 deals with the design and control of heat pumps integrated into the building technology in nZEB in terms of performance, cost and demand response capability for self-consumption optimisation.

Project duration:
October 2016 - September 2019

Participating countries:
Belgium, Germany, Norway, Sweden, Switzerland, and the United States.

Interested countries:
Austria, Finland, Estonia, Japan, and the United Kingdom.

Annex website:
http://heatpumpingtechnologies.org/annex49/

Contact:
Operating Agent was Carsten Wemhoener, carsten.wemhoener@hsr.ch, on behalf of the Swiss Federal Office of Energy (SFOE) in Switzerland.

ANNEX 50 — HEAT PUMP SYSTEMS IN MULTI-FAMILY BUILDINGS

The building sector plays a significant role for the energy consumption in every country.

Apart from the power generation and transport sector, it is the most important sector regarding the emission of greenhouse gases. Accordingly, the radical reduction of CO_2 emissions from buildings is crucial for achieving climate neutrality in the building sector.

For multi-family buildings, the challenge to applying heat pump technologies and renewable energy is more complex than it is for single-family dwellings. The type of ownership varies among member countries of the IEA HPT TCP. While in some countries multi-family houses are often owned by municipalities, communities or housing corporations, in other countries ownership is private and divided into separate flats.

Multi-family houses are associated with a range of heat demand characteristics. Firstly, the share of domestic hot water in the overall heat demand varies due to varying building standards as well as different climates. Secondly, the temperature level of the heating system is influenced by these aspects as well as by the installed heat transfer system. Thus, dealing with the variety of heat demand characteristics is the challenge on the way to a broader spread of heat pumps in multi-family buildings.

Annex 50 will focus on solutions for multi-family buildings with the aim of identifying barriers for heat pumps on these markets and how to overcome them. With respect to the demand from the participating countries, new buildings and retrofit will be considered, together with buildings with higher specific heating demand.

> ***"Annex 50 focuses on solutions for multi-family buildings with the aim of identifying barriers for heat pumps on these markets and solutions for how to overcome them."***

As the end user on the demand side, city councils and housing corporations owning large housing estates are important target groups. On the supply side, heat pump manufacturers, power companies, technical consultants as well as planners/installers will be addressed. Furthermore, political decision makers are of interest since governments are setting the boundary conditions for future development for Energy Zero in 2050.

Objectives

- Enhancement of heat pump systems and/or heat pump components for their adaptation to multi-family buildings;
- Development and demonstration of concepts for application of heat pumps in buildings renovated in terms of energy and in buildings without improved building envelope;
- Finding the optimal bivalence temperature for bivalent or hybrid systems;
- Identification of the characteristics of heat pump components and identifying the characteristics that are neither fulfilled by market-available products nor a scope in ongoing research and development projects;

Figure 1. Examples of multi-family buildings.

Figure 2. Examples of heat pumps in a multi-family building.

- Present recommendations for the optimal (multi) heat source and operating mode (fuel driven, electric driven, hybrid) solutions depending on building type and ecologic-economic situation and climatic zone.

Overview of tasks

- ***Task 1 - Market overview, barriers for application, system classification***
  Task 1 focuses, among other things, on the analysis and classification of products with regard to different types of multi-family buildings, legislation, energy supply scenarios etc.

- ***Task 2 - Modelling and simulation of systems, economic models***
  The focus of Task 2 will be on the simulation of various systems in a wide range of operating conditions (type of buildings / insulation, climates, applications, energy scenarios, heat sources etc.).

- ***Task 3 - Technology development, evaluation and system assessment***
  Among other things, heat pumps with better modulation or cascaded systems, as well as hybrid systems will be investigated within Task 3.

- ***Task 4 - Demonstration and monitoring***
  The first step of Task 4 will be a definition of the system boundaries and performance evaluation figures. After a period of monitoring, the measured data will be analysed.

- ***Task 5 - Dissemination and communication***
  Within Task 5, the results of the Annex will be provided for a broad audience spectrum.

Project duration:
January 2017 - December 2020

Participating countries:
Austria, France, and Germany.

Interested countries:
Canada, the Netherlands, Sweden, Switzerland, and the United Kingdom.

Annex website:
http://heatpumpingtechnologies.org/annex50/

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ANNEX 51

ACOUSTIC SIGNATURE OF HEAT PUMPS

Reduction of acoustic emissions is important to further increase the acceptance of heat pumps as air-to-water, water-to-air, air-to-air and brine-to-water (ground source) units. To increase this acceptance and minimize noise annoyance, more focus has to be put on the acoustics emissions at steady state and on the transient behaviour of acoustic signatures during different operating conditions (e.g., icing, de-frosting, capacity control, and cooling mode). Depending on the end user, or the end-user's neighbour, the noise emissions under investigations are an indoor and/or outdoor issue, requiring appropriate treatment.

Air to water heat pumps provide a convenient and effective way to exploit potential energy savings and are often used in retrofit installations. Thus, acoustic improvements are important for both the new and the retrofit market.

Acoustic emissions will be accessed in a hierarchical approach considering the following levels: Component level - Low noise components (e.g., fans and compressors); Unit level - System approach of combining the components, unit control, transient acoustic features; Application level – Building and neighbourhood including smart grid, psychoacoustic effects and acoustic propagation.

Options for noise measurement techniques (see Figure 1-3) for improved understanding, measuring and description of the acoustic performance will be an important focus of the Annex. Seen from a global perspective, the current legislation – serving the needs of the different locations and countries – is very diverse. The Annex will contribute to guidance and future standards in this field in the short and long term to help in harmonizing the different local approaches, for the benefit of all involved stakeholders.

> ***Acoustic training ensures that optimal installation complements good acoustic design - further increasing the acceptance of heat pumps.***

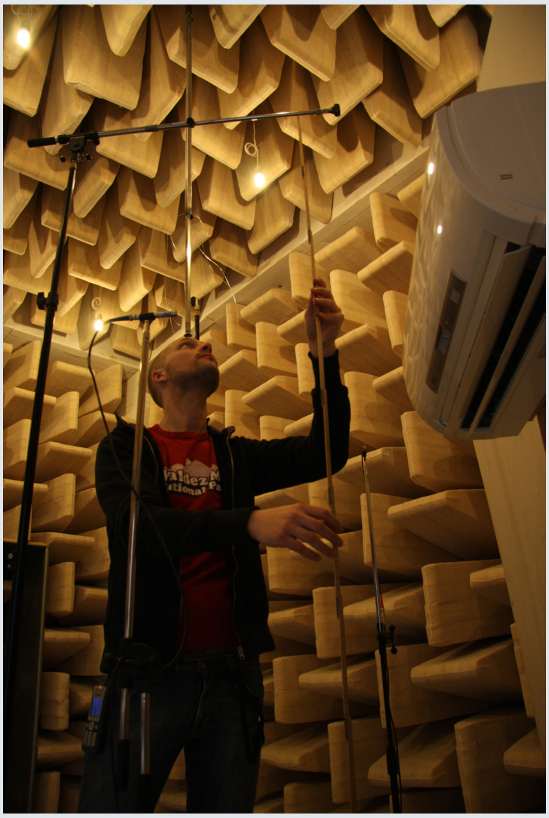

Figure 1. Noise measurement of an air-to-air heat pump in the hemi-anechoic room at RISE in Sweden. [Source: RISE Research Institutes of Sweden]

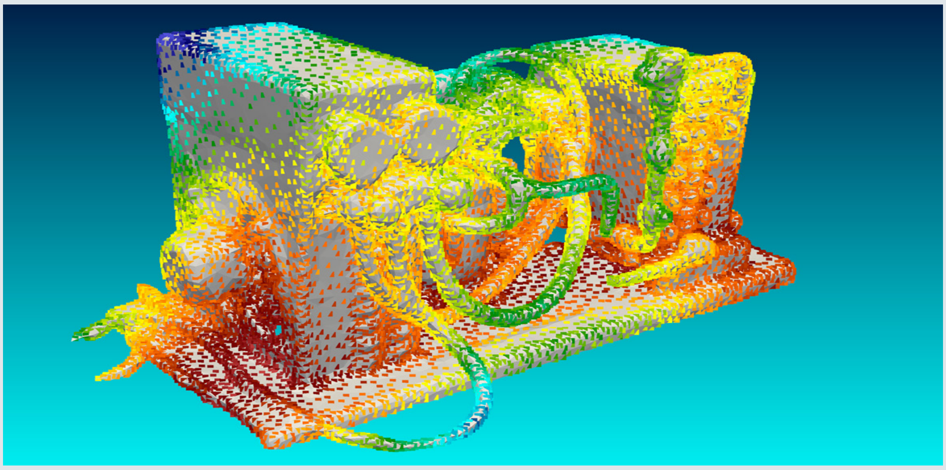

Figure 2. Three-dimensional visualization of the sound source distribution of an educational heat pump at a frequency of 1250 Hz [Source: AIT Austrian Institute of Technology]

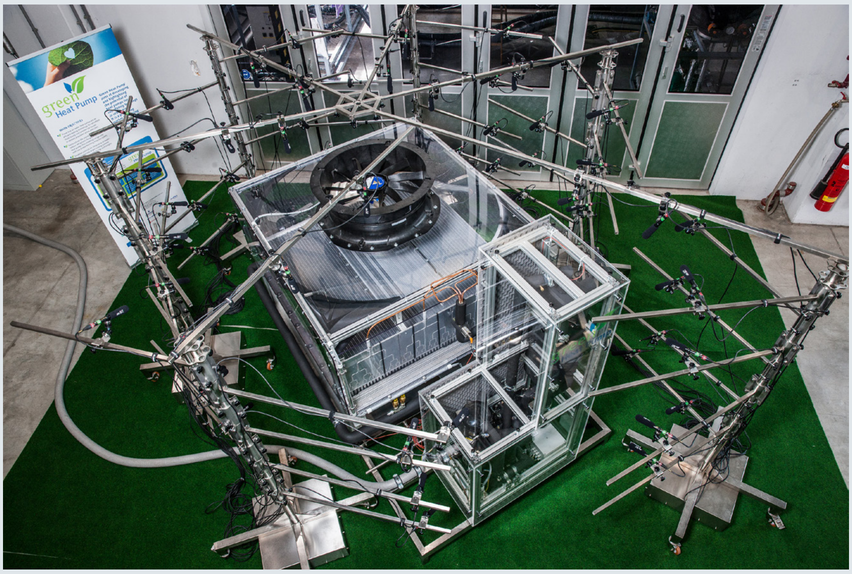

Figure 3. Demonstration Setup of a 64 microphone Acoustic Dome around the GreenHP Heat Pump [Source: AIT Austrian Institute of Technology]

Education and training are very important aspects in heat pump acoustics (placement, noise reduction measures, modes of control and operation) so that bad installations will not go against good acoustic design and construction of the units. Guidelines will be prepared for component and heat pump manufacturers, heat pump testing laboratories, engineering consultants, installers and designers.

Participants of the Annex will contribute through presenting and discussing the results of their corresponding ongoing and starting acoustic research projects. Furthermore, national guidelines that are already in place will be improved and prepared for broader use.

Objectives

- Further increase the acceptance of heat pumps for comfort purpose with respect to noise and vibration emissions;
- Increasing knowledge and expertise at different levels (manufacturers, acoustic consultants, installers, legislators);
- Input to national and international standardization;
- Preparation of six Annex meetings on acoustics in the participating countries;
- Organization of a concluding international workshop and compilation of proceedings;
- Worldwide dissemination to heat pump manufacturers via already available dissemination media and additionally a special Annex Newsletter which can be subscribed to; Acoustic Guidelines for the different levels (Component Level, Unit Level, Application Level).

Overview of tasks

- ***Task 1 - Legislation and standards*** - Gathering and comparison of acoustic regulations and standards, measurement techniques and certification schemes;.
- ***Task 2 - Definition of heat pump units to be covered by the study*** - Compilation of a list of representative products used in the Annex;
- ***Task 3 - Identification of noise at component and unit levels and noise control techniques*** - Generation of an overview on component and unit noise as well as design and control strategies;.
- ***Task 4 - Analysis*** - Analysis of the effect of operating conditions of heat pumps on acoustic behaviour;
- ***Task 5 - Heat pump installation and effects on surrounding environment*** - Focussing on acoustic perception, heat pump installation and its environmental effects;
- ***Task 6 - Improved measuring and description of the acoustic performance*** - Discussion on future options for more detailed and significant acoustic performance figures;.
- ***Task 7 - Diffusion, dissemination*** - Preparation of Guidelines, recommendations and educational material on heat pump acoustic.

Project duration:
April 2017 - March 2020

Participating countries:
Austria, France, and Sweden

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

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

Recently Completed Annex in HPT TCP

ANNEX
40

HEAT PUMP CONCEPTS FOR NEARLY ZERO ENERGY BUILDINGS

> ***Heat pumps are a highly-efficient technology that is well-suited for application in nZEB due to their unique features***

With the recast of the Energy Performance of Buildings Directive of 2010, the introduction of nearly Zero Energy Buildings (nZEB) as the future target for high performance buildings has started in Europe. The definition of nearly zero energy refers in the main to the annual energy balance, where the energy consumption of the building will be mostly met by renewable energy production on-site on an annual basis. Also in the USA and Japan, nZEB are the strategy for future high performance buildings.

Thus, there is a strong interest in building technology concepts fulfilling the criteria for nZEB from various stakeholders, such as building companies, designers and building equipment manufacturers, as well as from policy makers. IEA HPT Annex 40 has investigated heat pump applications in nearly zero energy buildings across different countries regarding system performance and cost. Concepts have been investigated by simulation and new prototype technologies have been developed in the laboratory and in field monitoring. Field monitoring of already built nZEB confirms the good performance of heat pumps in nZEB as well as some remaining optimisation potential, which may even increase the performance values. Results confirm that heat pumps are a technology well-suited for the specific use in nZEB buildings, contributing to a future, highly efficient and sustainable built environment. These results support the introduction of nZEB and could boost the markets for heat pumps and promote this efficient building technology for the application of heat pumps in nZEB.

Objectives

1. Characterisation of the state-of-the-art of realised nZEB and heat pump application in these buildings.
2. Assessment and improvement of different building concepts and technology options regarding the performance and cost of heat pump application in nZEB
3. Technology development of new heat pump prototypes suited to fulfil nZEB requirements in lab and field testing
4. Evaluation of results from field monitoring of heat pumps in nZEB regarding performance and optimisation potentials in real operation

Results

A. Case studies and technology comparisons of HVAC systems in nZEB across different countries and regions in Europe, Canada, and Japan have been performed. The results regarding system performance and cost show that heat pumps are among the most

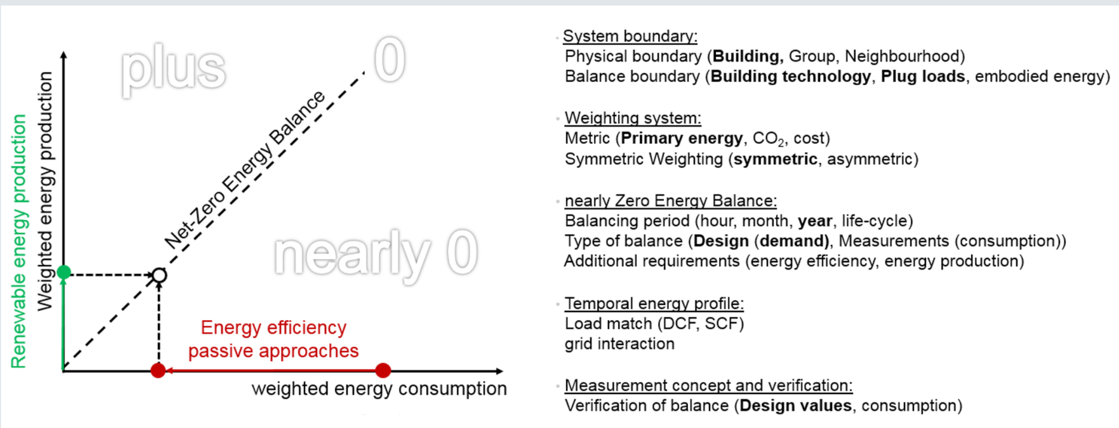

Figure 1. Criteria for definitions of nearly and net zero energy (based on Sartori et. al., 2012). The basic principle of nZEB is shown on the left, where both efficiency measures to reduce the needs (red dots) and renewable on-site generation (green dots) contribute to the nearly zero energy balance. Even though the principle seems simple, various criteria have to be defined for the precise definition, as shown on the right (bold words correspond to the most common criteria chosen in present definitions).

energy-efficient and cost-effective system solutions in this type of buildings. These findings confirm that heat pumps are a key technology for the future.

B. Integrated heat pump development in the USA have led to different ground-source and air-source prototypes, for which simulations and field monitorings have shown that they will reach the DOE targets of 50 % reduced energy consumption for the equipment. The ground-coupled integrated heat pump is already on the market, while the air-source prototype showed an average summer performance above 5 in combined cooling operation and 4.4 in DHW production in field monitoring. Different variants of the air-source prototype will be investigated further in field monitoring.

C. Technology developments of an HVAC system in Japan have resulted in a highly efficient VRF technology by decoupling temperature and humidity loads. The system consists of a heat pump desiccant system and a capacity enhanced VRF heat pump. Humidity loads are covered by desiccant technology, while the VRF heat pump can work at higher evaporation temperature and lower pressure differences to cover temperature loads effectively. By using new heat exchanger and compressor developments, the system performance has been increased significantly. Field monitoring results have confirmed a 70 % reduction in energy consumption with improved comfort values compared to a conventional reference system.

Publications

- Wemhoener, C., Schweizer, R., Schwarz., R. 2016. *Results of IEA HPT Annex 40 on Heat Pumps in Nearly Zero Energy Buildings*, 12th REHVA Clima World Congress 2016, Aalborg, May 24, 2016.
- Fanney, A. H., Payne, V. W., Ullah, T., Ng, L., Boyd, M., Omar., F., Davis, M., Skye, H., Dougherty, B., Polidoro, B., Healy, W., Kneifel, J. und Pettit, B. 2015. *Net-zero and beyond! Design and performance of NIST's net-zero energy residential test facility*, Energy and Buildings, Vol. 101, pp. 95-109.
- Winiger, S., Kalz, D., Velle, M. 2013. *Energy and Efficiency Analysis of Heat Pump Systems in Non-residential Buildings by Means of Long-Term Measurements*. 11th REHVA World Congress & 8th International Conference on IAQVEC, 16-19 May 2013, Prague.
- Final reports (4 parts), Executive Summary, and Two-page summary of Annex 40 are available at http://heatpumpingtechnologies.org/publications

Participating countries:
Canada, Finland, Germany, Japan, the Netherlands, Norway, Sweden, Switzerland, and the United States.

Annex website:
http://heatpumpingtechnologies.org/annex40/

Contact:
Operating Agent was Carsten Wemhoener, carsten.wemhoener@hsr.ch, on behalf of the Swiss Federal Office of Energy (SFOE) in Switzerland.

Single-family building

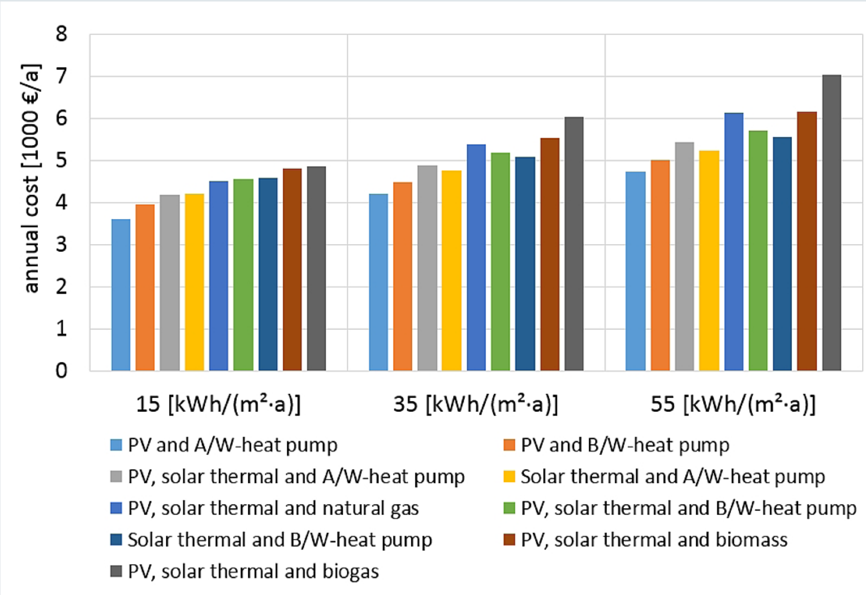

Figure 2. Cost-comparison of different heating systems as case study for a single family nZEB in Switzerland [Source: Institute of Energy Technologies, Univ. Appl. Sciences HSR Rapperswil]. In the single family buildings with different space heating demands heat pumps are the most cost-effective building technology regarding 20-year life-cycle cost. Also in multi-family building and office application, heat pumps are among the best systems with respect to life-cycle cost.

Dishwasher with Integrated Heat Pump

Stefan Flück, Mirko Kleingries, Ernst Dober, Beat Wellig - Switzerland

Everyday appliances such as refrigerators, dryers, washing machines or dishwashers add to a household's electricity demand considerably. To reduce their consumption of electricity, these appliances can be equipped with heat pumps to provide the necessary heating and cooling. This article describes a domestic dishwashing machine with an integrated heat pump that reduces the energy consumption by up to 50 % compared to conventional dishwashers with electrical resistance heating.

Introduction

The use of heat pumps for the heating of buildings has rapidly grown over the last decades. In Switzerland, for instance, the market share of newly built single and multi-family houses that include a heat pump reached over 80 % in the last few years (FWS, Heat Pump Association in Switzerland, www.fws.ch). This trend towards an increasing adoption of heat pumps can be seen in other household applications as well. Table 1 gives an overview of household appliances containing heat pumps that are currently available on the market. The table shows the typical ranges of electrical energy consumption for conventional appliances and those with an integrated heat pump for the respective standard process.

In Switzerland, sales information and statistics are recorded for household appliances [1]. Most significantly, the energy label given to each appliance shows that they are becoming increasingly more energy efficient. This fact is due, on the one hand, to incremental efficiency increases as a result of continuous development and improvement of the units, e.g. through process optimization or installation of more efficient electric motors. On the other hand, it is due to the implementation of new technology. Both aspects result in the energy demand being substantially reduced. As an example, the energy requirement for a dishwasher can be reduced by up to 50 % by the integration of a heat pump [2]. This dishwasher, which has been available on the market since 2014, is described in this article.

Dishwasher with integrated heat pump

Several requirements apply to household dishwashers with a monovalent heat pump program and an open drying process. In this context, the dishwasher's door is physically opened during the drying process (i.e. open drying process) as opposed to conventional dishwashers where the door remains closed (i.e. closed drying process). The term monovalent means that only one heating system is employed for the respective program. However, the dishwasher with the monovalent heat pump program is also equipped with electrical resistance heaters which are used in further washing programs additionally to the heat pump.

The following list provides the specifications for the dishwasher:

a. Duration of 130 min (excluding drying process) for dishwashing program.
b. Compliance with the standard test: The period of time between the start of two dishwashing programs is 24 h [3].
c. Installation limited to a "Standard Euro Niche" covering a ground area of 60 cm by 60 cm.
d. Common, competitive costs of manufacturing for the additional components.

Figure 1 illustrates the design of the household dishwasher with a monovalent heat pump program. As the figure shows, a latent heat storage filled with water is employed as the heat source for the heat

Table 1. Comparison of the energy requirements of different household appliances. A distinction is made between conventional appliances and those with an integrated heat pump. The electrical energy consumption refers to the respective standard process for one wash load or dish load.

	CONVENTIONAL TECHNOLOGY	WITH HEAT PUMP
Tumble dryer (7 kg dry clothes)	ca 4 900 Wh	1 400 Wh - 2 250 Wh
Washing machine (7 kg dry clothes)	ca 950 Wh	ca 560 Wh
Dishwasher	ca 1 000 Wh	490 Wh

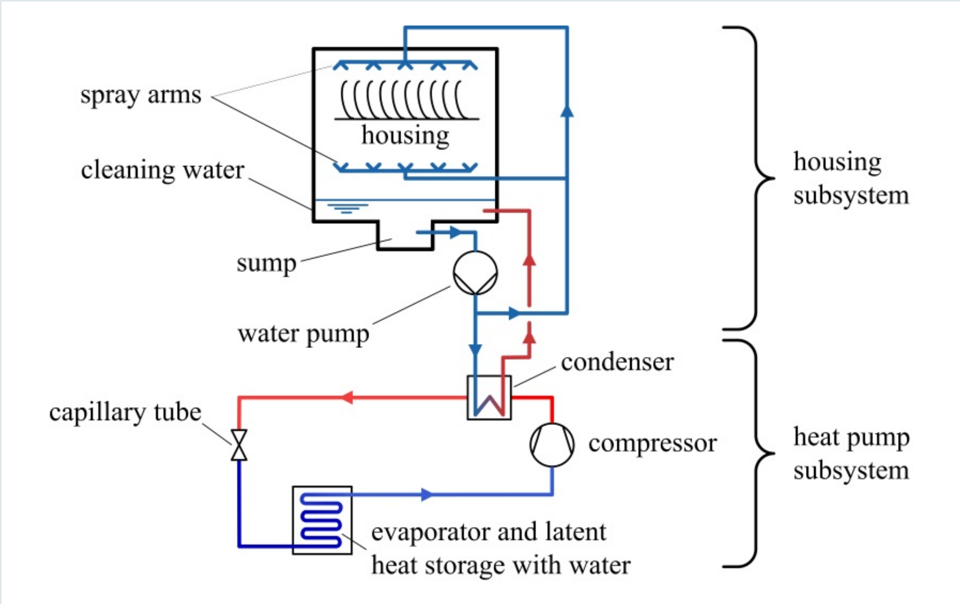

Figure 1. Simplified scheme of the household dishwasher's design with a monovalent heat pump program.

pump [4]. This storage offers a high energy storage density due to the phase change between liquid water and ice. Using this approach, the heat pump can provide the entire required process heat monovalently. After the washing program has finished and the storage tank has been discharged, the heat storage is recharged, i.e. heated, passively via the heat from the surroundings. According to the specifications, see previous page, the storage must return to its initial state after 24 h.

The water pump draws the cleaning water out of the sump of the dishwasher into the water circuit whereby it is split into two different lines. In the first line, the water is pumped to the spray arms in the housing and distributed by means of washing jets, so the dirty dishes are cleaned and heated up. In the second line, the cleaning water is pumped through the condenser and heated by the condensing refrigerant before flowing back to the sump. The condenser used is a horizontally arranged tube-in-tube heat exchanger, whereby the outer tube is made from flexible plastic tubing and the inner tube is made from stainless steel. The cleaning water flows in the annular gap and the refrigerant R-134a inside the inner tube. The materials were selected due to the corrosive nature (acidic or basic) of the cleaning water.

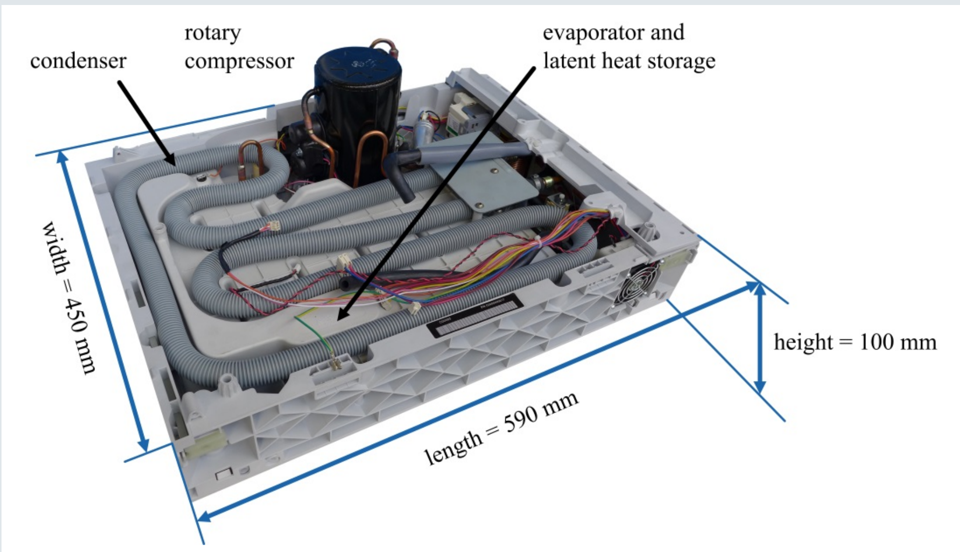

Figure 2. Assembled heat pump unit of the serial dishwasher.

At the start of the dishwashing process, the evaporator coil in the latent heat storage is immersed in liquid water. The water then cools and partially freezes as the evaporating refrigerant extracts energy from the water. Next, the evaporated refrigerant passes through a rotary compressor before going to the condenser. Following the condenser, the pressure level of the refrigerant is lowered to the evaporation pressure using a capillary tube.

The entire heat pump unit with latent heat storage (i.e. heat pump subsystem) is placed underneath the housing. With this arrangement, the dishwasher can still fit into a Standard Euro Niche. Moreover, the latent heat storage is thermally separated from the housing and no heat is transferred between the housing subsystem and the heat pump subsystem.

Figure 2 shows the assembled heat pump unit of the serial dishwasher. The components are labeled and the outer dimensions are given.

Dishwashing process

Figure 3 presents the dishwashing process for the dishwasher featuring the monovalent heat pump program with an open drying process. For the various cleaning steps, it is necessary to identify the curve of the cleaning water temperature over time, which approximately corresponds to the temperature of the dishes, the housing, and the water masses involved in the different dishwashing baths. At the beginning of the dishwashing process, 4.4 kg of water are filled into the sump and the heat pump warms the housing subsystem (i.e. housing, dishes, and washing water, see Figure 1, from 20 °C to 50 °C. Then the water is circulated and the dishes are cleaned. The temperature in the dishwasher steadily decreases during this period because of heat losses through the housing and the transient heat absorption of the dishes. When washing is completed, the dirty water is pumped out at a temperature of about 42 °C, and the sump is filled with 3.4 kg of fresh water at a temperature of 15 °C. The mixing temperature is approximately 36 °C. During this intermediate washing step, the dishes are cleaned again to remove any remaining residues. At the end of this cleaning step, the cleaning water is again pumped out.

In the final rinse cleaning step, 3.5 kg of fresh water are added, resulting in a mixing temperature of around 30 °C. Then the housing subsystem is heated by the heat pump to 45 °C for drying. At the end of this cleaning step, the water is pumped out. During the subsequent drying process, the water remaining on the dishes evaporates and part of the water condenses on the cooler housing walls. The energy necessary for evaporation comes from the dishes. After a defined waiting period, the dishwasher door opens automatically and room air flows in to help complete the drying of the dishes. The rinse temperature is lower for the open drying process than for closed drying process (45 °C instead of 65 °C) resulting in a smaller temperature lift and thus greater efficiency.

Regeneration of the latent heat storage

After the end of the dishwashing process, the ice in the latent heat storage must be thawed and heated up for the next dishwashing process. This regeneration process is accomplished using the surrounding room air and takes around 20 h assuming standard conditions (22 °C, 55 % RH) [3]. If a new washing program is initiated before the regeneration process is finalized, the heat pump operates at lower efficiencies because of lower

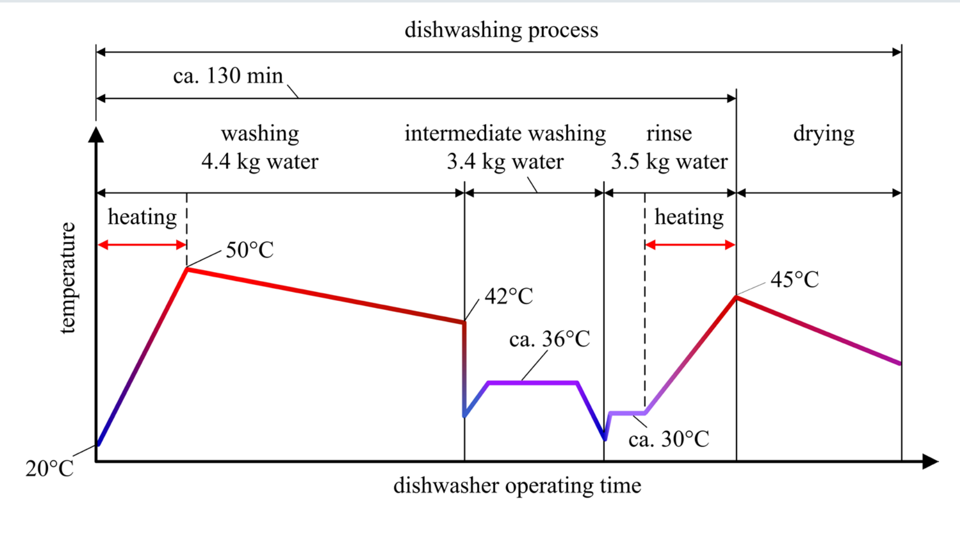

Figure 3. Dishwashing process for a dishwasher with a monovalent heat pump program and open drying process (not to scale).

Table 2. Comparison of the electrical energy needs of different dishwashers.

DISHWASHERS	SOURCE	ELECTRICAL ENERGY NEED [WH]	ENERGY REDUCTION* [%]
Standard dishwasher with electrical resistance heating and closed drying process (Adora N)	V-ZUG Ltd.	930	47.3
Dishwasher with open adsorption system	[5]	800	38.8
Dishwasher with bivalent heat pump system	[6]	910	46.2
Standard dishwasher with electrical resistance heating and open drying process (Adora SL)	V-ZUG Ltd.	750	34.7
Serial dishwasher with monovalent heat pump program and open drying process (Adora SL WP)	V-ZUG Ltd.	490	0

* The energy reduction expresses how much lower in percent the energy needs are for the dishwasher with monovalent heat pump program and open drying process compared to other dishwashers

average evaporation temperatures. The air cools off in the process due to the melting of ice. However, as the warm dishwasher itself cools to room temperature, it releases thermal energy into the air and warms the surrounding room air. Owing to the supplied electrical compressor energy, the air is supplied with more energy than is extracted by regeneration of the latent heat storage resulting in a net energy input to the room. However, compared to a conventional dishwasher the internal heat load of the room is reduced.

Electrical energy need

Table 2 compares the electrical energy needs for different dishwashers. The results show that the use of a monovalent heat pump program in a dishwasher with an open drying process can reduce the electrical energy needs by up to 50 % compared to dishwashers with electrical resistance heating and a closed drying process. The reduction is 38.8 % compared to dishwashers with an open adsorption system [5] and 46.2 % compared to a dishwasher with a bivalent heat pump system [6]. Compared to structurally similar dishwashers (Adora SL from V-ZUG Ltd.) with electrical resistance heating and open drying process, the reduction is 34.7 %.

The heat pump is not exclusively used for the "energy saving program", but is also used for other washing programs to provide additional heating utility. For example, in the so called "sprint program", the program duration can be reduced by 10 %, since the additionally installed resistance heaters are operated simultaneously with the heat pump resulting in an increase in the overall heating power. Besides the shorter program duration, the energy consumption of this program can also be reduced in comparison to purely electrical heating.

The installation of a heat pump increases the energy required for production, transport and disposal ("grey energy") of the dishwasher. An internal investigation has shown that after around 20 % of the overall number of dishwashing processes (according to the design specifications) the break-even in terms of grey energy is reached. The prerequisite is that the energy saving program is selected consistently and the dishwasher is equipped with the maximum possible load.

Conclusion

The integration of a heat pump in a dishwasher is an illustrative and positive example for a new application of the heat pump technology. The dishwasher with the monovalent heat pump program presented in this article clearly shows that the energy consumption can be reduced by up to 50 %. In addition to the benefit of employing the energy saving program where only the heat pump is used, other washing programs will also be improved with the heat pump. In particular, the total heating powers can be increased by the parallel use of the heat pump and electrical resistance heaters leading to shorter program durations. Also, compared to pure electrical resistance heating, the energy consumption of these programs is reduced as well. The increasing proliferation of energy-efficient household appliances can significantly reduce the energy demand of private households. Therefore, it is useful to incorporate this technology in other applications. For example washing machines with heat pumps have been already available on the market since 2013.

Acknowledgments
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Heat Pumps and Public Swimming Pools, a Perfect Match

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Public swimming pools have a very high energy consumption, due to high demands of heating and climatisation of the swimming pool hall, heating of the supply water for the pools, and hot water for showering, all resulting in a considerable demand for heat, also during the summer period.
By smart integration of different heat pump technologies in the building concept, the energy consumption of a public swimming pool can be reduced significantly.

Introduction

In the construction of the swimming pool Nekker-pool (Mechelen, Belgium) - see Figure 1- the theme of sustainability is extensively applied throughout the design, both in used materials and equipment.

By smart selection of matching heat appliances, a major part of the high heat demand of the swimming pool can be supplied by low temperature heating technologies, in particular heat pump systems.

This article describes the different heat pump technologies integrated in the concept, supplemented by available monitoring data on the operation of the heat pumps.

Heat pump concept

A major challenge during the design was to reduce the energy and water consumption of the swimming pool. The high energy demand of the swimming pool is reduced as much as possible by the use of advanced recovery of waste heat using different heat pumps:

- through integrated heat pumps in the air handling units of the swimming pool hall, heat is recovered directly from the exhaust air of the pool hall;
- via the combination of a heat exchanger and a

Figure 1. Nekkerpool inside view, showing the swimming pools with adjustable floors.

heat pump, residual heat is recovered from the shower water and waste water of the swimming pool;

- the remaining heat demand is filled to a large part by a heat pump connected with the energy roof: a solar collector, integrated in the entire roof of the swimming pool, allows to use the radiation of solar heat on the roof, through a heat pump into the HVAC system.

Other sustainable applications:

- water treatment installations are provided to reduce the consumption of fresh water while minimizing the discharge of waste water;
- in the choice of the building materials, requirements were imposed on the origin of the materials. Where possible, a sustainability certification was requested. The most visible application is the façade of the entire building with recycled ceramic tiles.

Heat pump with energy roof

The 1 300 m² roof of Nekkerpool is designed as an integrated solar collector that converts solar energy into usable heat, see Figure 2.

The principle of underfloor heating was reversed: the heat is captured from the roof in order to use it elsewhere.

The basics of the energy roof consists of a classical flat roof thermal insulation system, combining an insulating mortar and EPS (expanded polystyrene) insulation to provide a well-insulating layer. On top of this insulation layer, PE (polyethylene) tubes are placed into profile strips. Between the PE tubes an "energy mortar" is applied, smoothed out with the top side of the tubes. The finishing consists of a black water sealing coating. Through the tubes a glycol-liquid mixture flows absorbing radiation heat from the sun and then releasing it through the heat pump into the heating installation. The system also contributes to cooling of the roof, since it dissipates excess heat.

Waste water heat recovery with heat pump

Residual heat from waste water is recovered by a unit with recuperator and heat pump, that is specifically designed to heat fresh water using energy recovered from waste water. The unit is equipped with a fully automatic heat exchanger cleaning system, where, at regular intervals, cleaning pellets pass through the waste water pipework, removing dirt that adheres to the pipework walls. This ensures a clean surface and constant, high efficiency heat transfer, see Figure 3.

This is a very interesting appliance for swimming pools where waste water has to be regularly replaced by warm, fresh water and shower water also is required.

In Nekkerpool, waste heat is recovered both from waste showering water and filter backwash water, with two separate heat recovery units.

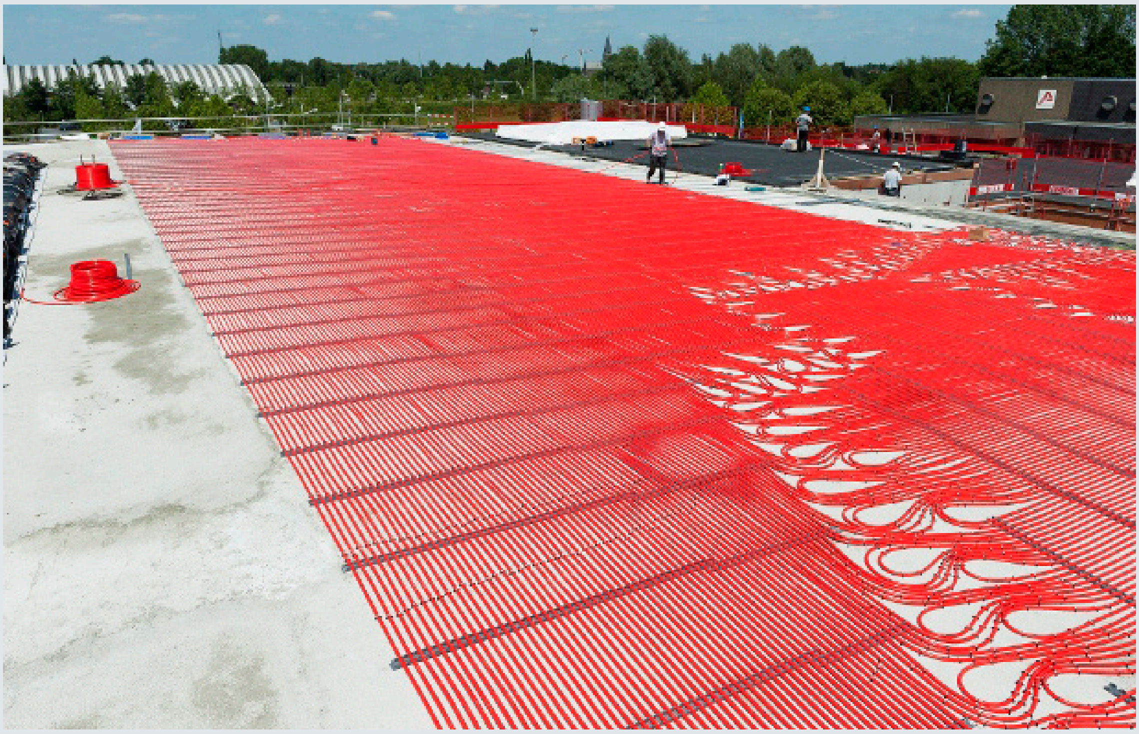

Figure 2. Build-up of the energy roof.

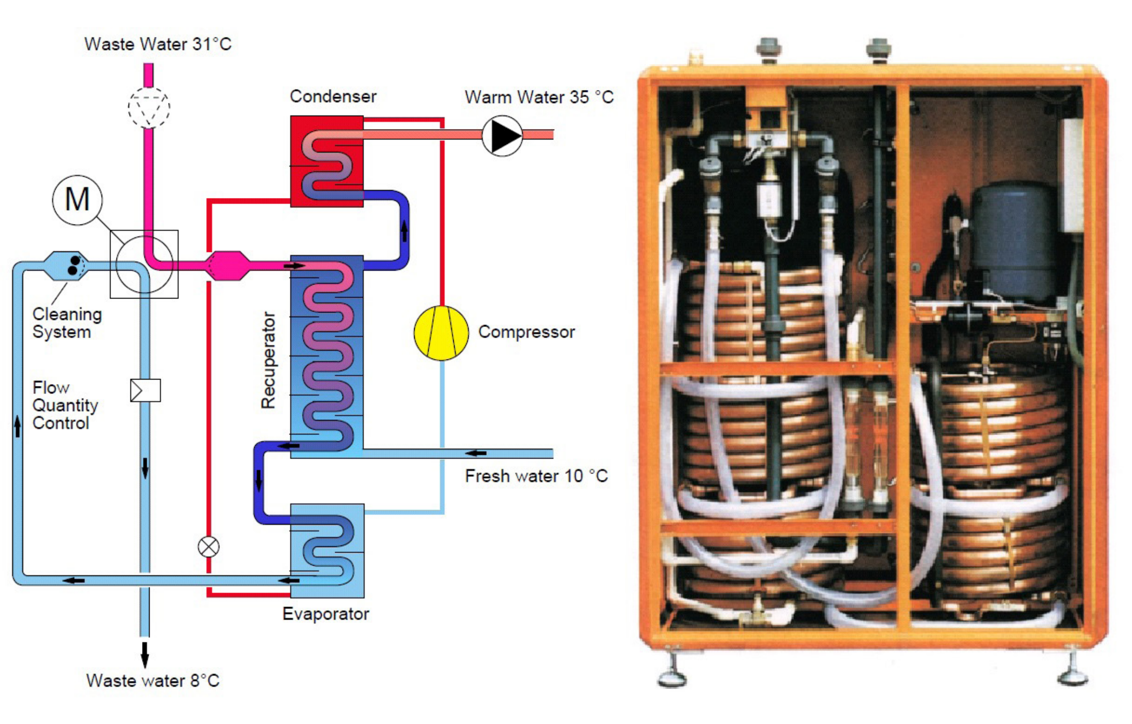

Figure 3. Waste water heat recovery unit with recuperator and heat pump.

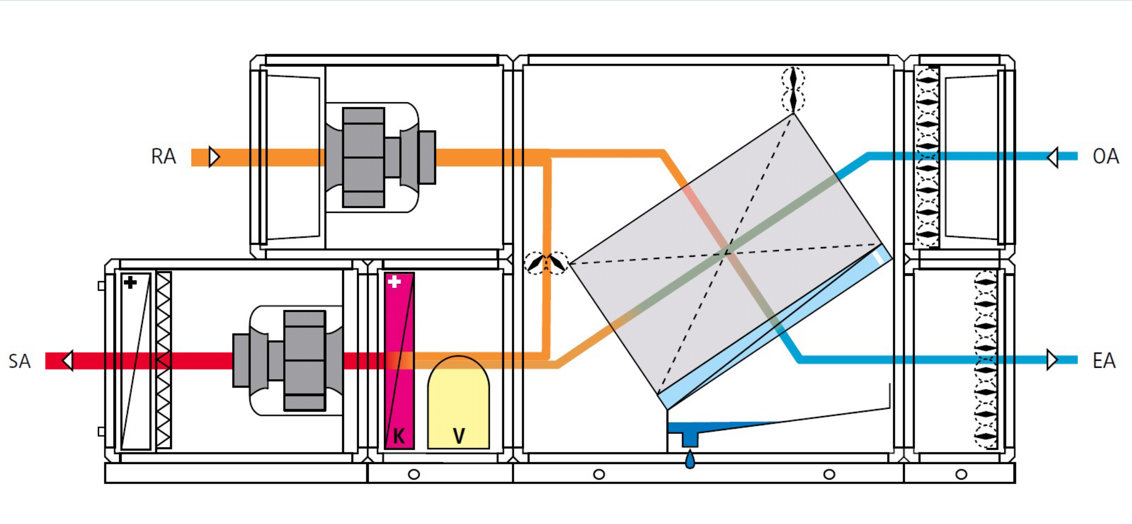

Figure 4. Air handling unit with integrated heat pump (evaporator in blue, condenser in red, compressor in yellow) for climatisation of the swimming pool hall.

Climatisation with integrated heat pump

The air handling units dehumidify, heat and ventilate the swimming pool hall, and simultaneously create good climate and protection for the used building materials. An integrated output-regulated heat pump increases the total efficiency of the system, see Figure 4.

When the swimming pool is in use, return air is cooled and dehumidified in the evaporator of the heat pump, reinforced by the upstream heat exchanger. The evaporator cools the exhaust air below its dew point, causing condensation and simultaneously recovering latent heat from the exhaust air. The outside air is

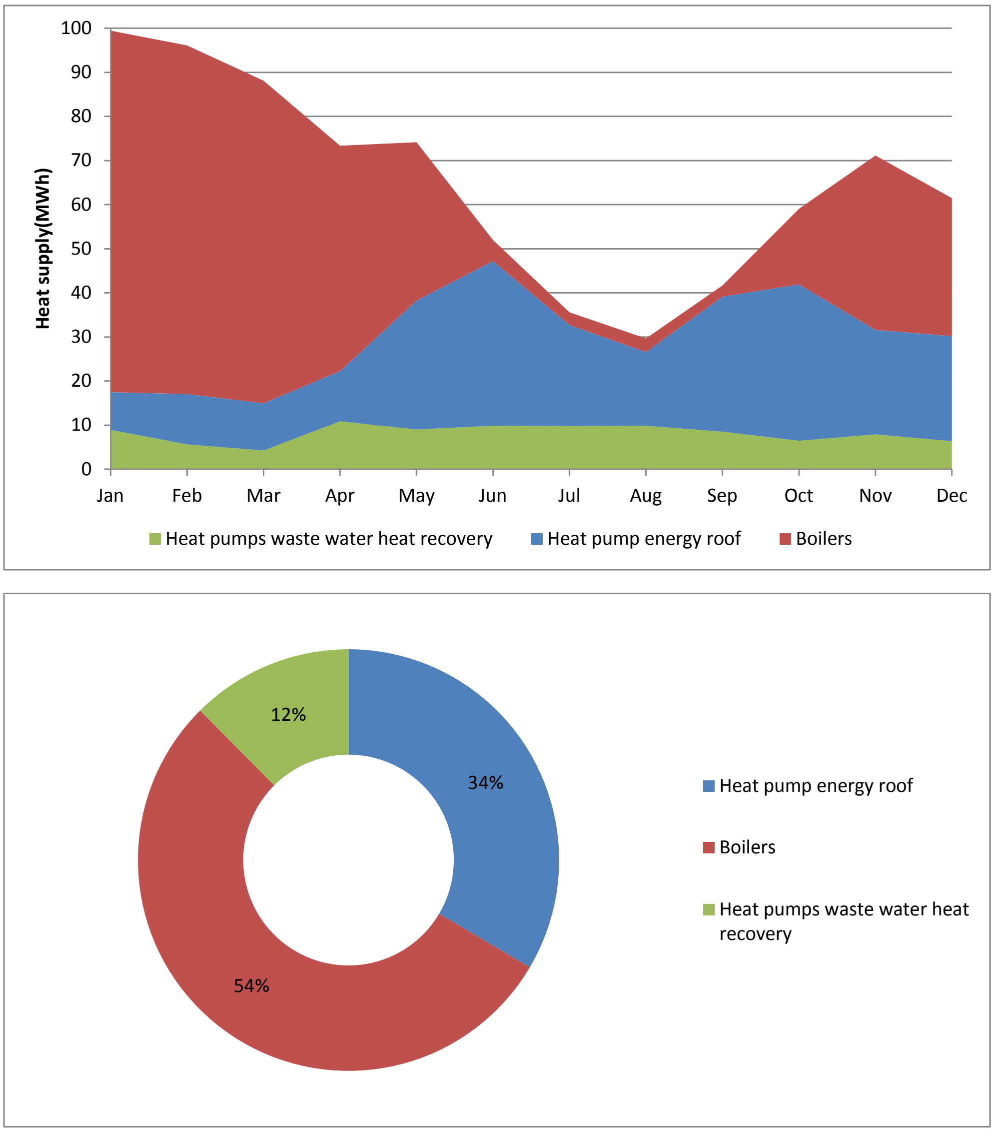

Figure 5. Monitoring data on the heat supply for Nekkerpool.

preheated in the heat exchanger, and is subsequently mixed with a proportion of untreated recirculated air, heated in the condenser of the heat pump, recovering the heat energy from the dehumidification process of the return air, and fed into the swimming pool hall as supply air.

This makes it possible to recover the latent heat, stored in the exhaust air, as sensible heat into the supply air. The energy consumed by the compressor of the heat pump system is entirely incorporated in the supply air, in the form of heat energy. For hygienic reasons, a minimum of outside air is fed into the swimming pool hall during swimming pool mode. The proportion of outside air is determined based on the current evaporation of water (and therefore the occupancy level of the swimming pool hall) and is continuously adjusted.

Monitoring data on the operation of the heat pumps

Figure 5 shows monthly heat supply data for Nekkerpool.

The graph shows that during the summer period (June – September), more than 90 % of the heat demand of the swimming pool building is supplied by the heat pump systems. The remaining is 10 % supplied by the boilers, necessary for Legionella treatment of the sanitary hot water for showering, which is not possible through the heat pumps.

Overall, the graphs show that 46 % of the total annual heat demand is supplied by the heat pumps.

There is no data available on the heat supply of the integrated heat pump in the air handling units for the swimming pool hall. Thus, we assume that more than

50 % of the total heating demand will be supplied by the heat pump systems.

Based on an integrated energy performance contract, concluded with the service company on site, plans are to further optimise the total energy performance of the swimming pool.

Conclusions

It is shown that the high energy demand of public swimming pools can be significantly reduced by smart integration of heat pump technologies for heating.

If proper attention is given to the design of matching heat appliances, over 50 % of the total heat demand of a public swimming pool can be supplied by heat pump systems.

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The Role of Heat Pumps in Future Urban Energy Systems

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In one of our recently published scientific articles we provide a holistic view on the role of heat pumps in the context of smart grids. Three main categories of heat pump applications in a smart grid context have been identified: stable and economic operation of power grids, the integration of renewable energy sources, and operation under variable electricity prices. In all these categories, heat pumps - when controlled in smart way - can help easing the transition to a decentralized energy system accompanied by a higher share of renewable energy sources and more importantly, empowerment of the future "prosumers". In this short article, we provide a brief summary of the role of heat pumps in future urban energy systems, breaking it down to four different boundary levels. We also introduce the concept of Integrated Design, Dimensioning and Control as a part of a holistic approach towards the future energy systems.

Introduction

We are moving towards a new energy paradigm characterized by:

i. a growing penetration of intermittent and decentralised renewable energy sources,
ii. emergence of millions of households acting as local producers and consumers (prosumers) of the energy, and
iii. increased electrification in all energy sectors, from transport to building heating and cooling.

These changes challenge the traditional power system which is designed for a small number of large power plants, operated to supply the demand at all times. A growing penetration of renewable energy sources such as solar and wind with their nature of intermittency and high fluctuation makes stable and profitable operation of the electric power system a challenging task. To accomplish this task, the energy infrastructure needs to be upgraded to accommodate higher flexibility, on both the supply and the demand side. Short term energy storage in the form of batteries or thermal-electric systems connected to thermal storage can provide some of the needed flexibility.

This paper deals with the role of heat pumps in the future energy system and highlights how heat pumps can contribute to this process towards net primary

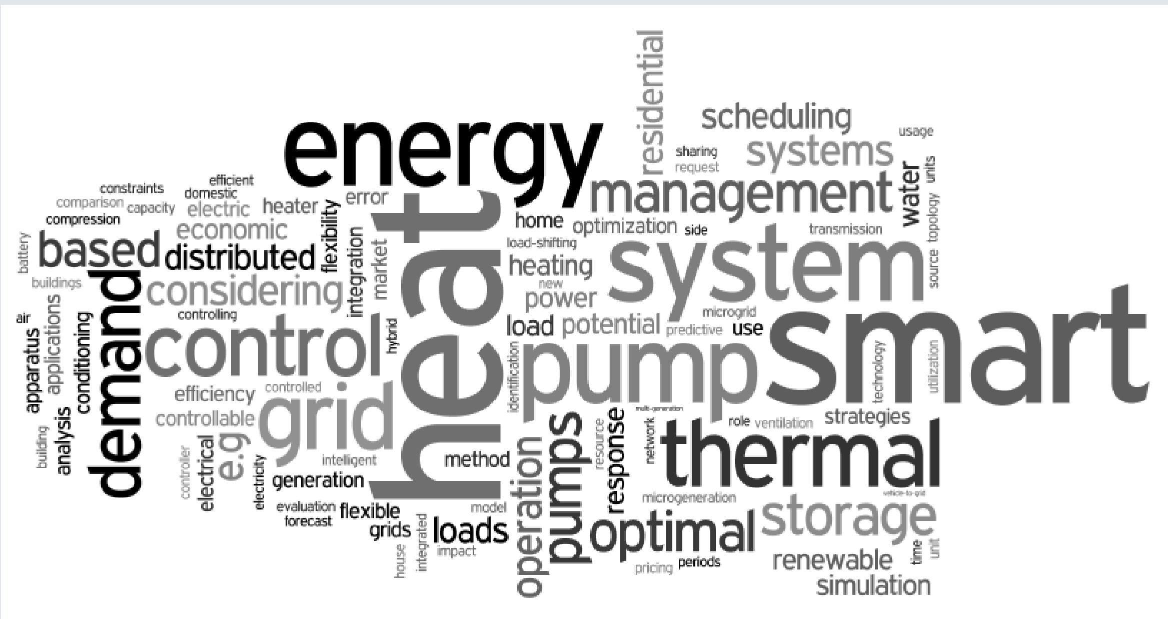

Figure 1. Wordcloud of the 100 most frequent words in paper titles when querying for "heat pump", "smart grid" at Reuters Web of Science.

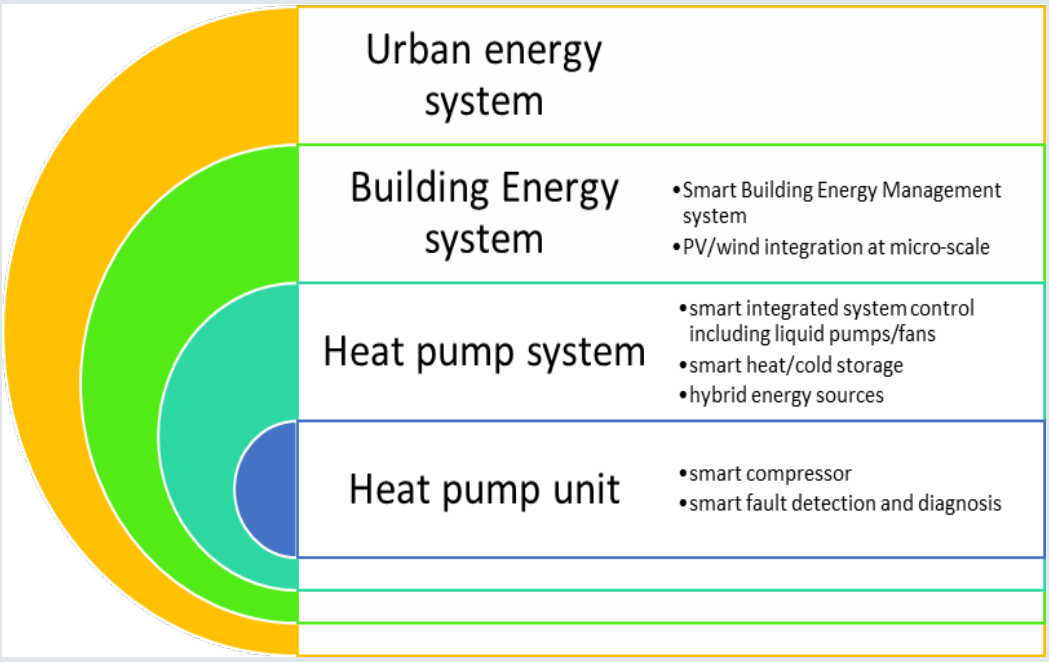

Figure 2. Smart heat pump system viewed from four different levels depending on where the system boundary is drawn.

energy savings and optimised operation of the demand side at the same time. Several important concepts are briefly mentioned in this short article and treated more comprehensively in [1].

Heat pumps' role in the future smart energy systems

Heat pumps link the thermal and the electric sector. In the future these systems will play a pivotal role in the energy infrastructure due to the ability to modify their electric demand for a certain time and thereby providing flexibility to the power system. This will facilitate the integration of distributed renewable power generation as managing electricity demand is a core requirement when dealing with fluctuating electricity generation sources. In order to discuss how to realize the role of heat pumps in a renewable and interconnected energy system we define four different system levels (see Figure 1). Each of them with a different system boundary reaching from the narrow perspective, which deals with the pump unit only, up to a wider system perspective taking the entire urban energy system into account (see Figure 2). We suggest that the different benefits and possibilities by using smart heat pumps are revealed by extending the boundary of the heat pump systems beyond the heat pumping cycle. The heat pump system not only provides a sustainable heating and cooling solution for the buildings but can also act as an enabling technology in future energy systems.

The heat pump unit level – level 1

The most narrow and common system is the heat pump unit itself. It comprises an evaporator, a condenser, an electrically driven compressor, an expansion valve and a working fluid which together, through the thermodynamic process, enable the "pumping" of heat from the low temperature renewable heat source to higher temperature useful for space heating and/or domestic hot water. A smart heat pump at the "heat pump unit level" can for example use a control system to detect and diagnose any fault at the unit level such as a faulty compressor or a frozen evaporator. This type of control is more or less becoming standard. The typical measure of performance is the Coefficient Of Performance (COP) rated at some typical temperature lift and operating conditions.

The heat pump system level – level 2

In order to make sense and bring more possibilities, the boundary level for heat pumps can be extended to include the heat source (outside air, exhaust air, shallow or deep geothermal energy, lake or sea water), the liquid pumps, fans, the heat distribution system, the auxiliary heater, or hot/cold storage. For example, a smart heat pump at the "heat pump system" level can do a lot more than at level 1. It can change the pump or fan speed for the source or sink side to meet the heat demand or minimize pressure drop. Thermal storage can be used to decouple heat generation, and thus electricity demand from the heat demand of the building. The complexity of controls increases significantly due to difference in dynamics (time scales) and information exchange with surrounding systems. This may open up many new possibilities such as using weather forecasts, price signals and so on. The full potential of these are difficult to harvest unless the characteristics of the building are taken into account.

The building system level – level 3

At the building level where the whole building is included within the system boundary, advanced control strategies can be used taking the inhabitants' behaviour, the thermal inertia of the building, or weather forecast into account. The system adjusts the control parameters continuously based on the static or dynamic behaviour of the building and the building inhabitants. A smart heat pump at the building level could monitor and predict the future space heating and domestic hot water demand based on measured data and weather forecast. This information can be used to plan heat pump operation in advance and use the given storage opportunities in the best possible way. It could also communicate with the building inhabitants via smart phones or tablet apps in order to provide the comfort condition in the most cost-effective way. If the building is equipped with solar PV, the heat pumps can help the building optimize the use of the solar PV-system.

The urban energy system level – level 4

An even more inclusive system boundary level, the "urban energy system" level, has a wider perspective on the heat pump and takes the primary energy supplied to the system into account. The smart heat pump at the "urban energy system" level is a part of a smart grid. EU directives, such as the Renewable Energy Sources (RES) directive, promote increasing the share of renewable energy sources in the electricity generation. This can lead to residual loads, caused by large amounts of highly volatile renewable electricity generation such as wind turbines or solar PV cells. Load management with heat pumps can be used to ease grid congestion during peak hours or to align electricity demand of the heat pump with the availability of renewable electricity. Furthermore, time variable electricity prices can be used to incentivise heat pump operation whenever the cost of electricity generation is low. In such a case, locally optimized controls can help reducing the operating cost of heat pump systems.

Heat pumps, if used in a smart way, can provide flexibility to urban energy systems and facilitate the transition towards a future fully operated by renewable energy sources. Electrification of building heating and cooling technologies and a decarbonized electricity sector using technologies such as photovoltaic or wind turbines can be regarded as the most natural path towards the more sustainable future within the 2 K or even the 1,5 K scenarios. Heat pumps can support the future prosumers to consume their on-site generated renewable electricity, store the energy in the form of hot and cold storage, and ultimately use the heating and cooling energy when needed.

The essence of integrated design, dimensioning, and control

To unlock the full potential of heat pumps in the future energy systems, we propose a new concept called Integrated Design, Dimensioning and Control (IDDC) for heat pump systems. Today, heat pump systems including the energy storage mechanisms are designed, sized, and controlled in separate processes. But several of our studies [2-5] show that the system configurations, component sizes and the control strategies are strongly inter-connected and a trivial change in one can considerably affect what should be chosen for the other ones. For example, a control strategy which is appropriate for one system layout can become inappropriate for another layout. Similarly, the system layout and control strategies can strongly influence the optimal size of the system components. Despite the strong inter-connection between design, dimensioning and control processes, there is no coordinated effort between the ones who design and dimension the system and the system operators who control the system.

Consequently, in order to exploit the potential of heat pump in future energy systems, better system management is required integrating the design, dimensioning, and control processes; thus, the system designer is well-informed about the control strategy applied in advance and can optimize design and dimensioning process based on the control strategy and vice versa.

Keep in mind: Heat pumps are not black boxes!

There have been several comprehensive studies on the role of heat pumps in load management and integration of decentralized renewable electricity [6-8]. In addition to these efforts, we should also consider the fact that the heat pump is not a black box whose electricity consumption can be easily ramped up or down based on the grid requirement. The heat pump system efficiency is strongly influenced by the variation of the electricity consumption, caused by variation of compressor speed or switching of the unit. Therefore, a control solution which is cost-effective from the power system perspective may add to the operating cost of the heat pumps, which is paid by the end-user. Conversely, the best control strategy or the customer which yields an optimum seasonal performance factor, SPF, for the end-user may lead to higher costs and higher CO_2 emissions in the electric power system. Consequently, a holistic planning and operation procedure is essential to allow for the most cost-effective control strategy considering the net benefit of the whole system, from both the power system and the end-user perspectives.

Final remarks

Heat pumps can have a unique role in the energy system of the future. The system integration capabilities of heat pumps, bridging the electric power and the heating and cooling sector for enhanced overall energy efficiency, can be used as an asset in the future energy system.

Besides lower carbon emissions compared to boilers fed by fossil fuels, the possibility to decouple heating demand from electricity consumption, and thereby offering flexibility to the power system, can be considered as the key benefit of heat pumps. To integrate heat pump systems into the future energy system in the best possible way, controls, sizing, and system layout need to be adjusted. To achieve the maximum benefit for the whole system, the concept of Integrated Design, Dimensioning, and Control (IDDC) is suggested by the authors and seen as a part of a holistic approach towards the future energy system.

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Ventilated Enclosures for Flammable Refrigerants

Asbjørn Vonsild - Denmark

If your heat pump application needs almost 5 kg of R-290 or 40 kg of R-32 to be placed indoors, then the safety standards offer the option of placing the system in an enclosure, and ventilating it to the outdoors.
In this article we will look at the requirements for a ventilated enclosure and what variations of this concept that may be relevant for the heat pump industry.

Introduction

In previous papers in the HPC Newsletter, the author has given an overview of the trends, legislation and standards for flammable refrigerants [1] and an overview of charge limits for heat pumps with flammable refrigerants [2]. However, the concept of "Mechanical Ventilation Within the Appliance Enclosure" or simply "Ventilated Enclosure" was not covered, as it is a complex topic and so important that it needs its own paper.

The first part of this paper is a brief introduction to the standards governing the domestic and light industrial heat pumps, with focus on the EU. This is followed by a description of the formal requirements for mechanical ventilation within the appliance enclosure, valid also for areas outside of the EU. The paper ends with a description of how the risk assessment approach can be used to modify the requirements from the system standards for a ventilated enclosure while still ensuring that the resulting system is safe.

Standards for heat pumps

The international application standard for domestic and light industrial heat pumps is IEC 60335-2-40 edition 5.1 from 2016 (this is the version from 2013 plus an amendment). In Europe, an older version of this standard is used with small modifications as EN 60335-2-40, and is harmonised to both the EU Machinery Directive and the EU Low Voltage Directive. Unfortunately, at the time of writing, the EN version is still based on the IEC 60335-2-40 edition 4 from 2002; although the EN version has been amended multiple times it is outdated in several aspects. Work is ongoing to create a new EN version, but has been delayed for several reasons. Still this author hopes that 2017 will be the year that a new EN 60335-2-40 will be published.

ISO 5149 is another international standard, which in principle covers all systems, including heat pumps. However, it is preferred to use the application-specific standard EN or IEC 60335-2-40. Still, it is worthwhile

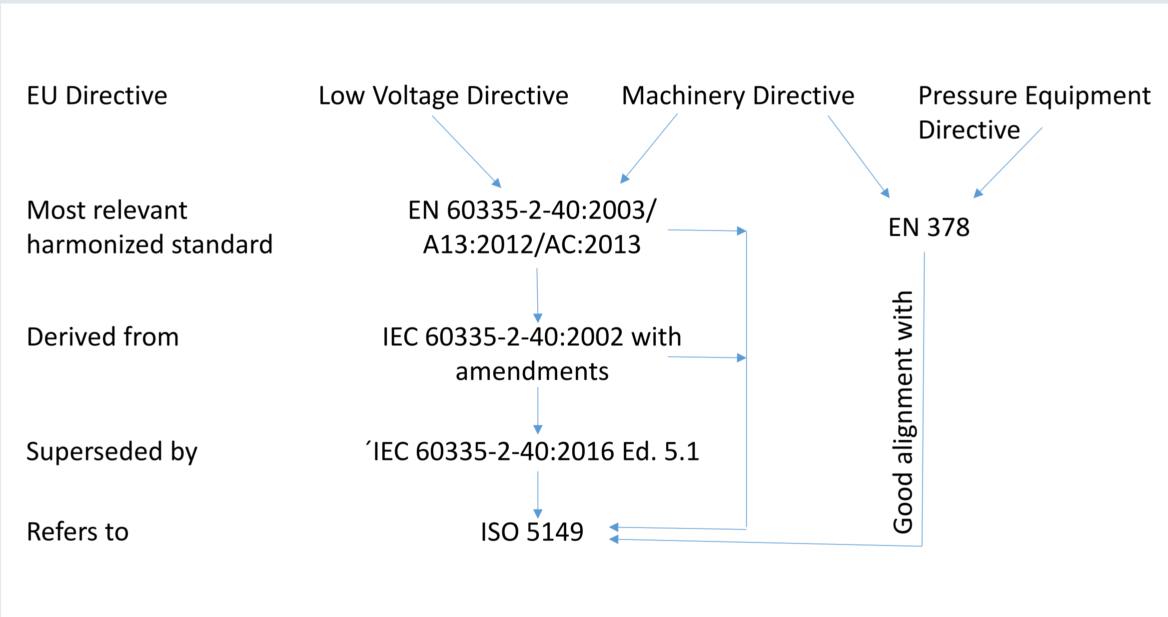

Figure 1. Relation between the standards and EU legislation.

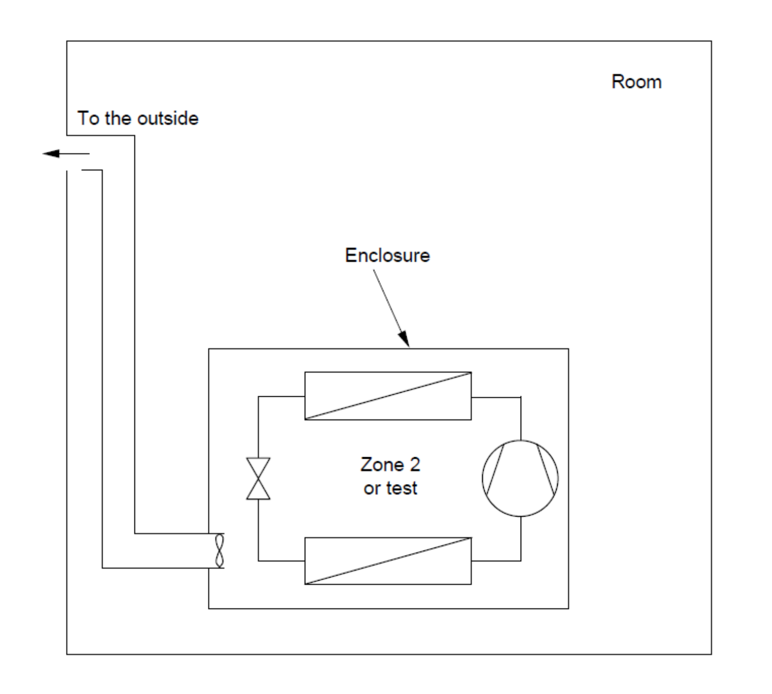

Figure 2. Illustration of ventilated enclosure from IEC 60335 2 40.

to consider ISO 5149, and in some cases it is even required by EN or IEC 60335-2-40. EN 60335-2-40 requires safety requirements of ISO 5149 to be followed as part of the clause on mechanical strength. The newer IEC 60335-2-40 is a bit more specific, as it only requires ISO 5149 to be followed for construction strength and for aspects not already covered by the IEC standard.

In the EU, there is also the EN 378 which covers all systems, such as the ISO 5149. EN 378-2 is harmonized to the EU Pressure Equipment Directive and for flammable refrigerants. Systems with pipes greater than DN25 or vessels with volume times maximum allowable pressure greater than 50 bar·l typically need to comply with the Pressure Equipment Directive. The easiest way to comply with the Pressure Equipment Directive is typically to follow EN 378-2.

The conclusion is that the primary standard to consider is EN or IEC 60335-2-40, but both EN 378 and ISO 5149 may be relevant. Luckily, the requirements of the three standards are quite similar, and especially the EN 378 and ISO 5149 are well aligned.

Mechanical ventilation within the appliance enclosure

EN and IEC 60335-2-40 use the term "mechanical ventilation within the appliance enclosure" to cover a box surrounding the refrigerating system which is ventilated through a ventilation duct to the outside and prevents air from moving from the refrigerating system to the room outside the box. EN 378 and ISO 5149 do not use this term, but simply call it a "ventilated enclosure".

The reason for using this ventilated enclosure is that leaking refrigerant is much less dangerous if it is ventilated to the outside, and the system builder is rewarded by being allowed 5 times larger flammable refrigerant charges than would normally be allowed indoors in very large rooms. This is enough to cover most heat-pump applications.

The charges allowed is one of the issues where EN 60335-2-40 does not agree with IEC 60335-2-40. The charges depend on the LFL, the Lower Flammability Limit of the refrigerant, which is the lowest concentration of refrigerant in air which can be ignited. Below the LFL, the air/refrigerant mixture is too thin to be flammable. The allowed charges also depend on the flammability class, which is either 3 for higher flammability, 2 for flammability or 2L for lower flammability. These flammability classes are normally written together with the toxicity class, and in this article we will only consider toxicity class A, lower toxicity. The safety classes are therefore A3 (for instance R-290), A2 (for instance R-152a), or A2L (for instance R-32 and R-1234ze).

EN 60335-2-40 allows charges up to 130 m^3 × LFL for A3, A2 and A2L refrigerants. IEC 60335-2-40 along with ISO 5149 and EN 378 also allows charges up to 130 m^3 × LFL for A3 and A2, but up to 195 m^3 × LFL for A2L refrigerants.

For A3 refrigerants (such as hydrocarbons) the charge is typically just below 5 kg (e.g., for R-290 the LFL is 0.038 kg/m^3 and 130 m^3 × 0.038 kg/m^3 is 4.94 kg). For A2L refrigerants (like R-32 and R-1234ze(E)) the charge according to EN 60335-2-40 is typically just below 40 kg, but according to IEC 60335-2-40, ISO 5149 and EN 378 it is typically just below 60 kg.

To allow larger charges, there needs to be a ventilation duct leading to the open air. For some heat pumps, such as typical sanitary hot water heaters or heat pumps reclaiming waste heat, this is not an issue, while for other heat pumps this adds an extra complication to the installation of the heat pump. ISO 5149 also allows the ventilation to go to a sufficiently large room, although for most applications this option is not of interest.

To ensure that the refrigerant does not leak out of the enclosure, the ventilation needs to create a pressure at least 20 Pa below atmospheric pressure and the ventilation rate needs to be high enough to remove the total refrigerant charge within 1 minute, and not less than 2 m^3/h. For 0.988 kg R-290 (density 1.80 kg/m^3) this is 33 m^3/h, while for 5 kg R-32 (density 2,13 kg/m^3) it is 131 m^3/h and for a R-1234ze(E) (density 4.66 kg/m^3) chiller with a charge of 50 kg it is 645 m^3/h.

The ventilation has to either run continuously or be started by a signal from a gas detector. The ventilation needs to be monitored, and if the ventilation fails, then the compressor needs to be switched off. If the ventilation is controlled by a gas detector, any failure needs to result in the system going into a safe-mode. The safe mode is not described in detail in the standards, and is left for the system builder to define.

From a practical point of view, today's energy efficiency requirements make continuous ventilation difficult. Even for sanitary hot water heaters and heat pumps with heat reclaim, where ventilation air is fed through the heat pump, it can be difficult to maintain ventilation when heating is not needed. This leads to either choosing the gas detector option, or to consider alternatives with a risk assessment. More on this later.

Both EN 378 and ISO 5149 require the room where the appliance is installed to be at least 10 times the volume of the appliance and with sufficient make-up air to replace any air exhausted. This is, however, not a requirement in the application standards EN and IEC 60335-2-40, but the need to replace any air exhausted is fundamental if air is taken from the room where the appliance is installed. A practical solution to this is often to have two ventilation ducts, one letting air from the outside into the appliance, and another one for the exhaust air. In this case, the risk of air re-entering from the air exhaust to the air intake needs to be considered.

Ignition sources are not allowed where leaked refrigerant could be ignited. This means that there should not be any ignition sources inside the enclosure or in the ventilation duct. Avoiding ignition sources can be achieved by selecting ATEX or IECEx components. There are other alternatives in EN and IEC 60335-2-40 clause 22.116 which may be cheaper when mass-producing components or systems.

Variation with risk assessment

Often it is easy for systems to match most of the requirements of standards, but on a few points the requirements can be impractical or do not fit with the conditions of the specific application. In these cases it is usually permissible to apply a risk assessment to cover these last requirements.

In the EU system, the logic is that the safety directives such as the Low Voltage Directive, Machinery Directive, and Pressure Equipment Directive give a list of "essential requirements", where the manufacturer has to comply with those which are applicable for the product. As shown in Figure 3, there are two pathways to complying with the applicable essential requirements. The most commonly used is to comply with a harmonized standard, but it is also allowed to use any other specification, for instance the manufacturer's own specification. When using another specification, the manufacturer cannot presume conformity with the essential requirements; instead the manufacturer has to show, through a risk assessment, that the specification covers the essential requirements.

The essential requirements of the directives are sometimes written very broadly, and it is difficult to prove that the specification used actually covers a specific essential requirement. For instance, the Low Voltage Directive requires "that persons and domestic animals are adequately protected against the danger of physical injury or other harm which might be caused by direct or indirect contact", which is not an easy thing to prove. In these cases the preferred approach to using an "other specification" is to follow a harmonized standard except for the few details which are impractical or do not fit. For these few details a thorough risk assessment is created to ensure that the solution actually used is safe.

For ventilated enclosures, the risk assessment approach can for instance be used if the required ventilation rate or the required sub-atmospheric pressure cannot be achieved without too large an impact on the energy efficiency or cost of the system.

When choosing a risk assessment to replace a requirement in a standard, the first step is to identify the purpose of the requirement. In the case of ventilation rate and negative pressure the purpose has to be to keep any leaking refrigerant from getting into the room surrounding the enclosure to create a sufficient concentration to be ignited. See Figure 3.

A manufacturer is free to choose a way of making the system safe with less ventilation, and the below should be seen as an inspiration list rather than a limited set of choices.

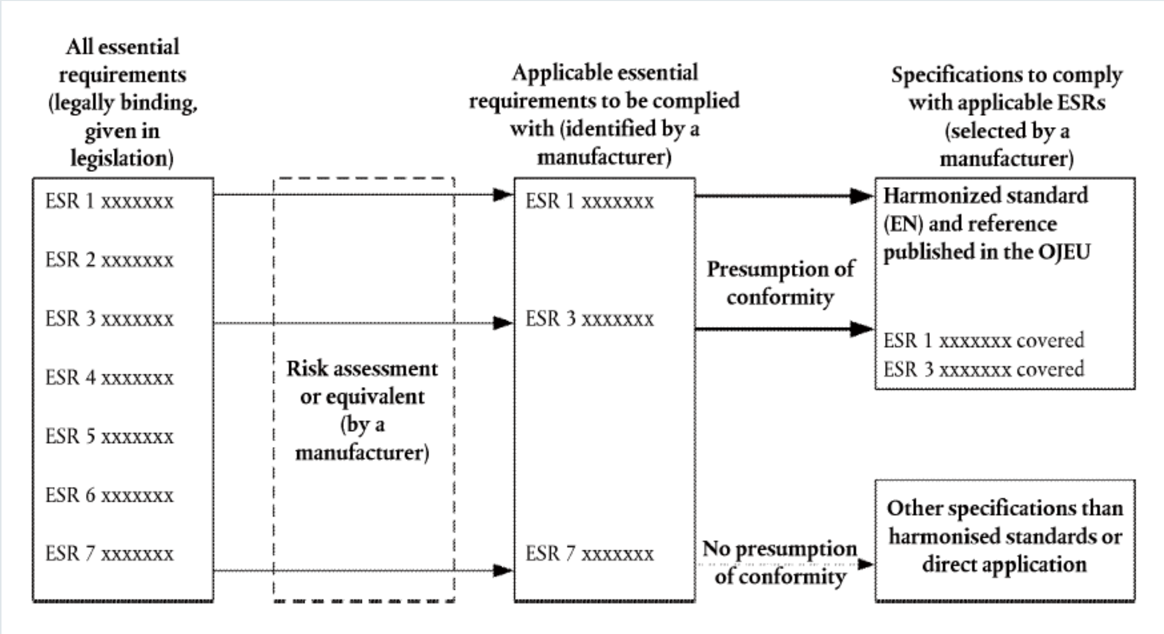

Figure 3. Product safety requirements from EU Blue Guide.

An option would be to simulate the airflow inside the enclosure with Computational Fluid Dynamics (CFD) to prove that the lower ventilation rate will keep a refrigerant leak inside the enclosure. The simulation can also be replaced with tests where refrigerant or a gas with similar density is leaked inside the enclosure (R-290 and CO_2 happen to have the same density).

For these simulations or tests it is necessary to use a relevant leak rate. The leak rate used for small systems in the safety standards are the full charge leaking in 4 minutes. For most systems this leak rate is too high, but rather too high than too low. If the "4 minute leak rate" is too high, then tests on the system can be used to determine what a realistic worst case is.

Another option would be to make the enclosure very tight, and have make-up air coming through a ventilation duct. The risk of refrigerant leaking to the room is handled by the tightness of the enclosure, so the purpose of the ventilation is only to ensure that the leaked refrigerant does not create a permanent flammable atmosphere inside the enclosure. The ventilation rate can be very low, and the ventilation "ducts" could have a very small diameter. In this case the enclosure would need to be tested for tightness at a small pressure differential to the surroundings.

Other options which may be considered are the ability to replace the gas detector with an algorithm monitoring the pressures and temperatures in the system and detecting leakage that way, or showing that the amount of refrigerant leaking from the enclosure is too small to present a hazard, or feel free to come up with your own ideas.

What is important is that a thorough risk assessment is carried out. The details of doing risk assessments are outside the scope of this article, but the reader needs to keep in mind that a risk assessment is a team effort, where risks are identified, categorised and addressed. The process is normally facilitated by tools and involves considering the whole lifecycle of the system. The difficult point in risk assessments is typically to determine when a risk is sufficiently small to be ignored. A good rule of thumb is that two or more unlikely events at the same time can be ignored, but not without first considering whether they really are that unlikely.

Conclusions

The concept of mechanical ventilation within the appliance enclosure, or simply ventilated enclosure, is important for heat pumps as it allows up to 5 kg hydrocarbon refrigerant or 40 kg or more of A2L refrigerant.

According to the safety standards, the ventilation rate needs to be high enough to create a pressure at least 20 Pa below atmospheric pressure and high enough to remove the complete refrigerant charge in 1 minute. The ventilation can either be continuous and monitored, or it can be triggered by a gas detector.

If specific requirements are either impractical or do not fit the application, then it is possible to replace them with a risk assessment of the actual specifications used. This allows the use of lower ventilation rates with sufficient evaluation of safety.

Acknowledgements

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Events 2017

23-26 April
5th IIR International Conference on Thermophysical Properties and Transfer Processes of Refrigerant
Seoul, South Korea
http://tptpr2017.org/

10-11 May
Beyond nZEB Buildings
Matera, Italy
http://www.aicarr.org/Pages/EN/Upcoming%20Events/2016/50AiCARR.aspx

11-12 May
Decarb Heat 2017
Brussels, Belgium
http://decarbheat.eu/

11-13 May
7th Conference on Ammonia and CO_2 Refrigeration Technologies
Ohrid, Macedonia
http://www.mf.edu.mk/web_ohrid2017/ohrid-2017.html

12-13 May
Climamed 2017 - Historical Buildings Retrofit in the Mediterranean Area
Matera, Italy
http://www.climamed17.eu/

15-18 May
12th IEA Heat Pump Conference
Rotterdam, the Netherlands
http://hpc2017.org/

15-19 May
14th Cryogenics 2017 IIR International Conference
Dresden, Germany
http://www.cryogenics2017.eu/

19-20 May
HPT TCP: ExCo meeting
(open/closed)
Rotterdam, the Netherlands

5-7 June
ATMOsphere America 2017
San Diego, California, USA
http://www.atmo.org/events.details.php?eventid=53

20-22 June
EU Sustainable Energy Week - Conference
Brussels, Belgium
http://www.eusew.eu/about-conference

24-28 June
ASHRAE Annual Conference
Long Beach, California, USA
https://www.ashrae.org/membership--conferences/conferences/2017-ashrae-annual-conference

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

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

7-10 August
International Sorption Heat Pump Conference (ISHPC 2017)
Tokyo, Japan
http://biz.knt.co.jp/tour/2017/ISHPC2017/congress.html

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

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

26 October
National Experts Meeting of the HPT TCP
Nuremberg, Germany

Events 2018

20-24 January
ASHRAE Winter Conference
Chicago, Illinois, USA
https://ashraem.confex.com/ashraem/w18/cfp.cgi

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

6-8 April
5th IIR Conference on Sustainability and the Cold Chain
Beijing, China
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