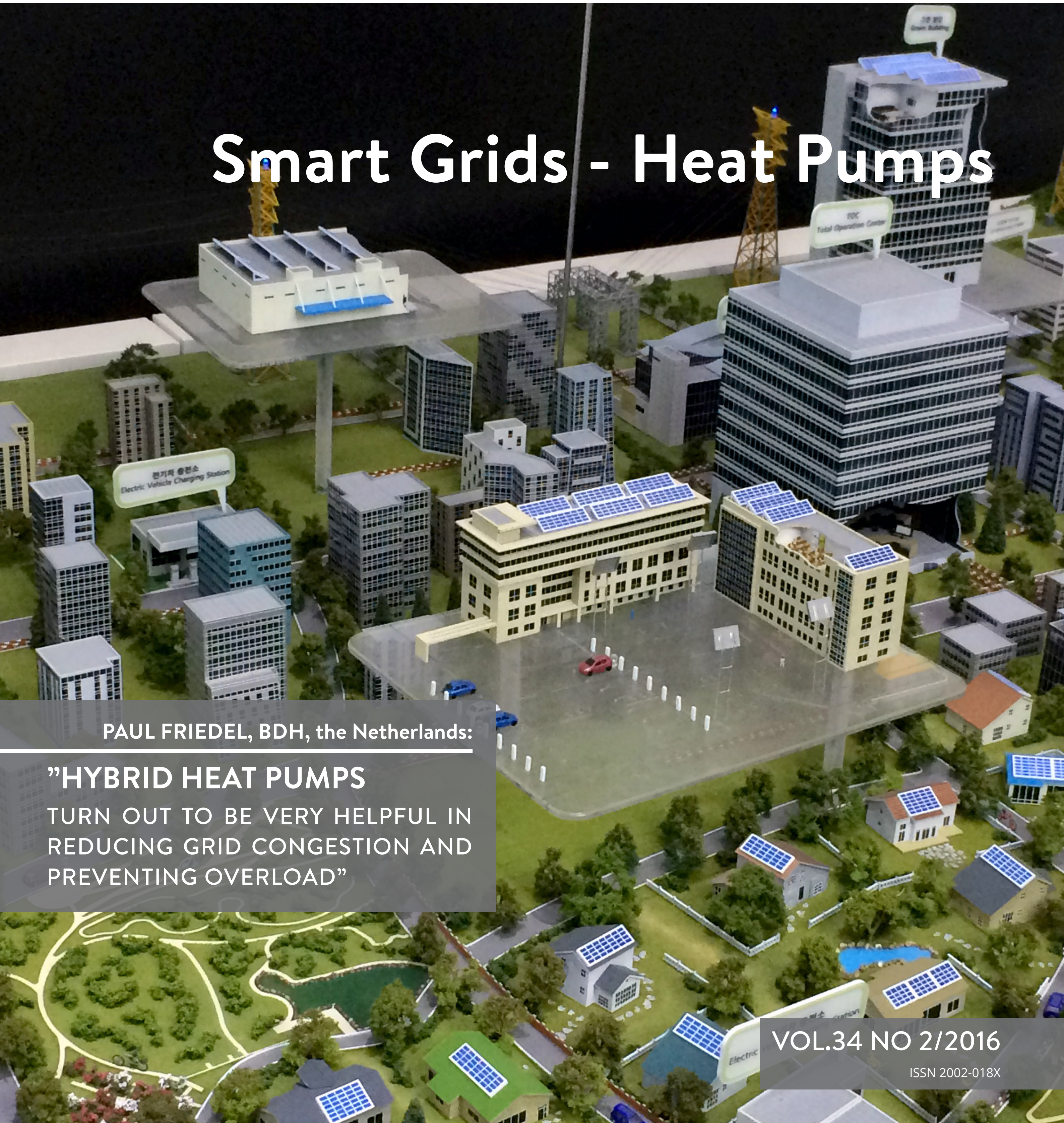
Heat Pumping Technologies MAGAZINE

A HEAT PUMP CENTRE PRODUCT



Smart Grids - Heat Pumps

PAUL FRIEDEL, BDH, the Netherlands:

"HYBRID HEAT PUMPS TURN OUT TO BE VERY HELPFUL IN REDUCING GRID CONGESTION AND PREVENTING OVERLOAD"

VOL.34 NO 2/2016
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Heat Pumping Technologies
MAGAZINE

VOL.34 NO.2/2016

In this issue

Welcome to the new **Heat Pumping Technologies Magazine** – or in short: **HPT Magazine**! The Magazine is a development of the former HPC Newsletter, updated with a new layout, more focus on the Annexes and the possibility to read it on issuu (a digital publishing platform). Another update is that the News section has moved out to the website, which means that the Magazine will not publish yesterday's news. We hope that you will like the new look, that soon will be followed up by a new, modern website!

The topic for the kick-off issue of the HPT Magazine is *Smart Grids - Heat Pumps*. Smart Grids is a very hot topic, with a number of expectations, such as being able to handle grid congestion, and enable the inclusion of electricity from intermittent sources. Heat pumps, being able to convert electric energy to heat, are an obvious part of the Smart Grid concept.

In this issue, we are provided different views of heat pumps in Smart Grids. After an introductory Foreword, and a Column by our sister TCP on Smart Grids, ISGAN, four Topical articles each provide their angle of the topic. An article on flammable refrigerants connects back to the previous issue (HPC Newsletter 1/2016), which had *Refrigerants* as the Topic. We are also given an account on CO_2 heat pump water heaters, as well as a market overview for space cooling in the US.

I hope to see you all at the Heat Pump Conference in Rotterdam, the Netherlands, in May 2017! See the feature on the Conference in this Magazine issue.

Enjoy your reading of the new HPT Magazine!
Johan Berg, Editor

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FOREWORD

Heat Pumps in Smart Grids

The obvious effects from climate change set mandatory requirements on energy conservation and use of renewable energy sources. Heat pump markets and policy makers in many countries have a focus on heat pumps for space heating and domestic hot water in the built environment. Therefore, there will be an increased need to adjust user-consumption to the production from intermittent energy sources, since energy consumption will become more tuned to the moment of availability, instead of the randomly occurring moment of demand by the consumer/user.

Our energy system will have to change so significantly that managing supply and demand to an extend unknown previously will be a fiercely strict requirement. So it is of paramount importance to unlock the potential of heat pumps related to smart grids with regard to managing peak loads and/or congestion management in the electricity.

In recent years several demonstration projects have been started/carried out in various countries concerning the implementation of heat pumps in domestic housing. Among these are the implementation of heat pumps in combination with district heating or district cooling, and several smart city projects are in the pipeline.

Flexibility (and storage) are essential elements for successful implementation of heat pumps in smart grids. Determination of implementation barriers for implementing the suggested systems per country is essential, since the energy system varies country by country. For such processes, a thoroughbred roadmap for smart connection of heat pumps that stipulates how the challenges to be met is of significant value.

In the Topical articles of this issue, one can read valuable insights which have been gained during the execution of the HPT TCP Annex 42, 'Heat Pumps in Smart Grids'. Insights on flexibility and/or load management with electrical heat pumps, as well as on congestion management in power grids with hybrid heat pumps, as well as an account of some projects led from Japan.

The final reports of Annex 42 will be online available in Spring 2017. The content of the articles will also be subject to presentations and workshops during the IEA Heat Pump Conference in May 2017 in Rotterdam.

PETER WAGENER
Operating Agent for Annex 42
Heat Pumps in Smart Grids
Business Development Holland b.v
the Netherlands

ISGAN's Global Work on Smart Grids and Why Flexible Heat Pumps Are Important

ISGAN (International Smart Grid Action Network) is an IEA Technology Collaboration Programme (TCP), similarly to the Heat Pumping Technologies TCP. It is also an initiative of the Clean Energy Ministerial (CEM). ISGAN is creating a mechanism for multilateral government-to-government collaboration to advance the development and deployment of smarter electric grid technologies, practices, and systems. In its strategic focus, ISGAN notes five major global trends for electricity networks, namely *decarbonization*, *decentralization*, *integration*, *digitalization*, and broader *economic growth and access*. Their combined effects result in fundamental changes in how power systems are designed, developed (or in many cases redeveloped) and operated. One crucial area of development for ISGAN is the increased need for flexibility in the present and future energy system. Using smart grids as an important enabling technology will accommodate the increasing share of variable renewable energy and can address problems related to ageing infrastructure managing the rapid growth of electrification in both developing and developed economies. A specific but important example of this is letting Internet connected heat pumps collaborate and work in cooperation with the grid and the market as one way to obtain a flexible and smart grid.

In a deregulated electricity market supply and demand defines the electricity price. If the price is high, demand decreases. But what if lots of Internet connected smart ground source heat pumps at the same time turn on three kilowatts of electric heating, because electricity price is low? Similar situations have happened in the UK known as "TV-pickups", when the football referee blows the whistle in the break of a national game. Synchronously, millions of water kettles are switched on, resulting in peak loading of the electricity grid. In Sweden, the research report Demand flexibility on an energy only market shows that with as little as 100 000 heat pumps reacting on the price of electricity on the Nord Pool spot market, not only the grid but also the market may become totally unbalanced and stochastic. No market works well if customers can react on pricing known 24 hours in advance.

These Internet controlled heat pumps operating in cooperation with the grid and the market constitute a collaborative smart grid. In a project in Sweden, New collaborative models in the energy market, smart heat pump control systems are being installed. The focus is on customer comfort and lower costs, but at the same time a one megawatt flexible unit is created, including 500 homes.

The goal of the project is sustainable comfort and enabling houses to participate in demand response, completely transparent to the user. But in what business model should the flexibility be used?

There will be periods when there is a conflict between optimizing local grid peaks, to reduce loading on a transformer or cable, and the overall electricity wholesale. It is in these situations that the flexibility could actually be part of several business models. As more systems are getting connected to the Internet, we will see more business models arising. They are being tested in this project. With 1.5 million homes in Sweden we would get three gigawatts of flexibility, and at the EU level we can attain as much as 100 gigawatts.

This is a concrete example of using smart grid technologies for flexible demand as a powerful tool to enable more volatile renewable electricity from solar and wind, which is increasingly important in the transition of power systems towards climate neutrality.

In one of ISGANs annexes, ISGAN Smart Grid Case studies, various cases of demand flexibility are presented. For more information, see ISGAN Annex 2 Spotlight on demand side management.


JOACHIM LINDBORG
CTO Sustainable Innovation
Sweden

Dr. MAGNUS OLOFSSON
National expert ISGAN Annex 2
Sweden


12th IEA Heat Pump Conference 2017 in Rotterdam

The Netherlands is organizing the 12th IEA Heat Pump Conference at the World Trade Centre in Rotterdam under the theme: 'Rethink Energy, Act NOW'!

The Conference will start on Monday 15th May with a number of workshops and a number of excursions. That evening there will be a welcome reception at Rotterdam City Hall. On Tuesday 16th May the Conference will continue with a plenary opening session with high level speakers and then three days of presentations. Keynote presentations will open each morning and afternoon session. The very successful call for papers has generated more than 350 high quality abstracts. The Conference therewith will have the unique opportunity to present four main conference tracks.

- Smart Grids, District Heating
- Nearly Zero Energy Buildings
- Industrial Heat Pumps and Waste Heat
- Sorption Technologies and Working Fluids

Each of these tracks will have up to 40 oral presentations and a large number of poster presentations. Within those main tracks topics such as Air Conditioning, Ground Sources and Combination with other renewable technologies will also be highlighted.

In the draft program the track on **Smart Grids, District Heating** will focus on the important link between smart grids, hybrid solutions, storage and district heating as part of an integrated community energy supply system for residential as well as commercial and industrial areas. These presentations range from business models for contracting the flexibility of residential heat pumps to a virtual energy storage network providing flexibility for the power system. They also include presentations on the testing of smart heat pump controllers and hybrid heat pumps providing demand flexibility with hybrid heat pumps in combination with district heating. As for Smart Grids, storage will be the game changer; there are presentations on storage systems and domestic hot water as solutions.

The track on **Nearly Zero Energy Buildings** will show a number of practical solutions, with domestic hot water becoming the key factor in the overall energy demand and renovation as the main challenge. In addition to R&D, the presentations will also show project examples. As NZEB's

will be mandatory in the EU in 2020 in new buildings, there will a presentation on experiences with a Zero Energy district in Netherlands, showing their first results at the conference.

Fairly unique at this conference are the tracks on **Industrial Heat Pumps and Waste Heat** and **Sorption and Gas Technologies**. For each of these tracks over 45 abstracts have been submitted.

The interest from industry in heat pumps is growing as High Temperature applications are reaching the market and industry can benefit from fluctuating electricity prices by using CHP during high rates and heat pumps and vapour recompression at low electricity rates. This hybrid energy supply leads to a robust energy supply system whereby companies are less vulnerable to fluctuations in the electricity market. A number of presentations in the track on industrial heat pumps and the sessions on working fluids focus on these developments.

The workshops on the first day of the conference will be held in a format where discussions with the experts will provide answers to questions such as *what to do and how to organise*, keeping in mind the theme of the Conference, 'Rethink Energy, Act NOW'. The workshops will start with a number of elevator pitches, challenging the experts into discussion.
There will be five workshops focusing on themes:

- NZEB for renovation residential applications
- Smart grids, community energy supply systems and district heating
- Industry closing the production cycles
- Heating, Ventilating and Air Conditioning
- Ground Sources and ATES

The results and recommendations of these workshops will be presented at the final plenary session of the conference.

During the conference an exhibition will be held in the main hall of the World Trade Centre. Suppliers and manufacturers can and will showcase their products. The venue of the World Trade Centre is located in the central heart of Rotterdam; this location offers a full-service concept. The 37 different rooms accommodating from 10 to 1000 people do not only vary in size but also in ambience and design.

This conference is the perfect forum to learn from and communicate with industry and research experts from all over the world.

With participants from 32 countries, the event is a key event for policymakers, executives and representatives from industry, utilities and the public sector, R&D managers and technology supporters, energy managers, planners, consultants, etc. This is the place to be for all those who wish to learn about the market trends and the future applications of heat pumps.

Time to prepare for an extraordinary 4-day meeting in Rotterdam!

Register now, as the registration for the Conference is now open http://hpc2017.org/registration and keep yourself informed through the website of the Conference subscribing to the Conference Newsletter/mail. Travel information to this great city of Rotterdam can be found on the website under http://hpc2017.org/about-rotterdam and under https://www.lonelyplanet.com/the-netherlands/rotterdam. Follow us on Linkedin, Twitter and Facebook.

Report from Clima 2016 in Aalborg, Denmark

Clima 2016 was an interesting and intense conference event with three days filled of presentations and posters. Of course I was only able to attend a small fraction of the presentations, but here is a short report based on some topics and findings which I consider especially interesting.

A lot of focus was given to low energy buildings (nZEB buildings) and the different national approaches to the Energy Performance of Buildings (EPBD) Directive. The different national versions of the rules create incentives for studies with similar approach but applying the boundary conditions of the different countries.

Another topic that several studies focused on was the challenges related to the retrofit of buildings. Several aspects were analyzed: energy, indoor environment, and costs. Also, a lot of the presentations were based on studies were a single or a few buildings were analyzed. Hence, it is a challenge to translate the conclusions from each of these studies into general knowledge that later can reach the market.

Indoor environment (indoor air quality, temperature, etc) gained a lot of focus, in line with one of the points made by the keynote speaker Lone Feifer (Velux). She referred to an investigation that shows that it is up to 100 times more efficient from a cost point of view to influence the efficiency of the workers in an office building via improvements in indoor air quality, compared to the benefits of a reduction of the energy use of the building.

Other interesting findings from the Keynote lectures:

- Researchers and engineers must be better to transform research results into a language that investors understand. It is not until we can translate the technical potential into risk, security and liquidity that we truly can make an impact on the building stock (*Frank Hovorka, REHVA*)
- Low energy buildings are very sensitive, indicating that a small change in internal load or a badly tuned heating system can result in relatively large deviations from the requested temperature. Therefore low energy buildings need more and better tuning of the installations (*Martin Dieryckx, Daikin*).

In line with the general focus of the conference on nZEB, the HPT Annex 40, Heat Pump Concepts for Nearly Zero Energy Buildings, had an open Workshop with about 25 attendees. A number of presentations were given by the six participating countries, covering technology development, monitoring, case studies, and policy issues.

I believe that international conferences, such as Clima, and projects with several international participants are very important in order to push the technology in the right direction in all regions of the world. Disseminating the latest findings and information about mature technologies may give countries and regions with less experience the possibility to leapfrog intermediate technological steps and head directly for the most cost and energy efficient technologies.

OLA GUSTAFSSON
SP Technical Research Institute of Sweden
Sweden

New Residential Water Heater Concept Promises High Efficiency, Lower Cost

A team of scientists from the Department of Energy's Oak Ridge National Laboratory and the University of Florida has developed a novel method that could yield lower-cost, higher-efficiency systems for water heating in residential buildings.

The theory behind the newly termed "semi-open" natural gas-fired design, explained in an ORNL-led paper published in *Renewable Energy: An International Journal*, reduces the cost and complexity of traditional closed gas-fired systems by streamlining, and even eliminating, certain components.

Figure 1. Oak Ridge National Laboratory and the University of Florida researchers are developing a prototype based on a new low-cost, high-efficient water heater concept for residential buildings. Image courtesy of University of Florida, https://www.ornl.gov/sites/default/files/ORNL%20media_rev.jpg

"When applied, the new concept could result in better than 100 percent energy efficiency, because the system draws energy from the surrounding air as well as from the natural gas," said ORNL's Kyle Gluesenkamp, lead author of "Efficiency analysis of semi-open sorption heat pump systems."

The versatile design combines water heating and dehumidification functions, which are typically found in separate architectures. In the semi-open scenario, the novel absorber device acts in place of the traditional evaporator component, pulling water vapor directly from the air through a membrane into a liquid solution. As the vapor is absorbed, much of the heat is transferred to domestic hot water.

The simpler semi-open system would operate at the surrounding atmospheric pressure, using an inexpensive, non-sealed solution pump. This approach eliminates the need for vacuum pumps found in closed

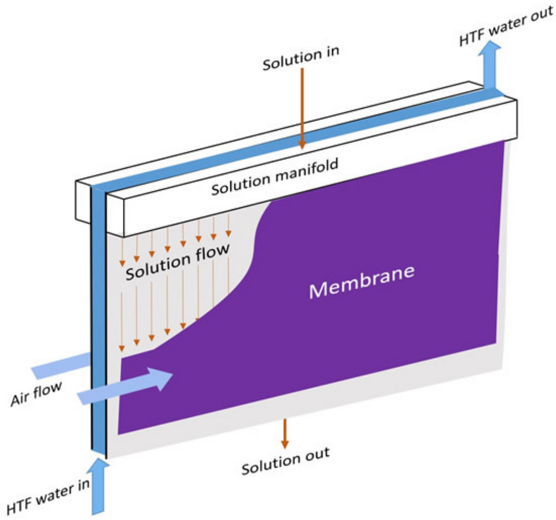


Figure 2. A new class of gas-fired heat pump water heater systems, based on a novel semi-open sorption concept, replaces the evaporator in a traditional closed sorption device with a vapor-permeable membrane that more efficiently absorbs and transfers heat for residential applications. Image courtesy of Oak Ridge National Laboratory, Dept. of Energy,https://www.ornl.gov/sites/default/files/Semi-open%20sorption%20heat%20pump%20concept_image2.jpg

systems that purge gas build up. It also allows manufacturers to consider lower-cost, lightweight polymers instead of costly, bulkier metals to build equipment, making it less susceptible to corrosion.

"The semi-open architecture introduces a new class of ultra-efficient heat pump water heaters that could become commercially available in a few years to homeowners seeking to replace their existing gas water heater," Gluesenkamp said.

UF researchers are leading the development of a semi-open gas-fired heat pump prototype and are using both ORNL's Building Technologies Research and Integration Center, a DOE user facility, and UF facilities to evaluate the potential of commercial applications.

Co-authors of the study include UF's Devesh Chugh and Saeed Maghaddam, and ORNL's Omar Abdelaziz. The research was supported by DOE's Building Technologies Office.

Source: www.ornl.gov

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.

NEW HEAT PUMP SYSTEMS IN MULTI-FAMILY BUILDINGS	50	AU, **DE**
NEW DESIGN AND INTEGRATION OF HEAT PUMPS FOR NZEB (CONTINUATION OF ANNEX 40)	49	**CH**, DE, US
NEW INDUSTRIAL HEAT PUMPS, SECOND PHASE	48	**DE**, FR, JP, UK
NEW HEAT PUMPS IN DISTRICT HEATING AND COOLING SYSTEMS	47	**DK**
DOMESTIC HOT WATER HEAT PUMPS	46	FR, JP, **NL**, KR, UK
HYBRID HEAT PUMPS	45	DE, FR, **NL**, UK
PERFORMANCE INDICATORS FOR ENERGY EFFICIENT SUPERMARKET BUILDINGS	44	DK, **NL**, SE
FUEL-DRIVEN SORPTION HEAT PUMPS	43	AT, **DE**, FR, IT, UK, US
HEAT PUMPS IN SMART GRIDS	42	AT, CH, DE, DK, FR, KR, **NL**, UK, US
COLD CLIMATE HEAT PUMPS (IMPROVING LOW AMBIENT TEMPERATURE PERFORMANCE OF AIR-SOURCE HEAT PUMPS)	41	AT, CA, JP, **US**

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

ANNEX 40	HEAT PUMP CONCEPTS FOR NEARLY ZERO ENERGY BUILDINGS
ANNEX 49	DESIGN AND INTEGRATION OF HEAT PUMPS FOR NZEB (continuation of Annex 40)

Conclusion of HPT TCP Annex 40 and continuation in Annex 49

HPT TCP Annex 40 has investigated heat pump applications in nearly Zero Energy Buildings (nZEB). nZEBs are to be widely introduced in Europe after 2020 according to the recast of the Energy Performance of Buildings Directive (EPBD recast, 2010) and also in North America and Japan in the time period between 2020 and 2030. The nine countries CA, CH, DE, FI, JP, NL, NO, SE and the USA have participated in the Annex 40 project. Annex 40 has been concluded and final reports of the Annex 40 are currently published on the HPC website.

Results of Annex 40 confirm that heat pumps are a well-suited building technology for achieving nZEB targets both energy- and cost-efficiently. A number of case studies have been completed for climate zones of central European and the Nordic climate, and various applications for both residential and office use have been considered. Also, case studies for hot and humid climates with pronounced cooling and dehumidification loads have been performed. All case studies yielded the result that heat pumps are among the best performing and most cost-effective system solutions. For high dehumidification loads and high office loads, however, it may be difficult to reach net zero energy balance, if also the appliances are taken into account in the balance, as depicted in Fig. 1.

Field monitoring results confirm the good performance of the heat pump in real operation, but optimisation potential was identified in the monitoring projects regarding design and hydraulic integration.
Information on the Annex 40 can be found on the project website http://www.annex40.net and on the HPC website.

As the topic of nearly Zero Energy Building will remain current due to the approaching deadlines of the EPBD, work on heat pumps in nZEB will continue in Annex 49, entitled "Design and integration of heat pumps in nZEB". Topics will be: to follow the state of implementation and definition of nZEB in the single participating countries, since the definition may have an impact on favourable system solutions. Monitoring of real nZEB will also be continued in order to obtain more feedback on real performance. Furthermore, a more in-depth design analysis of the heat pumps including different integration options will be performed; this also concerns demand response capabilities and the associated cost to make them accessible. Thereby, also groups of buildings or neighbourhoods will be considered, since there may be load balancing opportunities among different building loads. Also storage integration options will be evaluated. Annex 49 will start in autumn 2016.

Annex website: http://heatpumpcentre.org/en/projects/completedprojects/annex40
Contact: Carsten Wemhöner, carsten.wemhoener@hsr.ch

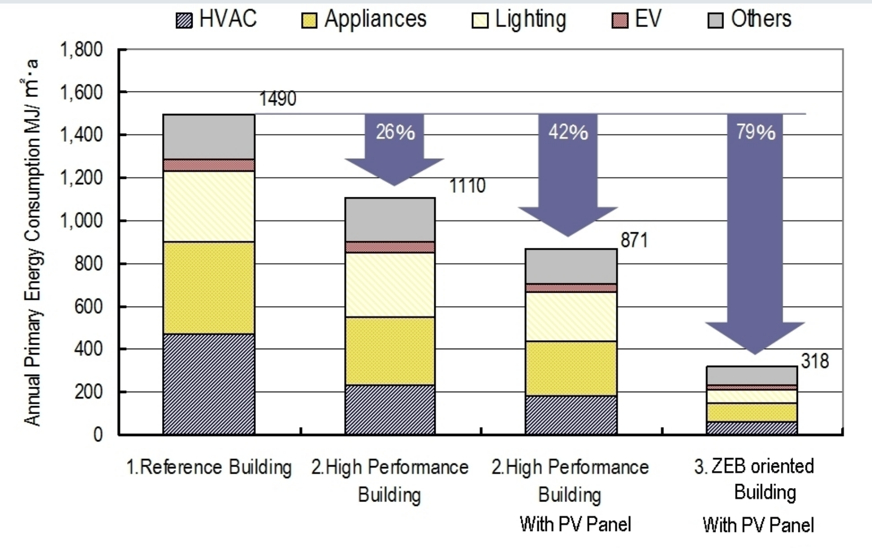


Figure 1. Results of a Japanese case study for medium size office buildings including appliances in Tokyo climate, i.e., pronounced dehumidification loads (source: Okumiya et al., 2015)

ANNEX
41
COLD CLIMATE HEAT PUMPS (CCHP)

In the past quarter, almost all of the Annex 41 participants have completed their country project report drafts – only one is outstanding.

The OAs have begun working to compile a draft final report for the Annex, according to the revised schedule below. The draft Annex final report is now planned to be distributed to the Participants for review towards the end of September 2016.

At the 2016 ASHRAE Summer Conference (June 25-29), see Table 2, two papers from the Canadian Annex 41 team and one from the Austrian team were presented and are published in the Conference Proceedings.

All of the papers can be downloaded for a small fee from the ASHRAE Bookstore at http://www.techstreet.com/ashrae?ashrae_auth_token. Click on the "Papers/Reports" tab at top of the page and browse ASHRAE Transactions for Technical papers or Conference Proceedings for Conference papers.

Annex website: http://web.ornl.gov/sci/usnt/QiQmAnnex/indexAnnex41.shtml
Contact: Van D. Baxter, baxtervd@ornl.gov

Table 1: Annex 41 - Final Report schedule

TARGET DATE	RESPONSIBLE GROUP	ACTION ITEM OR ACTIVITY
15 April 2016	Each Annex Participant	Participants forward draft final country reports to OA
30 Sept 2016	Operating Agent	OA compiles draft final report & forwards to participants for review
15 Oct 2016	Each Annex Participant	Participants return comments on final report draft to OA
15 Dec 2016	Operating Agent	OA finalizes Annex report and forwards to ExCo and Heat Pump Centre for review/approval

Table 2: ASHRAE 2016 Conference and Technical papers related to Annex 41

DATE	PAPER NUMBER	AUTHORS	TITLE
January 26, 2016 Orlando, FL	OR-16-C039, conference paper	Bo Shen, Omar Abdelaziz, Keith Rice, and Van Baxter (ORNL)	Cold Climate Heat Pumps Using Tandem Compressors
January 26, 2016 Orlando, FL	OR-16-C041, conference paper	Christian Bach (Oklahoma State Univ.), and Eckhard Groll, James Braun, and Travis Horton (Purdue Univ.)	A Non-Dimensional Mapping of a Dual-Port Vapor Injected Compressor
January 26, 2016 Orlando, FL	OR-16-C042, conference paper	Christian Bach (Oklahoma State Univ.) and Howard Cheung (Purdue Univ.)	Mapping of Vapor Injected Compressor with Consideration of Extrapolation Uncertainty
June 25-29, 2016 St. Louis, MO	ST-16-C035, conference paper	Andreas Zottl and Thomas Fleckl (AIT), and Björn Palm (KTH)	GreenHP: Design and Performance of the Next Generation Heat Pump for Retrofitting Buildings
June 25-29, 2016 St. Louis, MO	ST-16-006, technical paper	Ali Hakkaki-Fard, Zine Aidoun, Parham Eslami-nejad (CanmetENERGY)	Evaluation of Refrigerant Mixtures in Three Different Cold Climates Residential Air-Source Heat Pumps
June 25-29, 2016 St. Louis, MO	ST-16-027, technical paper	Parham Eslami-nejad, Ali Hakkaki-Fard, Zine Aidoun, and Mohamed Ouzzane (CanmetENERGY)	Assessment of Ground-Source, Air-Source, and Hybrid Heat Pumps for a Single Family Building in Cold Climates

ANNEX 44 — PERFORMANCE INDICATORS FOR ENERGY-EFFICIENT SUPERMARKET BUILDINGS

In earlier findings within this Annex we have concluded that conventional technical parameters alone cannot sufficiently explain the practical annual energy consumption of a supermarket. "Non-conventional" technical parameters such as system dynamics, and non-technical parameters such as management focus, probably play an important role in the overall energy consumption. The 2014 data set for Dutch supermarkets provides, when compared to the 2013 data set, an example of the influence of management focus.

Comparing the energy intensity versus sales area (VVO) plots for both years, highlighting the new and refurbished supermarkets against the existing ones (see figure 1 below), we see a shift in management focus. In 2013 there was no specific focus for building new (or refurbishing) supermarkets; it was done for all sizes and with an energy intensity for the new markets comparable to existing ones. In 2014 however, the attention in building and refurbishing supermarkets was directed only at larger supermarkets, and accomplishing low energy intensities.

The effect of this change in management focus becomes very apparent when we plot the regression lines for the complete data set, as in the figure 2. In 2013, the regression did not show the "common trend" of decreasing energy intensity for increasing sales area. But the regression for the 2014 data set does show this trend, which is familiar from existing international studies. In the international studies this trend is associated with an increasing "non-food" share for larger supermarkets (and thus a relative lower need for refrigeration). For the supermarkets in our data set the trend is associated with management focus; there is no particular increase of the "non-food" share.

The above analysis focuses on energy intensity (kWh/m² and year) as the performance indicator. A group of students at KTH (Sweden) has been examining alternative performance indicators, including the installed refrigerating capacity in the indicators. These alternative indicators must be assigned to specific intervals of supermarket size, as they vary considerably with size. Including the refrigeration system's COP (Coefficientof Performance) in performance indicators is an interesting option that was studied by means of simulation results. However, measured COP values are hardly ever available in supermarkets.

Annex website: http://heatpumpcentre.org/en/projects/ongoingprojects/annex44
Contact: Sietze van der Sluis, s.m.vandersluis@gmail.com

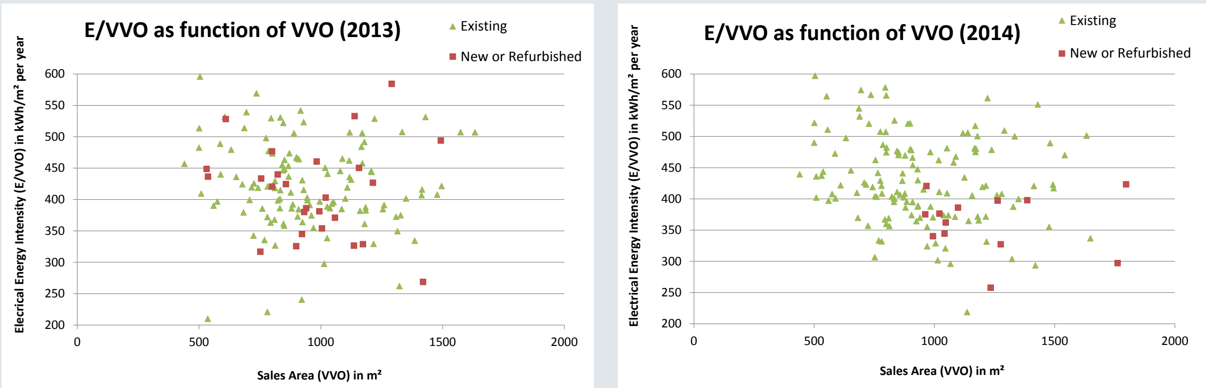


Figure 1. Electrical energy intensity versus sales area highlighting the new and refurbished supermarkets against the existing ones in year 2013 (to the left) and 2014 (to the right)

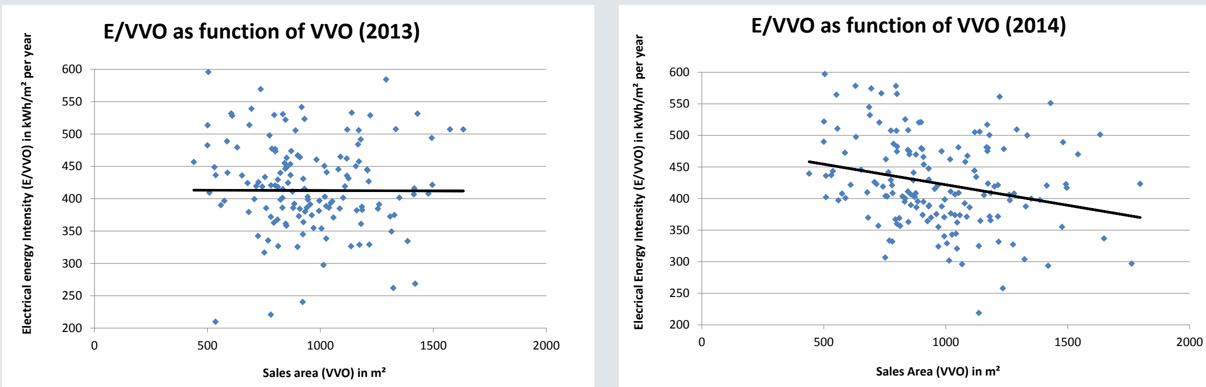
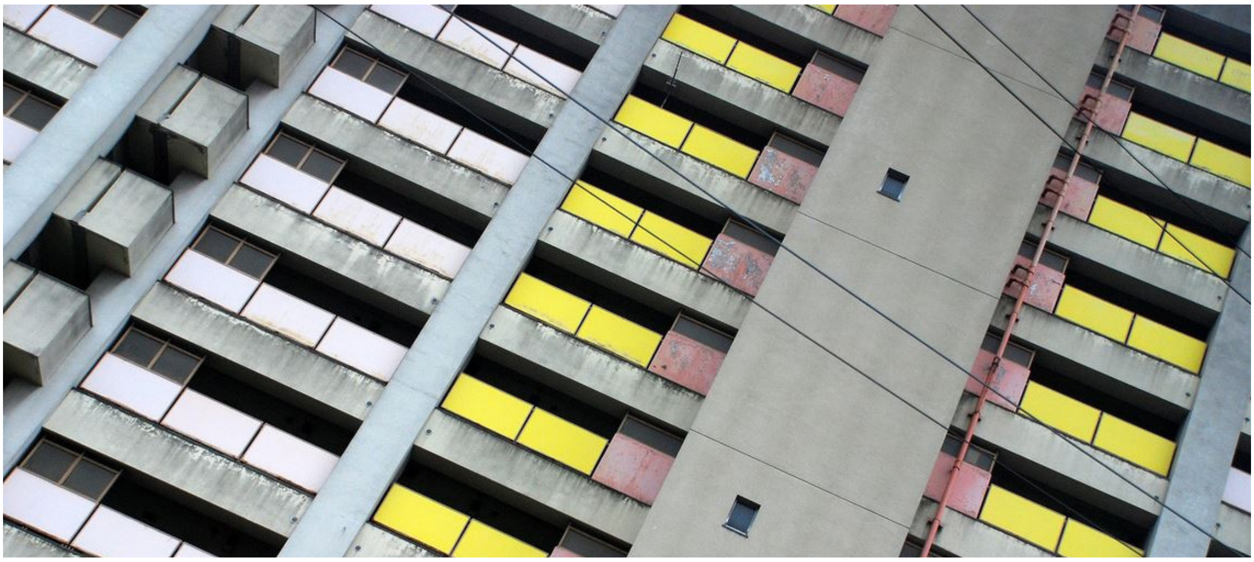


Figure 2. Electrical energy intensity versus sales area with regression line in year 2013 (to the left) and 2014 (to the right)



Annex 50: Picture of a multi-family building

ANNEX 50 | **HEAT PUMP SYSTEMS IN MULTI-FAMILY BUILDINGS**

The building sector plays a significant role in energy consumption and in emission of greenhouse gases everywhere in the world. New single-family houses are often built with a potential for application of renewable energy technologies, such as heat pumps. For multifamily buildings, however, the challenge to apply heat pump technologies is more complex. Among the member countries of the IEA Heat Pumping Technologies TCP, there is a large variation between the countries regarding ownership as well as regarding heat demand characteristics.

There are still technological and non-technical barriers hindering the broad implementation of heat pumps in multi-family buildings, in both new and existing buildings. Beside the above mentioned aspects, obstacles include potentially limited space for the heat source, the control of bivalent systems, as well as the high investment costs (longer terms of investment than for other heat sources).

Annex 50 focuses on solutions for multi-family houses, with the aim to identify barriers for heat pumps and how to overcome them. Given the demands of the participating countries, new buildings and retrofit are considered, along with buildings with higher specific heating demand.

Annex website: http://heatpumpcentre.org/en/projects/ongoingprojects
Contact: Marek Miara, marek.miara@ise.fraunhofer.de

Have you nominated anyone yet?

Nominate Candidates for Rittinger Award

The Technology Collaboration Programme om Heat Pumping Technologies **seeks candidates for the Peter Ritter von Rittinger Award**.

This award, presented for the first time at the IEA International Heat Pump Conference in 2005, is awarded to deserving individuals or teams who have achieved distinction in the advancement of heat pumping technologies, applications, market development and management or organization of activities with lasting international impact.

The awardees will be presented at the banquet held in conjunction with the IEA Heat Pump Conference on May 16, 2017 in Rotterdam.

The award is named after Peter Ritter von Rittinger, an Austrian engineer who is credited with design and installation of the first practical Heat Pump system at a salt works in Upper Austria in 1856.

For more information, see www.heatpumpcentre.org/en/aboutHPT/news/Sidor/NominateRittingerAward.aspx and hpc2017.org/award/. Here is also a direct link to the Nomination form.

Space Cooling in the United States: A Market Deep Dive

Van D. Baxter, Karen Sikes, and Gannate Khowailed, USA

The American space cooling market is experiencing stricter efficiency standards, prosperous economic conditions, a steadily recovering housing market, population migration shift to warmer climates, and declining electricity prices. These factors have yielded a climate conducive to growth in air conditioning (AC) and air source heat pump (HP) shipments in the recent past with total AC and HP shipments in 2015 accounting for 6.8 million units, showing a growth of 32 % relative to 2010. In this article, the authors investigate the impact that regulatory changes and economic changes have had on unit shipments and identify future market influencers, including the introduction of advanced HVAC technologies and transition to more environmentally friendly refrigerants.

Introduction

Many variables play a role in driving the cooling industry. Among the most influential are regulatory standards that the U.S. Department of Energy (DOE) and the U.S. Environmental Protection Agency leverage to reduce energy consumption and emissions to acceptable levels. The overall health of the U.S. economy is also a strong market driver since it dictates, to some degree, new building construction, manufacturer research and development (R&D) budgets, consumers' willingness to pay for certain systems/features, and the magnitude of industry initiatives. The impacts of these drivers on annual unit shipments are analyzed in this article.

Space Cooling Historical Shipments

Most households (93 % in 2015) and commercial buildings (80 % in 2012) in the United States are equipped with cooling equipment, mostly either central air-conditioning (AC) systems or air-source heat pumps (HP), using ducts to distribute cooled or dehumidified air throughout multiple rooms [1] [2]. These percentages have grown over time as consumers expect this comfort feature to be included, and this trend has contributed to the growing cooling market. Figure 1 traces the yearly shipments of AC and HP systems from 1973 through 2015. One trend evident in this figure is how HPs have gradually increased their share of this market, from about 4 % in 1973 to 33 % in 2015.

Another trend to note is the volatility that the cooling market (especially for ACs) has experienced over the years, particularly since the peak shipment year of 2005. The following sections investigate the market drivers responsible for much of these shipment variations.

Impact of Regulatory Changes

Manufacturers of central ACs and HPs have been required by law to comply with DOE's energy conservation standards since 1992. These standards have required ever-increasing minimum efficiency levels over the years, pushing manufacturers to find innovative and cost-effective methods for improving product efficiency. Although they follow a similar trend, residential and commercial energy conservation standards have varied slightly over the years. Figure 2, for example, compares residential and commercial standards for central ACs.

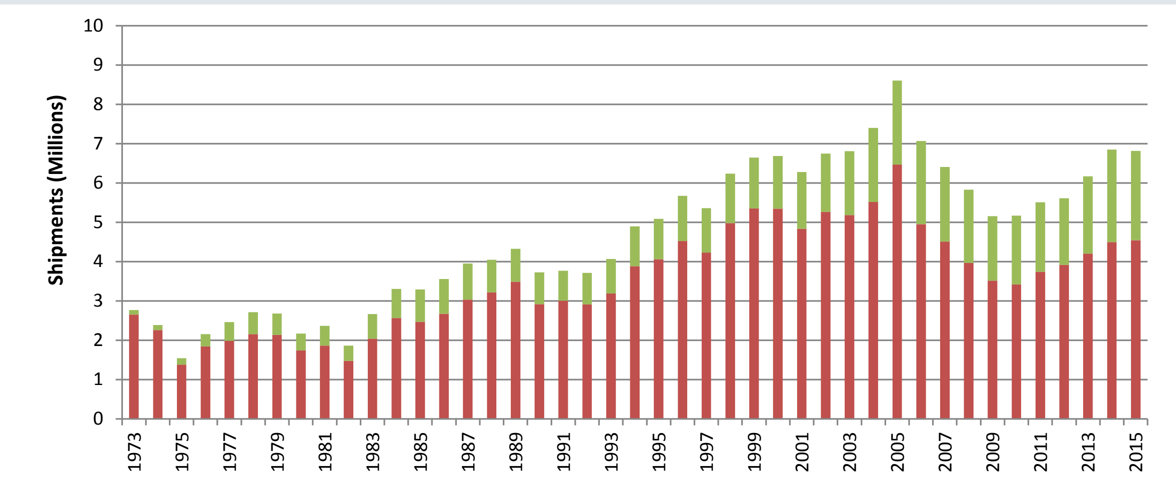


Figure 1. Historical unit shipments for central ACs and air-source HPs [3]

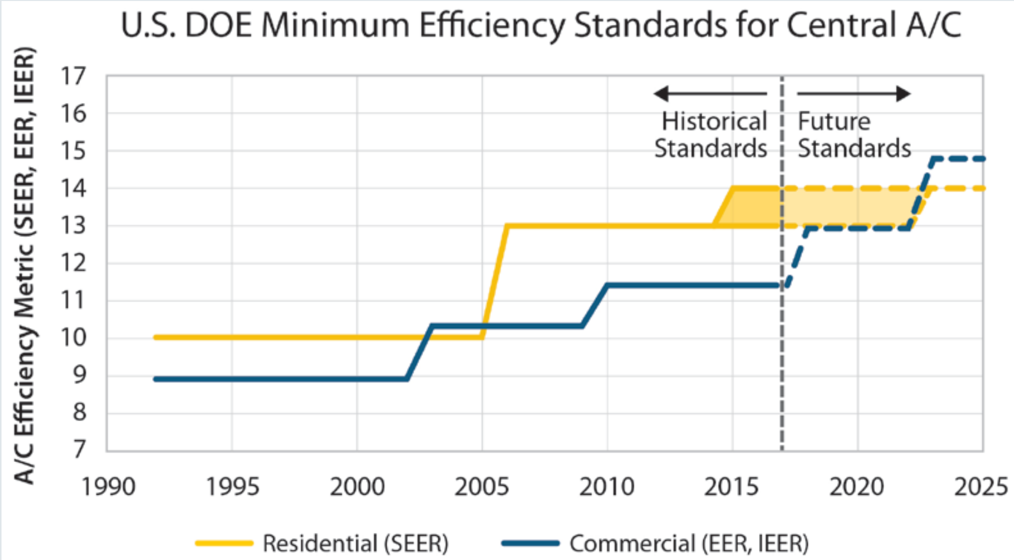


Figure 2: Progression of DOE Minimum Efficiency Standards for Central AC Systems in the United States [4]. Unit on vertical axis: Btu/Wh

Residential Sector

Residential ACs and HPs are rated based on the seasonal energy efficiency ratio (SEER). To date, the most substantial increase in minimum SEER took effect in 2006, when it rose by 30 % from 10 to 13 Btu/Wh [2.93 to 3.81 seasonal cooling COP (SCOPc)]. Consequently, unit shipments skyrocketed in 2005 (see Figure 1) as manufacturers aggressively moved out existing inventory before it became non-compliant. This market flood led to a shipment slump in early 2006, likely compounded by diminished production capacity that occurred as manufacturers retooled their production lines to assure that future systems complied with the new SEER requirement. Furthermore, compressor shipments surged in 2006 indicating that many homeowners opted to repair their central ACs and air-source HPs rather than buying newer, more expensive 13 SEER units.

On January 1, 2015, the residential sector standards for ACs became region-specific to more accurately account for various environmental factors, like the length of the cooling season. As a result, each region – North, South, and Southwest (Figure 3) – received its own minimum efficiency requirement (note the shaded area of Figure 2) [5]. The new minimum SEER for single package AC systems in all regions increased from 13 to 14 (SCOPc from 3.81 to 4.10). For split AC systems in the North the minimum SEER remained at 13. In the case of HP systems the minimum SEER increased from 13 to 14 for all regions. To avoid a shipment spike like the one observed in 2005, DOE allowed dealers an 18-month “sell through” period (ending on June 30, 2016) to help deplete inventory at a reasonable pace.

Figure 3: Regional standard zones for DOE's Federal Minimum Standards as of January 1, 2015 [5]

Commercial Sector

Commercial systems are rated using energy efficiency ratio (EER) and integrated energy efficiency ratio (IEER) metrics[1]. These have undergone two minimum efficiency increases in 2002 and 2009, as shown in Figure 2. Most recently, in January 2016, DOE unveiled new minimums to be implemented in two phases. First, commercial ACs must show a 13 % efficiency improvement by 2018. Then, manufacturers have five years (by 2023) to achieve an additional 15 % increase in efficiency. DOE and the 17 stakeholders it convened to finalize the new standards consider them a game-changer for the commercial sector as they are projected to save more energy than any other standard ever issued by the department [6].

1 *EER is a single-point rating at 95 °F (35 °C) outdoor temperature. IEER is a weighted average rating based on test results for 100 %, 75 %, 50 %, and 25 % capacity levels at 95, 81.5, 68, and 65 °F (35, 27.5, 20, and 18.3 °C) outdoor temperatures, respectively, with heaviest weighting given to the 75 % level (61.7 %). Both are in units of Btu/Wh and can be converted to dimensionless equivalents by dividing by 3.412 Btu/Wh.*

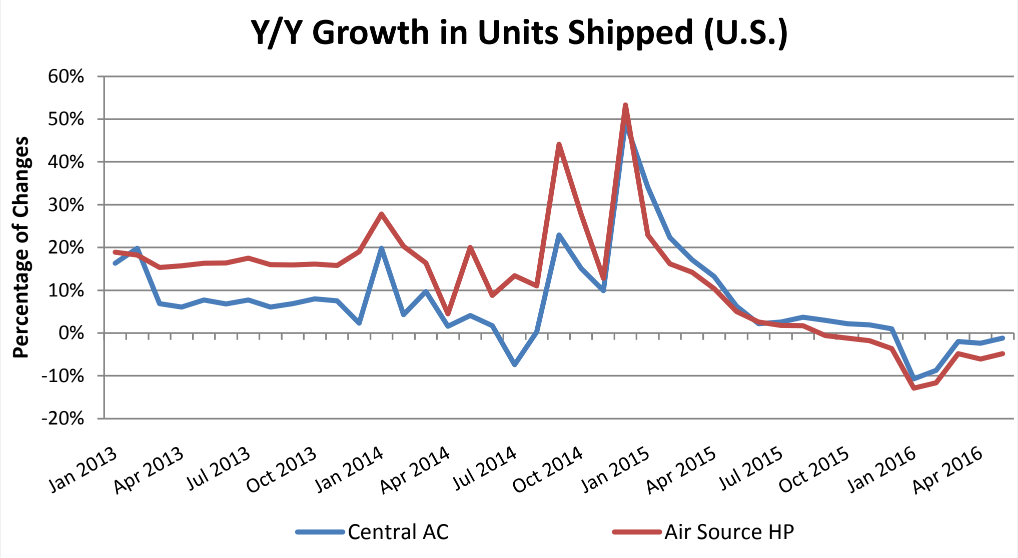


Figure 4: Year-over-year changes show impact of most recent DOE minimum efficiency standards on U.S. shipments [3].

Standards Effect on Shipments

Figure 4 shows year-over-year changes by month in the cooling market over the past three years, broken down by central ACs and air source HPs. Here, we see the "ebbs and flows" absent any normal seasonal variations and can link the implementation of the most recent standards to changes in the market. For example, December 2014 shipments were approximately 50 % higher compared to December 2013, supporting the hypothesis that the new minimum efficiency standard taking effect the following month likely motivated manufacturers to quickly move out older, non-compliant models. Thanks to the 18-month sell through period, unlike in 2006, manufacturers had more time to ship out older units, hence, the continued high year-over-year growth through the first quarter of 2015. As expected, 2016 unit shipments to date are lower than 2015 (see Figure 4) for similar reasons cited for the 2006 slump.

Impact of Economic Health

As mentioned above, economic conditions can have a significant impact on the cooling market by affecting new building construction, manufacturer R&D budgets, consumers' willingness to pay for certain systems/features, and the magnitude of AC-related industry initiatives / incentive programs. A strong indicator of U.S. economic health is the Leading Indicator of Remodeling Activity (LIRA) published by the Joint Center for Housing Studies of Harvard University (JCHSHU), which

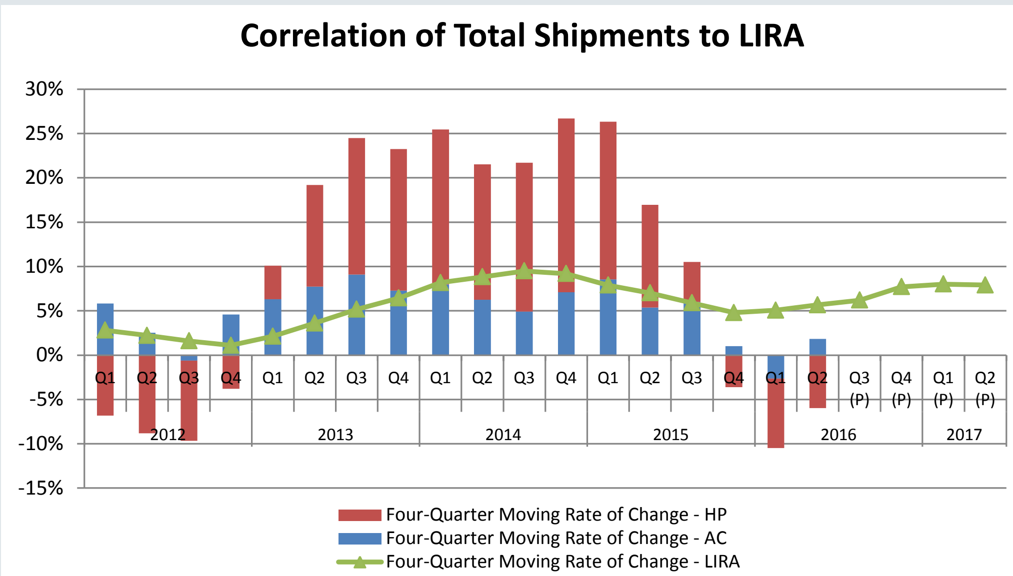


Figure 5: Cooling equipment shipments' high correlation with the LIRA indicates strong link with economic health [3] [8]

tracks home improvement spending through the current quarter, plus projections for the upcoming four quarters. Measured as an annual rate-of-change of its components, the LIRA provides a short-term outlook for national home improvement and repair spending in owner-occupied homes and may help identify future inflection points in the home improvement market. Based on estimates that 74 % of AC and 77 % of HP shipments are for the replacement or add-on single-family (SF) home markets (assuming two units per new SF home) [2] [7], LIRA projections should align to some degree with future HP and AC shipments.

In Figure 5, four-quarter moving rate of changes for HP and AC shipments are overlaid with the LIRA indicator from the beginning of 2012 through the second quarter of 2016 [8]. A correlation analysis yielded a coefficient correlation of 0.65 between total shipments (both AC and HP) and the LIRA, indicating a fairly strong relationship between economic conditions (via LIRA) and growth in the space cooling market as measured by shipments. Based on this assumption, we would expect growth in the cooling market over the next year since the LIRA projects growth in home improvement and repair expenditures to reach 8.0 %, well above its historical average of 4.9 %. However, we will have to wait and see whether the influence of this indicator will outweigh that of recent regulatory changes in the cooling market.

Market Drivers on the Horizon

While improvements in energy efficiency are critical for reducing energy consumption and thereby indirect greenhouse gas (GHG) emissions across the nation, it will need to happen in unison with the United States' transition to more environmentally-friendly refrigerants. The vast majority of new ACs and HPs use the hydrofluorocarbon (HFC) refrigerant R-410A. R-410A has zero ozone depletion potential (ODP) but a relatively high global warming potential (GWP). Future alternatives may include lower-GWP HFCs (e.g., R-32), hydrofluoroolefins (HFOs, e.g., R-1234yf), hydrocarbons, carbon dioxide, and blends of two or more of these.

So what does this mean for manufacturers, contractors, and end-users? Expect to see the introduction of unconventional cooling system designs that can achieve these energy efficiency and/or refrigerant requirements while remaining cost-effective. Advanced vapor compression systems, non-vapor compression systems, and integration of AC with other building systems (where excess or waste energy from one building process can offset the consumption of another process) are likely to make their way into the market in the next 5 to 10 years. Some, like ground-source integrated HPs and commercial gas-engine HPs, are already commercially available [4].

Conclusion

After holding steady through the implementation of stricter standards last year, 2016 shipments through June are slightly below those of 2015 but improving economic factors could see an increase relative to 2015 in the remainder of 2016. These factors include increased consumer demand for cooling equipment in new construction, increased home improvement budgets, and economies of scale for higher-efficiency products. Over the next year, higher-than-average LIRA projections could indicate an improving economy that will continue to support consistent growth in this market. Further on the horizon, manufacturers will continue to pursue innovative cooling systems that will enable major boosts in efficiency while accommodating low-GWP refrigerants.

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Thermal Storages Improve Heat pump Flexibility for Smart Grids in Residential Heating

ANNEX 42

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A heat pump is flexible for a smart grid when it can be switched on or off according to the load of the electric network. To fulfil the heat demand asynchronously from the building, the heat produced by the heat pump has to be stored intermittently. Here, we explore the limits of flexibility for a residential heating system with varying heat pump capacity when thermal storage systems (additional systems or building) are integrated. In our simulation study, the flexibility can be increased by up to 50 % at 10 to 20 % loss in seasonal performance factor.

Introduction

To maintain the voltage and frequency in an electrical network, supply and consumption of electric energy have to be mutually balanced. As space heating is one of the major consumers of primary energy, heat pumps could become a major actor for the energy balance. The successful integration of heat pumps into smart grids requires that heat pumps can be operated according to the grid's requirements and not according to the heating schedule of the building. To prevent discomfort for the inhabitants, the produced heat has to be stored either in the building, in the heating system or in an additional thermal storage element. See figure 1.

In this article, we explore how much flexibility is gained if thermal storage capacity is exploited. In a first section, three measures for flexibility are introduced. Subsequently, a computer model and heat pump control for an in-silico study is described. In the results sections, we describe which limits of flexibility have been identified and how adverse effects of increased flexibility control (such as reductions in efficiency) could be amended in the future.

Which flexibility and why to care?

So far, no commonly accepted definition of flexibility exists. Here, we focus on three different aspects.

The first aspect is the fraction of the day the heat pump is switched off during the heating period (defined by the days with average temperature below 15 °C). To penalise operation outside the allowed time windows, these windows are counted as running time. This quantity measures how well the heat pump operation times can be compacted into larger blocks. These large blocks can then be called according to the grid's needs. Further, it penalises running times during unscheduled periods, which cause an unexpected load increase in the network.

The second aspect is the number of time blocks longer than twelve hours that the heat pump is switched off, compared to the total number of blocks with stopped heat pump.

To quantify the capability of following a demand curve, the costs of the electricity at the German EPEX SPOT Day Ahead market is considered as a third key figure. This electricity market is supply and demand driven and fixes the energy prices at 23:00 on the evening of the day before, which yields a natural 24-hour planning horizon.

Computer model for residential heating

The flexibility is assessed with a computer model implemented in Matlab/Simulink [1]: A residential heating system is modelled based on models of the individu-

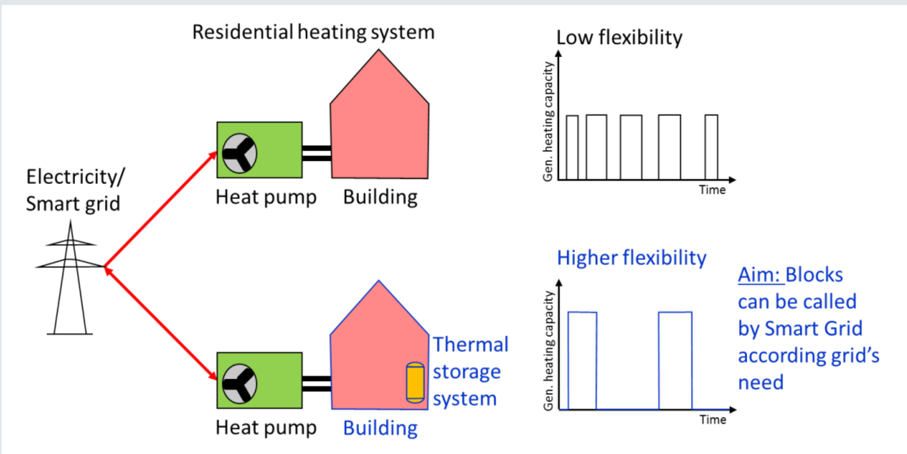

Figure 1. Concept overview for flexibilisation of heat pump operation by integration of thermal storage (additional systems, building or heating system). Suitable control of the heat pump exploiting the intermittent storage of heat enables a heat pump operation following the needs of the electricity/smart grid

al components. As one example of the building stock in Switzerland, a single family house with an annual heating energy demand of 100 kWh/a/m² is considered [2], [3]. The complex building dynamics are simplified with an established three-parameter model [4]. This model formulates an energy balance between the summative losses, solar irradiation, room temperature changes, and summative heat contributions from appliances and persons living in the building. The heating system is radiator based and modelled by a heat transfer model. The heat pump dynamics are modelled by extracting profiles for the heat generation capacity at different inlet and ambient temperatures from a detailed component model [5]. To provide additional heat pump capacity besides a conventionally designed heat pump (8 kW at the design temperature of –10 °C), also 25 %, 50 % and 75 % more powerful systems are considered. The models for piping and additional thermal sensible storages are extracted from the Carnot toolbox [6]. As additional storage elements, we consider sensible water storages with a capacity of 1, 2, 4 and 8 m³ of water, respectively.

The configuration of the residential heating system is selected according to the Swiss standard configuration (STASCH 6 [7]). The climatic information (ambient temperatures and solar irradiation) are taken from Meteosuisse for Zurich in the year 2013. As an example for a demand/supply curve, the prices on the German EPEX SPOT Day Ahead market for the year 2013 were considered.

Each component has been verified by comparison with experimental data.

Heat pump control for high flexibility

To explore the limits of flexibility, different control algorithms are required depending on the target function [8]. In this article, we focus on three different algorithms: For the target "optimum reproduction of supply/demand curve" (expressed here by the electricity costs), the operating hours for the heat pump are selected according to lowest price for each day. More precisely, the heating demand of one day is determined based on the ambient temperature data and the operation hours are selected starting from the hour with the cheapest electricity until the total energy is collected.

To prevent a too severe reduction of the efficiency, a similar control with a target on "high ambient temperatures" is formulated. For this algorithm, the operating hours are selected according to high ambient temperatures (when the heat pump efficiency is higher compared to colder periods).

As a reference, a conventional two-point control is implemented: The heat pump is switched on or off whenever the inlet-temperature leaves a 5 K wide corridor around the target temperature defined by the heating curve. In case the room temperature drops below 19.5 °C (i.e. more than 0.5 °C below the target temperature of 20 °C), the optimum inlet temperature is temporarily raised by the six-fold difference between target and actual room temperature. An excess of the room temperature above 20.5 °C is treated analogously.

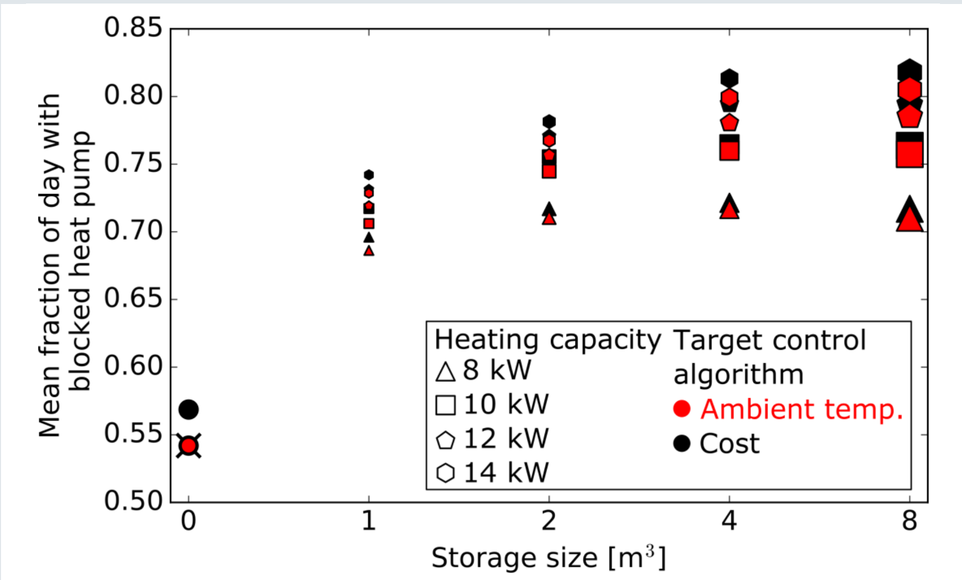

Figure 2. Flexibility dependence on the size of the thermal storage. The flexibility is quantified in the mean fraction of a day with blocked heat pump. The black and red symbols indicate a controller with cost and ambient temperature target, respectively (similar in Figs. 3-6). The cross indicates the results for a conventional two-point control employed here as a reference. The simulations are performed for a model of a single family house with an annual heat energy demand of 100 kWh/a/m². To improve the potential of flexibility besides the conventionally designed 8 kW heat pump also models with scaled power are considered.

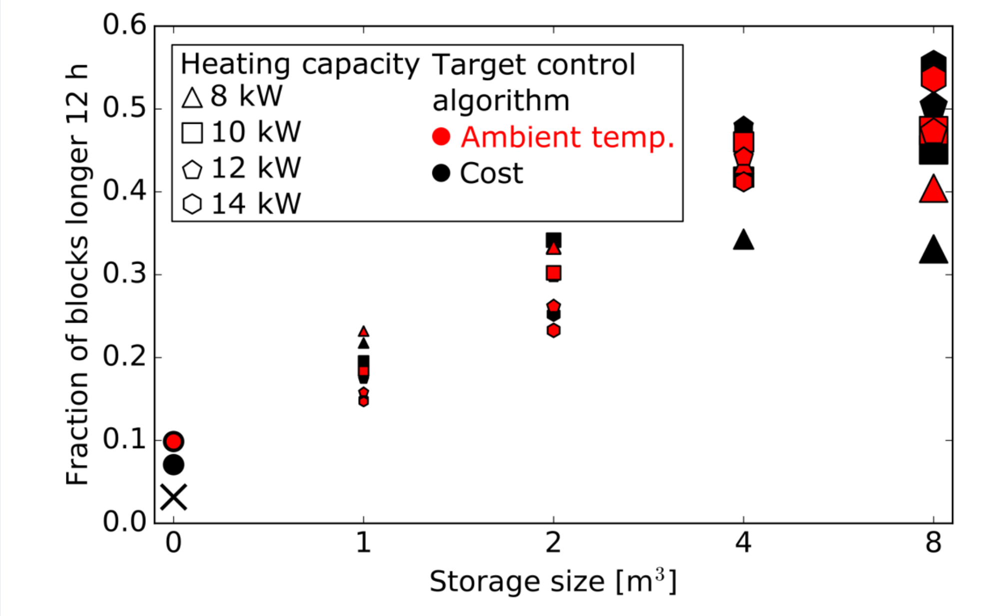

Figure 3. Dependence of the fraction of blocks with heat pump switched off on the size of the thermal storage (expressed in size of a sensible water storage). The cross indicates the results with the reference control (two-point). A heat pump capacity of 8 kW corresponds to the heating demand of the model building (single family house with an annual heating energy demand of 100 kWh/a/m²) at the design temperature of -10 °C.

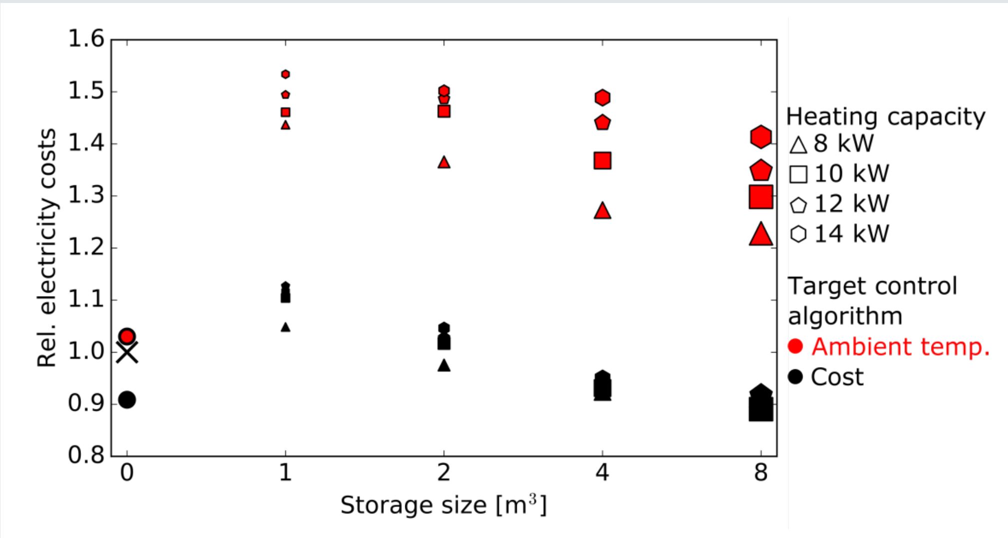

Figure 4. Dependence of electricity costs for the different sizes of the thermal storage. The electricity prices are adopted from the German EPEX SPOT Day ahead market in the year 2013. The high values for the small storage systems can be explained with the substantially higher storage temperatures in some cases.

Limits on flexibility

In Figures 2 – 4, the flexibility of the simulations in the different configurations is displayed. It is important to note here that the simulations are performed with an additional thermal storage system (water tank). However, given suitable capabilities of the building and the heating system, also the thermal inertia of the building can be exploited. The integration of a small storage system already increases the flexibility, measured as a mean fraction of the day the heat pump is blocked, by 25 – 40 %. If a large storage system is installed and the capacity of the heat pump is scaled, the flexibility can be boosted by up to 50 %. The control algorithm only has a minor impact on this result as can be seen from the results without storage system. The number of blocks longer than 12 hours (cf. Figure 3) can even be increased by a factor up to 16. For this indicator, the control algorithm bears a larger share and gives rise by a factor of 3 to 4 in the number of 12 hour-blocks (cf. results with 0 m³ water storage). As a third quantifier for flexibility, the electricity costs are considered (cf. Figure 4). Here, a cost reduction of up to 11 % can be achieved considering the prices

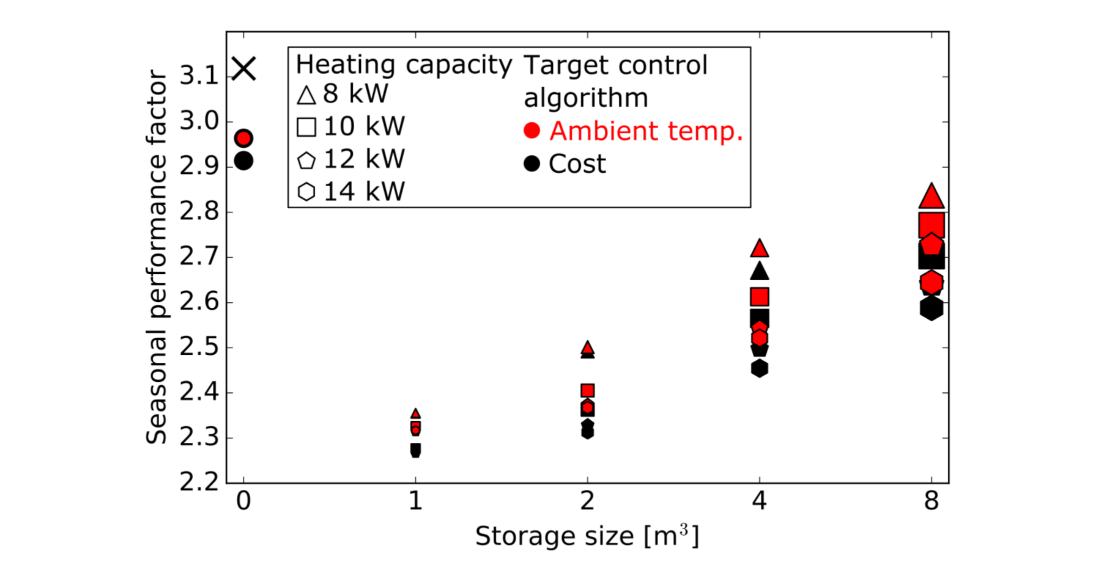

Figure 5. Dependence of seasonal performance factor on the size of the thermal storage. In the simulations, a model for a single family house with an annual heating energy demand of 100 kWh/a/m2 is considered. A heat pump capacity of 8 kW corresponds to a conventional design based on the heat demand of the building at design temperature (-10 °C). The cross indicates the results of the simulation with two-point control.

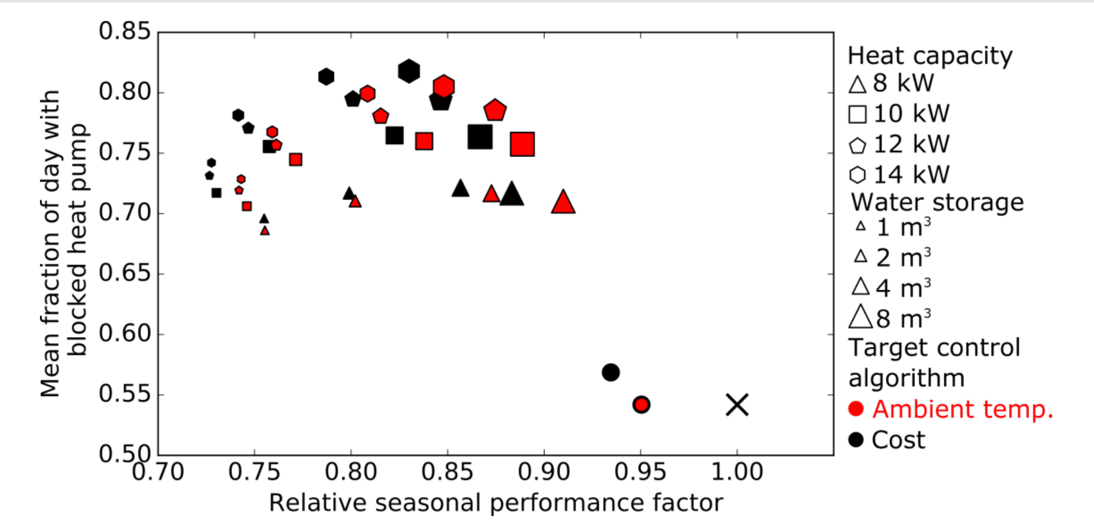

Figure 6. Dependence of seasonal performance factor on average fraction of the day with blocked heat pump for a single family house with 100 kWh/m² annual energy consumption. The reference two-point control solution (x) is compared with the results of predictive control algorithms with different target functions. For comparison, the solutions without additional thermal storage (o) are shown.

at the EPEX SPOT market. However, even without additional storage systems, a cost reduction of 9 % can be achieved given a suitable control algorithm. Therefore, if high flexibility is desired from the smart grid, additional incentives are required to motivate heat pump owners to invest in additional storage systems for flexibility.

Which factors drive flexibility?

Depending on the desired aspect of flexibility, a scaling of the heat pump capacity and the size of the storage system have different impacts. In case focusing the operation times to a narrow time corridor is key, the mean fraction of hours with blocked heat pump is essential (cf. Figure 2). This indicator can be more pronouncedly increased by a scaling of the heat pump power. Only for already scaled heat pump capacities, a scaling of the storage capacity by a factor of 8 has a comparable impact as increasing the heat pump power by 50 %, see Figure 5.

If a significant share of the load shall be transferred to the other half of the day, the number of blocks with stopped heat pump longer than 12 hours is key. For this indicator, the effect of the size of the storage system displays a logarithmic behaviour. The influence of the heat pump scaling is dominated by the size of the storage system for this quantifier.

As an additional storage and heat pump capacity requires further investments, the electricity costs are also vital (cf. Figure 4). In contrast to the previous two indicators, the target for the control algorithm plays a crucial role here. A target on high ambient temperatures (to achieve higher seasonal performance factors) causes additional costs of the order of 40 %. For small storage systems, even the algorithm with cost target does not find a solution with reduced electricity costs. For larger storage systems, solutions with cost reductions exist. However, the size of the storage system apparently has a higher impact on the cost saving potential than the scaling of the heat pump. If the target is purely economic, a change of the control algorithm helps to lower electricity costs by 9 % (given the max. 11 % reduction for the scaled heat pump with additional storage system).

Disadvantages of high flexibility

In Figure 6, the seasonal performance factors for the various configurations are shown.

In particular, small additional storage systems give rise to substantial reductions of the seasonal performance factor. To store a sufficient amount of heat, the temperature of the storage medium has to be lifted substantially above the medium temperatures required by the heating system. This overheating causes a substantial reduction of the efficiency. Combined with the losses of the storage system, this gives rise to a substantial reduction of the seasonal performance factors. Larger storage system can partially compensate these drawbacks.

Which thermal storage?

As pointed out earlier, the storage system does not always have to be an additional storage vessel with water. Alternatives can also be exploiting the thermal inertia of the building or the heating system (e.g. floor-based heating systems) or latent heat storage systems. However, radiator-based systems may be insufficient to activate the building mass.

An advantage of latent heat storage systems is that a significant amount of heat can be stored at a fixed temperature. In consequence, the heating medium has to be overheated less to improve the seasonal performance factor. However, the heating medium temperatures of the building have to be in a narrow range. The building considered in this study does not fulfil these conditions. Other buildings such as modern houses (SFH45) [2], [3] or Minergie P buildings (SFH15) would offer a much wider potential, which is explored elsewhere [1], [9].

Conclusions

Thermal storages (additional systems or the building/heating system inertia) offer a substantial improvement potential of flexibility. 50 % more off-time for heat pumps, 16 times more long blocks, and 11 % less electricity costs are the key findings. However, depending on the flexibility target, different configurations are optimal. Simulations help, in a cost-effective manner, to elucidate the different options and quantify the impact of the individual measures. In particular, with the current electricity markets and pricing schemes, the economic potential of flexibility revenues is small. To foster flexibility, future additional incentives are required.

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Smart Controls for Hybrid Heat Pumps May Solve Grid Congestion

ANNEX 42

Paul Friedel, the Netherlands

Hybrid heat pumps (i.e. a combination of heat pump and fossil-fired backup heater) have a large and unique potential for flexibility. By switching to the back-up heater, electricity demand can be completely reduced to zero, whereas for stand-alone heat pumps, the load can only be shifted in time. Simulations for the Dutch market have shown that – surprisingly – this feature does not help to a decrease in either heating costs or CO_2 emissions. However, hybrid heat pumps turn out to be very helpful in reducing grid congestion and preventing overload.

Introduction

Hybrid heat pump systems (in the remainder of this text, I will simply call them "hybrids") provide an optimal mix of renewable energy use and fossil-fuelled backup capacity. By installing this back-up heater, it is possible to cover a large part of the heating demand in an efficient way, even if the building is not suitable for low temperature heating throughout the whole heating season. As a side effect, the size of the heat pump can be reduced compared to a stand-alone system and this leads to significantly lower installation costs.

Such a hybrid setup has been used in business settings for a long time. In the last decade, single-house hybrids have become commercially available throughout Europe.

Business Development Holland (BDH) has conducted a simulation study to investigate the potential of smart-controlled hybrids for the Dutch market. [1] When installed in large numbers, the total effect on CO_2-emissions, heating costs and grid load can be assumed to be quite significant.

The context for hybrid heat pumps

All hybrids by definition contain a backup heating system. This has two important consequences:

1. Hybrids can be used in houses with a traditional (i.e. high-temperature) hydronic heat transfer system. For most of the heating season, output temperatures are low and the heat pump can be employed. It is only under cold weather conditions that the backup heater must be used.
2. When required, the heat pump can be switched off at any time.

This second aspect allows for a much higher amount of flexibility than a stand-alone heat pump can offer.

With a stand-alone system, smart controlling and demand management can be used to shift electricity demand in time. Ultimately, however, the energy-demand must be supplied by the heat pump and electricity will be needed from the grid.

A hybrid, in contrast, allows for complete elimination of electricity demand in favour of fossil fuel use. Generally, this will not lead to the most efficient fuel use, but in specific situations, a gain in CO_2-performance, cost of operation, or electrical grid load is possible.

Aim and setup of the study

The aim of our simulation study has been to investigate the potential benefits of smart controls for hybrids.

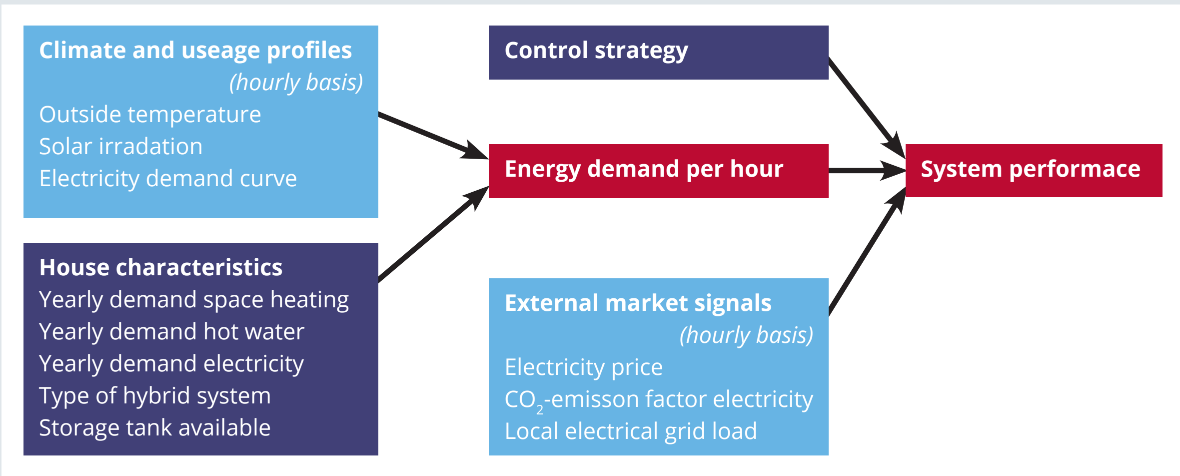

Figure 1. Schematic diagram of the modelling process.

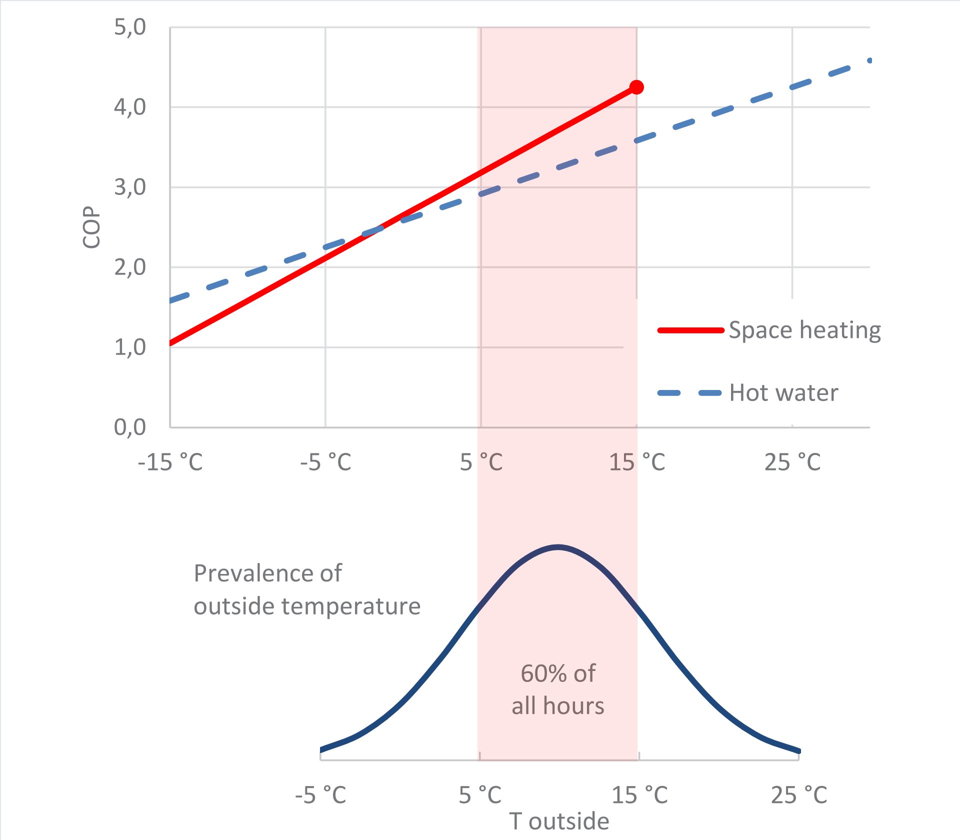

Figure 2. The COP of an outside-air heat pump in relation to the outside temperature.

This has been done by simulating the use of the system throughout a standardized climate year for typical Dutch household setups. In the Netherlands, the most likely heat pump systems to gain a large market share are air-water setups. Due to space constraints, ground-water systems can not be used in many locations. Therefore, the study has focussed on hybrids using outside air or ventilation exhaust air as the heat source.

The COP of an outside air heat pump depends directly on the outside temperature, but also indirectly, through the heating source: at colder temperatures, a higher heating temperature is needed, increasing the temperature jump between condenser and compressor.

For the Dutch situation, a heat pump is more efficient than a boiler when the COP is about 2.5 or higher. This holds for CO_2-emissions as well as marginal running costs.

Climate data, heating demand, source temperature, COP etc, have all been calculated or used on an hourly basis. Using several different control strategies, results have been compiled for the total CO_2-output, total cost of operation and maximum grid load.

Control strategies

Four different control strategies have been investigated.

The first strategy uses a fixed switching point between condensing boiler and heat pump. The other strategies use a dynamic switching point, taking into account the hourly values of market signals.

1) Fixed switching point, or "stupid control"

The reference strategy is no smart control at all. We use the average values of CO_2-emissions for central electricity production and for natural gas usage. From these numbers we have calculated the COP boundary between heat pump and condensing boiler. Above a COP of around 2.5, the heat pump is more efficient, below 2.5, a condensing boiler is more efficient [1].

For this strategy, no further information is taken into consideration. Throughout the year the same average COP boundary is used. If the real-time COP is high enough, the heat pump is used. In all other cases, the condensing boiler is used.

1 *It is also possible to calculate the switching point on the basis of electricity and gas prices. In the Netherlands, this COP boundary also turns out to be around 2.5.*

2) Minimize real-time CO_2-emissions

For our reference year, we have a complete set of real-time CO_2-emission values for the Dutch electricity production park. These values can now serve as input for our hybrid: each hour, we calculate whether the heat pump or the condensing boiler has a better CO_2-emission, using the real-time data. Whichever system has the lowest CO_2-production, is used.

3) Minimize operational cost

For our reference year, we also have a complete set of hourly electricity prices. Depending on these real-time prices, we can again determine whether we should use the heat pump or the condensing boiler.

4) React to grid-congestion

For the last strategy, we developed a standardized electricity use profile [2] that mimics the average grid load in the neighbourhood of our hybrid. When this grid load stays under 2 kW per household [3], the hybrid just follows the fixed strategy. However, if the grid load rises above 2 kW per household, the heat pump is *switched off* to lower the grid load.

If the grid load drops below -2 kW (massive solar PV electricity production), the heat pump is *switched on* if possible, to maximize the use of PV production.

Simulation results

Figure 3 shows the electricity demand for our four control strategies [4]. The average consumption for each season is given by coloured lines. Especially in the winter season, heat load will be partly covered by the boiler, but the corresponding natural gas demand is not shown in the figure. Naturally, electricity usage is highest in winter (top line), followed by spring and autumn.

Electricity usage from the heat pump part of the hybrid system varies throughout the seasons. The fixed strategy shows an expected result: lowest demand in summer, and highest demand in winter. Both the CO_2-drive and the €-drive optimization stay very close to this fixed strategy outcome. A strategy based on minimizing grid congestion gives a radically different result. Around 18:00, when families start arriving at their homes, a sharp drop in electricity demand occurs as a reaction on the increasing local grid load (caused by the shut-down of other heat pumps and electrical vehicles in the neighbourhood). In the winter season, the heat pump is effectively switched off for one hour each day.

2 *We modelled a use profile for a neighbourhood containing a fair amount of electrical vehicles, heat pumps and PV*

3 *The Dutch electricity distribution grid can typically handle around 2 kW load per household.*

4 This is the electricity demand of the heat pump only, not the full household demand.

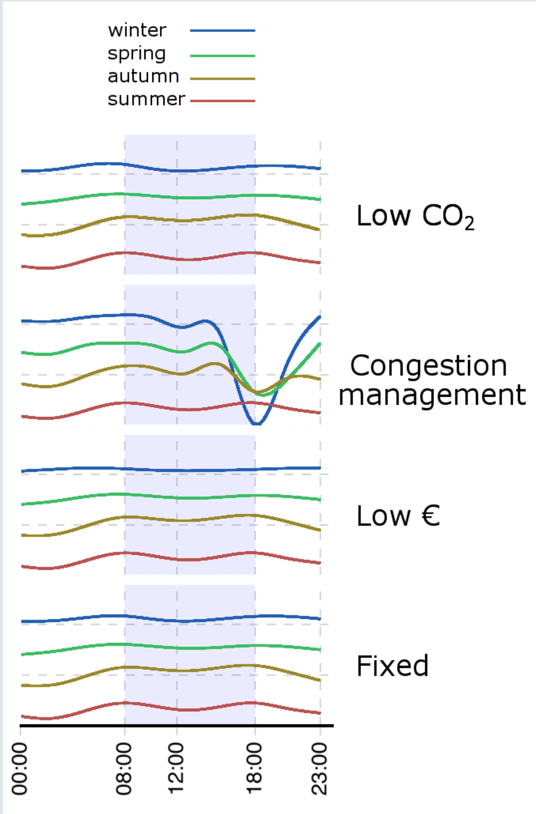

Figure 3. Electricity demand from the heat pump for several operating strategies.

The lowermost graph gives the results for the fixed operating strategy (***Strategy 1***). Throughout the day, minor fluctuations are visible, indicating the response of the heat pump to the heating demand. Interesting results arise when we compare the other operating strategies with this simple ("stupid") approach.

CO_2- or €-driven strategies have no significant impact

For both the CO_2-driven and the €-driven control strategies, there is only a tiny difference in the electricity consumption as compared to the fixed operating strategy. The electricity use profile is almost identical for all seasons, the total CO_2-emissions are nearly equal, and the total operational costs are also very similar in all three cases.

Apparently, reacting to real-time fluctuations in electricity prices or CO_2-emission factors does not bring any advantage in terms of total emissions or total operating costs. In hindsight, we can easily understand this behaviour.

First we'll discuss the minimal cost strategy (***Strategy 3***).

In the Dutch electricity market, the consumer price consists for about 2/3 of various taxes. This means that any fluctuations in the wholesale electricity price will only reach the consumer market in dampened form. For example: a wholesale price increase of 30 % will only lead to a 10 % increase in the tax-included consumer price.

Secondly, at an average price level, the cross-over point between heat pump and boiler occurs around a COP of 2.5. During most of the year, weather conditions are moderate and this cut-off COP is easily topped by the heat pump. Only severe electricity price increases will shift the balancing point far enough to force heat pump close-down. In practice, there is thus only a slight effect of this operating strategy if outside temperatures are in the vicinity of 0 °C, when the COP lies close to the cross-over point.

The minimal CO_2 strategy (***Strategy 2***) fails for similar reasons. For the largest part of the year, the COP of the heat pump is so high, that even a major increase of the electricity CO_2-factor can do no harm. Heat pump operation is thus nearly always better than the back-up boiler, even if the electricity is supplied by coal-fired power plants. Again, minor effects of this strategy can only be observed when the outside temperature is around 0 °C.

Large potential for preventing grid overload

Looking at the last strategy (***Strategy 4***), we discover more interesting results. In the summer season, performance with the anti-congestion strategy is identical to the fixed operating point. As soon as the space heating demand becomes significant, however, a remarkable change can be observed. In the early evening hours, around 18:00, electricity demand suddenly drops. The heating demand is now taken care of by the back-up boiler. The timing of this switch corresponds to the peak load in Dutch local electricity grids.

This peak load is mainly caused by electrical vehicles and heat pumps increasing demand in conjunction with household usage, which also tends to peak in the early evening hours.

The drop in electricity demand from the hybrids closely follows the magnitude of the congestion. In the winter season, when congestion is most severe, heat pump operation is effectively shut down for one hour each day.

Using this type of congestion management, already a small share of hybrids in a city block may help to stabilize the grid. Especially under extremely harsh temperatures, all-electric heat pumps must run 24/7, without options to cut back on demand. Hybrids facilitate this by allowing all-electric heat pumps to use maximum power.

The effect of this operating strategy on the CO_2- and €-performance is slightly negative. However, given the limitations of present distribution networks, this price may be well worth paying, since it allows for a much better overall performance of the whole neighbourhood.

Conclusions

In our simulation study, we focussed on very basic smart strategies, not using any sophisticated predictions or market behaviour. Already by just reacting to real-time information on congestion (***Strategy 4***), it is possible to make a major contribution to grid stability.

Reacting to real-time price and CO_2 signals does not seem to pay off very well. Moreover, consumer prices in the Netherlands do not reflect real-time market fluctuations[5]. Prices are basically fixed for at least a one month period. Real-time CO_2 data are actually not available at all. Basing a smart control strategy on these information sources is thus still largely a theoretical exercise.

Data on local grid congestion are also not available from any central authority. Using measurements from *within private houses*[6] might however still be possible to use in order to infer the local network status in real time, making flexible congestion responsiveness a viable proposition in the very near future.

Due to differences in the electricity market structure, it is likely that smart operation of heat pumps using CO_2 or price data may still be a good idea elsewhere. From the Dutch market simulations alone, it is impossible to generalise this result.

The potential for congestion management is, however, present in all locations where grid load is hitting its maximum value. Especially when electrical heat pumps face must-run conditions and are least flexible (i.e., in mid-winter), hybrids can grant some "breathing room" on the grid. The costs in terms of extra CO_2-emissions and extra fuel use amount to only a small percentage. Pilot projects could show whether the positive effects are worth this price.

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References

[1] Berenschot, BDH, DNV GL, 2016. "Flex-potentieel hybride warmtepomp" (English: "Flex-potential of hybrid heat pumps"). Netherlands.

5 Pilot projects with real-time consumer prices are being planned, however.

6 In particular, it may be feasible to monitor slow voltage drops as an indication of increasing grid load.

ANNEX 42

Heat Pumps Offer a Huge Potential for Flexibility on a Smart Grid and Unlocking it is Not (Just) a Technical Issue

Dennis Mosterd, Peter Wagener - the Netherlands

Domestic heat pumps will be the largest electricity appliance in the house. These heat pumps can shift electrical power to heat, and with thermal storage postpone demand. Therefore, heat pumps can potentially deliver flexibility to the grid and enable intermittent renewable energy integration. But in order to unlock this flexibility, these heat pumps must be made smart to have some sort of communication with the grid (or with other consumers or producers of energy). This article will explore this broad topic and will show that this are not just technical barriers that have to be overcome.

Introduction

Flexibility in the power grid is essential for the desired sustainability of our energy system. Flexibility is determined by the degree to which producers, consumers and prosumers are able to react to the fluctuating supply on the electricity market so that shortages and surpluses of electricity can be balanced and any capacity shortages can be prevented.

If electricity from sustainable sources, not all of which is available on demand, continues to increase, the demand will have to be geared to the supply. If consumers can adjust their use of electricity over time (hourly or daily), the total system will need less reserve capacity.

Heat pumps are a likely instrument for demand management in smart grids because they can convert (sustainably generated) electrical energy into thermal energy, which can be used in the built environment at a later point for space heating or domestic hot water (DHW).

Next to e-mobility (completely electric vehicles & plug-in hybrids), the heat pump is the largest energy user in a residential building, and thereby the device with the greatest impact if it is managed 'smart'. In smart grid test projects, much attention is often paid to managing all kinds of household devices in a 'smart' way, but their impact is much smaller.

By combining heat pumps with thermal storage (which also can be the thermal mass of the building), a relatively large user of electricity in the building can be applied as a regulatory instrument within the fluctuating supply of sustainably produced electricity. It can ramp up in minutes and postpone for days with thermal storage.

But if heat pumps are installed on a large scale in existing buildings, there is a potential threat for the grid, especially in regions that currently rely on natural gas as the energy carrier for heat and domestic hot water. The electricity grid in those regions was not designed for the extra power that is needed for the heat pumps. Large scale deployment of heat pumps can therefore also mean relatively large loads, where a local transformer cannot handle the extra load from heat pumps. And if those heat pumps are not managed smartly, the heat pumps will have a large coincidence factor as well (when it is cold, they will all switch on).

So heat pumps in domestic buildings offer a potential threat to the grid, because they will be the largest electricity consumer in the house. But they also offer great opportunities for flexibility in the grid since they can convert electrical power to heat and store it, can ramp up fast and postpone for days, and are predictable in demand for some days ahead.

Although smart-grid pilot projects and many studies have demonstrated the advantage of smart-driven heat pumps, commercially available heat pumps are not, as standard, currently able to communicate via the grid. On the other hand, neither can the grid communicate with heat pumps, which can result in a classical 'chicken or egg' situation.

Flexibility potential

A heat pump generates sustainable heat with the help of electrical energy. Heat that can be simply and cheaply stored in a thermal storage, for instance in a water tank, as thermal mass in the building or in the ground. In addition, much research is being done on phase changing materials (PCMs) and thermochemical storage as storage medium that can further increase the energy density (more heat stored in less volume) or make summer heat available in winter.

Many heat pumps already have a thermal buffer (particularly heat pumps installed in new housing) in the shape of a water boiler vessel. And all heat pumps have a control system. This means that heat pumps already have the potential to create a link between electricity network and heat and its storage, provided that the systems have been designed and installed correctly. The heat pump will, however, need to be given a smarter control so that it, based on for example price signals from 1 day before, or a 'maximum allotted power', can determine when to start and when not to. In addition, the control must take in account the consumer's behaviour, climate data and the thermal inertia of the building.

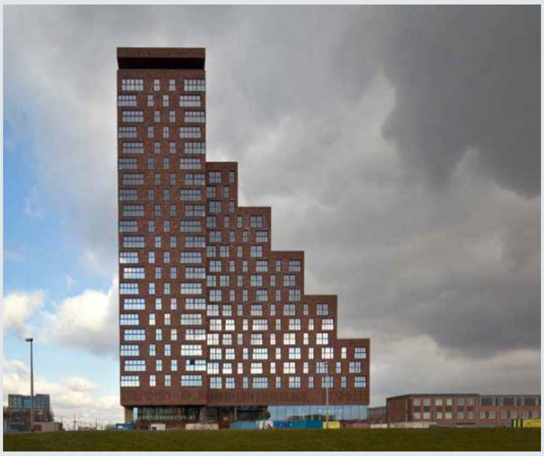

Figure 1. The Couperus building.

A real life demonstration project that was performed in the Netherlands was the 'Couperus' project. The Couperus building (Figure 1) is a residential building in The Hague, with 300 dwellings where all the energy needed for the building is sustainably generated. It was also a real-life test site for testing a smart grid principle. 150 individual heat pumps of 1 kW and a combined seasonal storage were controlled by Powermatcher technology. This is a market based demand and supply matching smart grid coordinator, an auctioneer model (Figure 2) where biddings from all consumers and producers of energy that are connected meet at an equilibrium price. Bids express the instant willingness to consume and/or produce.

Results in Figure 3 show that it was possible to realise a huge total power reduction of the combined heat pumps

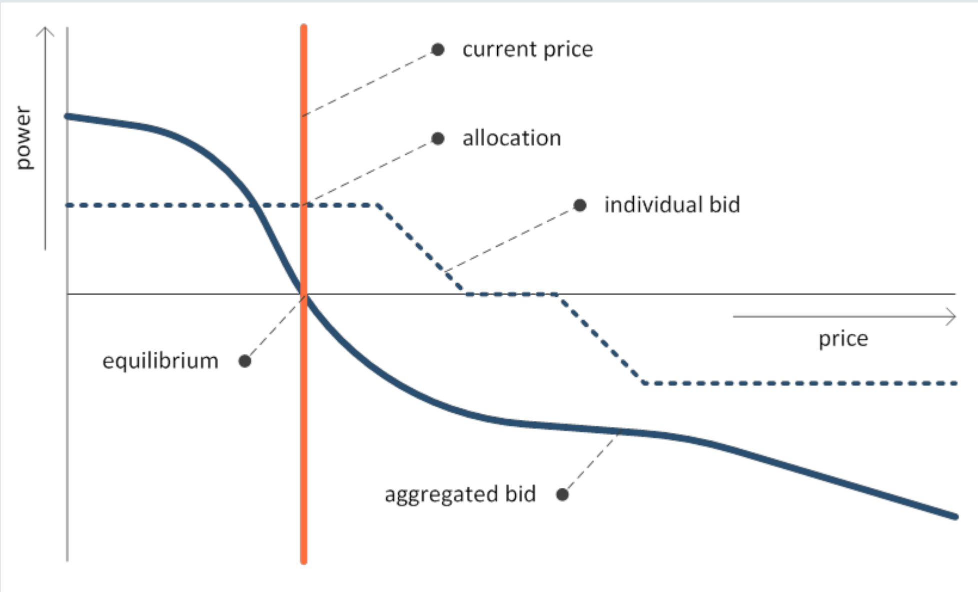

Figure 2. The market model of the smart grid coordinator used is based on the aggregation of individual bids from power consumers and producers to find an (instant) equilibrium price. On the x-axis is the price per unit of energy (e.g. €/kWh) and on the y-axis power, where a positive power capacity is production and a negative power capacity is consumption.

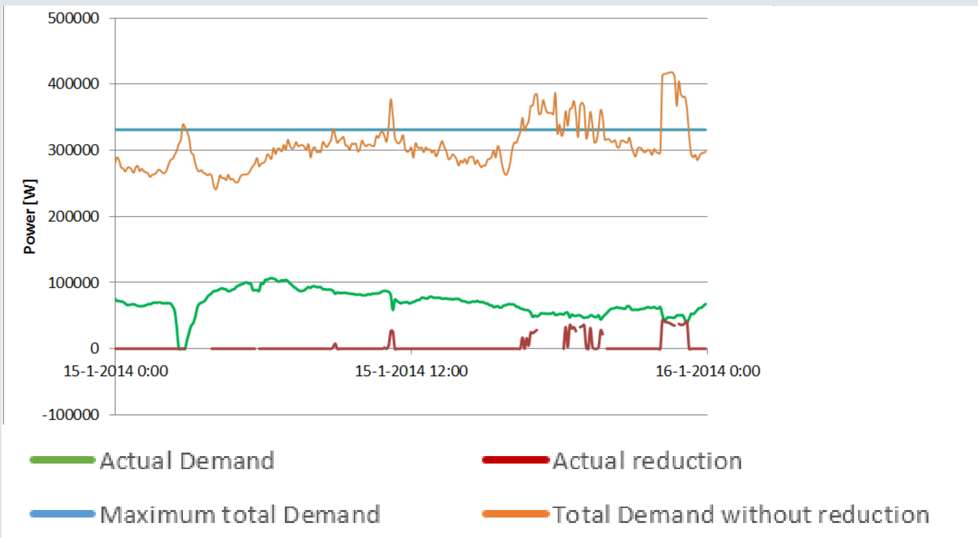

Figure 3. Peak shaving with heat pumps. Results from the Couperus project.

and stay under the maximum power capacity (e.g., the max capacity of the local transformer). This shows that on a day basis there is a huge flexibility offered by the heat pumps.

The project also tested demand response with heat pumps and a local wind turbine. Figure 4 shows that it also was possible to follow the availability of wind power with the heat pumps. The red and gray lines are the total maximum and minimum demand, respectively; thus, the flexibility power is between these lines. The blue line is the demand if no compensation was requested and the brown line is the requested compensation power. The green line is the actual demand which is a response to the base demand (blue) and the compensation (brown). It shows that it is possible to get flexibility from heat pumps and follow the availability of power within its flexibility potential.

In conclusion, it was possible to reduce the imbalance generated from a connected wind turbine and peak shave the total load of the grid. 21 % of the total heat pump power turned out to be flexible. As was calculated by TNO (one of the participating partners in the Couperus project), 500 MW could potentially be made flexible in the Netherlands. Compared with a current spare capacity of 101 MW, this flexibility is substantial.

But the project also showed that further involvement of the tenants of the building was problematic. The control of heat pumps in this project was not optional, it was a mandatory condition in the rental contract. In order to get more flexibility, the idea was to connect more appliances to the smart grid, but there was little interest from the tenants to participate in this.

How to unlock flexibility potential

Control

Building type, heat pump type, storage size and the amount of systems installed create flexibility potential, but the different signals and levels of control will have a large impact on unlocking this potential. These demand response signals can vary based on different principles. Possible control signals to heat pumps are: electricity price signals, availability of renewable power generation, scheduled periods with high demand anticipated, continuous one way signal from aggregator, two way communication or even frequency and voltage control. The heat pump can only contribute to flexibility on the grid if it is able to respond to these signals. This means that there is a need to choose what type of signal principle that will be used AND that communication protocols must be implemented to make communication or response technically possible.

And it is exactly the control principle that raises a conflict of interest between different participants on the smart grid. The consumer will have no other interest than to maximize his or her own comfort, especially in the Netherlands where the energy tax is the largest part of the total energy price and therefore control signals based on fluctuations in the wholesale energy price will have little impact on energy savings. Manufacturers will

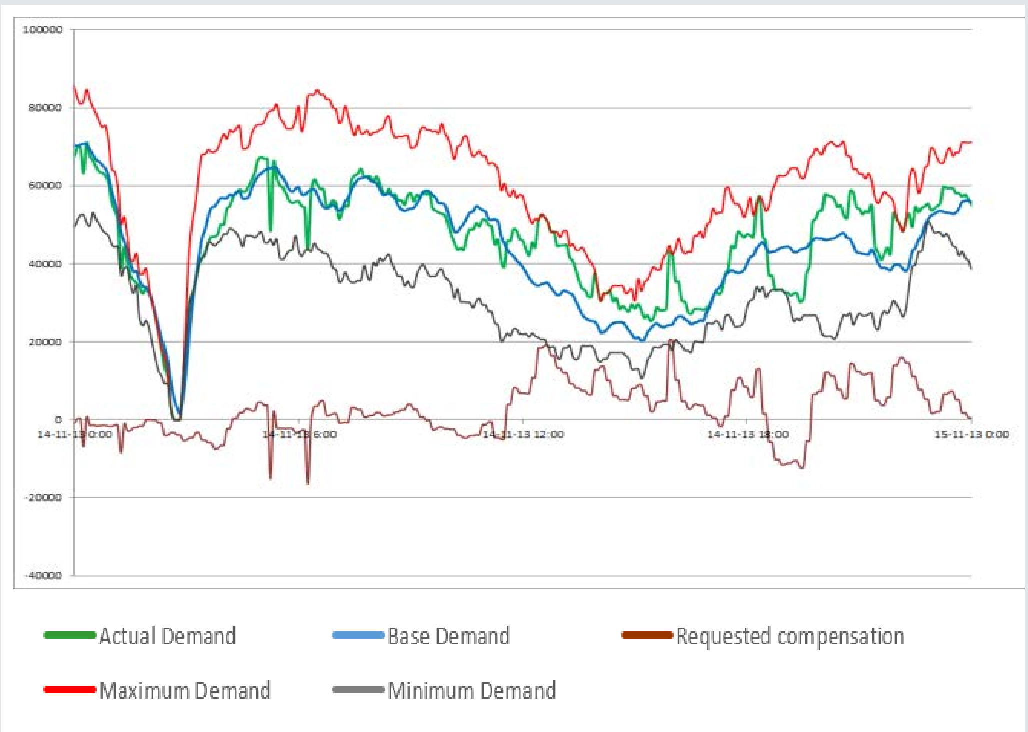

Figure 4. Demand response with heat pumps and a local wind turbine.

Table 1. Different demand side issues , with different dimensions of solutions

DEMAND SIDE MANAGEMENT (DSM) ISSUE	DIMENSIONS OF DSM LEVELS
Heat pump power control	Inverter controlled compressor, power demand more gradual
	On/off switched compressor, power demand is binary
Control strategy: in the building	Preheating algorithms
	Adaptive capacity thermal inertia of the building
	Optimizing storage capacity
Control strategy: outside the building	Outside temperature
	Interaction with weather forecasts and climate data
Control strategy: economically	Dynamic interaction with price signal
	Interaction with pre-set pricing or CO_2 emission targets
Communication	Bi-directional communication
	1-way communication (on/off pricing based)
Reaction on communication	Dynamic (minute-based)
	Pre-set scheme (hours/days)
Thermal storage	Heat storage in tank (hours - max. 1 day)
	Latent heat storage in PCM (hours/days)
	Thermal chemical storage (season)
Integration with 2nd energy source	Bi-valent system with switch option
	Hybrid controlled by pricing or CO_2 pre-set boundaries
	Hybrid controlled by dynamic pricing or CO_2 pre-set boundaries

want to minimize the impact of a heat pump shut down and keep performance at its best. Utilities will want to maximize the demand side flexibility and governments will want to maximize renewable energy integration.

Monitoring is an important first step
The behaviour of a heat pump system on the electricity grid is determined by a combination of factors. Transmission speed, infiltration, heat pump size, outside temperature, inside temperature set point, control system, installation settings, buffer size are the most important, but there are more. This makes it hard to predict its behaviour on the grid. Furthermore, predicting the flexibility capacity is even harder.

Monitoring is an instrument for charting buffer capacity at district level and the associated switching potential.

A nationwide online facility for heat monitoring operated by a neutral independent party in cooperation with the grid administrators could offer added value (by means of aggregating functions) for all stakeholders in this process. For many involved in the implementation of heat pumps, such a facility would offer the instrument for successfully managing, maintaining and following this technology in energy use (energy performance guarantee) and, where necessary, offer remote technical support. Nationwide monitoring would be based on heat pumps that can deliver data to a central database.

Online monitoring in this way can have its advantages for all those involved with the implementation of heat pumps:

1. With this kind of facility, many functionalities are available for a large group of people involved at various authorisation levels.
2. Monitoring electricity consumption offers the possibility of building up general profiles, on the basis of which end users can offer smart energy concepts.
3. Following the performance of the installed heat pump. The consumer knows beforehand that he is able to monitor the performance of the heat pump in real-time.

4. Acquiring insight in the effect of users' behaviour and the results thereof for the energy consumption.
5. Planning preventive maintenance on the basis of actual consumption rather than per time interval.
6. Heat pumps with auxiliary electrical heating cannot run on the auxiliary electrical heating unnoticed by the consumer.
7. Measured consumption offers valuable information that can be used in "peak-shaving" and "load balancing" of the electricity, and help grid administrators to give better dimensions to the construction of new grids.

Example

If smart heat pumps can send information to grid administrators, it becomes possible to acquire a picture of the total virtual buffer to absorb much more wind and solar energy. In addition, it is possible to lower the total average district demand to reduce the need of grid reinforcement or the risk of blackouts. It has been demonstrated that district demand actually can be significantly reduced by smart management of heat pumps. This led to a reduction of at least 50 % of the required transformer capacity and avoided grid costs between € 250 000 and € 1 450 000 in a district of 1 400 buildings. This interval of cost savings is so large because the avoided grid costs depend largely on the location and situation.

Conclusions

To unlock flexibility potential from heat pumps it can be concluded that there are technical and non-technical barriers to overcome.

Policy-related or non-technical barriers:

1. A lack of standardized control and communication solutions.
2. No clear defined roles and responsibilities in new smart grid applications.
3. The sharing of costs and benefits among participants.
4. Consumer resistance to participation in trials.
5. The range of regulatory arrangements in Europe hampering replicability of project results in different countries.
6. The need for new contractual arrangements.

Technical barriers:

7. Clear rules are needed for technical validation of flexible supply/demand transactions by system operators.
8. Technical and commercial arrangements for the exchange of physical and market data.

Recommendations

Develop an integral roadmap

Within the HPT TCP Annex 42 'Heat pumps and smart grids', one of the goals is to develop a roadmap to implementation of smart heat pumps. The findings from running programmes performed by the participating institutes, group discussions at Annex 42 meetings and the outcome of simulations of different scenarios will be the main input for this roadmap.

More active sharing of knowledge

Within the IEA there are many groups working on different overlapping topics in the smart grid field, but there is not much cooperation between these groups or

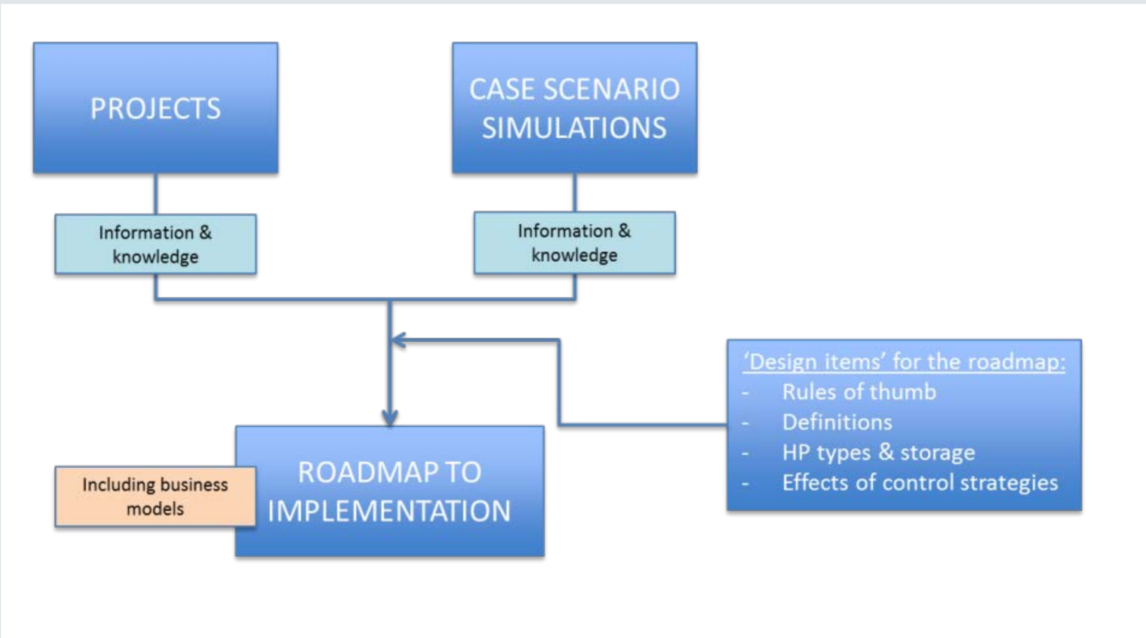

Figure 5. The structure of Annex 42.

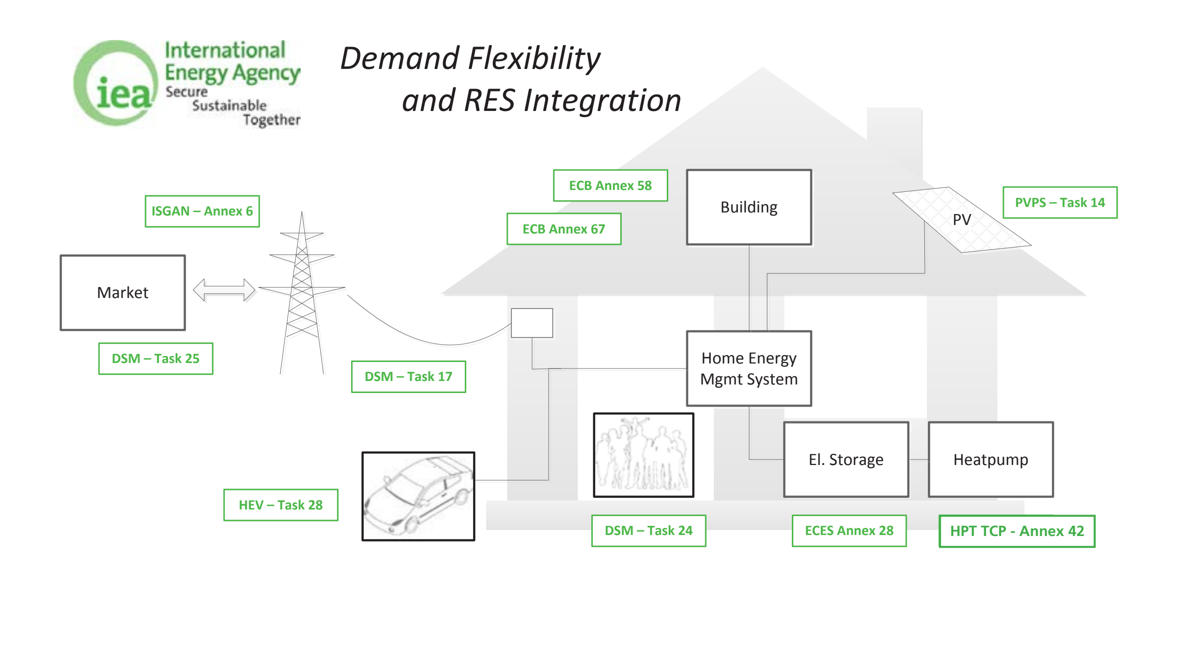

Figure 6. Schematic for IEA projects within smart grids. Used with permission of Matthias Stifler.

active sharing of knowledge, so far. To overcome this, a symposium was held in Linz organized by AIT and TNO to see 'who is doing what' within the IEA; work related to demand flexibility and RES integration. It is recommended to proceed in these type of meetings.

Actively involve the end-user

Active participation on a large scale by individual consumers/owners of heat pumps is a critical success factor of the highest rank for the successful rollout of load management/demand response activities and programmes. It is not inconceivable that parties in the current market of grid administration are not adequately equipped at this time. For this, new business models would have to be included in a new organisation that must be able to operate very flexibly and effectively. Smart grids, of which demand management is a component, is only successful if all 'chain parties' benefit.

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NEDO Heat Pump Related Smart Community Demonstration Projects

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The Japanese New Energy and Industrial Technology Development Organization (NEDO) is one of the largest technology development organizations owned by the Japanese government, and it promotes several international "Smart Community"-related international projects. This concept involves not only smart grids, but also smart customers (users) in a certain local area. The smart community concept not only comprises utility-side energy management systems such as Supervisory Control And Data Acquisition Energy Management Systems (SCADA EMS), but also several user side management systems such as Home Energy Management Systems (HEMS), Building Management Systems (BEMS) or Factory Energy Management System (FEMS), which operate the best solution for each participant of the power system. Some of these demonstration projects include heat pumps as the energy storage element for establishing smart energy management under those management systems. This paper introduces various heat pump applications within three projects.

Introduction

In July 2016, NEDO operated ten international smart community-related demonstration projects worldwide. Figure 1 shows locations and the contents of these demonstrations, as well as of two finished projects. Some of these demonstration projects include heat pumps as the thermal energy storage element to establish smart energy management. This paper presents the projects in New Mexico, Manchester and Speyer. The latter part of this paper describes the objectives and demonstration methods of each demonstration project.

New Mexico Smart House Demonstration

The New Mexico Demonstration project was the first international smart grid related demonstration project run by NEDO, starting in 2009 and finished in 2015. This smart grid project was a collaboration between the New Mexico state government, U.S. Department of Energy (DOE), two U.S. National Laboratories (Los Alamos National Laboratory and Sandia National Laboratory), a real estate company and two utilities (Public service of New Mexico and Los Alamos County utility). NEDO carried out a smart grid-related demonstration test, which involved a multiple micro-grid operation using a utility side local Energy Management System and a customer side Energy Management System at two sites in New Mexico: Los Alamos County and Albuquerque.

At the Los Alamos site, NEDO constructed a feeder level micro grid with 1700 houses, 1 MW land fill type solar power system (PV), 1.8 MW battery storage systems and utility side Energy Management Systems (Micro EMS) to realize a micro grid operation. Moreover, there was one smart house (Fig. 2) where three different types of

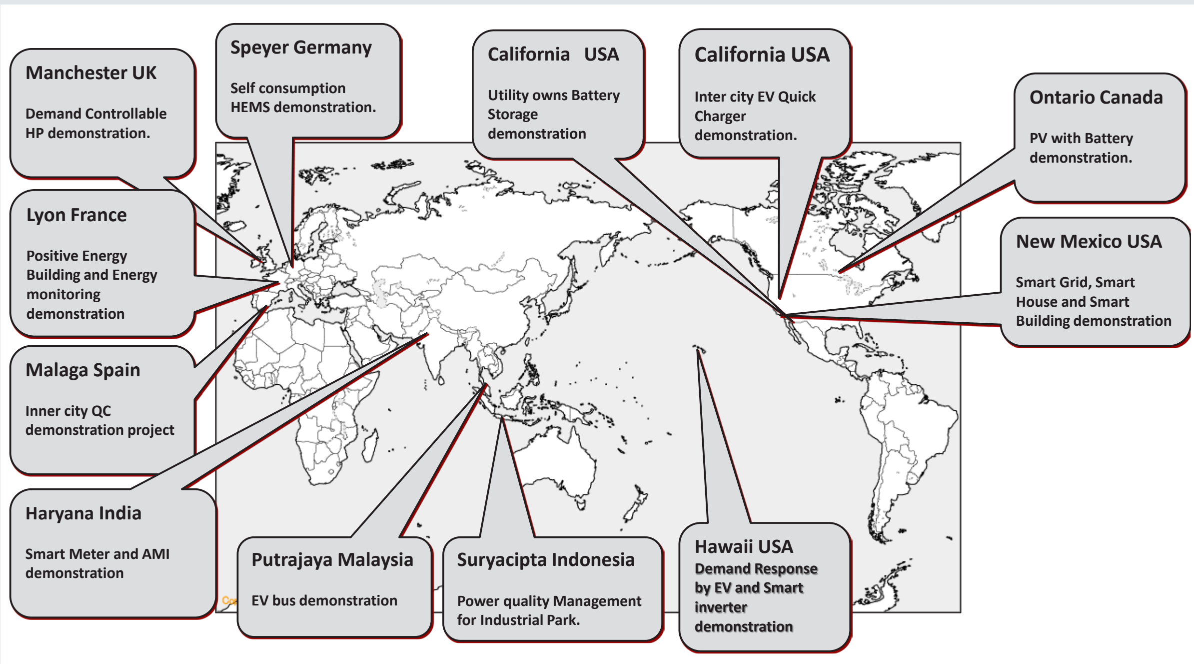

Figure 1. NEDO International Smart Community Demonstration Sites

Figure 2. Smart House in Los Alamos (NM, USA)

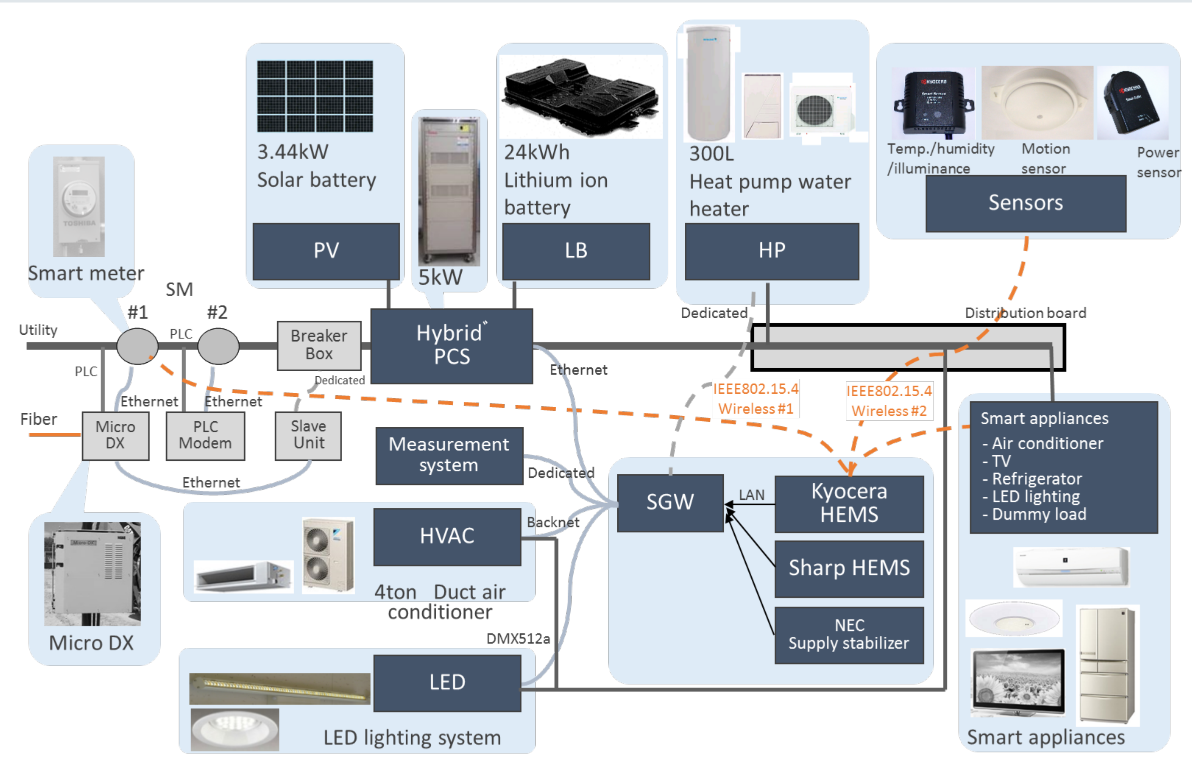

Figure 3. Smart House HEMS and controlled home appliances

Home Energy Management Systems (HEMS) from different vendors were tested. This smart house had 25 kWh Li-ion battery storage and one standard "Heat Pump Water Heater" as the energy storage element. Also, it had several controllable home appliance elements (Fig. 3).

NEDO successfully completed a demonstration of an automated HEMS, an advanced form of visualization-oriented HEMS, which can automatically control the power supply in houses with distributed power sources and storage batteries or heat pumps. In this project, HEMS successfully demonstrated the potential of cooperative control capabilities by integrating utility side EMS requirements (pricing signals and load control signals) received from utility companies. The purpose of this demonstration was to absorb surplus energy, from for example, solar PV, through distributed energy storage. If the price of utility energy falls, HEMS controls the battery system to increase the charge and to purchase electricity from this utility.

Home appliance technologies in homes will be integrated in automated HEMS throughout the project. Visualization-oriented HEMS that are currently commercially available, have been used. However, we expect automated HEMS technologies to be introduced on the market in response to the needs of greater local power production and consumption control associated with increased on-site power generation (such as photovoltaics). In addition, Smart House can switch to islanding operation mode utilizing PV and storage in accordance with a request from the grid in the event of a grid failure, and return to a normal grid-connected operation mode when the grid has been restored. In islanding mode, the ability to balance the power supply and demand of in house switching of the energy storage element, such as a heat pump, becomes very important.

In conclusion, the heat pump has three roles in the smart house: the first is to create hot water (DHW); the second, to absorb surplus energy from PV connected to the grid system under control of HEMS communicating with utility Micro EMS and the third the Demand Response (DR) function, to realize a balance between demand and supply when the smart house is separated from the grid system.

Manchester Heat Pump with DR Demonstration

In the UK, the capacity of renewable energy on the grid system, especially wind power, is increasing. In addition, the country is facing future reductions in domestic natural gas production. Consequently, the UK government is very interested in switching fuel for heating, from natural gas to renewable electricity.

NEDO has held discussions with UK agencies and understands the issue. This resulted in NEDO starting a demonstration project in collaboration with the UK government and Greater Manchester by introducing several hundred "Heat Pump Water Heaters" (Fig. 4) into public houses, from 2014.

In 2014, NEDO signed a memorandum of understanding (MOU) with the Department for Business Innovation & Skills (BIS), the Department of Energy and Cli-

Figure 4. Heat Pump Unit introduced in Public Houses in Manchester (UK)

mate Change (DECC) of the British government and the Greater Manchester Combined Authority (GMCA) to conduct a smart community demonstration project in Manchester. This project leverages Japan's heat pump technology and Information and Communication Technology (ICT) to integrate a large amount of Heat Pump operation through local management systems.

Another important function, besides the heat pumps, is the Demand-Response (DR) capability. Employing an ICT infrastructure, the heat pumps were connected to the management system and, by controlling switching, it became possible to control the total demand value. This DR capability will be important for the balancing group, which means, for example, a retailer purchasing energy from generators on the wholesale electric market and selling to customers on the retail market. This balancing group usually has responsibility on both markets to keep a balance between demand and supply. If there is a large amount of intermittent renewable energy, there is a high risk that demand and supply cannot be matched during a certain period due to unexpected generation changes in renewable resources caused by variations in wind and sun radiation. In this case, the retailer on the electric market must compensate the energy imbalance by buying expensive energy from a system operator when there is a shortage of purchased energy from the generator or release surplus energy without any income when purchased energy from the generator is in abundance. Anyway, such penalized imbalance costs should be minimized for the balancing group (retailer) if the penalty is too heavy. This kind of control on Heat Pumps can reduce the imbalance on the demand side and will become a powerful tool if their sales energy includes a high percentage of renewable energy.

In the demonstration project, two different types of DR functions were adopted. The first was the fast DR for keeping the 30-minute energy balancing rule, which must be observed by market participants. The second was the long term balancing between the daily load curve and daily supply curve. Both types of control make it possible for an participant on the energy market to avoid an imbalance penalty payment or the purchase of expensive spot energy. This Heat Pump related demonstration will start during winter 2016. After the demonstration, discussions regarding standardization of the ICT system interface and establishing metering of the DR result by smart metering will be necessary in order to realize such DR capability.

Speyer Self Consumption Model Demonstration

In some parts of the world, so-called "grid parity" may be attained through roof top PV systems in the low-cost range, according to several estimations. In the southern part of Germany, utilities are facing a large amount of reverse power flow from a large number of roof top PV systems. In addition, these PV systems will reduce the amount of energy sold by the utility. Accordingly, several utilities are interested in introducing an energy management system on the customer side, reducing reverse power flow and creating new services to keep customers. This led "Stadtwerke Speyer", a local utility company owned by the city of Speyer, to look into introducing cloud HEMS technology in an attempt to keep departing customers, and to also achieve a high degree of self-consumption of generated PV energy on the customer side.

NEDO started the new demonstration project with Stadtwerke Speyer in 2015, through the installation and operation of a demonstration system based on Japanese energy storage technology, including heat storage technologies using heat pump water heaters and battery technology, as well as introducing information

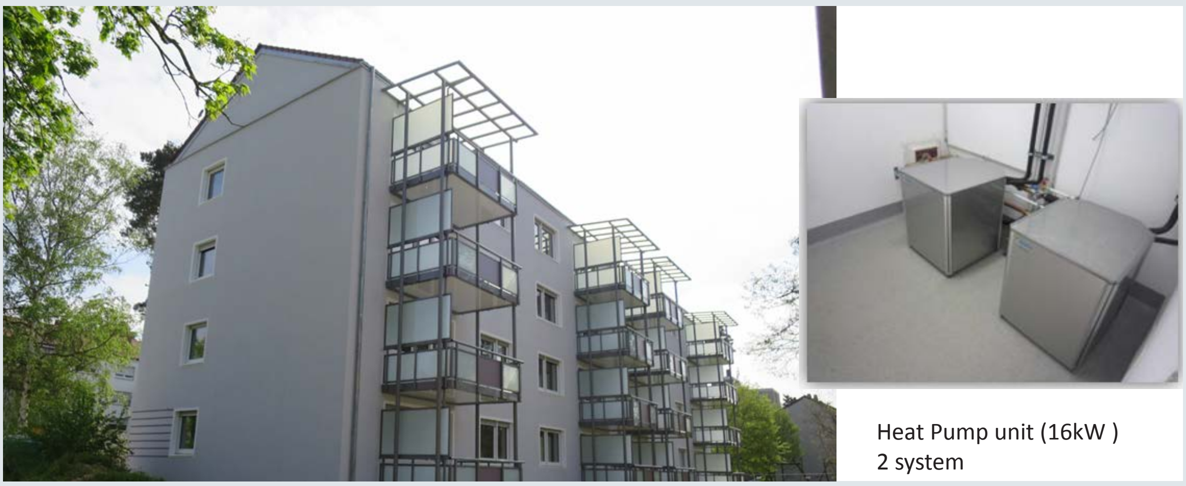

Figure 5. Demonstration apartment building and heat pump units (Germany)

and communication technologies (ICT) connected with HEMS. The HEMS functions were achieved in a real life environment in Germany. The aim of the project was to establish the "self-consumption model" for local production and consumption of PV generated power, as well as to demonstrate a reduction in total household energy costs including heating costs through HEMS control.

In cooperation with GEWO Wohnen GmbH (Public houses supply organization owned by city), NEDO is continuing the demonstration project in twelve family-apartment buildings (Fig. 5), as well as in the public area of another apartment building to achieve self-consumption of generated energy by roof top PV.

Conclusions

In the Smart Community world, the energy storage element is a very important facility to add flexibility to energy systems, especially the Demand Response function on energy storage elements. This can easily contribute to the balance between supply and demand without causing inconvenience or discomfort to customers. This function is mainly obtained by installing distributed battery storage. However, heat pumps are also able to deliver the same function, where heat demand becomes a high percentage of energy consumption.

For example, through the New Mexico demonstration, it is shown that a house side Heat Pump can absorb fluctuations in PV generation on the grid system through cooperation between the utility side EMS and the customer side HEMS. Through the starting Manchester project, Demand Response by switching control of a group of Heat Pumps, it will be demonstrated that Heat Pumps can contribute to balancing supply and demand on the electricity market. In the Speyer project, Heat Pump technology can reduce congestion on the distribution grid system by reducing reverse power flow from roof top solar generators.

NEDO has a strong belief in this technology, and promotes the application of energy storage elements, including heat pumps, in future smart community and energy systems by means of these demonstration projects.

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Charge Limits for Heat Pumps with Flammable Refrigerants

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There has long been a focus on the climate impact of refrigerants, and now the political climate and legislation is forcing all users of traditional HCFC and HFC refrigerants to consider options with lower climate impact.
Lower GWP refrigerants include CO_2 (R744) and NH_3 (R717), but the focus of this article is on the charge limits set by the safety standards when using flammable A2L and A3 refrigerants, including propane (R290), R32 and the unsaturated HFC (HFO) options.

Introduction

HCFC's and HFC's are hydrocarbons where halogens (fluorine and chlorine atoms) have been added to lower the flammability. The downside of this is that the molecules become more stable in the atmosphere, significantly increasing the amount of time that the molecule will contribute to global warming. To lower the climate impact (the GWP) the industry is now working with less atmospheric stable refrigerants. This decreased stability gives increased flammability, which raises issues over how to deal with the flammability risks.

Lower GWP refrigerants also include CO_2 (R744) and NH_3 (R717), but the focus of this article is on the flammable A2L and A3 refrigerants, and how to handle the flammability risk.

The lower GWP flammable refrigerants mainly consist of

- Hydrocarbons, of which propane (R290) is the most important, although propene (R1270) is also in use, and for high temperature heat pumps iso-butane (R600a) is interesting.
- Unsaturated HFC's and HCFC's also known as HFO's or HCFO's. These are low pressure refrigerants with very low flammability. Especially R1234ze(E) is interesting for larger systems. The family also includes R1234yf used in automotive A/C, and two non-flammable refrigerants, R1233zd(E) used as a replacement for R123, and R1336mzz(Z), which may be interesting in the Organic Rankine Cycle (ORC) and very high temperature applications.
- R32, an HFC similar to R410A, but with higher discharge temperature and higher pressures.
- Blends between traditional HFC's, unsaturated HFC's and R32, often referred to as HFO blends. These blends are very similar to the traditional HFC's in terms of capacities, pressures, and temperatures.

Hydrocarbons are of course highly flammable, safety class A3, which is why they are used in gas stoves for cooking.

The other refrigerants all have lower flammability, safety class A2L, which means (among other things) that a flame will spread at no more than 10 cm/s, slow enough for buoyancy to move the flame upwards faster than it can spread downwards. A2L refrigerants are quite difficult to ignite. Still, precautions must be taken to avoid the risk, and most of the precautions are the same as for A3 refrigerants, mainly *Avoid leaks and ignition sources*.

Selected refrigerants and their properties are listed in Table 1.

In the safety standards most limits to the allowed charge size depend on the Lover Flammability Limit (LFL), which

Table 1. Selected refrigerants and properties

REFRIGERANT	SAFETY CLASS [2]	GWP [5]	LOWER FLAMMABILITY LIMIT (LFL) [2]	BOILING POINT [2]	PRESSURE SIMILAR TO
R32	A2L	704	0.307 kg/m³	-52 °C	R410
R290	A3	5	0.038 kg/m³	-42 °C	R22/R404A/R407C
R1234yf	A2L	<1	0.289 kg/m³	-26 °C	R134a
R1234ze	A2L	<1	0.303 kg/m³	-19 °C	R134a
R1270	A3	1.8	0.046 kg/m³	-48 °C	R22/R404A/R407C

is the lowest concentration of refrigerant in air which can be ignited. Below the LFL the air/refrigerant mixture is too thin to be flammable.

The best refrigerant for a given heat pump depends on a variety of factors, including cost, capacity, energy efficiency and safety. For hydrocarbon-based refrigerants (HC's, HFC's, HCFC's) there seems to be a trade-off between the flammability on one hand and on the capacity and climate impact (the GWP) on the other. It is therefore a good rule of thumb to start the search for a new refrigerant at the refrigerant with the highest flammability which is allowed by the safety standards.

The safety standards impose several requirements on system design. The requirements with the strongest impact on system design are the charge limits. This is important since the maximum amount of charge in a heat pump indirectly determines the maximum heating capacity, and this is the main focus of this article.

That said, it is worthwhile to keep in mind that safety standards often can be replaced by a risk assessment approach, where part of the requirements are replaced by a thorough risk assessment. Such an approach has the advantage of being able to add credits for mitigation measures not imagined when the safety standards were written. However, it is generally a good idea to start with the safety standards, and only go to the risk assessment approach as a last resort.

Safety standards

The design of systems is governed by safety standards. Which standard applies to a system depends on the type and size of the system and where it is sold. This implies that there may be more than one safety standard which needs to be adhered to.

The two most common international standards are

- IEC 60335-2-40 for residential and light commercial heat pumps
- ISO 5149 for heat pumps which are not within the scope of IEC 60335-2-40.

EU has adopted the IEC 60335-2-40 with minor changes in EN 60335-2-40, and uses EN 378 instead of ISO 5149. EN 378 has many similarities with ISO 5149, also in the area of charge limits, but also includes requirements related to the EU Pressure Equipment Directive (PED).

In the US, the standards still do not cover flammable refrigerants, but work is ongoing on UL and ASHRAE standards to include flammable refrigerant, with the current focus on the A2L refrigerants.

As mentioned above, the requirements with the strongest impact on system design are the charge limits, as the maximum amount of charge in a heat pump indirectly determines the maximum heating capacity. The charge limits generally limit the charge per circuit, so using multiple circuits allows for higher capacities, but the increase in cost is often prohibitive.

For the purpose of simplicity this article will describe the most common charge limits, namely the cases of

- Confined space
- Indoors
- Outdoors
- Outdoors, and fenced off or machine rooms

There are a number of special cases, such as VRF systems or locations where one or more people have special knowledge about the system, but most heat pumps fit within one of the above four categories.

Confined space

This is the situation where the heat pump is to be installed in a very small space, or where the manufacturer does not wish to set limits to where the heat pump may be installed. For A3 refrigerants, such as R290, this limit is the charge which would give rise to a concentration of LFL (= Lower Flammability Limit) in 4 m^3 of air, and for R290 this is 152 g (4 m^3 x 0.038 kg/m^3). The reader may have heard the number 150 g, and this is effectively the 4 x LFL for hydrocarbons, a number that is too low for most heat pump applications.

For A2L refrigerants, such as R32, the current standards deviate. The IEC 60335-2-40 allows 4 x LFL, while ISO 5149 allows 6 x LFL. For R32 (and most other A2L's) this is 1.2 kg and 1.8 kg, respectively. The current EN378 is aligned with IEC 60335-2-40 while the next version of EN 378 (PrEN 378:2016), which has just passed the final vote and is expected to be published this year, agrees with ISO 5149 on this topic. The 1.2 kg or 1.8 kg are very interesting for heat pumps, since these charges are large enough for small heat pumps which can be placed in closets, under stairways or similar confined spaces.

Indoors

Another set of limits depends on the area (in m^2) of the room where the system is installed. This is the so-called "human comfort" formula. The formula has this name because it originated in the domestic and light-commercial standard for air-conditioning and heat pumps, and differs significantly from the charge limits used by ISO 5149 (and EN 378) for refrigeration applications. The formula is a little complex:

$$\textit{Max Charge} = 2.5 \times LFL^{5/4} \times h_0 \times Area^{1/2}$$

The variable h_0 represents the installation height, for specific values see Table 2.

Table 2. Values of h_0

INSTALLATION TYPE	h_0
Floor location	0.6 m
Window mounted	1.0 m
Wall mounted	1.8 m
Ceiling mounted	2.2 m

There is an upper limit to how high a charge is allowed, even in very large rooms. It depends on the specific safety standard, typically it is 26 x LFL (close to 1 kg of R290 or 8 kg of R32), but for A2L in ISO 5149 (and PrEN 378:2016) it is 39 x LFL (12 kg for R32). However, for most applications it is the room area which limits the charge. To illustrate the charge sizes allowed by this approach the "human comfort" formula is plotted for R290 and R32 in Figures 1 and 2, respectively. Note the difference in scale of the vertical axis between the two diagrams.

The charge limits for hydrocarbons, with safety class A3, do make it possible to make small heat pump systems only, while a very wide range of heat pumps can use A2L refrigerants.

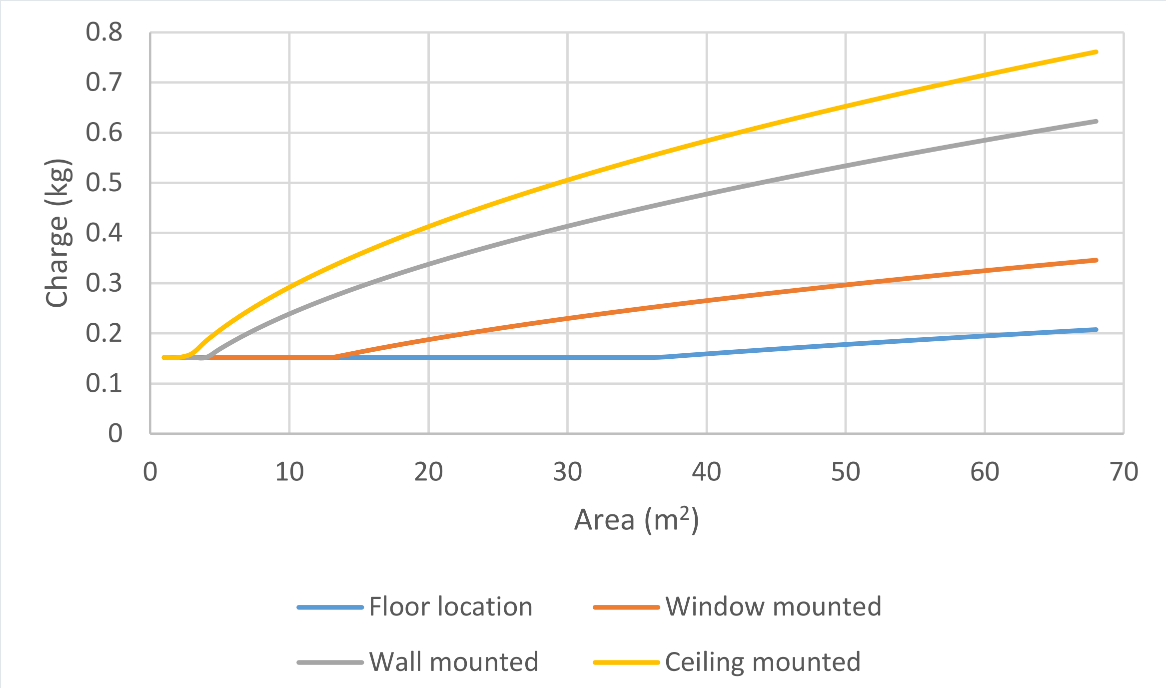

Figure 1. Charge limit for R290

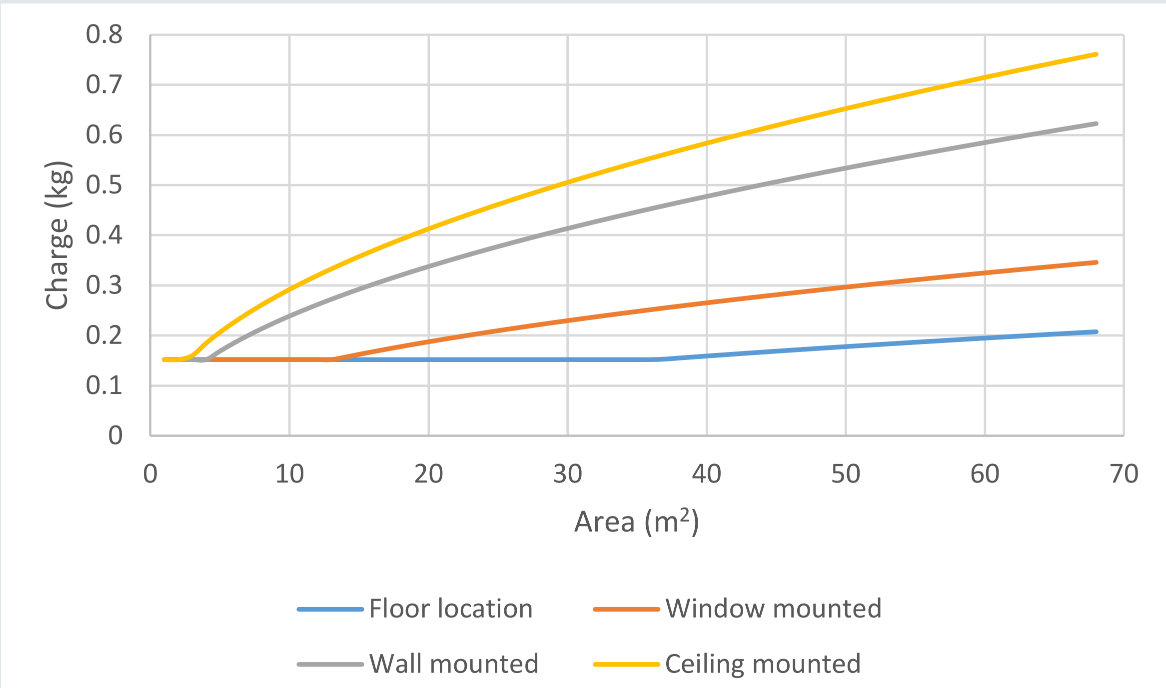

Figure 2. Charge limit for R32

Outdoors

For systems placed outdoors, typically using a brine to transfer the heat to the indoors, the limits are more relaxed. For A3 refrigerants, IEC 60335-2-40 allows 130 x LFL which for hydrocarbons is close to 5 kg, which is what ISO 5149 and EN 378 allow. 5 kg of propane is enough to cover most household applications. For A2L refrigerants the 130 x LFL limit of IEC 60335-2-40 is 40 kg, enough for the majority of applications.

Outdoors and fenced off or machine rooms

If larger charges are needed for outdoor system, then it is out of the scope of IEC 60335-2-40. Instead ISO 5149 (or EN378) has to be used. If the heat pump is placed so there is no access to the public, for instance behind a fence or in a machine room, there are no charge limits. The "no charge limits" should be taken with a grain of salt, since the local regulations or fire marshal may impose limits, but systems with 50 kg of R290 are not unheard of.

Standards under update

There is currently great activity in the standardisation world related to flammable refrigerants.

There are two working groups working on proposals for updating IEC 60335-2-40 with more detailed requirements for flammable refrigerants. One IEC/TC61D/WG09 group works on A2L refrigerants, while the other IEC/TC61D/WG16 group works on A2 and A3 refrigerants, and is fairly new, so most proposed changes are currently for A2L refrigerant. The proposed changes for A2L refrigerants include

- Increasing the charge limit for confined spaces to 8 x LFL (2.4 kg R32), which is even more than in ISO 5149 and PrEN 378:2016.
- Take active mixing into account, to allow much higher charges indoors.
- New methods for evaluating ignition sources for A2L refrigerants.

Another proposal in IEC 60335-2-40 is to use the actual installation height as h0 instead of the predefined numbers given in table 2. For some systems this will increase the allowed charge considerably, since they are almost invariably installed higher than indicated in table 2. An example is window units, which are often installed in special holes in the wall rather than in real windows, and therefore installed much higher than the 1 m assumed by the "human comfort" formula.

As previously mentioned, EN378 is also under update, with the new version expected to be published late 2016. The update of EN378 touches many areas, including many which are related to flammable refrigerants. Part of the update is an alignment with ISO5149 on the structure of charge limits. However, the alignment is not perfect. For A3 refrigerants, such as R290, EN378 will still allow up to 1.5 kg indoors, where ISO 5149 allows 1.0 kg.

At the same time the working group behind ISO 5149, i.e., ISO/TC86/SC1/WG1, is discussing how to simplify the structure of charge limits. Hence all the major standards are evolving, and even though the working groups want the standards to be aligned, it is at best only loosely coordinated.

The general trend is to allow more charge with flammable refrigerants. This effectively shifts the borders between which systems are most optimally designed with hydrocarbons, which are better designed with A2L refrigerants such as R32, and which are better with non-flammable refrigerants.

Conclusions

In this article we have shown how the system safety standards sets limits to what amount of charge can be contained in a heat pump circuit. Hopefully the reader has also seen how most systems will be able to use A2L refrigerants, and how many applications will also be able to use A3 refrigerants, such as R290.
The exact refrigerant to choose for each application is of course a function of many variables, but as a rule of thumb it is a good idea to consider the highest flammability refrigerant allowed by the safety standards.

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Literature

[1] IEC 60335-2-40:2013. Household and similar electrical appliances – Safety – Part 2-40: Particular requirements for electrical heat pumps, air-conditioners and dehumidifiers.
[2] ISO 5149:2014. Refrigerating systems and heat pumps -- Safety and environmental requirements, all 4 parts.
[3] EN 378:2012 Refrigerating systems and heat pumps -- Safety and environmental requirements, all 4 parts.
[4] PrEN 378:2016 Refrigerating systems and heat pumps -- Safety and environmental requirements, all 4 parts.
[5] 2014 Report of the Refrigeration, Air Conditioning and Heat Pumps Technical Options Committee (2014 RTOC assessment report).

High-efficiency, Eco-friendly CO2 Heat Pump Water Heaters

Jørn Stene, Norway

CO_2 heat pump water heaters (HPWH) represent the most energy efficient and eco-friendly heat pump technology for domestic hot water (DHW) heating. After the fundamental research at NTNU-SINTEF in Norway during the 1990s and the commercialisation in Japan in 2001, components and units have reached a high technological level for both residential and non-residential applications. In Japan more than 5 million residential CO_2 HPWH have been sold, and in recent years an increasing number of large-capacity CO_2 HPWH for e.g. blocks of flats, hotels, hospitals, nursery homes and sport centres have been installed in Asia, Europe and the USA. This article provides an overview of the basis of the technology, and presents some interesting installations in Norway, the origin of the technology.

CO_2 as Working Fluid

The main reason for introducing carbon dioxide (CO_2, R744) as a working fluid was the search for environmentally acceptable fluids that could replace the ozone-depleting CFCs. From an environmental point of view, CO_2 can be regarded an almost ideal working fluid since it is non-toxic, non-flammable and does not contribute to ozone depletion (ODP=0); its Global Warming Potential is very low (GWP=1) compared to many other refrigerants.

Many of the thermophysical properties of CO_2 differ considerably from the HFCs, HFOs, ammonia and hydrocarbons. CO_2 has an especially low critical temperature (31.1 °C), which means that a CO_2 heat pump will have to reject heat above the critical point at a supercritical pressure. At supercritical pressure, heat is not rejected by means of condensation of the fluid, but by the cooling of high-pressure gas in a gas cooler (heat exchanger). In a CO_2 HPWH, city water at 5 to 15 °C is heated in a counter-flow gas cooler to the set-point DHW temperature (65 to 90 °C) while the CO_2 gas is cooled down correspondingly. Due to the considerable cool-down of the CO_2 gas, the average CO_2 temperature during heat rejection is rather low, leading to a high cycle COP, cf. the 2nd Law of Thermodynamics. Since CO_2 HPWH can provide Legionella-safe DHW (>65-70 °C) there is no need for external DHW reheating as for conventional HPWH.

Another unique property of CO_2 is the high critical pressure (73.8 bar). The operating pressure in CO_2 heat pump systems is typically 5 to 10 times higher than that of plants using HFCs, and this has been a challenge when designing compressors, heat exchangers, valves and pipe connections. On the other hand, the high pressure level, and with that the high vapour density, reduces the

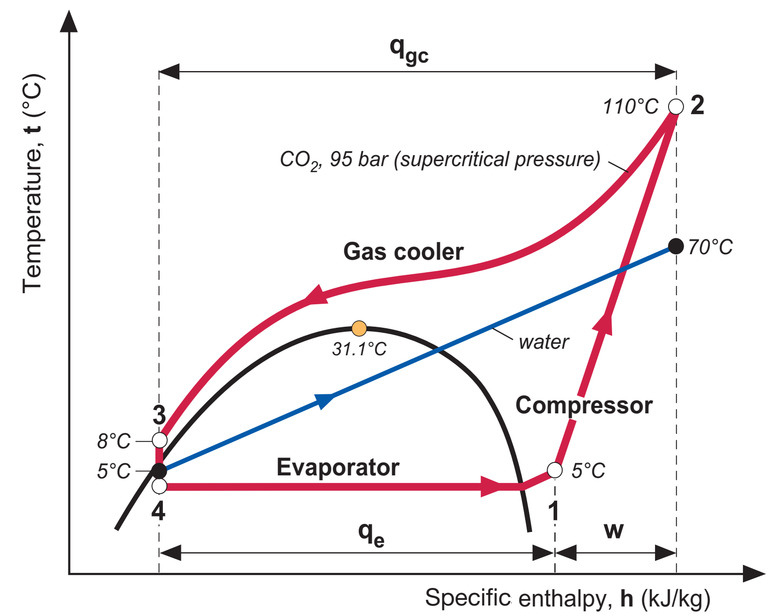

Figure 1. Principle example of the CO_2 HPWH cycle in a temperature-enthalpy diagram

required compressor volume by 35 to 85 % compared to the HFCs. Despite the high absolute pressure level in the evaporator (20 to 30 bar) and the gas cooler (80 to 110 bar), the low pressure ratio leads to excellent compressor efficiencies. CO_2 also has superior heat transfer properties, thus contributing to the high COP for CO_2 HPWH.

In order to achieve a high COP for a CO_2 HPWH, it is crucial that the high-pressure CO_2 gas is cooled down as much as possible in a counter-flow gas cooler. Figure 1 shows the principle of the CO_2 HPWH cycle in a so-called temperature-enthalpy diagram. In the example, CO_2 gas is cooled down from 110 °C to 8 °C in the gas cooler (red line, 2–3) while municipal water is heated from 5 to 70 °C (blue line).

The CO_2 technology was re-invented and developed during the 1990's at The Norwegian University of Science and Technology (NTNU) headed by the late professor Gustav Lorentzen as well the research organisation SINTEF. The fundamental research was to a large extent funded by Norsk Hydro ASA and The Norwegian Research Council. In 2001, Denso Corporation in Japan launched the first residential air-source CO_2 HPWH (EcoCute) based on CO_2 patents from Norway. The energy utility Tokyo Electric Power Company (TEPCO) provided subsidies and marketing, and was a crucial party in the commercialization of CO_2 HPWH in Japan. By 2015, more than 5 million units have been sold in Japan, thus providing a considerable reduction in greenhouse gas emissions.

Compressors, heat exchangers, valves and pipe connection technologies for CO_2 HPWH have eventually reached a high technological level, and a number of large-capacity air-source and water/brine-source systems have been installed in Asia, Europe and the USA the recent years. The following presentation describes three installations in Norway.

Block of Flats, Oslo – 2011

Tveita borettslag, a housing cooperative in Oslo, comprises three blocks of flats with 819 apartments. In 2011 the buildings were refurbished and the oil-fired boilers in each block of flats were replaced by a 260 kW brine-to-water heat pump for space heating and a 100 kW CO_2 HPWH. The buildings still have the original exhaust air ventilation system, and the exhaust air at approx. 22 °C from two ventilation ducts serves as a heat source for the heat pumps. The heat is transferred from the ventilation air to the evaporators by means of a closed-loop secondary system with circulating anti-freeze fluid (brine). The DHW system comprises thirteen 400 litre single-shell hot water tanks that are connected in series. Small diameter tanks are favourable since conductive heat transfer between hot and cold water during tapping and thermal charging of DHW will increase the average inlet water temperature to the gas cooler and thereby reduce the COP.

The CO_2 HPHW has a reciprocating compressor with intermittent (on/off) operation, a plate-and-shell heat exchanger as evaporator, two plate heat exchangers in series as gas cooler, a suction gas heat exchanger and a low-pressure receiver (liquid separator). The heat pump supplies 73 °C DHW, and no reheating is required. Since the evaporator for the space heating heat pump is connected to the same secondary system as the CO_2 HPWH, the brine temperature varies during the heating season, and the heating capacity for the CO_2 heat pump fluctuates between 85 and 110 kW.

At The Norwegian University of Science and Technology (NTNU) a master student estimated a seasonal COP of approx. 4.4 for the CO_2 HPWH excl. the energy use for the pumps in the secondary system and DHW system. He recommended a number of improvements including optimum high-side pressure control for the CO_2 HPWH due to the variations in the brine temperature, installation of diffusers at the inlet/outlet of the DHW tanks in order to minimize water velocities and mixing of hot and cold water, replacement of control valves with variable speed pumps and improved insulation of the DHW pipelines. In 2013 Tveita borettslag received the Norwegian Heat Pump Award from the Norwegian Heat Pump Association since they were future-oriented and installed the first large-capacity CO_2HPWH in Norway.

Hospital, Tromsø – 2014

In 2012 COWI Norway carried out an energy analysis at the University Hospital of North Norway (UNN) in Tromsø. One of their recommendations was to install a combined 350 kW CO_2 liquid chiller and HPWH to cover the base load for process cooling and the entire DHW heating demand at the hospital. Prior to the installation of the CO_2 HPWH, the existing hot water tanks were connected in series in order to achieve the lowest possible water temperature at the gas cooler inlet and with that maximize the COP. The heat pump is equipped with reciprocating compressors, a shell-and-plate heat exchanger as the evaporator and plate heat exchangers as the gas cooler. The capacity of the compressors is controlled according to the set-point temperature in the cooling system, and the heat pump supplies 70 °C DHW.

Figure 2. 350 kW CO_2 HPWH at UNN. Photo – Kuldeteknisk AS.

The CO_2 heat pump, that was put into operation in 2014, is the largest CO_2 HPWH in Norway and probably the largest installation in Europe. The system achieves an average COP of approx. 3.5. The relatively low COP is due to, among other things, poor insulation standard for the existing DHW pipelines and a non-optimized pipeline system. When the existing DHW system has been upgraded the COP is expected to reach about 4. Since the CO_2 liquid chiller and HPWH provides simultaneous cooling and heating, the current total COP is about 7, i.e. 3 kWh cooling and 4 kWh heating for each kWh supplied electricity. The combined operation is an excellent example on how to minimize primary energy use in buildings with both heating and cooling demands.

Block of Flats, Trondheim – 2014

The CO_2 heat pump technology was developed at NTNU-SINTEF in Norway. In 2014 the company Cadio AS became the first Norwegian manufacturer of water/brine-to-water CO_2 HPWH. The low-pressure receiver (LPR) comprises three smaller vessels connected in series in order to minimize the CO_2 volume and thereby the PV value (cf. requirements in the EU Pressure Equipment Directive). The compressor has intermittent (on/off) operation, and a correctly designed unit will have about 18 to 20 hours operating time a day. A variable speed drive pump in the gas cooler circuit controls the water flow rate to maintain a constant 70 °C DHW temperature at the gas cooler outlet. The control system is based on in-house software, and the unit is equipped with thermal and electric energy meters.

Figure 3. Norwegian CO_2 HPWH at UNN. HPWH. Photo – Cadio AS

In 2014, a 30 kW CO_2 HPWH was installed in a block of flats in Trondheim. The heat pump replaced an old, inefficient R-22 HPWH. The heat source is exhaust air from a centralized ventilation system, and a secondary system with circulating brine transfers heat from the ventilation air to the evaporator. The CO_2 HPWH supplies DHW at 70 °C, and the DHW is stored in nine large-capacity tanks that are connected in series. The heat pump is operated with a constant gas cooler pressure of 100 bar, and covers the entire DHW heating demand for the 56 apartments.

On-site measurements have documented an average COP of 3.7 including the energy use for the brine and DHW pumps. This corresponds to about 70 % reduction in bought energy compared to a DHW heating system based on electric immersion heaters or district heating.

Conclusion

CO_2 heat pumps represent the most energy efficient and eco-friendly technology for DHW heating, and there is a considerable world-wide potential for this technology in buildings with a large DHW demand, e.g. hospitals, nursery homes, hotels, sport centres, blocks of flats and apartment buildings. In order to attain trouble-free operation and maximum COP, it is crucial that the design and operation of the DHW system is adapted to the special characteristics of the CO_2 heat pump cycle. For retrofitting installations the DHW system normally has to be redesigned.

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Events 2016

7 November
HPT TCP: IOC meeting
(closed meeting designated IOC delegates)
Sophia Antipolis, France

8 November
HPT TCP: Strategy workshop
(closed meeting designated ExCo delegates and IEA representatives)
Sophia Antipolis, France

9-10 November
HPT TCP: ExCo meeting
(open/closed)
Sophia Antipolis, France

1-2 December
International Symposium on New Refrigerants and Environmental Technology 2016
Kobe, Japan
http://www.jraia.or.jp/english/symposium/

13 December
EUREKA 2016: Heating, Cooling & Ventilation
The Hague, The Netherlands
http://www.eureka-hvacr.eu/

Events 2017

28 January-1 February
ASHRAE Winter Conference
Las Vegas, Nevada, USA
https://www.ashrae.org/membership--conferences/conferences/2017-ashrae-winter-conference

14-16 March
International Ground Source Heat Pump Association (IGSHPA) Technical Conference and Expo
Denver, USA
http://www.igshpa.okstate.edu/conf/

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

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

10-12 May
EHPA Heat Pump Forum 2017
Brussels, Belgium
http://www.ehpa.org/events/upcoming-events/httpforumehpaorg/

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

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

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

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

24-28 June
ASHRAE Annual Conference
Long Beach, California, USA
http://ashraem.confex.com/ashraem/s17/cfp.cgi

20-22 July
8th International Conference on Compressors and Refrigeration (ICCR)
Xi'an, China
http://www.iifiir.org/medias/medias.aspx?instance=EXPLOITATION&set-language=EN

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

6-8 September
9th International Conference on Compressors and Coolants
Bratislava, Slovakia
http://szchkt.org/compressors/Contents/2017_intro.html

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

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

Vision
The HPT TCP is the foremost worldwide source of independent information and expertise on environmental and energy conservation benefits of heat pumping technologies (including refrigeration and air conditioning). The HPT TCP conducts high value international collaborative activities to improve energy efficiency and minimise adverse environmental impact.

Mission
The HPT TCP strives to achieve widespread deployment of appropriate high quality heat pumping technologies to obtain energy conservation and environmental benefits from these technologies. It serves policy makers, national and international energy and environmental agencies, utilities, manufacturers, designers and researchers.

IEA Heat Pump Centre
A central role within the HPT TCP is played by the IEA 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 or the address above.

The IEA Heat Pump Centre is operated by SP Technical Research Institute of Sweden.

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