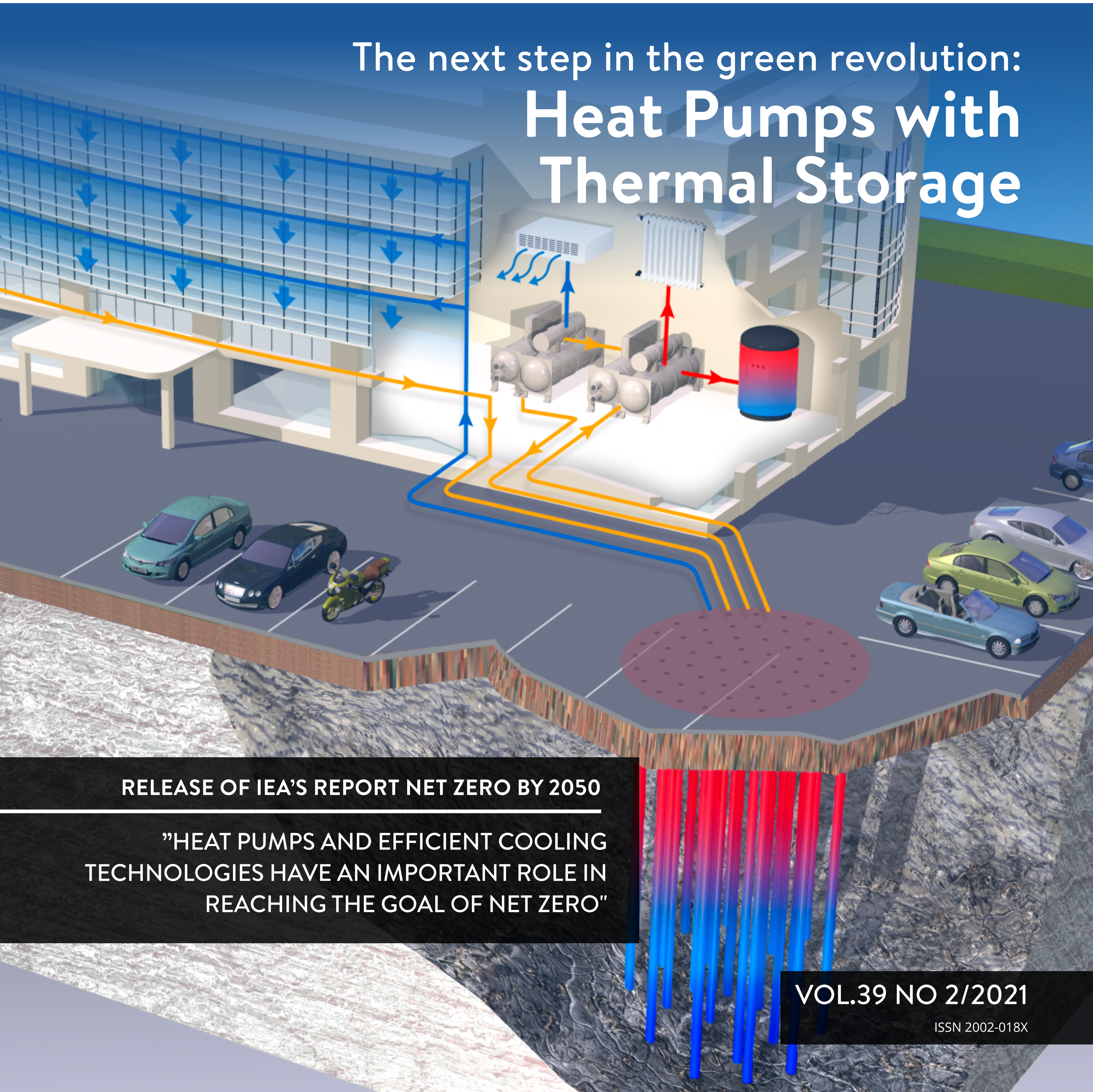
Technology Collaboration Programme
by iea

Heat Pumping Technologies MAGAZINE

A HEAT PUMP CENTRE PRODUCT

The next step in the green revolution: Heat Pumps with Thermal Storage



RELEASE OF IEA'S REPORT NET ZERO BY 2050

"HEAT PUMPS AND EFFICIENT COOLING TECHNOLOGIES HAVE AN IMPORTANT ROLE IN REACHING THE GOAL OF NET ZERO"

VOL.39 NO 2/2021
ISSN 2002-018X

Heat Pumping Technologies
MAGAZINE

VOL.39 NO.2/2021

In this issue

Heat pumps have an important role to play in the future energy system. The IEA's Roadmap for the Global Energy Sector, Net Zero by 2050 that was published in May states that the heat pump market should grow with a factor 10 until 2050 to reach a net zero energy system in 2050. This very important topic is addressed in both the foreword and one of the news articles in this issue.

April and May was important months for the heat pump market. Not only the IEA report was published but also the 13th IEA HPC conference took place in Jeju. Due to Covid 19 the conference was held as a successful hybrid event with presentations from all around the world. You can read a summary of the contents of the conference in the news section.

The topical articles of this issue are all addressing the integration of thermal energy storages in heat pumping and cooling systems. Two different types of thermal energy storages are covered, and they are both most likely important for the energy system of the future. Storage in the form of bore hole systems and thermal storages integrated as a part of the heating/cooling system of a building. The former solution provides seasonal storage of energy, and the latter solution provides short term energy flexibility to the electricity grid.

Enjoy your reading!

Sara Skärhem, Editor
Heat Pump Centre
The central communication activity of Technology Collaboration Programme on Heat Pumping Technologies (HPT TCP)

Published by Heat Pump Centre
c/o RISE - Research Institutes of Sweden,
Box 857, SE-501 15 Borås, Sweden
Phone: +46 10 516 53 42

Publisher:
Heat Pump Centre
P.O. Box 857, S-501 15 BORÅS
SWEDEN
Tel: +46-10-516 53 42
hpc@heatpumpcentre.org

www.heatpumpingtechnologies.org

Front page: SENS, Sustainable Energy Solutions, www.sens.se

ISSN 2002-018X
https://doi.org/10.23697/5rz3-x622

Heat Pumps and Storage

As I am writing this foreword, social media are inundated with euphoric and optimistic posts about the global energy transition. For starters, the IEA itself has announced its roadmap to a net zero carbon society by 2050. This report is nothing short of a revolution. For the first time, the IEA is proposing a radical and sudden break in the way we manage our global energy sector. We should stop looking for new fossil energy sources right now, and we should drastically accelerate the transition to a carbon-neutral industry, emission-free transportation, and renewable heating and cooling. Secondly, a Dutch court has ordered Royal Dutch Shell to cut emissions by 45% of 2019 levels by 2030. This unprecedented court order is the first time a commercial business is being held responsible for possible future environmental impact.

Could this really be the start of a new take on the energy transition? Are we starting to understand that a sudden and dramatic transition to renewable energy is to be preferred over an uncertain future with uncontrollable global warming? I do indeed hope so!

To make the transition happen, all sectors must act. In particular, the heat pump market will have to grow at breath-taking speed. Not only in existing markets, but also in new markets, such as cold climates, densely packed cities, retrofit buildings and industrial processes.

The only way to achieve this is to broaden our focus. We cannot afford to be content with a highly efficient heat pump alone. Instead, we need an integrated solution for heating and cooling, where heat pumps and storage units are seamlessly integrated into the energy system.

Within Annex 55, Comfort and Climate Box, participants from 11 countries are participating to delineate and accelerate the market for integrated heat pump and storage systems (or Comfort and Climate Boxes). One of the main recommendations is to start working with implementation strategies for heat pumps and thermal storages.

We have identified four of those strategies:

- Maximal efficiency (traditional focus of research and policy)
- Maximal flexibility
- Maximal compactness
- Maximal affordability

Depending on local conditions, the best implementation strategy can be selected. The next step then is to establish a package of specific policy support measures, tailored to that strategy. The technical solutions are available already; our present task is to establish and develop new heat pump and storage markets.

The thematic articles in this magazine all focus on the integration of heat pumps and storages, to help us begin to understand the challenges ahead. Because indeed, *the times they are a'changin.*

Paul Friedel
Annex 55 Operating Agent
Business Development Holland, Harderwijk/Rotterdam, The Netherlands
friedel@bdho.nl

French Building Regulations: A Key Driver for Heat Pump Market Deployment

The R&D efforts carried out by the Annexes of IEA HPT TCP represent an important contribution to the technological development of heat pumps and the demonstration of their relevant use in various applications. National or regional regulations are also an efficient driver for accelerating the market penetration of heat pumps. The French regulation RT2012 is one successful example of such a regulation that has ramped up the roll-out of heat pumps.

In an application of the European Directive on the Energy Performance of Buildings (EPBD 2010/31/EU), France implemented the RT2012 regulation for new buildings with a calculation of their energy consumption expressed in kWh/m^2 per year. In addition, by legislating the use of renewable energy with a minimum of 5 kWh/m^2 per year or the use of a heat pump water heater with a minimum COP of 2 in individual residential buildings, the French regulation has accelerated the success of this latter technology, which has taken precedence over many other renewable energy technologies. The regulation has thus strongly contributed to the penetration of heat pumps in new building construction: heat pumps for heating (mainly air-to-water units) rose from around 50,000 units in 2012 to 175,000 in 2020. For heat pump water heaters, 115,000 units were installed in 2020 compared to 30,000 in 2012.

Since its application, the RT2012 regulation has been amended to take into account technological advances in heat pumping products. This adaptability has enabled innovative heat pump technologies to emerge, such as heat pumps providing two or more services (heating, domestic hot water, cooling, ventilation), hybrid units, heat pumps using waste water or solar collector as a heat source, CO_2 transcritical heat pumps. Specific features, such as free cooling or geo cooling, can also be taken into account.

In January 2022, RT2012 will be replaced by a new regulation, RE2020, which will reinforce building energy consumption requirements and implement new environmental requirements, such as reducing CO_2 emissions from the building, mainly during its use phase. First to be implemented in residential buildings, the regulation will support the deployment of thermodynamic systems and restrict the use of other systems, such as boilers or Joule effect heating systems.

When applied, this regulation is expected to significantly contribute to meeting the challenges of global warming in the building sector through the deployment of heat pump technologies, while requiring minimum energy efficiency thresholds for each heat pump technology.

The market penetration of heat pumps is also linked to the confidence that prescribers and customers have in the energy performance of products. This confidence relies on the certification of product performance, and the French regulations have always encouraged it, so far based on COP values.

Today, the implementation of European Ecodesign and Energy Labeling regulations for heat pumps, air conditioners and chillers introduces a new characterization of their performance through seasonal energy efficiency.

Discussions are underway within the CEN-CENELEC Coordination Group "Harmonization/ Coordination ErP / EPBD" Task Force to establish calculation methods on the energy performance of buildings based on the seasonal performance data declared according to the Ecodesign regulations. France will contribute to this Task Force by leading a project that brings together CETIAT, CSTB, EDF and UNICLIMA that aims to evaluate different calculation methods to be proposed for standards or future revisions of the French regulation.

In line with product standards, building regulations in France will continue to play a key role in the deployment of heat pumps in new buildings as well as existing buildings.

MICHÈLE MONDOT
Cetiat
(Technical Centre for HVAC Industry)
Direction of Development and Partnerships Thermodynamic Systems Project Manager

VALÉRIE LAPLAGNE
Uniclima
(French Association for Heating, Cooling and Ventilation Industry)
Head of renewable heating sectors, heat pumps, solar thermal and biomass

Release of IEA's Net Zero by 2050 – A Roadmap for the Global Energy Sector

The special report released by IEA on May 18, 2021 shows that the pathway to the critical and formidable goal of net zero emissions is narrow, but it brings huge benefits. The report shows that heat pumps and efficient cooling technologies have an important role in reaching the goal.

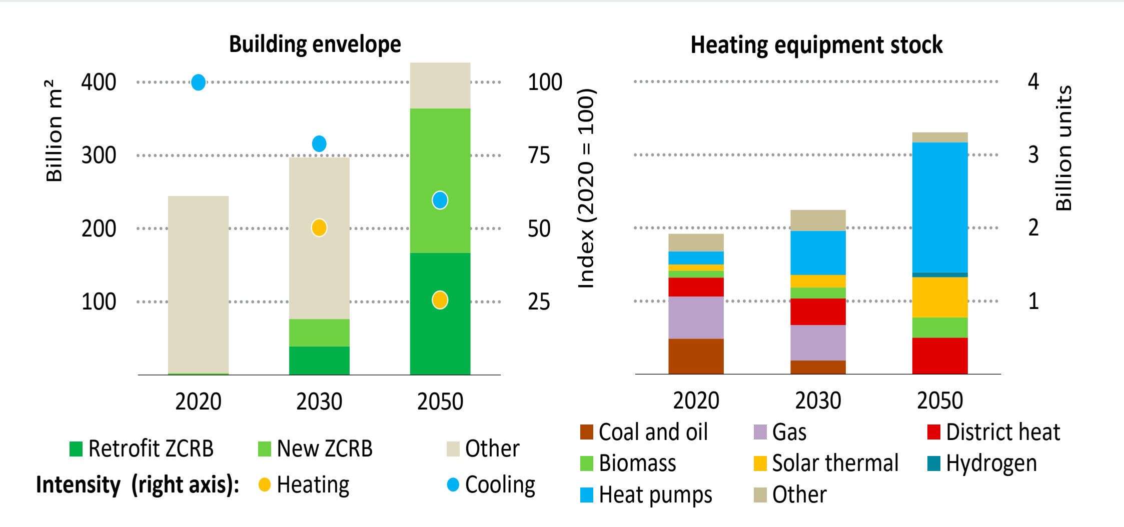
The pathway requires an unprecedented transformation of how energy is produced, transported and used globally. Climate pledges by governments to date – even if fully achieved – would fall well short of what is required to bring global energy-related carbon dioxide (CO_2) emissions to net zero by 2050 and give the world an even chance of limiting the global temperature rise to 1.5 °C, according to the new report, Net Zero by 2050 – A Roadmap for the Global Energy Sector.

The report is the world's first comprehensive study of how to transition to a net zero energy system by 2050 while ensuring stable and affordable energy supplies, providing universal energy access, and enabling robust economic growth. It sets out a cost-effective and economically productive pathway, resulting in a clean, dynamic and resilient energy economy dominated by renewables like solar and wind instead of fossil fuels. The report also examines key uncertainties, such as the roles of bioenergy, carbon capture and behavioral changes in reaching net zero.

Building on the IEA's unrivalled energy modelling tools and expertise, the Roadmap sets out more than 400 milestones to guide the global journey to net zero by 2050. These include, from today, no investment in new fossil fuel supply projects, and no further final investment decisions for new unabated coal plants. By 2035, there are no sales of new internal combustion engine passenger cars, and **by 2040, the global electricity sector has already reached net-zero emissions.**

In addition, other defined key milestones, are **"no new sales of fossil fuel boilers by 2025"** and that **"50% of heating demand is met by heat pumps in 2045"**, see Figure 4.1 below (page 152 in the report). The share of existing buildings retrofitted to the zero-carbon-ready level need to increase from <1% in 2020 to 20% in 2030 and >85% in 2050. The corresponding share for new buildings must be 100% already in 2030. The stock of installed heat pumps needs to increase from 180 million units in 2020 to 600 million units in 2030 (more than triple) and thereafter a tenfold increase to 1800 million units in 2050, see Figure 3.29 below (page 145 in the report).

Figure 3.29 Global building and heating equipment stock by type and useful space heating and cooling demand intensity changes in the NZE



Over 85% of buildings meet zero-carbon-ready building energy codes by 2050, reducing average final heating intensity by 80%, with heat pumps meeting over half of heating needs.

Figure reference: International Energy Agency (2021), Net Zero by 2050, IEA, Paris. All rights reserved.
https://www.iea.org/reports/net-zero-by-2050

Most of the global reductions in CO2 emissions between now and 2030 in the net zero pathway come from technologies readily available today. But in 2050, almost half the reductions come from technologies that are currently only at the demonstration or prototype phase. This demands that governments quickly increase and reprioritise their spending on research and development – as well as on demonstrating and deploying clean energy technologies – putting them at the core of energy and climate policy.

Emissions from light industries, such as e.g. paper, food, vehicles etc need to decline by around 30% by 2030 and around 95% by 2050 in the NZE (Net Zero Emission Scenario). In contrast to the heavy industries, most of the technologies required for deep emission reductions in these sub-sectors are available on the market and ready to deploy already today. This is in part because more than 90% of total heat demand is low/medium temperature, which can be more readily and efficiently electrified. For low- (<100 °C) and some medium- (100-400 °C) temperature heat, electrification includes an **important role for heat pumps** (accounting for about 30% of total heat demand in 2050). In the NZE, around **500 MW of heat pumps** need to be installed every month over the next 30 years, see Figure 3.20.

The special report is designed to inform the high-level negotiations that will take place at the 26th Conference of the Parties (COP26) of the United Nations Climate Change Framework Convention in Glasgow in November. It was requested as input to the negotiations by the UK government's COP26 Presidency.

The full report is available for free on the IEA's website along with an online interactive that highlights some of the key milestones in the pathway that must be achieved in the next three decades to reach net-zero emissions by 2050.

[Read the press release from IEA and the full report here >](https://www.iea.org/reports/net-zero-by-2050)

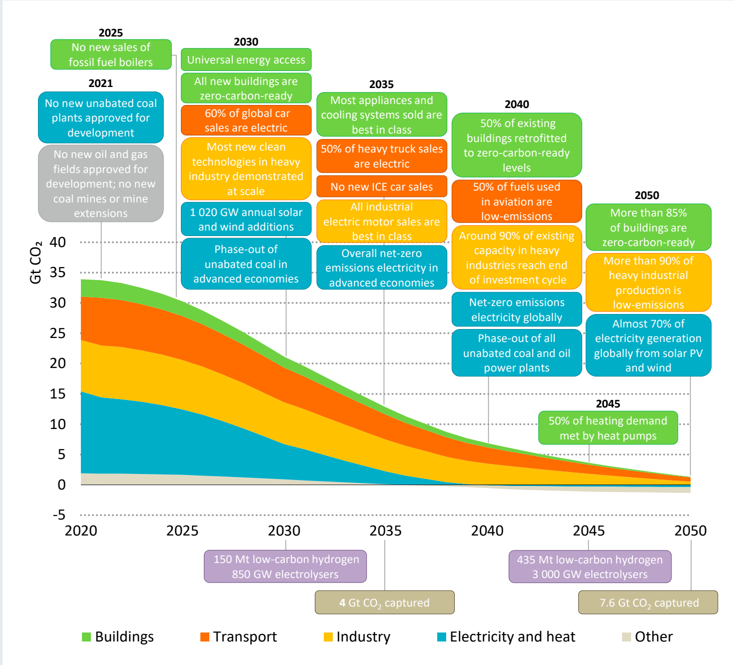


Figure 4.1 Selected global milestones for policies, infrastructure and technology deployment in the NZE.

There are multiple milestones on the way to global net-zero emissions by 2050. If any sector lags, it may prove impossible to make up the difference elsewhere.

Figure reference: International Energy Agency (2021), Net Zero by 2050, IEA, Paris. All rights reserved. https://www.iea.org/reports/net-zero-by-2050

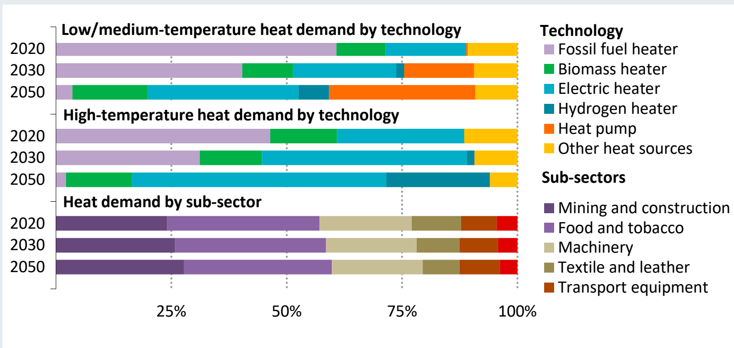


Figure 3.20 Share of heating technology by temperature level in light industries in the NZE.

The share of electricty in satisfying heat demand for light industries rises from less than 20% today to around 40% in 2030 and about 65% in 2050.

Figure reference: International Energy Agency (2021), Net Zero by 2050, IEA, Paris All rights reserved. https://www.iea.org/reports/net-zero-by-2050

The Highlights of the 13th IEA Heat Pump Conference

Heat Pumps – Mission for the Green World
April 26 – 29, 2021, Ramada Plaza Jeju Hotel, Jeju, South Korea

By Professor Minsung Kim

Summary of HPC2020

The 13th IEA Heat Pump Conference (HPC2020) was held on April 26-29, 2021. Due to the COVID-19 outbreak, the conference was held on both online and offline platforms. The offline venue was the Ramada Plaza Hotel Jeju, Korea. This year's HPC 2020 was unique in not only the hybrid platform but also the program which featured all phases of heat pumping technologies. Despite the enormous challenges of the pandemic, the conference was successful, and attendance exceeded our expectations. I could not be prouder of the commitment and efforts that went into making this conference possible.

Despite the discomfort of remote discussions and online presentations, six plenary speeches from renowned speakers and 201 technical papers enlightened the conference. More than 370 participants from 26 countries attended the conference, listened to meaningful presentations, and had fruitful discussions with experts from around the world on scientific and technological heat pumping issues.

Conference Program

Workshops

On Monday, 26 May, the first day of the Conference, six workshops were held fully online actively involving around 200 participants. In the workshops, on-going and recently finished HPT Annex projects were introduced. The up-to-date technologies discussed were heat pumping technologies related to smart grid connection, energy storage, and nZEB integration. In addition, low GWP refrigerant issues, cooling CCB (Comfort and Climate Box) solutions, and large demo-projects held the focus of the participants.

Opening Ceremony

The opening ceremony of the 13th IEA Heat Pump Conference was officially held at 9 am KST on April 27, 2021 with a welcoming address made by Stephan Renz, Chair of IEA HPT TCP. Opening remarks were provided by Min Soo Kim, NOC (National Organizing Committee) Chair and Hee-ryong Won, Governor of Jeju Province, who delivered a congratulatory message.

Plenary Speakers

Six influential plenary speakers presented their vision of the heat pump industry. The introduction of global heat pump markets and policies made by the first three speakers was followed by three eminent speakers providing excellent summaries on key heat pump system technologies.

Mechtild Worsdorfer, IEA Director for Sustainability, Technology and Outlooks provided the opening plenary speech "Heat Pumping Technologies in Clean Energy Transitions". She spoke of the

Welcome speech from Stephan Renz (IEA HPT TCP Chair)

Opening remark from NOC Chair Min Soo Kim

Congratulatory address by Hee-ryong Won, Governor of Jeju Province potential heat pumps have in reducing the carbon footprint. For the Paris Agreement, a 3-pillar action plan consisting of greater deployment rates across all applications, the integration of heat pumps with power systems, and enhancing heat pump technologies were emphasized.

Martin Forsén, President of EHPA (European Heat Pump Association) presented the efforts of the European Commission to reach climate neutrality by 2050 in his presentation "The European Legal Framework is Well Set for a Massive Roll-out of Heat Pumps - but More Efforts are Needed". In his speech, he emphasized how the energy system integration strategy with electrification based on heat pumps will double the share of heating produced by heat pumps by 2030, reaching 50-70% by 2050.

Min Soo Kim, President of SAREK (Society of Air-conditioning and Refrigerating Engineers of Korea) and NOC Chair, presented "Korean policy for green world and heat pumping technologies". He introduced the New Deal strategy of the Korean Government which will invest KRW 73.4 trillion for transitioning to a low-carbon, green economy.

Saikee Oh, Vice President of LG Electronics, provided excellent summaries on recent air-source heat pump technologies. He also presented some fundamental bottlenecks as well as the cutting-edge heat pump technology that will overcome them.

Xudong Wang, Vice President of AHRI (Air-Conditioning, Heating, and Refrigeration Institute) presented the transition to flammable low GWP refrigerants. The presentation covered the current status of developing relevant codes and standards in the US. It was clear after the speech that more research and efforts are needed to enable safe transition to low GWP refrigerants in the future.

Noboru Kagawa, Professor of the National Defense Academy in Japan, presented experiences caused by health problems and how the pandemic has changed the design of HVAC systems in the presentation "Clean and Safe Air by HVAC Systems – Laws and Advanced Technologies in Japan". The presentation showed that accumulated knowledge can improve HVAC technologies. An overview of related laws and new technologies in Japan was given.

Technical sessions

Tuesday, April 27

After the plenary speeches, the twelve general technical sessions were opened. An invited speaker, Dr. J.B.V. Reddy from the Government of India, presented the facts and policies on air-conditioning and cooling in India. Didier Coulomb, IIR Director, presented the low GWP challenge and barriers. Among the keynote speeches, the water vapor high temperature heat pump was introduced by Di Wu from Sanghai Jiao Tong University.

Wednesday, April 28

In the morning session of the second day of the conference, Tetsusiro Iwatsubo presented on innovative thermal management R&D projects by NEDO. In a session on low GWP refrigerants, various papers on policy and technical considerations were reported. Bamdad Bahar, President of Xergy Inc., gave an overview of hydrogen compressors for heat pump systems. Mr. Bahar also gave several more interesting presentations introducing heat pump technologies of the future. Tor-Martin Tveit introduced the very high temperature heat pump applied at a pharmaceutical research facility.

Thursday, April 29

On the last day of the conference, many interesting papers were presented. Topics ranged from state-of-the-art dehumidification technology, food-storage systems and heat pumps for nZEB.

Closing Ceremony

After three days of technical sessions, the closing ceremony was held. After the opening remarks by Per Jonasson, IOC Chair, the Peter Ritter von Rittinger International Heat Pump Awards (RvR Awards) were presented. The RvR Award is the highest international award in the air conditioning, heat pump and refrigeration field. As individual awardees, Jussi Hirvonen, Director of the Finnish Heat Pump Association and Prof. Ruzhu Wang, Shanghai Jiao Tong University received RvR Awards. The Center for Environmental Energy Engineering (CEEE) at the University of Maryland received an RvR Award as a team.

To promote student activities in this hybrid conference, a Global Student Video Competition was held. This competition provided an opportunity to create a video to exchange ideas and relevant knowledge on the topics of heat pump applications, environmental issues, energy, or what students do in the laboratory. The video from RWTH Aachen University won the gold medal for their video entitled "Sherlock HiLmes: The Adventure of the Hardware in the Loop Investigations of Heat Pumps - A Case of Efficiency".

Following the award ceremony, the promotion video of the 14th Heat Pump Conference was broadcasted. The conference will be held in Chicago, Illinois in the US on May 15–18, 2023. The proposed theme is "Heat Pumps – Resilient and Efficient".

Closing Remark

The National Organizing Committee (NOC) of the 13th IEA Heat Pump Conference would like to thank each and every person who contributed to this year's conference. Also, we would like to call for continued dedication in pushing this field of science forward. We wish you the best and until the next time we meet, please be safe and healthy.

See you all in two years in Chicago, Illinois.

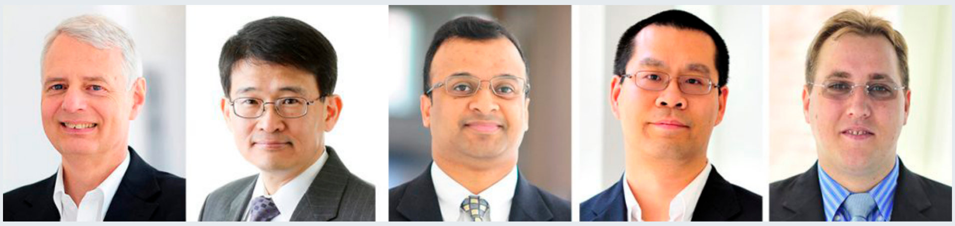
The Winners of the 2021 Rittinger Award

In a ceremony held digitally at the closing session of the 13th IEA Heat Pump Conference in Jeju Korea on April 29 2021, the winners of the prestigious Peter Ritter von Rittinger International Heat Pump Award, the highest international award in the air conditioning, heat pump and refrigeration field, were presented.

Jussi Hirvonen, Finnish Heat Pump Association, Professor Ruzhu Wang, Shanghai Jiao Tong University and the Center for Environmental Energy Engineering (CEEE) University of Maryland were given the 2021 Rittinger Award for their efforts in the field.

M.Sc. Jussi Hirvonen, was the initiator of heat pump business in the Finnish market and because of his tireless work, Finland has become one of the leading countries using heat pumps for space heating. Jussi's 20 years of remarkable lifework in the heat pump sector also includes a large number of commitments in different positions and organizations which have forwarded heat pump business locally and globally. Jussi was the founder member establishing Finnish Heat Pump Association and as well founder member establishing European Heat pump Association (EHPA). He was also one of the members establishing Eesti Soojuspumpa Liit (ESPL) heat pump association into Estonia. Finland participating IEA HPT TCP program was also consequence of Jussi Hirvonen activity.

Prof. Ruzhu Wang is full professor and the director of Institute of Refrigeration and Cryogenics, Shanghai Jiao Tong University (since 1993). His institute has been recognized a world leading research institute in Refrigeration and Heat Pump Technology. Prof. Wang's major contributions related to heat pumping technologies include adsorption heat pumps, desiccant based heat pumps and dehumidification, vapor compression heat pumps, absorption heat pumps, and heat pump applications in green building energy systems and industrial waste heat recovery. He has written 12 books regarding Refrigeration and Heat Pump Technologies (3 in English published by Wiley, Elsevier and Springer respectively). His publications have been extensively cited, thus he has been recognized as 2017 & 2018 Clarivate Highly Cited Researcher in the world.



Winners of the team from Center for Environmental Energy Engineering:
Dr. Reinhard Radermacher, Dr. Yunho Hwang, Dr. Vikrant Aute, Dr. Jiazhen Ling, Mr. Jan Muehlbauer.

Center for Environmental Energy Engineering (CEEE), this team of researchers from the Center for Environmental Energy Engineering at the University of Maryland works on cutting-edge heat pump technology research. They have one of the world's most comprehensive research portfolio on a wide range of heat pumping technologies both in terms of experiments and modeling. This remarkable group of researchers brings a wealth of experiences and expertise to the heat pump research community. Their contributions led to significant gains in technological development. They work collaboratively with researchers from other fields, other countries, and other institutions leading to great breakthroughs in both energy efficiency, improved performance, and reduction of manufacturing and energy costs.

The team from the Center for Environmental Energy Engineering that received the 2021 Rittinger Award consists of:

- Dr. Reinhard Radermacher, Director of the Center and Minta Martin Professor of Engineering, Professor of Mechanical Engineering
- Dr. Yunho Hwang, Co-Director and Research Professor
- Dr. Vikrant Aute, Co-Director and Research Scientist
- Dr. Jiazhen Ling, Assistant Research Professor
- Mr. Jan Muehlbauer, Faculty Specialist and Laboratory

Pressrelease Rittinger Award 2021 >

Reports from the Technical Sessions of the HPC2020

Proceedings from the 13th IEA Heat Pump Conference can be ordered from our publication database.

Air Conditioning and Cooling – *by Van Baxter **

The keynote speaker provided an overview of India's perspective on AC. India initiated a Cooling Action Plan (CAP) to reduce cooling energy use and refrigerant demand by 25-40% and 25-30%, respectively, over the next twenty years. The CAP also aims to train 100,000 AC technicians by 2023. The session also included several papers on improving heat pump and AC systems for electric vehicles (EVs) and one paper stated that the EV heat pump energy consumption can be reduced by almost 19% when using battery charging reject heat as a source.

New Heat Pump Technologies – *by Van Baxter **

The keynote described a novel system concept using a mixture of noble gases in a rotating system; centrifugal forces compress the working fluid inside the rotating heat exchanger. Other topics were; a 600 kW industrial heat pump development effort; an experimental evaluation of a rolling piston compressor, and test results for a low-lift heat pump using an oil-free centrifugal compressor using R-1234ze(E).

Electrochemical Related – *by Van Baxter **

This session included papers on a variety of non-traditional technologies for heat pumping systems including compression of hydrogen (keynote) and ammonia/hydrogen blends, thermoelectric (TE) cooling/heating, proton electrolyte membrane fuel cell, and a combined absorption system. The keynote speaker noted that electrochemical compression (ECC) of hydrogen likely offers the best long-term efficiency potential but is currently at a low technology readiness level (TRL). Using a traditional hermetic refrigerant compressor offers the best near-term potential but has efficiency limitations. TE systems offer advantages for certain applications including heat pumps for clothes dryers.

Ground Source Heat Pumps – *by Signhild Gelin **

Two sessions were dedicated to ground source heat pump (GSHP) systems. The keynote presentation of the first session covered the development and simulation of a dual-purpose underground thermal battery with phase change material and active charging. The system allows for electricity peak shaving. The second presentation showed results from three years of performance monitoring of a GSHP system for heating and cooling, serving a Swedish mix-use building. The third paper covered a feasibility study of a GSHP system for a typical residential building block in Ontario in Canada. The following presentations covered a case study on measured performance of a GSHP system in Japan, where the ground was significantly influenced by groundwater flow and a liquid natural gas (LNG) system, where the LNG was vaporized by heating it with a hybrid GSHP system, combining ground heat exchangers and air-water heat exchangers.

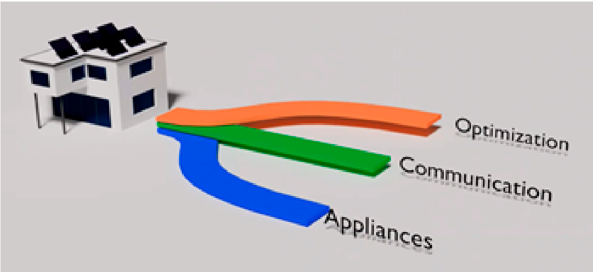
The keynote of the second session gave an overview of the results from the first three years of IEA HPT Annex 52, which addressed long-term performance measurement of large GSHP systems. The second presentation promoted the use of a low-GWP refrigerant twin-cycle GSHP configuration for building retrofit projects to enhance energy efficiency.

The following topics covered were:

- Results from multiple years of performance measurements from six German GSHP systems for large buildings.
- Short-term storage for cooling of office buildings.

Market and Policy for Heat Pumps – *by Caroline Haglund Stignor **

The keynote speaker introduced the first session by talking about that the mass market is the "next stop" for heat pumps in Europe and that the technology is on the verge of large scale deployment. He presented a qualitative assessment of the impact of European energy and climate-based



legislation on heat pump technology. He concluded that the outlook for heat pumps is positive for three reasons: a strong market foundation, a first legislative acceleration and an expected legislative booster. In another presentation, the three main benefits of heat pumps were outlined – they contribute to energy efficiency, decarbonization and cost savings. However, in many countries, policies that make the polluter pay are still lacking. The price ratio electricity/gas is still a barrier in several countries. The session also included a presentation about new possible business models for heat pumps, which means shifting from selling boxes to selling comfort, which concluded that there is a huge opportunity for innovative 'Heat as a Service' models to enable real growth in the heat pump market.

Other topics presented were:

- The strongly growing Finish heat pump market and the reasons behind
- An investigation about diffusion barriers and strategies for increase implementation of heat pump systems with integrated storage and photovoltaic in Austria.

The keynote of the second session about market and policy presented the NEDO R&D Project for Innovative Thermal Management in Japan, who relies heavily on fossil fuel and a lot of thermal energy is wasted. By use of heat pumps, a considerable amount of the wasted heat could be used, which would result in energy and CO_2 savings. The session also included presentations giving an overview of the US heat pump market in 2020, which has shown steady growth since 2010. Moreover, it included a techno-economic assessment of air-source heat pumping technologies in the Canadian residential sector, to find out under which circumstances the added investment in a variable speed or cold-climate heat pump, compared to a single-stage one, was justified.

One of the presented papers dealt with existing "roadblocks" to use of heat pumps in residential buildings for demand response, and how to overcome them. The presenter talked about the role of aggregators to give the end user access to the ancillary market, and about the hardware and software that is required to ensure successful implementation of demand response for heat pumps.

Smart Applications of Heat Pumps – *by Caroline Haglund Stignor **

In one of the last sessions of the conference, European Heat Pump Association gave a presentation about the communication campaigns that they had shaped, aiming at a positive emotional perception of the technology while trying to achieve a high level of recognition.

Thereafter researchers from Fraunhofer talked about a small charge heat pump with propane, with max 150 g propane and a capacity of 5-10 kW, they had built by only components available on the market.

The session was concluded with a presentation about heat pumps for nZEBs in a Nordic climate, where comparison of field measurement data with predicted performance, based on the same calculation models that are applied in the European Ecodesign and Energy Label regulations, had been done.

Heat Pumps Applications – *by Marek Miara **

The presentations in the session "Heat Pumps Application" mirrored the general research and development trend towards high-temperature heat pumps, heat pumps for industry and large-scale heat pumps. The primary markets for heat pumps are currently the residential, commercial and district heating/cooling markets. The penetration status of industrial heat pumps is so far very low. Most industrial heat pump applications involve the preparation of hot water for processes. As the demand for energy savings has grown in the industrial sector, so has interest in heat pumps that recycle waste heat, for example, to produce low-pressure steam.

The increase in number of applications in commercial, institutional, and multi-family buildings makes the measurement of long-term performance data vital. The content from IEA HPT Annex 52 is focused on this task. The results of Annex 52 show that performance vary, and we need more knowledge on the underlying causes. An important part of Annex 52 is to develop a methodology for measurement strategies and common system boundaries for larger heat pump systems.

Space and Hot Water Heat Pumps – *by Marek Miara **

The two main presentation topics in the session "Space and Hot Water Heat Pumps" addressed the field performance measurement of domestic heat pumps and heat pumps in multi-family buildings. Between 1996 and 2017, more than 600 heat pump systems, mainly in single-family houses, were investigated across Europe. On average, slightly more brine to water heat pump systems were recorded than air to water heat pump systems. Although the amount of data collected over these years is important, it can only be used in part for comparison because of different definitions of key figures and system boundaries or long sampling intervals. For drawing the correct conclusions when comparing heat pump systems, it is crucial to use the correct system limits and boundaries.

Heat Pump Performance – *by Marek Miara **

The presentations in the session "Heat Pump Performance" reflect broad application possibilities and types of heat pumps. The following were presented: heat recovery of wa-

ter-heating heat pumps, Hybrid HVAC System of Air Source Heat Pump and Natural Gas Furnace for Cold Climate, an air-water dual-source heat pump system for shrimp ponds, as well as a load-based testing methodology for evaluating advanced heat pump control design and a dynamic modeling and charge minimization study of a packaged propane heat pump with external flow reversal for cold climates.

Heat Transfer – *by Reinhard Radermacher **
This session was started with a paper presenting insightful experimental results on two-phase flow distribution in the refrigerant distributor of VRF systems. The impact of gravity, position of the inlet and differences between horizontal and vertical installation was discussed.

The following presentations covered the following topics and results:

- Mass transfer resistance for zeotropic mixtures during nucleate boiling on a copper surface.
- Effects of tube shape on boiling heat transfer of low-pressure refrigerant R1233zd(E) outside horizontal tubes.
- Evaporating thin film thickness is predominantly affected by the properties of the fluid, such as wettability, and not by the droplet size.
- A novel method to increase the durability of lubricant-impregnated surfaces on condenser tubes.

Variable Refrigerant Flow Heat Pumps and Air Conditioners – *by Reinhard Radermacher **
The keynote presentation introduced the test results of a heat pump with fixed speed compressor and fan that was retrofitted with a novel electronic drive that enables the variable-speed
control of conventionally single-speed PSC motors. The test results were very promising as both compressors and fans were operated at variable speed and could be increased to a 40% energy savings.

Other topics covered were:

- A parameter-estimation model for VRF heat pump systems.
- An effort to increase the performance of VRF systems based on field test results and a machine learning-based model for better control logic development. Results show that compressor frequency and condenser temperature are the two most important factors affecting outdoor unit power consumption.
- Development and validation of a model for a variable speed of a residential 5-ton heat pump using R410 with a prototype of a variable speed expansion work-recovery device.
- Laboratory and field test results of a next-generation residential space conditioning system.

Dehumidification Technology – *by Reinhard Radermacher **
The keynote of the session discussed the comparison of vacuum membrane dehumidification systems with moisture selective dense membrane. Simulation results were reported and surprisingly the version that compresses only water vapor to atmospheric pressure came out to be the favorite. The following presentation reported another use of membranes, employing a solid-state method of humidity control based on an electrolysis cell that can either humidify or dehumidify. The proposed application is food preservation, and the device is said to greatly reduce the defrost load for refrigeration applications. After this, a method and the result of a theoretical analysis of mass transfer in a vacuum membrane dehumidification system was presented.

The last two presentations in this session covered an empirical analysis of dehumidification performance of a hollow-fiber-membrane dehumidifier, and ionic membranes with the goal of maximizing performance and tailoring properties to various HVAC and Energy Recovery Ventilation (ERV) applications.

Heat Pumps for Industrial Process Heat Supply
*– by Benjamin Zühlsdorf **
Heat pumps for process heat supply in industrial applications are considered as a key technology for reducing CO_2 emissions from industrial processes and are accordingly the focus of various R&D activities. The IEA Heat Pump

Conference included three sessions about industrial heat pumps, underlining the relevance of heat pumps in an industrial context. The contributions covered a variety of aspects, while various studies focused on the development and demonstration of high-temperature heat pumps, as well as on system integration aspects.

High-Temperature Heat Pumps – *by Benjamin Zühlsdorf **
Process heat supply at temperatures above 100°C with so-called high-temperature heat pumps has great application potential, while various activities are aiming at the development and demonstration of suitable technologies.

Two studies on the comparison of technologies for steam generation were presented, considering technical, thermodynamic and economic aspects. The studies concluded that both natural and synthetic refrigerants are promising solutions, and that the final choice of the most optimal solution depends on economic parameters and product availability. Also steam generation was the focal point of three different studies.

The technology aiming for the highest temperatures, at a heat supply above 250°C, was presented. The study focused on the development of a capacity regulation approach.

System Integration Aspects – *by Benjamin Zühlsdorf **
In addition to the development of technologies capable of high temperatures, there was a strong focus on system integration approaches. Various studies were presented in which the heat pump was integrated into the process and often optimized simultaneously.

The most relevant applications were drying processes, for which several studies were presented. Flower bulb drying, brick drying, tumble dryers and desalination was covered.

In addition, the following topics related to system integration were covered:

- » Estimation of thermodynamic and economic performance
- » Optimal system configuration and control
- » Heat pumps in the food industry in combination with thermal storages
- » Integrated system coupled to solar thermal collectors and buffer tanks.

From the studies, it may be concluded that process integration and optimization of the integrated energy systems are crucial aspects for best leveraging heat pump performance.

Heat Pumps in Smart Grids and District Heating and Cooling Systems – *by Svend Vinther Pederssen **
The session should have been called "Projects that show the unlocked potential for renewable and creation of flexibility created by the use of heat pumps". The keynote addressed both district heating networks and the need for storage. This is needed if the Netherlands want to implement district heating where the potential is that 57% of the building mass can be heated with DH. The possibilities of high-temperature aquifer thermal energy storage as well as low-temperature district heating systems based on low-temperature geothermal heat was described.

The potential of heat pumps with seawater as a source and how such a project could be developed for different urban areas was addressed in the following presentation. The city councils are some of the main drivers of the implementation and transition away from fossil fuels to renewable heating. Also, the state of the electrification of heat and decarbonisation of the electricity system and how sector coupling is creating opportunities for heat pumps was covered.

Simulation and optimization of district heating systems and heat pumps were popular topics. Different simulation and control strategies were described. We also got to hear about the impact of weather forecasts in model predictive controls, as well as the development procedure for the simulation tool based on different software tools. The potential of flexible control of different heat pump types, both new and old, was presented. Finally, simulation results of smaller DH grids with GSHP and booster heat pumps and how they could be optimized through rule-based control strategies was discussed.

Heat Pumps for nZEB – *by Carsten Wemhoener **
The session "Heat pumps for nZEB" comprised of four presentations of heat pump applications in nearly Zero Energy Buildings, of participants who also contributed to the IEA HPT Annex 49 on heat pumps for nZEB. It thus covered aspects of design, modelling, system configurations and smart control for heat pumps in nZEB.

The initial presentation dealt with the cost-based design of a borehole field with regeneration for high-performance buildings. The simulation study revealed that there is a trade-off between borehole design and regeneration share. Detailed modelling of two multi-family nZEBs with double-stage groundwater heat pumps based on 4-year monitoring data was the basis for the evaluation in the second presentation.

In the third presentation, PV control was investigated in order to enhance the self-consumption of the on-site PV generation for eight single-family plus energy buildings. The concluding presentation also addressed energy flexibility using a price-based control strategy as an incentive for the user in order to unlock energy flexibility for the grid by residential heat pumps.

Residential Heat Pumps – *by Carsten Wemhoener **
The session "Residential heat pumps" covered heat pump applications for all building services including heating, cooling, DHW and dehumidification.

The initial presentation addressed the integration of a free cooling function for heat pumps with a solar absorber as heat source, which can be operated as a free cooling heat exchanger during nighttime. This was followed by a presentation of test results of 60 existing buildings with heat pumps were analysed in a recent field test in Germany, which measured performance values of an average SPF of 3 for A/W and 3.9 of B/W heat pumps. Heat pumps thus offer large CO_2 reduction potential compared to common fossil-fuel boilers.

Other topics covered were:

- A model-based approach which predicts the optimum air flow for each seasonal performance condition to better assess and improve seasonal performance in part load conditions.
- A heat pump system for cooling, heating, dehumidification and outdoor air supply.
- The energy performance of an air-source heat pump heating system and a radiant floor heating system with an energy recovery ventilator in an apartment building evaluated by simulations.

Components and Cycles – *by Veronika Wilk **
This session addressed research and development of components in order to increase the efficiency or simplify heat pumps.

The following components were discussed:

- Vortex tube as an alternative expansion device for high-temperature heat pumps
- Maldistribution of propane in brazed heat exchangers for evaporators
- An expander in an absorption chiller with NH3/water as working fluid in a combined cooling and power cycle application.
- The condensing boiler of a gas-fired absorption heat pump.

The session was concluded by a study of the economics of heat pumps for non-residential buildings in Germany in 2050. The results underline the importance of the future development of energy prices.

Advanced Controls and Modeling – *by Veronika Wilk **
Topics such as fault detection, power and capacity determination and optimized AC control was discussed in this session. The first presentation was about a convolutional neural network that was trained to detect refrigerant charge faults and to determine the power consumption, cooling and heating capacity of an HVAC system. This was followed by a study about optimized AC control used for temperature control and high energy efficient pre-cooling.

The last two presentations addressed a thermal resistance model for the design and cost optimization of thermal storages with phase change materials and a transient building performance model using Python and Modelica.

** This report has been shortened by the HPC team.*

Launch of the 14th IEA Heat Pump Conference "Heat Pumps – Resilient and efficient", in Chicago 2023

During the closing ceremony of the 13th IEA Heat Pump Conference, which took place onsite in Jeju, Korea and online, the 14th IEA Heat Pump Conference was launched by Brian Fricke, the Chairman of the National Organizing Committee. The conference will have the theme "Heat Pumps – Resilient and Efficient" and take place in Chicago on May 15-18, in 2023.

The conference will include workshops, oral and poster presentations, technical exhibits, a banquet, technical tours and an evening social event option as well as a spouse/guest program.

The conference will be held at Renaissance Chicago Downtown Hotel, close to the Theatre district in Chicago. The 10 Must Do's When Visiting Chicago, the Windy City, including attractions, shopping and dining, were presented during the launch.

Brian Fricke concluded the presentation by welcoming everyone to Chicago in two years.

Meet us in social media

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.

DESIGN AND INTEGRATION OF HEAT PUMPS FOR nZEB (FINALIZED)	49	AT, BE, **CH**, DE, NO, SE, UK, US
HEAT PUMPS IN MULTI-FAMILY BUILDINGS FOR SPACE HEATING AND DHW	50	AT, CH, **DE**, DK, 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	DE , FI, NL, NO, **SE**, UK, US
ADVANCED COOLING/ REFRIGERATION TECHNOLOGIES DEVELOPMENT	53	CN, DE, IT, KR, **US**
HEAT PUMP SYSTEMS WITH LOW GWP REFRIGERANTS	54	AT, DE, FR, IT, JP, KR, SE, **US**
COMFORT AND CLIMATE BOX	55	AT, BE, CA*, CH*, CN, DE, IT, **NL**, SE, TR*, UK, US
INTERNET OF THINGS FOR HEAT PUMPS	56	**AT**, CH, DE, DK, FR, NO, SE
FLEXIBILITY BY IMPLEMENTATION OF HEAT PUMPS IN MULTI-VECTOR ENERGY SYSTEMS AND THERMAL NETWORKS (NEW)	57	**DK**, NL
HIGH-TEMPERATURE HEAT PUMPS (NEW)	58	AT, BE, CA, **DK**, DE, FR, NL, NO, JP

*) Participates from ECES TCP

NEW FINALIZED

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 49 — DESIGN AND INTEGRATION OF HEAT PUMPS FOR nZEB

The final report of Annex 49 is now published together with four extensive reports that are focusing on heat pumps in nearly Zero Energy Buildings (nZEB).

The Annex 49 was a follow-on of the work in Annex 40 on heat pump concepts for nZEB, with an extended scope from the balance of single buildings to groups of buildings.

The dominating concept was to reach the zero-energy balance over an annual period for nZEBs.

Annex 49 is sharing experiences on heat pumps in nZEB as well as design of HVAC systems for nZEB in different countries. Development and market situation of heat pump systems in nZEB has also been investigated through this annex that was active during 2016 to 2020.

Results

The results from this project show that heat pumps can become the standard building technology for nearly Zero Energy Buildings (nZEB). Due to the high performance of heat pumps, nZEB can be achieved cost-effectively. Further on, heat pumps can increase on-site electricity self-consumption and unlock flexibility potentials by smart controls. In this way heat pumps become the backbone of a future sustainable and renewable built environment and energy system.

Read all reports and summaries here >

» Final report Annex 49 Design and Integration of heat pumps for nearly Zero Energy Buildings
» Executive Summary Annex 49
» 2-page Summary Annex 49

Annex 49 has been structured into four parts that are being presented in four reports:

» Annex 49 Final Report part 1: State of the Art of heat pump application in nZEB
» Annex 49 Final Report part 2: Field monitoring in nZEB with heat pump
» Annex 49 Final Report part 3: Simulation of System integration, Design and Control for heat pumps in nZEB
» Annex 49 Final Report part 4: Heat pump prototype developments and testing for nZEB application

ANNEX 53 — ADVANCED COOLING/ REFRIGERATION TECHNOLOGIES DEVELOPMENT

Introduction

It is widely acknowledged that air conditioning (AC) and refrigeration systems are responsible for a large share of worldwide energy consumption today, and this demand is expected to increase sharply over the next 50 years. IEA projects that AC energy use by 2050 will increase 4.3 times over 2013 levels for non-Organization of Economic Coordination and Development (OECD) countries and 1.3 times for OECD countries (see figure below).

Worldwide action, both near-term (e.g., increase deployment of current "best" technologies) and longer-term (RD&D to develop advanced, higher efficiency technology solutions), is urgently needed to address this challenge. HPT Annex 53 was initiated in late 2018 and focuses on the longer-term RD&D need. Technologies under investigation include the vapor compression (VC) based systems, thermal compression-based systems (absorption and adsorption), and non-traditional cooling approaches.

Advanced VC R&D underway by participant teams includes a combined absorption/VC/thermal storage concept, a large chiller based on water (R-718) as refrigerant, a novel pressure exchange (PX) concept for expansion work recovery, and enhanced source and sink stream matching using zeotropic refrigerants. Significant efforts are also underway aiming at advancing state of development of systems based on magneto caloric (MC), elastocaloric (EC), and electrocaloric effect (ECE) cooling cycle concepts. This includes work on identifying materials with improved fatigue performance, etc., for MC, EC, and ECE concepts.

Objectives

Annex 53's main objective is longer term R&D and information sharing to push development of higher efficiency and reduced greenhouse gas (GHG) emission AC/refrigeration focused HP technologies.

Specific areas of investigation include but are not limited to the following:

» Advance the technology readiness level (TRL) of non-traditional cooling technologies and alternative compresson technologies to the point that forward-thinking manufacturers could be encouraged to engage in subsequent partnerships in bringing them to market;
» Independent control of latent and sensible cooling and tailoring systems for different climates (e.g. hot dry or hot humid).
» Advances to VC-based technologies, both conventional and non-traditional.

Progress highlights

Italy's Annex 53 team at CNR-ITAE is working to develop innovative adsorption cooling/heating/refrigeration systems. The latest research is focused to develop plastic adsorbent heat exchangers manufactured by 3D printing technique with the goal to reduce capital costs of adsorption machines and optimizing the design to fit specific performance. First prototypes have been developed employing the most promising polymeric materials and the performance were investigated both experimentally, to measure the dynamic performance of the new adsorber configurations, and theoretically, to evaluate the influence of plastic materials on the cooling COP. Results showed that both in terms of thermodynamic and dynamic performance the plastic adsorbers are competitive with metallic ones with a relevant mass reduction and the possibility to manufacture complex geometries (Figure 1). The potential application of plastic material and 3D printing manufacturing will positively impact the technical and economic feasibility of adsorption cooling technology.

> ***"3D printed plastic components could positively impact technical/economic feasibility of adsorption cooling technology."***

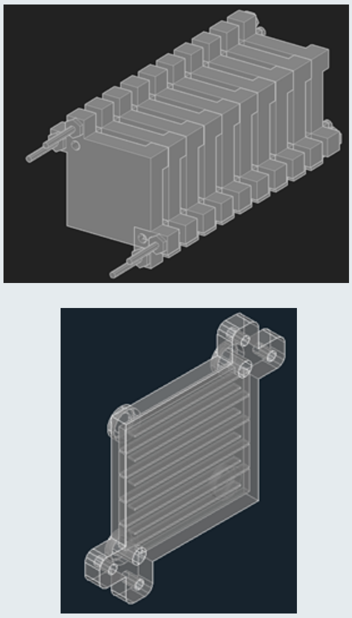


Figure 1. A potential modular complex layout for plastic adsorbers [ref. Alessio Sapienza, Vincenza Brancato, Yuri Aristov, Salvatore Vasta, ***Plastic heat exchangers for adsorption cooling: thermodynamic and dynamic performance.*** *Applied Thermal Engineering, Accepted-In press].*

Publications

Alessio Sapienza, Vincenza Brancato, Yuri Aristov, Salvatore Vasta, Plastic heat exchangers for adsorption cooling: thermodynamic and dynamic performance. Applied Thermal Engineering, Accepted-In press

Meetings

- The last experts web meeting took place in June 2021 in conjunction with the virtual IIR THERMAG IX Conference.
- Several Annex 53 Participants participated in a workshop of the SHC TCP Task 65 held in March.

Key data

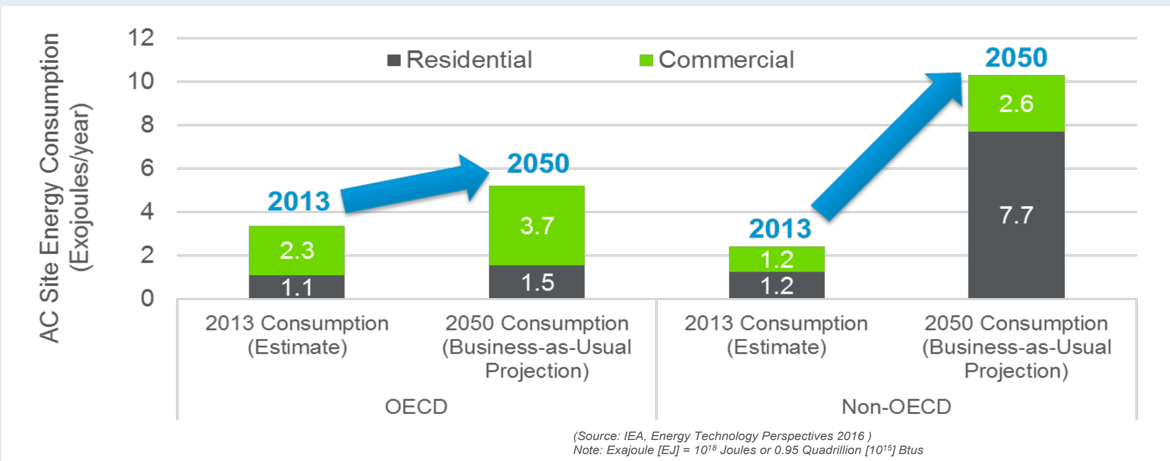
- Project duration: from January 2019 to December 2022
- Participating countries (as of 12/31/2020): China, Germany, Italy, South Korea, and USA

Contact

Operating Agent is Van Baxter from ORNL, USA, vdb@ornl.gov

Annex website

https://heatpumpingtechnologies.org/annex53/



Current and projected space cooling site energy consumption for OECD and Non-OECD countries. Courtesy W. Goetzler, Guidehouse, Inc.; Source: IEA ETP 2016.

ANNEX
54

HEAT PUMP SYSTEMS WITH LOW GWP REFRIGERANTS

Introduction

Low-GWP refrigerants are considered long-term solutions for environmentally friendly heat pump systems. Numerous studies have shown that design modifications are necessary to be optimized for low-GWP refrigerants. In particular, component-level design and optimizations are much needed. There hasn't been a clear picture of recent R&D progress. Further, there are not enough studies on how to optimize components and provide guidelines for various heat pump systems.

Objectives

Annex 54 aims at promoting the application of low-GWP refrigerant to air-conditioning and heat pump systems with the following objectives:

» A comprehensive review of recent R&D progress on component optimization using low-GWP refrigerants (fulfilled)

» In-depth case studies of component optimization, which can provide design guidelines and real-world cases (fulfilled)

» Optimization of heat pump systems for low-GWP refrigerants (planned)

» Analysis of the LCCP impacts of the current design and optimized design with low-GWP refrigerants (planned)

» An outlook for heat pumps with low-GWP refrigerant for 2030 (planned).

Progress

In 2020, we achieved considerable progress in the following two areas: 1) review of the state-of-the-art technologies in HVAC components using low-GWP refrigerants, and 2) case studies and design guidelines for optimizing components and systems. As stated below, the progress achieved by the participating countries can be a valuable reference for researchers, engineers, and policymakers across the HVAC industry. It is especially interesting for people who want to dive deep into the components R&D of heat pumps, including but not limited to heat exchangers, compressors and valves.

Significant progress has been made on designing and optimizing components using low-GWP refrigerants for heat pump applications.

The U.S. team conducted a comprehensive review of R&D progress on components using low-GWP refrigerants for residential air conditioning applications. The review mainly focused on heat exchangers and compressors. Furthermore, the team performed a study on tube-fin heat exchangers' circuitry optimization. As an example, one project from the University of Maryland addressed the circuitry optimization of tube-fin heat exchangers, shown in Figure 1.

The German team carried out several projects on heat pumps using low-GWP refrigerants. The projects covered novel components investigations, design guidelines and field testing. The Italian team conducted various R&D projects from academic and industry institutions. The activities focused primarily on developing novel components and systems for low-GWP refrigerants. Figure 2 shows a solar-assisted heat pump being installed and field-tested at the University of Padova. The French team conducted extensive investigations of low-GWP refrigerants for residential heat pumps, air conditioners and heat pump water heaters. A total of 10 alternative refrigerants with low-GWP were evaluated with at least 130 performance tests. These experimental results will be useful by the HVAC community

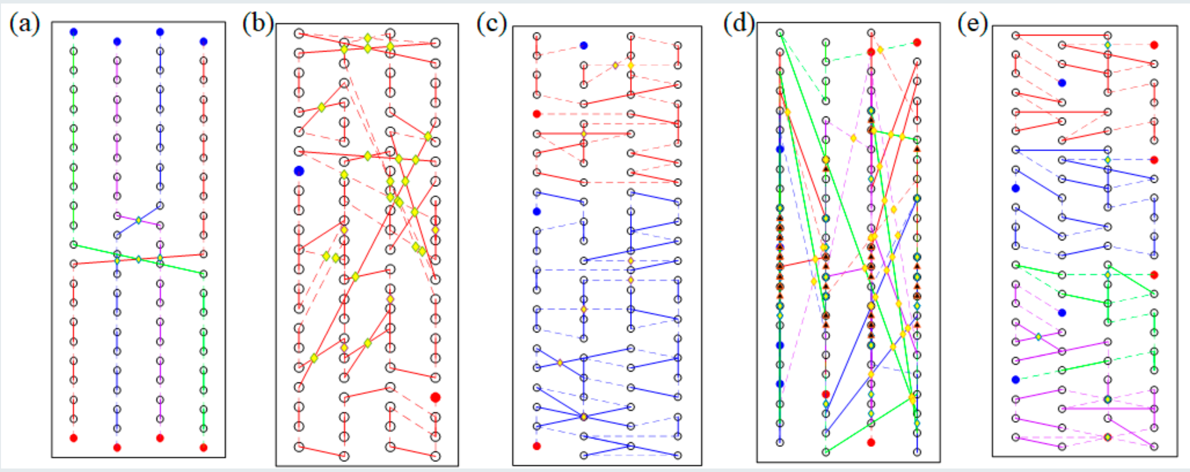


Figure 1: Optimal circuits under different constraints (a) baseline; (b) unconstrained; (c) with manufacturing (mfg) constraints; (d) with refrigerant pressure drop (DP) constraint; (e) with mfg. and refrigerant DP constraints. (Li et al., 2019)

for facilitating the selection of the most promising candidates to replace R-410A, R-134a, and R-407C in residential heat pumps. New to the Annex last year, the Swedish team initiated several efforts on case studies and design guidelines for component and system optimizations, particularly for Northern European climates.

Publications/Journals

- Li, Z., V. Aute, J. Ling, "Tube-fin heat exchanger circuitry optimization using integer permutation based genetic algorithm", International Journal of Refrigeration 103, 135-144, 2019.
- Berto, M. Azzolin, S. Bortolin, C. Guzzardi, D. Del Col. Measurements and modelling of R455A and R452B flow boiling heat transfer inside channels. International Journal of Refrigeration, 120, 271–284, 2020.
- Colombo, L.P.M., Lucchini, A., Molinaroli, L. Experimental analysis of the use of R1234yf and R1234ze(E) as drop-in alternatives of R134a in a water-to-water heat pump. International Journal of Refrigeration 115, 18-27, 2020.

Meetings

- Hosted online workshop on December 7, 2020, during the 14th IIR-Gustav Lorentzen Conference on Natural Refrigerants – GL2020. During the workshop, we presented natural refrigerant utilizing technologies from Japan, Germany, Italy and the U.S.
- Hosted two online business meetings on June 24, 2020, and on December 7, 2020. During the meetings, we shared research progress from each participating country and discussed the 2020 annual report preparation.
- The fifth workshop was during IEA HPC in May 2021 and the sixth workshop was during HFO Conference in June 2021.
- The next workshop is planned to take place on September 1, 2021, during the IIR's TPTPR conference.

Figure 2: Solar-assisted heat pump prototype installed at the Solar Energy Conversion Laboratory (Department of Industrial Engineering, University of Padova).

Key data

- Project duration: Jan. 2020 to Dec. 2020
- Participating countries: Austria, France, Germany, Italy, Japan, Korea, Sweden and the U.S.

Contact

Operating Agent is Yunho Hwang from the University of Maryland, College Park, USA
yhhwang@umd.edu

Annex website

https://heatpumpingtechnologies.org/annex54/

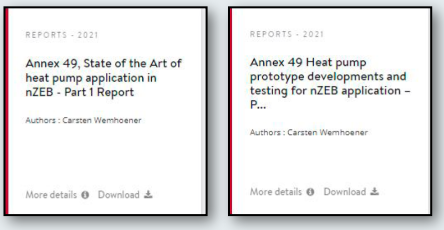
INFORMATION

Do you want to read more about the results and outcome of the HPT TCP Annexes?

Welcome to the HPT TCP publications database

Here you find the results of the projects implemented by the Technology Collaboration Programme on Heat Pumping Technologies, HPT TCP, and Heat Pump Centre, HPC.

Publication database:
https://heatpumpingtechnologies.org/publications



ANNEX 58

HIGH-TEMPERATURE HEAT PUMPS

Annex 58 – High Temperature Heat Pumps has been started

High-temperature heat pumps are a promising alternative for replacing fossil fuel-based heat supply by electrifying the processes at the highest efficiencies. The potential for industrial heat pump applications is considerable as market conditions become more and more advantageous. Industrial heat pumps are expected to play a key role in industry's transition to sustainable production processes, since the technology is driven by potentially emission-free electricity and operates at the highest efficiencies.

In general, the application potential for heat pumps in industrial applications is great. When considering the temperature levels of the heating, it becomes apparent that a large share of the application potential requires supply temperatures above 100°C, which is above the temperatures that can be supplied with state-of-the-art equipment.

During recent years, activities focusing on research, development and demonstration of high-temperature heat pumps with supply temperatures above 100°C increased considerably. In addition to the various R&D projects, initial demonstration projects are being conducted as more and more equipment becomes commercially available.

Annex 58 on high-temperature heat pumps has been initiated to increase awareness of the technologies and their potential by providing a technology overview as well as information and tools facilitating the spread of the technology. The Annex will provide an overview of the technological possibilities and applications and develop concepts and strategies for the transition to heat pump-based process heat supply.

Activities

The activities for the Annex comprise the following five tasks:

- Task 1: Technologies – State of the art and ongoing developments for systems and components
- Task 2: Concepts – Development of best practices for promising application areas
- Task 3: Applications – Strategies for the conversion to HTHP-based process heat supply
- Task 4: Definition and testing of HP specifications – Recommendations for defining and testing specifications for high-temperature heat pumps in commercial projects
- Task 5: Dissemination.

Technology review is ongoing

Task 1 will provide an overview of the current status of technologies and developments in the field of high-temperature heat pumps and set the direction for further work. The review includes technologies, demonstration cases and most relevant R&D projects for systems and components. Task 1 will be concluded with an outlook of technology development perspectives. The activities for Task 1 have recently been initiated and are currently ongoing.

In addition to the ongoing review activities, there will be a range of deep dives on various focus topics. The deep dive topics are to be agreed with the Annex participants and will include contributions from various Annex participants as well as external partners.

Activities on concepts, applications and testing to be initiated

Further tasks focus on the development of heat pump-based solutions for process heat supply (Task 2 – Concepts) and the development of decarbonization strategies for the transition to these heat pump-based solutions considering the challenges arising from real-world installations (Task 3 – Applications). Furthermore, suitable procedures for defining and testing performance requirements of industrial high-temperature heat pump systems will be derived (Task 4: Definition and testing of HP specifications). Tasks 2, 3 and 4 will begin during the second half of 2021.

Key data

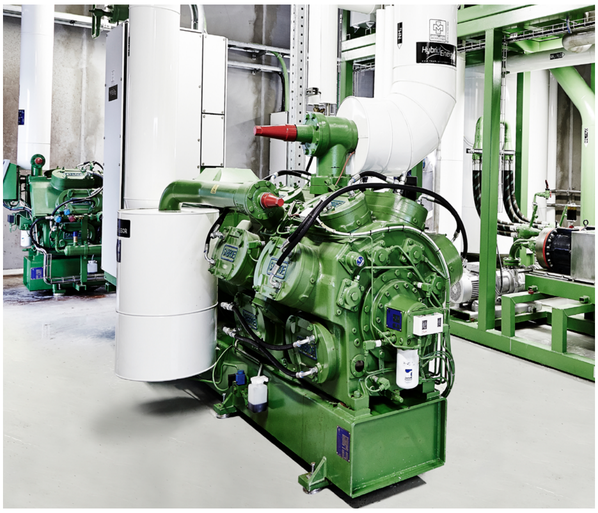
- Currently, the following countries are participating: Austria, Belgium, Canada, Denmark, France, Germany, the Netherlands, Norway and Japan.
- The Annex is still open for new participants, and 10-12 countries are expected to participate.

Contact

Operating Agent is Benjamin Zühlsdorf, from the Danish Technological Institute.
bez@dti.dk

Annex website

https://heatpumpingtechnologies.org/annex58/



Installation of a hybrid absorption/compression heat pump using a mixture of water and ammonia at Arla, Denmark

Heat Pump System Improved High-Temperature Borehole Thermal Energy Storage Efficiency

Olof Andersson, Geostrata HB Sweden
Leif Rydell, Reikab AB Sweden
Niklas Håkansson, Xylem Sweden

In 2010 Xylem, in Emmaboda, Sweden, installed a High-Temperature Borehole Thermal Energy Storage (HT-BTES). The idea was to store waste heat in the summer season to use later for space heating in the winter. The system worked adequately for charging the storage, but turned out to be much less effective for extracting the stored heat. By installing a heat pump system to support heat extraction, the system now works properly both ways. This article presents the energy performance and economics of such a system.

Introduction

In 2010 an HT-BTES was put into operation at Xylem factories in Emmaboda. The storage was designed for charging 3.6 GWh of waste heat in summer, of which 2.6 GWh was estimated to be recovered for space heating the winter. In this way, a significant amount of purchased district heating was expected to be replaced (Figure 1).

Until 2014 the storage was heated to around 40°C. However, during this period the storage acted perfectly as a relief for the cooling tower. Some heat was recovered during the following years, but much less than expected. To improve the recovery, a heat pump system was installed in 2018. The reconstructed system is now being used for performance measurements and evaluation in IEA HPT Annex 52 (Long term performance measurement of GSHP systems), and this article summarizes the findings after three seasons.

System description

The storage consists of 140 boreholes, 150 m deep and with a borehole distance of 4 m. It is located just outside the factory area and has a rectangular shape measuring 60 x 40 m. On top there is a layer of sand, foam glass, and humic soil as insulation.

A coaxial type heat exchanger was developed as borehole heat exchanger (BHE). It consists of two pipes with intermediate insulation by unmovable water. A helical spacer was placed in each joint. An advantage of using this type of BHE is that it enables bidirectional flow. Thus, the highest storage temperature can always be at the bottom of the storage. The use of coaxial BHE means that the heat carrier is in direct contact with the groundwater in the bedrock, approximately 3.5 m below the surface. This also means that the heat carrier must be circulated under vacuum pressure (35 kPa) in the storage. The

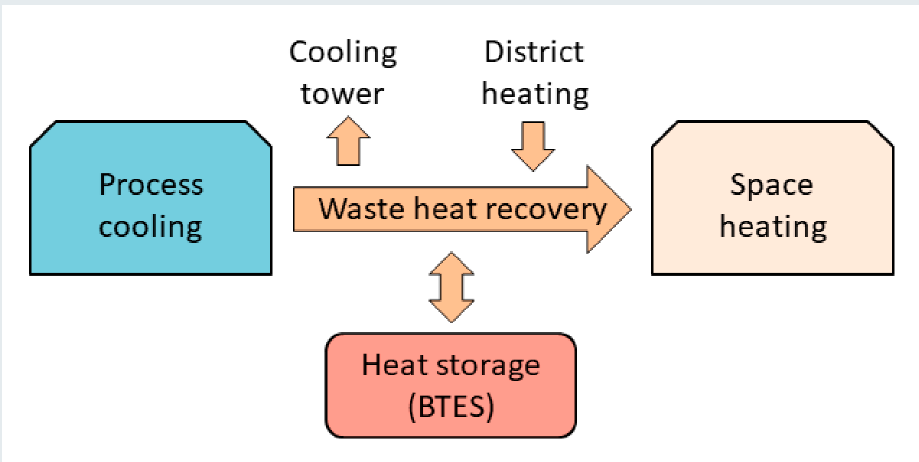


Figure 1.

Xylem's system for heat recovery from process cooling, including BTES heat storage for seasonal storage of waste heat. This reduces energy losses through the cooling tower for cooling and purchased district heat for space heating.

vacuum created problems with cavitation of the circulation pump during the first years of operation, as well as problems with degassing the fluid. These problems, and how they were solved, are described in reference [1].

The borehole field is divided into seven sections with 20 holes in each. The three inner sections form an "inner core" intended to have the highest temperature, and the four outer sections form a "buffer zone" with a slightly lower temperature. The idea behind this design is simply to have demand-adapted temperatures at charging and discharging modes. This function is achieved by using control valves for each section, as shown in Figure 2.

The storage is connected to the main technical central by a 200 m long steel culvert in which the heat carrier is circulated by using a frequency-controlled circulation pump. The pump is designed for a maximum flow rate of 21 l/s. Heat is stored into, or extracted from, the storage through a large heat exchanger. The system has sensors for instantaneous recording of temperatures, flow rate and pressure. Furthermore, the rock temperature in the storage (MW-1) and just outside is measured in two monitoring boreholes (MW-2). Also, the function of the insulation on top of the storage is measured by three temperature sensors, see Figure 2.

Operational results

During the first years of operation, the expected amount of waste heat with a high enough temperature was found to be insufficient. Therefore, a number of measures were taken to capture low-value heat sources by using heat pumps. A heat pump was installed to extract heat from the foundry's ventilation system. As a bonus, this solution also provides air conditioning for this otherwise "hot" workplace.

During 2014-2015, the storage temperature was stabilized to be approximately 40-45°C even though the availability of waste heat remained high. It became more and more obvious that instead of an increased temperature, a lateral growth of the storage took place. Hence, the storage temperature was not high enough for heat recovery by direct heat exchange only. Actually only some 10-15% of the stored heat could be recovered this way during 2015-2017.

To achieve an enhanced withdrawal of heat, a heat pump system [1] was recommended. It was also recommended to lower the working temperature of storage to a working temperature of 40/20°C. In this way, the thermal gradient should be turned towards the storage during the winter season and thus the spread sideways would cease. At the same time, the capacity using the storage for cooling would be increased by the reduced temperature.

In the autumn of 2018, the heat pump system shown in Figure 2 was put into operation. The system consists of 8 parallel-connected aggregates (NIBE F1345-60). The evaporator side connects to the storage and the condenser side to the internal heating network. The evaporator side works at the temperature 26/20°C, while the condenser side delivers a temperature up to 55°C. The system covers the heat demand down to an outdoor temperature of about -5 degrees. At lower temperatures, the external district heating is used as backup. The high temperature of the evaporator side allows the system to deliver a condenser capacity up to 800 kW. This is significantly higher than the nominal, 480 kW.

As shown in Figure 3, the heat pump system has provided a drastically increased recovery from the storage since the start in September 2018. Consequently the storage temperature has been gradually lowered. At the end of April 2021, it was down to 28°C and still leaves a large portion of earlier stored heat to be recovered from the sides of the storage.

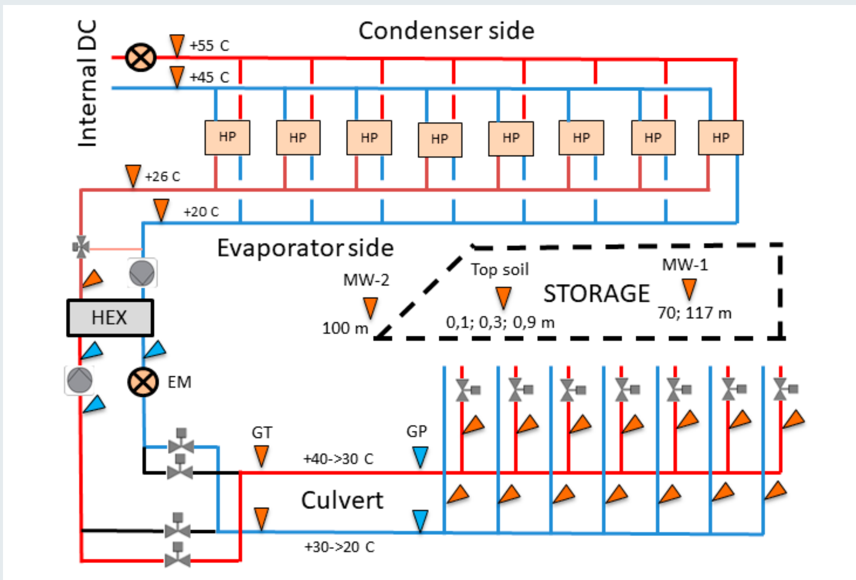


Figure 2.

Principal system flowchart with sensors for temperature (GT), pressure (GP) and energy (EM). In addition, electricity use for heat pumps and circulation pumps are measured. The storage temperature is monitored in two monitoring wells (MW) as well as in the insulation top layer.

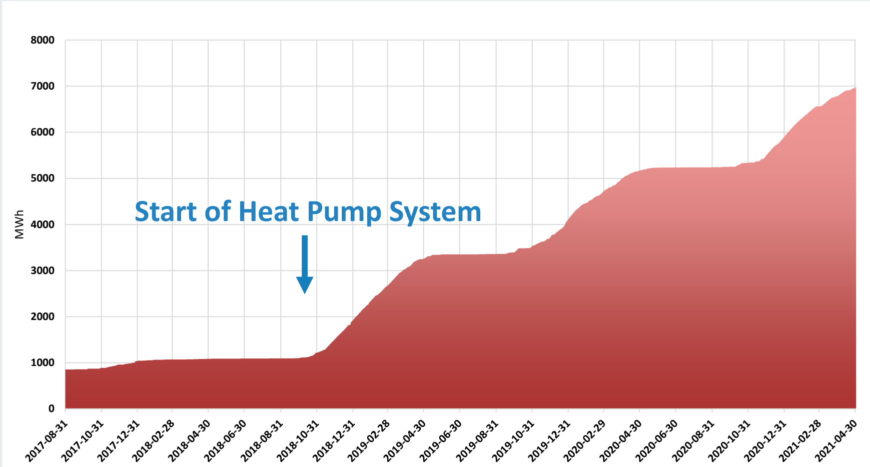


Figure 3.

Accumulated heat recovery from the storage over the last five years.

Table 1. Production of heat from the heat pumps and the system performance factor (SPF), electricity for circulation pumps included, for the heating seasons 2018/19-2020/21.

Heat from BTES (MWh)	Produced by HP (MWh)	Electricty used (MWh)	SPF (-)
5 060	6 500	1 440	4.5

The lowered storage temperature also brings several other advantages:

- Significantly higher cooling capacity during the summer, which in turn means less use of the cooling tower and a higher COP for low-grade waste heat capture by the heat pumps.
- Reduced heat losses, modeled to be on the order of 20-30% less [1].
- Reduced cavitation risk of the storage circulation pump that works under vacuum pressure and less need for degassing the heat carrier fluid.

Economics and efficiency

The investment cost of the BTES system in 2010 was approximately SEK 12 million. By replacing 2000 MWh/year of district heating, the investment payback period was calculated as 5-6 years. However, only some 1200 MWh was recovered by the spring of 2017. This was a disappointing result. On the other hand, the investment in the storage concept led to an enhanced recovery of low-grade heat by using heat pumps. These installations were in themselves profitable by increasing the direct heat recovery to increase from 2000 up to 7000 MWh the last winter. Thus, the BTES system became a profitable investment, even without the anticipated extraction of stored heat.

Other not priced advantages have been noted. For example, the foundry got "free" climate cooling, the amount of city water for cooling in test pools declined significantly, and the operating and maintenance costs of the cooling tower decreased.

The additional investment in the new heat pump system 2018 totaled SEK 2.5 million. The system has delivered 6500 MWh to the heat network during the first three winter seasons. The electricity used for the heat pumps and the circulation pumps was 1440 MWh. This means a system performance factor of 4.5 and a net saving of 5060 MWh, (78%). For Xylem this is worth about SEK 3.8 million, which means that the additional investment payback took place after just 2 years.

Conclusions

The HT-BTES case at Xylem showed that a heat pump system for heat recovery is needed for full recovery of stored heat. It also serves as proof that such a system in itself is highly profitable and can be operated at a high system performance factor, in this case a SPF of 4.5. The additional investment was paid off in less than three years. Hence, it is highly recommended for similar projects to consider using heat pumps for heat extraction already from the start.

The use of high-efficiency borehole heat exchangers with double flow direction has not helped to obtain a long-lasting high temperature upon recovery. Such a type of BHE may instead create technical problems, such as cavitation and striping of gas, as has been experienced in Emmaboda. Using conventional collectors (U-pipes) is therefore recommended in order to avoid such problems.

References

[1] Nordell, B., Liuzzo Scorpio, A., Andersson, O. Rydell, L., Carlsson, B. 2016. "The HT BTES plant in Emmaboda. Operation and experiences 2010-2015". Div. of Architecture and Water, Luleå University of Technology, January 2016.

OLOF ANDERSSON
Geostrata HB
Sweden
olle.geothermal@hotmail.com
https://doi.org/10.23697/b8tt-8130

Heat Pumps and Thermal Storage: Canadian Perspectives

Justin Tamasauskas, Arash Bastani, Canada

Heat pump and thermal storage systems can support an increased adoption of heat pumps by providing a more flexible link between the building and electrical grid. This article explores the development of these systems from a Canadian perspective, outlining key design requirements, presenting potential system solutions, and examining demand reduction potential through initial simulations. Findings provide an important basis for ongoing research to better adapt these systems to the Canadian climate and market.

As the world transitions towards a decarbonized economy and infrastructure, efficient renewable energy technologies are of great importance. Canada's Market Transformation Roadmap [1] presents a framework for the increased adoption of these systems, outlining aspirational goals regarding system performance (seasonal heating efficiency >100%) and the integration of renewable energy. Heat pumps respond well to these objectives, but their widespread adoption can be challenging for electrical utilities.

Despite their energy savings potential, heat pump use coincident with other electrical end uses can increase house-level electrical demand. This increased demand can be particularly problematic for utilities when it occurs with a high degree of simultaneity (i.e., for many homes in a given region at the same time). Air-source heat pumps are a popular choice of heat pump integration in Canada, but can be especially problematic in this context. These systems tend to experience capacity degradations at colder outdoor temperatures, necessitating the use of supplemental electrical resistance heating. Given the link to outdoor temperatures, this tends to occur with a high degree of simultaneity across a given region [2], creating larger aggregated loads. This added electrical demand can challenge the generating capacity of the grid, imposing practical limits on heat pump adoption. Furthermore, in regions where electrically based heating is already common, it also presents a challenging business case for utilities, as heat pumps may reduce overall electricity use but still account for large peak demands.

Despite these challenges, heat pumps can also be an important tool in supporting more energy-flexible electricity grids. Integrating heat pumps with thermal storage can provide a flexible link between the thermal and electrical networks of the building, allowing the heat pump to adapt its operations to the needs of the grid without sacrificing thermal comfort. This article explores Natural Resources Canada's ongoing research on air-source heat pump and thermal storage systems, providing Canadian perspectives on design requirements and system solutions in line with contributions to IEA HPT Annex 55.

System Design: Requirements and Design Objectives

Annex 55 outlines nine key quality criteria to structure the discussion on heat pump and storage systems. While criteria such as affordability and customer appreciation are clearly important, from a technical perspective, Canadian work has focussed on addressing three criteria:

Suitability: An emphasis on air-based distribution (common in Canadian homes), supplying both heating and cooling (growing demand for cooling), and maintaining strong cold climate performance (to reduce electrical peaks associated with activation of electric resistance auxiliaries).

Integral Design: A focus on an integrated set of physical components and controls, in a similar manner to current generation heat pump systems. This supports ease of installation and commissioning, and better ensures consistent performance.

Compactness: An emphasis on minimizing storage size, as Canadian homeowners and builders typically place a high value on maximizing livable area, at the expense of added space for mechanical systems. Prioritizing compactness is particularly important for the retrofit market, where system installation must be designed around existing constraints.

Exploring Storage Options: Thermal Storage for Canadian Homes

Selecting a target for the energy storage capacity of the system is a critical design decision, influencing size, cost and load shifting potential. In this study, sizing is based on covering the maximum thermal demands of the building for a 2H peak event occurring during either morning (6 AM – 9 AM) or evening (4 PM – 8 PM) hours. For a typical new construction home in Montreal, this equates to a required storage capacity of 15 kWh. However, given variations in climate and housing size/construction, a flexible approach is likely required in Canada to adapt capacity to the context of the actual installation.

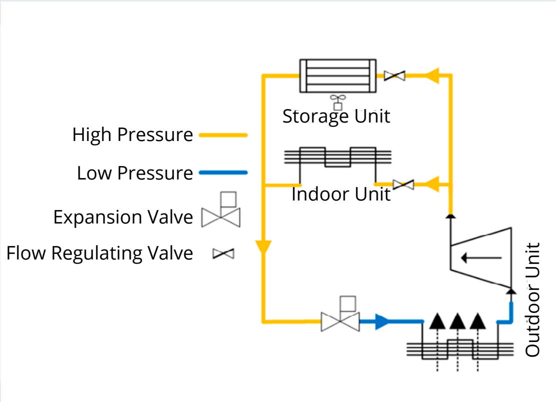


Figure 1: Diagram of a Heat Pump and Storage Concept

Material selection also has an impact on the physical size of the thermal storage. Given the emphasis on compactness, phase change materials (PCMs) are of particular interest in the Canadian context. An initial analysis shows that, by using commercially available PCMs with phase change temperatures of 40-45°C, storage volumes can be reduced by as much as 60% (vs. water-based storage, temperature rise 15°C). These reductions show the potential benefits of using PCMs, although final material selection must consider additional factors, including thermal conductivity, chemical stability, and relative price.

Integrating Heat Pump and Thermal Storage: A Cycle-Level Analysis

The way in which thermal storage is integrated with the heat pump has important implications for the performance, energy flexibility potential, and suitability of the system. For the Canadian systems examined in Annex 55, the heat pump and storage system consists of three main components: an outdoor unit (Refrigerant - Outdoor Air HX and Compressor), indoor unit (Refrigerant - Indoor Air HX), and thermal storage unit (Refrigerant - PCM heat exchanger and fan). Despite the relative simplicity of this component list, system performance is closely tied to the way in which these components are configured.

Figure 1 shows one configuration examined under Canada's contribution to Annex 55, suitable for both ducted and ductless air-to-air heat pumps. The concept uses excess thermal energy stored during off-peak hours to directly heat the building, avoiding heat pump compressor use during peak periods. Energy is added to the storage unit (i.e., charged) by using the storage as an additional condenser. During off-peak hours, a portion of refrigerant exiting the compressor passes to the storage unit. Here, the refrigerant passes through a series of pipes surrounded by a storage material, allowing a direct refrigerant-storage heat exchange without the need for secondary heat transfer fluids.

During peak periods, energy may be removed from the storage unit (i.e., discharged) by passing room air over the surface of the storage via a fan. This provides a degree of space heating, without the need to operate the heat pump compressor.

One major challenge in designing heat pump and storage systems is ensuring sufficient charging times. Heat pump and storage systems may be required to respond to multiple peak periods during the same day (e.g., morning and evening events), necessitating sufficiently fast charging during off-peak hours. These charging times are closely related to the amount of heat pump capacity dedicated to charging (i.e., whether the storage can be charged using the full, or partial, capacity of the heat pump).

Figure 2 examines the impact of part load on idealized charging times, tabulated using a simple heat pump cycle model of a two-ton air-source heat pump. Results clearly show that, in order to sufficiently charge between morning and evening peak periods, systems would need to charge above 70%-part load.

Enhancing the Energy Flexibility of Canadian Homes: A Building-level Analysis

A simulation-based approach is used to illustrate the performance of these systems in a newly constructed single-family home in Montreal, Canada. The studied heat pump and storage system follows the configuration outlined in Figure 1, and is operated to avoid compressor operation during peak periods. During these times, the storage unit is used to directly heat room air. Charging occurs during off-peak hours, when the heat pump is operating below its maximum capacity.

Figure 3 compares the electrical demand during peak hours for three space-heating systems: Electric baseboards (Elec. BB), a variable capacity heat pump without storage (VCHP), and a variable capacity heat pump with storage (VCHP + Storage). While the VCHP (without storage) greatly reduces electrical demand for 99% of operating hours vs. electric baseboards, maximum demand for the two systems is similar. During the coldest winter periods, outdoor temperatures fall below the minimum operating temperature for the selected heat pump (TOutdoor <-25°C). The VCHP is therefore unavailable to operate and auxiliary resistance elements must be used to provide space heating, increasing demand. This operation clearly poses a challenging business case for grid operators, who may sell less electricity but still be required to maintain infrastructure for the worst-case peak. On the other hand, the VCHP + Storage case appears to offer meaningful demand reductions vs. both systems throughout the operational window, primarily because auxiliary resistance heating can be offset through the storage.

It is important to note that these results are highly specific to the case examined. The ability of the system to displace electrical demand is closely tied to whether the heat pump is able to charge the storage during off-peak hours. Should the building thermal load remain high during these periods, the system may have limited ability to charge, reducing the magnitude of demand reductions obtained. This impact may potentially be mitigated

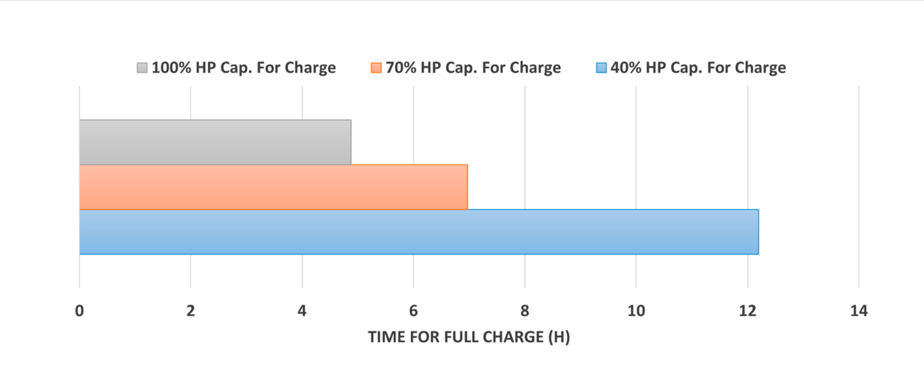


Figure 2: Impact of Part Load on Charge Times

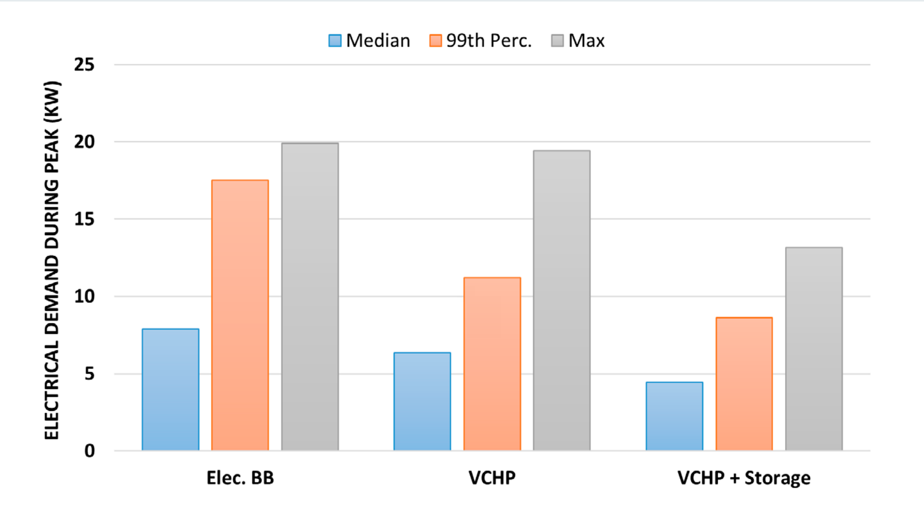


Figure 3: Impact of heat pump and storage on electrical demand in a single-family Canadian home

by selecting a larger capacity heat pump, or by taking advantage of the additional thermal storage inherent in the building mass. Regardless, it is clear that system sizing and integration is a critical issue that must be addressed to capitalize on the potential of these systems.

Conclusions and Future Work

Heat pump and thermal storage systems can improve the interaction between the building and electrical network by allowing heat pumps to adapt their operations according to grid needs without sacrificing thermal comfort. This ability positions heat pumps as a key tool to support future smart grids, thus facilitating a more widespread adoption of heat pumps and renewable energy systems. However, these systems must be well adapted to their target market. This article has examined the development of air-source heat pump and storage systems from a Canadian perspective, tracing how design requirements impact system solutions, and examining potential demand reductions in Canadian residential buildings. This article presents initial results from an ongoing project exploring heat pump and thermal storage systems in Canada. Recent work has focussed on enhanced modeling to better assess energy transfer rates to/from the storage, and support the examination of additional system configurations. Simulation work will also be expanded to further assess performance in other buildings and regions in Canada. Experimental activities are also planned to provide a practical understanding of performance in the Canadian climate.

References

[1] Natural Resources Canada, 2017. Paving the Road to 2030 and Beyond: Market transformation road map for energy efficient equipment in the building sector. Govt. of Canada, Ottawa, CA.

[2] Protopapadaki C., Saelens D., 2017. Heat pump and PV impact on residential low-voltage distribution grids as a function of building and district properties. Applied Energy 192, p. 268-281.

JUSTIN TAMASAUSKAS
Research Engineer
Canada
Justin.Tamasauskas@canada.ca
https://doi.org/10.23697/sa3c-sr82

The State of Art of Heat-Pump integrated Thermal Energy Storage for Demand Response

Sara Sultan, Kyle R. Gluesenkamp, United States

Heat pump integrated thermal energy storage is analyzed for demand response in grid-interactive buildings. We have reviewed various configurations presented in the literature, in both active and passive storage, and analyzed the reported demand impact, energy savings, and cost savings.

Introduction

Buildings are responsible for about 40% of the total energy consumed in the U.S. [1], accounting for 75% of the total electricity consumption, and 78% of the 2–8 PM peak period electricity use [2]. Heating, ventilation, and air conditioning (HVAC) loads account for nearly half of the building electricity consumption and exacerbate demand issues.

Thermal Energy Storage (TES) has been identified as a key enabler to reduce peak energy demands and grid stress through demand response strategies as described in the Department of Energy's Grid-Interactive Efficient Buildings (GEB) report [2]. TES may even allow refrigeration or HVAC systems to operate during outages, though this requires larger storage capacities than a system strictly intended for diurnal load shifting [2].

TES technology with greater flexibility presents research and development opportunities in materials, configurations, and controls: novel TES materials can be developed to increase energy storage density, many configurations can be explored to reduce installation complexities and TES footprint, and TES operation can be optimized through controls for demand response in grid-interactive buildings to offer greater energy and demand reduction potential.

More than 44% of the houses in the U.S. were built before 1970 [3] based on outdated building codes. Typically, in US residential buildings, there is no mechanical outdoor air exchange, or cross ventilation using natural resources, therefore, heat pumps are important to regulate the humidity inside the house as well as the indoor temperature. Thus, retrofit technologies are needed for a rapid transition to heat pump integrated storage.

It is often cost-prohibitive to rebuild houses or update the conventional air conditioning methods, but heat pump systems can be made smart to respond to peak demand. Today's high-efficiency HVAC and appliance products can provide energy savings, but do not generally help with demand management and grid stress.

Thermal energy storage can provide benefits when integrated with the heat pump components. TES materials can be charged and discharged to store and release energy, respectively, thus reducing the time and shifting heating or cooling energy demand. Despite diurnal changes in outdoor temperatures, the high-thermal-mass buildings can maintain inside temperature in a comfortable range without expending an excessive amount of HVAC energy.

Path Forward

This article summarizes the state of art of heat pumps integrated with thermal energy storage. Phase change materials (PCMs) are thermal storage materials that can be embedded into heat pump equipment or building envelope. Research has explored a wide variety of methods to incorporate PCM into systems for space heating and cooling, in both active and passive storage, as well as being incorporated into buildings using various configurations.

The majority of the existing commercial PCMs are incorporated in passive storage and they charge and discharge depending on the ambient temperature. In passive storage, PCM can be installed in the building envelope such as walls, ceiling, windows, or embedded directly into the building material such as concrete. Ideally, the materials in passive configuration can offset the peak demand by shifting loads, but they are unable to control the charging or discharging operation to optimize grid benefits.

Active TES systems on the other hand use mechanical work to transfer heat between the space and the PCM, hence there is some control over when the TES system is charged and discharged. Examples of this setup are a standalone storage tank system with an integrated heat exchanger coupled to the building's ventilation system or a vapor compression system. The TES system may be separate and removed from the space. One advantage of these active configurations is the ability to add these systems to existing building infrastructure without significant construction.

For grid-interactive buildings, a demand response strategy can be designed for building load and grid stress management. The utility providers may define peak hours and off-peak hours of operations based on a

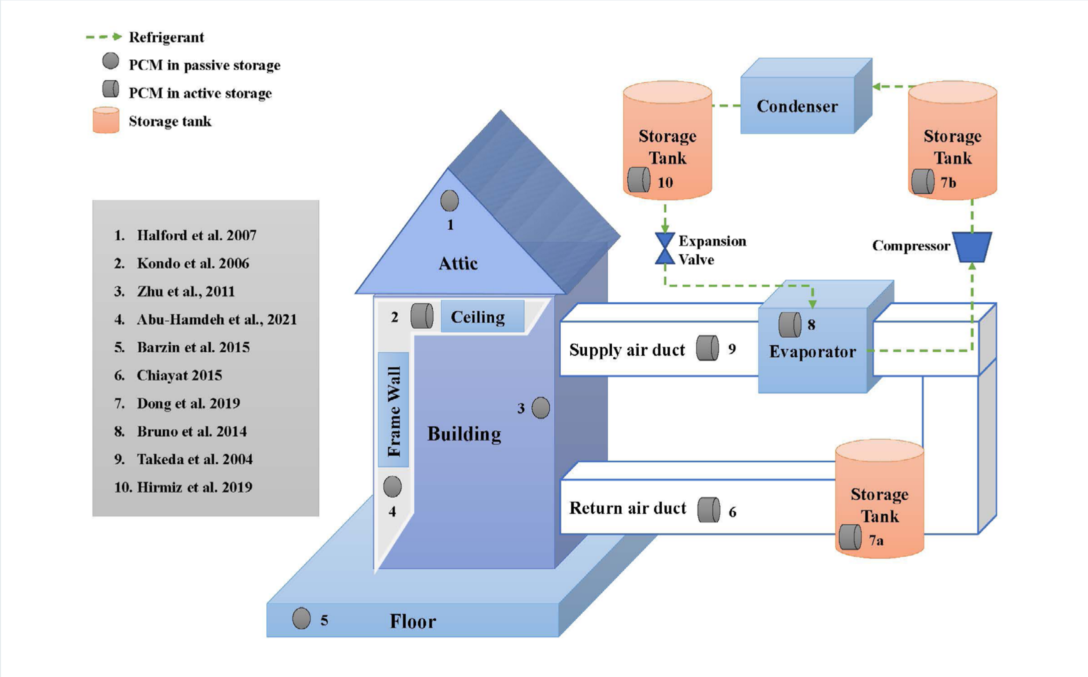


Figure 1: Ten ways to integrate TES with heat pump were identified in the literature, as summarized here.

pre-determined schedule or a high demand-based charge schedule. During the time of high demand or peak hours, the utility rate tends to be higher than what is normally charged to customers during normal or off-peak hours. Load shifting can manage the demand by shifting peak load to off-peak or normal operating hours, hence reducing the utility cost and grid stress.

When properly controlled, thermal storage can be useful in an economic or behavioral curtailment scenario for demand response. Major factors influencing an appropriate TES system's choice include the energy storage period and duration, cost and economic feasibility, and operational conditions. The key to using this technology to provide grid benefits is the development of materials or packaging in an active storage configuration that allows real-time control of the charging and discharging processes for grid-interactive operation. The energy savings and grid benefits in such configurations would be particularly significant in regions of high peak demand [2].

The use of phase change materials as TES has its advantages reported in the literature. Researchers have used various demand management systems to take advantage of lower utility rates during the off-peak hours and used TES in various configurations for storing the energy to be used later during peak hours, as shown in Table 1 and Figure 1.

A selection of ten references is shown here to represent the state of art available in the literature, with one reference chosen to represent each configuration type. The figure shows building and heat pump components with embedded TES in various possible configurations. Some are used in passive configurations and installed in building envelopes like frame walls, ceilings, floorboards, and attic insulation. The passive configurations included are connected to the air conditioning system and the effect of air conditioning load reduction is studied.
The active configurations reported here are the ones integrated with air conditioning or heat pumps. Most researchers have commonly used a standalone storage tank containing a PCM and heat exchanger, while others have incorporated PCM into heat pump system components like the supply and return air ducts, and evaporator. Another common practice is to use two storage tanks for both cold and heat dissipation (see 7a and 7b in the figure).

There is a large variation in the benefits provided by TES depending mainly on the system configuration, TES location, and TES type. Peak load reduction ranges from 12% to 57%, and electricity consumption savings ranged from 9% to 62%. In this work, we have tried to present a comprehensive review of various heat pump integrated PCM-based TES configurations with a demand impact and economic analysis.

The thermal energy storage systems (TES) incorporation with current cooling, heating, and ventilation systems has been shown to shift the load and energy use of the HVAC systems from on-peak to off-peak times to bypass the peak charges due to high demand. TES has also been shown to improve energy efficiency by controlling the energy supply and energy demand gaps. Active heat pump integrated TES configurations generally outperform passive TES-HP configurations because acti-

*Table 1: The ten representative heat pump integrated configurations included here have been shown to reduce peak load by 12% to 57%. *Calculated based on the data provided in the paper*

Reference	Configuration	TES Location	Outcomes
Halford et al., 2007	Passive	Modeled to be installed in the attic	19 - 57% peak load reduced
Zhu et al., 2011	Passive	In the walls to enhance envelope of air-conditioned PCM building	Daily electric consumption reduced by 10% 17-20% peak demand reduction 11% cost reduced
Barzin et al., 2015b	Passive	In wallboard with underfloor heating	44.4% energy savings 3-4 hr of Peak load shifted 35% cost savings
Abu-Hamdeh et al., 2021	Passive	In frame wall of air-conditioned building	11.25% energy savings Air handling unit's power usage decreased by 11.73% 18.6 years payback
Bruno et al., 2014	Active	In chiller used as evaporator	13% cooling energy savings
Takeda et al., 2004	Active	In supply air duct of ventilation system	42.8 to 62.8% ventilation load reduced
Kondo et al., 2006	Active	In ceiling board coupled with air handling unit	9.4% load reduction
Chaiyat, 2015	Active	In the return air duct coupled with evaporator	Cooling load decreased by 3.09 kWh/d 9.1% cost saved, 4.15 years payback
Hirmiz et al., 2019	Active	Integrated with heat pump via condenser storage tank	6 hr Load shift
Dong et al., 2019	Active	Direct coupling with the electrical heat pump via storage tanks	13% power savings 12.7% peak load shifted* 19% electricity cost savings

ve storage systems offer a high level of control of indoor conditions and improve heat energy storage.
A particularly promising configuration is the directly coupled active TES-HP configuration by Dong et al., which requires small modification and offers large performance improvement while reducing the TES footprint.

Challenges and Future Work
The HVAC system incorporating TES is beneficial to both residential and commercial buildings by providing grid value, though the residential system requires more installation costs making it challenging for many consumers to adopt this technology. The end-user would need to purchase the equipment for new construction, replacement of an old heating/cooling system, or retrofit applications. The most financially motivated users tend to be the consumers paying demand charges or on tariffs like Time-Of-Use (TOU) rates, as TES is ideal to shift the predictable daily load for demand response. The performance of active TES systems can be optimized by taking advantage of favorable environmental conditions and pre-scheduled utility tariffs to charge the storage medium efficiently. However, careful scheduling is required to maximize the benefit to avoid round-trip energy losses.

Conclusions
This article reviews the state of art of heat pump integrated TES in grid-interactive buildings. Various configurations are reviewed and active storage is found to be more beneficial for daily load shifting, where PCMs can be charged for generation during off-peak hours.

TES has been shown to reduce building energy consumption from 9% to 62% and building peak load from 12% to 57%.

Heat pump integrated TES allows the use of already established technology and resources, with minimal equipment that can reduce the installation complexity. Heat pump-integrated TES equipment is also programmable with the thermostat for demand response and can provide building flexibility. With the number of possibilities, novel configurations can be explored that offer maximum benefits to both consumer and grid, while minimizing the TES footprint.

Research is needed in controls to optimize performance under various utility tariffs for demand response as well as develop novel directly coupled configurations to reduce the TES footprint.

References

[1] U.S. EIA, "Annual Energy Outlook 2020," 2020. Accessed: Apr. 20, 2020

[2] B. Goetzler, M. Guernsey, and T. Kassuga, "Grid-interactive Efficient Buildings Technical Report Series: Heating, Ventilation, and Air Conditioning (HVAC); Water Heating; Appliances; and Refrigeration," 2019.

[3] M. Sarkar, "How American Homes Vary By the Year They Were Built; How American Homes Vary By the Year They Were Built," Washington, DC, 2011. Accessed: May 20, 2021. http://www.census.gov/const/www/charindex.html.

[4] C. K. Halford and R. F. Boehm, "Modeling of phase change material peak load shifting," Energy Build., vol. 39, no. 3, pp. 298–305, Mar. 2007

[5] N. Zhu, S. Wang, Z. Ma, and Y. Sun, "Energy performance and optimal control of air-conditioned buildings with envelopes enhanced by phase change materials," Energy Convers. Manag., vol. 52, no. 10, pp. 3197–3205, Sep. 2011

[6] R. Barzin, J. J. J. Chen, B. R. Young, and M. M. Farid, "Application of PCM underfloor heating in combination with PCM wallboards for space heating using price based control system," Appl. Energy, vol. 148, pp. 39–48, Jun. 2015

[7] N. H. Abu-Hamdeh, A. A. Melaibari, T. S. Alquthami, A. Khoshaim, H. F. Oztop, and A. Karimipour, "Efficacy of incorporating PCM into the building envelope on the energy saving and AHU power usage in winter," Sustain. Energy Technol. Assessments, vol. 43, p. 100969, Feb. 2021

[8] F. Bruno, N. H. S. Tay, and M. Belusko, "Minimising energy usage for domestic cooling with off-peak PCM storage," Energy Build., vol. 76, pp. 347–353, Jun. 2014

[9] S. Takeda, K. Nagano, T. Mochida, and K. Shimakura, "Development of a ventilation system utilizing thermal energy storage for granules containing phase change material," Sol. Energy, vol. 77, no. 3, pp. 329–338, Sep. 2004

[10] T. Kondo and T. Ibamoto, "Research on thermal storage using rock wool phase-change material ceiling board," in ASHRAE Transactions, 2006, vol. 112 PART 1, pp. 526–531.

[11] N. Chaiyat, "Energy and economic analysis of a building air-conditioner with a phase change material (PCM)," Energy Convers. Manag., vol. 94, pp. 150–158, 2015

[12] R. Hirmiz, H. M. Teamah, M. F. Lightstone, and J. S. Cotton, "Performance of heat pump integrated phase change material thermal storage for electric load shifting in building demand side management," Energy Build., vol. 190, pp. 103–118, May 2019

[13] J. Dong, B. Shen, J. Munk, K. R. Gluesenkamp, T. Laclair, and T. Kuruganti, "Novel PCM Integration with Electrical Heat Pump for Demand Response," 2019

KYLE R. GLUESENKAMP
Senior R&D Scientist
United States of America
gluesenkampk@ornl.gov
https://doi.org/10.23697/62tr-nt79

INFORMATION

Save the date – IEA HPT TCP National Experts meeting 2021, October 28, Nuremberg

The Technology Collaboration Programme on Heat Pumping Technologies (HPT TCP) by IEA will organize a National Experts meeting on October 28, 09.00-16.30, in Nuremberg, Germany, in conjunction with the European Heat Pump Summit, which will take place on October 26-27 in the same location.

The main purpose with the meeting is to **develop new ideas and proposals for future Annexes** (international collaboration projects) within the HPT TCP. Examples of topics to be discussed during the meeting is how to stimulate mass deployment of heat pumping technologies, how to improve the affordability, how to explore the flexibility potential, how to integrate with other renewable technologies and which measures to be taken to extend the use of both the cold and the warm side of the cycle.

You are welcome to participate and to invite other researchers and industry representatives from your country!

Please **register** for the meeting on **September 15** as the latest.

If you have ideas or proposals for new annexes that you want to discuss during the meeting, please inform us by sending an e-mail and we will take that into consideration when outlining the agenda for the meeting.

Read more >

Simulations of Grid-Responsive HVAC Cooling Measures via Ice/PCM storage

Bo Shen, Oak Ridge National Laboratory, USA

This study uses EnergyPlus building energy simulations to assess grid-responsive HVAC cooling measures during peak hours having high electricity prices, including: lock the high capacity of a two-speed cooling coil during grid-response hours; and use ice/PCM energy storage to drive a chilled water coil and meet the cooling load, when shut off the main electric cooling coil. The impacts on peak power reductions, energy and utility cost savings, as well as comfort levels in residential buildings of two U.S. cities, were revealed.

Grid response involves strategically shifting demand for electric power to avoid overloading the grid during peak demand. The effect of demand response is usually referred to as "peak shaving" and "valley filling".

Over the past decade, a number of control strategy and scheduling planning methods have been developed to address the demand response problem of DX (direct expansion) cooling systems. For example, cooling system energy costs can be reduced using thermal storage in building mass, or ice storge/phase change material (PCM) storage. Very few studies are available addressing how to achieve grid response by directly modulating the speed of compressor. Compared with other strategies, such as regulating the set-point temperature of smart thermostat and scheduling the heat pump to periodically start up and shut down, modulating the compressor speed does not require a balance period between building load and cooling capacity, and therefore is highly responsive.

Before implementing the grid-responsive load shifting measures, it is necessary to simulate the impact on peak power reduction, energy and utility cost savings, and comfort levels in template buildings over a wide range of climate conditions. EnergyPlus is a whole-building energy simulation engine developed by the U.S. Department of Energy. This study aims to utilize and improve EnergyPlus to simulate grid-responsive, flexible HVAC (heating, ventilation, air conditioning) cooling measures.

Energyplus grid-responsive cooling measures

Grid Signal Schedule

A grid signal can represent any variations related to the power grid. Figure 1 depicts hourly electricity prices (cents) in the summer (cooling season). This is the typical pricing pattern in the cooling season based on average prices for January 2016 through December 2019 provided by the ComEd Company, the sole electric provider in Chicago and much of Northern Illinois. The grid signal can be described using the EnergyPlus feature of Schedule: Compact.

Grid-Responsive Multi-Mode Coil Collection with Ice/PCM Storage

During a grid-responsive period, a cooling coil may be required to run at a reduced capacity than what is required by the building load. It may operate differently from its normal mode, for example, reduce the air flow ratio

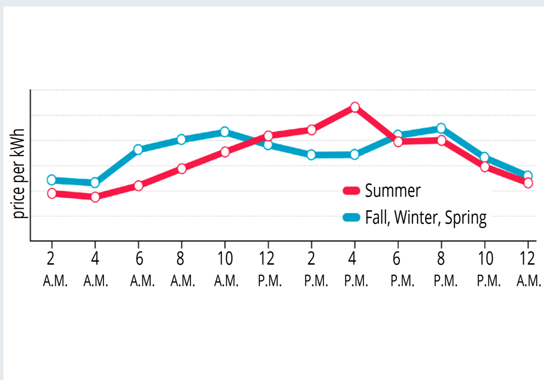


Figure 1: Grid signals (hourly electricity prices) represented by a schedule.

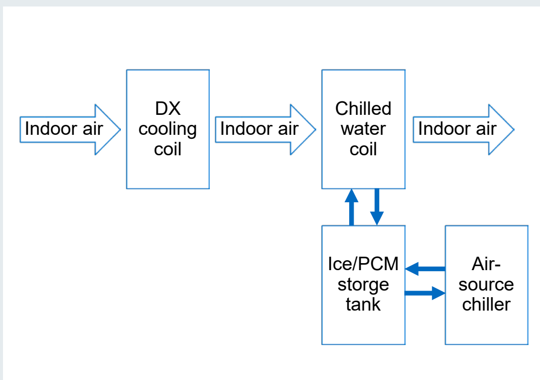


Figure 2: System configuration of a variable-speed DX cooling coil integrated with an ice/PCM energy storage, water cooling coil and an air source chiller.

relative to its delivered capacity, and thus the moisture removal may be enhanced for better comfort level. We need to incorporate multi-mode cooling coils with capacity modulation and enhanced dehumidification.

The multi-functional unit used in the simulation is based upon the EnergyPlus air-source Integrated Heat Pump (IHP). The IHP object was expanded to include a variable-speed air-source chiller, which charges an ice/PCM storage tank defined in the IHP. The configuration of integrating a DX cooling coil with supplemental chilled water coil, ice/PCM storage tank and an air-source chiller to charge the tank is given in Figure 2.

Building Energy Simulations

We selected single-family homes with slab foundations in Atlanta, Georgia (representing a typical southern climate), and Indianapolis, Indiana (representing a typical northern climate), to assess the grid-responsive cooling measures via building annual energy simulations. The single-family homes were from the EnergyPlus library of template buildings. They were built according to the IECC (International Energy Conservation Code) 2006 energy code specific to individual climate zones. The cooling set point is 23.3°C throughout the year.
To assess the grid-responsive cooling measures, we follow the grid schedule in Figure 1, and start a grid-responsive operation when the hourly electricity price is above 10 cents/kwh, which roughly covers the period from 12 pm to 6 pm in each cooling day.

Limit high capacity of modulating cooling coil with/without enhanced dehumidification
A two-speed DX cooling coil in each home was auto-sized to match the building design cooling load at the high speed. The low speed has approximately 75% capacity of the high speed. In the two cities, we conducted annual simulations, comparing three scenarios: 1) the DX cooling coil to match the building load as needed, without a grid response (baseline); 2) turn on a grid responsive control to only run the compressor low speed with its normal air flow rate, during the specified grid-responsive hours (modulating with normal flow); 3) use a grid responsive control with enhanced dehumidification, i.e. running the compressor at a low speed with 50% reduced indoor air flow rate (enhanced dehumidification). Figures 3 and 4 below illustrate a controlled zone temperature and relative humidity during a peak cooling day in Atlanta. After locking the top capacity, neither the operation at the low speed with normal air flow nor with enhanced dehumidification can meet the zone sensible load, which resulted in lost control of the zone temperature. The option with enhanced dehumidification resulted in the highest impact on the temperature because of its smaller capacity. On the other hand, this option controlled the indoor relative humidity below 40%.

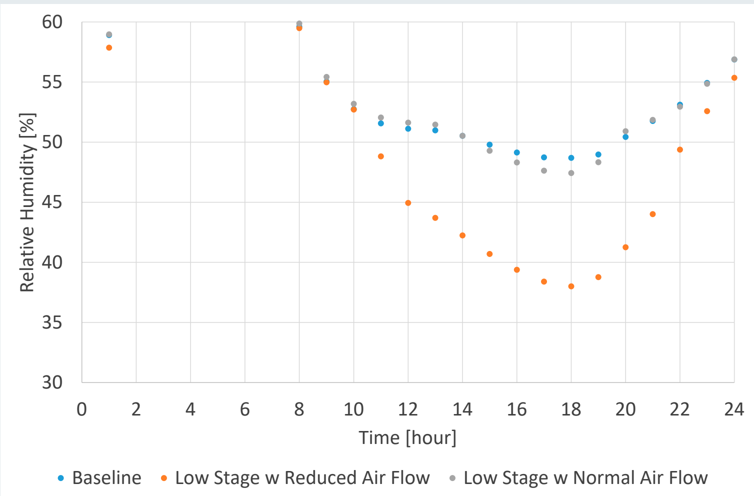


Figure 3: Controlled zone temperature during a peak cooling day.

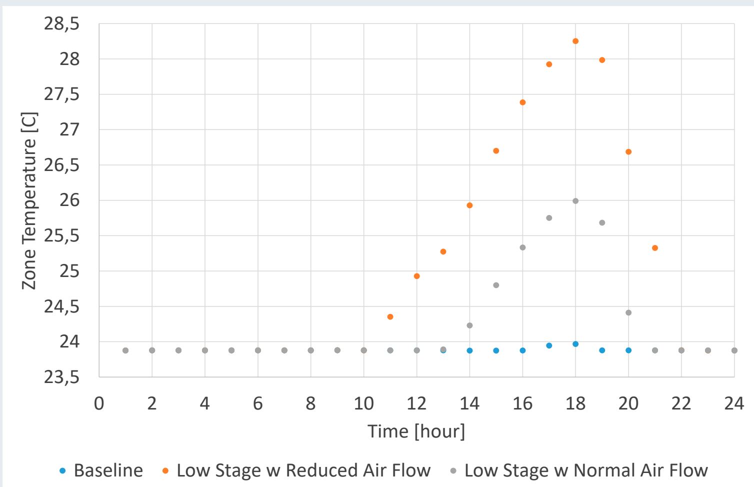


Figure 4: Controlled zone relative humidity during a peak cooling day.

Table 1: Cooling seasonal energy simulations in Atlanta, with locking high speed during grid-responsive hours.

Atlanta	Cooling Delivery	Electricity consumption	Seasonal COP	Price	Un-comfort hours	Peak Power Reduction
Unit	kwh	kwh	W/W	USD	> 27°C, 50% RH	%
Baseline	11069.8	2423.0	4.57	251.1	0	0
Modulating w Normal flow	10957.1	2381.1	4.60	246.1	0	26%
Enhanced dehumidification	11187.2	2691.2	4.16	281.9	0	28%

Table 2: Cooling seasonal energy simulations in Indianapolis, with locking high speed during grid-responsive hours.

Indianapolis	Cooling Delivery	Electricity consumption	Seasonal COP	Price	Un-comfort hours	Peak Power Reduction
Unit	kwh	kwh	W/W	USD	> 27°C, 50% RH	%
Baseline	8351.5	1797.5	4.66	191.7	0.0	0%
Modulating w Normal flow	8205.3	1741.8	4.72	184.7	6.0	27%
Enhanced dehumidification	8346.4	1954.5	4.28	209.0	12.0	28%

Table 1 shows the annual energy simulation results from Atlanta. The total cooling energy delivered is identical among the three scenarios. Generally, a cooling coil is sized to match the building's maximum cooling load at the peak ambient temperature in the climate zone. Therefore, the low-speed operation (75% capacity) is still able to satisfy the building load on most occasions except a small range around the highest ambient temperature. During the grid-responsive hours, the zone temperature increases due to top capacity locking. After the grid-responsive period, the DX cooling unit recovered the zone air and envelope to the original setting temperature. Consequently, the grid responses did not reduce the total cooling demand noticeably. Due to the reduced indoor air flow rate, the enhanced dehumidification causes lower seasonal cooling COP, i.e., 4.16 versus 4.57 of the baseline. As a result, the enhanced dehumidification leads to more seasonal electricity consumption and higher electricity costs. Limiting the top cooling capacity did not reduce the electricity cost, but resulted in a 26–28% peak power reduction. Both the modulating with normal flow and enhanced dehumidification maintained the zone temperature below 27°C and relative humidity below 50%, i.e., with minor impact on the comfort level.

Table 2 shows the annual energy simulation results from Indianapolis. The trends are the same as Atlanta, except with more uncomfortable hours with the indoor air temperatures >27°C and relative humidity >50%.

Ice/PCM Storage

When coupled with an ice/PCM storage as shown in Figure 2, the compressor is turned off during grid-responsive hours, while running the air flow rate corresponding to the high (nominal) compressor speed. The storage tank drives the chilled water coil to provide supplemental cooling. The water coil supply air temperature is controlled at 13.0°C.

The air-source chiller was auto-sized together with the DX cooling coil to maintain a constant ratio between the rated capacities. When the solid ice/PCM fraction is below 90%, it calls the chiller to start charging until the fraction reaches above 99%. The chiller is only allowed to run when the electricity price is below 10 cents, i.e., during non-grid-responsive hours.

To simplify the analyses, it is assumed that the ice storage tank has a constant exit temperature of -0.5°C to the chiller during charging, and 7.2°C to the water coil during discharging. The PCM storage tank has an exit temperature of 4.5°C to the chiller during charging and 10.0°C to the water coil during discharging. The PCM has an onset phase change temperature of 5°C and termination temperature of 6°C. The heat transfer UAs (U = overall heat transfer coefficient, A = heat transfer area) are auto-sized to satisfy the temperature settings.

Table 3 presents cooling energy simulation results when coupled with ice storage and PCM storage in Atlanta. During the grid-responsive hours, the ice/PCM cooling storage drove the water coil to meet the zone load. The total cooling energy delivered and total electricity consumption contains the energy from both the DX cooling coil and the air source chiller during non-grid-responsive hours. It can be seen that the chiller delivered capacity to the storage tank, amounting to 70% of the total cooling energy delivered, because the grid-responsive periods involve the major cooling load. Although the energy consumptions of ice and PCM storages are higher than the baseline, their seasonal electricity price are lower, since the charging operations use low-cost electricity in off-peak hours. The electricity consumption and cost of the PCM storage is lower than the ice storage because the PCM storage corresponds to higher coolant charging temperature, which elevates the chiller COP.

Table 3: Cooling seasonal energy simulations in Atlanta, coupled with ice/PCM energy storage.

	Total Cooling Delivery	Total Electricity consumption	Total Seasonal COP	Price	Chiller Delivery	Chiller Electricity Consumption	Chiller COP
	kwh	kwh	W/W	USD	kwh	kwh	W/W
Baseline	11069.8	2423.0	4.57	251.1	0	0	0
Ice Storage	11004.1	2830.0	3.90	191.9	7842.0	2189.3	3.6
PCM Storage	10806.7	2523.6	4.28	175.0	7634.2	1881.8	4.1

Table 4: Cooling seasonal energy simulations in Indianapolis, coupled with ice/PCM energy storage.

	Total Cooling Delivery	Total Electricity consumption	Total Seasonal COP	Price	Chiller Delivery	Chiller Electricity Consumption	Chiller COP
	kwh	kwh	W/W	USD	kwh	kwh	W/W
Baseline	8351.6	1797.6	4.66	191.7	0	0	0
Ice Storage	8526.6	2156.2	3.96	150.1	6313.6	1715.8	3.7
PCM Storage	8374.9	1921.9	4.37	137.1	6155.5	1481.1	4.2

Table 4 presents cooling energy simulation results when coupled with ice storage and PCM storage in Indianapolis. It indicates the same trends as for Atlanta.

Conclusions

The EnergyPlus building energy simulations imply that locking the high capacity of a modulating, cooling coil, from 100% to 75% during the grid-response hours, can effectively reduce the peak power consumption up to 28%. The strategy impairs the comfort level only to a minor extent. Enhanced dehumidification at the low speed is able to reduce the indoor relative humidity at the expense of lower cooling efficiency. Ice/PCM storages coupled with a DX cooling coil are able to eliminate nearly all the peak power consumption, excluding the indoor fan power. They result in lower electricity bills due to mainly using low-cost electricity during off-peak hours.

References

[1] ComEd Company, typical pricing pattern in cooling season based on average prices for January 2016 through December 2019, https://hourlypricing.comed.com/live-prices/

[2] U.S. Department of Energy, EnergyPlus, https://energyplus.net/

BO SHEN
Oak Ridge National Laboratory
United States of America
shenb@ornl.gov
https://doi.org/10.23697/z1jv-1x76

Events 2021

Please check for updates for any conference that you plan to attend. Venues and dates may change, due to the pandemic.

2021

1–3 September
13th IIR Conference on Phase-Change Materials and Slurries for Refrigeration and Air Conditioning
http://static.gest.unipd.it/PCM2021/

1–3 September
6th IIR Conference on Thermophysical Properties and Transfer Processes of refrigerants
Online event only
http://static.gest.unipd.it/TPTPR2021/

3–4 September
52nd AiCARR International Conference
Vicenza, Italy and Online
http://www.aicarr.org/Default_en.aspx

6–8 September
12th International Conference on Compressors and their Systems
Online event only
https://www.city.ac.uk/events/conferences/compressorsconference

16–18 September
(postponed from 13-15 May 2021)
9th IIR Conference on Ammonia and CO² Refrigeration Technologies
Ohrid, Macedonia
https://iifiir.org/en/events/9th-iir-conference-on-ammonia-and-co2-refrigeration-technologies

21–23 September
AHR Expo Mexico
Monterrey, Mexico
https://www.ahrexpomexico.com/en/

5–7 October
IIR International Conference, 16th Cryogenics 2021 conference
Online event only
www.cryogenics-conference.eu/cryogenics2021

14–15 October
International Symposium on New Refrigerants and Environmental Technology 2020
Online event only
https://jraia-symposium.org/Kobe2021/en/index.php

26–27 October
European Heat Pump Summit
Nuremberg, Germany and online
https://www.hp-summit.de/en

10–12 November
2021 ASHRAE Building Performance Analysis Conference
Denver, Colorado, USA
https://www.ashrae.org/conferences/topical-conferences/2021-ashrae-building-performance-analysis-conference

16–18 November
SIFA
Paris, France
https://www.expo-sifa.com/en

16–19 November
C&R
Madrid, Spain
https://www.ifema.es/en/cr

2022

29 January–2 February
2022 ASHRAE winter Conference
Las Vegas, USA
https://www.ashrae.org/conferences/2022-winter-conference-las-vegas

31 January–2 February
AHR Expo
Las Vegas, USA
https://www.ahrexpo.com/

1–4 February
HVAC&R JAPAN 2022
Tokyo, Japan
https://www.jraia.or.jp/hvacr/en/index.html

17–19 February
ACREX India 2022
Bengaluru, India
https://www.acrex.in/home

8–10 April
The 10th Asian Conference on Refrígeration and Air-Conditioning (ACRA 2022)
Chongqing, China
https://acra2022.scimeeting.cn/en/web/index/

11–13 April
7th IIR Conference on Sustainability and the Cold Chain
Newcastle, United Kingdom
https://ior.org.uk/the-7th-iir-conference-on-sustainability-and-the

4–6 May
(postponed from 13-15 September, 2021)
IAQ 2020: Indoor Environmental Quality Performance Approaches - Transitioning from IAQ to IEQ
Athens, Greece
https://www.ashrae.org/conferences/topical-conferences/indoor-environmental-quality-performance-approaches

22–25 May
CLIMA 2022
Rotterdam, The Netherlands
https://clima2022.org/

13–15 June
15th IIR-Gustav Lorentzen Conference on Working Fluids
Trondheim, Norway
https://www.sintef.no/projectweb/gustavlorentzen_2022/

IN THE NEXT ISSUE
Climate Leap – how investors reach major emission cuts in existing property portfolios

Volume 39 - NO 3/2021

National Team CONTACTS

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

BELGIUM
Ellen Van Mello
ODE – Organization for Sustainable Energy
Tel: + 32 476792824
ellen.vanmello@ode.be

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

CHINA
Prof. Xu Wei
China Academy of Building Research
Tel: +86 10 84270105
xuwei19@126.com

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

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

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

GERMANY
Dr. Rainer Jakobs
Informationszentrum Wärmepumpen und Kältetechnik
Tel. + 49 6163 57 17
jakobs@izw-online.de

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

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

Mr. Hideaki Maeyama
Heat Pump and Thermal Storage Technology Center of Japan (HPTCJ)
Tel: +81 3 5643 2404
maeyama.hideaki@hptcj.or.jp

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

NORWAY
Mr. Rolf Iver Mytting Hagemoen
NOVAP
Tel. +47 971 29 250
river@novap.no

SOUTH KOREA
Mr. Hyun-choon Cho
KETEP
Tel: +82 2 3469 8301
energykorea@ketep.re.kr

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

SWITZERLAND
Mr. Stephan Renz
Beratung Renz Consulting
Tel: +41 61 271 76 36
info@renzconsulting.ch

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

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

Ms. Melissa Voss Lapsa – Coordinator
Building Envelope & Urban Systems Research
Building Technologies Research & Integration Center
Tel: +1 865 576 8620
lapsamv@ornl.gov

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

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

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

The Programme is a key worldwide player in this process by communicating and generating independent information, expertise and knowledge related to this technology as well as enhancing international collaboration.

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

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

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

Heat Pump Centre
c/o RISE Research Institutes of Sweden
P.O. Box 857
SE-501 15 Borås
Sweden
Tel: +46 10 516 53 42
hpc@heatpumpcentre.org

www.heatpumpingtechnologies.org