Heat Pumping Technologies MAGAZINE

A HEAT PUMP CENTRE PRODUCT

Cooling for the Future

David Catalini, University of Maryland, USA

”ONE WAY TO TACKLE GLOBAL WARMING IS TO DEVELOP HEAT PUMPING CYCLES USING SOLID-STATE REFRIGERANTS”

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In this issue

Heat pumps – the mere term implies that the technology is used for heating. And heating has been in focus for the Heat Pumping Technologies TCP over the years. But this is slowly changing. As ever more people can afford installations for cooling, there is a rising need for novel cooling technologies world-wide, preferably without refrigerants with high climate impact. Therefore, the topic for this issue of HPT Magazine is "Cooling for the Future". We hope that this will be of interest to even more than the present HPT member countries!

The challenges that result from a growing need for cooling is pointed out in the Foreword. There it is also outlined what is currently done within the HPT TCP to meet this challenge, namely within Annex 53. The Annex is a result of the new HPT TCP strategy.

The issue carries two topical articles, each covering a cooling technology that is new for heat pumping technologies. One of them describes how electrochemical compression of gas can replace mechanical compression in a heat pumping or refrigerating cycle. The other explores how so-called caloric materials, solid-state refrigerants, can be used in cooling systems as a replacement for present-day refrigerants.

Some articles go beyond the focus area. One non-topical article is focusing on heat pump applications with thermal batteries. Another addresses the situation of industrial heat pumps in Denmark. The issue also includes a strategic outlook for the Netherlands, and the Column sheds light on the weak market for heat pumping technologies in Eastern Europe.

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 Articles

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FOREWORD

Cooling and refrigeration: what lies in the future?

Growing populations and improving economies worldwide, especially in the developing world, are projected to lead to huge increases in global demand for air conditioning (AC), dehumidification, and refrigeration. The International Energy Agency's (IEA) report, Energy Technology Perspectives 2016, projects that AC energy consumption and concomitant greenhouse gas emissions will, by 2050, increase 4.3 times over 2013 levels for non-OECD countries and 1.2 times for OECD countries (if no actions are taken to mitigate the increased demand). Similarly, demand for refrigeration is related to food preservation and storage and demand for food is expected to grow by 70% by 2050 relative to 2010, according to the 2015 report Doing Cold Smarter by the University of Birmingham, UK.

The large growth in demand will make global energy and climate goals much more difficult to achieve. Worldwide action, both near-term and longer-term, is urgently needed to address this challenge. Surely one immediate near-term approach is to maximize deployment of existing "best in class" AC and refrigeration equipment and systems throughout the world. Longer-term RD&D is needed, as well as to develop advanced, higher efficiency technology solutions.

In order to help address the longer-term need, in 2018 the HPT Executive Committee approved formation of the HPT Annex 53 "Advanced Cooling/Refrigeration Technologies Development." Members currently include China, Germany, Italy, South Korea, Sweden, and the USA. The goal is to share RD&D results to advance the development status of future refrigeration and AC systems. Technologies of interest follow two distinct paths: those based on the well-known and widely used vapor compression (VC) system, and the non-traditional cooling approaches, which are being increasingly investigated. VC technology has had decades of RD&D to date. This is continuing, and VC-based systems are likely to continue to be the system of choice for many applications in the coming decades. However, they are also vulnerable to further refrigerant restrictions. Non-traditional technologies (e.g., magnetocaloric (MC), elastocaloric (EC), electrochemical compression (ECC), membrane-based systems, etc.) generally are not subject to this challenge, since they do not rely on refrigerants in the traditional sense. However, these approaches still need further development before any will be ready for the market. The topical articles in this issue of the HPT Magazine provide more in-depth information about two attractive non-traditional technologies currently under development: the thermoelastic cooling and electrochemical compression concepts.

Van D. Baxter
Operating Agent for Annex 53
Oak Ridge National Laboratory, USA

Why we should take a closer look at Eastern Europe

Market statistics is a nice thing. Especially when it comes to sales figures for heat pumps, and especially when annual double-digit growth rates are reported. Europe seems to be on the right track as far as the distribution of heat pumps is concerned, and thus the distribution of the most important renewable heating and cooling technology. However, for a complete decarbonisation of the building sector even higher growth figures are necessary - and European policymakers are called upon to create the appropriate framework conditions quickly.

A closer look at the market statistics of the European Heat Pump Association (EHPA) reveals a highly differentiated picture in the regional distribution of sales figures in Europe. Almost 90% of heat pumps are sold in ten countries and the Scandinavian countries have the highest penetration rates (installed systems per capita). However, no figures are available from the South-eastern European countries and most of the Eastern European countries. It can be assumed that heat pumps in these countries tend to lead a shadowy existence, and that it will still be a long way to go to establish the technology there.

The reasons for this are manifold and presumably cannot be explained solely by economic conditions. I recently read a very interesting interview with Bulgarian political scientist Ivan Krastev in the Austrian weekly "Die Furche". He deals with the connections between democracy and demography in Eastern European countries and their repercussions on the current political situation in these countries and on possible signs of disintegration of the European Union. In his opinion one of the causes of the current political crisis lies in the way the West, after the end of the Cold War, went about "socializing" the East according to its own ideas and making it "socially acceptable". This kind of forced "imitation" led to the Eastern countries feeling that they were only copies and being constantly commented on by the Western countries in a better-knowing way. Another aspect is the strong emigration of educated and well-qualified workers. The societies not only lose their visionary and ambitious people, but also the money and know-how invested in them. Billions of Euros are shifting from East to West as a result. The resulting demographic crisis triggers fears, which in turn leads to the increased choice of populist and extreme parties, which in themselves are strongly national and little pro-European in character. This complicates and delays common European decisions, which in turn can have repercussions for energy and climate policy. In order to solve this problem, local people must be more closely involved and regional circumstances taken into account.

It may seem far-fetched, and even arbitrary, to link these hypotheses to the limited distribution of heat pumps in eastern European countries. In any case, it highlights aspects of challenges for political actors which we probably do not know and are aware of, but which could be essential for the establishment of heat pumps and the decarbonisation of the building sector in these countries.

THOMAS FLECKL
Head of Competence Unit, Sustainable Thermal Energy Systems
AIT Austrian Institute of Technology, Austria

HPT TCP welcomes Annex 55

ANNEX 55 COMFORT AND CLIMATE BOX

The pace and scale of the global clean energy transition is not in line with climate targets. Energy-related carbon dioxide (CO_2) emissions rose again in 2018 by 1.7%. The buildings sector represented 28% of those emissions. The growing global need for thermal comfort is a large contributor to emissions of greenhouse gases worldwide, and the transition to renewable energy is too slow.

Objective

The goal of this project is to speed up market development for smart integrated heating, cooling and energy storage solutions through the development of a so-called Comfort and Climate Box (CCB) solution. There is potential for cost-effective technologies to deliver energy savings of 500 Mtoe per year in the building sector worldwide between 2020 and 2050. Heat pumps have the potential to massively reduce carbon emissions for heat. By combining them with energy storage and control in a CCB they can also contribute to the decarbonization of the energy sector by increasing the capture of renewables, such and wind and solar power, in the electricity grid, balancing and stabilizing the grid and providing optimal security of supply to buildings.

Read more on the Annex homepage:
https://heatpumpingtechnologies.org/annex55/

Who are you nominating for the Peter Ritter von Rittinger International Heat Pump Award?

Every three years the Peter Ritter von Rittinger International Heat Pump Award is awarded in conjunction with the International IEA Heat Pump Conference. The Peter Ritter von Rittinger International Heat Pump Award is the highest international award in the air conditioning, heat pump and refrigeration field.

The Peter Ritter von Rittinger International Heat Pump Award is named for Peter Ritter von Rittinger who is credited with the design and installation of the first energy-conserving heat pump system at a salt works in Upper Austria in 1855. The award highlights outstanding contributions to the advancement of international collaboration in research, policy development and applications for energy-efficient heat pumping technologies.

Read more about the criteria, previous awardees and nominate your candidate at https://heatpumpingtechnologies.org/about/rittinger-award/

Rittinger Awardees at the 12th IEA Heat Pump Conference in Rotterdam, the Netherlands, in 2017.

Welcome to the IEA Heat Pump Conference in 2020

January 1, 2019	Abstract submission open
June 30, 2019	Abstract submission due
November 15, 2019	Full paper submission due
February 15, 2020	Final paper submission due
May 11-14, 2020	13th IEA Heat Pump Conference 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 successful histories in Japan and China, it is the fourth Heat Pump Conference to be held in Asia, and the first to be held in the Republic of Korea.

Conference Venue

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

Conference Goal

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

Conference Topics

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

- Recent Advances on Heat Pumping Technologies
- Environment-friendly Technologies
- Systems and Components
- Field Demonstration 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, connected to annexes in the HPT TCP
- Technical tours
- Sight-seeing programs
- Social gatherings

Paper Review Process

The abstract submission has been closed. The abstracts have been screened by a Regional Coordinator and authors have been advised of acceptance. Full paper submission was due by November 1 and has been extended to November 15.

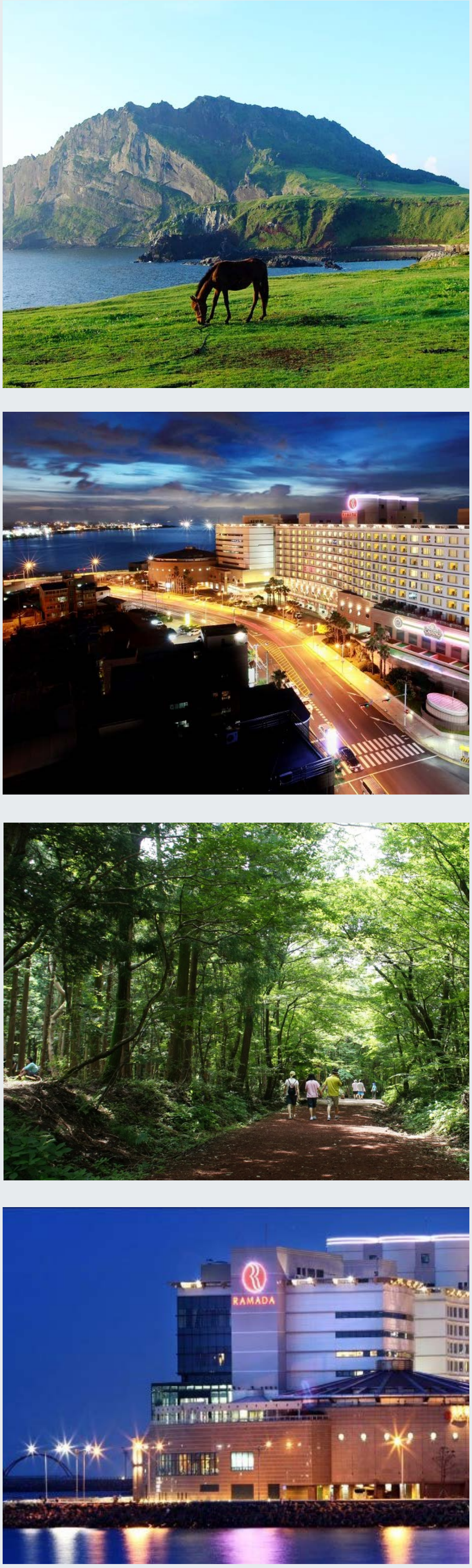
Organization

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

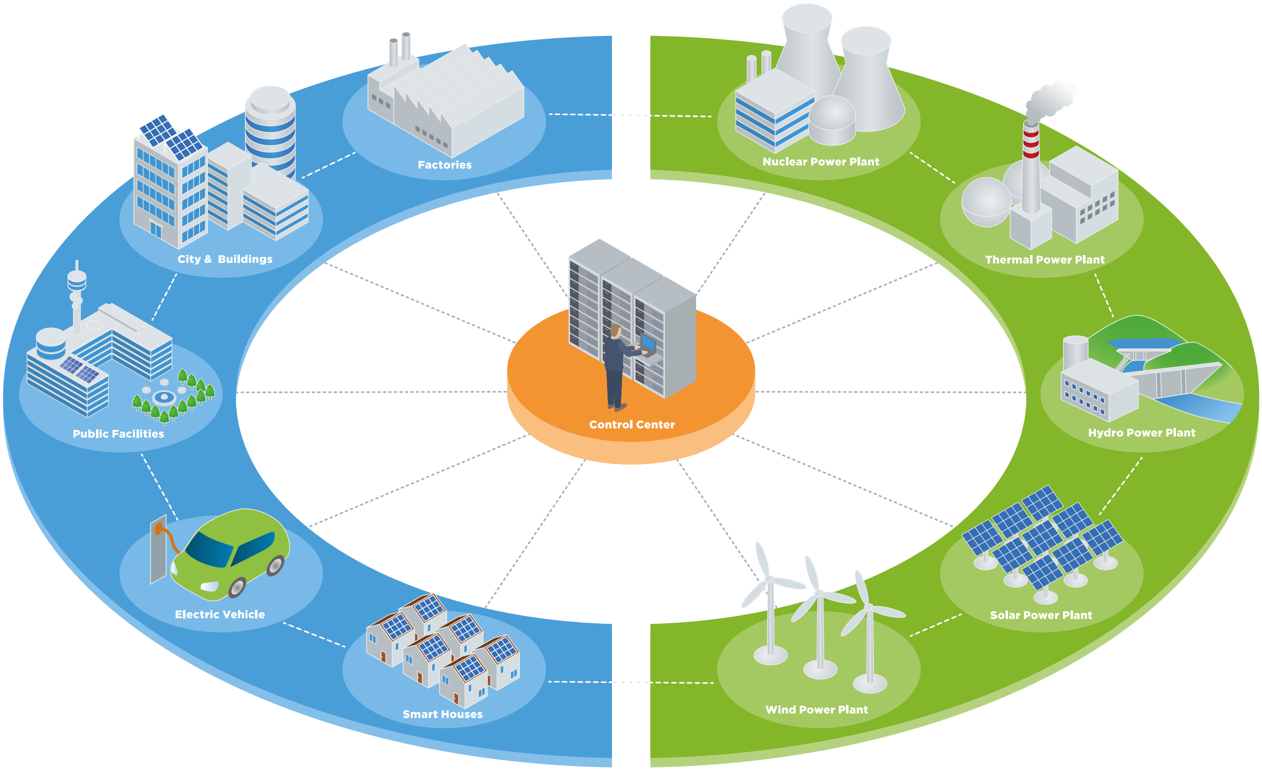
Per Jonasson	Chairperson IOC, Swedish Refrigeration & Heat Pump Association, Sweden
Sophie Hosatte	Vice-Chairperson IOC, CanmetENERGY, Canada
Hideaki Maeyama	Vice-Chairperson IOC, HPTCJ (Heat Pump and Thermal Storage Technology Centre of Japan)
Min Soo Kim	Chairperson NOC, Seoul National University,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

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

13th IEA HEAT PUMP CONFERENCE
2020 | JEJU KOREA



Images of Jeju and Night view of Ramada Plaza Hotel Jeju



Positive energy districts in Europe – a definition is on its way

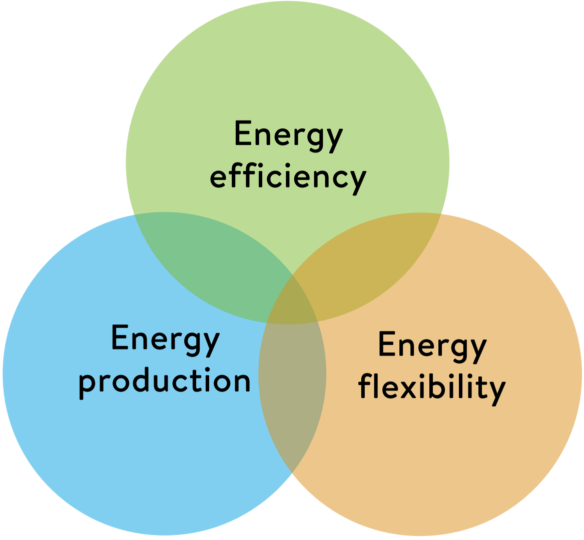
For some years now, there has been an interest in Europe regarding positive energy districts, or PEDs in short. But there exists no thorough common definition of what a PED really is. To change this, multiple member countries are currently involved in the creation of a framework definition.

The basic definition of a PED is that it generates more energy than it consumes, during a given period of time. But in order to use the PED concept to drive change, also other aspects need to be included in a definition: energy efficiency, energy flexibility and energy production. The European initiative is striving to optimize between these three functionalities, as well as stressing the need for implementation of renewable energy, and reduction of greenhouse gases.

In most cases, many different energy sources will be needed in a PED. Among these, heat pumps will often be one of the natural options, given their possibilities. When integrated with the rest of the energy system they can contribute flexibility service, e.g. facilitating the introduction of intermittent electricity production. They can also be used to take proper care of waste heat. When operated with renewable electricity, heat pumps also offer a completely renewable alternative with zero greenhouse gas emissions.

The European idea is not to create a very specific definition. This is based on the understanding that preconditions vary significantly between countries and cities, meaning that all PEDs cannot be created in the same way. Instead a framework definition is investigated, being neutral to technologies, energy needs, policy and other place-based circumstances.

The need for a common PED definition for the EU stems from a target set in the union, aiming at creating at least 100 PEDs until 2025, with at least one in each member country. There are already initiatives going on, and a common and widely accepted framework definition is seen as a facilitator to strengthen the work even further.



Ongoing Annexes in HPT TCP

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

FUEL-DRIVEN SORPTION HEAT PUMPS	43	AT, **DE**, FR, IT, KR, SE, UK, US
HYBRID HEAT PUMPS	45	CA, DE, FR, **NL**, UK
DOMESTIC HOT WATER HEAT PUMPS	46	CA, CH, FR, JP, **NL**, KR, UK, US
HEAT PUMPS IN DISTRICT HEATING AND COOLING SYSTEMS	47	AT, CH, **DK**, SE, UK
INDUSTRIAL HEAT PUMPS, SECOND PHASE	48	AT, CH, **DE***, DK, FR, JP, UK
DESIGN AND INTEGRATION OF HEAT PUMPS FOR nZEB	49	AT, BE, **CH**, DE, NO, SE, UK, US
HEAT PUMPS IN MULTI-FAMILY BUILDINGS FOR SPACE HEATING AND DHW	50	AT, **DE**, FR, IT, NL
ACOUSTIC SIGNATURE OF HEAT PUMPS	51	**AT**, DE, DK, FR, IT, SE
LONG-TERM MEASUREMENTS OF GSHP SYSTEMS PERFORMANCE IN COMMERCIAL, INSTITUTIONAL AND MULTI-FAMILY BUILDINGS	52	FI, NL, NO, **SE**, US, UK, DE
ADVANCED COOLING/ REFRIGERATION TECHNOLOGIES DEVELOPMENT	53	CN, DE, IT, KR, **US**
HEAT PUMP SYSTEMS WITH LOW GWP REFRIGERANTS	54	IT, JP, KR, **US**
◖ COMFORT AND CLIMATE BOX	55	AT, IT, **NL,** SE, US

◖ NEW

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

The Technology Collaboration Programme on Heat Pumping Technologies participating countries are:
Austria (AT), Belgium (BE), Canada (CA), China (CN), 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
43
FUEL-DRIVEN SORPTION HEAT PUMPS

Within Annex 43, a consortium of industry and academic partners has worked together to widen the market acceptance of fuel driven sorption heat pumps, identify market barriers and opportunities, quantify the performance of such heat pumps in typical heating systems, identify the most suitable system layouts and propose technical procedures for standardized performance evaluation. Sorption technology can reduce gas consumption for domestic heating by 40% (existing products) and may increase the saving to 60%, with corresponding benefits in GHG emissions.

Introduction

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. 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 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 had 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 are 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 results

Within the Annex, a common view on market requirements and potential was found for different markets. Amongst other, this led to a report within the Mission Innovation Heating&Cooling Innovation Challenge on Sorption Heat Pumps. Gas (natural gas, biogas, hydrogen etc.) heat pumps for domestic use are potentially a very large market if they can become the successor technology to the condensing boiler whose worldwide production exceeds 13 million/year (China, South Korea and UK being the largest individual markets). Sorption technology can reduce gas consumption for domestic heating by 40% (existing products) and may increase the saving to 60%, with corresponding benefits in GHG emissions.

Regardless of the technology, the major challenge for sorption heat pumps to become established as mainstream systems is a large reduction in capital cost. The only product of less than 20 kW capacity is made in small numbers, and retail cost is around €10,000. There is consensus that, due to economies of scale, with a production of >100,000 per year, costs could drop to €3,000. There is also a need for lower capacity systems (ca 10 kW) and for compact units that do not require special skills to install.

There has been progress within the Annex on several ongoing developments both for ad- and absorption gas heat pumps (GHP). At Politecnico di Milano (Italy), a water-ammonia absorption gas heat pump based on plate heat exchangers (PHE) is under development and shows promising results both in terms of compactness as well as efficiency at high supply temperatures, see Figure 1. Also, the company Ariston (Italy) is working on

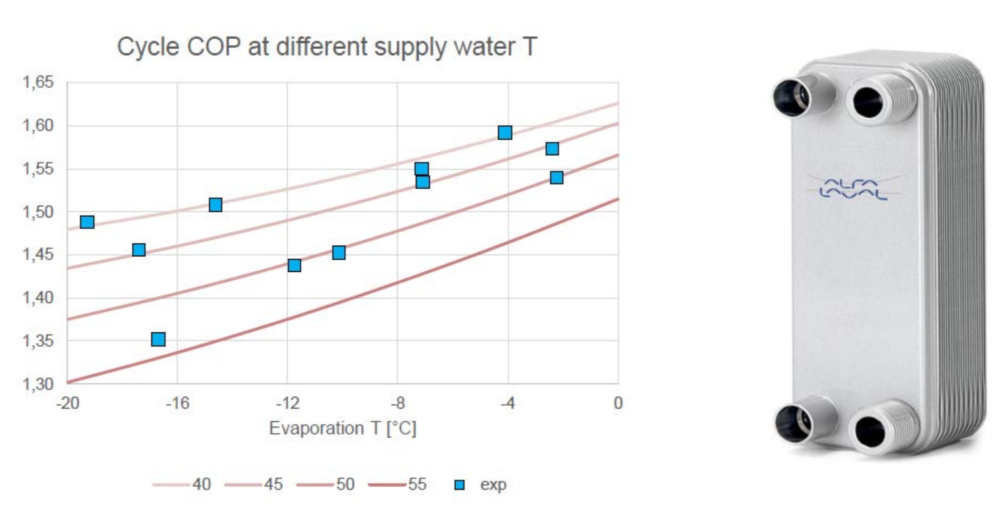


Fig. 1: Polynomial interpolation of experimental results achieved by a single channel PHE adsorber (Alfa Laval) at 75% of nominal load (Politecnico di Milano, project i-GAP)

an absorption gas heat pump for the residential market. University of Warwick (UK) has received funding for the development of an adsorption gas heat pump based on active carbon and ammonia as working fluid, using a promising new adsorber design, Figure 2 [1]. Fraunhofer ISE (Germany) works on the development of a zeolite-water based GHP with a consortium of industry partners and has developed a binder-based coating technology, Figure 3.

A Sorption System Simulation program (SorpSim) has been developed by Oak-ridge National laboratory (ORNL, USA) and Purdue University (USA) for flexible steady-state simulation and analysis of a wide range of sorption cycles with user-friendly features & parametric analysis functions, Figure 4. The isotherm database SorpPropLib developed with input from Annex 43 participants has been dynamically linked as an external library to SorpSim, supporting simulation and isotherm inquiry function in the SorpSim GUI. This allows users to evaluate the effects of new materials for sorption heat pumps.

Several simulation studies have been performed, e.g. deriving the potential of gas-driven Sorption Heat Pumps for different building types, climates and heat distribution systems. It is shown that compared to a condensing boiler savings in primary energy use of up to 40% are feasible with existing products and 60% in reach with ongoing developments.

EHPA Working Group Thermally Driven Heat Pumps

Within the European Heat Pump Association (EHPA), the Working Group Thermally Driven Heat Pumps (WG-TD-HP) continues part of the work of Annex 43, such as networking, policy and legislation information, exchange between industry and academia and common strategies for entering the heating market with efficient and cost-effective heat pumping technology.

Contact

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Fig. 2: The "Kebab design": Novel finned tube and shell adsorber with compacted active carbon for ammonia adsorption (University of Warwick)

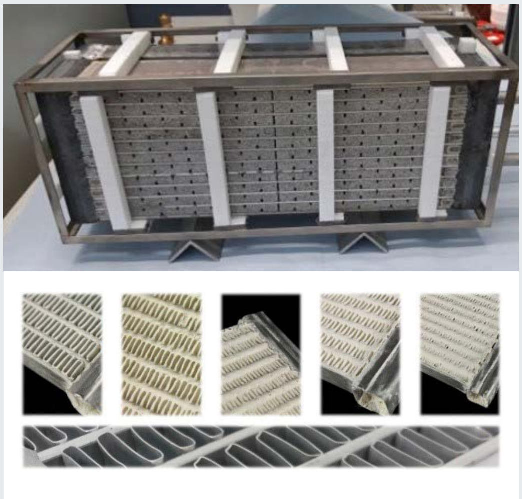

Fig. 3: Compact zeolite-water adsorption module based on aluminum fibre heat exchangers (Fraunhofer) with direct crystallization coating (Fahrenheit), top; novel binder-based zeolite coating (Fraunhofer), bottom.

Annex website

https://heatpumpingtechnologies.org/annex43/

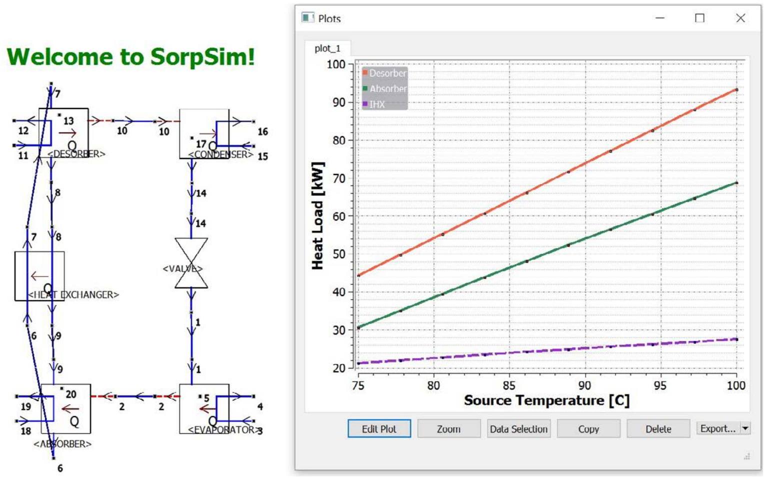

Fig. 4: Screenshot of Sorption system Simulation program (SorpSim) developed by ORNL and Purdue University.

ANNEX 47

HEAT PUMPS IN DISTRICT HEATING AND COOLING SYSTEMS

District heating in general, and heat pumps connected to the grids in particular, are predicted to play a key role in the energy grid and supply for the future. With the implementation of district heating, it is possible to cover up to 50% of the heating demand in Europe, and heat pumps can deliver around 25% of the energy to the district heating grid. The *Heat Roadmap Europe 4* scenarios (HRE4) with a larger share of district heating in the energy system show that the CO_2 emissions can be reduced with more than 70% compared to today's situation.

Heat pumps can be a key technology in the future district heating grid in different ways:

1: Heat pumps can act as a balancing technology when the electrical production fluctuates.
2: Heat pumps phase out fossil fuels from the energy system.
3: Heat pumps make it possible to use very low (below 60 °C) and ultra-low (below 45 °C) temperatures in the district heating grid.
4: Heat pumps make it possible to minimize grid losses in the district heating grid.

Introduction

Annex 47 regarding heat pumps in district heating systems has been an important annex under the IEA Heat Pumping Technologies TCP, since gradually more countries are realizing that district heating is a way to phase out fossil fuels. The Annex is now finalized, and all reports and case studies are available at the web site of the Annex . The project group consists of members from Austria, Denmark, Sweden, Switzerland and United Kingdom, and during the project period the interest for heat pumps in district heating has grown in other countries; a follow-up annex will most likely be started regarding "Flexibility by implementation of heat pump in multi-vector energy systems and thermal networks".

Market overview

The HRE4 project showed that for the vast majority of European urban areas district heating (DH) is a cost-efficient solution, which can provide at least half of the total heat demand in the fourteen countries included in the study, while efficiently reducing CO_2 emissions and the primary energy demand of the heating and cooling sector. Based on its results, the project suggests that large-scale heat pumps (HP) have a large role to play in future DH systems in order to develop flexible and supply-safe systems.

According to the HRE4 project, the European share of DH in the heating sector should increase from 12% (current value) **to 50% by 2050**. This is an important shift in the European heating sector, and it shows that DH can be cost-effective and essential to significantly reduce CO_2 emissions in the energy sector. In the HRE4 project, three main scenarios were developed:

- » **BL 2015** – baseline scenario representing the current situation of the heating and cooling sector, based on data from 2015, see Figure 1.
- » **BL 2050** – this scenario represents the development of the baseline scenario under the current agreed policies regarding savings and RES, etc., but without any additional measures to improve the decarbonisation of the system.
- » **HRE 2050** – scenario representing a highly decarbonised energy system with redesigned heating and cooling sector that also includes energy savings. This scenario is solely based on proven technologies and does not depend on unsustainable amounts of bioenergy.

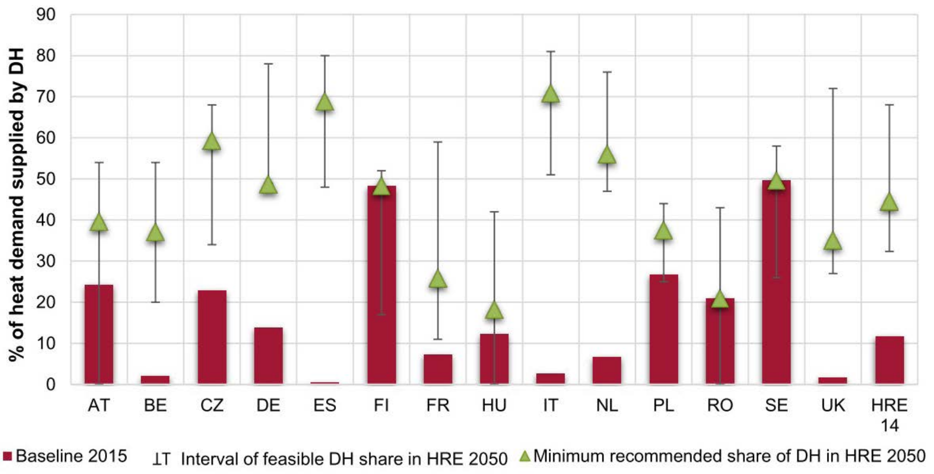

Fig. 1: Share of district heating in 2015 (Baseline 2015), recommended level of district heating share in Heat Roadmap Europe 2050 (HRE2050), and the range of economically feasible district heating within a 0.5% total annual energy system cost change sensitivity.

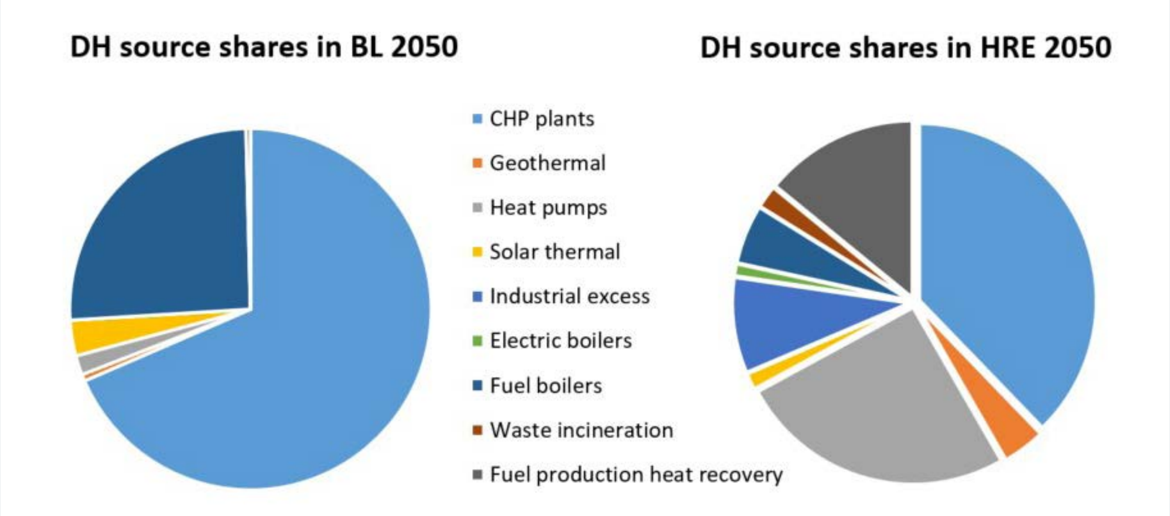

Fig. 2: District heating sources share for BL 2050 and HRE 2050 scenarios.

In the modelled energy efficiency scenario for 2050 (HRE 2050), DH is supplied mostly by decarbonised energy sources and **25% of the total DH demand is met by large-scale HPs**, see figure 2. This scenario would bring a higher variety of energy supply to the DH, which will increase the flexibility of the system as well as the security of supply. The HRE 2050 scenario shows that it would be possible to achieve a much more decarbonized DH in 2050 than in the BL2050 scenario, which **reduces CO_2 emissions with more than 70%**.

Demonstration projects

One of the main objectives of Annex 47 is to show the possibilities regarding the implementation and integration of heat pumps in district heating grids. It was, therefore, an aim to create an idea catalogue which shows different implementation cases. It has been possible for the project group to describe 39 different cases where heat pumps are integrated in a district heating grid. All the cases can be found at the Annex 47 webpage.

Review of different concepts/solutions

The research shows that large heat pumps have been integrated in the district heating networks since the 1980s, especially in the Scandinavian regions. The widespread use of district heating networks as well as the increasing share of fluctuating power sources such as photo voltaic (PV) and wind power, combined with decreasing electricity prices, have been the driving factors. Currently, Sweden is a forerunner using heat pumps in district heating and cooling networks. Approximately 7% of the district heating demand is produced by heat pumps. In other countries, the heat pump market consists mainly of devices for the supply of single and multi-family houses. Because of high system temperatures prevailing in many of the heating networks, adapted concepts are needed in order to be able to guarantee the cost-effectiveness of the systems. The aim of current research projects such as fit4power2heat is, therefore, to establish heat pumps by participating in various energy markets as an attractive alternative. It must be mentioned that especially in the last few years many efforts have been initiated all over Europe to foster heat pump integration in district heating and cooling (DHC) networks.

Above all, the basis for economical operation is the correct design and hydraulic integration of the systems. Advantages can be achieved through different modes of operation. Instead of monovalent operation, additional heat generator(s) for peak load times can save a large part of the investment costs and risks.

Furthermore, different circuit options can be used in order to achieve the optimum operation of the system. Depending on which framework conditions exist, it is possible to exploit considerable potentials in terms of efficiency and therefore also in terms of costs. The correct design of the heat source system and the heat sink plays as much a role as the dimensioning of the heat pump itself.

As a first clue, AIT internally developed an Excel-based tool which can be used to pre-estimate feasibility and cost-effectiveness. With the help of simple calculations and comparing them to already realized plants, first conclusions can be drawn. The more detailed information about the planned project, the more accurate the initial assessment can be. The calculations can be carried out relatively easily and without prior knowledge of special software, through the conversion into Excel by means of VBA and the database integrated in the tool, as well as the user interface. The quick and simple adaptation of the underlying database is, therefore, also guaranteed.
In addition to the electrically driven compression heat pumps, also thermally operated heat pumps are used. Depending on the field of application, the advantages of the different technologies can be used.

With reference to the results achieved by the above-mentioned investigations, the importance and contributions of heat pumps in district heating networks were

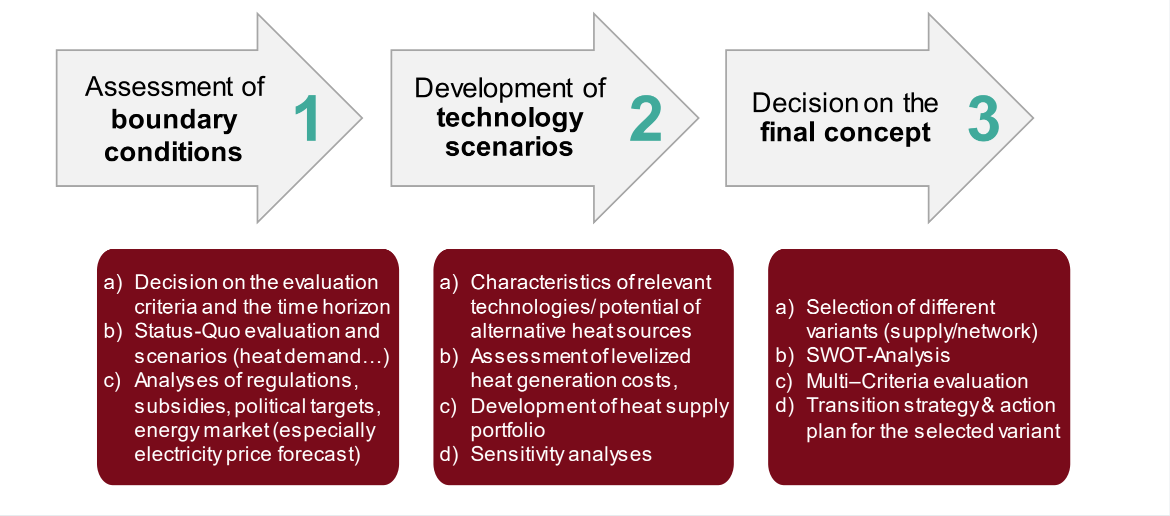

Fig. 3: Three phases for the development of a heat supply strategy (Source: AIT)

pointed out. In addition, recommendations for "best practice" strategies for the operation of heat pumps in combination with a central storage unit were presented:

- Heat pumps with dynamic pricing and demand-side management (DSM) are more resilient to market risks, since dynamic operation counteracts fluctuations in fuel and electricity prices;
- Heat pumps increase the flexibility of district heating systems by expanding the heat generation portfolio, which enables higher reactivity through fast commissioning and low start-up costs as well as takes advantage of the volatility of the electricity market and thermal batteries;
- Heat pumps can be used to increase renewable heat generation. In addition, low-temperature heat sources and alternative heat sources (e.g., waste heat) can be used.

Implementation barriers, possibilities, and solutions

District heating networks are essential for future energy system, especially in urban areas. The integration of heat pumps can reduce investment risks in DH networks, increase supply security, reduce CO_2 emissions and thus contribute to the COP 21 objectives agreed in Paris. At present, heat pumps play a minor role in European district heating networks.

Barriers to the large-scale integration of heat pumps are, i.a., the lack of heat sources (often only available in small decentralized quantities) or a low temperature level of the sources (low efficiency). Similarly, most operators (still) have a lack of experience regarding the integration and operation of heat pumps in existing district heating systems (compared to well-known biomass or gas-based generation units).

Another barrier is the high temperature of the existing heat networks which reduces the heat pumps efficiency. Furthermore, the high temperatures of these networks lead to high heat losses especially in residential buildings which make heat networks almost unsustainable in very energy efficient buildings. Therefore, the low temperature networks implementation would help to increase the use of heat pumps in these networks.

Nevertheless, in recent years there has been greater acceptance of heat pumps among district heating operators. This has led to many innovative heat pump projects as shown in Task 2.

The optimum combination of heat generation plants in DH networks depends on the various parameters and is correspondingly individual for each network. A method for the development of sustainable heat supply concepts for district heating networks is described in Task 3, and consists of three phases as shown in Figure 3.

To achieve a sustainable heat supply which includes a significant proportion of alternative heat sources, the implementation of more demonstration sites is necessary.

Success factors are:

- **Strong partners** (companies, institutes, start-ups, etc.);
- **Projects** (demo, best practice, show up experiences, and motivation to install HPs);
- **Learning by doing** (requires pioneers who are willing to "pay their dues“);
- **Energy spatial planning** (localizing waste heat, avoiding double infrastructure);
- **Standardized solutions** (R&D, cost degression/ economy of scale);
- **Price signals** (to the use of fossil fuel; reduce the burden from tax and levy on clean energy).

Annex website

https://heatpumpingtechnologies.org/annex47/

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ANNEX 48
INDUSTRIAL HEAT PUMPS, SECOND PHASE

Industrial heat pumps (IHP) are active heat-recovery devices. The aim of the Annex is to understand the worldwide activities of industrial heat pumps which are necessary for the reduction of energy consumption and GHG emissions through the increased utilization in industry. The goal of Annex 48 is to concentrate on the development and distribution of condensed and clear information material for policy makers, associations, and industries.

The latest workshop took place at the IIR International Congress of Refrigeration in Montreal 2019 on August 28 with seven presentations and a panel discussion.

R. Jakobs introduced the subject with the history of industrial heat pump annexes, since the 1980s, and the main goal of the current work.

V. Wilk talked about the increasing energy efficiency in the industry of Austria. More than 70 interesting examples of IHPs have been collected. Especially in the food industry, simultaneous heating and cooling applications in the range of 10-100 kW with internal heat demand for space heating have been identified. Other applications are in the power plants for district heating for the flue gas condensation with absorption and compressor HPs.

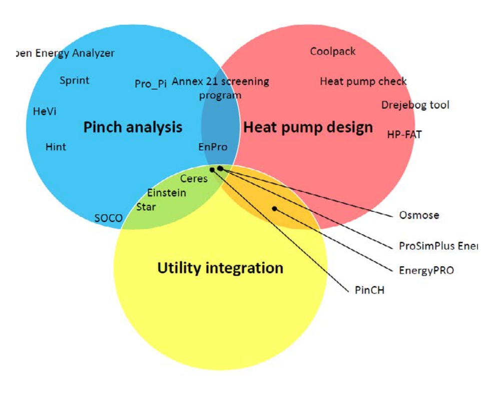

Fig. 1: Design methods of heat pump integration (I. Kantor)

I. Kantor from Switzerland identified optimal placements of IHPs in processes. He gave an overview regarding pinch analysis and the state of art of design methods of heat pump integration, see Figure 1.

N. Hewitt presented IHPs applications in UK. The research of High Temperature Heat Pumps showed the direction with transcritical fluids to 200 °C. Combined Heat Pump with Organic Rankine Cycles were discussed and

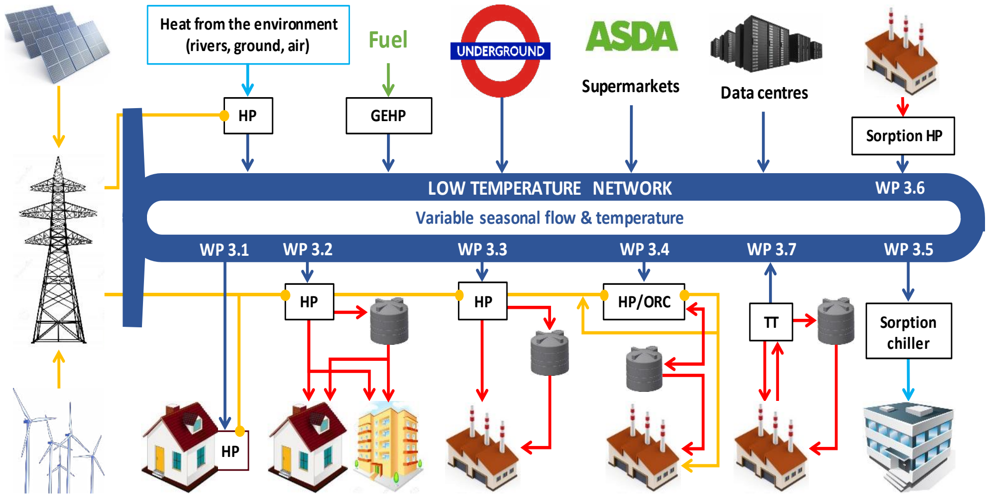

Fig. 2: Possibilities of Low Temperature Nets for district heating grids (N. Hewitt).

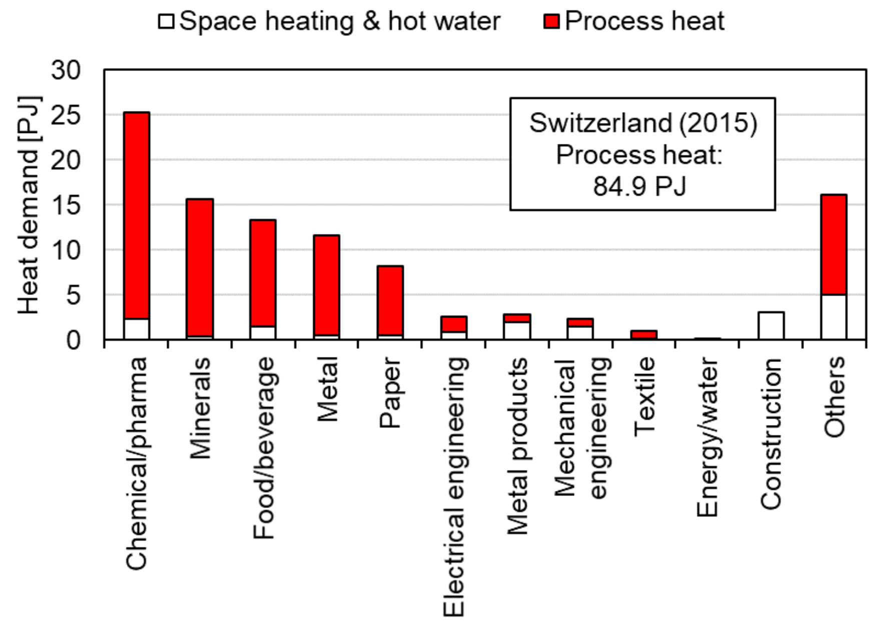

Fig. 3: In industry, the need for process heat is much larger than the need for space heating and hot water (C. Arpagaus).

showed ambitious possibilities for Low Temperate Nets (LoT-NET) as a promising improvement step for district heating grids.

B. Zühlsdorf presented IHP applications especially for district heating and industry in Denmark. He discussed the special political targets for the energy systems in his country. For more details, see the article in this Magazine issue, p 38.

District heating with IHPs is a special application with more than 100 MW heating capacity. The situation is understood by all involved parties, solutions are becoming standardized, different tools for planning support are available (planning guidelines, incl. all required information, structured overview with possible scenarios, catalogue with inspiration and best-case examples, and calculation tools). Heat pumps are becoming the preferred solution for district heating.

Y. Uchiyama presented the Evaluation of Good Practices for Industrial Heat Pumps in Japan. He started with the mitigation targets for GHG emission. In 2030, the reductions will be →26%; in 2050 →80% and in 2100 →100%. Regarding the 112 samples of good practices he showed the application sectors, the supply temperatures and the effects of primary energy, CO_2, and energy cost savings. The selection of best practices was done by a special criteria analysis. Four important items required for the best practice are: Recovery or recycling of low temperature heat; Reduction of steam heat loss; Separate heat supply for different production processes and Simultaneous heating & cooling operation.

C. Arpagaus demonstrated the growing importance of heat pumps in the Swiss industry. Priority 1 is Food industry, 2 is Chemical industry and 3 is Metal products. See also Fig. 3.

The utilisation of waste heat from a server room as heat source for a cheese factory was a further promising example for low temperature nets which combine heat source and heat sink demands in a local area. For more details, see the article in the HPT Magazine issue 2/2019, p 23.

Annex website

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ANNEX 49

DESIGN AND INTEGRATION OF HEAT PUMPS FOR nZEB

Building technology concepts of Nearly Zero Energy Buildings (nZEB) gain importance, since the requirement to achieve nearly zero energy consumption has been introduced for all new public buildings according to the EU Energy Performance of Buildings Directive (EPBD) on January 1, 2019. In around one year, by the beginning of 2021, this requirement will be extended to all new buildings. Heat pumps are already well represented as building technology for the nZEB due to their unique features of high efficiency, in particular at the favourable boundary condition of lower temperature requirements in high performance buildings, and multifunctional operation, since DHW and space cooling also gain importance in nZEB. In IEA HPT Annex 49, the heat pump application and integration in nearly Zero Energy Buildings is investigated in detail.

Task 1, the state-of-the-art analysis, a comparison of the different definitions of nZEB in the participating countries is made, since despite different attempts of a harmonization, the resulting definitions in the countries remain quite different. Therefore, it is also hard to tell the ambition level in the different countries.

In Task 2, Task 3 and Task 4, the integration and design of heat pumps and the monitoring of realized nZEB with heat pumps is examined, not only for single buildings, but also for groups of buildings and neighbourhoods. In some countries, these Tasks are interlinked, and monitoring projects are analysed by simulations in parallel.

Germany, for instance, has an ongoing monitoring project of eight plus-energy single family houses, which are supplied by two central capacity-controlled ground source heat pumps using a low temperature thermal grid, see Figure 1 (left). The central heat pumps can also work as a central heat storage, which enhances load management options by the heat pump operation regarding the self-consumption of the PV-electricity, since a large PV system of 88 $\mathrm{kW_p}$ is installed for the houses. Additionally, an electrical battery is included as storage for the PV electricity. The domestic hot water is heated by decentralized DHW storages with booster heat pumps, which use the thermal grid as source. The corresponding simulation studies (Figure 1, right) are dedicated to the performance evaluation of the system as well as the control optimization regarding the PV self-consumption and the grid interaction.

Monitoring results confirm the good performance of the central ground-coupled heat pumps, which reach a seasonal performance factor of 5.4 and 6 in the system boundary of the COP. An overall performance of 5.6 for the generation system, including the two heat pumps and source pumps, has been calculated, which is even better than the simulated values. For the decentralized booster heat pumps, an SPF of 4.1 excluding pumps and 4.0 including pumps has been extracted from the monitoring data. However, the booster heat pumps are a cascade system, using the thermal grid as heat source. Regarding the control optimization (Figure 1, right), the demand side management (DSM) of the heat pump with the electrical and thermal storage can increase the PV-self consumption and reduce the feed-in to the electrical battery. In a case study, evaluated by simulation, the direct PV consumption could be increased by 21%, while battery feed was reduced by 10% and grid feed-in by 11%.

Further interim results of the Annex 49 will be presented at a half-day workshop of Annex 49 at the IEA Heat Pump Conference in Jeju, South Korea, in May 2020.

Annex website

http://heatpumpingtechnologies.org/annex49/

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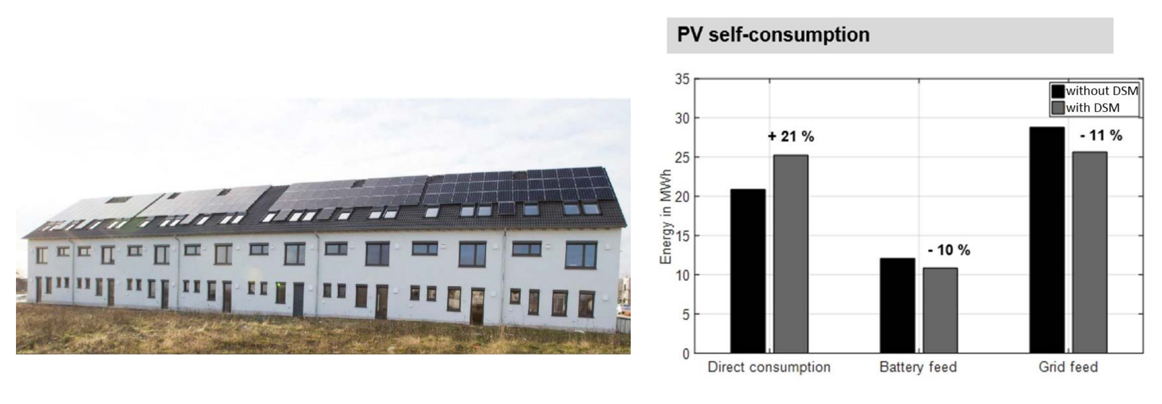

Fig. 1: Group of 8 terraced houses "Herzo Base" in Germany (left), and results of corresponding simulations for control optimization of PV-electricity self-consumption and reduction of grid interaction (right).

ANNEX
52

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

HPT Annex 52 – *Long-term performance monitoring of GSHP systems for commercial, institutional and multi-family buildings*, is now reaching its midway point. As of August 2019, seven countries are participating in this annex (Sweden, the USA, Finland, Norway, Germany, the UK and the Netherlands). At the 3rd Annex 52 experts' meeting in Finland in May, a first outline of an instrumentation guideline was presented and discussed, and a new system boundary schema, an extension of the SEPEMO schema, but applicable for larger and more complex GSHP systems, was introduced. The annex has so far resulted in an annotated bibliography comprising 65 publications describing a total of 55 GSHP systems that report on SPFs, four published international conference papers, and two peer-reviewed journal papers. One of the important goals of HPT Annex 52 was to provide at least one set of open access monitoring data for a large commercial GSHP system. The two published journal papers by Naicker and Rees (2018) and Spitler and Gehlin (2019) both provide high quality open access measurement data, which may be used by researchers and developers in their future work.

Naicker and Rees (2018) present seasonal system performance factors for a GSHP system serving a university building in Leicester, England. Seasonal performance factors are presented for SEPEMO levels C1 and H1, and combined cooling and heating SPF, referred to as SPF_1, SPF_2, and SPF_4, are also defined corresponding to SEPEMO levels H1, H2 and H4. The authors show that cycling losses increase with decreasing cycle time, and that SPF_2 and SPF_4 are affected by the pumping controls that start the circulating pumps three minutes before the compressors. Under low load conditions, with short cycles, the pumping energy consumption can be as high as 30% of the heat pump energy consumption. Several approaches to improving the system performance are identified, including incorporating buffer tanks, use of a smaller capacity "lead heat pump", and use of variable speed compressors.

Fig. 1: The PhD student Selvaraj Naicker at the Hugh Aston Building, DeMontfort University, Leicester, England. Photo credit: J.D. Spitler

Fig. 2: One issue identified in the Studenthuset GSHP system was excess pumping power. Photo credit: J.D. Spitler

Spitler and Gehlin (2019) analyze one year of monitoring data for a mixed-use commercial GSHP system in Stockholm, Sweden. The building owner has long experience with GSHP systems in buildings and the system is thoroughly instrumented and monitored by experienced staff. SPF values for SEPEMO boundaries H2, H3 and C2 are calculated. Airflow rate measurement is not available for the building, which precludes calculating COP and SPF for the entire system. The authors show that the system provides space heating consistent with the design values, and that the cooling provided is about four times higher than anticipated in the design. A key finding is that the measured COPs are more affected by the amount of heating and cooling provided than by the entering fluid temperature to the heat pumps. Heating COPs are actually higher at lower entering fluid temperatures, which correspond to higher run-time fractions for equipment and less influence of "parasitic" loads such as pumps and unit control boards. The *Legionella* protection system and DHW recirculation system run all the time, causing the COP to approach one at times in the summer. In addition, the minimum flow rate set point in the borehole circuit leads to excess flow and excess energy consumption by the circulating pump. The paper includes a comprehensive review of the performance measurement literature for large GSHP systems. The authors identify several issues in calculation of SPF and COP for commercial buildings not previously addressed in the literature or by existing boundary definition schema. One of these issues is the treatment of electricity used by ventilation fans, for which the main purpose is providing ventilation, but which also provide significant amounts of heating and cooling.

The next steps within the Annex 52 work are to complete the on-going work with an instrumentation and measurement guideline, and to define useful key performance indices for various system boundaries. The fourth Annex 52 Experts' meeting took place in London on September 16-17. The fifth Experts' meeting will be held in Germany in the spring of 2020. Updates on the Annex 52 work and results are continuously posted on the Annex web site.

Fig. 3: Studenthuset building at the University of Stockholm. Photo credit: J.D. Spitler

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Annex website

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ANNEX 53

ADVANCED COOLING/ REFRIGERATION TECHNOLOGIES DEVELOPMENT

Growing populations and improving economies worldwide, especially in the developing world are projected to lead to huge increases in global demand for space cooling, dehumidification, and refrigeration. This will make reaching global energy and climate goals extremely challenging. In order to help address this challenge the HPT approved Annex 53 with a focus on longer-term RD&D to advance the efficiency of cooling and refrigeration systems. Technologies of interest include both those based on the well-known and widely used vapor compression (VC) systems and non-traditional cooling approaches being increasingly investigated.

Since the last report (in HPT Magazine issue 1/2019/) the newest member of the IEA HPT TCP, The Peoples Republic of China, has officially joined the Annex. They have an Annex technical expert team representing four universities and plan to investigate elastocaloric cooling, electrocaloric cooling, advanced VC cycles with zeotropic refrigerants, and absorption-compression cycles.

All the Annex participants have been busily preparing Task 1 reports to describe their respective technical projects and progress to date. Four examples are described herein. The Ames Laboratory (Ames, IA, USA) project goal is to demonstrate system-level performance of high-power density magnetocaloric (MC) systems using gadolinium (Gd)-based MC materials to support a 35 K temperature span or lift with a hot environment (heat sink) temperature of 308 K. Performance targets include operation frequencies ≥10 Hz, magnetic fields of ≤1 Tesla, and equivalent or better efficiency compared to current state of the art MC systems. Increasing frequency of operation for MC AMR systems increases the power density resulting in a more compact device with a smaller magnetic field.

The second example involves development of high-performance MC regenerators at Oak Ridge National Laboratory (ORNL). Highly porous regenerators with low pressure drop are critical for efficient operation at high frequencies as shown in Figure 1. Numerical models, finite element models, and bench testing will be used to evaluate regenerator concepts and size components for high frequency heat exchange.

Another project by Xi'an Jiaotong University and Gree (Chinese manufacturer) aims to develop a new class of elastocaloric (EC) cooling system driven by low-grade thermal energy. The concept is to use a heat-activated actuator made of high temperature shape memory alloy to drive the low-temperature shape memory alloy refrigerant. Theoretical investigation on the potential of the system was completed in 2019. Modeling results indicated that a heat source at 80 °C could be applied to

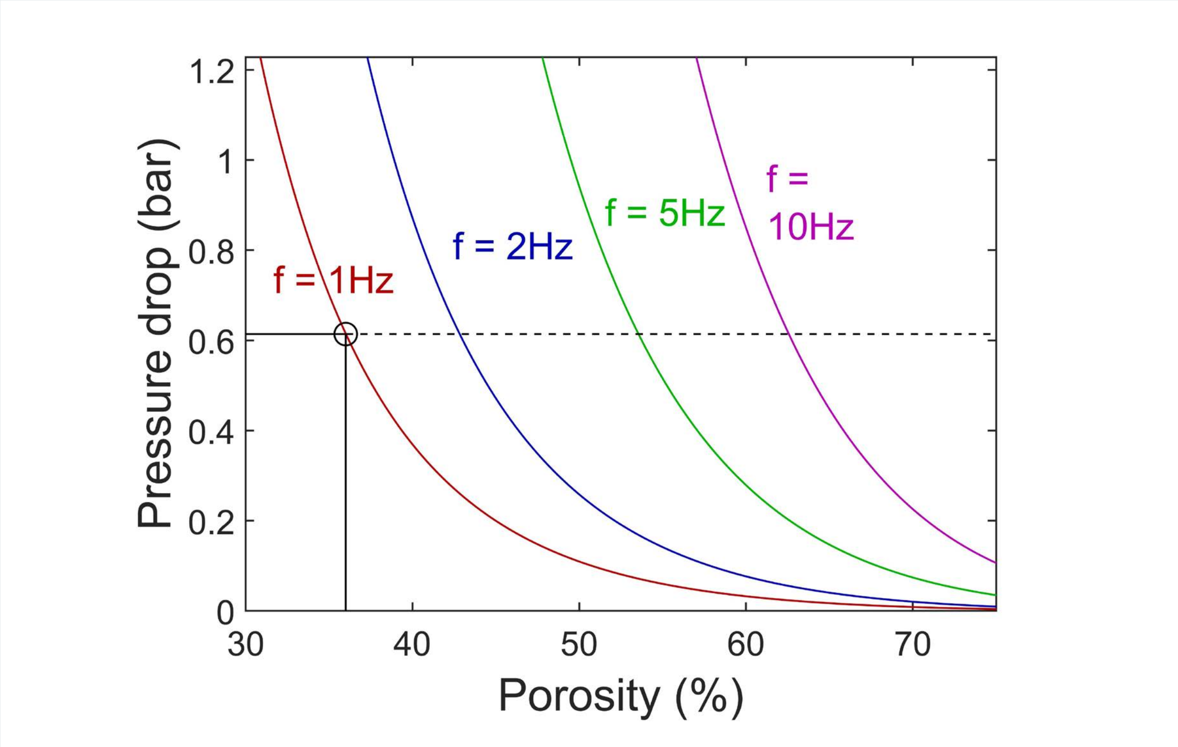

Fig. 1: Pressure drop for water across an active magnetic regenerator (AMR) consisting of a packed bed of 200 µm diameter Gd spheres. Courtesy of Ames Laboratory, USA

drive a cooling device. Such low-grade thermal energy source can be a solar thermal collector, a combined PV-T collector or an engine jacket-coolant. The next step is to optimize current design of a proof-of-concept system with an estimated temperature lift of 25K and cooling capacity of 10 W. A prototype is expected to be completed by Q2, 2020 and be subjected to extensive tests aimed at physically proving the concept.

Finally, the University of Maryland (UoMD), has an ongoing project related to electrochemical compression (ECC), schematically illustrated in Figure 2. An ECC is a mass transport device capable of selectively pumping fluids via an electro-chemical process, requiring no moving mechanical parts. UoMD is investigating an ammonia ECC system for its potential for use in VC heat pump cycles. Experiments are underway to measure steady-state performance under varying operating conditions. Additionally, they are working with a corporate partner to develop and evaluate a scaled-up ammonia ECC, capable of compressing large volumes of gas. Thus far, they have demonstrated continuous ammonia compression from 1.5 to 9.5 bar with isentropic efficiency reaching up to 70%.

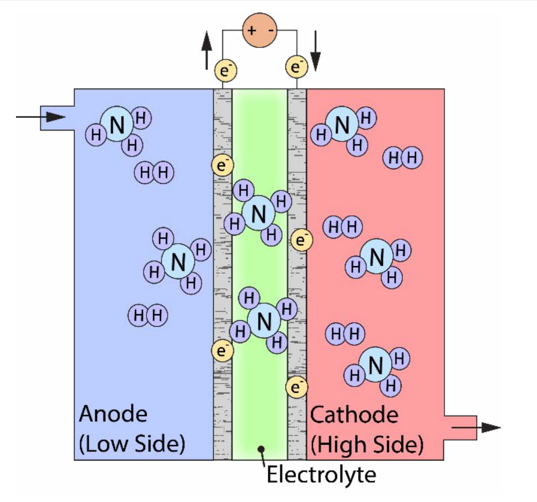

Fig. 2: Schematic diagram of an ammonia ECC process. Courtesy of the University of Maryland, USA

The 2nd Annex meeting was held on October 22-23 at the Fraunhofer Institute in Freiburg, Germany. More about that meeting and results update in the next issue.

Annex website

https://heatpumpingtechnologies.org/annex53/

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ANNEX 54

HEAT PUMP SYSTEMS WITH LOW GWP REFRIGERANTS

The global use of air conditioning system is projected to increase threefold during the next three decades, especially in the world's hottest regions, and so does the electricity demands due to cooling (IEA, 2018). If we are unable to switch current high-GWP refrigerants to low-GWP refrigerants quicker, this demand growth would significantly increase the consumption of high-GWP refrigerants.

Annex 54 aims at reversing this climate harming trend by promoting low-GWP refrigerant application for air-conditioning and heat pump systems, for accelerated phase down of high-GWP HFCs. Annex 54 plans to develop design guidelines of optimized components and systems for low-GWP refrigerants to achieve this goal. Current Annex 54 participants are Italy, Japan, South Korea, and the US. Three countries (Austria, Germany, and Sweden) are considering joining Annex 54.

Annex 54 started with a kick-off meeting in Atlanta, US on January 12. Annex 54 organized two workshops for "Heat Pumps for Low-GWP Refrigerants" at the 25th IIR Conference ICR 2019 in Montréal, Canada on August 26. Seven presentations were held by experts from the participating countries in the Annex and invited speaker from Germany. Below is summary of the presentations.

1. Dr. Piotr A. Domanski from NIST, USA presented for "Screening for Next Generation Refrigerants." He presented screening results of low-GWP refrigerants and concluded that there is no direct HFO replacement candidate for R-410A, tradeoff between GWP and flammability is needed, and recommended to redesign new equipment.

2. Dr. Xudong Wang from AHRI, USA presented for "Ensuring a Safe Refrigerant Transition.". He introduced AHRI's Low GWP Alternative Refrigerants Evaluation Program (AREP) and presented the US pathway for using flammable refrigerants.

He shared AHRTI's project 9007 on flammable refrigerants for whole room scale testing of A2L and A3 refrigerants, to understand the ignition event severity, not probability, of event. He suggested assessing refrigerant detector characteristics for use in HVACR equipment, conducting combustion by-products risk studies, and assessing the effectiveness of mitigation requirements as future research projects.

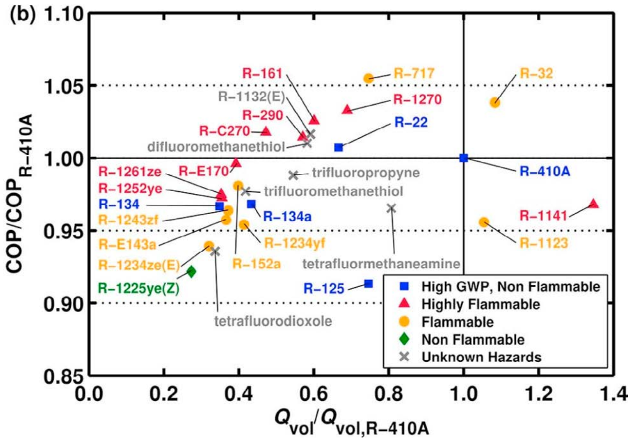

Fig. 1: COP and Qvol of selected fluids referenced to R-410A values for air-conditioning application using the basic cycle and optimized heat exchanger circuitry.
(Source: International Journal of Refrigeration, Vol. 84, December 2017, pp.198-209)

Table 1: Progress of AHRI's Research Project 9007 for whole room scale testing

Equipment	A2Ls	A3 (R290)
PTAC	X	X
Mini-spirit		X
RTU	X	
Residential AC	X	
Reach-in cooler	X	X
Walk-in	X	
Service error and electricity feedthrough failure	X	

Table 2: Performance of R410A Replacements

Name	Class	GWP (AR4)	Capacity Cooling	COP Cooling	Capacity Heating	COP Heating	Diff. $T_{-discharge}$ [°C]	$P_{-discharge}$	Evap. Glide [K]
R-410A	A1	2088	100%	100%	100%	100%	0	100%	0,1
R-32	A2L	675	105%	100%	105%	100%	+ 17.2	102%	0,0
R-466A	A1	766	99%	100%	97%	100%	+ 8.0	95%	1,2
HDR-147	A1	<400	95%	103%	93%	101%	+ 10.8	89%	3,8
HDR-139	A1	<300	92%	103%	90%	100%	+ 14.0	86%	5,2

3. Professor Luca Molinaroli from Politecnico di Milano presented for “Experimental Analysis of the Use of R134a, R1234ze(E) and R1234yf in a Small Water-to-water Heat Pump.” He showed test results and concluded that the heating capacity of the heat pump working with the two HFOs could be matched to the R134a level by increasing the compressor speed, but the COP is further reduced. R1234yf exhibited higher COP than R1234ze(E). He planned for testing of R450A and R513A.

4. Professor Eiji Hihara from University of Tokyo presented for “Risk assessment of A2L refrigerants implemented in Japan.” He presented Japanese collaborative research results for risk assessment of A2L refrigerants and mentioned that the risk assessment for the safe use of flammable gases such as hydrocarbons is underway.

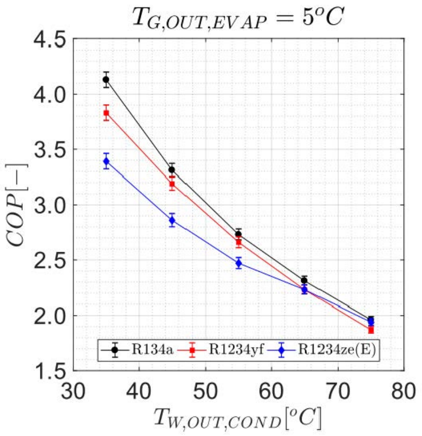

Fig. 2: Test Results of R134a, R1234yf and R12345ze with Water-to-Water Heat Pump

5. Dr. Samuel Yana Motta from Honeywell, USA presented for “Low GWP Refrigerants for Heat Pump Systems.” He compared four alternatives to R410A, and suggested that R-466A (GWP<750) is closest match to R410A’s performance amongst A1 class refrigerants while using the same size/design of compressor and heat exchangers.

6. Dr. Lena Schnabel from Fraunhofer Institute for Solar Energy Systems presented for “R290 Researches at Fraunhofer ISE”. She presented efforts for charge reduction of R290 in heat pumps and leakage prevention, detection and control.

After the workshops, Annex 54 organized a joint meeting with IIR Commissions B1 and B2, attracting 45 participants, to discuss the cooperation between IIR and IEA HPT. After the joint meeting, participants from member countries had a short business meeting to discuss the progress of Task 1 by participating members and plan for 2020 meetings.

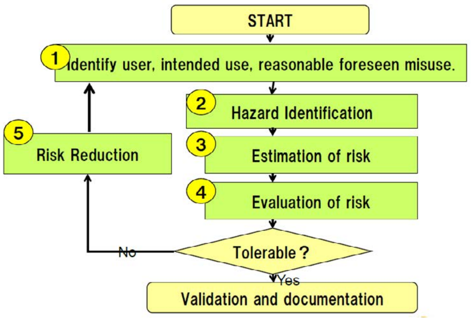

Fig. 3: Methodology of Risk Assessment

All presentation material, the meeting agenda, the minutes and attendee list are available from the Annex website.

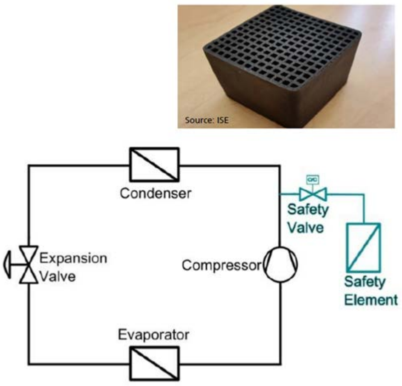

Fig. 4: Refrigerant Capturing using Sorption Materials

Annex website

https://heatpumpingtechnologies.org/annex54/

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ANNEX 55

COMFORT AND CLIMATE BOX

Integrated systems consisting of heat pumps and storage are an important technological option to accelerate the use of renewable energy for heating and cooling. By combining heat pumps and storage, several issues may be tackled, such as

- Balancing & controlling electricity grid loads;
- Capturing a larg(er) share of renewable (local/regional) input (i.e., solar thermal, solar PV);
- Optimizing economics, CO_2 emissions, fuel use over time;
- Providing optimal supply security to buildings.

This Annex has been set up together with ECES, the IEA TCP on energy storage. It has generated a broad interest from several countries. Currently, 13 countries have expressed serious interest in joining the Annex. Although not all participations have been formalized yet, we expect the following countries to join, either through HPT or ECES: Austria, Belgium, Canada, China, France, Germany, Italy, Sweden, The Netherlands, Switzerland, Turkey, UK and USA.

Work packages

Work package leaders have been appointed, and during the previous meeting (17-18 October in Freiburg, Germany), details of the WPs were discussed.
WP 1 – Switzerland – Market overview
WP 2 – UK – Prototyping
WP 3 – Italy – Testing and standardization
WP 4 – Sweden – Roadmap
WP 5 – Netherlands – Dissemination and communication

For most work packages, the main work is still to commence. But for most participating countries at least one project has been granted funding and we expect several contributions involving 'real world' testing of actual Comfort and Climate Boxes (CCBs).

WP 1 should be nearly completed by mid-2020. This WP should focus on recent projects that will serve as the basis for the following work packages. Many of these 'preliminary' projects was presented at the Freiburg meeting.

We have agreed on a standard 'country status format' to show the present state of play in each participant country. As shown in Figure 1 for the Netherlands, this representation uses a traffic light scale for each of the nine quality criteria for CCBs. We consider – for instance – that suitability and smart-grid-readiness will be the most significant present obstacles in the Netherlands, while integral design and efficiency are not expected to cause much difficulties in the Dutch market.

Planning

After the meeting in Freiburg, we had a workshop at the European Heat Pump Summit (EHPS) in Nürnberg in October. During this workshop, we aimed to integrate knowledge from completed and ongoing annexes into the work from this annex.

Annex website

http://heatpumpingtechnologies.org/annex55/

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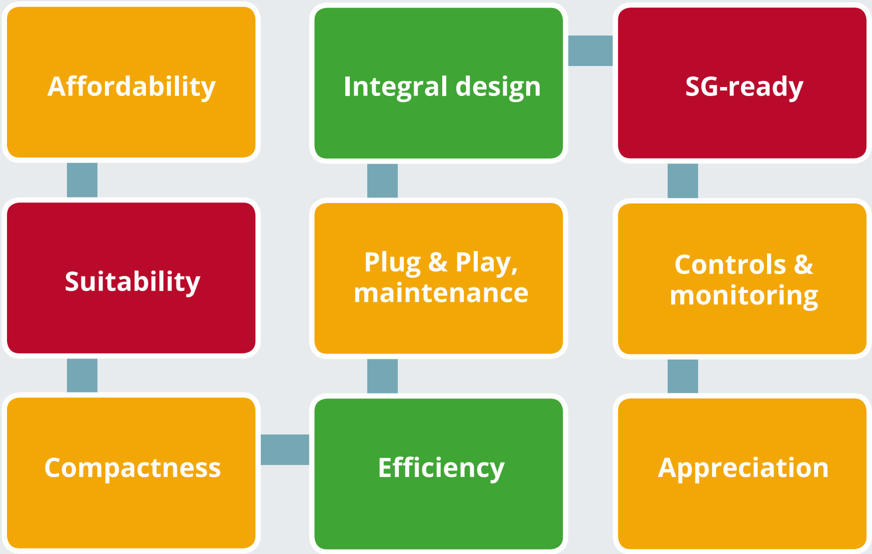

Fig. 1: Status indicator diagram for the Netherlands

Strategic Outlook for the Netherlands: Climate Agreement

Marion Bakker, Netherlands Enterprise Agency, The Netherlands

By 2030, the Netherlands aims to reduce its greenhouse gas emissions by 49% compared to 1990 levels. More than a hundred Dutch parties (a mixture of government, businesses, and NGO's) have jointly worked on a cohesive set of proposals which are laid down in the national Climate Agreement. For the built environment sector, it means that roughly 1.5 million existing homes and 1 million utility buildings will have to be made more sustainable by 2030. With the present phasing-out of natural gas policy, a big role is foreseen for heat pumping technologies. A large number of commitments have been set or are being announced to make all of this possible.

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National Climate agreement

The main goal of the National Climate Agreement of the Netherlands (see links at the end of the article) is to achieve a 49% reduction in national greenhouse gas emissions by 2030, compared to 1990 levels. The consultations on how to achieve this target took place within five sector platforms (Built environment, Mobility, Industry, Agriculture and land use and Electricity) and issues that affect multiple sectors (innovation, labour, finance, and spatial planning). Each sector platform was assigned a sector-specific target regarding the reduction in Mton CO_2-equivalent emissions, which would have to be realised by 2030 (48.7 Mton in total).

Built environment

In order to achieve the emissions reduction target for 2030 of 3.4 Mt worth of cuts in the built environment, the main focus is to increase the pace of sustainability efforts to over 50,000 existing homes per year by 2021, and by 2030 this should have accelerated to 200,000 homes per year. A structured approach has been selected, tackling one district at a time. The municipalities play a crucial role in this regard by drawing up a transition vision for heat in consultation with stakeholders and end-users by the end of 2021, in which they will establish the timetable for a step-by-step approach to phasing out natural gas. The potential alternative energy infrastructures (all-electric, heat, green or possibly hydrogen gas in the future) will be set out for districts planned for transition ahead of 2030, and municipal authorities will provide insight into the social costs and benefits and the integral costs for the end-users.

The preferred solutions may vary from one district to another. If the area has been densely developed, contains many high-rise buildings or has homes that were built before 1995, then a district heating grid could be the most suitable solution. If the area contains new homes set out in a spacious district, then an all-electric solution may be better. For many districts, the natural gas network will remain in place beyond 2030 and may even be used for green gas. Insulating and burning less gas, sustainable or otherwise, with a boiler in combination with a hybrid heat pump might offer a sensible temporary solution. However, the condition of the homes is not the only relevant factor; the wishes of the residents in the district, other than energy supply, will equally determine the pace and the outcome. Housing associations also play an important role in making their homes more sustainable, and to connect them to a different heating supply than natural gas in the years to come, under the condition that the monthly costs for rent and energy bills do not rise.

A large number of commitments have already been made and are required to enable all of this: commitments on how significant cost reductions can be achieved with the construction of heating grids, the fitting of insulation solutions, or the installation of heat pumps. Commitments on an amendment of the energy tax, which would involve lower taxation of the commodity we need more of – electricity – and higher taxation of the commodity we want to use less – natural gas. Commitments regarding more renewable heating from the ground beneath our feet, or from the large bodies of surface water in the Netherlands. Commitments regarding an opportunity for all home buyers to insulate their homes, if renovation work anyway is taking place, with attractive loan conditions. These commitments have been laid down in the Climate Agreement. They form an integrated approach between the sectors, to achieve the 2030 target, and to realise the vision for 2050.

The built environment sector platform has proposed a phased and pragmatic approach that, on the one hand, will seek to achieve a good head-start and, on the other, will develop the conditions and requirements for the scale-up and roll-out of measures for the future. Regarding homes, an approach of incentivisation and district-oriented management has been opted for. At an individual level, building owners can also be offered incentives to make their properties more sustainable. This approach will be successful if the sustainability efforts can be recouped through tenants' lower energy bills. Numerous innovations and significant cost savings will be required in order to fund these investments and make them affordable by means of energy savings and cost reduction. To this end, Test Beds for Natural Gas-Free

Districts (Proeftuinen Aardgasvrije Wijken) and an innovation programme have been launched, which will allow us to experiment systematically, to learn, and to move forward with cost-effective up-scaling and implementation beyond the current government's term of office.

The development of heating devices that do not use gas (or do so to a lower extent) is in full swing. A Mission-Driven Innovation Programme (MMIP) focuses on technical and socio-economic innovation for the rapid growth of sustainable heating systems. The objective is to improve existing types of devices and systems (available <5 years), the development of new concepts (available >5 years) and corresponding services. Further, the Programme is intended to promote user interest and enthusiasm regarding scope, comfort (noise, thermal), integration capacity and affordability (housing costs). The innovations will primarily be focused on applicability in existing inhabited situations, a lower overall cost at the systems level, and acceleration towards natural gas-free solutions. Providing access to new sustainable heating and cooling sources and thermal storage is required to meet the sharply growing demand for sustainable heat.

A large number of commitments are required to make this possible. The following mix of pricing and subsidy instruments have already been set or are being announced:

- ISDE subsidy scheme (small-scale heat pumps), 100 million euros/year;
- Landlord charge, 100 million euros/year discount ;
- Energy Investment Allowance for landlords, 50 million euros/year from 2020 to 2023;
- The neighbourhood approach and the renovation accelerator from the climate budget funds, 100 million euros/year up to 2021 and 70 million euros/year from 2020, respectively;
- Non-revolving heat fund for private property owners, 50 to 80 million euros/year;
- Multi-year Mission-driven Innovation Programme (built environment), > 40 million euros;
- Changes will be made to the energy tax to provide a stronger incentive to improve sustainability, by ensuring that investments in sustainability are recouped within a shorter time period. The government has opted for the budget-neutral version, which will see the energy tax rate for the first bracket for natural gas increase by 4 cents per m^3 in 2020 and +1 cent per m^3 during the following six years. Households benefit more from this change than businesses.
- 300 000 euro - Green deal education installers heat pumps (education centers).

Conclusions

EHPA statistics already show that the Netherlands belong to the top three countries in Europe in heat pump sales growth. At the same time there are concerns about the affordability and quality of installation (noise, comfort) of the heat pumps. With the proposed balanced package of commitments from the Dutch Climate agreement innovative consortia are invited to come up with affordable and robust solutions. The projects (referred to as “Annexes”) within the framework of the IEA Technology Collaboration Programme (TCP) network are very useful in this perspective and will be even more so in coming years.

Links

[1] https://www.government.nl/documents/parliamentary-documents/2019/06/28/letter-to-the-house-of-representatives-about-the-proposal-for-a-national-climate-agreement

[2] https://www.government.nl/topics/climate-change/climate-policy

[3] https://www.bakermckenzie.com/en/insight/publications/2019/07/highlights-of-the-dutch-climate-agreement

Table 1: Emission reduction targets by 2030, per sector.

Sector	Indicative CO_2-equivalents reduction target by 2030. Mton.
Industry	14.3
Transport	7.3
Buildings	3.4
Electricity	20.2
Agriculture & Land-use	3.5
Total	48.7

Fig. 1: Dutch Minister of Economic Affairs and Climate Policy Eric Wiebes (left) receives the Dutch Climate agreement report, specifying CO_2 targets per sector.

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Electrochemical Membrane Technologies for use in Energy Systems

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This article concerns the electrochemical compressor, which is a mass transport device capable of compressing gases via a chemical process, rather than a mechanical process. Solid-state pumping for a variety of working fluids is attainable through electrochemical processes in membranes. Similar principles that work to generate electricity in fuel cells may also have practical applications in heat pumping and air conditioning, as they can be exploited to reliably transfer selected gases from reservoirs of low concentration to those of high concentration. In this article, we present two such technologies: electrochemical ammonia compression and electrochemical dehumidification, as well as some of their potential uses. We present empirical findings, which detail the performance of these technologies as well as strategies to use these technologies most effectively.

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Introduction

In virtually all commercial heat pumps and refrigeration units around the world, a mechanical compressor is responsible for supplying the work needed for useful heating and cooling. However, there may be an alternative that does not rely on moving parts. The electrochemical compressor (EC) is a mass transport device capable of compressing gases via a chemical process, rather than a mechanical one. The EC uses the same ion exchange membranes found in hydrogen fuel cells, but the EC consumes electricity without creating any net chemical changes in the working fluid while fuel cells consume gas to generate electrical potential.

The electrochemical hydrogen compression phenomenon has been known for decades and commercial hydrogen EC devices are available for purchase today. However, recent experiments have demonstrated that electrochemical compression is possible with a variety of working fluids, including, but not limited to, gaseous ammonia and water vapor [1]. In this article, two applications for the EC are presented: electrochemical ammonia compression and electrochemical dehumidification.

The current project work aims to demonstrate the steady-state compression of ammonia vapor at practical pressure ratios with efficiencies that rival those of conventional mechanical compressors. The ammonia EC is being investigated for its potential use in vapor compression heat pump cycles as well as in energy storage applications. Furthermore, electrochemical water transport could be applied to air conditioning applications as a means of separate sensible and latent cooling.

The electrochemical compression device

The EC device consists of three main components: the gas distribution channels, the electrodes, and the membrane. The gas distribution channels, shown in Figure 1, supply the working fluid to the electrodes, which are made of a porous, electrically conductive material. The electrochemical reactions occur in the membrane electrode assembly (MEA), which is the assembly of both electrodes and the ion exchange membrane. An external voltage is supplied across the two electrodes. Under the external voltage, the working fluid reacts with a carrier gas to form an ion. The ion is then able to traverse across the membrane, which is impermeable to electrons. When the ion reaches the opposite electrode, the ion then reforms into its constituent molecules. This process is able to push ions across the membrane even in the presence of an opposing concentration gradient, which is how we are able to get useful compression out of this phenomenon. A diagram of the EC cell is provided in Figure 1.

Although a single cell does not provide a practical amount of compression work, several compression cells may be stacked together to increase either the pressure lift or the mass flow rate of the working fluid. Combining two compressors in series increases the total pressure ratio and combining two compressors in parallel increa-

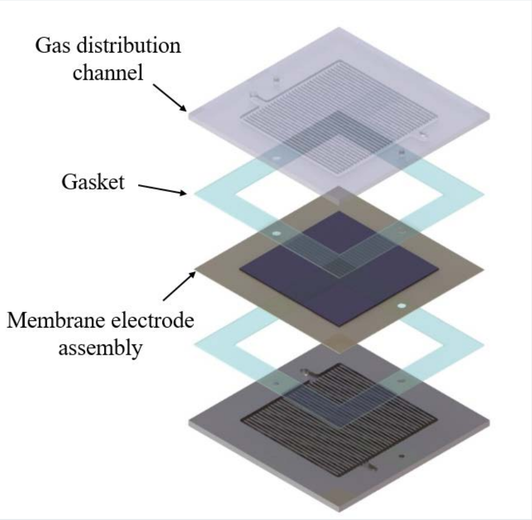

Fig. 1: Exploded diagram of an electrochemical compressor cell.

ses the total flow rate. Because the ammonia EC has demonstrated the required pressure ratio in a single stage, we do not need to combine cells in series. Instead, the current research looks to create several parallel connections.

Electrochemical ammonia compression

Ammonia, which is one of the most commonly produced chemicals in the world, is one of the oldest known refrigerants and has negligible ozone depletion and global warming potentials. Additionally, provided carbon-neutral raw materials and process energy are used for the manufacture of the ammonia, liquid ammonia can be used as carbon-neutral fuel for ammonia fuel cells and ammonia-driven internal combustion engines. Such energy storage applications require high pressure storage of ammonia; therefore, an efficient ammonia compressor becomes necessary for both refrigeration and energy storage applications.

The ammonia EC depends on a series of electrochemical half-reactions. In the first half-reaction, the ammonia reacts with hydrogen, which acts as a carrier gas, to form ammonium ions, according to equation (1), below. The ions then pass from the anode to the cathode via the cation exchange membrane, after which the second half-reaction occurs. In the second half-reaction, the ammonium ions react to reform ammonia and hydrogen gases at an elevated pressure, according to equation (2). This process is illustrated in Figure 2.

$$2NH_3 + H_2 \rightarrow 2NH_4^+ + 2e^- \quad (1)$$
$$2NH_4^+ + 2e^- \rightarrow 2NH_3 + H_2 \quad (2)$$

We tested the ammonia EC under a variety of different pressure ratios and observed the power consumption for each. For stoichiometric inlet conditions at room temperature, while humidifying the inlet gas stream to around 40% relative humidity, the best observed EC performance is summarized in Figure 3. In the figure, the compressor power consumption per gram per second of fluid flow is plotted against the pressure ratio. The ammonia EC curve was generated based on the governing electrochemical laws for the EC and the observed losses in the cell during the test condition showing the best performance. The ammonia EC curve has the same slope as the curve of ideal isothermal compression because, in the observed experiment, the EC power consumption was too small to give rise to any increase in temperature. Thus, the small-scale compression processes are said to be isothermal.

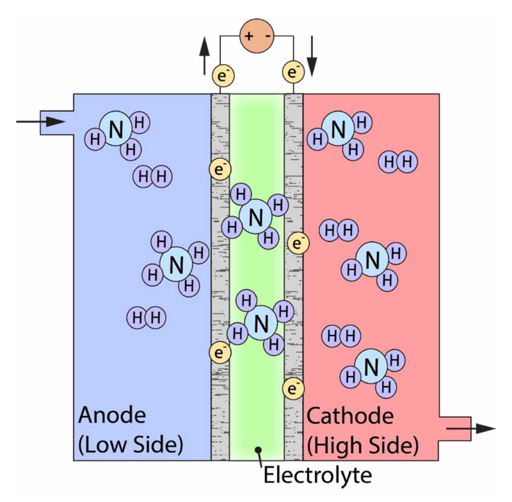

Fig. 2: Diagram of electrochemical transport of ammonia with hydrogen acting as a carrier gas.

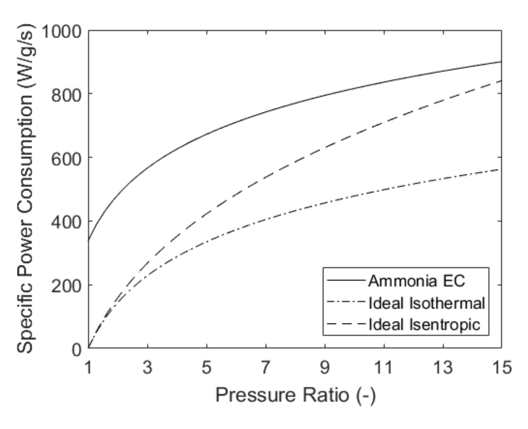

Fig. 3: Specific power consumption of an ammonia EC under a range of pressure ratios.

Electrochemical dehumidification

Another area of interest deals with electrochemical transport of water vapor for dehumidification applications. Currently, the most common methods for dehumidification involve water vapor condensation or desiccant absorption. Because it does not rely on either of these technologies, the electrochemical process provides an interesting alternative. In previous research efforts into electrochemical membrane dehumidification, researchers observed that the dehumidification performance may be limited by poor mass transfer [2]. However, in this novel approach to membrane water transport, a high voltage field, causing an electrohydrodynamic (EHD) effect, may increase the rate of water vapor transport through the membrane. This effect, which is used in food processing to dry perishable foodstuffs, increases mass transfer rates by destabilizing fluid boundary layers and increasing the partial pressure of water near the membrane surface.

Unlike the ammonia EC, the electrochemical dehumidifier relies on the transfer of negatively charge ions, so it uses an anion exchange membrane to complete the process. The dehumidification principle is that oxygen along with water vapor is electrochemically reduced to form hydroxide in the cathode through reaction in equation (3), below. Subsequently, the hydroxide is oxidized back to oxygen and water on the anode side, as explained by equation (4).

$$2H_2O + O_2 + 4e^- \rightarrow 4OH^- \quad (3)$$
$$4OH^- \rightarrow 2H_2O + O_2 + 4e^- \quad (4)$$

The molar ratio of water vapor to oxygen is fixed to 2 and is independent of the dehumidification ratio ensuring a steady rate of dehumidification under any operating conditions. To increase water transfer through the membrane, we use a high voltage source, generating an EHD force, which helps to push water vapor in main air stream towards the membrane, as well as en-

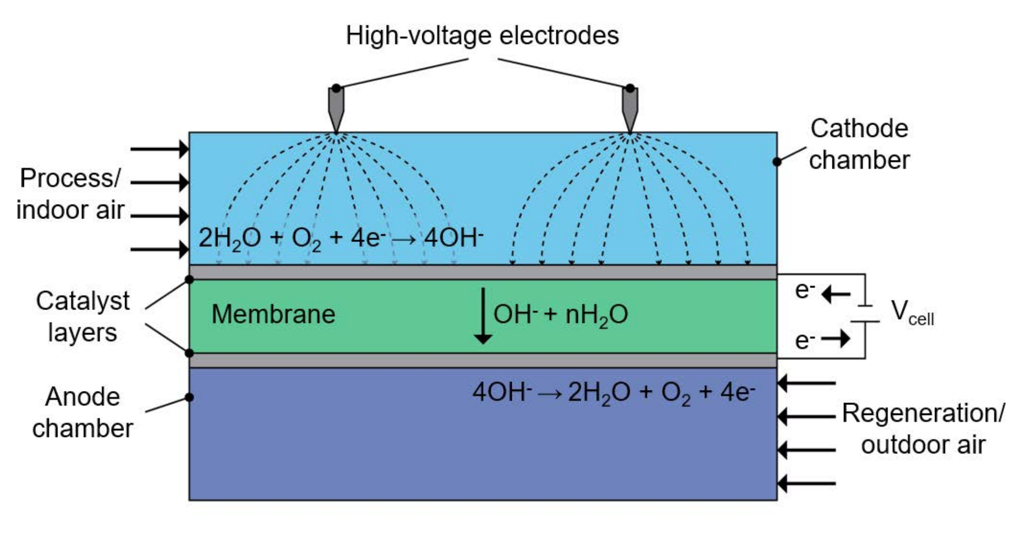

Fig. 4: Diagram of the electrochemical dehumidification process integrated with a high-voltage field, generating an electrohydrodynamic force.

courage effective mass transfer of water vapor. Figure 4 shows this process.

There are several possible modes of water transport in the membrane. Principally, there is electrolytic water transport, which is the water transfer governed by the electrochemical reactions. There is also diffusive water transport, which is the movement of water due to a concentration gradient. Lastly, there is electroosmotic transport, which is the phenomenon of water transfer through the membrane due to dipole interactions with the negatively charge hydroxide ion. The goal of this research is to develop a method for electrochemical dehumidification that maintains a stable rate of electrolytic transport, while maximizing the electroosmotic transfer and minimizing parasitic drag of water molecules.

The fundamental advantage of this method of water removal is that it does not rely on condensation. While vapor compression dehumidifiers must cool the water vapor below the dew point to condensate water vapor and separate out the liquid water, there is no net phase change in the EC dehumidification process. Therefore, the only energy consumption comes from the energy requirement for the electrolytic process. In the ongoing research efforts, we will conduct experiments to determine the rate of water transport in the anion exchange membrane under practical operating conditions. Additionally, we will investigate the benefits of the EHD component and determine the effectiveness of the electrochemical dehumidifier as compared to the current state-of-the-art in conventional dehumidification.

Conclusions

Both electrochemical compressor (EC) technologies are intended for use in energy systems. The ammonia EC could be used to drive a heat pump or refrigeration cycle using ammonia as the refrigerant. Additionally, the ammonia EC is being investigated for use in energy storage technology. Experimentation revealed that steady-state ammonia compression is attainable under a range of pressure ratios with reasonable energy consumption. Moreover, it is possible to separate ammonia from a dilute stream using the EC. While challenges persist in the integration of the EC into practical energy systems, this technology exhibits potential, especially in applications requiring high pressure ratios, for example liquid storage of ammonia for use as carbon-neutral fuel, provided carbon-neutral raw materials and process energy are used for the manufacture of the ammonia.

The water EC could be used as a dehumidifier to reduce latent cooling load in air conditioning applications. The electrohydrodynamic (EHD) component could help increase the rates of water transfer and decrease the parasitic diffusive losses in the membrane.

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Elastocaloric Cooling

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The use of the vapor compression cycle (VCC) has resulted in unpredicted environmental damage such as depleting the ozone layer and promoting global warming when its refrigerant leaks into the atmosphere. One way to tackle this problem is to develop cooling cycles using solid-state refrigerants: the caloric materials. The main characteristic of caloric materials is that it is possible to induce a phase transition in solid phase with the application of an external field, which translates in an adiabatic temperature increase or an isothermal entropy change. In this work, we present the main steps to use this caloric effect for cooling and two system integration possibilities for elastocaloric cooling systems.

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Introduction

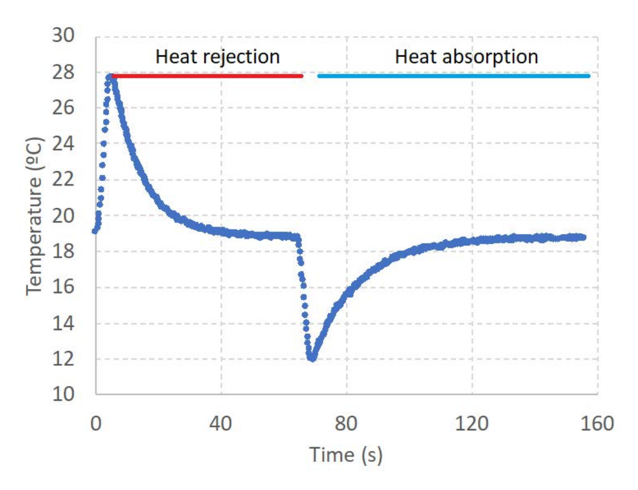
The vapor compression cycle (VCC) has been developed and optimized over the last hundred years to provide cooling in residential and industrial buildings, and vehicles. However, its usage has resulted in unpredicted environmental damage such as depleting the ozone layer and promoting global warming when its refrigerant leaks into the atmosphere. Because of this, it is important to replace VCC by developing a superior alternative cooling technology, without the environmental cost. One way to tackle this problem is to develop heat pumping cycles using solid-state refrigerants since a solid is incapable of leaking into the atmosphere. Caloric materials can be used as solid-state refrigerants. It is also desirable to make these new systems more energy-efficient than VCC. The grand challenges are to keep developing materials with better performance and, just as important, to integrate these materials into systems efficiently.

Generally speaking, the main characteristic of caloric materials is that it is possible to induce a phase transition in a solid phase with the application of an external field. The particular characteristics of this phase transition depend on the material, but it always involves a significant change in entropy. The entropy change manifests itself as a temperature change of the material when the external field is applied or removed adiabatically and as a heat exchange between the material and the surroundings under the constant external field.

Based on the type of external field to which the caloric materials respond, they are classified as magnetocaloric (the phase change is induced by a magnetic field), electrocaloric (the phase change is induced by an electric field) and elastocaloric materials (the phase change is induced by a stress field). This last category is the one that we are focusing on in this report.

Development of Elastocaloric Cooling Technology

A commercially available elastocaloric alloy was used in this study. Conceptually, in order to use it as a solid-state refrigerant it is necessary to apply the following four processes (see Figure 1).



1) **Loading:** A stress is applied adiabatically to the material and its temperature increases.

2) **Heat rejection:** While maintaining the stress, the material cools down to its original temperature by rejecting its heat to a heat sink.

3) **Unloading:** The stress is removed adiabatically from the material. The phase transformation is reversed, and its temperature decreases below its room temperature.

4) **Heat absorption:** The material absorbs heat from a heat source and increases its temperature back to the original one, and the cycle can begin again. During this step of the process, the material supplies cooling.

Fig. 1: Temperature variation during loading and unloading of the elastocaloric alloy.

The main purpose of a cooling cycle is to pump heat from a low temperature level to a high temperature level. In a power cycle, it is necessary to supply heat to produce work output. The heat pump cycle is a reverse power cycle. Therefore, the heat pump cycle and the power cycle can be analyzed in very similar manners. The elastocaloric material can be integrated into a system in different configurations.

Example 1: Elastocaloric cooling cycle with internal heat recovery

As an example, an elastocaloric heat pump cycle was achieved by using the reversed Brayton thermodynamic cycle (Qian et al., 2015). The Brayton cycle represents the thermodynamic operation of a constant pressure heat engine for a power cycle. The reversed Brayton requires a net-work input in order to supply cooling. It comprises the four steps listed above, plus two heat recovery steps to improve the temperature lift that can be achieved. Figure 2, left, shows a schematic of the cooling system. Two sets of elastocaloric materials can be loaded and unloaded by moving the middle crossbar to the left and to the right. The left end of the elastocaloric bed #1 and the right end of elastocaloric bed #2 are fixed. When the crossbar is in the middle, both elastocaloric beds are compressed half way through. When the crossbar moves all the way to the left to fully compress bed #1, bed #2 is allowed to be fully relieved. When the crossbar moves all the way to the right to fully compress bed #2, bed #1 is allowed to be fully relieved. Since the beds are opposing each other, it is possible to recover the unloading work of one bed, and using this to assist the loading of the opposite bed, reducing the necessary amount of work that needs to be supplied in each cycle. By having two elastocaloric materials working in tandem it is also possible to exchange heat between them internally, to preheat and precool each bed before loading and unloading, using the thermal energy stored in them after the heat exchange steps. To further this concept, note that since the materials are solid, it is necessary to have a heat transfer fluid to exchange heat between the elastocaloric materials and the sink and reservoir. The orange tubing connects the elastocaloric materials to the heat sink, the light blue tubing connects them to the heat reservoir and and purple tubing connects the elastocaloric materials with each other. By opening or closing valves V1 to V8 and HRV it is possible to direct the heat transfer fluid to reservoir, sink or internal heat exchange during the correct step.

Figure 2, right, shows the representation of the different steps in an entropy-temperature plot. The state points related to the operating sequence are the following:

1. The cycle starts in state point 1, with the elastocaloric material bed #1 in the austenite phase with no stress applied to it. The material is then compressed until it reaches state 1’. That is the moment when the critical stress is reached and the martensitic transformation begins. Simultaneously, the elastocaloric material in bed #2 is in state point 4, and 4’ when the reverse transformation begins upon unloading.

2. The increase in stress continues until the transformation is completed, reaching state point 2. During this process the heat of the transformation is released and the temperature of the elastocaloric material increases. Simultaneously the stress keeps decreasing for the elastocaloric material in bed #2, completing the reverse transformation, decreasing its temperature and reaching state point 5.

3. Valves 1 and 3 are open, pump 1 starts and flows heat transfer fluid through bed #1 towards the heat sink (valves 2 and 4 remain closed). The elastocaloric material in bed #1 cools down to reach state 3 while the stress is still applied. Simultaneously, valves 6 and 8 are open,

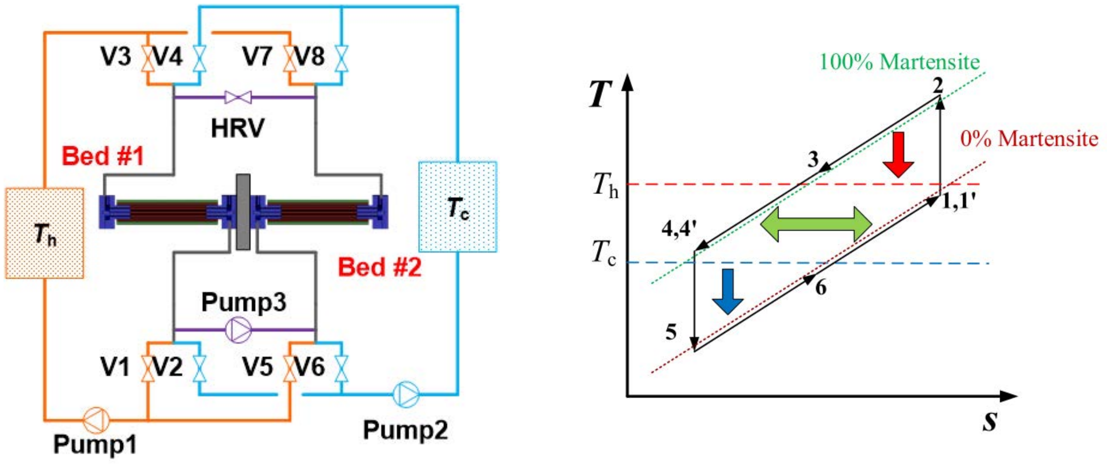


Fig. 2: Left: Schematic of the cooling system. Right: Thermodynamic representation of the reversed Brayton cycle applied to elastocaloric cooling

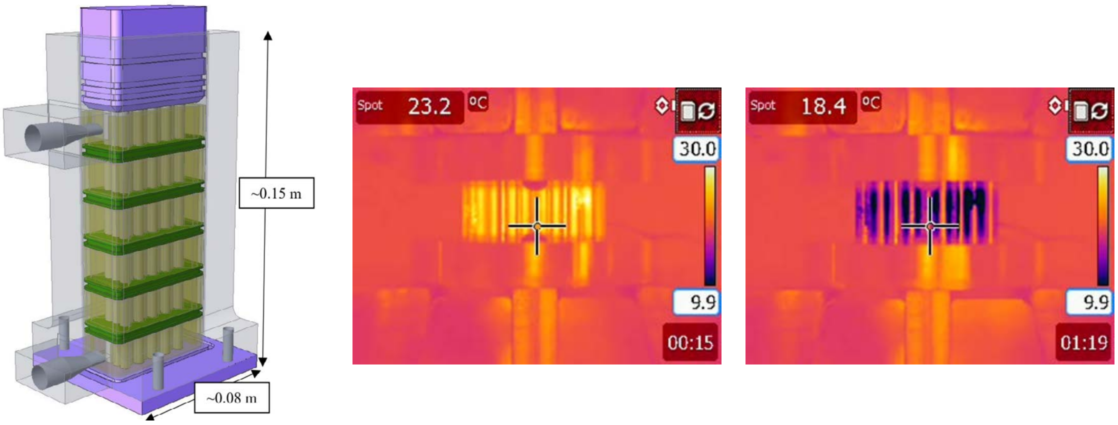


Fig. 3: Left: Regenerator diagram. Right: Proof of heating and cooling.

and pump 2 starts and flows heat transfer fluid through bed #2 towards the heat source (valves 5 and 7 remain closed). The elastocaloric material in bed #2 heats up to reach state 6, with no stress applied.

4. Before the stress is removed, the material in bed #1 can be further cooled down to state 4 by allowing it to exchange heat with the material in bed #2, which is at that moment in state 6. This is what the purple tubing is for. Valves 1 to 8 are closed, pump 1 and 2 are off, HRV is open, and the HR pump is turned on. Ideally, the material in bed #1 should reach the temperature of state 4 which could be equal to the one in state 6, and material in bed #2 should reach the temperature in state 1 which could be equal to the temperature in state 3.

5. The stress in bed #1 is removed, and upon unloading, the material reaches state 4’, when the reverse transformation back to austenite begins, and later state 5, when the reverse transformation is completed. This results in a decrease of temperature of the elastocaloric material in bed #1. Simultaneously, the material in bed #2 should begin its loading process, reach state 1’ when the forward transformation begins and finally reach state 2 when the transformation is completed. This results in an increase of temperature of the material in bed #2.

6. Valves 2 and 4 are open, pump 2 starts and flows heat transfer fluid through bed #1 towards the heat reservoir (valves 1 and 3 remain closed). The elastocaloric material in bed #1 heats up to reach state 6 still unloaded. Simultaneously valves 5 and 7 are open, and pump 1 starts and flows heat transfer fluid through bed #2 towards the heat sink (valves 6 and 8 remain closed). The elastocaloric material in bed #2 cools down to reach state 3, with no stress applied. After this, the heat recovery step brings everything to the original state and the cycle begins again.

Example 2, “active” elastocaloric regenerator

Another way to integrate the system is to make an active regenerator with the elastocaloric material (Tušek et al., 2016). A regenerator is a storage-type heat exchanger. Cold and hot fluids flow alternatively through the same flow passages, and hence the heat transfer is intermittent. When the hot fluid flows over the heat transfer surface the thermal energy from the hot fluid is stored in the regenerator wall, and thus the hot fluid is being cooled. As a cold fluid flows through the same passages later, the regenerator wall gives up thermal energy, which is absorbed by the cold fluid. During steady state operation, a temperature gradient is developed along the length of the regenerator, the high temperature end is connected to the heat sink and the cold end to the heat reservoir. It is called “active” elastocaloric regenerator, unlike “passive”, because an elastocaloric material serves the dual function as heat storage medium and a heat source (or sink) when the forward (or reverse) transformation takes place.

The difference between the previous configuration (example 1) and this one (example 2) is that there is no dedicated heat recovery step. Moreover, a temperature gradient is developed along the regenerator as the hot and cold fluids flow alternatively through the passages. Significant enhancement of the materials capabilities in terms of temperature lift have been measured in magnetocaloric and elastocaloric materials. The largest temperature lift so far published is 19.9K (Engelbrecht et al., 2017) in a laboratory prototype. Another prototype at the early stage of development is currently under development at the University of Maryland (Emaikwu et al., 2019), and can be seen in Figure 3. The compression of a single stage of 23 tubes was achieved successfully, and the proof of heating and cooling can also be seen in Figure 3.

The regenerator design consists of layered stacks of short tubes of the elastocaloric alloy and the transformation is induced by compression. The flow pattern inside the regenerator is similar to the one that can be observed in a shell-and-tube heat exchanger. The length of the tubes is calculated such that buckling is prevented. The distance between tubes is one of the most important variables expected to influence the structural stability of the system, the heat transfer coefficient and the pressure drop.

Conclusions

Due to recent environmental concerns, the development of cooling technologies that do not use refrigerants with high global warming potential and ozone depletion potential and are more efficient than current vapor compression technology has become an important research topic. The development of elastocaloric cooling technologies is rather new, but progress has been made during the last few years. In this paper, two examples of system integration options have been presented: one with a dedicated heat recovery process and another one avoiding the heat recovery process by building a regenerator into the system. Even though the cooling capacity of the prototype systems is still far from the requirements of a commercial application, the temperature lift performance is growing and getting closer to the minimum requirements needed.

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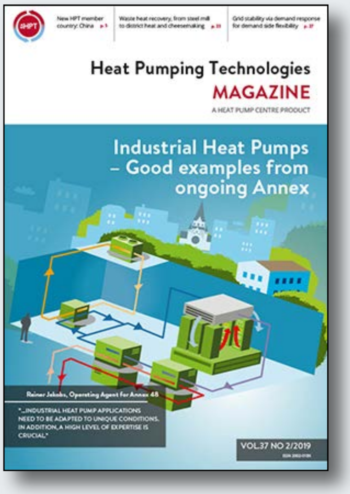

Development of an Underground Thermal Battery for Enabling Ground Source Heat Pump Applications and Shaping Electric Demand of Buildings

Xiaobing Liu, Joseph Warner, Mingkan Zhang, Ming Qu, Liang Shi, Kaushik Biswas, USA

An innovative underground thermal battery (UTB) can provide not only a stable heat sink or heat source for efficient heat pump operation, but also a thermal energy storage to overcome the mismatch between intermittent renewable power supply and fluctuating thermal demands of a building. This article introduces the recent developments of the UTB, including concept design, lab tests, and modeling. Initial results indicate that the UTB has a potential to enable both efficient air-conditioning and active demand side management without sacrificing the desired comfort condition and convenience in the building.

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Introduction

Ground source heat pump (GSHP) is an energy efficient technology for space heating, space cooling, and water heating. It is estimated that 6 trillion Megajoules of primary energy can be saved per year in the United States by retrofitting the existing heating and cooling systems with GSHPs due to their high efficiency (Liu et al. 2019a). GSHP systems utilize a ground heat exchanger (GHE) to extract heat from the ground in winter or reject heat to the ground in summer. The vertical bore ground heat exchanger (VBGHE) is the most commonly used GHE in the United States due to its reliability and small footprint. However, the high installation cost of the VBGHE, which accounts for more than 30% of the total installation cost of a GSHP system (NYSERDA 2017), limits a broader adoption of GSHPs in the United States. Previous efforts to reduce the cost of VBGHE have mostly focused on improving heat transfer inside the borehole. However, the small diameter of the borehole (< 0.15 m) restricts the potential for performance improvement and cost reduction. A recent study (Liu et al. 2018) concluded that the cost reduction potential of improving borehole heat transfer is less than 30% and dependent on the ground thermal conductivity. New GHE designs that can more drastically reduce the installation cost of the GHE are highly desirable for broader adoption of GSHPs in the United States.

On the other hand, the stability of the electric grid has been a growing concern in recent years as the intermittent renewable power generation causes large swings in the demand of the electric grid. The "duck curve" phenomenon, as shown in Figure 1, reflects the mismatch between the intermittent renewable power supply and

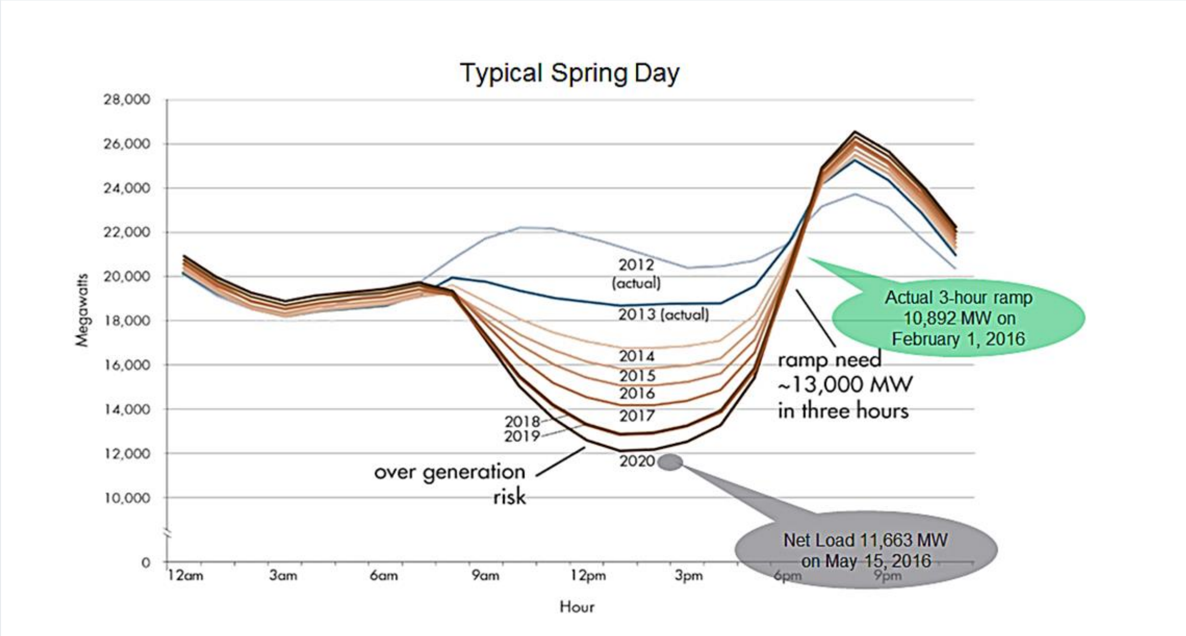


Fig. 1: "Duck Curve" of electricity demand due to intermittent renewable power. Reproduced with permission from California ISO (CAISO 2013).

the demand of the grid. The rapid ramp-up and large fluctuations in the electricity demand significantly challenge the operation of the electric grid. Furthermore, the excess of renewable power generation has to be curtailed, resulting in limited use of renewable power (NREL 2015). Measures to reduce the “duck curve” effect can significantly improve the stability and cost-effectiveness of the electric grid (Klein et al. 2016).

Because approximately 40% of electricity consumed in buildings is for thermal demands, including space heating, space cooling, and water heating (IEA 2018), thermal storage could be an effective method to solve the mismatch between the intermittent renewable power supply and the fluctuating building electric demand.

An innovative low-cost underground thermal battery (UTB) has been invented to provide not only a stable heat sink or heat source for efficient heat pump operation, but also a thermal energy storage to overcome the mismatch between the intermittent renewable power supply and building’s thermal demands. This article introduces the recent developments of the UTB, including concept design, lab tests, and modeling.

UTB as a low-cost ground heat exchanger

Figure 2(a) is the prototype of the UTB designed as a low-cost GHE. It is a tank filled with water and buried in the shallow subsurface of the ground. There is a helical heat exchanger immersed in the center and panels of a customized phase-change material (PCM) suspended in the water to increase the thermal storage capacity of the UTB. A full-scale UTB has a diameter of 1 m, and a depth of 6 m, so that it can be installed by using auger drill rigs with a lower cost than the installation of small diameter but deep boreholes used for conventional VBGHE. A 1:5 small-scale prototype of the UTB was built, and tested to characterize its performance, as show in Figure 2(b). The dimensions of a full-scale UTB, the small-scale UTB, and a conventional VBGHE are listed in Table 1.

Both a detailed 3D numerical model (Zhang et al. 2019) and a 1D numerical model (Warner et al. 2019) were developed for evaluating the short- and long-term performance of the UTB. The numerical models have been validated against the experimental data from the

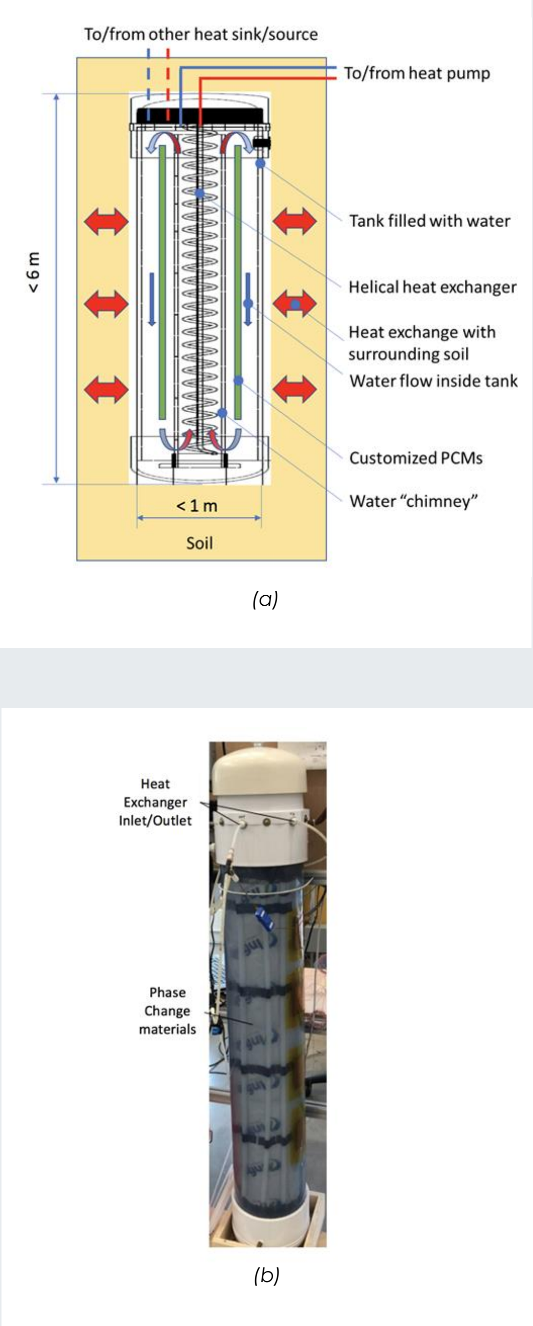
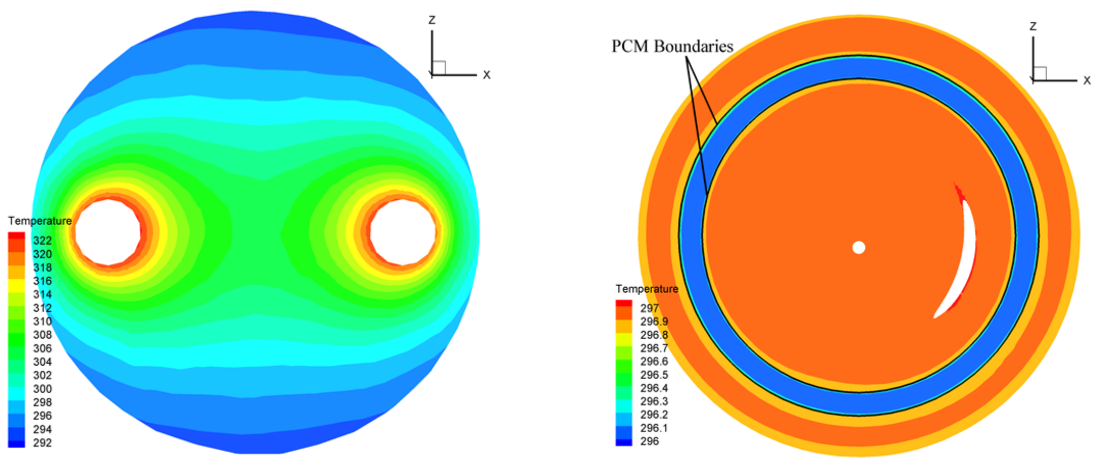


Fig. 2: The first UTB prototype: (a) schematic design; and (b) a small-scale prototype for lab testing.

Table 1. Dimensions of conventional VBGHE, a full-scale UTB, and a small-scale UTB

Dimension	VBGHE borehole	Full-scale UTB	Small-scale UTB
Depth (m)	61	6	1.2
Diameter (m)	0.15	1	0.2
Volume (m^3)	1.08	5.49	0.04
Surface Area (m^2)	28.8	22.3	0.9
Surface area to volume ratio	26.7	4.1	20.3



(a) *(b)*

Fig. 3: The 3D model predicted temperature distributions in the horizontal cross-section at the middle of the borehole after 6 hours of 4 kW heat rejection: (a) with conventional vertical bore ground heat exchanger; and (b) with underground thermal battery (filled with water and PCM).

small-scale UTB prototype. Figure 3 shows the comparison, predicted by the 3D simulation, between the temperature responses of a full-scale UTB and a conventional VBGHE after applying a constant heat input (4 kW) for 6 hours. Conventional VBGHEs exchange heat between the heat carrier fluid and the surrounding solid material (i.e., grout and soil) through conduction heat transfer. There is a significant temperature difference between the heat carrier fluid and the surrounding soil, as indicated by the significantly different colors surrounding the heat carrier fluid and the borehole wall. In contrast, the heat rejected to, or extracted from, the UTB causes natural convection within the tank, resulting in a well-mixed tank water temperature, as indicated by the uniform orange color in the UTB. The large thermal capacity of the UTB keeps its leaving fluid temperature much lower than that of the conventional VBGHE.

Figure 4 shows the measured leaving fluid temperature resulting from three different fillings in the tank of the small-scale prototype—water only (UTB baseline), both water and PCM (UTB with PCM), and dry sand only (to emulate a basket heat exchanger). It is clear that the leaving fluid temperature of the basket heat exchanger rose much faster than the other two configurations in response to the same heat input (75W, equivalent to 9.375 kW heat input to a full-scale UTB). It is because the basket heat exchanger transfers heat solely through conduction, which results in a large temperature gradient between the fluid in the heat exchanger and the

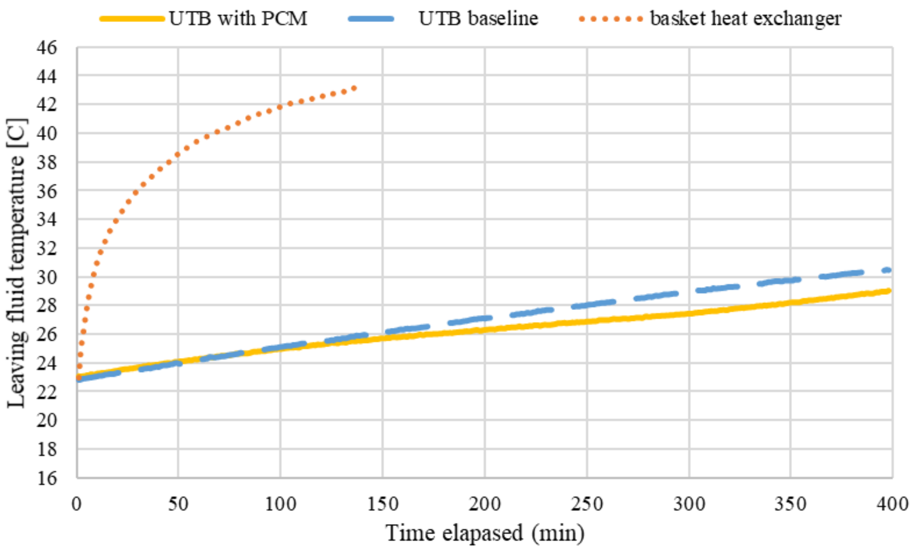


Fig. 4: Measured leaving fluid temperatures resulting from three different fillings in the tank of a small-scale prototype in response to a 75 W constant heat input.

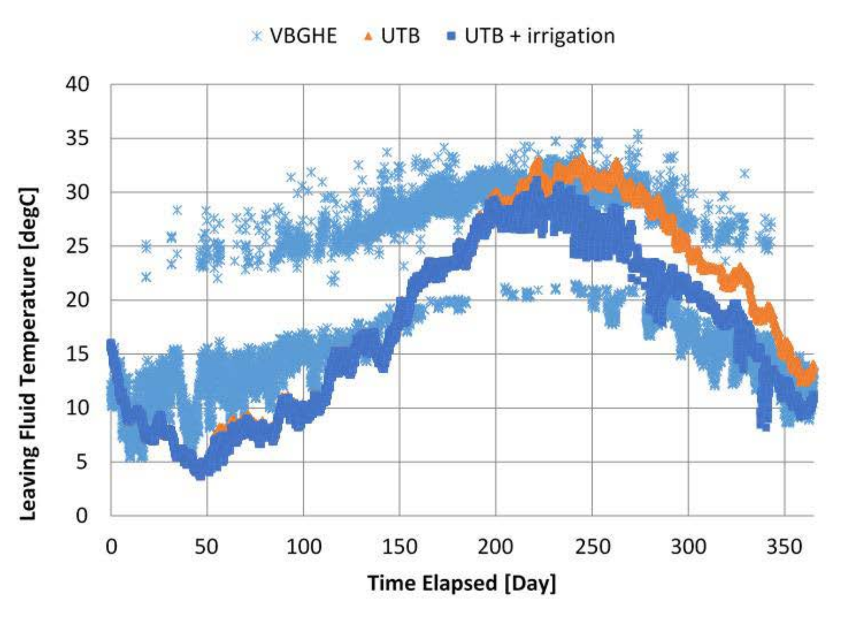


Fig. 5: Comparison of leaving fluid temperature of a conventional VBGHE and two UTBs.

surrounding sand. In contrast, although water has a low thermal conductivity similar to the sand, the natural convection of water inside the UTB makes the tank water well mixed (i.e., the large thermal capacity of the entire tank of water is utilized), resulting in a slow temperature increase. The melting process of PCM further slows down the temperature rise.

Figure 5 depicts the 1D model predicted leaving fluid temperature from two UTBs (with 0.8 m diameter and 6 m depth) and a conventional VBGHE (installed in a borehole 61 m deep and with 0.15 m diameter) during a full year of operation of a residential GSHP system in Knoxville, Tennessee. As shown in Figure 5, UTB avoids the wide daily swings in the leaving fluid temperature seen from the VBGHE. However, the smaller ratio of the surface area to volume of UTB limits the amount and rate of heat exchange with the surrounding soil, compared to the VBGHE. As a result, the tank water temperature keeps increasing during the summer and the annual maximum leaving fluid temperature of the UTB is slightly lower than that of the VBGHE. Simulation results indicate that using the two UTBs to replace a VBGHE can result in about 2% operating cost savings of the GSHP system at locations with high ground thermal conductivity (> 2.67 W/m-K). Figure 5 also shows that the leaving fluid temperature of the UTB can be lowered in the summer by integrating it with a lawn irrigation system of the house conditioned by the GSHP system, further improving the heat pump performance. In this case, the warm water in the UTB is flushed out regularly to irrigate the lawn, and the cold city water refills the UTB to restore its cooling capacity. Notably, no additional water consumption is required besides what would have been used by the existing irrigation. A preliminary cost analysis indicates that the installed cost of the two UTBs could be 39% lower than that of the VBGHE if casing is not needed for drilling the large diameter shallow boreholes (Warner et al. 2019).

Dual-Functional UTB for Load Shifting

The UTB is further developed to enable thermal energy storage in addition to ground heat exchange (Liu et al. 2019b). Figure 6 is the second prototype of the UTB with dual functions (patent pending). It consists of a small enclosed inner tank within the original water tank. The inner tank is wrapped with a blanket filled with customized PCMs, which act as both an insulator (due to the low thermal conductivity of the PCM) and an energy storage medium. A heat exchanger is submerged in the inner tank, and another heat exchanger is installed in the annulus. This design allows for storing chilled water or ice in the inner tank which can provide direct cooling to eliminate the electricity consumption of the heat pump during the peak hours of the electric grid. The annulus of the UTB is used as a ground heat exchanger.

By integrating the second prototype UTB with a dual-source heat pump, which has both a water-cooled and an air-cooled condenser, multiple operation modes can be utilized based on the renewable power supply and building thermal demand, as depicted in Figure 7. During the off-peak hours (for example, late evening or early morning), or when there is an overproduction of renewable power (for example, early afternoon), the heat pump runs at its full capacity with the air-cooled condenser to provide space cooling and in the meantime make chilled water or ice in the inner tank (Mode 1). During the peak hours, or the ramping up period of the electricity demand in the late afternoon, the stored chilled water or ice is used to provide direct cooling to the building, and the heat pump is turned off (Mode 2). Once the ice is melted, and the inner tank water temperature is above the temperature threshold for providing direct cooling, the heat pump is turned on to provide space cooling using the water-cooled condenser and reject heat to the annulus of the UTB (Mode 3). Because water in the annulus is cooled by both the surrounding soil and the in-

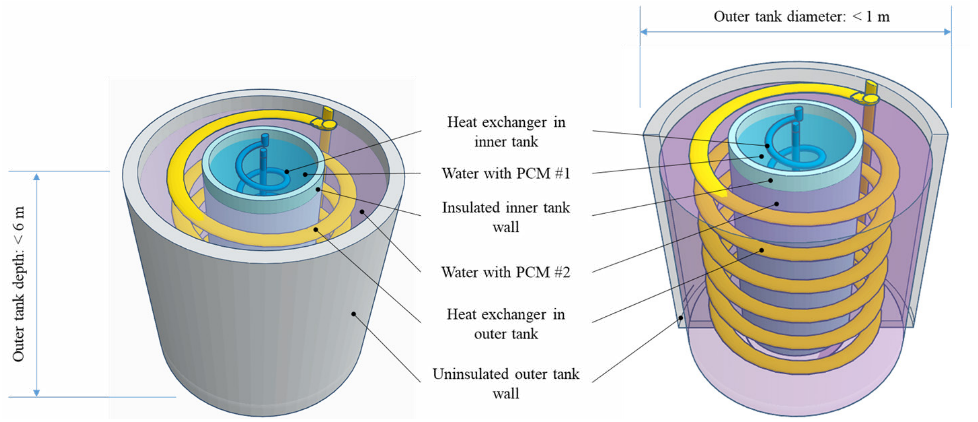


Fig. 6: Schematic of the second prototype of UTB.

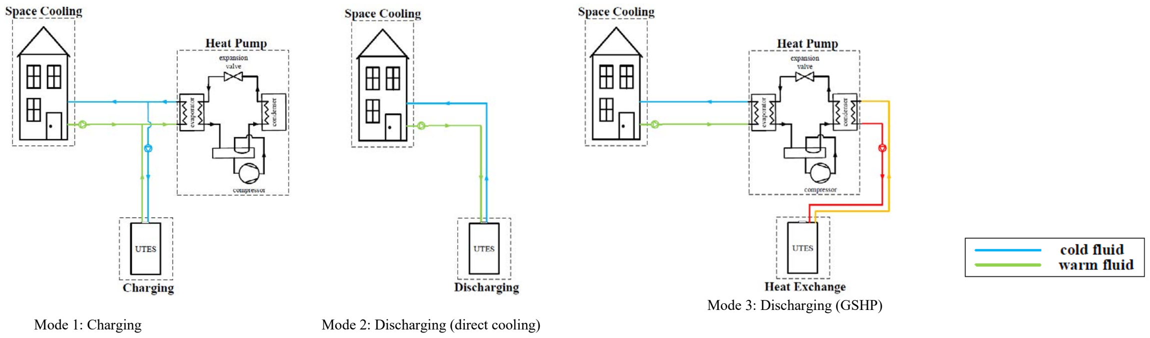


Fig. 7: Multiple operation modes of the dual function underground thermal battery for cooling operation.

ner tank, the heat pump can run efficiently, and thus the power consumption is low. The cooling-storage (Mode 1) and heat rejection (Modes 2 and 3) modes alternate daily so that the PCM in the UTB cycles more often between freezing and melting. It thus makes the PCM more effective in mitigating the rapid change of the leaving fluid temperature of the UTB.

A 1:5 small-scale prototype of the dual function UTB was also built and tested. Figure 8 shows the temperature response of a 14-hour test of the prototype when it was installed in a lab space with controlled ambient temperature. It can be seen from Figure 8 that the water in the inner tank can be cooled down from 17 °C to 3 °C during the 6-hour charging period (Mode 1) while the water in the annulus was above 13 °C. During the direct cooling period (Mode 2), a constant heat input (35 W, equivalent to 4.375 kW cooling load for a full-scale UTB) was rejected to the inner tank, the leaving water temperature from the heat exchanger in the inner tank (HX1) increased from 3 °C to 16 °C in two hours. The direct cooling can be prolonged at lower temperature by increasing the thermal storage capacity of the inner tank (e.g., making ice or adding PCM). After 2 hours of direct cooling operation, the UTB was run as a ground heat exchanger (through HX2 in the annulus of the UTB) and the 35 W heat input cycled on and off in 15-minute intervals to simulate the GSHP operation in part-load conditions. The leaving fluid temperature of the UTB is maintained below 20 °C for about 6 hours, which enables the GSHP to run at a high efficiency.

The primary advantage of the dual function UTB over conventional thermal energy storage technologies (e.g., ice storage) is that the hybrid nature of the design allows for shaping the electricity demand profile while satisfying the building's thermal load (both for heating and cooling) efficiently. Because the UTB is buried in the ground, it not only eliminates the need for insulation and building floorspace, but also makes use of the ground as a heat sink or heat source for efficient operation of the heat pump. Furthermore, integrating thermal energy storage and ground heat exchanger into one device is less expensive than using multiple individual components for the same purpose.

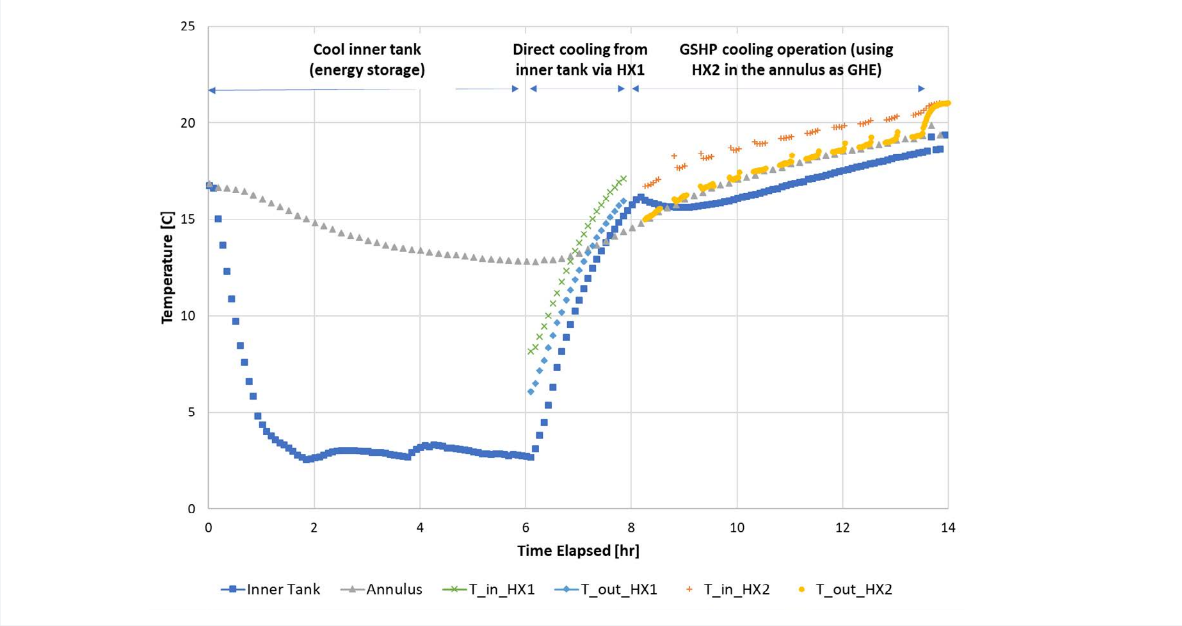


Fig. 8: Lab test results for a 14-hour operation of a dual-function UTB.

Conclusions

A new design of ground heat exchangers, the underground thermal battery (UTB), was developed. Lab tests and computer simulation results indicated that the UTB could achieve the same performance as the conventional VBGHE. A preliminary cost analysis indicates that, for achieving the similar annual performance, the installed cost of the UTB could be 39% lower than that of the conventional VBGHE. Further development of UTB enables active thermal energy storage so that it can be used to overcome the mismatch between the intermittent renewable power supply and fluctuating building thermal demands. It provides a new solution for both efficient air-conditioning and active demand side management without sacrificing the desired comfort condition and convenience in the building.

Acknowledgement

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Industrial Heat Pumps in the Danish Energy System – Current Situation, Potentials and Outlook

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Heat pumps are considered to be a key technology in the transition of the Danish energy system. The technology was successfully demonstrated by several installations in district heating, while the number of industrial applications is limited. In the context of district heating, the focus of R&D is shifting to issues of upscaling and operation as well as to exploiting further benefits. For industrial applications the focus lies on simplifying the optimal integration of heat pumps and enabling higher supply temperatures. This article summarizes the current situation and gives an overview of current and future developments in the field of industrial heat pumps.

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Introduction

Denmark aims to reduce the greenhouse gas emissions (GHG) by 40% by increasing the renewable energy production to 55% of the total demand and by increasing the energy efficiency by 33% by 2030, as well as other actions. The share of renewables in the electricity production in 2017 was 64% with 43% wind power, while heat supply to a large extent is based on biomass and waste incineration, but also on fossil fuels, such as gas, oil and coal. This yielded a 33% share of renewables in the total energy consumption. These boundary conditions result in a high potential reduction of GHG emissions associated with the implementation of electricity-based heat pumps, in addition to the improvements in overall energy efficiency.

Accordingly, heat pumps play an important role in the Danish energy scenarios and there are many projects aiming to enhance the number of applications. This article gives an overview of the situation of heat pumps in district heating and industry and describe areas with requirements for further developments.

Heat pumps in district heating

77 industrial heat pump installations with a total supply capacity of approximately 120 MW were identified, out of which 66 were in district heating. The wide distribution and the currently increasing request of heat pumps in district heating can be associated with several different factors.

Certainly, a main aspect is that district heating operators are legally obliged to consider the socioeconomic cost as the main criterion. In addition, it may be noted that the boundary conditions are becoming more beneficial for heat pumps. The electricity prices are decreasing due to the ongoing phase-out of the public service obligation and the reduction of taxes on electricity used for heating purposes. Heat pumps in district heating systems are furthermore eligible for subsidies for energy efficiency improvements.

Another aspect contributing to heat pumps being widely requested is that the technology has reached the status of being known and acknowledged by all involved par-

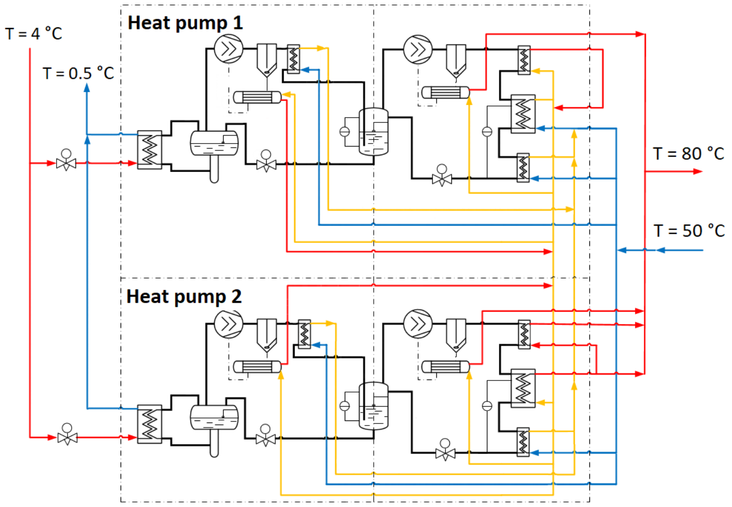

Fig. 1: System layout for the two two-stage R-717 heat pumps in the SVAF project in the configuration in which the source side uses seawater and the two heat pumps are connected in parallel

ties. The district heating network operators know the peculiarities of heat pumps and how to integrate them in the most beneficial way. The integration process is supported by publicly available information material, such as detailed guidelines and catalogues with realized cases for inspiration and planning tools [1].

Also, the solutions provided by heat pump suppliers are becoming more standardized, which reduces the engineering efforts.

It may be concluded that heat pump technology has become an established technology in district heating, and it is expected that several projects will follow during the coming years. The expected increase of applications is associated with certain challenges that translate into demand for further research and development. In the following we provide an overview of expected challenges and introduce corresponding development projects.

Heat sources

The increasing propagation of heat pumps for district heating supply comes with a demand for heat sources of considerable size. Copenhagen plans to become carbon-neutral by 2025 and expects a capacity of district heating supply of up to 300 MW to be covered by heat pumps. In general, there are different heat sources available with a variety of characteristics:

- Flue gas
- Industrial excess heat
- Geothermal sources
- Wastewater
- Groundwater
- Water from lakes and rivers
- Seawater
- Air

These heat sources have different characteristics regarding installation and operation [2,3] and may be dependent on geographical conditions or constrained in quantity. Flue gases from boilers and industrial excess heat are often available at comparably high temperatures and therefore constitute a promising source if located in the vicinity of the network. Geothermal sources are constrained by their location while the installation implies a certain investment risk at the current state of development. The utilization of groundwater is associated with large initial costs for pre-studies and is subject to concerns regarding the impact of the groundwater quality. Utilizing water from lakes, rivers and especially the sea is promising in Denmark, as seawater is available in abundance around all large Danish cities. Air is another potential heat source and especially used by smaller networks with limited access to other sources. However, it is often associated with large area demands, noise from the evaporator fans, and needs defrosting during cold periods.

In order to explore the possibilities with cleaned wastewater and seawater as heat sources for heat pumps with a capacity up to 100 MW, the R&D project SVAF on large heat pumps in district heating [4] was initiated. A demonstration plant as described in Figure 1 and Table 1 with a heat supply of 5 MW was constructed. The plant is configured with two two-stage heat pump units with ammonia as refrigerant. The heat pumps are connected serially on the sink side and may be operated both in parallel and in series on the source side. The project aims to collect operating experiences with these heat sources while developing strategies to ensure an optimal operation throughout the plant's lifetime. The plant was taken into operation in spring 2019 and is undergoing performance tests at a range of capacities and temperatures, including supply temperatures of up to 90 °C.

Table 1: Design specifications of the heat pump in the SVAF project

System	Two serially connected two-stage R-717 heat pumps with screw compressors		
Source	Medium	Seawater	Wastewater
	Temperatures	4 °C → 0.5 °C	10 °C → 4 °C
	Heat flow	3672 kW	3732 kW
Sink	Medium	District heating	
	Temperatures	50 °C → 80 °C	
	Heat flow	5194 kW	5177 kW
Performance	Power	1635 kW	1552 kW
	COP_h	3.2	3.3

Tuning of operating parameters and predictive maintenance

The large-scale heat pump tested in SVAF is subject to varying boundary conditions, e.g., seasonal variations of the supply temperatures and the heat source temperatures, as well as to shifting component performances, e.g., due to fouling in the heat exchangers. The heat pump system is relatively complex, and its control system implies 18 set points, such as desired temperatures and intermediate pressures of the cycle. Finding the optimal operating conditions is accordingly demanding and two strategies are tested.

Firstly, a validated numerical model is used to study the sensitivities and to adjust the set points [5]. This may further require a continuous tuning of the component parameters to account for the ongoing fouling, and is numerically demanding. Secondly, it is tested to analyze the sensitivities by variations of the operating plant. This gives more accurate results while a direct impact on the operation is inevitable.

The heat pump operating parameters are furthermore intended to be monitored and compared to numerical simulations to observe the conditions of selected components. These observations enable the prediction and scheduling of the required cleaning and maintenance downtimes, caused by the fouling of the heat exchangers as well as typical component wear.

Exploiting secondary benefits of heat pumps

Another unit, which has recently been installed in district heating in Copenhagen is located in the new development area of Nordhavn for heat supply for a warehouse and terminals for cruise ships. The unit is an 800 kW heat pump unit supplied by Johnson Controls/Sabroe. It is combined with 200 kW direct electric heating units and a heat storage of about 5 MWh. The system will supply the demand in an island configuration without connec-

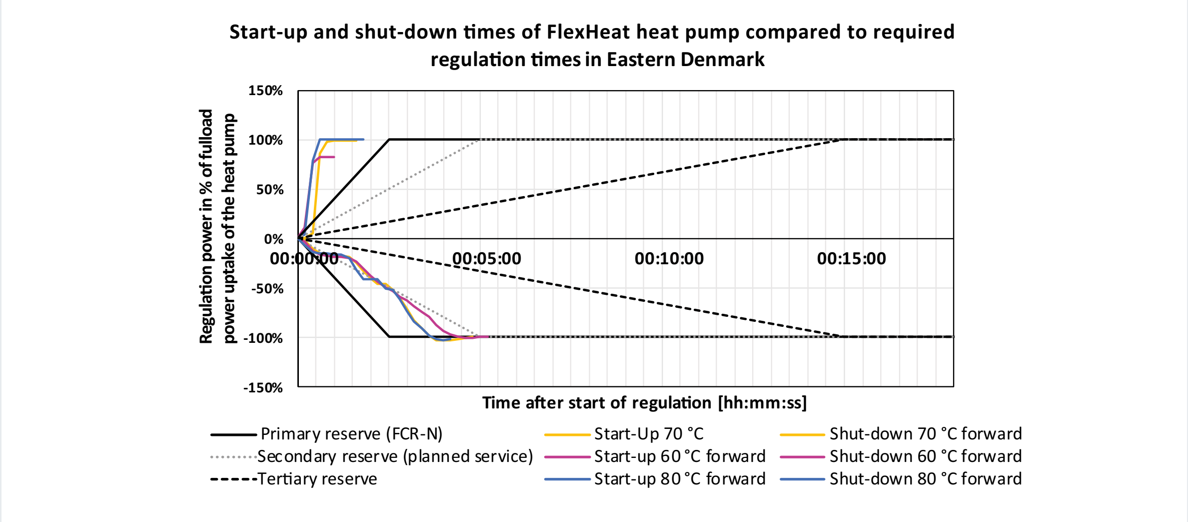

Fig. 2: Realizable and required regulation power of the heat pump in the Nordhavn Project

tion to the remainder of the city network. This makes the system well suited for testing flexible operation and thereby exploit secondary benefits, such as cost optimal operation, peak shaving of the district heating demand and delivery of ancillary services to the power system. Initial tests have been made and have shown that it is possible to deliver secondary and tertiary reserve power, as presented in Figure 2. Further development is expected for the heat pump to enable faster regulation and avoid any risks of surpassing operating limits provided by the supplier.

Heat pumps in industry

The integration of heat pumps in industrial applications is found to be rather challenging. The boundary conditions are more diverse, there is an additional degree of freedom in the level of integration and the available technologies do not cover the entire range of applications.

Level of integration

In addition to the diversity of the processes, there is also a certain degree of freedom in the level of process integration. The implementation of energy efficiency measures and electrifying process by means of heat pumps may be categorized by the following levels:

1. Integration on the process level without interaction among sub-processes
2. Integration on the process level with potential connection between different sub-processes
3. Integration on the utility level with different levels of interaction with the processes

Bühler et al. [6] studied the different possibilities and found that the system on utility level with a high degree of interaction with the process, i.e., different heat recovery loops and process heat supply at different temperature levels, showed the highest thermodynamic and economic performance. The integration at the process level does, however, enable a gradual implementation and may be more appropriate for integration in existing plants. The optimal placement of the heat pump unit is thereby not only dependent on technical and economic constraints, but also on the company's strategy to implement energy efficiency measures.

High-temperature heat pumps

In addition to the challenging integration of industrial heat pumps, there are technological challenges in the development of high-temperature heat pumps. An analysis of the demand identifies several processes that require heat at temperatures above 100 °C. Examples are sterilization processes with heat demands above 120 °C, drying processes with heat demands at up to 200 °C or higher, and chemical processes and refineries with demands of up to 300 °C. However, readily available heat pump systems are limited to supply temperatures of 100 °C to 150 °C. While natural gas boilers including a compensation for the emissions are considered as medium-term alternatives, biomass boilers and electrical boilers are considered as long-term alternatives. This raises the question what role high-temperature heat pumps are going to play in future energy scenarios.

Zühlsdorf et al. [7] analyzed the technical and economic feasibility of heat pump-based utility systems for process heat supply. The study evaluated two technologies for two case studies considering different fuel cost scenarios. There were three scenarios corresponding to the fuel cost in Denmark, Germany and Norway in 2020 and one scenario corresponding to operating own renewable electricity generators, such as windmills or PV. Both a reversed Brayton cycle using CO_2 and a cascade multi-stage steam compression system were considered. The two case studies were a spray dryer application for milk powder production with a supply of 8.2 MW at 210 °C and an alumina production case study with a supply of 50 MW at up to of 280 °C.

Figure 3 shows the specific levelized cost of heat for both cases and both technologies as well as for the alternative heat supply technologies. The levelized cost of heat is broken down to the contributions for investment, fuel cost, electricity cost, and an exemplifying tax for CO_2 emissions. The results indicate that the heat pump solutions using electricity from renewable sources are

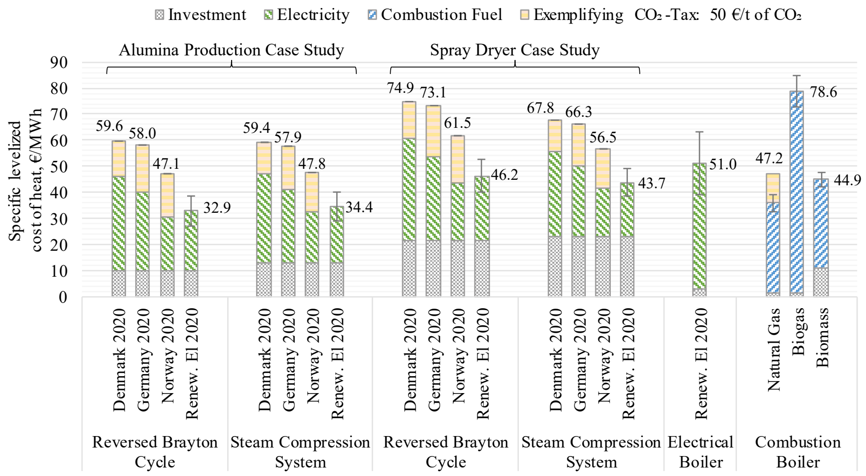

Fig. 3: Levelized cost of heat for an alumina production case study (heat source: 110 °C ➞ 60 °C, heat sink: 140 °C ➞ 280 °C & 50 MW) a spray dryer case study (heat source: 50 °C ➞ 25 °C, heat sink: 64 °C ➞ 210 °C & 8.2 MW) for a cascade multi-stage steam compression system and a reversed Brayton cycle using R-744, in comparison to electrical and combustion based boilers [7]

economically competitive compared to natural gas boilers (with a CO_2 tax of 50 €/ton) as well as biomass in the spray dryer case. Further, similar heat pump solutions outperform both biomass and gas boilers in the case of the alumina production.

The considered concepts were based on components from oil and gas industries that are commercially available but that were not demonstrated in the suggested concept.

Conclusions

The number of heat pump installations in district heating is increasing significantly. The technology was successfully demonstrated in many applications and the development focus shifts to the upscaling, operational issues and exploitation of secondary benefits. In the context of industrial applications, the increasing complexity of the systems as well as technological constraints with respect to high-temperature heat supply are considered as limiting factors. However, it is expected that ongoing developments and the shifting boundary conditions will contribute to an increased number of demonstrations and enable similar dissemination as that observed in district heating.

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Events 2019/2020

This section lists workshops, conferences etc. related to heat pumping technologies.

2019

19-21 November
7th International Conference On Energy Research and Development
State of Kuwait
https://www.ashrae.org/conferences/topical-conferences/7th-international-conference-on-energy-research-development

4-6 December
50th International HVAC&R Congress and Exhibition
Beograd, Serbia
https://www.ashrae.org/conferences/ashrae-endorsed-conferences/international-hvac-r-congress-and-exhibition

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

2020

1-5 February
ASHRAE Winter Conference
Orlando, Florida, USA
https://www.ashrae.org/conferences/2020-winter-conference-orlando

12-14 February
Energise 2020: Energy Innovation for a Sustainable Economy
Hyderabad, India
https://www.energiseindia.in/

15-17 April
6th IIR Conference on Sustainability and the Cold Chain (ICCC 2020)
Nantes, France
http://www.iifiir.org/clientBookline/recherche/NoticesDetaillees.asp?VIEWALL=TRUE&ToutVisualiser=1&INSTANCE=exploitation&iNotice=1&Idebut=

11-14 May
13th IEA Heat Pump Conference 2020
Jeju, South Korea
http://hpc2020.org/

7-11 June
9th International Conference on Caloric Cooling and Applications of Caloric Materials (Thermag IX)
College Park, Maryland, USA
https://www.ashrae.org/File%20Library/Conferences/ASHRAE%20Endorsed%20Conferences/DRAFT_Thermag2020-3_VA1_Redlined.pdf

27 June – 1 July
ASHRAE Annual Conference
Austin, Texas, USA
https://www.ashrae.org/conferences/2020-annual-conference-austin-texas

1-3 July
Asian Conference on Refrigeration and Air-conditioning
Hangzhou, China
https://10times.com/acra-hangzhou

1-3 July
8th Iberian-American Congress of Refrigeration Science and Technology (CYTEF 2020)
Pamplona, Spain
http://www.unavarra.es/cytef2020/?languageId=1

13-16 July
Purdue International Compressor Engineering, Refrigeration & AC, High Performance Buildings Conferences
West Lafayette, Indiana, USA
https://engineering.purdue.edu/Herrick/Conferences/2020

26-29 July
Rankine 2020 Conference – Advances in Cooling, Heating and Power Generation
Glasgow, United Kingdom
https://ior.org.uk/rankine2020

12-14 August
2020 Building Performance Analysis Conference & Simbuild
Chicago, Illinois, USA
https://www.ashrae.org/conferences/topical-conferences/2020-building-performance-analysis-conference-simbuild

16-21 August
2020 Summer Study on Energy Efficiency in Buildings
Pacific Grove, California, USA
https://aceee.org/conferences/2020/ssb

14-16 September
Indoor Environmental Quality Performance Approaches - Transitioning from IAQ to IEQ
Athens, Greece
https://www.ashrae.org/conferences/topical-conferences/indoor-environmental-quality-performance-approaches

1-2 October
The Fourth International Conference on Efficient Building Design
Beirut, Lebanon
https://www.ashrae.org/conferences/topical-conferences/the-fourth-international-conference-on-efficient-building-design

6-9 December
14th IIR-Gustav Lorentzen Conference on Natural Refrigerants (GL 2020)
Kyoto, Japan
https://biz.knt.co.jp/tour/2020/12/gl2020/program.html

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

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.

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