Heat Pumping Technologies MAGAZINE

A HEAT PUMP CENTRE PRODUCT

Flexible, sustainable and clean system solutions

LARS REINHOLDT & SVEND PEDERSEN, Denmark

”MORE EFFICIENT SYSTEMS AND SOLUTIONS ARE NEEDED”

VOL.36 NO 1/2018

ISSN 2002-018X

Heat Pumping Technologies
MAGAZINE

VOL.36 NO.1/2018

In this issue

Flexible, sustainable and clean. That is the necessary future for the energy systems world-wide. The focus of this issue of HPT magazine is how heat-pumping technologies can contribute to that development. The contribution comes in two forms: heating energy can shift from fossil fuels to renewable electricity, and at the same time reduce the need for bought energy. But for this to happen at a larger scale, heat pump components and systems must be developed and deployed. Another aspect is that heat pumps may be part of a larger system, be it a building, city or even a region of a country.

The area is outlined in the Foreword, with more in-depth insights presented in two Topical articles where one discusses urban energy savings in a district heating and cooling network, and the other pooling of heat pumps to reduce electricity use. A Non-topical article written by the International Renewable Energy Agency (IRENA) gives us a super-overview of the future role of heat pumps in the energy system. Inspiration can be taken from the Column, describing the success story of heat pumps in Finland. News in Focus describes some unintentional negative consequences of the EU F-gas directive.

Enjoy your reading!

Johan Berg, Editor

Heat Pump Centre

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

Topical Articles

Non-topical article

Published by Heat Pump Centre
c/o RISE - Research Institutes of Sweden,
Box 857, SE-501 15 Borås, Sweden
Phone: +46 10 516 55 12

Publisher:
Heat Pump Centre
PO Box 857, S-501 15 BORÅS
SWEDEN
Tel: +46-10-516 55 12
hpc@heatpumpcentre.org

www.heatpumpingtechnologies.org

Editor in chief: Monica Axell
Technical editors: Tommy Walfridson, Caroline Haglund Stignor, Johan Berg, Louise Quistgaard, Kerstin Rubenson

Front page: Model of Smart City in Smart Grid Information Centre, Jeju Island, South Korea. Photo: HPC

ISSN 2002-018X

FOREWORD

Flexible, sustainable, and clean system solutions - building heating in the future

Energy is the dominant contributor to climate change and accounts for nearly 60 % of global greenhouse gas emissions. The global emissions of CO_2 have increased by almost 50 % since 1990. Studies show that heat savings can cost-effectively reduce the total heat demand in Europe by 30-50 % if waste heat is used. Today, 30 % of the Danish total energy consumption is used for heating of buildings, and although future buildings will be Zero Energy Buildings, the replacement of old buildings in Denmark is only 1 % per year. Thus, as the share of energy for heating will be just as high in the future, more efficient systems and solutions are needed.

District heating systems are one way to obtain a more efficient energy supply - through more efficient central heating plants and the possibility of utilizing surplus (or waste) heat from industrial sites. The district heating network transports energy to (heating) and from (cooling) the consumers. Today, this is mostly based on hot water (and steam) in some systems, but new interesting concepts using CO_2 are being investigated.

Both central and decentralized heat pumps are central technologies in the transformation to the future energy system based on electric renewable power. Heat pumping is a very efficient way to level the different required temperature levels in these efficient systems – to consumers and from possible suppliers of waste heat. Heat sources for central large heat pumps are necessary in order to reach high COPs. Sea water heat pumps based on vacuum ice, as well as MW-scale air to water heat pumps, are planned to be implemented in Denmark.

Heat pump technologies are also a way to reach the goals of creating affordable, reliable, sustainable, and modern energy for all as stated in the Sustainable Development Goals from the United Nations. Today, one out of five people does not have access to electricity, and three billion people rely on wood, coal, charcoal, or animal waste for cooking and heating. Combinations of heat pump technologies with energy storage, solar, and wind energy are possible solutions to fulfil these goals. For remote areas with little access to central generation stations or costly connection to the grid, systems with solar geothermal heat pump systems could be a solution.

Most countries focus on the electrification of the energy system and the phase-out of fossil fuels to decarbonise the energy system. As the production cost per kWh electricity has reduced to a level competitive with fossil fuels, most countries are investing in both photovoltaic panels and wind power to stabilise, optimise, and increase the renewable electricity production. Many solutions are available, but there are also (regulation) barriers, and the incentive or economical gain is currently very low for the consumer with around 18-73 Euro per heat pump annually. Thus, the demand side needs to be more flexible. Heat pumps, large scale and low-consumption, clustered in pools, can act as balancing units in the grid. Heat pumps are already starting to play a major role in the transformation of the energy system but work still needs to be done in the field of choosing the best mode of integration of heat pumps into thermal heating/cooling systems and the electrical grid, including energy storage.

Lars Reinholdt & Svend Pedersen
Danish Technological Institute,
Refrigeration and Heat Pump Technology
Denmark

Energy cost savings and new business models promote heat pump investments in Finland

During 2017, Finnish house owners' investments in the more than 60 000 installed heat pumps were as much as half a billion euros. More than 800 000 heat pumps have been installed over the years. They produce 6 TWh/a of renewable energy. It is noteworthy that this huge investment in the environment and in climate-change prevention is made mainly by home owners using their own money.

More than 70 % of new builders of single-family houses decide to choose a heat-pump solution. They mainly choose geothermal heat or an exhaust-air heat pump. Approximately 5 000 oil-fired boilers are replaced by geothermal heat, but oil exhausts are still billowing out of chimneys from 200 000 houses. Air-source heat pumps most often replace oil-fired and electric-boiler systems, or they operate alongside them.

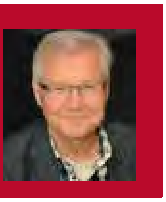
The number of exhaust-air heat pumps in apartment buildings is increasing rapidly. They can reduce up to 50 % of the consumption of district heat of an apartment building. The potential of these solutions is considerable: 5 TWh/a available as exhaust air. Increasingly, many apartment buildings have decided once and for all to replace district heating with a heat pump-based solution.

During 2017, new business models also took their first steps in the heat pump industry. The heat-pump heat-sales model means that the actual service-provider company is the one that makes the heat pump investment and delivers the thermal energy, as well as cooling when desired, to the customer. The customer is invoiced for the energy in the same way as for electricity or district heating. This service model became more common, not only in service-buildings and industrial sites, but also in apartment buildings, using exhaust air and geothermal heat. This is a simple and rewarding choice for apartment buildings. It requires no investments, it merely means making a deal, sitting back and enjoying lower energy costs.

According to the most recent studies, heat pumps reduce the overall need for electric energy and electric power, when replacing electric heating. Heat pumps are installed in houses that are heated by electricity, oil and district heating. Every time an electricity-heated house has a full-power heat pump installed, two oil-heated or district-heated houses can be heated with the power and energy that have been saved if these houses also are converted to full-power heat pumps. There are about 700 000 electricity-heated houses in Finland.

Even more important is that heat pumps provide an excellent means for electricity-grid power-demand management. A heat pump is a unique bridge technology between heat and electricity. It can use water volumes, buildings, geothermal wells as well as bidirectional cooling/heating features, such as energy storage. Already now, heat-pump thermal power, when linked to demand-side management, can provide approximately 4 000 MW. Controllable electric power provides approximately one third of the thermal power, according to the operational principles of heat pumps. The remaining two thirds is the cost-free energy and power that this brilliant apparatus recovers.

JUSSI HIRVONEN
Executive Director
The Finnish Heat Pump Association SULPU ry
jussi.hirvonen@sulpu.fi



Heat Pumps – Mission for the Green World. Welcome to the Heat Pump Conference in Jeju 2020

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

Previous Conferences

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

Conference Venue

The conference venue is Ramada Plaza Hotel Jeju, located in Jeju city. Easily accessible from Jeju airport, it is a perfect accommodation for nearly 600 participants and those accompanying them. Jeju Island is a famous holiday destination in Southeast Asia, with its beautiful beaches, volcanic mountains, and extraordinary cuisine. Home to the natural World Heritage Site Jeju Volcanic Island and Lava Tubes, participants and those accompanying will certainly enjoy visiting the beautiful island. In addition to sightseeing opportunities, technical tours such as trips to the Jeju Smart Grid Center of Korea Institute of Energy Research (KIER) are planned.

Conference Goal

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

Conference Topics

Within the conference program, participants will discover a series of leading-edge information on the following issues:

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

Conference Structure

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

Statue of Haeneyo (UNESCO Intangible cultural heritage)

Call for Paper

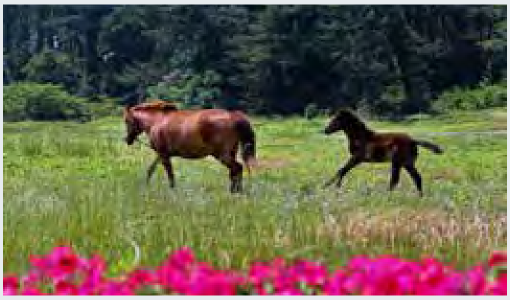
Abstract submission will open 2019. The abstracts will be screened by an appropriate Regional Coordinator and authors will be advised of acceptance. Full papers will be required by January 2020. The detailed schedule will be updated in the first announcement.

Organizations

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

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

For further information, please refer to the Conference website (to be opened when the 1st announcement of the 13th IEA Heat Pump Conference is published).



A Jeju native horse and foal

Cheonjiyeon Waterfall

Welcome to Nordic Clean Energy Week – where the clean energy revolution is accelerated

During five inspiring days in May the energy world will gather in Copenhagen and Malmö. The Nordic Clean Energy Week is co-hosted by Denmark and Sweden and offers a variety of energy-related events, starting the 21st of May. The corner stones of the Week are the ministerial meetings with participants from around the globe, aiming at accelerating the green transition. The 3rd Mission Innovation Ministerial will be held on the 23rd of May and the 9th Clean Energy Ministerial on the 24th of May.

Among the many activities and events, extra interest should be given to Arena: Sustainable Heating and Cooling, held in Malmö on May 22. The Arena offers a setting where the future possibilities for decarbonised heating and cooling are outlined and discussed. The most forward-looking agents in the Swedish energy business will contribute to this conference co-organised by the Swedish HPT ExCo delegates.

US claims magnetic refrigeration advance

Researchers in the US claim to have made a breakthrough in achieving refrigeration-level cooling by using very small quantities of magnetocaloric materials.

Staff at the US Department of Energy's Ames Laboratory claim that the development marks an important step in creating new technologies to replace gas compression refrigeration with solid-state systems up to 30 % more energy efficient. Called CaloriSmart – Small Modular Advanced Research-scale Test-station – the system was designed specifically for the rapid evaluation of materials in regenerators without a large investment in time or manufacturing.

The initial test subjected a sample of gadolinium to sequential magnetic fields, causing the sample to alternate between heating up and cooling down. Using precisely timed pumps to circulate water during those heating and cooling cycles, the system demonstrated sustained cooling power of about 10 W, with a 15 °C gradient between the hot and cold ends using only about 3 cm^3 of gadolinium.

"Despite predictions we would fail because of anticipated inefficiencies and losses, we always believed it would work," said CaloriCool project director and Ames Laboratory scientist Vitalij Pecharsky, "but we were pleasantly surprised by just how well it worked. It's a remarkable system and it performs exceptionally well. Magnetic refrigeration near room temperature has been broadly researched for 20 years, but this is one of the best systems that has been developed," he claims.

The system, which took roughly five months to build, used 3D printing technology to custom-build the manifold that holds the sample and circulates the fluid that actually harnesses the system's cooling power. The system also features customised neodymium-iron-boron magnets that deliver a concentrated 1.4 Tesla magnetic field to the sample, and the precision in-line pumping system that circulates the fluid.

"We only need 2-5 cm^3 of sample material – in most cases about 15-25 g," explained project scientist Julie Slaughter. "We are setting the benchmark with gadolinium and we know there are other materials that will perform even better. And our system should be scalable (for commercial cooling) in the future." "But the main reason we conceived and built CaloriSmart is to accelerate design and development of caloric materials so they can be moved into the manufacturing space at least two to three times faster compared to the 20 or so years it typically takes today," added Pecharsky.

The team maintain that magnetocaloric testing is just the beginning. The plan is to upgrade the system to work with elastocaloric materials – that reversibly heat up and cool down when subjected to cyclic tension or compression – and electrocaloric materials – that do the same when subjected to changing electric field. It is said that the system will even operate in a combined-field mode that allows a combination of techniques to be used simultaneously.

"There are a handful of places studying elastocaloric and electrocaloric materials, but nobody has all three in one place and our system now gives us that capability", Percharsky claims.

Source:
https://www.coolingpost.com/world-news/us-claims-magnetic-refrigeration-advance/

Source: https://www.coolingpost.com/world-news/us-claims-magnetic-refrigeration-advance/

Source: https://www.coolingpost.com/world-news/california-approves-original-snap-rules/

California approves original SNAP rules

The California Air Resources Board (CARB) has adopted the EPA's proposed SNAP rules to reduce emissions of HFC refrigerants despite the US Court of Appeal declaring them illegal.

Last year, the US Court of Appeals for the District of Columbia' decided that the EPA could not use a section of the Clean Air Act to target HFCs. Under the EPA rules, high GWP refrigerants (including R404A, R134a, R407C and R410A) were to be removed from the EPA's SNAP list for use in certain new products.

"The Board's action today preserves the federal limits on the use of these powerful chemicals and refrigerants, and provides more certainty to industry," board chair Mary D Nichols said. "We applaud the actions of many industries, which already have made significant investments in developing and using more climate-friendly alternatives to the high-global warming HFCs."

California says it has taken the action to meet state and federally mandated emissions reduction goals. Under a Senate Bill authored by Senator Ricardo Lara in 2016, California must reduce HFC emissions by 40 % below 2013 levels by 2030. CARB maintains it was relying substantially on the US EPA's SNAP rules to help meet California's emission reduction goals for HFCs. As a result of the recent court decision, California has had to pass its own regulation to ensure it could meet those goals.

Source:
https://www.coolingpost.com/world-news/california-approves-original-snap-rules/

Unforeseen consequence of the EU F-gas regulation: decreased reduction of green-house gas emissions

The F gas regulation entered into force in EU in 2015. It states, inter alia, that the use of hydrofluorocarbons (HFCs) should be phased down to a level of 21 % relative to the average consumption in GWP equivalents during the reference years 2009-2012.

In general, the heat pump industry and organisations have been positive to the principles of this phase down, and have supported it, well aware that it may lead to a shortage of HFCs and accompanying price increases. However, recent developments indicate that the F gas regulation may actually make it harder to reach the EU climate goals.

Heat pumps provide a very effective means to heat buildings and produce hot water and are also a cornerstone to the future energy system, based on fossil-free and renewable energy. For instance, the International Energy Agency (IEA) states in its report “Energy Technology Perspectives 2017” that in order to stop global warming at less than 2 °C, 50 % of heating needs to be by heat pumps.

The slow-down in heat pump market development, caused by the phase down of HFCs within the F gas regulation, will cause a delay in the transition to fossil-free heating, which favours the fossil alternatives, in most cases. During the life cycle of the equipment, this will lead to a doubling of emissions, compared to a heat pump-based alternative. This is in complete contrast to the underlying intention of the F gas regulation.

The heat pump industry has sought for alternatives to F gases, initiated even before the regulation came into force. Several interesting alternatives have been found. However, there are certain challenges and barriers specific to the heat pump industry:

- most of the low GWP alternatives are flammable, to a lower or higher extent. This causes problems in most EU countries, since neither building regulations nor branch standards have been updated or adapted;

- the market price of F gases has increased tremendously during the last year, in some cases by nearly 1000 %. Still, most actors in the heat pump area, be it manufacturers, wholesalers, or installers, have a hard time to find sufficient amounts of refrigerants to secure deliveries of equipment and operation of installations;

- the use of low GWP refrigerants requires a nearly completely new construction of the equipment. This needs to take into account technical and safety challenges, as well as the requirements for energy efficiency and reliability;

- some necessary components, such as compressors and heat exchangers, have so far been developed for the applications of industrial cooling and air conditioning. The smaller segment heat pumps has, until recently, not been prioritized. The consequence is a lack of key components, both regarding numbers and capacity.

Source: https://www.coolingpost.com

Another consequence of the F gas regulation (due to price increases) is that illegal refrigerant import and sales have occurred, to a level previously un-heard of. Further, retrofits of AC equipment with mildly flammable gases (R32) have also occurred. This may lead to impaired performance, with a risk of significant breakdown, personal danger for the person conducting the retrofit and for subsequent service personnel, in addition to possible fines and jail sentences. This is over and above any other possible penalties in the event of an accident.

This is not the first time that the heat pump industry experiences a refrigerant shift. Many within the area remember when the CFC refrigerants, with a high Ozone Depleting Potential, were to be replaced by HFC refrigerants. Like the situation now, the heat pump industry had to stand back while solutions were developed for the larger market applications industrial cooling and air conditioning. It took a long time until components specifically developed for the heat pumps began to enter the market. The possibilities for R&D, and especially long-time tests of products, was then very limited. This resulted in a catastrophe for the heat pump industry, with a large number of disruptions and breakdowns, inferior performance, and significant concern for both industry and end consumers.

In view of the above, a number of actors in the heat pump industry are reacting. As an example, the Swedish Refrigeration and Heat Pump Association has requested an exemption to give the industry access to refrigerants outside the quota system of the F gas regulation.

Sources:

Letter from SKVP to SNV (in Swedish)
Text from Kyla&Värme (in Swedish)
Cooling post
Illegal imports:
https://www.coolingpost.com/uk-news/uk-hub-illegal-refrigerant-sales/
https://www.coolingpost.com/world-news/phase-sparks-rise-illegal-sales/
Retrofit with R32:
https://www.coolingpost.com/world-news/italians-face-jail-r32-retrofits/

Ongoing Annexes in HPT TCP

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

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

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 47

HEAT PUMPS IN DISTRICT HEATING AND COOLING SYSTEMS

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.

Heat pumps is a technology which is expanding in district heating systems, as more district heating systems are making use of 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, the so-called 4th generation district heating, is being implemented at the moment, and heat pumps then will be necessary for the production of Domestic Hot Water.

The objective 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. This info will be disseminated to policy makers, decision makers and planners of energy systems in urban areas.

Task 1 (finalized) has shown that there is a large potential for implementation of Heat Pumps in District Heating Systems. Heat savings can cost effectively reduce the total heat demand in Europe by approximately 30-50 %. District heating can capture excess heat, which is currently wasted, and replace natural gas for heating in EU cities. It should increase from today's level of 10 % up to 50 % in 2050. Heat pumps play a major role in the conversion of excess heat to district heating.

Figure 1. Case studies from task 2

In task 2, existing District Heating and Cooling (DHC) systems, and demonstration projects where heat pumps are used for heating or cooling in DHC systems, are described on a country basis. The task describes and presents an idea and inspiration catalogue, with more than 29 different cases. The intention is that the catalogue should be used for planners and project developers for new projects.

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

Contact
Svend Pedersen, Danish Technological Institute,
Denmark, svp@dti.dk

Figure 2. A DHC network in Finland, unsing heat pumps. [Source: calefa.fi]

ANNEX 49

DESIGN AND INTEGRATION OF HEAT PUMPS IN NZEB

Nearly Zero Energy Buildings (nZEB) are high on the agenda of many countries, especially in Europe, where the Energy Performance of Buildings Directive (EPBD) requires the EU member states to introduce nZEB for all new public buildings by the end of this year, or precisely by January 1, 2019. Only two years later, by January 1, 2021, all new buildings are required to fulfill this requirement. Despite this tight time schedule, definitions in EU member states vary both in criteria, metrics and limits.

Based on this situation, favourable system technologies to reach nZEB targets are of high interest. Results of the preceding Annex 40 have already confirmed that heat pumps are a particularly well-suited system technology for the application in nZEB due to their high performance that perfectly matches with the lower required supply temperatures in nZEB, due to high-performance building envelopes. Furthermore, the heat pump can provide various required building services, space heating, DHW and space cooling with one generator.

The objective of Annex 49 is to provide a more in-depth analysis of how heat pumps can contribute to reach nZEB targets. The focus is laid on integration options with other building technology, and design of components, since active components like solar thermal, and in particular PV or PV/T systems, are integrated in the envelope of nZEB in order to meet the balance. These components may also yield source energy for the heat pump. Moreover, both thermal storage, in terms of water storage or the ground, and electrical battery storage are candidates to improve the self-consumption of on-site renewable energy production, which may positively affect the economy and energy flexibility of the system, but also may cause losses and higher investment cost.

Thus, the Annex 49 has been structured into the following tasks:

- In Task 1, the state-of-the-art of nZEB in the participating countries has been updated and technology options for the heat pump application under current market conditions are evaluated.

- Task 2 is dedicated to integration options both for the building technology and for the connection of the nZEBs to energy grids. Since neighbourhood concepts are included in the scope, both the interaction with the electricity and the thermal grids are considered in the contribution of some countries.

- In Task 3, on the one hand prototype technologies will be evaluated, but on the other hand, also the real performance by field monitoring of nZEB is investigated.

- In Task 4, the focus is on design and control of the heat pump and integrated building systems which are characterized based on performance, cost and energy flexibility by demand response.

Participants of the Annex 49 working meeting in Nuremberg in October 2017

The last working meeting was held in Nuremberg, Germany, in October 2017. The eight countries AT, BE, CH, DE, NO, SE, UK and the USA collaborate in Annex 49. EE/FI (Estonia/Finland) intends to join Annex 49.

At the meeting, the first results on the Tasks 2, 3 and 4 were presented. In Germany, for instance, a concept for a group of eight houses with central heat pump for the space heating supply and decentralized DHW booster heat pumps as well as integrated thermal and electric storage has been investigated by simulations. In September 2017, the real building process of the house in the neighbourhood has started. It is intended to also cover the first monitoring results of the neighbourhood in the time frame of Annex 49. Also in Norway, different concepts for groups of buildings are investigated in the frame of the new research centre for Zero Emission Neighbourhoods (ZEN). In Austria and Switzerland, monitoring projects of multi-family buildings and a building with mixed residential and commercial/office use are ongoing. Furthermore, a methodology for the comparison of nZEB requirements in different countries was presented by Estonia.

Moreover, based on the state-of-the-art results in Task 1, a common definition of nZEB for the work in Annex 49 has been elaborated. A framework for system simulations has been discussed and boundary conditions have been fixed. The simulation framework can be used to compare requirements in the different countries on a common basis and it can also be used to compare different system solutions on a common basis. Currently, a calibration of results of the different simulation programs which are in use in the participating countries is in progress.

In connection to the working meeting, an outline of Annex 49 and interim results were presented at the European Heat Pump Summit in Nuremberg.

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

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

ANNEX 51

ACOUSTIC SIGNATURE OF HEAT PUMPS

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

In Annex 51, acoustic emissions are covered in a hierarchical approach considering the following levels: the component level (low noise components), the unit level (system approach of combining the components, unit control, transient acoustic features) and finally the application level (building and neighbourhood including smart grid, psychoacoustic effects and acoustic propagation).

Options for noise measurement techniques for improved understanding, measuring and description of the acoustic performance is an important focus of Annex 51. Serving the needs of the different locations and countries, the current legislation is very diverse. An overview is prepared in detail for the participating countries and a review is given for other countries.

Good acoustic design and construction of the units should not be compromised by bad installations. Therefore, training and education are of utmost importance in heat pump acoustics (placement, noise reduction measures, modes of control and operation). Guidelines are prepared for component and heat pump manufacturers, heat pump testing laboratories, engineering consultants, installers and designers.

Participants of the Annex have now distributed and established the task leads in January 2018 and will contribute by presenting and discussing the results of their heat pump-related acoustic research projects. Several appliances are currently selected and will consecutively be characterized by the participating institutes in the months to come. Related national projects supporting Annex 51 are running in Sweden and Denmark, new projects have been granted funding in Germany and Austria and are gaining momentum.

Annex website

http://heatpumpingtechnologies.org/annex51/

Contact

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

Participants of Annex 51, at the meeting at CETIAT, France, January 2018.

ANNEX 52

LONG-TERM MEASUREMENTS OF GSHP SYSTEMS PERFORMANCE IN COMMERCIAL, INSTITUTIONAL AND MULTI-FAMILY BUILDINGS

First Annex 52 experts' meeting in May

Annex 52 officially started in January this year and will conclude in December 2021. So far, Sweden, the Netherlands and the USA have formally joined HPT Annex 52 and additional countries are expected to join this spring. This annex is open to participation from countries that belong to these IEA Technology Collaboration Programs: HPT, ECES and Geothermal. The deadline for joining Annex 52 is October 2019.

The first experts' meeting will take place in Malmö, Sweden, on May 24th-25th in conjunction with the HPT workshop on May 22nd and HPT ExCo meeting on May 23rd-24th. Parallel to these meetings, the Nordic Clean Energy Week and Mission Innovation meeting take place in Malmö and Copenhagen, with the EU energy ministers meeting in Malmö on May 23rd and in Copenhagen on May 24th.

Sweden has formed a national work group within Annex 52 where a number of Swedish GSHP systems will be monitored and evaluated through the Annex. These GSHP systems include a range of system designs, such as small and large office buildings, multi-family buildings and commercial buildings in different parts of Sweden. Most of these system designs include borehole storage systems, and also some aquifer storage systems are included. Several research institutions are involved (the Royal Institute of Technology, Chalmers, Lund University and RISE - Research Institutes of Sweden), as well as established real estate owners and industry representatives.

In the Netherlands, the company Groenholland Geo-energy Systems has been contracted by RVO Netherlands (part of the Ministry of Economic affairs) to coordinate the Dutch contribution to Annex 52. Groenholland will contact installers and GSHP system owners to make available existing system performance data. Within the Dutch Annex 52 work, an inventory of available performance data and their quality will be evaluated.

In the USA, a previous monitoring study of a closed-loop ground-source heat pump system in a two-story office building covered a two-year period ending in 2013. This study will extend the analysis to the present day. Additional systems are also being sought.

At the Annex 52 website you will find the legal text for the annex under the Documents tab.

Annex website
http://heatpumpingtechnologies.org/annex52/

Contact
Operating agent is Signhild Gehlin,
signhild@geoenergicentrum.se
Swedish Geoenergy Center

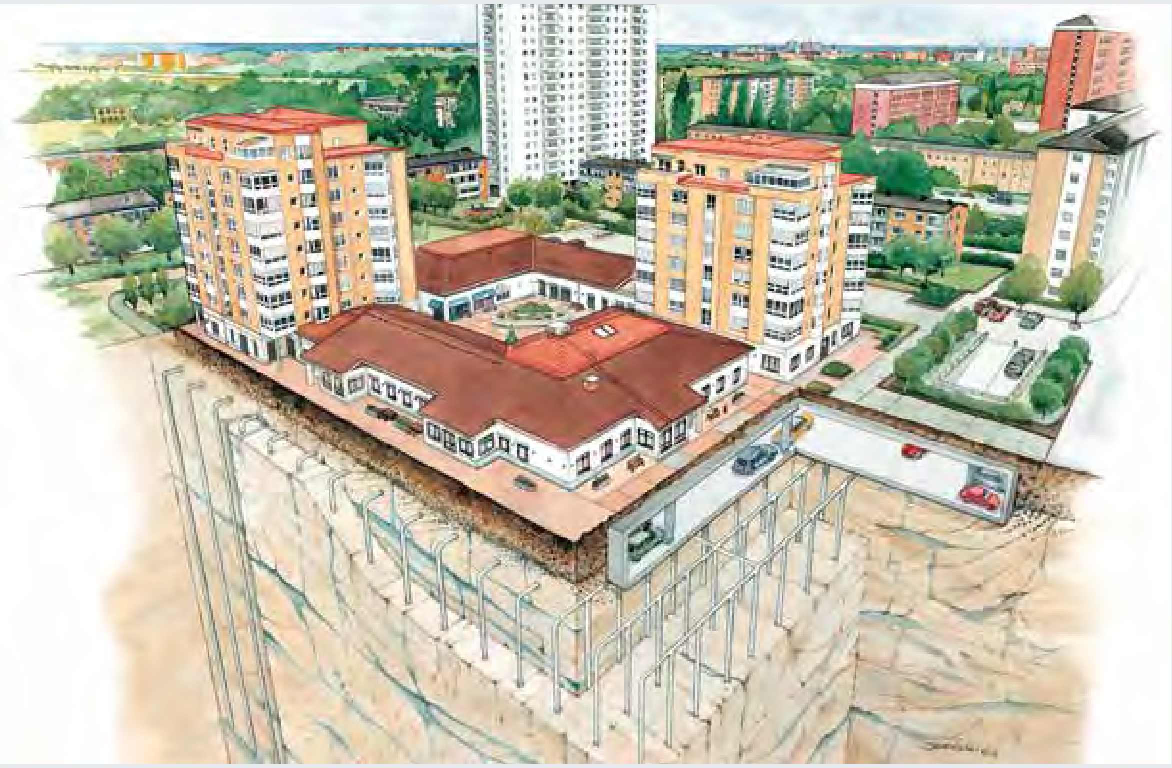


Figure 1. Borehole thermal energy storage. Source: Geotec, Sweden.

Pooling of smart heat pumps provides flexibility to the electricity market and grids

Johanna Spreitzhofer, Tara Esterl, Roman Schwalbe and Matthias Stifter - Austria

Smart heat pumps can offer their flexibility to the future energy system. They can be pooled together to become an active player on the electricity markets. Energy costs can be saved by using temporarily low energy prices to fill their storages and avoid operating at high price peaks. Furthermore, offering negative balancing services can be a profitable business case for the customer, if the IT costs can be held sufficiently low. However, if operated unfavourably, the thereby increased simultaneity might pose problems to the local distribution grid.

Introduction

The share of heat pumps in the distribution network has increased significantly during the last years, which may lead to the need for grid reinforcements in the future. On the other hand, smart heat pumps can be operated in a so-called "pool" and their operation can be optimized for the electricity market. However, this pooling leads to more simultaneity in the operation of heat pumps and could thereby cause additional grid problems.

This article analyses the potential future role of the heat pumps in the energy systems; it shows the possibly conflicting interests of the local grid and the electricity markets regarding optimal heat pump operation. It is accompanied by the results from a simulation case study conducted for the Austrian electricity market and three simulated local grids.

Heat pumps in electricity markets

Heat pumps - especially modulating ones - have very fast reaction times and can change their electric consumption within seconds. Heating systems often have a thermal buffer storage as well as a storage for hot water, and the building itself can act as a thermal storage. This makes the heating times quite flexible: after being heated up the system can usually run without power for several hours, since the buffer storage and the building have enough thermal capacity to still keep the air warm enough. If necessary, the heat pump can switch on very fast and consume electricity. This flexible behaviour can be used to optimize the electric consumption of the heat pump towards cheap prices on the short-term electricity markets, like the day-ahead and intraday spot market. The heat pump can be controlled so that it is turned on during low price times and switched off during high price times.

Another option is to use the flexibility to support the transmission system operator by providing balancing services. When the system needs positive capacity, the heat pump can switch off temporarily and when negative capacity is needed it can increase its consumption. Especially the second case can be a very interesting business case, since it (usually) means that the heat pump operator gets paid to consume energy. However, to participate in the balancing market, certain prerequisites must be fulfilled, such as market structures and prequalification criteria, which vary between countries. There is usually a minimum bid size of, for instance, 1 MW; this means that a single residential heat pump cannot participate in the market on its own. However, if several hundred heat pumps are aggregated and controlled together as one "pool" they can offer enough flexibility to participate in the market.

The flexibility influences the operation of the heat pump (e.g. operation cycles), hence a techno-economic assessment between flexibility and a possible increase of shut off/on times as well as the consideration of dead times is important. Moreover, the impact of flexibility on the comfort of heating and hot water supply has to be limited.

Heat pumps in electricity grids

The share of heat pumps in the residential sector has been rising continuously during the last few years, which leads to an increasing demand in the low voltage distribution grid [1]. This electrification of the heating sector, and the resulting increased consumption, may make grid reinforcements necessary in the future. However, with the above-mentioned pooling of the heat-pumps, the resulting simultaneity effect poses an additional threat: if several heat pumps in the same local grid area belong to one pool and react to the same market signal, they are prone to be switched on and off synchronously. This simultaneity could lead to grid congestions (thermal overload of assets or voltage limit violations) of typically between 94 and 106 % [2].

One method practiced by Austrian grid operators are so-called "interruptible tariffs". Then the heat pump owners allow the grid operator to switch them off during some time of each day ("blocking times"). In exchange they get a lower grid tariff. Another option would be the consideration of the heat pump locations: when sending a market activation signal, the aggregator could distribute it between heat pumps of different grids and activate heat pumps within one grid region slightly after each other. Thus the simultaneity could be reduced as the activation would be more evenly spread out by the variation of location and timing.

Operating strategies

As shown in Figure 1, heat pumps can follow different operating strategies. During conventional operation, the heat pump just takes the desired temperature levels in the building and the storage tanks into account. When adding a controller with a communication interface (see Figure 1), it can also react to external signals. In market-driven operation, those signals could indicate cheap prices on the spot market or required balancing services for the transmission grid operator. When following a grid-friendly operation strategy, the signal could come from the local grid operator to avoid congestion.

There are two general operating approaches that can be distinguished: central and decentral. In central operation there is one central intelligent controller, which is usually part of an aggregator. The aggregator receives the different external signals (grid, market, balancing services) and distributes them to the customers in the pool. However, in this case the aggregator needs information about the heating system (current temperatures, desired comfort levels). This means that a large amount of information will be exchanged. In the decentral approach, the controller and the information remain locally. Therefore, it is not guaranteed that heat pumps actually react to incoming signals, since the current status of the customer's system is not known exactly and needs to be predicted. This could lead to problems for the aggregator if the contracted flexibility cannot be provided.

An Austrian case study

The potentially opposing interests of the grid friendly operation and market optimization were analysed for a case study in Austria. With a group of heat pumps for single-family homes, potential revenues for the customers were calculated (Table 1). A model-based portfolio optimization was used for cost minimization on the day-ahead spot market as well as revenue maximization by providing manual frequency restoration reserve. This balancing service is used by the transmission grid operator, when longer imbalances occur between electricity supply and demand. Furthermore, the influence on three rural distribution grids for both existing and future heat pump penetration scenarios were analysed. Thus, electrical power flow simulations were used to compare the different heat pump operation strategies and their impacts on the electrical grid, namely: thermal overload of assets (lines, transformers), grid voltages (levels and unbalance) and heat pump coincidence factors.

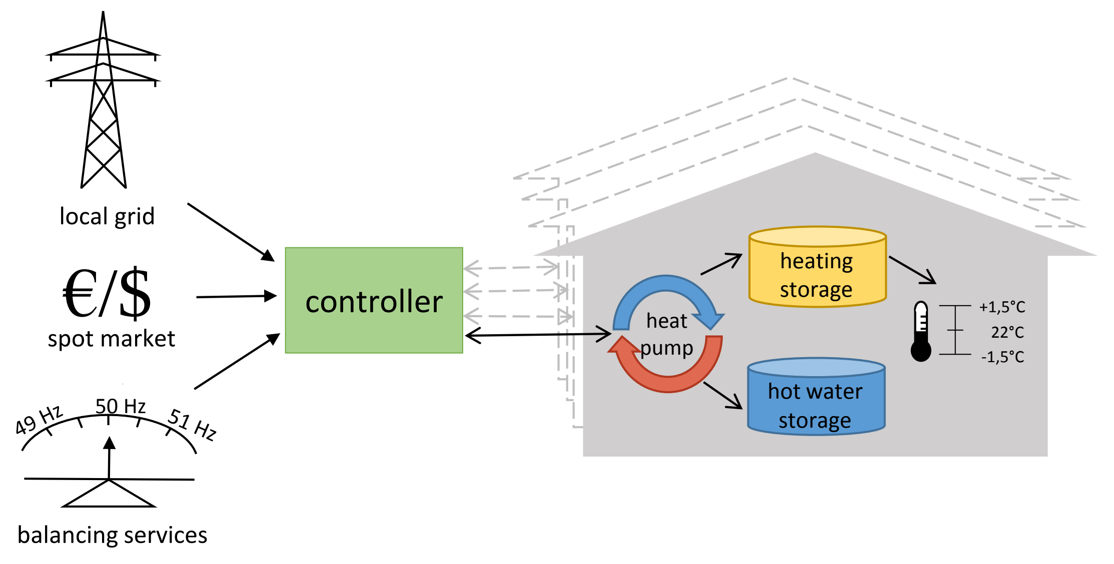


Figure 1: Schematic of different heat pump operation scenarios: grid friendly, spot market and balancing market.

	Passive house	Low energy building A	Low energy building B	Existing building	Renovated building
Heating demand	15 kWh/m²a	45 kWh/m²a	45 kWh/m²a	100 kWh/m²a	75 kWh/m²a
Heating system	Floor heating	Floor heating	Floor heating	Radiators	Radiators
Heat pump	Air-water	Air-water	Brine-water	Brine-water	Air-water
Thermal/ electrical power	3 kW/1 kW	5 kW/1.5 kW	5 kW/1.2 kW	12 kW/4 kW	7 kW/2.7 kW
Storage	DHW: 300 l	DHW: 300 l SH: 300 l	DHW: 300 l	DHW: 300 l SH: 500 l	DHW: 300 l SH: 500 l

Table 1: Analysed building types for the Austrian case study. The colors for the different types are the same as in Figure 2. [1]. (SH – System Heating, DHW – Domestic Hot Water)

Economic analysis

The economic analysis showed that a business case especially for the tertiary balancing market can be interesting, if integration cost for information and communications technology (ICT) are low [1]. Moreover, a combination of use cases, such as for example the combination with the increase of PV self-consumption, improves the business case. In 2016, the additional revenues for the participation in the tertiary balancing market were 18 – 73 € (20 - 79 USD)[1] per heat pump and per year. The heat pump pool participates more in the negative balancing products (the pool is paid to consume energy). With the optimization on the spot market, electricity cost reductions of 23 – 35 % (11 – 53 € / 12 - 58 USD) were possible for the year 2016.

The analysis shows that the flexibility potential of the building highly influence the results. In contrast to older and less efficient buildings, the passive house has a high potential for pre-heating, but has lower cost reduction potential due to lower energy consumption as well as lower power to offer on the balancing markets. The highest revenues could be gained with the existing buildings, since they have the highest heat demand. The season highly influences the flexibility potential; the pool has a higher potential during winter times.

Technical analysis and impact on grid

Grid simulation is performed in one minute time resolution with measured household load and PV in-feed profiles and heat pump simulations with realistic domestic hot water (DHW) and space heating (SH) demand profiles. A simplified heat pump model is implemented in the grid simulation application. The conventional operation is compared to grid friendly and market participation via arbitrage. In the grid friendly operation, the above mentioned blocking times are used, during which the heat pumps can be switched off by the grid operator. In a second improved grid-friendly strategy, the so-called “pre-charging”, the thermal storages are filled before the off-period to avoid a high power demand after the blocking time.

The case studies of the three Austrian low voltage grids show that the impact of heat pump installations on the grid is lower than expected, see Figure 3, which shows the simulation results for one of the grids. The left-hand figure shows the variation of the lowest grid voltage while the right-hand figure shows the variation of the highest line loading, for the different scenarios. Even in the most extreme future grid penetration scenario, with more than 50 % of all buildings equipped with heat pumps (hp50), the median of the lowest voltage does not decrease significantly (left figure). Although grid constraints are violated in the shown grid, this grid is very close to its capacity limits even without heat pumps (scenario hp00). In addition, the median of the highest loading of the lines only increases by up to 10 %, as can be seen in the right figure.

Simulations showed that the blocking hours do not significantly relieve the grid, concerning the lowest grid voltage. The introduced pre-charging of the storages tends to bring some improvements. Furthermore, dynamic setting of blocking hours according to the actual grid loading in combination with a decentral control could further improve the situation for the grid.

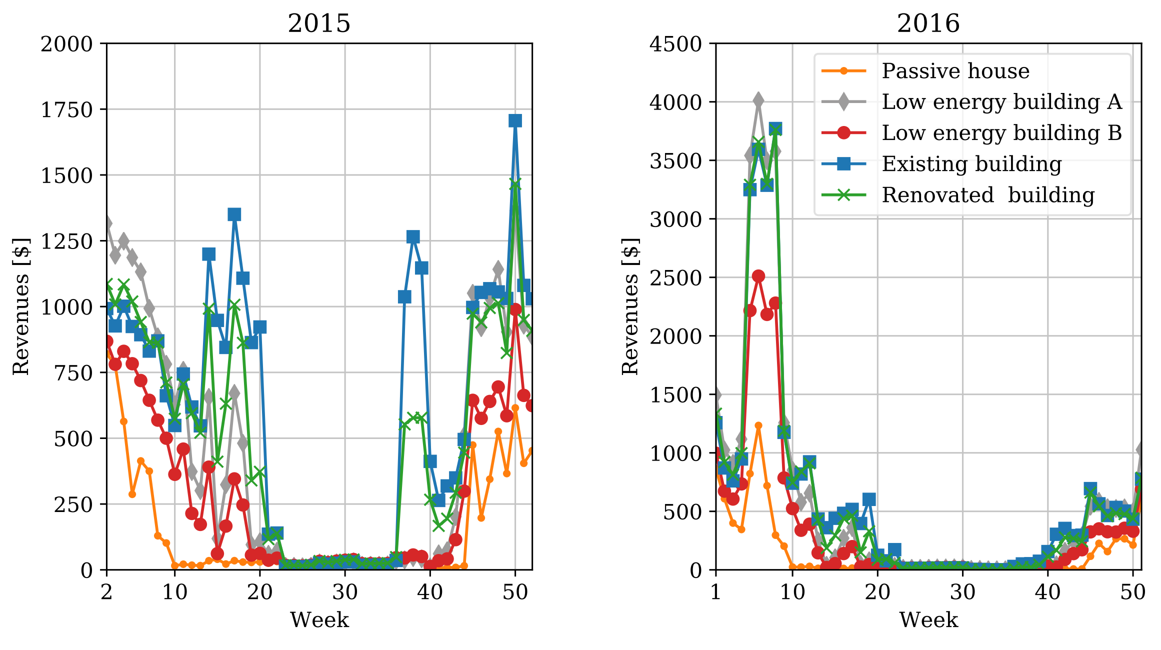


Figure 2: Possible weekly revenues for the customers, of a pool of 400 heat pumps with different building types, providing manual frequency restoration reserve (i.e. supporting the electricity grid during imbalances), for the years 2015 and 2016.

---

[1] 1 € = 1.086 $ (January 1, 2016)

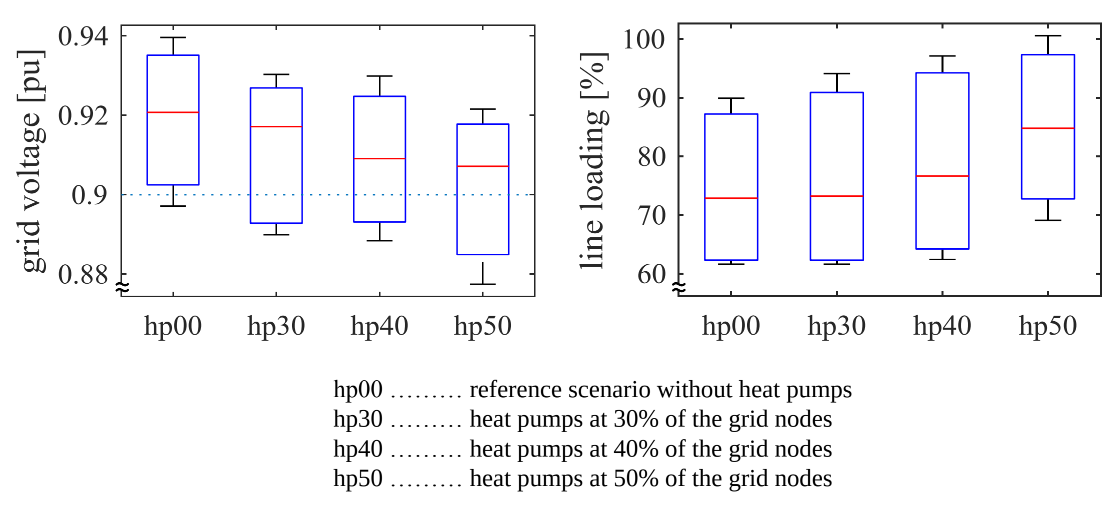


Figure 3: Variation of the lowest grid voltage (left) and the highest line loading (right) for the investigated heat pump penetration scenarios in one of the simulated grids. The dotted line in the left figure shows the minimum allowed voltage in the grid. The box plots indicate the median values (red lines) as well as the lower and upper quartiles (boxes) and the minimum and maximum values (whiskers). [2]

Conclusions

It has been shown that heat pumps potentially can earn revenues on the short-term electricity markets. Especially the negative balancing market can be an interesting business case if the ICT costs are sufficiently low. It will be important to also consider the heat pump characteristics and their efficiency to find the overall optimum. In the analysed case study, the impact of the heat pump pool on the distribution grid was not very large. However, in countries with weak distribution grids, this may still pose a problem in the future. Particularly the combination with other electrification trends, e.g., electric vehicles, can put further stress on the grids.

References

[1] T. Esterl, iWPP-Flex final project report, Austrian research project (FFG-Number 848894), 2016-07-29, [to be published]

[2] R. Schwalbe, M. Häusler, M. Stifter, T. Esterl, Market driven vs. grid supporting heat pump operation in low voltage distribution grids with high heat pump penetration – an Austrian case study, 12th IEA Heat Pump Conference 2017, Rotterdam 2017.

JOHANNA SPREITZHOFER
AIT – Austrian Institute of Technology
Giefinggasse 2, 1210 Wien, Austria
johanna.spreitzhofer@ait.ac.at
+43 664 88256109

ROMAN SCHWALBE
AIT – Austrian Institute of Technology
Giefinggasse 2, 1210 Wien, Austria
roman.schwalbe@ait.ac.at
+43 664 88256109

TARA ESTERL
AIT – Austrian Institute of Technology
Giefinggasse 2, 1210 Wien, Austria
tara.esterl@ait.ac.at
+43 664 88256109

MATTHIAS STIFTER
AIT – Austrian Institute of Technology
Giefinggasse 2, 1210 Wien, Austria
matthias.stifter@ait.ac.at
+43 664 88256109

District heating and cooling energy network using CO_2 as a heat and mass transfer fluid

Henchoz S, Favrat D, Girardin L, Marechal M - Switzerland

The 5th generation compact district heating and cooling networks in a temperature range of 10 to 16 °C have a great potential for energy savings by providing a heat source for decentralized heating heat pumps, a cold source for air-conditioning and a heat sink for refrigeration or cogeneration units. The energy balance of the network is achieved by a central plant equipped with a heating heat pump in winter operation and a heat dissipator in summer operation. They typically facilitate the synergy between users and allow the concept of a city without chimneys or cooling towers in the various buildings. One such concept is based on using the latent heat of the transfer fluid (CO_2), with one saturated CO_2 vapor pipe and one saturated CO_2 liquid pipe. Studies show that up to 80 % of the final energy can be saved in urban areas, at a cost that is lower than the conventional technologies.

Introduction

Since a growing part of the population worldwide will live in cities, urban energy supply is very important when considering improved energy efficiency strategies. However, as a result of the different willingness of building owners to invest in energy renovation of their buildings, the building stock is often very diverse. A result of this is that the energy demand and the required temperature levels for each building tend to differ within a given part of a city. Moreover, cooling loads tend to increase in the central city district with a large share of shops and offices, including data centers. Hence, there is an increase in both heating and cooling networks in already crowded city undergrounds. To face the temperature heterogeneity of building requirements, concepts of medium to low temperature district heating (DH) systems, with or without decentralized heat pumps, have been proposed and implemented [1, 2, 3]. Other concepts combine heating and cooling (DHC) supply in very low temperature networks where the transfer fluid acts as a cold network for cooling purposes and supplies evaporator heat to decentralized heat pumps heating buildings. These buildings have the advantage of better efficiency, since the individual heat pumps supply just the temperature level needs of the individual buildings, and they consist of a 2-pipe rather than a 4-pipe system. However, to limit the exergy losses, and since they are only based on the specific heat of water, they need to have a reduced difference of temperature between the supply and return pipes (down to a few degrees) implying the transport of large amounts of water and therefore large pipes and trench requirements. This paper summarizes a series of papers [4, 5, 6] on an alternative concept of significantly more compact, very low temperature network using the latent heat of CO_2 that is used both as a refrigerant and an energy transfer fluid. Furthermore, CO_2 does not run a risk of freezing and, therefore, street implantation does not require any significant depth for freezing protection in case of trouble. Like the very low temperature DHC heating and cooling networks based on water, and since the temperature level is closed to that of the surrounding ground, insulation can be reduced to a minimum allowing a further gain in ditch width requirements. Furthermore, the temperature level corresponds to ground vertical probes for thermal storage or geothermal heat capture. Several other alternative uses of such networks are described in the next sections. Note that here the terminology of 5th generation DHC is used in order not to be confused with the so-called low temperature of the 4th generation review defined by Lund et al. in [7, Table 1].

Description of the 5th generation DHC

Figure 1a and 1b illustrate the network with the central plant and the first users in summer and in winter. The network consists of one saturated liquid pipe and one saturated vapor pipe, both in a saturated temperature range of 10 to 16 °C. In summer, free cooling is provided for air conditioning by evaporating liquid taken from the liquid pipe and releasing it in the form of vapor to the vapor pipe. In winter, vapor is taken out of the vapor pipe, condensed in a condenser-evaporator of a decentralized heat pump and then released in the liquid pipe. Direct use of the CO_2 vapor is also an option, particularly for hot water-heating using a supercritical heat pump with oil-free compressor. Overall, this implies that the flow in the pipes can go in both directions depending on the relative ratio between the cooling and heating duties, allowing heat recovery when both services are required at the same time. Ideally, the central plant that balances the energy demand uses high grade environmental sources such as surface water (lake, sea, river), geothermal probes or industrial waste heat sources.

Because of the very low temperature of this system, a real synergy between heat providers and heat users can be achieved. This is in contrast to the present situation, seeing side by side the cooling tower of a shop and the chimney of a fuel-based hot water heater. It is a step towards future districts without chimneys or cooling towers. A recent theoretical study on a real district in Geneva shows that more than 80 % of the energy could be saved, compared to today's energy system using predominantly fuel boilers and conventional single stage refrigeration and

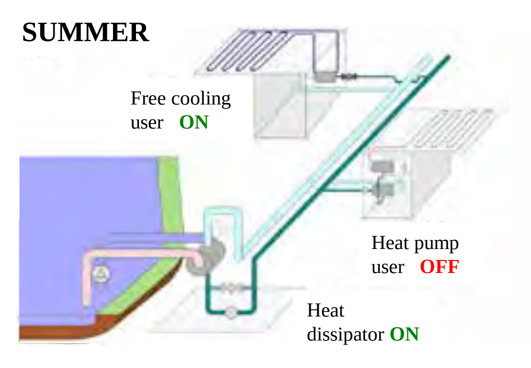


Figure 1a. Central plant and first users in summer of a CO_2-based DHC network (light blue pipe=vapor pipe and dark green pipe =liquid pipe)

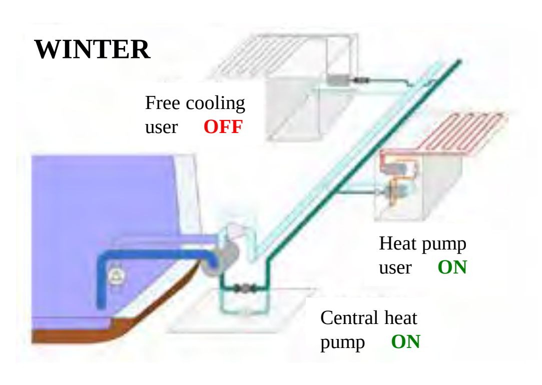


Figure 1b. Central plant and first users in winter of a CO_2 based DHC

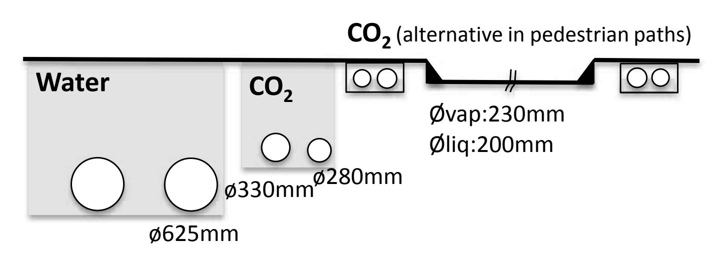


Figure 2. Size comparison between a water-based and a CO_2-based very low temperature DHC

air-conditioning units [4]. In addition, the size of piping is significantly reduced, as shown in Figure 2, to the point that the pipes could be implemented in utility channels or in pedestrian paths.

The main drawback is the high pressure of the order of 50 bars and the large amount of CO_2 that could cause some safety concerns in case of a major leak. However, several hundreds of supermarkets in Europe [8] are already equipped with direct CO_2 networks supplying cold at slightly lower pressures of the order of 40 bars with safety valves calibrated at 70 bars.

Experimental proof of concept

A scaled-down lab facility [Figure 3] was built to have a proof of concept to demonstrate the feasibility using only existing components, with scalable results and in which the potential hydro-acoustic phenomena could be observed and measured. Furthermore, the test rig has been used for experiments with various control schemes. The tests run so far did not indicate any major operational difficulties such as strong pressure surges or two-phase flow instabilities in the main network.

Figure 3. Picture of the test rig installed at the industrial energy services in Geneva

Further extension of the concept

The proposed two-pipe CO_2 energy network does not only allow for cold and warm energy supply via decentralized heat pumps when required but can also be a real umbilical cord in the city for further duties and improved synergies. Other uses include:

1) Supply of an extinguishing agent in case of fire, either directly in non-occupied rooms or indirectly using mixing ejectors to reduce the excessive concentration of CO_2;
2) Supply of a cold source for Organic Rankine Cycles or other waste heat conversion or cogeneration devices;
3) Integration with daily electricity storage at the central plant, like the reversible trans-critical CO_2 heat pump-power cycle shown in [10];
4) Integration with photovoltaics that allows to drive the heat-pumps with renewable energy.

In addition, the excess of PV electricity can be converted into methane by electrolysis and the Sabatier reaction. The resulting methane can be stored in summer in the form of liquid methane that can be converted into heat and electricity in winter. The use of combined cycles with CO_2 capture or fuel cells that separate the CO_2 such as SOFC [9] allows to collect CO_2 in the network and store it to recycle it as methane in summer. Studies have demonstrated that cities in this way may become self-sufficient in energy [11].

Conclusion

The 5th generation district heating and cooling networks, based on the use of the latent heat of a natural fluid such as CO_2, represent an interesting option to develop high efficiency city districts by providing a very compact energy network allowing to make use of the synergies between the needs of the various users. Based on existing technologies, we have demonstrated that this technology can save more than 80 % of the final energy consumed in a city center while being cheaper than conventional solutions. Combined with solar PV, it allows to design districts with nearly zero emissions. In spite of the relatively high pressures required by a CO_2 DHC network, experiments at a reduced scale have not shown any major pressure surge concerns so far.

References

[1] Lorentzen G., 1990. “Heat pumps for district heating applications” 3rd IEA heat pump conference Tokyo, Japan

[2] Pelet X., Favrat D., “Performance of a 3.9 MW Ammonia Heat Pump in a District Heating Cogeneration Plant: Status after eleven years of operation”, 1997, IEA Annex 22 Workshop, Gatlinburg, TN, USA

[3] Curti V., Favrat D., von Spakovsky M. An environomic approach for the modeling and optimization of a district heating network based on centralized and decentralized heat pumps, cogeneration and/or gas furnace. Part II: Results. Int. J. of thermal sciences 2000; **39**:731-741.

[4] Henchoz S., Weber C., Marechal F., Favrat D. Performance and profitability perspectives of a CO_2 based district energy network in Geneva’s city center. Energy 2015; **85**:221-235

[5] Henchoz S., Chatelan P, Marechal F., Favrat D. Key energy and technological aspects of three innovative district energy networks. Energy 2016;117 part 2: 465-477

[6] Henchoz S., Favrat D., Marechal F., Girardin L. Novel district heating and cooling energy network using CO_2 as a heat and mass transfer fluid. IEA heat pump conference, Rotterdam, May 2017

[7] Lund H., Werner S., Wiltshire R., Svendsen S., Thorsen J, Hvelplund F., Mathiesen B.,4th generation District Heating (4GDH): Integrating smart thermal grids into future sustainable energy systems. Energy 2014; **68**:1-11

[8] Masson N. 2014 Natural refrigerants in Europe: The drivers and challenges for food retailers

[9] Facchinetti E., Favrat D., Marechal F., Innovative hybrid cycle solid oxide fuel cell-inverted gas turbine with CO2 separation, Fuel cells 2011;11:565-572

[10] Morandin M., Mercangoez M., Hemrle J., Marechal F., Favrat D., Thermoeconomic design optimization of a thermo-electric energy storage system based on trans-critical CO_2 cycles, Energy 2013;58:571-587

[11] Suciu, R. A., Girardin, L., Maréchal, F. (2017). Energy integration of CO_2 networks and Power to Gas for emerging energy autonomous cities in Europe. In Proceedings of ECOS 2017

SAMUEL HENCHOZ
Ecole Polytechnique Federale de Lausanne
Switzerland

DANIEL FAVRAT
Ecole Polytechnique Federale de Lausanne
Switzerland
Daniel.favrat@epfl.ch

LUC GIRARDIN
Ecole Polytechnique Federale de Lausanne
Switzerland

FRANÇOIS MARÉCHA
Ecole Polytechnique Federale de Lausanne
Switzerland

A sustainable energy future: the role of heat pumps in a fossil-free system

Michael Taylor - IRENA

Combined, renewable energy and energy efficiency measures have the potential to deliver 90 % of the reduction of greenhouse gas emissions needed by 2050. With the IRENA tool "REmap" it is possible to analyse for each country which technologies should be used for decarbonisation of the energy system, in order to find the potential of cost-effective low-carbon solutions in line with the Paris Agreement and a 2 °C scenario. It is clear that heat pumps could have an important role to play in this development, and the business case development seems positive.

Introduction

Today, countries around the world are more firmly committed than ever to accelerating renewable energy deployment. Technological innovation, enabling policies and the drive to address climate change have placed renewables at the centre of the global energy transformation. Yet alongside these developments, the chief driver of renewable energy is its strong business case, which offers increasingly exciting economic opportunities.

IRENA's "REmap" approach to analysing which technologies are required for an energy transition or a decarbonisation of the energy sector is an important tool to identify the most cost-effective technology solutions for different countries. The REmap technology option analysis is carried out at the sub-sector level for the world as a whole, with energy demand of each end-use sector disaggregated into the main energy-consuming applications. 1 The common goal is to explore technology deployment pathways in line with the goals of the Paris Agreement and to assess the implications of a 2 °C scenario (with a 66 % probability of meeting that target).

To achieve these goals, energy CO_2 emissions need to fall from 33 gigatonnes (Gt) in 2015 to below 10 Gt per year in 2050, then drop to zero by 2060 and stay at that level (emissions must drop below zero to limit the increase to 1.5 °C). The 2°C target requires energy-related CO_2 emissions to drop to 20-22 Gt per year by 2030. Such a reduction translates to a decrease in the average CO_2 emissions per unit of gross domestic product (GDP) (or the carbon intensity of the global energy supply) by more than 85 % between 2015 and 2050 (IRENA, 2016).

The REmap framework and analysis

The aim of REmap is to communicate results to a diverse audience. This includes policy makers to technology developers, academia and the general public. Therefore, REmap employs a unique methodology to assess the potential of low-carbon technologies. The identification of the additional low-carbon technology potential is the most important step of the process. The aim is not to apply complex models or sophisticated tools to assess the potential, but to facilitate an open framework with countries to aggregate the national energy plans, and subsequently identify technology options and is not meant as a target-setting exercise.

Given its nature, the REmap approach also has a number of limitations. For instance, REmap looks at discrete time steps, focusing on 2030 and 2050. For example, the analysis does not take into account interactions, developments and dynamics across technologies or feedbacks in energy prices due to demand and supply changes (e.g. rebound effects). Moreover, inter-temporal dynamics and inertia that determine deployment, system constraints, path dependencies, and competition for resources, etc. also are not explicitly taken into account (Saygin et al., 2015).

However, a comparison of the findings of REmap with the results of the IEA-ETSAP models at both national and global level has shown that for a number of countries and regions, the results are directly comparable to the REmap country results (Kempener et al., 2015). This is important, as it suggests that the sequence of technology options selected in REmap's cost-supply curves, despite lacking the dynamic temporal modelling in IEA-ETSAP models, still yields similar results to the technology options selected by the ETSAP models (as they increase the required share of renewables in their energy system).

The key role of renewable energy toward 2050

Accelerated deployment of renewable energy and energy efficiency measures are the key elements of the energy transition. By 2050, renewables and energy efficiency would meet the majority of emission reduction needs (90 %), with some 10 % achieved by fossil fuel switching and CCS. Crucially, sooner rather than later, the world must address emissions from the end-use sectors, an area where heat pumps will play a crucial role.

---

[1] For more details, see the suite of IRENA REmap publications, background documents and data available at http://irena.org/remap.

Energy and materials efficiency improvements can reduce emissions by about 4 Gt by 2030, about 30 % of the emissions reductions needed (Figure 1). Electrification cuts another 1.5 Gt, or 10 % of what is needed. Renewable energy options that were identified based on the bottom-up analysis of the G20 countries can reduce emissions by another 10 Gt. As a result of these measures, 2030 emissions would fall to 25.5 Gt in 2030, with the remaining fossil fuel combustion emitting about 22 Gt of CO_2 emissions per year.

This level is sufficient to put the world on a 2 °C pathway in 2030. But to keep the world on this pathway, efforts need to be strengthened further between 2030 and 2050. This would require energy-related CO_2 emissions to drop to below 10 Gt by 2050, which would be 70 % lower than 2015 levels and 31 Gt less than in the Reference Case. About half of these reductions would come from renewable energy technologies. Energy efficiency improvements and electrification would account for the bulk of the other half. The remaining 10 % of reductions would come from additional measures in industry, notably CCS, material efficiency improvements and structural changes.

As a result, emissions from all sectors must be cut. The power generation and buildings sectors would see the largest percentage reduction in emissions by 2050 in the REmap case (Figure 2). The largest CO_2-emitting sectors are electricity generation and industry. They are responsible for about 65 % of all energy-related CO_2 emissions today. The remaining 35 % comes from transport, buildings and district heating. Buildings have a low share, but this increases if indirect emissions related to electricity use are included.

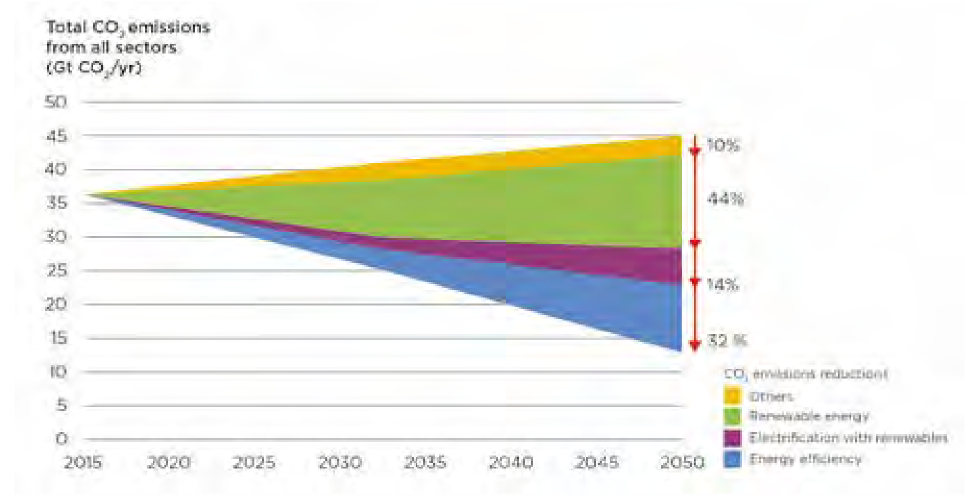


Figure 1: Primary CO_2 emission reduction potential by technology in the Reference Case and REmap, 2015-2050
Source: IRENA, 2017

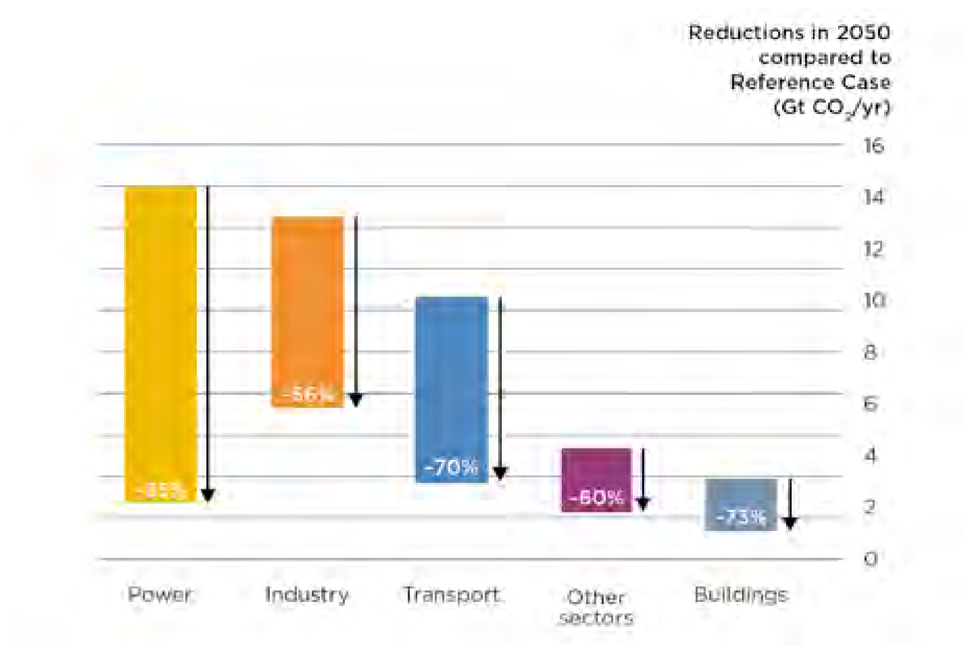


Figure 2: CO_2 emissions by sector in REmap relative to the Reference Case, 2015-2050
Source: IRENA, 2017

The building sector is growing quickly with today's 150 billion square meters of residential and commercial floor area projected to increase to 270 billion m^2 by 2050. Most of the growth will be in urban areas. Over the next two decades, two billion more people will live in cities, requiring the equivalent of 2 000 new cities of one million inhabitants. This is an unprecedented challenge.

Heating and cooling represents 80 % of the building sector's total energy demand. Space heating alone accounts for the largest share of all thermal energy needed in a building, at about 60 % of the total. The share for cooling is small today but demand for cooling is expected to increase to more than that of space heating by 2050. It will be critical that new cities (and in fact, all new buildings in all locations) are built according to the highest energy efficiency standards to minimise energy demand. Using modern building shell insulation technology, heating and cooling demand can drop by one order of magnitude compared to conventional buildings. This will allow highly efficient heat pumps to provide cost-effective heating and cooling services, complemented by other renewable solutions such as solar thermal and bioenergy. In developed countries, accelerated renovation and refurbishment offers great potential to improve energy efficiency and reduce emissions. More attention will need to be paid to retrofit or replace existing inefficient buildings and upgrade their heating and cooling systems to utilize renewable energy.

With the decarbonization of the electricity sector gathering pace, the opportunities to electrify larger parts of end-use energy service demand arises as an important solution to the goal of overall energy sector decarbonization. Heat pumps are thus an important part of the mix of technologies to provide cost-effective decarbonization, but could also play an increasing role in helping manage the growing share of variability renewable electricity (VRE) generation technologies in the electricity system. Heat pumps, when aggregated, can provide some of the ancillary services that the electricity sector will increasingly call on as the share of VRE technologies grows (e.g., frequency response, voltage control, etc.), while heat pumps with low-cost thermal energy storage can take VRE electricity when abundant and draw down the heat as required. Overall, the role of heat pumps for space and water heating will grow rapidly in the REmap case to meet the target, with heating-focused heat pumps growing from an estimated 4 million units in 2015 to 232 million units by 2050.

It is not just in buildings, however, where heat pumps will play a role. Electricity-based process heating technologies, such as heat pumps, can help industry raise its electricity share, enabling a higher penetration of renewables. These technologies are limited by the level of temperature of process heat (up to 250 °C), but the REmap case anticipates that globally, large-scale heat pumps in industry could grow from around 200 000 in 2015 to 80 million by 2050, with sectors such as the food industry being an important market due to the simultaneous need for heating and cooling in many cases.

IRENA's analysis of the potential for renewables in the European Union(EU) (IRENA, 2018) goes into more detail. The largest markets for heat pumps in Europe (in terms of renewable heat captured) are Italy, France, Sweden and Germany (Eurostat, 2017). The REmap analysis reveals significant potential to accelerate the deployment of heat pumps – which could account for about 9 % of heating needs by 2030 in industry and buildings. The potential for heat pumps in industry is particularly economic (Figure 3),

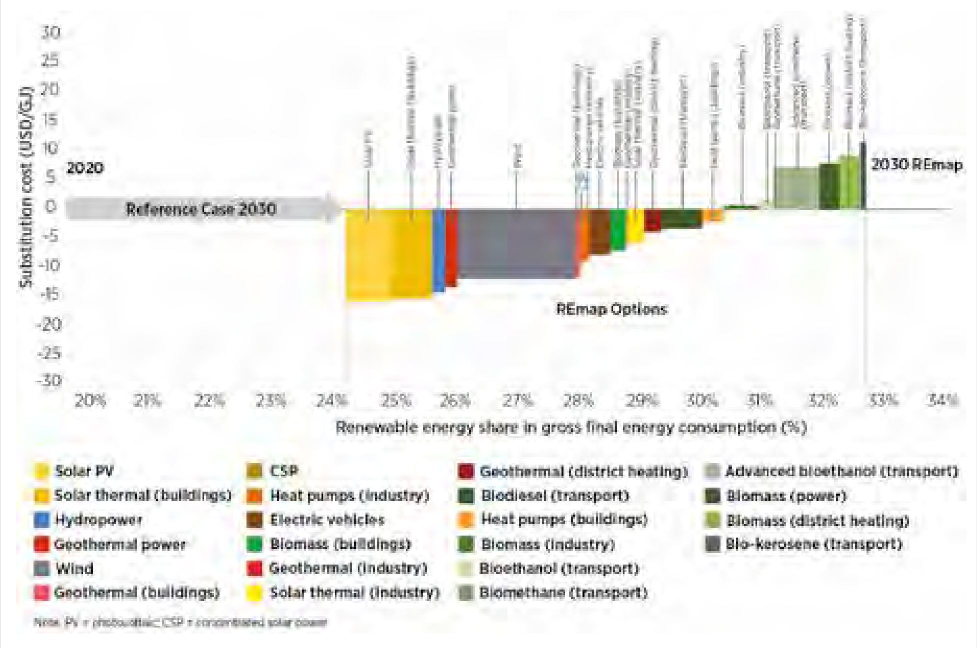


Figure 3: Cost-supply curve of renewable energy options for the EU to go beyond the 27 % target for 2030
Source: EU and IRENA, 2018

while there is significant cost-effective potential for heat pumps to provide decarbonized heat in buildings as well.

However, there are challenges to achieving these figures. About half of the EU-28 building stock was built before 1970, with limited energy efficiency considerations and no renewable energy requirements. These buildings will either need to be renewed and/or some of their equipment retrofitted over time. Another consideration is that renewables are easier to introduce in newly constructed buildings and for heat pumps, using low-temperature heating systems make the use of heat pumps much more efficient. Heat pumps additional barriers to implementation, including higher initial investments, sometimes difficult to access finance, landlord-tenant issues and insufficient knowledge of the advantages of the technology. As a result, it is imperative – if heat pumps are to deliver on their potential to help the EU decarbonise its energy system – that energy efficiency and renewable energy policies be co-ordinated to recognise the complementarity of heat pumps and support them by mitigating existing barriers to deployment.

Demonstrating the business case for heat pumps

IRENA has, since 2012, invested significant resources into collecting comprehensive, transparent and up-to-date data on renewable energy costs and performance to ensure that policy makers have the latest data on which to make decisions about the role of renewables in the energy sector. Given the, sometimes very, rapid improvements in the costs of renewable energy technologies (notably for solar electricity and wind power) this data plays a vital role in ensuring that policy makers make decisions based on real-world costs, that energy and climate modelers don't underestimate the potential contribution of renewables and that industry stakeholders discuss issues based on facts, not assertions.

In 2017, IRENA started working with the European Heat Pump Association to start collecting cost and performance data for heat pumps, as well as promoting the potential role of heat pumps in providing additional flexibility to the electricity system as the share of VRE rises.

Figure 4 presents the cost data that has been collected for small-scale German heat pump systems installed to provide space and/or water heating in 2013 and 2016. In this market, there has been a significant shift toward technologies that provide higher performance, this has seen the total installed costs rise from USD 1747/kW in 2013 to USD 1925/kW in 2016. The 10% increase in total installed costs between 2013 and 2016 has, however, purchased an 18% increase in the weighted average seasonal performance factor of systems installed.

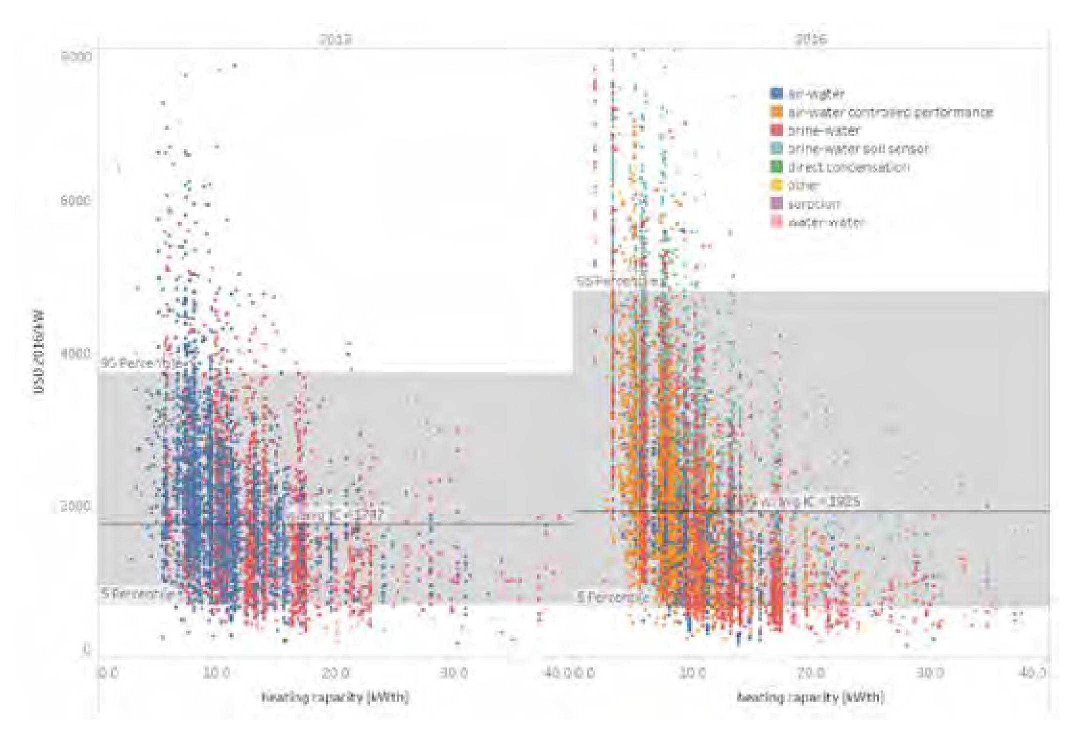


Figure 4: Heat pump total installed costs in the residential and commercial sectors in Germany, 2013 and 2016
Source: IRENA, based on Bundesamt für Wirtschaft und Ausfuhrkontrolle (BAFA)

---

[2] Data provision to IRENA is covered by the Confidentiality Protocol of the IRENA Renewable Costing Alliance, see www.irena.org/costs for more details.

Data for large-scale heat pumps are not as readily accessible as for small-scale units, while the data available is typically for the equipment costs only and exclude installation costs. However, the data available for 2013-2015 in Europe suggests that weighted average costs are coming down, as system sizes increase (Figure 5). The data collected so far represents a start, but more data is required to develop a comprehensive overview of heat pump costs and performance and IRENA would welcome new partners who could share, confidentially, real-world project data[2] to help convey the compelling message about the business case for heat pumps as part of the suite of solutions to our energy and environmental policy challenges.

Conclusions

Major changes are needed to reach the 2.0-scenario needed according to the Paris agreement. One way to find a set of actions for each country is to use the IRENA tool REmap. It has also shown to give comparable results with the IEA-ETSAP models at both national and global level. This suggests that the sequence of technology options selected in REmap's cost-supply curves yields similar results, despite lacking the dynamic temporal modelling in IEA-ETSAP models. According to REmap, the power generation and buildings sectors would see the largest percentage reduction in emissions by 2050, and the role of heat pumps for space and water heating would grow rapidly. The REmap case actually anticipates that globally, large-scale heat pumps in industry could grow from around 200 000 in 2015 to 80 million by 2050. The REmap analysis reveals significant potential to accelerate the deployment of heat pumps – which could account for about 9 % of heating needs by 2030 in industry and buildings.

Sources

Eurostat (2017), Short Assessment of Renewable Energy Sources (SHARES) 2015, European Commission. http://ec.europa.eu/eurostat/web/energy/data/shares. [Accessed: September 2017].

IRENA (2016), REmap: RoadFmap for A Renewable Energy Future: 2016 Edition, IRENA, Abu Dhabi

IRENA (2017), Chapter 3 and 4 of Perspectives for the energy transition – investment needs for a low-carbon energy system, ©IRENA 2017, Abu Dhabi.

EU and IRENA (2018), Renewable Energy Prospects for the European Union, EU and IRENA, Brussels/Abu Dhabi.

Saygin, D. et al. (2015), "The Implications for Renewable Energy Innovation of Doubling the Share of Renewables in the Global Energy Mix between 2010 and 2030", Energies, Vol. 8, pp. 5828–5865.

Kempener, R. et al. (2015), "A Global Renewable Energy Roadmap: Comparing Energy Systems Models with IRENA's REmap 2030 Project", Informing Energy and Climate Policies Using Energy Systems Models, Giannakidis, G. et al. (eds.), Springer International Publishing, pp. 43–67.

MICHAEL TAYLOR
International Renewable Energy Agency
MTaylor@irena.org

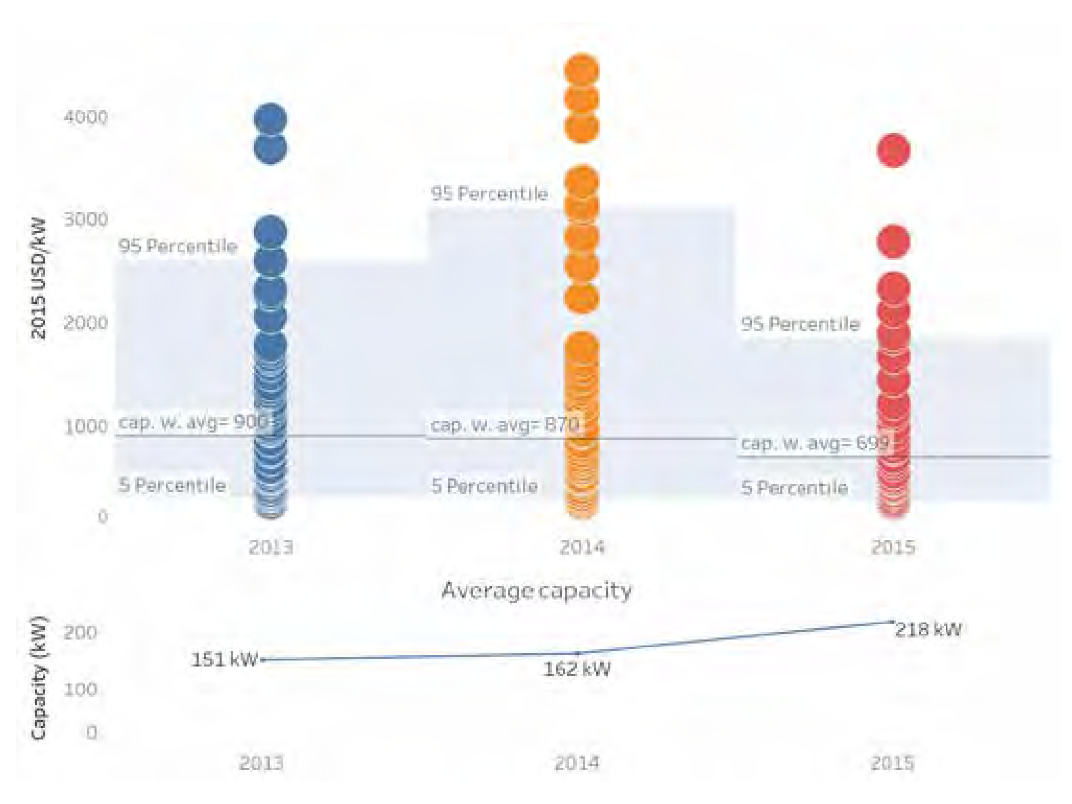


Figure 5: Large-scale heat pump equipment costs in Europe/mena, 2013-2015
Source: IRENA and the IRENA Renewable Costing Alliance

Events 2018

10-13 June
The 9th Asian Conference on Refrigeration and Air-conditioning
Sapporo, Japan
http://www.acra2018.org/

12-14 June
ATMOsphere America 2018
Long Beach, California
http://r744.com/events/view/atmosphere_america_2018

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

23-27 June
ASHRAE Annual Conference
Houston, Texas
https://www.ashrae.org/membership--conferences/conferences/2018-ashrae-annual-conference

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

27-28 July
International Conference on Emerging Technologies for Sustainable and Intelligent HVAC&R Systems
India
http://iifiir.org/clientBookline/recherche/NoticesDetaillees.asp?VIEWALL=TRUE&ToutVisualiser=1&INSTANCE=exploitation&iNotice=7&ldebut=

2-5 September
1st IIR International Conference on the Application of HFO Refrigerants
Birmingham, UK
http://www.hfo2018.com/

18-20 September
2nd IGSHPA Research Track
Stockholm, Sweden
https://www.kth.se/itm/inst/energiteknik/forskning/ett/projekt/energibrunnar/events/conference/igshpa-research-trac/2nd-igshpa-research-track-1.743320

23-26 September
7th International Building Physics Conference
Syracuse, New York
http://ibpc2018.org/

4-5 October
The Third International Conference on Efficient Building Design — Materials and HVAC Equipment Technologies
Beirut, Lebanon
https://www.ashrae.org/conferences/specialty-conferences/the-third-international-conference-on-efficient-building-design

16-18 October
Chillventa 2018
Nuremberg, Germany
https://www.chillventa.de/en

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

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

Events 2019

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

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

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

National Team CONTACTS

AUSTRIA
DI Dr. Thomas Fleckl
Austrian Institut of Technology
Tel:+43 50550 6616
thomas.fleckl@ait.ac.at

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

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

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

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

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

ITALY
Dr. Maurizio Pieve
Italian National Research Council
Institute for Advanced Energy Technologies (CNR – ITAE)
Tel: +39 90 624 229
giovanni.restuccia@itae.cnr.it

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

NETHERLANDS
Mr. Tomas Olejniczak
Netherlands Enterprise Agency (RVO)
Tel: +31 88 60 226 77
marion.bakker@rvo.nl

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

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

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

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

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

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

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

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

Technology Collaboration Programme on Heat Pumping Technologies (HPT TCP)
International collaboration for energy efficient heating, refrigeration, and air-conditioning.

Vision
Heat pumping technologies play a vital role in achieving the ambitions for a secure, affordable, high-efficiency and low-carbon energy system for heating, cooling and refrigeration across multiple applications and contexts. The Programme is a key worldwide player in this process by communicating and generating independent information, expertise and knowledge related to this technology as well as enhancing international collaboration.

Mission
To accelerate the transformation to an efficient, renewable, clean and secure energy sector in our member countries and beyond by performing collaborative research, demonstration and data collection and enabling innovations and deployment within the area of heat pumping technologies.

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

The Heat Pump Centre is operated by RISE Research Institutes of Sweden.

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

www.heatpumpingtechnologies.org