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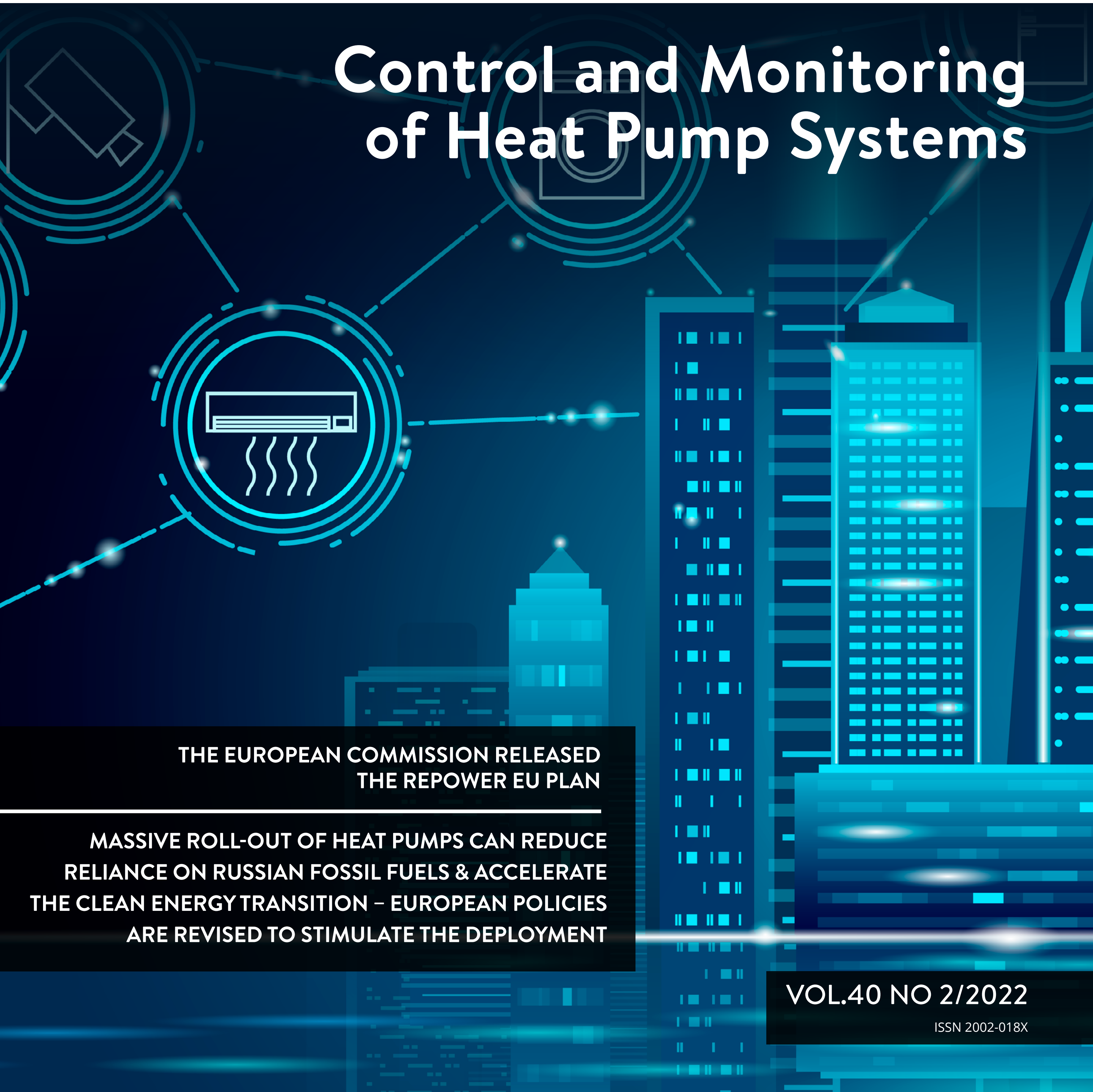
Heat Pumping Technologies MAGAZINE

A HEAT PUMP CENTRE PRODUCT



Control and Monitoring of Heat Pump Systems

THE EUROPEAN COMMISSION RELEASED THE REPOWER EU PLAN

MASSIVE ROLL-OUT OF HEAT PUMPS CAN REDUCE RELIANCE ON RUSSIAN FOSSIL FUELS & ACCELERATE THE CLEAN ENERGY TRANSITION – EUROPEAN POLICIES ARE REVISED TO STIMULATE THE DEPLOYMENT

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Heat Pumping Technologies
MAGAZINE

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In this issue

For over a century, societies have been reliant on fossil fuels for powering their economies, and even as we speak, many European countries' dependency on Russian-imported fossil fuels is becoming more apparent. In the face of the emerging global energy crisis, heat pumping technologies have never before had as much positive attention from policymakers as they have now. According to the IEA's Net-Zero by 2050- A Road Map for the Global Energy Sector, **digitalisation and smart controls will be critical in accelerating technology implementation and enabling efficiency gains** that could reduce emissions from the buildings sector by 350 million tonnes of CO_2 by 2050. The importance of knowing what and how to measure in order to achieve an optimized control system is discussed in the foreword of this issue.

Under the title of "How low can you go?" the column provides Netherland's experience in tackling the challenges for existing buildings to transition from a very efficient high-temperature gas boiler to a low-temperature efficient and affordable heat pump system.

In the Heat Pumping Technologies news section, you can read a summary of the IEA's 7th Annual Global Conference on Energy Efficiency, an excerpt from the European Commission on the REPowerEU Plan and a summary of the heat pump market trends, research activities and which policy measures have been successful and less successful in Norway.

The topical articles of this issue all address how to explore a new perspective for increasing heat pump system performance through (i) the development of advanced control and monitoring systems capable of achieving the best energy efficiency while reducing operating and maintenance costs, and (ii) smart integration of heat pumps into the energy systems.

Enjoy your reading!

Metkel Yebiyo, Editor
Heat Pump Centre
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"Messen ist wissen" – To Measure is to Know

"Messen ist wissen" – to measure is to know – is a well-known and frequently used quote by the German electrical engineer, inventor and industrialist Werner von Siemens. In 1847 he founded Siemens & Halske - a company that has grown to become the global industry conglomerate Siemens AG. Werner von Siemens was right – good quality measurements are essential for raising our knowledge and awareness. We must measure to see how well our heat pumps, systems and buildings work and perform. We must measure to increase experience and develop best practices. We must measure to ensure that we obtain the performance expected from our investment. But we must also know how to measure - and to do so cost-effectively.

Within the recently finished IEA HPT international collaboration project Annex 52, Long-term performance measurements of ground source heat pump systems for commercial, institutional and multi-family buildings, academic and industry experts joined forces to improve the state of the art. As part of this collaborative investigation, system performance of more than 30 large ground source heat pump systems in seven countries was measured. This experience was used to write three guideline documents on instrumentation, uncertainty calculation and key performance indicators, to support future heat pump system designers and owners. These guideline documents will improve the design and lower the analysis costs for all types of heat pump systems, whether they use the ground, water or air as an energy source. Thoughtful design of the instrumentation and measurement system prior to system installation can significantly lower the analysis cost.

The former ASHRAE headquarters building in Atlanta, Georgia, was renovated in 2008, and was at the same time made into a thoroughly instrumented living lab with three separate HVAC systems, of which one was a ground source heat pump system serving the second floor. Four years later, a knowledgeable engineer, Kirk Mescher, visited the building and noticed that the differential pressure setpoint controlling the loop circulating pump was set too high, at about 138 kPa. He recommended reducing the setpoint to 55 kPa. This simple change of the system control lowered the flow rate through each heat pump, significantly reducing the pumping energy and slightly increasing the heat pump energy. Taken together, though, the overall system performance factor for heating increased from 2.7 to 3.8 from one winter to the next.

This anecdote illustrates not only the importance of knowing what and how to measure but also points at the importance of an optimized control system. Knowledge about how our buildings and components perform, based on measurements and data analysis, also allows us to control and optimize our heat pump systems and save energy and money.

In turn, lowering the barriers for system performance measurement will lead to the implementation of more heat pump systems, improved energy efficiency and more renewable energy in our energy system. This is beneficial, not only for those who are wise enough to install heat pumps, but for our planet, and hence for all of us – heat pump enthusiasts or not. We know it.

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How low can you go?

After years of inexpensive and comfortable high-temperature natural gas-fired boilers, it is necessary for Dutch homeowners and tenants to prepare their homes for the adoption of a low-temperature heat pump system. The Dutch government just announced that from 2026 a hybrid heat pump or another renewable alternative would be mandatory if the gas-fired boiler system needs to be replaced. The government starts with the preparation of the standardization and regulation process.

The demand for heat pumps in the Netherlands is increasing due to the restriction on natural gas laws in new buildings and the overall increase in energy prices. The transition from a very efficient high-temperature gas boiler to a low-temperature efficient and affordable heat pump system is challenging for existing buildings. With a new support program, the introduction of the hybrid heat pump system in addition to the gas boiler is getting more successful. It saves 60-70% of the gas consumption and provides less congestion on the electricity network; according to the **Installatiemonitor**, a 600 dwellings smart metering measurement campaign initiated by the grid operators. The move to low-temperature (LT) heating might be beneficial for improving the efficiency of heat pump systems. However, there is no scientific proof of how much we can lower the temperature of current buildings' heating systems.

The **WarmingUp consortium** in the Netherlands is conducting a measurement campaign over 200 homes to determine whether homes could switch to low-temperature heating without modifying the building envelope or radiator system Preliminary findings show that 60% of the Dutch building stock might already LT-ready (T<55C). This is encouraging news for the installation of low-temperature heat pump systems in existing buildings. Peak shaving, however, is required for adoption due to the current status of the electricity grid. As a result, the Dutch government's policy prioritizes the development of hybrid heat pumps as the first step toward electrifying the existing building stock.

A sophisticated method like high-speed monitoring is essential to understand the performance and interaction between the hybrid heat pump, gas boiler, and radiator system. Netherlands Enterprise Agency challenged Dutch heat pump manufacturers to monitor their installed hybrid heat pump system and analyze the results after three modifications: standard cavity wall insulation, radiator fans and hydraulic commission of the heating system. It seems that relatively simple and affordable measures have already a significant impact on gas and electricity use. It was a more qualitative than quantitively measurement experiment, but it shows the importance of high-speed monitoring for understanding the performance of the installed heat pump system as well as for the house owner, the manufacturer and the installer. The experiment was a starting point for the government-financed measurement campaign **Demo Project Hybrid** wherein 200 hybrid heat pump systems get installed and monitored in cooperation with a group of heat pump manufacturers and installers. The campaign stimulates transparency for manufacturers, installers and house owners on the one side and model builders, grid operators and policymakers on the other side.

MARION BAKKER

MSc The Netherlands Enterprise Agency/
NL IEA HPT Delegate

It is time to communicate to a broader audience about the performance of an installed heat pump system. Not only to win trust and acceptance from the house owner or tenant but also to accelerate the adoption by analyzing and optimizing the heat pump system. The running data-driven campaigns show the importance, including the role of validation.

Heat pumps and ventilation systems with heat recovery can now be tested under realistic conditions with the modeling of insulation, ventilation, and consumer behavior, thanks to the installation of a **Heat Pump Application test facility** by Dutch TNO. With these types of facilities, TNO and other research institutes can play a larger role in the validation of installed heat pump systems for various types of typical Dutch dwellings in collaboration with manufacturers. The first test results provide insight into a variety of hybrid heat pump settings and control when used in conjunction with a gas boiler. The results of these types of dynamic experiments suggest that traditional analytical energy transition models should be reconsidered.

The focus is no longer solely on the operation of a single heat pump. Smart heat pump control in conjunction with an existing gas boiler, as well as a new storage tank, PV(T), and even an electric car are all possibilities. Due to the expansion of renewables, Dutch grid operators are seeing more unanticipated limitations on the electricity network. The **Flexible Power Alliance Network (FAN)** is dedicated to developing open standards for utilizing flexible energy in energy systems. FAN aspires to help create an open and equitable energy system in which local surpluses in sustainable energy supply and demand are absorbed by energy supply and demand flexibility. FAN's goal is to employ open standards to maximize and unlock flexibility in the energy system. FAN has invited Dutch and European heat pump manufacturers to incorporate key features and identify roadblocks in order to develop a more open standard.

In the coming years, the adoption of heat pumps in the originally gas-fired Dutch energy system will reach a crucial phase. The heat pump performance secrets are being revealed thanks to the ongoing measurement campaigns. The comfort requirements are critical for adoption. That is why we keep asking the Dutch house owner and tenant: How low can you go?

Release of IEA report "Technology and innovation pathways for zero-carbon-ready buildings by 2030 – A strategic vision from the IEA Technology Collaboration Programmes"

On September 1st, 2022, IEA released a report which provides the strategic vision of experts from the IEA Technology Collaboration Programmes (TCPs) on how to help achieve some of the most impactful short-term milestones for the buildings sector outlined in the IEA's Net Zero by 2050 Roadmap. The report consists of 10 articles and each article's title reflects one of these milestones.

The rapid deployment in the building sector of clean energy technologies and behavioral shifts, supported by innovation strategies, has the potential to significantly reduce carbon dioxide (CO_2) emissions by 2030 and paves the way to achieve the zero-carbon buildings stock targets under the IEA's Net Zero Emissions by 2050 Scenario (NZE Scenario). Buildings operations account directly and indirectly for approximately 30% of global energy sector emissions.

Reaching those targets for a zero-carbon buildings stock by 2050 is a significant challenge, but one that also opens important opportunities. The current decade is a critical period for governments to put in place policy frameworks and regulations to support this vision. Technologies that are available on the market today are theoretically able to provide nearly all of the emissions reductions required by 2030 in the NZE Scenario, but a multitude of complex issues make full implementation very challenging at present.

In this report, experts from the IEA Technology Collaboration Programmes (TCPs) provide their strategic visions on how to overcome the challenges and offer recommendations for the technology solutions, innovation strategies and policy instruments needed to help deliver the required milestones for buildings by 2030 outlined in the NZE Scenario—valuable benchmarks on the road to 2050.

Series of articles' titles based on some of the most critical IEA Net Zero by 2050's buildings milestones to 2030

- All countries targeted for **zero-carbon-ready codes** for new buildings by 2030
- **Renovation** of near 20% of existing building stock to zero-carbon-ready by 2030 is ambitious but necessary
- Installation of about 600 million **heat pumps** covering 20% of buildings heating needs by 2030
- Approximately 100 million households rely on **rooftop solar PV** by 2030
- **Solar PV and wind** supply about 40% of **building electricity** use by 2030
- 350 million building units linked connected to **district energy networks** by 2030, provide about 20% of space heating needs
- **Solar thermal technologies** deployed in around 400 million dwellings by 2030
- Targeting 100% **LED lighting** sales by 2025
- Residential **behavior changes** lead to a reduction in heating and cooling energy use by 2030
- By 2030 **EVs** represent more

The third article titled "Installation of about 600 million heat pumps covering 20% of buildings heating needs by 2030" has been authored and reviewed by experts from the Technology Collaboration Program on Heat Pumping Technologies (HPT TCP).

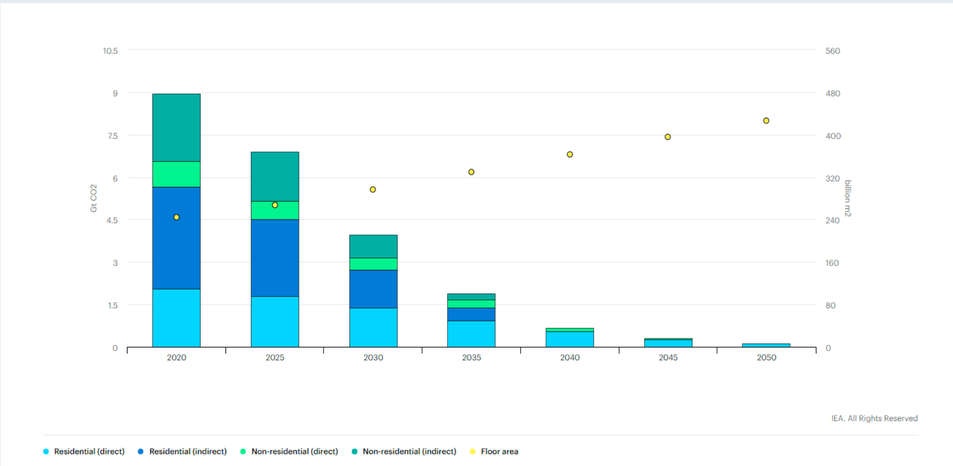

Figure 1. Global buildings sector CO_2 emissions and floor area in the NetZero Emissions by 2050 Scenario. Sources: Data from IEA's Net Zero by 2050: A Roadmap for the Global Energy Sector. All rights reserved.

Heat Pumps were highlighted as One of the most Important Super-Efficient Appliances paving the way to Net Zero at IEA's Global Annual Conference on Energy Efficiency

IEA's 7th Annual Global Conference on Energy Efficiency took place on June 7-9 in Sönderborg, Denmark. Energy efficiency is high on the agenda these days due to the climate crisis as well as the wish to reduce the dependence on Russian fossil fuels. The overall message from the conference is that energy efficiency measures should be the first choice in mitigating both these crises since it results in reduced cost, reduced dependence on fossil fuels and reduced emissions – moreover, it can be implemented right away! In many cases, we do not need to wait for future innovations. Heat pumping technologies were raised as an important part of the solution, both when it comes to heating buildings and industries and for efficient cooling. It contributes to improved energy efficiency as well as an increased share of renewables in the energy system. Thereby heat pumping technologies contribute to increased security of supply!

During the conference, a couple of speeches and presentations were given, but mostly the program consisted of panel discussions where policymakers and representatives from industry, the financial sector and technical experts held fruitful and interesting discussions. Many of the presentations and discussions revealed that actions to increase energy efficiency are not taken often and quick enough, even though the right technology is existing and the measures would be profitable. The various obstacles, barriers but also solutions were discussed during the days – and to conclude, in many cases, partnership and joint actions by policy, industry and financiers would be the key! However, investors need to be informed and educated about the possibilities.

ESCOs - Energy Services Companies
Brian Motherhood, from IEA, started on the first day of the conference. He said that governments from 60 countries, of which 20 on the ministerial level, were present at the conference. He stated that energy efficiency is of high importance, progress needs to double, and investments need to increase. However, governments cannot do this alone; they cannot cover all the investments needed. This is where ESCOs (Energy Services Companies) comes in. They have the right knowledge of what to be done. However, ESCOs cannot operate without the right policy measures in place and not without access to financing for the measures. Thereafter followed sessions about ESCOs and in what way they will be able to contribute to that energy efficiency measures are realized and which type of support they would need from a policy. It could be concluded that in many cases, a partnership between ESCOs, the client (building owner or industry), representatives from the financial sector as well as insurance companies could be the solution. Such partnerships must be able to deal with risks properly, and they should be supported by policy. Very often, ESCOs have challenges with financing. They get the needed loans for the first projects, but thereafter they get problems since they do not fulfill the normal financing requirements. Often, also their clients meet challenges with investments since energy efficiency is not their core business. To conclude, the financing market is not sufficiently well set for the financing of energy efficiency measures, even though it is a low-risk investment, although sometimes with longer payback times. In addition, financing alone is insufficient to solve the problem – aggregators, educators, and regulators are also needed.

Super-efficient appliances pave the way to Net Zero
On June 7, a fascinating panel discussion (Figure 1) about **Heat Pumps** and what can be done to deploy the most efficient equipment took place in a session titled **"Super-efficient appliances pave the way to Net Zero"**. Caroline Haglund Stignor from **Heat Pump Centre** was one of the panelists. During the discussion, the audience could learn about the Electric Ireland Superhomes,

a one-stop-shop for a home energy retrofit, challenges related to supply chains and the lack of components that manufacturers experience right now and that there is no lack of installers in Europe, maybe of heat pump installers, but installers could be retrained. It was also discussed how finance could be unlocked to enhance the energy efficiency, how to create incentives and that emissions should be controlled beyond reporting. Caroline Haglund Stignor shared in her intervention the success factors behind the phasing out of oil heating in detached houses in Sweden, to a large extent by the installation of heat pumps. To summarize, she concluded that it helps if clean heating is the most economically attractive solution for the end-user, and this can be achieved by the introduction of carbon pricing, adjusting levels of tax, VAT and subsidies. However, more than one policy measure is often needed to transform a market; a combination of measures that creates awareness and builds confidence in the technology must not be forgotten. Finally, investment in R&D to continue the development of the technology and its systems is of high importance! **Thomas Nowak, from EHPA**, emphasized in his concluding remark that if the massive roll-out of heat pumps envisaged in the IEA Net-Zero by 2050 Roadmap and in the REPowerEU communication shall be realized, policymakers need to set priorities for the technology and establish a Heat Pump Accelerator.

During this session, there was also a deep dive into industrial electric motors since they are significant electricity consumers on a global level. At the same time, efficient technology is available but not applied in many parts of the world. A policy solution to this would be to “maximize the minimum and incentivize the maximum”, referring to the MEPS (minimum efficiency performance standards).

The Value of Early Action on Energy Efficiency
On June 8, the **Minister of Energy from Denmark, Dan Jorgensen**, gave an opening presentation. He said that investments in energy efficiency would often pay themself in a few years. Energy efficiency is a win-win-win. It helps us save the planet, and we will save money doing it!

Fatih Birol, the Executive Director of IEA, (Figure 2) held an opening presentation. “We are in the middle of the first global energy crises – this crisis may be the turning point”, he said. He emphasized the triple benefits of energy efficiency – reduced cost, improved security, and reduced emissions. He also stated that **if all countries had the right energy policies and incentives and applied existing technologies, the world would save the same amount of energy that China uses today**. He also talked about cooling. In many countries, cooling is the number one driver of electricity consumption. In Southeast Asia, only 15% have Air Conditioners (AC), and in India, less than 10%. The numbers are much higher in Japan and USA. The very tragic fact, however, is that in Southeast Asia, an AC requires three times more electricity to give the same cooling as in Japan.

Figure 1: Members of the heat pump expert panel.

Figure 2: Presentation by Fatih Birol, the Executive Director of IEA.

Thereafter followed, a panel discussion. **Kadri Simson, the European Energy Commissioner**, talked about how the EU has decided to reduce its dependence on fossil fuels from Russia. There are three principles – diversification, accelerating the rollout of renewable energy and saving energy. The higher demand, the higher the prices will be. Immediate energy savings can be achieved by behavior. The deployment of **heat pumps** and the development of sustainable district heating systems is an important part of the strategy to reduce the dependence on fossil fuels. Phase-out of fossil fuel boilers just for space heating would reduce the energy use by 8%. She said that the cooperation between the EU and IEA has been tighter than ever.

During the discussion, it was also stated that the energy efficiency measures would work faster than building new renewables. The two strategies must go hand in hand.

Amina Mohammed, from the UN talked about the importance of making energy efficiency retrofits of buildings and using excess heat from supermarkets and data centers. This would result in lower cost, lower fuel imports, and lower emissions! Tripe benefits!

The CEO of Danfoss talked about how they work with energy management at their industrial sites. First, they make sure to use less energy; thereafter, they reuse the energy they have on the site (from ventilation, data centers and production). Finally, they use green renewable energy for the remaining part.

Minister of Energy of Ukraine, German Galushchenko, participated via a link in the conference (Figure 3). He told the audience about how they every day repair their energy infrastructure again and again. More than 5 million have been cut off from the electricity supply, and many have no gas in their house. He emphasized that they need more reliable sources – not only NOT from Russia, but also sustainable and low carbon.

Efficient Cooling for Global Development

On June 7, there was also a session about Efficient Cooling for Global Development

The question "How do we meet the rising demand for cooling?" was discussed. It is of importance not to lose the people part of the equations. Cooling is fans, cold chains and AC, and there was a call for policymakers and industry to collaborate and set common ambitions. On the question "What can be done to make energy-efficient cooling more affordable and accessible for more people?" several answers were given - the design can be changed, 3D printing can be used to enable local production, and R&D is needed, innovation is needed. As much as possible, the equipment should be produced locally.

Other questions discussed were "How can policy tools help us beat climate challenge in your country?" and "What do you want to happen at the next COP meeting related to cooling?" One of the answers given was that all governments should agree on the same ambitious efficiency standards for the most important product groups: AC, refrigeration devices, electric motors, and bulbs.

Accelerating policy implementation for resilience, affordability and climate

A panel discussion was held about accelerating policy implementation for resilience, affordability and climate. **Kelly Speakes-Backman from DOE, United States**, talked about Bidens' ambitions to cut the emissions by half until 2030 and to have a clean electricity grid by 2035. She said that the case for energy efficiency has never been more urgent since its booster energy security. Representatives from industry, i.e., the CEO of BASF

Figure 3: Presentation by the Minister of Energy from Ukraine, German Galushchenko.

and the CEO of Alfa Laval, talked about how they work with decarbonization and energy efficiency in their industries, e.g., to use **large-scale industrial heat pumps** to produce steam. A concern was also raised about the European regulatory landscape related to energy – there was a fear that Europe is getting "over-regulated", which will kill entrepreneurship. The regulatory framework should set the floor, and an efficient CO_2-price could be the solution, giving a sufficient framework. Decarbonization needs to be a business case to make sense. It is also of importance that policy sponsors the first movers - demonstrations and pilot plants – to reduce risks.

To conclude, quoting **Fatih Birol, the Executive Director of IEA**, "I don't know any other solution like #EnergyEfficency that can simultaneously address our economic crisis, energy crisis & climate crisis. And it is the reason why at the IEA we say efficiency is the very first fuel".

Read more:

- https://www.iea-events.org/energy-efficiency
- https://www.iea-events.org/energy-efficiency/session/ce53d871-94b5-ec11-997e-a04a5e7cf9dc
- https://www.linkedin.com/posts/caroline-haglund-stignor-70696390_iea-whyee-heatpumpingtech-activity-6940370159840735232-K7OP/?utm_source=linkedin_share&utm_medium=member_desktop_web

Massive Roll-out of Heat Pumps can Reduce Reliance on Russian Fossil Fuels & Accelerate the Clean Energy Transition – European Policies are Revised to Stimulate the Deployment

The European Commission released the REPowerEU Plan on May 18, along with a number of annexes, including an EU Save Energy Communication'. All documents are available at the bottom of this EC page.

This communication states, among many other things, "**Regarding heat pumps,** the EU aims to double the current deployment rate, resulting in a cumulative 10 million units over the next 5 years. Member States can accelerate the cost-effective deployment and integration of **large-scale heat pumps, geothermal** and solar thermal energy by developing and modernising district heating systems, which can replace fossil fuels in individual heating, and clean communal heating, especially in densely populated areas and cities; and by exploiting industrial heat whenever available. This accelerated deployment should be matched by a fast ramp-up of the production of **heat pumps**, including through facilitated access to finance."

The HPT TCP conducts several collaboration projects which will support this accelerated heat pump deployment rate, see, e.g. Annex 50 - Heat Pumps in Multi-Family Buildings for space heating and DHW, Annex 52 - Long term performance measurement of GSHP Systems serving commercial, institutional and multi-family buildings, Annex 57 - Flexibility by implementation of heat pumps in multi-vector energy systems and thermal networks and Annex 58 - High-Temperature Heat Pumps.

The Commission proposes a number of measures in its accompanying 'EU Save Energy' Communication to speed up and incentivize the use of heat pumps, including tougher energy efficiency criteria for buildings, which should see the end of 'stand-alone' fossil fuel boilers by 2029. According to the press release of the European Heat Pump Association, "the Commission also includes **many other points in REPowerEU which will help speed up the roll-out of heat pumps**. These include:

» Encouraging the Member States to accelerate the deployment and integration of large-scale heat pumps cost-effectively, for example, by exploiting industrial heat
» Encouraging the Member States to use supporting measures regarding pricing to encourage switching to heat pumps
» Encourages co-legislators to bring forward the cut-off date for public subsidies for fossil fuel-based boilers in buildings, from 2027 to 2025
» Creating a new window in the Innovation Fund – which is financed through the EU Emissions Trading System – to support innovative cleantech manufacturing, including heat pumps
» Proposing increasing the binding energy efficiency target to at least 13% by 2030 based on 2020 levels, from the current 9%.
» Proposing increasing the renewable energy target to 45% from the current proposed 40%
» Setting up a large-scale 'skills partnership' which should help train up people to work in the heat pump industry."

Some countries have already picked up the recommendations from the Commission for example, according to Clean Energy Wire, the German government outlined plans on Tuesday (17 May) to save more energy due to mounting pressure to reduce Germany's reliance on Russian fossil fuels.

The plan includes funding and incentives to promote more energy-efficient heating and building standards and the discontinuation of subsidies for gas heating and construction projects that do not meet the new Efficiency House 40 standard.

Renovation of buildings with the lowest energy performance is seen to have the greatest potential for reducing energy consumption and greenhouse gas emissions. Solar roofs are to become the norm in order to boost renewable energy generation swiftly. While the German government plans to make heat pumps mandatory by 2024, the new work program aims to retrain competent workers in the industry.

A new "Heat pump build-up programme" aims to incentivise workers and companies in the building sector to participate in upskilling programmes. The building sector will also be incentivised to direct more resources into heating renovations, with a focus on the installation of heat pumps.

The German government's objective is to have "more than 500,000" heat pumps installed every year until 2024 and 800,000 per year afterwards when heat pumps become mandatory.

Similarly, the Dutch government intends to ban new fossil fuel-centric heating system installations as of 2026 while introducing the mandatory use of heat pumps or connections to heat networks.

Few countries are as reliant on gas to heat homes as the Netherlands. In 2018, fossil gas covered [71% of residential demand,](#) while the liberal use of greenhouses in agriculture further adds to the situation. Thus, citizens have been hit hard by record gas prices.

The Netherlands will now become the next country in the EU to mandate heat pumps. The "trigger point" for the mandate will be the replacement of a house's heating installation, like a boiler.

Much like plans in neighbouring Germany to mandate at least hybrid heat pumps as early as 2024, the Dutch government is betting on the efficacy of so-called hybrid heat pumps, which run on electricity for most of the year. If you want to learn more about hybrid heat pumps, please see the reports from HPT Annex 45 Hybrid Heat Pumps.

Read more about the new policies in Germany and the Netherlands on the links below.

- » https://www.cleanenergywire.org/news/germany-presents-energy-efficiency-work-plan-reduce-fossil-fuel-demand
- » https://www.euractiv.com/section/energy/news/germany-presents-energy-efficiency-work-plan-to-reduce-fossil-fuel-demand/
- » https://www.euractiv.com/section/energy-environment/news/netherlands-to-ban-fossil-heating-by-2026-make-heat-pumps-mandatory/

INFORMATION

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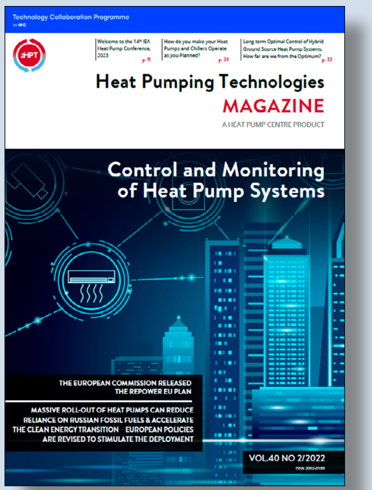
The Heat Pump Center publishes the Heat Pumping Technologies Magazine three times a year. The Magazine is available for free on the HPT website.

At the same time as the Magazine is launched, the Heat Pumping Technologies Newsletter is distributed. The Newsletter contains shorter versions of the Magazine articles with links to the full Magazine and is a good reminder that there is a new Magazine issue to read. In between the launch of the Magazine, the Newsletter is released on a monthly bases, summarizing some of the most interesting news within the field.



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Report from Norwegian National Workshop – The Heat Pump Market in Norway

The Norwegian National Team organized a hybrid onsite and online workshop on May 10 in conjunction with the IEA's HPT TCP Executive Committee (ExCo) meeting in May 2022, concentrating on the most current heat pump developments in market, policy, and research. The hybrid workshop was attended by more than 50 participants from 17 member countries around the world.

All presentations can be accessed here.

The workshop was opened by the chairman of the HPT TCP, Stephan Renz; he provided a quick introduction to the Technology Collaboration Programme on Heat Pumping Technologies by IEA (HPT TCP) and welcomed the attendees to the workshop. Mr Renz stressed the importance of the national workshop, adding that it provides an opportunity to examine Norway's energy infrastructure in greater depth by deploying heat pumps to decarbonize the building stock.

Next, Rolf Iver Hagemoen, Secretary-General of the Norwegian Heat Pump Association and delegate for Norway in the HPT TCP ExCo, gave a presentation on the heat pump market in Norway. He began by presenting background information about Norway, stating that it is a country of mountains and vast forests, vast empty expanses, and just around 3% arable. The population is over 5.3 million people, with around 1.2 million living in and around Oslo. People are also dispersed throughout the countryside. Sweden, for example, he claims, is significantly more centralized than Norway. Hagemoen emphasized that heat pumps are widely used in Norway; they can be found practically anywhere, even in areas with minus 30° or 35°C weather, in large cities, district heating, and large buildings.

His presentation used an Energy Sankey diagram to show the Norwegian energy system demographics, which show that renewables provide 98% in Norway, with 1690 hydropower plants accounting for 88% of Norwegian production capacity and 53 wind farms accounting for 10% of Norwegian production capacity. According to Hagemoen, most buildings in Norway are heated by electricity, either directly or through heat pumps, and heat pumps are used by more than half of all houses. Furthermore, Norway's whole transportation sector is being electrified; for example, 64.5% of cars sold in 2021 were fully electric, demonstrating that Norway has an energy system that is truly electrified in comparison to many other countries.

He stated that Norway currently has the highest electricity prices ever and that this is partly due to less rain than normal in the last years and lower filling level in the hydropower reservoirs. The Norwegian electricity system is also based on hydropower and is connected to the European energy system. Higher CO_2 and gas prices in Europe cause electricity prices to rise.

When it comes to the heat pump market in Norway, the European Heat Pump Associations put in a lot of effort to understand why some European marketers are strong and others are weak. He cited some of the significant variables that drove the heat pump market, such as the restriction of using fossil oil heating for most buildings since 2020 and increasing CO_2 levies for fossil fuels year after year from 2012 to 2020. In addition, incentives were doubled for 2018-2019 to assist people in replacing ageing oil burners with heat pumps. Also, the price difference between electricity and fossil fuels is critical.

In Norway, air-to-air heat pumps dominate the heat pump market, and one of the reasons for this, compared to many other countries, is that there are many buildings without hydronic systems. In countries like Finland, Sweden, France, and Italy, many buildings have direct electric heating and air-to-air heat pumps. Hagemoen provided an overview of the growth of the Norwegian heat pump market, which began in the 1970s and 1980s with various demonstration projects.

Figure 1: Attendees of the Norwegian national workshop.

According to his presentation, 105,000 heat pumps were sold in 2019, compared to 125,049 in 2021 and 91,894 in 2020, a 36% increase over the 2020 data and a significant number, when compared per capita to other countries. When it comes to the heat pump units sold, France and Italy are the leading countries. However, when it comes to per capita, Sweden, Finland, and Norway top the list. One of the major reasons is that Scandinavian countries began electrifying their societies considerably earlier than many other countries. Below is more information about the distribution of heat pumps in Norway.

In the period 1987 – 2020, almost 1.4 million heat pumps were sold in Norway.

- Air-to-air approx. 1.25 million
- Air-to-water over 50,000
- Brine-to-water over 55,000
- Ventilation heat pumps over 20,000

According to him, if the 2021 heat pump sales data are included, the total number of heat pumps sold in Norway since 1987 rises to over 1.5 million, with more than 1.1 million heat pumps in use, equating to more than 10 TWh of ambient heat.

2021 compared to 2020

- Air-to-air +38%
- Air-to-water +2.5%
- Brine-to-water +8%
- Exhaust air +29.9%

The second speaker was Synne Krekling, a researcher at SINTEF Community, who spoke about the potential for energy efficiency and heat pumps in Norwegian buildings. She discussed the range of energy efficiency measures, including retrofitting, more energy-efficient windows and doors, heat recovery ventilation, technical equipment, smart control, water-born heating, heat pumps etc.

Laurent Georges, an associate professor at the Norwegian University of Science and Technology (NTNU), spoke about analyzing energy upgrading projects of single-family houses towards a Norwegian nZEB level. He discussed the OPPTRE project, funded by the Research Council of Norway and led by the SINTEF Community, with NTNU as a research partner. This project investigated the renovation of Norwegian single-family wooden houses towards NZEB. In this context, the cost and energy performance of all-electric heating and ventilation solutions have been compared. Laurent said, most combinations investigated are based on heat pump technologies. According to his presentation, the heating of Norwegian residential buildings used to be dominated by direct electric heating. It was thus important to investigate whether heat pump solutions can compete with direct electric heating when renovated buildings get well insulated. Two houses, taken from an architecture competition in OPPTRE, were used as cases, and it was assumed that the thermal performance of their envelope had been improved significantly. Their research showed that the investment cost for the heat pump and ventilation technology is critical, and the payback time is relatively long. However, he said that many combinations with an intermediate investment cost, like compact heat pumps and exhaust air heat pumps, are also characterized by lower total costs. He mentioned that they represent a large potential to significantly decrease the electricity use without increasing the total costs for users. The study shows that it is important to account for the uncertainty in the investment cost in the lifecycle cost analysis of small residential buildings and that the uncertainty of future electricity prices (which used to be relatively low in Norway) significantly influences the cost-effectiveness of the heat pump solutions. In addition, their findings highlighted that the lack of a hydronic distribution system in existing Norwegian buildings is a barrier to implementing air-to-water and ground source heat pumps.

Under the title of High-Temperature Heat Pumps based on the international collaboration project (Annex 58), the researchers at SINTEF Energy Research gave a series of presentations. Dr Michael Bantle, a senior researcher, spoke about Electrification by High-Temperature Heat Pump and used the DryFiciency project as an industrial demonstration to highlight the operation experience and outlook. Ole Marius Moen presented findings from the international collaboration HPT project Annex 58: High-Temperature Heat Pumps State of the art, demonstration cases and development perspectives. Christian Schlemminger talked about SkaleUp: Industrial high-temperature heat pump for simultaneous process cooling and heating.

The talk by Kirsti Midttømme, Chief Scientist at the Norwegian Research Centre (NORCE), was titled Geothermal Heat Pumps (GHP) in Norway and was part of the international collaboration project HPT Annex 52. Her talk covered an overview of Norway's geothermal heat pumps. According to her, the prevalence of GHP is continuously rising, with a larger increase projected as electricity prices rise. She presented the findings of the Scandic Flesland Airport's IEA HPT Annex 52 monitoring project, which reveal that the as-built GHP system at the Scandic Airport Flesland has lower lifecycle costs than the alternatives. She also discussed environmental monitoring of GHP installations by satellite (InSAR), demonstrating that subsidence caused by the building and operation of GHP systems can be detected.

Dr.ing Randi Kalskin Ramstad, a consultant at Asplan Viak and an associate professor at NTNU, presented the results of the international collaboration project HPT Annex 52 at Fjell school in Drammen, Norway, under the title High-Temperature Borehole Thermal Energy Storage (HTBTES) – GeoTermos. She suggested that high-temperature seasonal heat storage in boreholes could be comparable to a thermal battery. She demonstrated that the school's heating needs were met by "free heating" from boreholes. This allowed them to create a practically off-grid system and had lower peak heat in the winter. According to his presentation, the next GeoTermos will be held at Krokstad elderly home in Drammen municipality. She concluded her talk by demonstrating how scaled, and adjusted systems can have a significant impact on Norway's energy system, including areas, cities, and industry.

The subsequent two presentations of the workshop were given by Veronika Wilk, a Senior Research Engineer at the Austrian Institute of Technology (AIT); she provided an update on the ongoing international collaboration project Internet of Things for Heat Pumps HPT Annex 56. And Ellika Taveres-Cachat from SINTEF Community talked about using IoT for Predictive Maintenance of Heat Pumps, and her presentation focused on using predictive maintenance to predict system failures to optimize maintenance efforts, and she used a case study of the ZEB Laboratory to highlight the challenges and opportunities of the method.

And the last two presentations were given by Dr. ing. Jørn Stene, a specialist heat pump and cooling systems at COWI AS, and he spoke about field studies and monitoring of commercial heat pump systems, which was part of the recently completed international collaboration project HPT Annex 52. Trond Berntsen, a project manager at Fortum Oslo Varme AS, discussed the potential of using heat pumps in district heating to utilize heat from a big data centre.

All presentations can be accessed here.

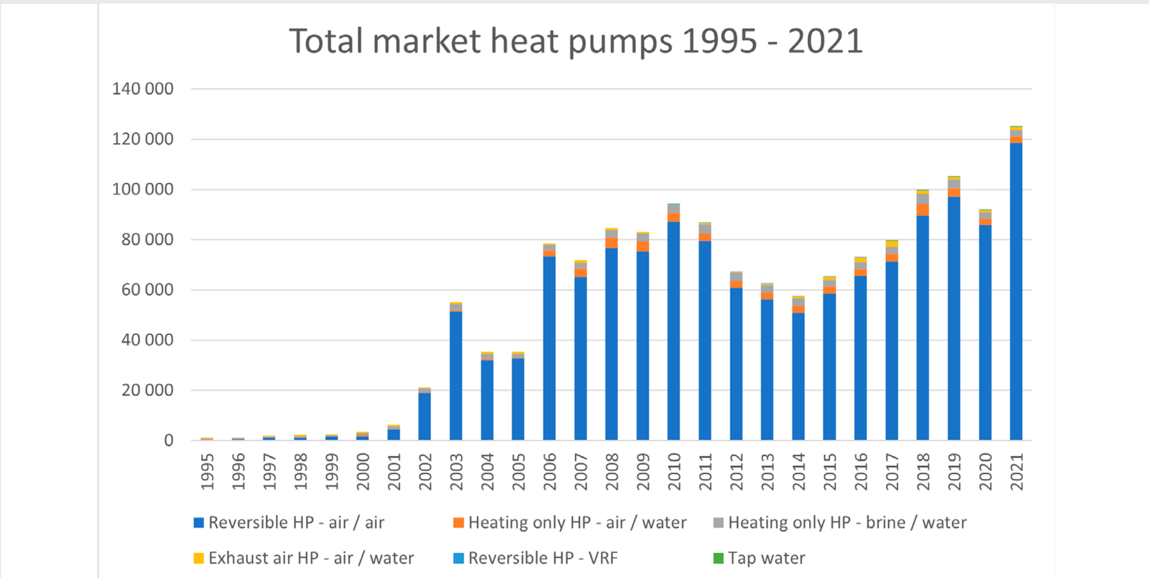
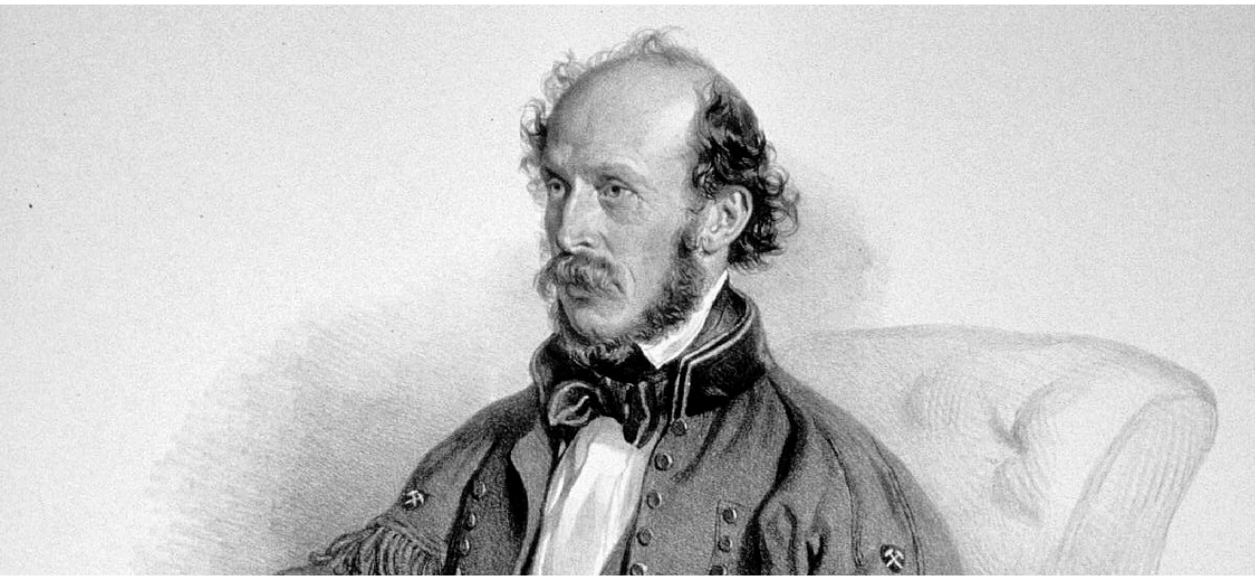


Figure 1. Total market heat pumps 1995 – 2021 in Norway.

Peter Ritter von Rittinger International Heat Pump Award – Nominate your candidate!



Peter Ritter von Rittinger who is credited with the design and installation of the first energy-conserving heat pump system at a salt works in Upper Austria in 1855.

Every three years the Peter Ritter von Rittinger International Heat Pump Award is awarded in conjunction with the International IEA Heat Pump Conference. The upcoming 14th IEA Heat Pump Conference will be held in Chicago on May 15–18, 2023. The Peter Ritter von Rittinger International Heat Pump Award is the highest international award in the heat pump, air conditioning and refrigeration field.

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

CRITERIA FOR THE AWARDS

- An award may be given to a team or group as well as to an individual
- The contribution(s) shall have been made in heat pumping market development, technology advancement or applications, or administration/organization of heat pumping activities with international involvement or impact.
- That the contribution(s) of the candidate(s) are truly significant (having made a significant and lasting difference) and are widely recognized as such.
- That the candidate(s) in fact played a key role in the contribution or achievement.
- That the candidate(s) persevered to achieve a significant contribution despite difficulties or opposition or lack of support.

Documents and guidelines for nomination

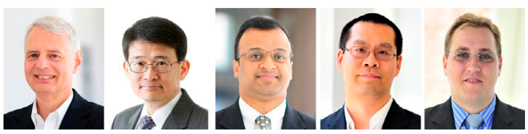
If you wish to nominate someone that has made outstanding contributions to the advancement of international collaboration in research, policy development and applications for energy-efficient heat pumping technologies – read more about the previous awardees, guidelines and find the nomination form by visiting the website at https://heatpumpingtechnologies.org/about/rittinger-award/

Welcome to nominate your candidate!

Deadline for nomination is November 30, 2022

The winners of the 2021 Rittinger Award

M.Sc. Jussi Hirvonen *Prof. Ruzhu Wang*



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

Welcome to the 14th IEA Heat Pump Conference, 2023

Every three years, the Technology Collaboration Programme on Heat Pumping Technologies by IEA (HPT TCP by IEA) convenes the IEA Heat Pump Conference. The United States is proud to announce that it will be hosting the upcoming 14th IEA Heat Pump Conference, which will be held in **Chicago on 15-18 May 2023**. The theme for the Conference is "**Heat Pumps – Resilient and Efficient**".

Conference goals

Clean, efficient, and reliable energy systems are essential to meeting basic needs for comfortable, secure, and environmentally friendly building environments, food processing, transport, storage; and industrial processes. Many analysts estimate that it will not be possible to achieve long-term climate, security, and energy goals without increasing the use of renewable heating and cooling technologies in conjunction with large-scale refurbishment and renovation of the world's existing buildings and industrial infrastructure. Heat pumps, driven with renewable power sources, are the key technical solution for meeting these challenges.

The upcoming 14th IEA Heat Pump Conference will serve as a forum to discuss the latest heat pumping technologies and applications, and exchange valuable knowledge in research, market, policy, and standards information on related technologies. Exhibitions will be held during the Conference to share heat pumping products and technologies.

Conference program highlights

The National Organizing Committee (NOC), chaired by Brian Fricke, looks forward to providing conference attendees with an exceptional conference experience, in keeping with the tradition of excellence established by all 13 of the preceding conferences.

Conference program highlights include the following:

- High level invited speakers for the opening plenary sessions
- High level invited keynote speakers leading each major conference oral technical session
- Poster presentation sessions associated with each oral technical session
- Exhibition of equipment and information kiosks
- Technical visits
- Social and sight-seeing program

The Conference will start on Monday (15 May 2023) with a series of Workshops on international collaborative projects (Annexes) within the HPT TCP by IEA and other related topics. After the main plenary opening sessions on Tuesday morning (16 May 2023), the remaining two and one-half days will consist of oral and poster technical sessions organized in parallel tracks, featuring a number of heat pump related topics including, but not limited to, the following:

- Residential and commercial building comfort conditioning, focusing on topics such as: space heating, air-conditioning, net-zero buildings, renovation, hybrids, domestic hot water, and multifamily buildings.
- Non-residential applications, focusing on industrial heat pumps, waste heat, district heating, commercial refrigeration, and transport air conditioning and refrigeration.
- Innovation and Research and Development (R&D), focusing on aspects such as ground sources, advanced storage systems, working fluids, sorption technologies, advanced vapor compression, non-vapor compression technologies, smart grids/energy, cold and hot climate applications, advanced air

conditioning technologies, gas-driven heat pumps and combinations with other renewable technologies.

» Policy topics and market status, trends, strategies, and future opportunities.

Who should attend?

The wide variety of heat pump related discussions that will take place during the Conference is intended to attract a diverse group of attendees, including:

» Policy makers, government officials, energy efficiency program leaders
» Executives and representatives from industry, utilities, and the public sector
» Manufacturers, distributors, and technology supporters
» Designers and developers of heat pump systems and components
» Researchers from industry, utilities, academia, and private and public R&D institutes

Conference information

Those wishing to attend the Conference should visit the conference website: www.hpc2023.org. Detailed information, including registration and hotel accommodation forms, will be available together with a second announcement in autumn 2022.

Conference venue

The Renaissance Chicago Downtown Hotel is excited to welcome the 14th IEA Heat Pump Conference attendees, "Resilient and Efficient." Located in the prime area of the Theater District, the venue provides attendees with easy access to Chicago's vibrant cultural infrastructure, including a wide variety of traditional pubs, eclectic bars, and clubs. Chicago is also home to a wide variety of restaurants satisfying most any culinary desire. The Chicago O'Hare International Airport (ORD) and Midway International Airport (MDW) are international and domestic arrival hubs offering light rail service to downtown Chicago, and ground transportation such as taxis and ride-share services are readily available.

Additional updates and details will be provided on the website of the conference www.hpc2023.org and via www.heatpumpingtechnologies.org.

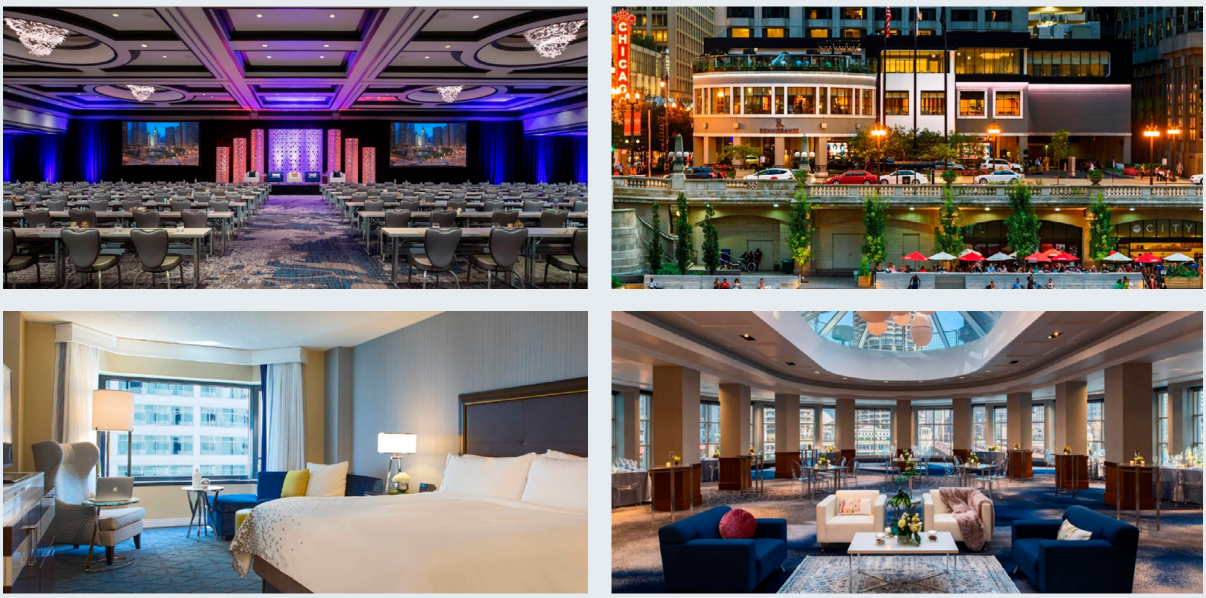
14th IEA HEAT PUMP CONFERENCE

Important conference dates!

» Abstract submission opened 15 November 2021
» Abstract submissions due 15 June 2022
» Authors advised of acceptance 31 July 2022

Close to 300 abstracts accepted for the conference

» **Full paper submissions due 15 November 2022**
» **Final paper submissions due 15 February 2023**



Chicago Venue

Ongoing Annexes in HPT TCP

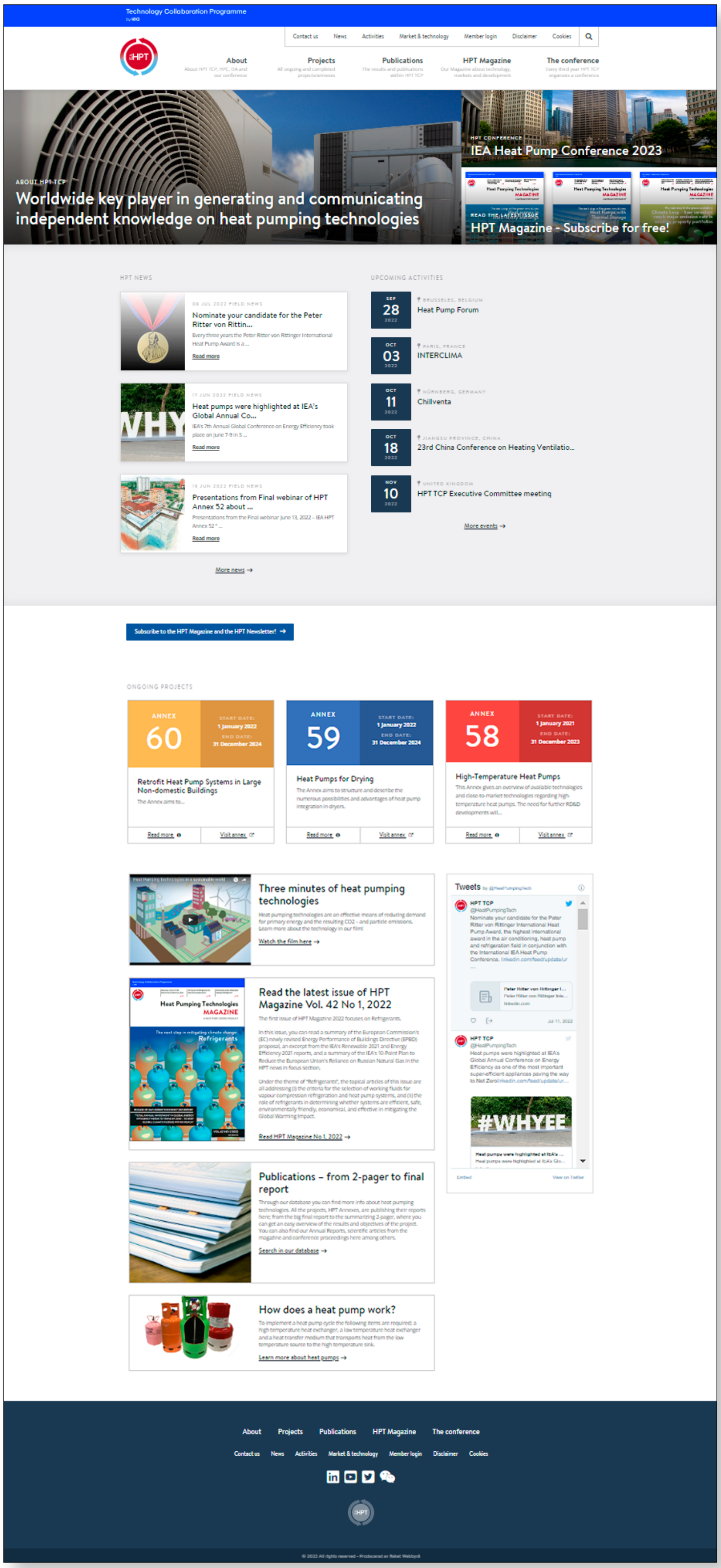
The projects within the HPT TCP are known as Annexes. Participation in an Annex is an efficient way of increasing national knowledge, both regarding the specific project objective, but also by international information exchange. Annexes operate for a limited period of time, and the objectives may vary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

ADVANCED COOLING/ REFRIGERATION TECHNOLOGIES DEVELOPMENT	53	CN, DE, IT, KR, **US**
HEAT PUMP SYSTEMS WITH LOW GWP REFRIGERANTS	54	AT, DE, FR, IT, JP, KR, SE, **US**
INTERNET OF THINGS FOR HEAT PUMPS	56	**AT**, CH, DE, DK, FR, NO, SE
FLEXIBILITY BY IMPLEMENTATION OF HEAT PUMPS IN MULTI-VECTOR ENERGY SYSTEMS AND THERMAL NETWORKS	57	AT, **DK**, DE, FR, NL, SE
HIGH-TEMPERATURE HEAT PUMPS	58	AT, BE, CA, CH, DE, **DK**, FR, NL, NO, JP
◖ HEAT PUMPS FOR DRYING	59	**AT**, CN, DK
◖ RETROFIT HEAT PUMP SYSTEMS IN LARGE NON-DOMESTIC BUILDINGS	60	**UK**, IT
◖ HEAT PUMPS IN POSITIVE ENERGY DISTRICTS	61	**CH**, DE, JP, US

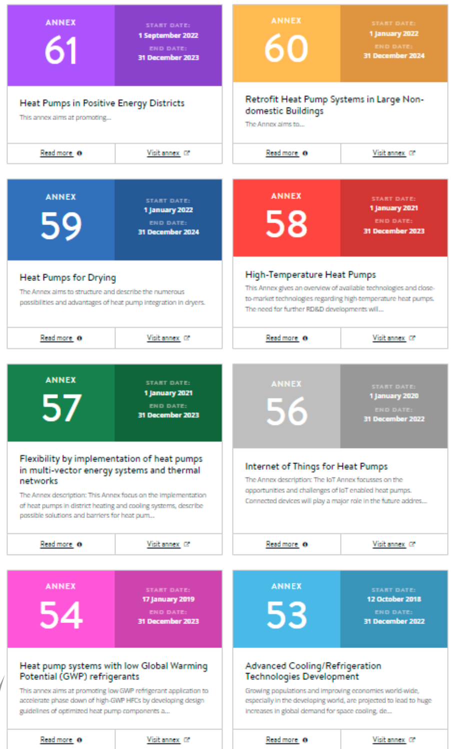
◖ NEW

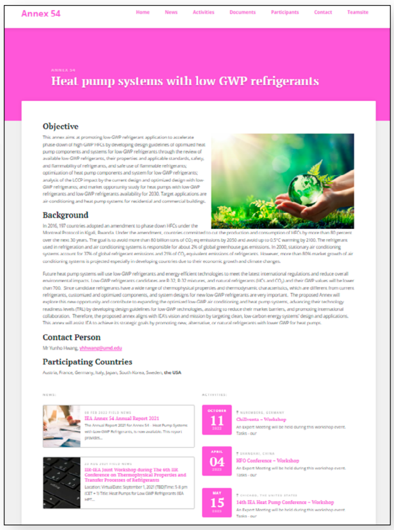
The Technology Collaboration Programme on Heat Pumping Technologies participating countries are:
Austria (AT), Belgium (BE), Canada (CA), China (CN), Denmark (DK), Finland (FI), France (FR), Germany (DE), Italy (IT), Japan (JP), the Netherlands (NL), Norway (NO), South Korea (KR), Sweden (SE), Switzerland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

Bold, red text indicates Operating Agent (Project Leader).



Ongoing Annexes





Visit our website for news, the latest updates and more information:

heatpumpingtechnologies.org

ANNEX **52**

LONG TERM PERFORMANCE MEASUREMENT OF GSHP SYSTEMS SERVING COMMERCIAL, INSTITUTIONAL AND MULTI-FAMILY BUILDINGS

Introduction
Carefully instrumented and analyzed long-term performance measurements from large Ground Source Heat Pumps (GSHP) systems are highly valuable tools for researchers, practitioners and building owners. Analyses of good quality long-term performance measurements of GSHP systems are sparse in the literature, and there is no consensus on key figures for performance evaluation and comparison. Within Annex 52, a bibliography on long-term measurement of GSHP systems has been compiled, and the participants measured performance of more than 55 GSHP systems. Based on this experience, the annex revised the current methodology to better characterize the performance of larger GSHP systems. These systems have a wide range of features and can be considerably more complex than single-family residential GSHP systems. The case studies provides a set of benchmarks for comparisons of such GSHP systems around the world, using an extended system boundary schema for calculation of system performance factors. This schema is a further development of the SEPEMO system boundary schema developed for non-complex residential heat pump systems.

The outcomes from this annex help building owners, designers and technicians evaluate, compare and optimize GSHP systems. It also provide useful guidance to manufacturers of instrumentation and GSHP system components, and developers of tools for monitoring, controlling and fault detection/ diagnosis. This will lead to energy and cost savings.

Objectives

- Survey and create a library of quality long-term measurements of GSHP system performance for commercial, institutional and multi-family buildings. All types of ground sources and ground heat exchangers are included in the scope.
- Refine and extend current methodology to better characterize GSHP system performance serving commercial, institutional and multi-family buildings with the full range of features shown on the market, and to provide a set of benchmarks for comparisons of such GSHP systems around the world.
- Refine and extend the guidelines provided by the SEPEMO project to cover as many GSHP system features as possible and formalize in a guidelines document.

Key data

- Project duration: Jan 2018 – Dec 2021
- Operating Agent: Signhild Gehlin, Swedish Geoenergy Center, signhild@geoenergicentrum.se
- Participating countries: Finland, Germany, Netherlands, Norway, Sweden, UK, USA
- Website: http://heatpumpingtechnologies.org/annex52/

Progress and Results
Annex 52 finished in December 2021, and the results are published on the Annex 52 website. Outcomes from the Annex include a new system boundary schema (Table 1) and guideline documents for instrumentation, uncertainty, key performance indicators (Figure 1), data management, and quality assurance. The final report, four subtask reports and 27 case study reports containing 29 monitoring projects comprise more than 1000 pages in total. In addition, the Annex has resulted in three sets of open-source measurement data from two GSHP systems; seven published peer-reviewed scientific journal papers and eleven peer-reviewed conference papers. Additional publications are in progress. The final webinar on June 13th 2022, presented the overall results and deliverables from Annex 52 together with examples from the many case studies. Although the focus has been on ground-source heat pump systems, much of the work is also relevant to air-source heat pump systems and air-conditioning systems.

Key findings from the work within Annex 52 can be summarized as follows:

- The Annex 52 system boundary schema, with six defined boundaries and an indicator for use of supplemental heating or cooling, better captures the complex nature of large GSHP systems than the SEPEMO system boundary schema.
- System boundaries, as well as the time frame at which the performance is evaluated, should be clearly stated. Seasonal performance factors (SPF) should be used only for measured performance over a full year. Measured performance over shorter time intervals - daily (DPF), monthly (MPF) or binned performance factors (BPF) - are also valuable performance indicators.
- The Annex, 52 uncertainty calculation guidelines help to design the measurement program and understand the significance of its results.

- The monitoring projects report a combined total of 119 years of data, with combined heating and cooling SPFHC1 in the range 1.5-7.2 with an average of 4, with 88% of the measured years having SPFHC1 of 3 or higher. SPFHC2 are in the range 1.4-13 with an average of 4.7, and 80% of the project-years having SPFHC2 of 3 or higher.
- Most measured systems worked satisfactorily, although there is room for further improvement and optimization in almost all cases. For central GSHP systems, the distribution system on the load side of the heat pump has a detrimental effect on the system performance at system boundaries 3-5. Energy use for hot water, distribution pumps and fans are common causes.

Table 1: Key Performance Indicators (KPI) for GSHP systems at four system levels, identified by Annex 52.

Overall building KPIs	**Ground source KPIs**
Building energy use intensity (EUI)	Annual heat extraction and rejection
Building energy signature	Specific heat extraction rate
Temperature signature	Specific energy extraction
Energy load fractions	Ground Thermal Imbalance Ratio (IR)
	Storage efficiency
	ATES well productivity
System level KPIs	**Component level KPIs**
Coefficient of Performance (COP and SCOP)	Compressor KPI – Compressor isentropic efficiency
Energy Efficiency Ratio (EER and SEER)	Condenser KPI – Condenser efficiency
Performance Factors (SPF, MPF, DPF, HPF, BPF)	Evaporator KPI
System Efficiency Index (SEI)	Cycle efficiency
Load factor average/peak per month	Heat pump cycling

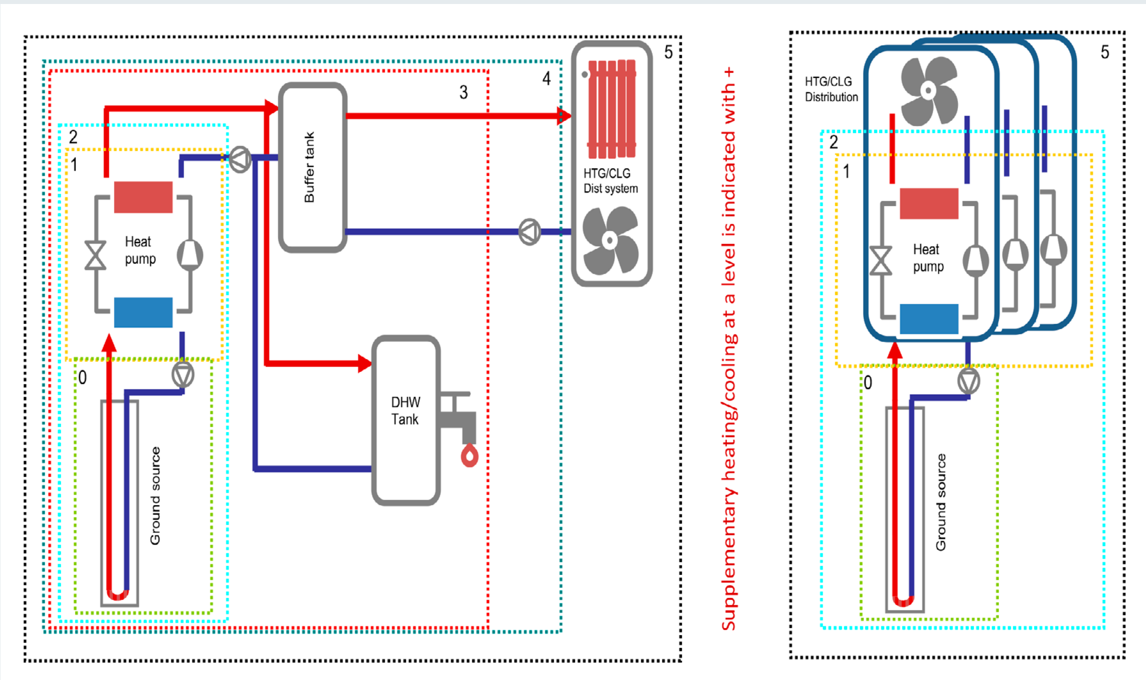


Figure 1. Key Performance Indicators (KPI) for GSHP systems at four system levels, identified by Annex 52. Illustration: Signhild Gehlin.

ANNEX
56

INTERNET OF THINGS FOR HEAT PUMPS

Introduction

Today, more and more devices are connected to the Internet and can interact due to increasing digitalization – the Internet of Things (IoT). In the energy transition, digital technologies are intended to enable flexible energy generation and consumption in various sectors, thus leading to greater use of renewable energies. This also applies to heat pumps and their components.

The IoT Annex explores the opportunities and challenges of connected heat pumps in household applications and industrial environments. There are a variety of new use cases, and services for IoT enabled heat pumps. Data can be used for preventive analytics, such as what-if analysis for operation decisions, predictive maintenance, fine-tuning of the operation parameters and benchmarking. Connected heat pumps allow for demand response to reduce peak load and to optimize electricity consumption, e.g. as a function of the electricity price. Digitalization in industry can range from automated equipment, advanced process control systems to connected supply value chains. IoT enabled heat pumps allow for integration in the process control system and into a high-level energy management system, which can be used for overall optimization of the process.

Each level of participation of a heat pump in a connected world (Figure 1) is also associated to different important risks and requirements to connectivity, data analysis, privacy and security for a variety of stakeholders. Therefore, this Annex has a broad scope looking at different aspects of digitalization and will create a knowledge base on connected heat pumps. The Annex will provide information for heat pump manufacturers, component manufacturers, system integrators and other actors involved in IoT.

Objectives

- Provide guidance, data and knowledge about heat pump technologies with respect to IoT applications.
- Review the status of currently available IoT enabled heat pumps, heat pump components and related services.
- Identify requirements for data acquisition from newly designed or already implemented heat pump systems considering types of signals, protocols and platforms for buildings and industrial applications and related privacy issues and ongoing standardization activities.
- Evaluate data analysis methods and applications (digital twins), including machine learning, semantic models, hybrid models, data-driven models and soft sensors.
- Analyse business models for IoT enables heat pumps (strengths, weaknesses, opportunities, threats).
- Evaluate market opportunities created by IoT enabled heat pumps and identify success factors and further demands to software and hardware infrastructure.

Key data

- Project duration: Jan 2020 – Dec 2022
- Operation Agent: Veronika Wilk, Austrian Institute of Technology GmbH, Austria veronika.wilk@ait.ac.at
- Participating countries: Austria, Denmark, France, Germany, Norway, Sweden, Switzerland
- Website: https://heatpumpingtechnologies.org/annex56

Progress

Digital twins are an ever-present term when it comes to new opportunities due to digitalization. A digital twin is a specific virtual representation of a physical object, which is updated repeatedly according to real-world data, representing the state of the physical object. In turn, it is possible to act on the physical object based on the knowledge inferred from the virtual representation (model), thus closing the cycle between physical and virtual representation.

Examples of digital twins of heat pumps:

Austria: AIT developed and implemented a digital twin of a heat pump connected to a complex laboratory test infrastructure to facilitate heat pump tests according to EN-14528 and EN-14511 standards. The efficiency of the test procedure depends strongly on the settings by the operators and their experience in the handling of interactions between the heat pump and the test infrastructure. A Modelica model of a heat pump is linked with the real data from the test to form a digital twin. The digital twin provides the operator with suggestions for optimal settings, which previously could only be derived in a time-consuming and iterative manner during test operation. Also, a calibrated heat pump model is created with each test that can be used further.
https://www.ait.ac.at/en/research-topics/sustainable-thermal-energy-systems/projects/digibatch-project

Denmark: Digitalizing heat pumps and refrigeration systems enables improved performances and sophisticated controls, which supports the integration into smart

grids. These services require increased knowledge about the system during operation, which may be obtained by the use of digital twins. DTI's project aims at making the use of digital twins for large-scale heat pump and refrigeration systems more accessible to potential users, to decrease the application barriers and to demonstrate the benefits of existing systems. Several reusable, modular, and self-learning models are developed to reduce modeling effort, as well as advanced methods for analyzing the systems with respect to specific services. This enables not only an efficient implementation process and thereby decreased investment cost of digital twins but also enhanced exploitation of the system potentials.
https://digitaltwins4hprs.dk/

Germany: Currently, the development phases of building energy technology components are often characterized by complex and time-consuming prototype tests in test bench environments. Particularly with regard to controller parameterization and optimization, boundary conditions on the test stand can only be varied to a limited extent or do not adequately reflect real conditions. RWTH's (see link below) research project aims to develop digital twins of heat pumps and fuel cells to reduce R&D times and to offer new services for optimized operation. In particular, digital twins serve as a solution for control platform development, model predictive control, fault detection, and predictive maintenance.
https://dzwi-waerme.com/

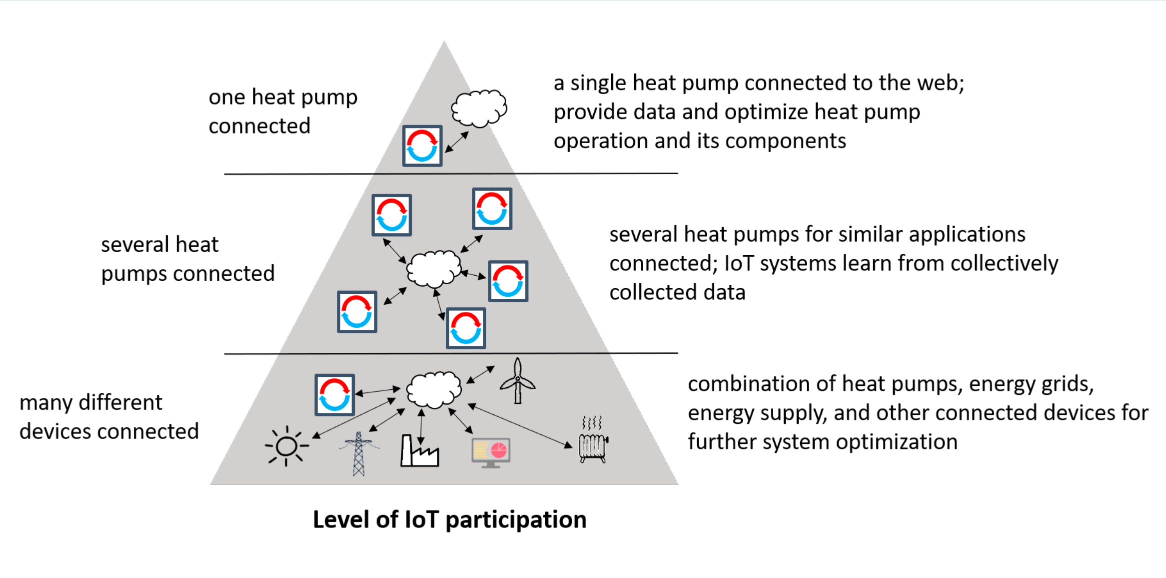


Figure 1. Heat pumps as a part of the Internet of Things. Source: AIT Austrian Institute of Technology GmbH.

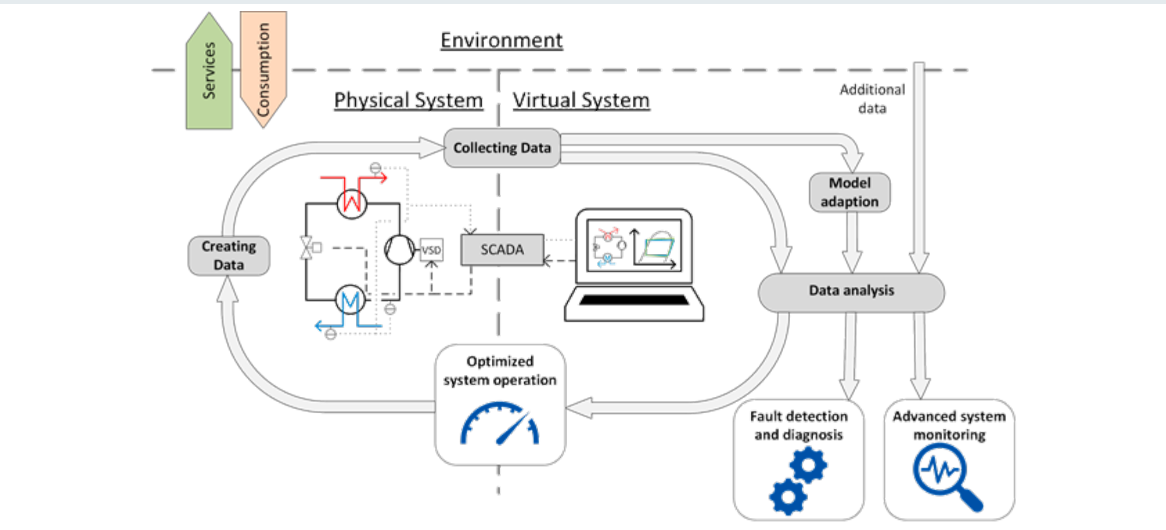


Figure 2. Digital twin concept for large-scale heat pump and refrigeration system
Source: Danish Technological Institute.

How do you make your Heat Pumps and Chillers Operate as you Planned?

Klas Berglöf, Sweden

International Energy Agency IEA HPT Annex 52 (see also page 20-21) recently published "New Guideline to Instrumentation and data" to address the challenges experienced with verification of performance of Ground Source Heat Pumps. With increasing energy prices and a focus on climate change, this guide will be useful for those pushing optimization and reliability based on documentation of performance. One of the methods described for performance analyzing is the "Internal Method", based on thermodynamic analytics of the processes. This article describes experiences of field monitoring with this method and faults that can be identified and corrected.

Download and share this article

Based on 40 years of experience in troubleshooting and optimization of heat pump/chiller installations, the question often comes up: "**How hard can it be to get things right?**" But the fact is that without the right information and clear responsibilities with monitoring performance, systems will not be efficient.

HVACR systems consume almost 20% of the global electricity. And it is often documented that 20-30% of the energy is wasted due to faults and lack of optimization. With experience from thousands of measurements, the conclusion is that virtually no systems are well optimized. Therefore, optimization of existing plants is a "low hanging fruit" when it comes to the reduction of carbon emissions.

The misconception that keeping the right temperature equals good performance "allows" many systems to run inefficiently.

Equipment owners hesitate to invest in performance analyzing when nobody knows there is a fault. Even a low investment is unattractive when ROI is uncertain without a baseline.

Problems are often recognized only when a system trips or the required temperatures are not maintained. The lack of focus on performance is a result of the structure of the property market and how HVACR systems are purchased. Property owners are seldom experts in heat pumps/chillers and purchase a building using consultants to specify the requirements they desire. The contracted builder, in turn, contracts a series of sub-contractors to supply all the necessary systems.

It has been extremely rare that the specification of Measuring and Verification (M&V) delivers the information required to ensure that systems operate as intended over varying conditions.

A HVACR system performance is affected by 5-6 subcontractors – all with their own specification to follow. Most specifications focus on peak load conditions which rarely or never occur. So, commissioning staff often run chillers/heat pumps in building with low load at whatever outdoor conditions that happen to be at the commissioning date.

If a system is operated to specified temperatures without tripping, it is assumed that the system operates as specified. It is becoming common to specify to check winter and summer conditions, but this is less fruitful than to continuously log information in a structured way. It is cost-effective to ensure that data is collected in a structured way on all sites. Essential is also to assign the responsibility to document total performance and verify subsystems versus specification at relevant conditions. This will minimize "reactive maintenance", which is costly for the equipment owner but profitable for a contractor.

Increasing pressure to improve efficiency and reliability

Rising energy prices, energy shortage and an increased focus on sustainability will force equipment owners to focus on efficiency. Maintaining a temperature will not be good enough. The industry needs to improve the specification of design as well as that M&V is a part of proper commissioning and maintenance.

International Energy Agency (IEA) HPT Annex 52 recently published "New Guideline for Instrumentation and Data" [1] that collect international experiences on what is recommended to make a cost-effective evaluation of performance. With a structured approach to data collection and analyses to evaluate each subsystem, commissioning and predictive maintenance can be implemented effectively. The required sensors are often standard today. It is not a question of adding many expensive sensors; it is a to follow “good practice” for what sensors are used and how they are mounted and verified. It is also important how data is collected and stored to turn data into information required to verify performance.

Digitalization is here to stay

Any building designed today will include a lot of sensors. A typical heat pump/chiller for commercial buildings will have pressure and temperature sensors, and it should be standard to sub-meter larger electrical loads.

Obviously, supply and return temperatures of chilled and cooling water and air temperatures are measured, but sampling should follow good practice. Some values are required every minute, whereas others make no sense to store more than hourly. To track energies, it is preferred to store hourly data together with outdoor conditions, whereas it is totally useless to have hourly averages on temperatures and pressures in a heat pump/chiller that can have started and stopped several times in that hour.

It all comes down to make information out of available data. Annex 52 Guidelines establish a good practice to make benchmarking possible.

What can go wrong?

It could be seen as if the heat pump/chiller is a simple product with four main components. However, when realized that every degree of increased temperature lift will cause a 2-5% increase in energy consumption, it should be obvious that it deserves more attention than an alarm when pressure or current goes out of the allowed envelope.

A common explanation I encounter in problematic installations is that the heat pump/chiller is too big. However, there is no site that does not have a load starting from 0 kW.

Nevertheless, it is effective, as site staff has minimal possibilities to question the statement and do not know how often it is used to point the finger at somebody else.

A control system should handle all loads from zero to full load, and the water volumes are often more than sufficient to give the inertia required to avoid short cycling with proper set-up. The hydronic systems have a significant internal volume in pipes and equipment and normally offer sufficient volumes even without extra accumulators. The all-too-common short cycling issues occurring are related to commissioning.

Besides the insufficient commissioning of the control system over the wide envelope, the system perspective is often missing when each sub-contractors take responsibility for their own delivery and nobody for the total. Obviously, distribution systems, heat source and heat sink must function well together with the heat pump/chiller. These temperatures, as well as ambient, should be logged with energy use for heat pump/chiller and preferably also for pumps and fans, see Figure 1 as an example.

When the distribution systems are balanced, the largest “electricity consumer” - the refrigeration process - remain unattended. In fact often 60% of the energy is neglected when the heat pump/chiller is assumed to work as rated. This leaves a huge, number of possible faults unattended and system efficiency and reliability reduced. This leaves a huge number of possible faults unattended and system efficiency and reliability reduced. It is necessary to ensure that the heat pump/

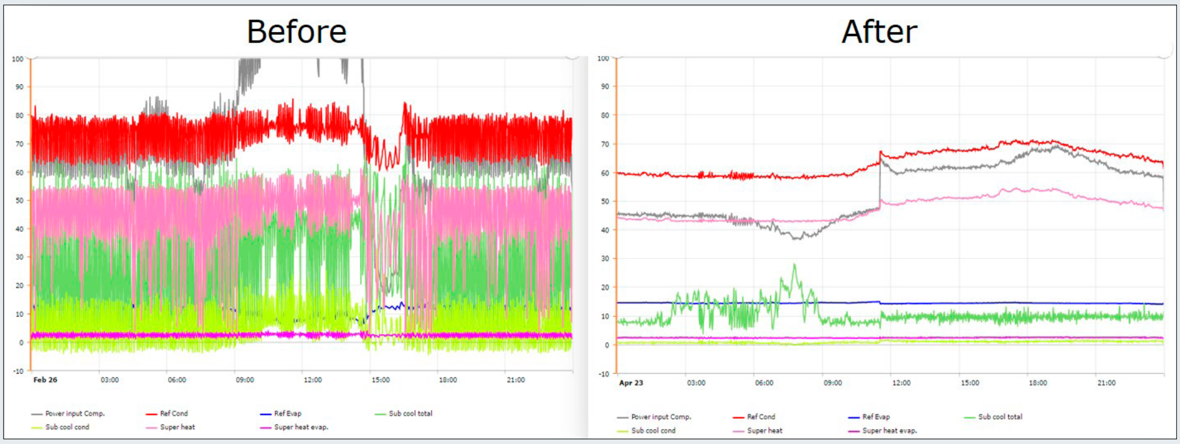


Figure 1. Erratic controls should be stabilized to avoid failures and waste of energy.

chiller itself is in good shape and have the best operation conditions possible, including:

A. Correct refrigerant charge
B. Correct superheat
C. No compressor problems
D. Evaporator efficiency
    a. Correct flow
    b. No air or fouling
    c. No oil issues
E. Condenser efficiency
    a. Correct flow
    b. No air or fouling
    c. No oil issues
    d. No none-condensables in refrigerant circuit.
F. No excess pressure drops in the refrigerant circuit.

Common practice for maintenance inspections do not verify performance, and it is virtually impossible to do that during a service inspection as the system is highly unlikely to operate stably at the time inspection is carried out.

How to find and fix the faults?
The "Internal method" described in IEA HPT Annex 52 makes it possible to measure the total System Efficiency Index (SEI) as well as all relevant KPIs in real-time (see Figure 2). Enabling alerts if any change of performance occurs as the thermodynamic evaluation establishes:

- System Efficiency Index
- Sub-efficiencies for:
    - Compressor
    - Condenser
    - Evaporator
- All key maintenance parameters
    - Refrigerant charge
    - Superheat
    - Subcool
    - Approaches
    - Flows

A dashboard, as in Figure 3, gives the same performance information in real-time as a test rig at a production facility, based on data from sensors that usually are standard today. If a sensor is missing in controls, it can be added at a marginal cost. The data is sent to cloud-based services, where it is analyzed. The information will be sent to the owner and available to experts that can take decision on corrective measurements.

The KPIs is compared with adjustable limits that should be but rarely are included in operating manuals.

The single most common issue is that controls are not properly set up to handle different operating conditions and loads. This result in all kinds of problems such as tripping on oil protection and failures.

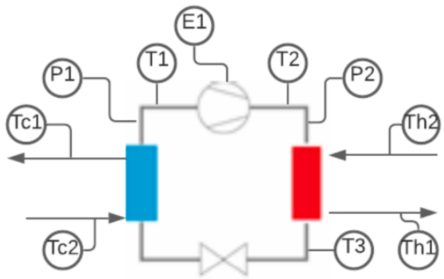


Figure 2-2. Measurement locations for the internal method of a heat pump as described in Lane et al (2014).

Table 2-2. Recommended measurement points for a basic ground-source heat pump using the internal method (see Figure 2-2).

Description	Fig. 2-2	Comments
Heat pump compressor electrical input	E1	Electric power of compressor
Source-side supply and return temperatures	Tc1, Tc2	May be paired for calibration of ΔT
Load side supply and return temperatures	Th1, Th2	May be paired for calibration of ΔT
Pressure and temperature of refrigerant	T1, P1	Before compressor
Pressure and temperature of refrigerant	T2, P2	After compressor
Liquid temperature of refrigerant	T3	After condenser and before expansion device

Figure 2. Sensors required for Internal method described in Annex 52.

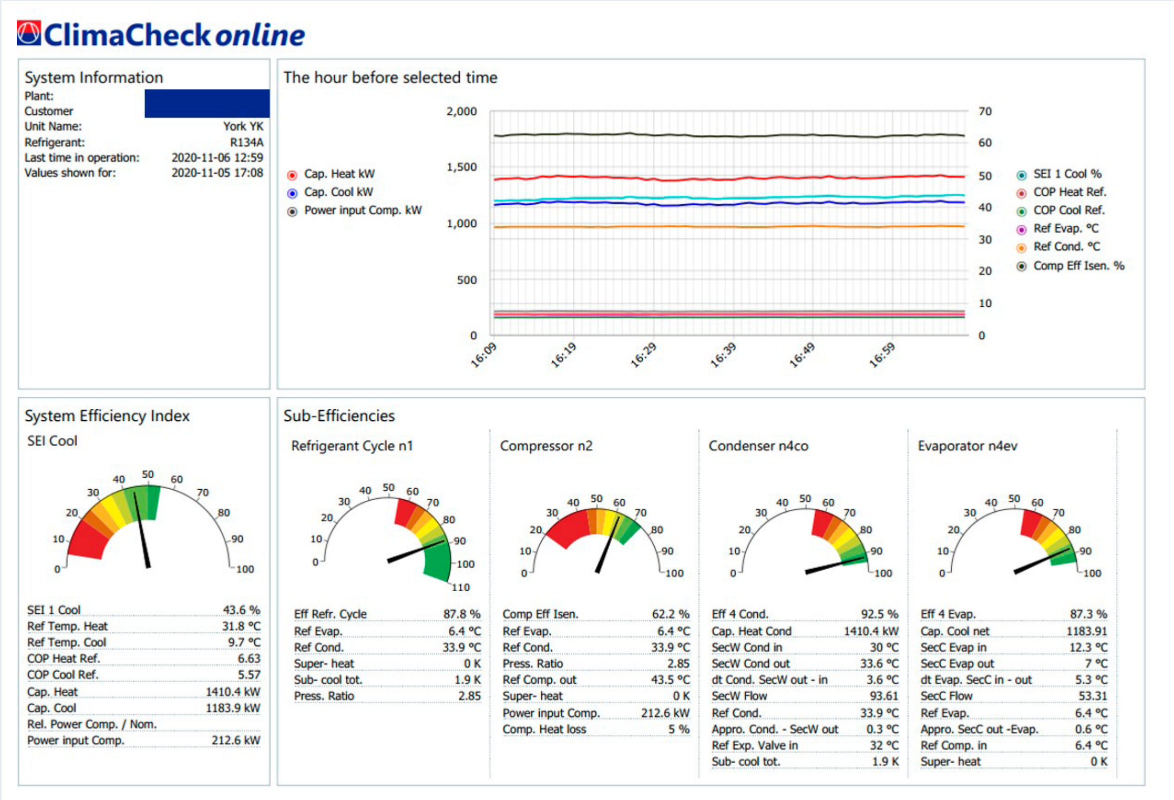


Figure 3. Dashboard with all KPIs required for maintenance and optimization.

One of the most obvious and easiest energy-saving measures is to use “floating set points” on both the cold and warm sides. Single set-points based on design conditions on the cold and warm side increases electricity consumption by 20-40%. There are few buildings that require the standard design of 7°C chilled water during mild temperatures (if ever). Even if the design would, e.g., a 7°C chilled water supply, it is common that there are safety margins to allow significantly higher set-points. For lower outdoor temperatures, a so-called floating set-point can be used to reduce operating cost by 3-5% for every degree. The lowest possible temperature lift that delivers the desired temperatures should always be established. The same with the “poor practice” of leaving air-cooled chillers and dry coolers on high set-points; this should have been history a long time ago, but we find that it is common that when systems have been optimized, somebody resets the system to his own “rule of thumb” without an understanding of the impact on running cost. Unless a site is commissioned as a complete system over different operating conditions, it will rarely work well.

When performance is analyzed in the cloud, the technician/ engineer receives a warning as soon as any performance deviation occurs, and before every site visit, a digital inspection can be done to ensure that any potential optimization measure is carried out during the site visit. Continuous performance monitoring also enables early detection of leaks, so-called “Indirect leak detection” in EU-vocabulary as changes in pressures and temperatures will indicate a decrease in refrigerant charge. As this “catch” all leaks, this is more reliable than gas detectors that are challenging to mount, so they catch all leaks. Obviously, the combination of leak detectors and “indirect leak detection” adds value for larger or critical plants.

Next step is predictive maintenance

The future is to implement guidelines such as IEA HPT Annex 52 and monitor systems 24/7 with state-of-the-art analytics to detect any deviation in performance. To pinpoint the cause instead of going to site on a schedule and handle failures when they happen. An introduction to the challenges in transiting from “Business as usual” in a conservative industry to predictive maintenance is available in the “Guide to Predictive Maintenance for HVACR systems” [2].

“To Measure is to know.”

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White-box Model Predictive Control: Optimal Control and System Integration of Heat Pumps

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Model Predictive Control (MPC) has a large sustainability potential for the optimal control of Heating, Ventilation and Air Condition in buildings. This article summarizes some of the main features of MPC, and the advantages and results (including real-life demonstrations) of our particular implementation, which uses detailed physics-based simulations and optimizations of both the building envelope and its HVAC. This research track has been developed at the Thermal Systems Simulation (The SySi) research group of KU Leuven over the past 12 years.

Building Heating, Ventilation, and Air Conditioning (HVAC) systems are becoming more complex due to the integration of renewable energy sources and heat pump-based technologies. We are evolving from a society where the building demand determines heating and cooling loads to a society where the availability of heat and cold, through price signals, determines when to heat or cool a building. Furthermore, renewable energy sources tend to use lower temperatures for heating and higher temperatures for cooling. E.g. heat pumps operate more efficiently at smaller temperature differences, and direct geothermal cooling is simply not available at temperatures lower than the soil temperature. Smaller temperature differences result in smaller thermal powers, meaning that sudden power peaks have to be spread over longer periods. In order to reach the building comfort set points in time, this typically means that heating and cooling has to start sooner, depending on the emission system inertia. Thermally massive systems such as Concrete Core Activation (CCA) can benefit from heating/cooling loads that are shifted to multiple hours before the heating/cooling is required.

The delayed temperature response is illustrated in Figure 1, as well as a significant lasting temperature influence during the days following the cooling peak. The model thus, in fact, predicts that the cooling peak introduces a heating demand for satisfying the lower temperature limit starting at hour 100, which illustrates the importance of dynamic simulations for the system design.

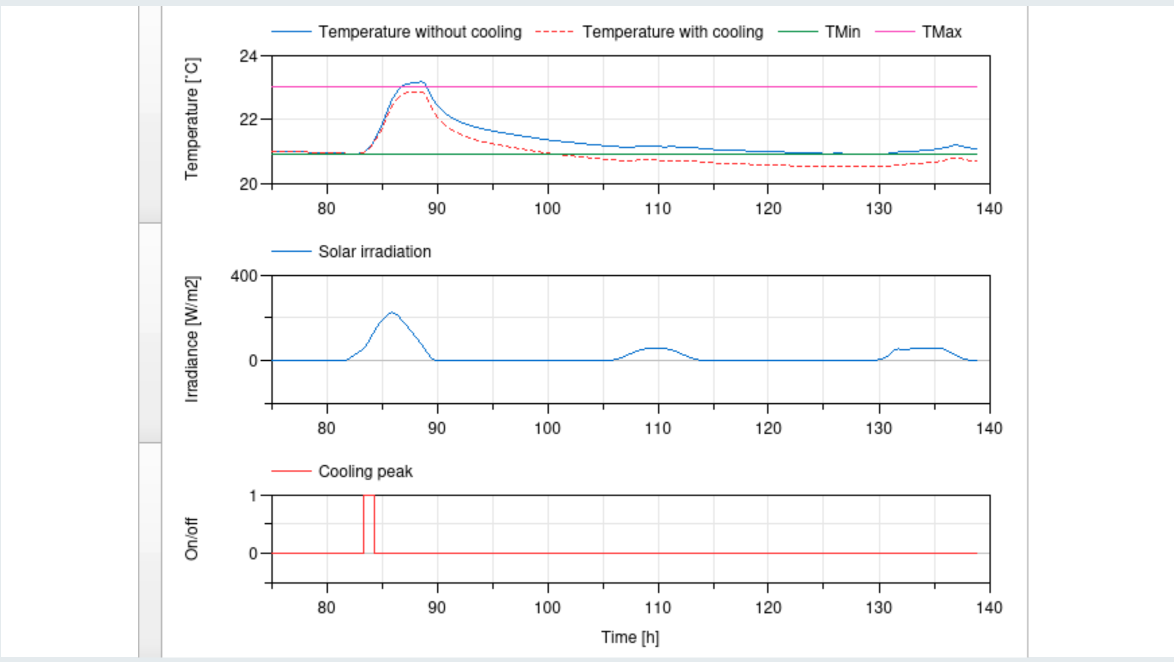

Figure 1. Delayed zone temperature response after a short cooling peak injection in a floor cooling slab.

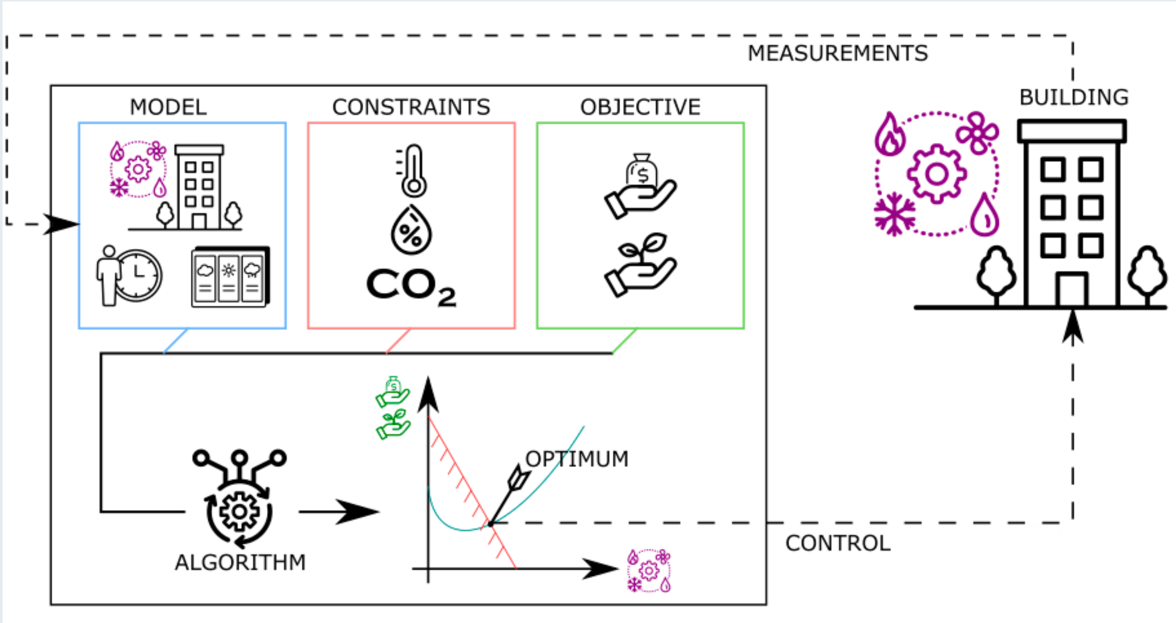

Figure 2. Illustration of the main MPC components and control loop.

Next to CCA, additional storage options such as thermal storage tanks could be considered, adding degrees of freedom where similar questions arise. How large should the tank be, and to what temperature levels should the tank be charged, and when?

This discussion firstly illustrates the need for adequate HVAC system selection and component sizing during the design stage. There no longer exists one correct design, rather a multitude of feasible designs that consider the local context and potential of the building and the sustainability ambitions of the stakeholders in the construction process.

Secondly, the flexible, timely and sustainable delivery of heating and cooling loads will require a predictive control solution. Heat supply to a building is an interplay of compressor speeds, pump speeds and valve openings, which will have to be coordinated with quarter-hourly changing electricity prices and the availability of renewable energy sources. The building use, and even climate changes throughout the building's lifetime calling for a tailored yet easily adjustable and reconfigurable control solution.

To tackle the aforementioned control challenges in commercial buildings, we propose white-box model predictive control (MPC). MPC is a predictive control methodology that relies on a mathematical model of a system to control that system, in this case, a building and its HVAC. The model considers weather forecasts, occupancy, the building envelope, and the HVAC devices that are connected to the building envelope. The model predicts the impact of the current control actions on the building energy use, emissions and comfort (KPIs) and on operational constraints during the coming days. It determines what control actions result in the best trade-off between these KPIs. Control signals are sent to the existing building management system, and 15 minutes later, the optimization is repeated. This is illustrated in Figure 2.

While this summarizes the main functionality of an MPC, various approaches exist for implementing the model, which has to be custom developed for a building. Differences are related mostly to 1) the number of components and 2) the level of detail of those components. Both aspects can strongly affect the computational effort for solving the model equations, causing problems to become practically insolvable by general-purpose solvers. Therefore, models are often either simplified by reducing the number of components, e.g. by representing a whole building using one or a few rooms only. Such implementations are consequently unable to provide individual set points for different rooms, which may have very different heating or cooling demands. Other model simplifications mostly focus on reducing the level of detail of the models. Such (linear) models generally have a strong mismatch between the model and the physical system, making it impractical to couple the model to the physical building. This is problematic from a business deployment point of view since every building requires an ad-hoc solution and consequently requires a high level of expertise to install the controller.

Our goal is to capture the full complexity of each building and exploit the full potential of its HVAC system. Therefore, we use models that are both detailed in the represented physics and in the spatial representation of the rooms of the building. Thanks to this, the model is aware of the full system complexity. While this approach is accurate and generic (applicable to all buildings), it leads to large models, which may be difficult to optimize and time-consuming to set up. Solving those issues has been the core of our research and development over the last eight years, and we have shown that our custom solver is able to optimize our complex models sufficiently quickly [1]. Our goal is to have no upper limit on the model complexity and size that our solver can optimize, starting from the practical and scalable model implementation methodology described below.

We use a library of physics-based (white-box) component models where each component model (e.g. a heat pump) has a set of characteristic parameters (e.g. the nominal heat flow rate and a COP curve). Physics do not change, and consequently, the main model equations have to be developed only once. These models are implemented using the equation-based modeling language Modelica and are available in the open-source Modelica library IDEAS (https://github.com/open-ideas/IDEAS) [2]. Model parameters are configured using available manufacturer specifications. Each component has connectors that correspond to relevant physical quantities (e.g. four fluid ports and an electrical power inlet for a heat pump model). Building hydronic and aerolic schematics are used to specify how all components are interconnected. Building plans are used to define the building geometry. The resulting modeling process is a simple mapping of physical components into component models, see Figures 3 and 4 and is easy to understand and execute. Ongoing developments related to Building Information Modeling (BIM) could even lead to further automation of this work. Differentiation between heat pumps could be facilitated by integrating manufacturer-specific performance curves. For existing buildings, the required as-built information may not be available. Extensions of the approach are being developed for these buildings.

Within the EU H2020 hybrid GEOTABS project and in collaboration with stakeholders such as Boydens engineering, part of Sweco, UGent, DTU, EnergoKlastr, Viessmann, Uponor, KU Leuven has demonstrated this technology within three large buildings (e.g. Figure 5, Ter Potterie), thanks to the building owners Fluvius, Mintus, Progroup and Schuler. These buildings had been thoroughly commissioned within the construction phase, but MPC was nevertheless able to achieve similar or improved thermal comfort, and reduced the energy use and associated CO_2 emissions. In some cases, the MPC relied on the existing sub-controllers of the building management system for conveying its set point to the system. A mismatch between the expected and observed system behaviour even pointed out some errors in the existing system and enables a higher degree of commissioning. Such errors could be identified automatically in the future, or could even be avoided entirely by no longer relying on these sub-controllers, thereby also removing the cost for implementing them.

One of the demonstration buildings is the four story, 3000 m^2 office building of Fluvius and Boydens engineering, part of Sweco in Brussels. In this building, energy savings of more than 40% were observed during long periods of the year. The building uses a geothermal heat pump, CCA, an Air Handling Unit (AHU) with a heating coil (HC1), heat recovery, and multiple VAVs with individual heating coils (HC2). The substantial savings could be explained as follows. For the relatively colder bottom floor, MPC managed to shift a larger fraction of the heating load to the CCA, which allowed the AHU flow rates and the supply air temperature for the whole building to decrease. Instead of supplying 100% air flow to the ground floor, about 50% sufficed, which could be heated up to the desired supply air tempera-

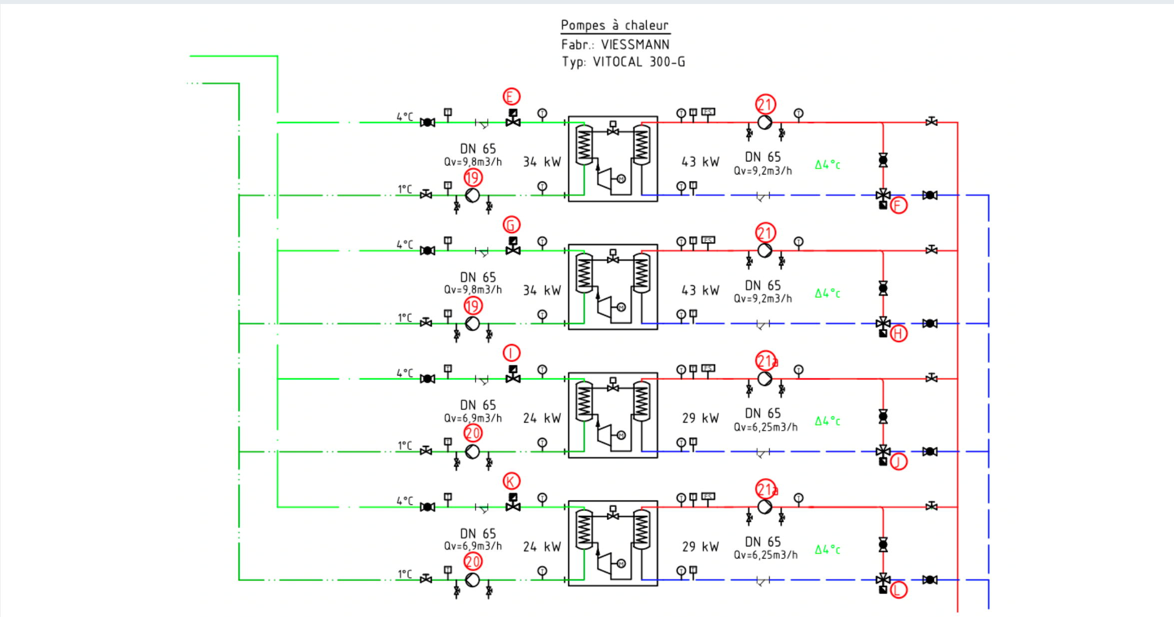

Figure 3. Schematic of a heat pump system. Source: Boydens Engineering, part of Sweco.

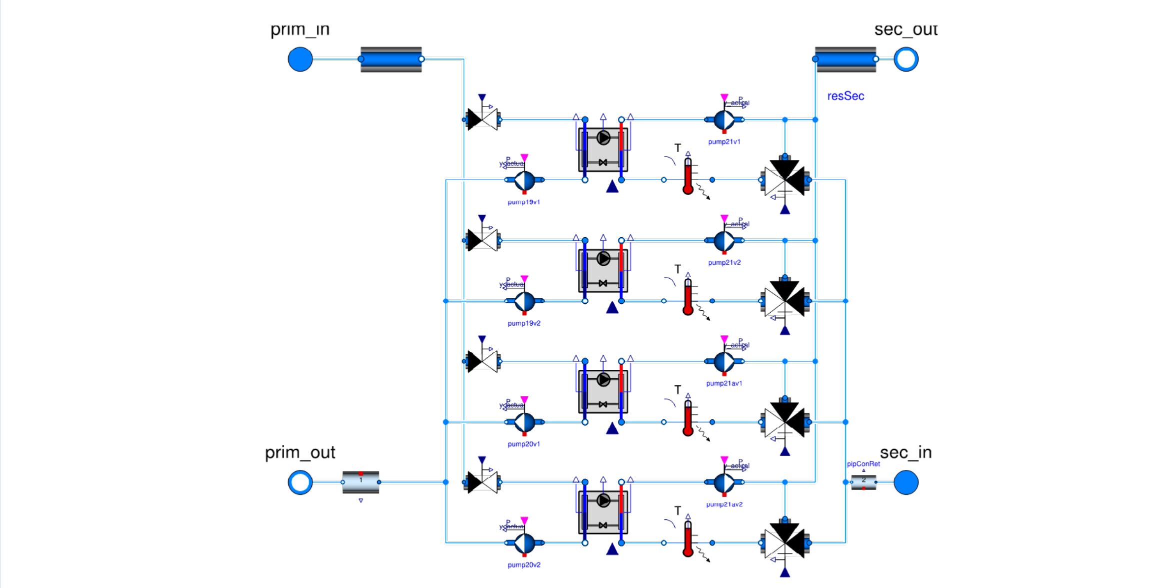

Figure 4. Mapped model of the heat pump system. Illustrated icons are components models.

ture by using only HC2, no longer requiring HC1, which would have increased temperatures supplied to the whole building. This removed a substantial heat load from HC1.

Furthermore, the smaller air flow rates allowed the supply and return air pressures to be lowered, which resulted in significantly reduced electrical power use for the AHU. Finally, the heat pump COP could be increased by lowering the condenser supply water temperature, albeit only slightly, since HC2 did, in fact, require relatively high supply water temperatures. Note that in this particular case, MPC decided not to significantly reduce the condenser water temperature, since that would have required the AHU flow rates and HC1 to pick up additional heat load again, which has a worse effect than the COP decrease. The strength of our detailed MPC implementation is that it was able to deal with these complex interactions of multiple zones and components, while at first sight, we, in fact, believed that the elevated condenser temperatures were a bug. Furthermore, these results were obtained without requiring substantial tuning of the controller.

Conclusions

Traditional rule-based controllers implement static control rules, which rigidly focus on tracking a particular set point. When tuned correctly, this can result in the desired comfort. However, many set points can lead to the same comfort level at different costs and CO_2 emissions. Practice has shown that in modern buildings, even tuning these parameters can be a challenge, let alone tuning them under varying occupancy levels, climates and time-dependent prices. Our results illustrate the true potential of MPC. It optimizes the operation on system level. It is bound by the real system constraints only, no extra rules, and is, therefore, able to identify control solutions that a human might not discover, for working conditions we did not expect, and a future climate we cannot yet predict.

Yet, the future climate is approaching, and we have to invest in our planet today to avoid crossing environmental limits and associated costs in the future, in fact, quite similar to Figure 1. We and the KU Leuven spin-off Builtwins believe that the outlined technology will play an important role as part of our mission towards climate-neutral building operation. We thank the Flemish government, KU Leuven and the European Commission for funding our research.

Figure 5. Photograph of elderly care home Ter Potterie. Source: Boydens Engineering, part of Sweco.

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Long-term Optimal Control of Hybrid Ground Source Heat Pump Systems. How far are we from the Optimum?

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Optimal control of buildings relies on predicting their behaviour using techniques such as mathematical modelling, data science or a combination of both. However, these predictions are typically limited to a few days. Consequently, in ground source heat pump systems, the controller is unaware whether abusive energy injection/extraction into/from the ground will deplete the source over the years. This article presents a simulation-optimization study that showcases the importance of accounting for the long-term behaviour of the ground towards the optimal operation of hybrid geothermal systems. Further theoretical energy use savings of 23.4% can be achieved compared to a baseline optimal controller that only accounts for the short-term future.

Over the last decade, intelligent building management and optimal control have demonstrated a large potential to mitigate the carbon footprint, energy use and monetary costs related to building operation [1]. Optimal control techniques found in buildings can be divided into model-based control approaches or Markov decision processes [2]. One common feature of both approaches is that they optimize towards future system behavior, typically for a few days.

However, the time constant of ground dynamics of the geothermal borefield is too large to be captured by the typical prediction windows used by these optimal control techniques. In that regard, it is uncertain in the long-term whether an optimal solution is being achieved or, even worse, the ground-source is being depleted. The borefield long-term dynamics can be well predicted using its characteristic thermal response function or g-function [3]. Thus, this article follows a physics-based Model Predictive Control (MPC) approach, eliminating the need for large training datasets.

Optimal control using MPC

MPC uses a mathematical model of the building envelope and its energy system. Using forecasted disturbances (i.e., weather, occupancy, appliances, etc.) and control inputs (temperature set-points, distribution signals, etc.), the model can predict the building's dynamic response and the energy system efficiencies. The mathematical model can be reformulated as an optimization problem to find the optimal control input sequence that minimizes a target or objective function (energy use, CO_2 emissions or monetary costs [4]) while at the same time a set of comfort constraints (thermal comfort, indoor environmental quality, etc.) is enforced. Due to the increasing uncertainty over time of the forecasts and the computational burden, the optimization is solved recursively at steps for the desired horizon.

We apply MPC to a building emulator depicted in Figure 1. The considered building is modelled as a 1200 m² single space using verified high-fidelity models from the IDEAS Modelica library [5]. The building is equipped with a ground source heat pump (GSHP) and a gas boiler for heat production (Q_{con}, Q_{boi}), and passive cooling from the geothermal borefield and an active chiller for cold production (Q_{pc}, Q_{chi}). The building can also choose between thermally activating the building structure (TABS) through embedded pipes (Q_{TABS}) and using air conditioning ($Q_{air,hea}$, $Q_{air,coo}$) as the slow and fast-reacting emission systems, respectively. Thus, the building case study is hybrid both at the production and emission sides. Still, the gas boiler and the chiller can only supply energy to the fast-reacting emission system, whereas the TABS are only fed by the GSHP or passive cooling heat exchanger. The performances of the GSHP and chiller are dependent on the borefield outlet and outdoor temperature, respectively. The system components are sized based on a previous dynamic simulation of this emulator, and the geothermal borefield is deliberately undersized due to the hybrid production system of the building. No occupant/appliances heat gains are considered to keep the building as a highly heating-dominated building. For the detailed model equations and design process, we refer to [6].

The building emulator equations are reformulated into a non-linear optimization problem using TACO [7]. This optimization problem is solved each hour recursively with a prediction horizon of one week and for a period

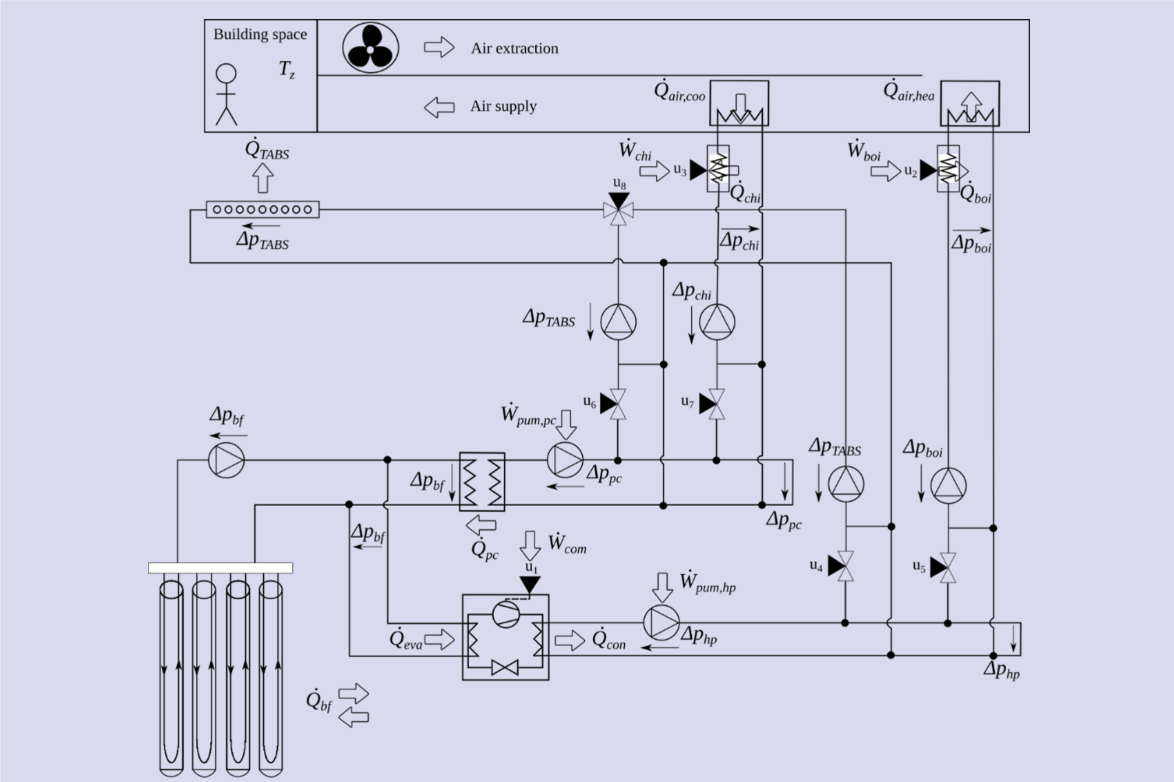

Figure 1. Schematic presentation of the considered building emulator, main energy flows and fluid network pressure drops.

of 5 years. The first set of inputs from the optimization is used to advance the simulation which starts at the beginning of the heating season, hence closing the loop. Weather forecast is considered to be perfect and deterministic. The optimization problem aims at minimizing the energy use of the installation while keeping thermal comfort in the space. Comfort is achieved when the space operative temperature is between 21°C and 25°C. A night-setback widens these bounds by ±5°C during the night.

The control input variables include the control of the production systems: u_1 for the GSHP, u_2 for the gas boiler and u_3 for the chiller; the valve openings that control the mass flow rates (and, in consequence, the heat/cold supply) to the different emission systems u_4, u_5, u_6 and u_7 and the 3-way valve that determines the TABS mode u_8. Since non-linear optimization problems do not accept binary inputs, this 3-way mixing valve needs to be considered as modulating in the simulation study. However, in practice, this valve is expected to be on/off to choose between heating or cooling mode in TABS. All pumps and fans work at a constant pressure head, although the pressure drops (Δp) they need to overcome can vary depending on their respective valve opening and, as a consequence, their energy use.

The energy distribution results over the 5 years simulation are shown in Figure 2a. Since the performance ratio between the GSHP and the gas boiler is around 5:1, MPC prefers the use of the GSHP to cover the heating energy needs of the building as much as it cans. However, the gas boiler energy shares increase each year due to the accumulated thermal imbalance in the borefield. This feature, in turn, favors passive cooling as the only cooling system being used in the building.

...but, how far are we from the true optima?

To answer this theoretical question, an Optimal Control Problem (OCP) is set up using the same building emulator equations and formulation. The only difference now is that the optimization is solved for a period of 5 years instead of recursively for 1 week at each control timestep. Computationally, solving this optimization problem is expensive and in the same order of magnitude as the full MPC simulation. Hence, a full OCP is non-applicable in real installations at the moment but serves as a theoretical benchmark.

The energy distribution results of the OCP can be observed in Figure 2b, revealing that the energy use of the building can be further decreased. To achieve this, the OCP increases the amount of cooling produced by passive cooling, thus reducing the thermal imbalance of the borefield and unlocking further use of the GSHP for the next heating season. This is possible thanks to the defined comfort bounds (instead of a fixed set-point), which confers freedom to the optimization. Figure 3 shows that the OCP keeps the building at the lower comfort bound during the summer season, whereas the MPC minimizes the short-term energy use and the space temperature is at the upper comfort bound.

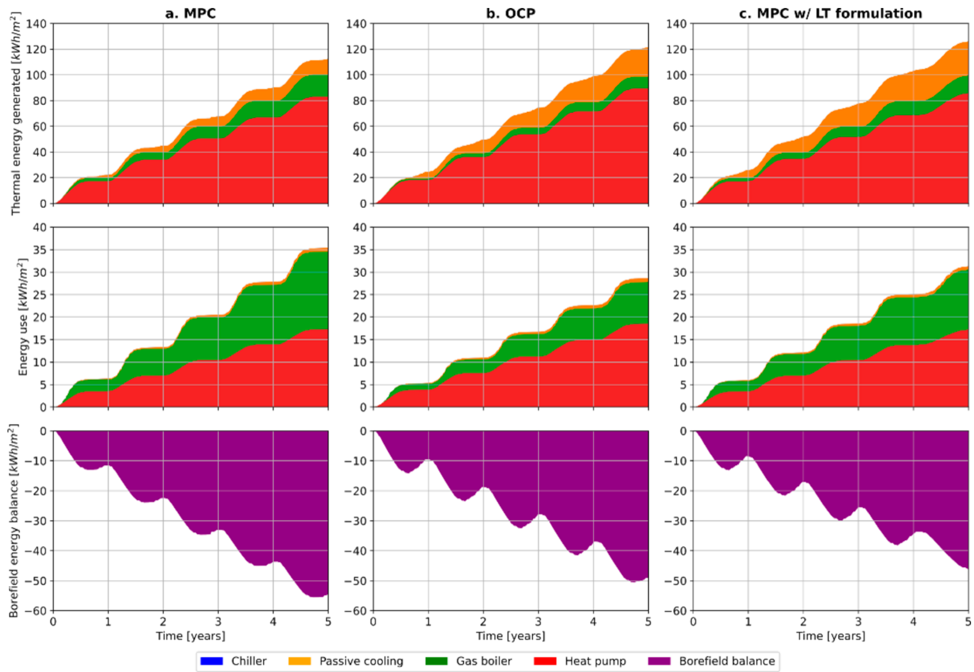

Figure 2. Energy distribution of the building HVAC components.

This behaviour is repeated for every year. The "short-term" MPC is not achieving its full potential in hybrid geothermal systems.

Can we do better than a "short-term" MPC?

Not many authors have proposed formulations that account for the borefield long-term dynamics. Typical approaches include a penalty term in the objective function to penalize the use of the borefield on the dominant energy side [8,9]. However, the determination of such a penalty relies upon trial-and-error. Imposing yearly cyclic conditions to the borefield by, for example, constraining the surrounding ground temperatures [10], can guarantee the sustainable use of the ground source. Still, the approach can be sub-optimal since (i) a yearly thermal imbalance can be allowed depending on the borefield size and (ii) it also limits the freedom of MPC to take optimal actions.

More recent research proposes extending the MPC objective function using a shadow-cost or cost of opportunity [11]. In summary, the shadow cost comprises the energy use of the building over a long-term horizon and can be computed using a set of prescribed predictions of the building heating and cooling needs (for example, using the building heating or cooling degree-days) and adding a set of static energy balance equations to the optimization problem. The short- and long-term optimizations are coupled by the load history of the borefield model, which in turn determines the predictions of the borefield outlet fluid temperature. Therefore, the actions of the short-term MPC optimization problem slightly influence the long-term optimization. Compared to the short-term MPC, the computational burden of the approach is increased, but still feasible towards real implementation.

The "short-term" MPC is extended by adding this shadow cost term to the objective function, estimating the energy use of the building emulator over one year. The building energy needs are estimated from the previous MPC simulation. The energy distribution results of this long-term MPC (MPC-LT) strategy are shown in Figure 2c, whereas the space temperatures are shown in Figure 3. It can be observed that the long-term MPC formulation overperforms the short-term MPC following a similar strategy as the OCP. Still, it cannot reach the full potential benchmarked by the OCP.

Several factors cause this loss of optimality. First, by imposing the use of fixed predictions coming from the short-term MPC, we mislead the long-term MPC during the mid-season when no heating is required by the short-term MPC, as shown in Figure 3. Therefore, the long-term MPC does not know that it needs a few days of extra heating per year. In addition, the long-term MPC drives the overuse of passive cooling since the beginning of the summer season at low pump speeds, whereas the OCP waits until the middle of the season using a higher pump speed. This results in a lower borefield energy imbalance, but it is not translated into a lower energy use probably due to (i) the effect of the loads farther in time having a lower effect on the borefield fluid temperatures and (ii) thermal losses into the ground.

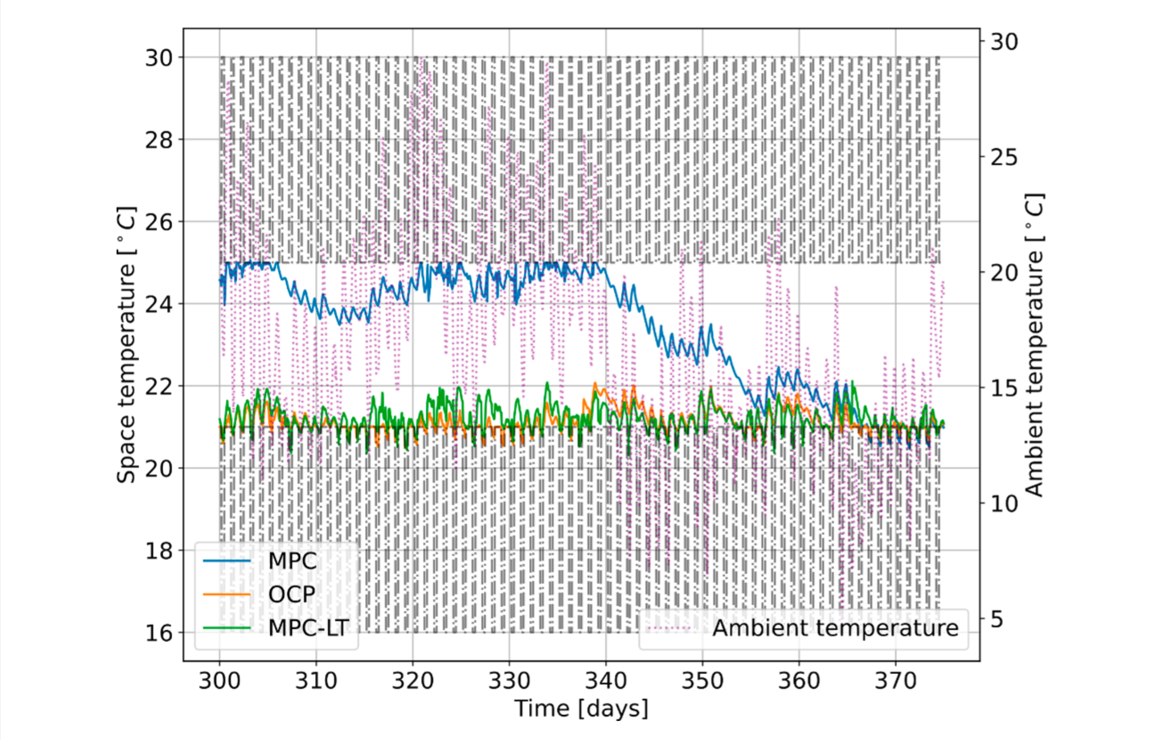

Figure 3. Temperature evolution of the building space at the end of the cooling season.

Table 1. Energy use comparison between the OCP and the MPCs with and without shadow cost

Energy use [kWh/m²]	OCP	MPC		MPC-LT	
		Absolute	Relative	Absolute	Relative
Heat pump	18.54	17.34	-6.4%	17.43	-6.0%
Boiler	9.28	17.26	+86.0%	13.33	+43.6%
Passive cooling	0.88	0.83	-5.6%	0.80	-9.1%
Chiller	0	0	0	0	0
Total	28.70	35.43	+23.4%	31.56	+10%

Conclusions

This study presents a simulation-optimization study of a heating-dominated building equipped with a hybrid geothermal system and whose borefield is deliberately undersized. MPC is applied to the building and benchmarked against an equivalent OCP for a period of 5 years. Then, the MPC is modified by introducing a shadow cost into its objective function.

The main numerics of the comparison are summarized in Table 1. Further theoretical energy savings of 23.4% can be achieved according to the OCP benchmark. The long-term MPC can reduce this gap down to 10%. If we define MPC efficiency as the ratio between the OCP and MPC energy savings, the short-term MPC is at 81.0% of its full potential, whereas the long-term MPC is at 91.0%.

This simulation study clearly shows that there is further potential in the optimal control of hybrid geothermal systems by accounting for the ground's long-term dynamics. If well formulated, the shadow-cost methodology can mitigate this performance gap. Still, further research should tackle the challenges regarding the quality and accuracy of the long-term predictions.

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Improving the Traditional Heat Pump System Control through Prediction of Daily Solar Radiation

Davide Rolando and Hatef Madani, Sweden

It's sunny outside: does your heat pump know?
Traditional control approaches for heat pump systems in residential buildings are based on the "heating curve" setting, where the supply temperature to the heating (or cooling) distribution system is defined as a function of the outdoor temperature. If the outdoor temperature is the only control input available, the heat pump system cannot take into account important additional inputs, like solar radiation, that can substantially vary on a daily basis throughout the year and negatively affect the indoor comfort and the energy-saving possibilities.

Heat pump systems represent a well-established technology that has been growing in the last decades, reaching a mature technical development. In parallel, a new perspective for improving the efficiency and flexibility of heating and cooling systems have been rising thanks to the availability of cost-effective and powerful controller units. The computational power of electronic devices has been increasing in the last decades, together with storage and connection capability [1], and there has been a growing interest in the possibility of introducing advanced features in the heat pump system controllers. With the decreased costs of data processing, storage and communication over recent years, the design and implementation of more complex control techniques have become accessible [2], and several studies have been dedicated to the development of advanced system control.

The EffSys Expand project P18, "Smart Control Strategies for Heat Pump systems" [3], is a research project co-founded by the Swedish Energy Agency and focused on the improvement of single-family house Heat Pump heating systems. The P18 project evaluated several methods that can be potentially implemented in the controller of heat pump systems in order to increase the overall energy efficiency while guaranteeing the indoor comfort conditions. The project focused on solutions that can effectively be adopted in both newly built and existing heat pump systems. The final goal of the project was the improvement of the annual system efficiency and the minimization of the annual operating cost of the system, exploiting predictive control strategies by analyzing the data available regarding people's behavior, weather forecast and environmental condition measurements. As a result, the maximization of the thermal comfort in single-family houses will be possible together with a reduction of the annual electricity consumption obtained through the minimization of the usage of electrical auxiliary heaters. This article presents a short description of one of the solutions proposed, considering the improvement of the traditional control approach for heat pump systems through the prediction of the daily solar radiation.

The traditional and basic control approach for heat pump systems in residential buildings is based on the calculation of the supply temperature to the heating (or cooling) distribution system based on the outdoor temperature. The function that expresses the supply temperature is called the "heating curve" and is typically defined as a piecewise function.

The heating curve is typically defined and set during the system installation phase depending on the building envelope characteristics, the heating distribution type (radiators or floor heating, for example) and the design temperature conditions for a given location. The approach is based on the idea that, for a given outdoor temperature, a supply temperature can be defined to balance the building heating demand in order to guarantee an indoor temperature that corresponds to the thermal comfort conditions. In Sweden, a large portion of the heat pump installations for residential buildings consider the heating curve as the only input for the system controller. The indoor temperature is in many cases monitored but not actively employed in the control logic implementation.

The indoor temperature is not univocally related to the outdoor temperature. The solar radiation and the occupant activities, for example, represent energy gains that can affect the indoor temperature stability and thermal comfort. The adjustment of the heating curve based on additional inputs has been considered in project P18, and the results of an improvement potential study have been presented [3]. Simulation models of single-family house heat pump installations have been developed in order to test advanced control strategies that could lead to minimize the Heat Pump energy consumption while maintaining the overall thermal comfort. The results show that an energy-saving greater than 10% could be potentially achieved by compensating for the free energy gain from the solar radiation in selected periods of the year, which for Sweden are typically from March to May and from September to October.

Figure 1 shows the monthly ambient temperature distribution in Stockholm over the period 2014-2017. Figure 2 shows the Monthly values of the daily solar radiation distribution in Stockholm over the same period. In the violin plots and box plots shown in the Figures, the white dots and the middle lines represent, respectively, the median values. It is interesting to notice, for instance, that the median temperatures in April and November are quite

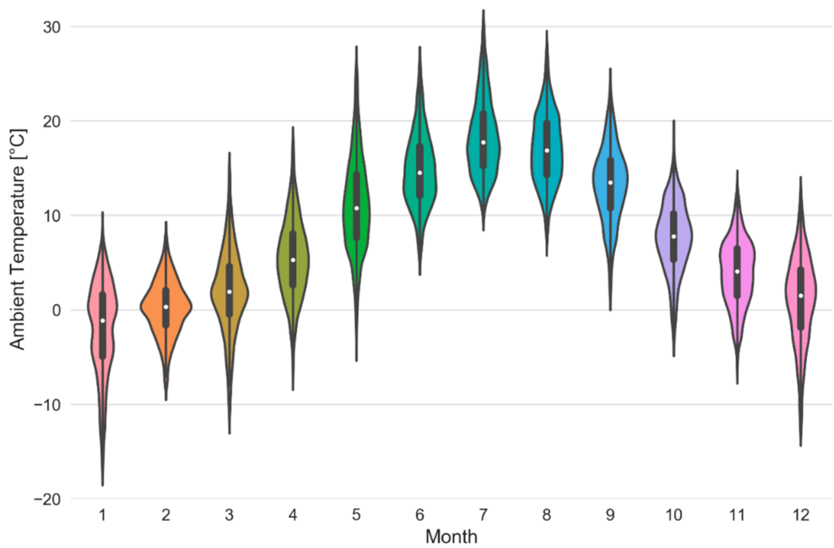

Figure 1. Monthly ambient temperature distribution in Stockholm over the period 2014-2017. Source: SLB-analys [5].

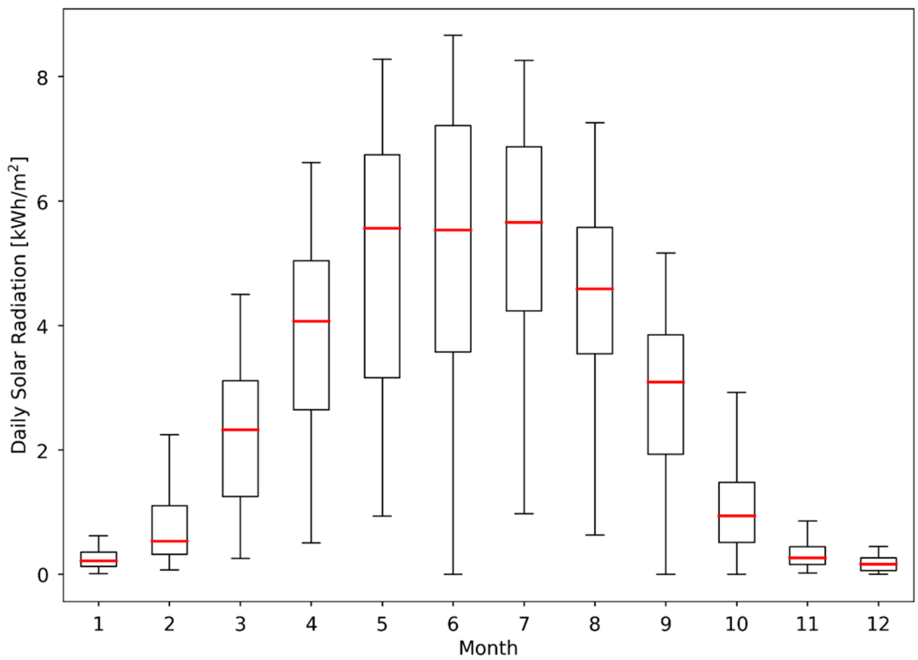

Figure 2. Monthly values of the daily solar radiation distribution in Stockholm over the period 2014-2017 Source: SLB-analys [5].

similar; the difference is, in fact, below 1.5ºC, and the temperature distribution is also comparable. On the other hand, the median value of the daily solar radiation in April is about 4 kWh/m², while in November is close to zero. The heating curve control clearly cannot distinguish between outdoor temperatures with or without of solar radiation. In principle, the prediction of the daily solar radiation would allow the heating curve to be adjusted to avoid, for example, the overheating of the indoor environment and, at the same time, reduce the energy consumption of the heating system.

Figure 3 shows the evolution of the solar radiation during one day of March, arbitrarily selected. The Figure shows both the clear sky radiation and the measured radiation. The clear sky radiation represents the maximum radiation that can be available at a given time and can be calculated considering the relative position of the sun to a given location. Worth noticing that the position of the sun is available for any time through astronomy calculations. The second curve in the Figure includes the actual measurements of the solar radiation recorded on the same day. The measured radiation is always lower than the clear sky radiation, and the ratio between the corresponding daily energy (in kWh/m²) can be calculated. In the project P18, a method to predict the daily solar radiation based on the prediction of the attenuation of the clear sky radiation was developed and implemented in simulation models of single-family house heat pump systems. The complete explanation of the method is available online in the project P18 report [4].

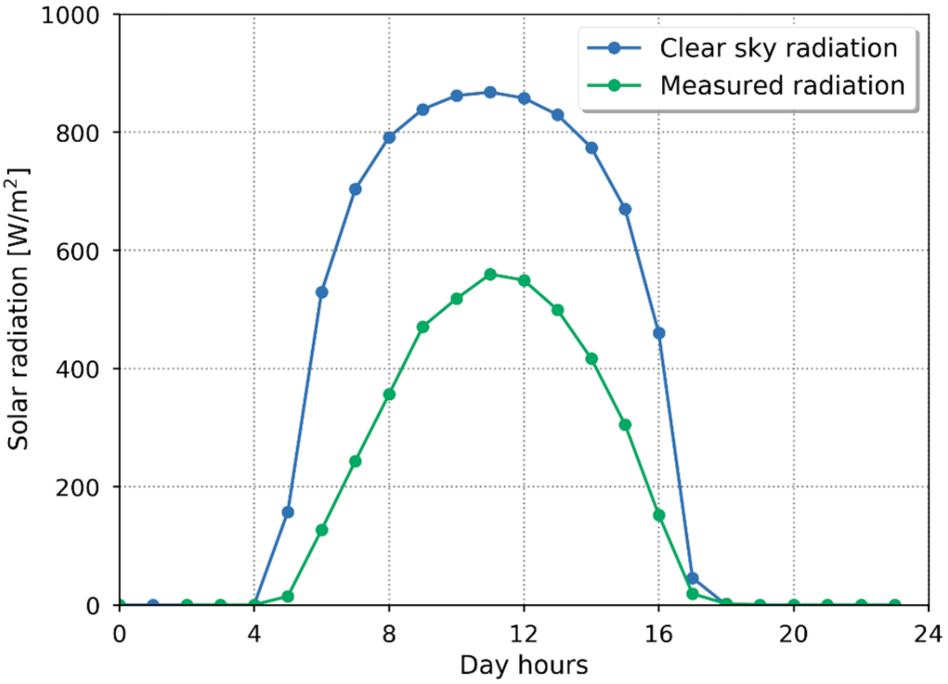

Figure 3. Example of the solar radiation profile ratio of one day in March. The theoretical clear sky radiation profile is compared to the measured data.

Figure 4 shows the results obtained through simulations performed in TRNSYS considering real weather data for Stockholm over the period 2014-2017. The results show that the modulation of the heating curve through predicting the daily solar radiation allows monthly energy-saving higher than 10% in some cases. The highest reduction of energy use occurs during the spring period while, as expected, no energy can be saved with this method during autumn and winter periods with the lowest daily solar radiation.

Conclusions

The method briefly described in this article allows energy saving that on a monthly basis can be greater than 10% compared to a basic heating curve controller and can be implemented in both new and existing heating system installations.

It is very important to mention that no additional sensors are required for the implementation of this control

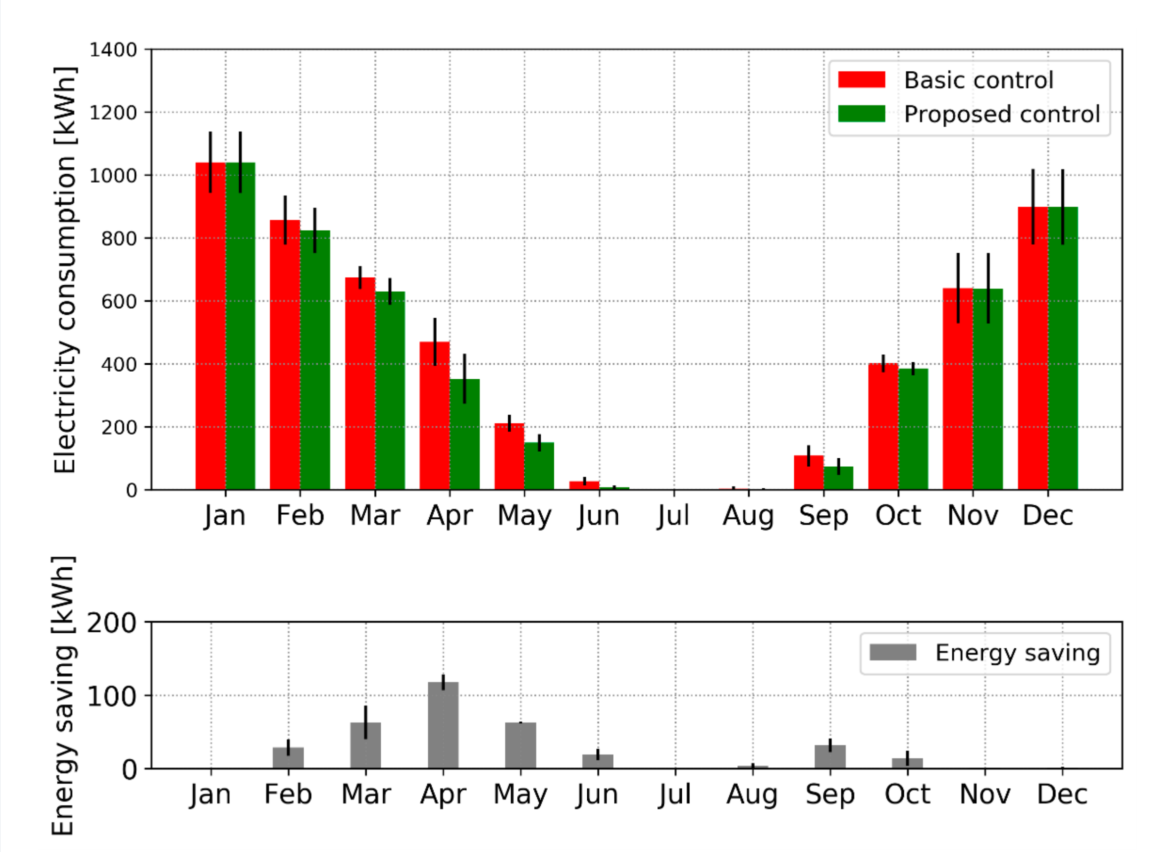

Figure 4. Summary of energy consumption and energy saving profiles resulting from the simulations with weather data considering the period 2014-2017.

strategy. In particular, no direct measurement of solar radiation is required, and no hardware modifications of the system are needed.

The proposed control strategy was developed with the clear intention of maintaining the simplicity of the traditional heating curve approach and could be implemented through a software modification of the controller.

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INFORMATION

The role of Heat Pump Control in Decentralized Energy Flexibility Exploitation

Maarten Evens and Alessia Arteconi, Belgium

Wide-scale adoption of heat pumps not only decarbonizes the heating and cooling sector but also increases the availability of energy flexible services. While new heat pump control strategies are investigated, the role of the implemented internal heat pump control by the manufacturer cannot be simply neglected, especially when third-parties want to directly control the heat pump. This article aims to summarize the effects of the internal heat pump control with the focus on energy flexibility provision while maintaining a system's perspective on the energy flexibility trading in a peer-to-peer manner.

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In 2019, the combination of space heating/cooling (SH/SC) and domestic hot water (DHW) accounted for more than 75% of the final energy consumption within the European residential sector [1], while the residential heat pump (HP) market share was only 6% at the end of 2020 [2]. Fuel burner replacement by HP allows further decarbonization of the energy sector while increasing the renewable energy production allows a more sustainable energy provision as well. In such a scenario, HPs use a sustainable thermal source, while electrical energy comes from renewable resources as well. Though, the volatility of renewable energy resources puts additional constraints on energy security and requires supplementary energy flexibility. Due to their market potential, renewable character and coupling to the electricity grid, HPs are seen as one of the appropriate technologies for energy flexibility services. Usage of thermal energy storage or the thermal building mass allows energy shifting towards moments of renewable energy surplus. In this context, smart HP control strategies are investigated. Though, reaching an accurate short-term behavior control of HP is not straightforward as HP manufacturers already implement internal control strategies to ensure safety, reliability and satisfaction of the end-user comfort. The development of smart HP control strategies should already incorporate these internal control rules as these manufacturer constraints can generally not be bypassed and influence the short-term behavior. As grid users will be allowed to trade energy and flexibility services in the near future [3], an accurate estimation of the

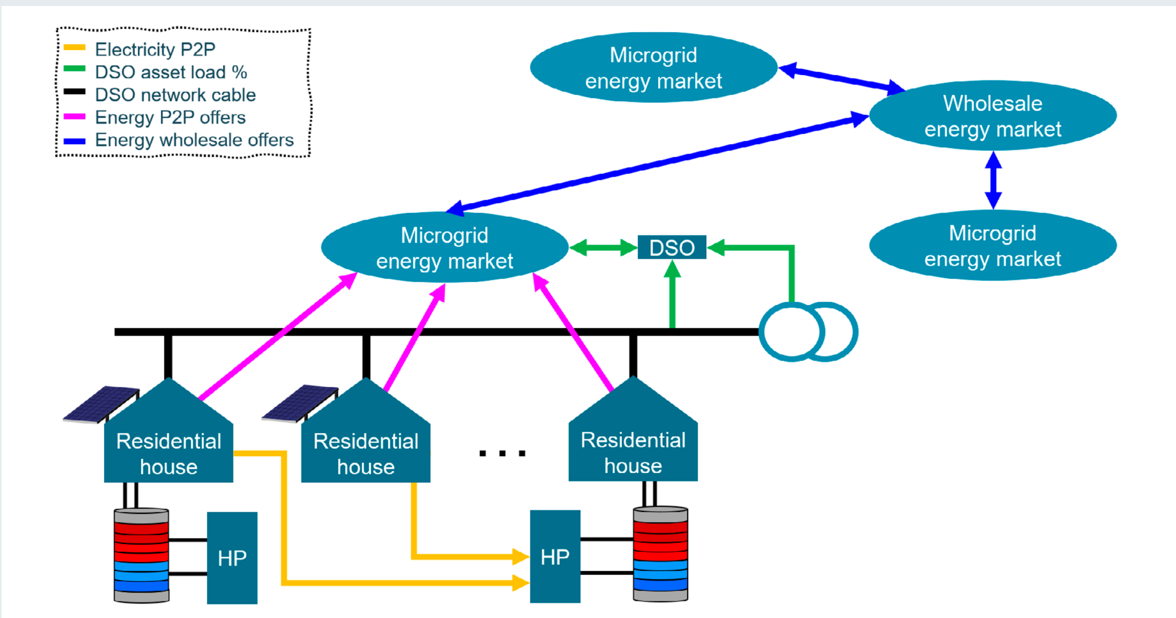

Figure 1. Microgrid energy trading.

real HP behavior is thus required. In this article, the role of HP control during energy trading will be summarized.

Microgrid energy trading

Figure 1 shows the transition towards distributed energy production with flexibility services. The distributed nature allows small groups of grid users, e.g. all users fed by a single distribution transformer, to join forces and introduce the concept of microgrids with peer-to-peer (P2P) energy trading. Within microgrids, users with energy excess (e.g. due to solar energy production) set a minimum selling price and energy level, while users with an energy shortage (e.g. due to a HP) determine a maximum buying price and energy level. After reaching an agreement, grid users directly trade energy among them. It allows to minimize grid losses and grid fees while local energy consumption is improved. Though, the coupling with the wholesale energy market is mainly kept for energy security and to allow users to buy/sell energy from/to energy retailers as well.

Considering a P2P market, the role of blockchain technology (BCT) is currently investigated as it allows transparent, secure and trustworthy transactions while excluding the full dependency on third parties. In contrast with public reading/writing access as in the domain of cryptocurrencies, energy trading via BCT has to meet more restrictive rules due to the grid infrastructure. In general, the goal of P2P energy trading is clear, while the system requirements, legal aspects, required grid parties, trading platforms and trading rules are still unclear.

Heat pump internal control strategies

Trading energy with HP is not straightforward as it requires an accurate knowledge of the actual HP behavior. Indeed, before submitting an energy bid, an estimation of the expected energy consumption is needed. Future energy trading within time slots of fifteen minutes is mainly expected due to the measuring frequency of smart meters, transmission system balancing processes, renewable energy volatility and due to the limited flexibility potential of residential appliances of a single user. Comparison of HP modeling approaches showed that an accurate energy performance representation is the main focus within the literature, while internal control strategies are mainly neglected. Figure 2 shows a general overview of the HP internal control strategies, including the coupling to an energy management system

In [4], Evens and Arteconi investigated the incorporation/neglection of these control strategies, both in the short- and long-term. While long-term effects were rather limited, short-term effects were clearly noticed and influenced the HP flexibility provision. By gradually increasing the modeling complexity and comparing annual short time step simulations, the duration curves of Figure 3 were constructed. Therein, the HP electricity consumption and HP outlet temperature of each modeling approach for each minute of the year were compared to a model closest to the expected HP behavior. It was shown that the HP operational schedule was not only time-shifted but also profile-modified due to the internal control. The HP model was built on a thorough understanding of the HP manufacturer manual.

To prove the validity of their model, a hardware-in-the-loop HP test bench was built. While the experimental campaign for the validation process showed the importance of the internal control strategies [5], a future work will include model calibration. Once a calibrated

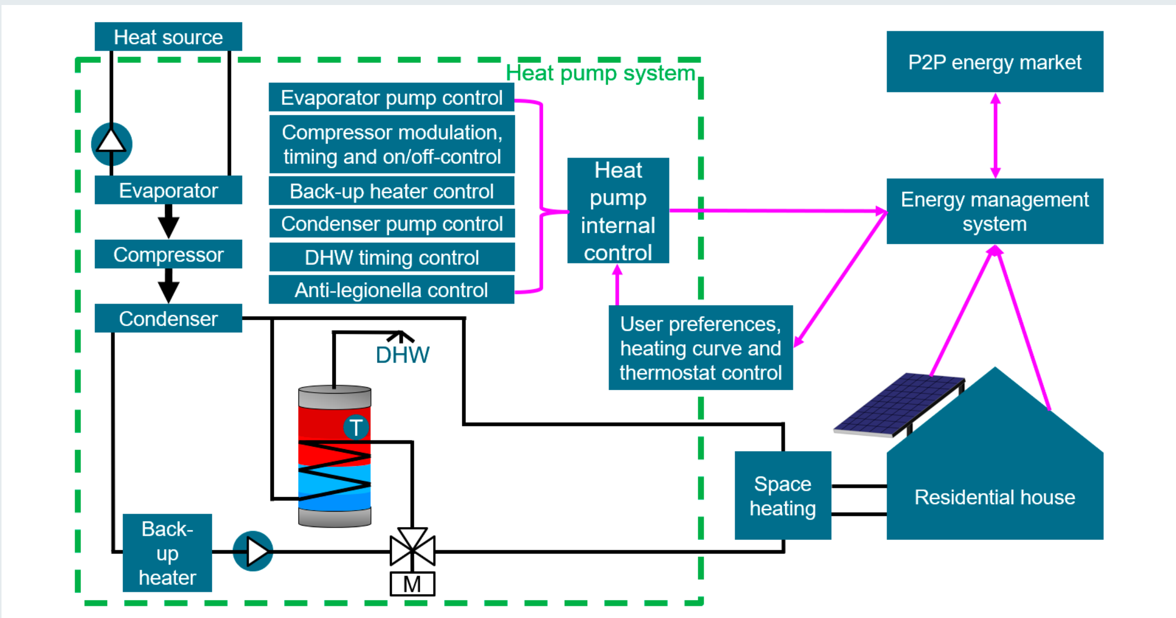

Figure 2. Overview of HP internal control strategies.

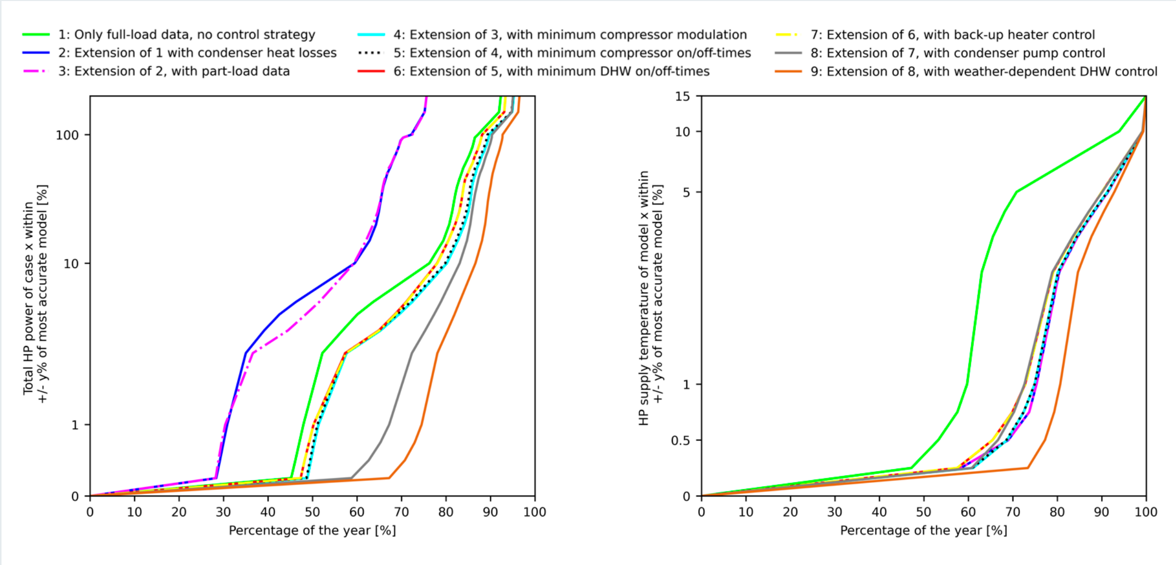

Figure 3. Duration curve HP modeling approaches [4].

HP model is obtained, it allows to accurately represent the actual HP behavior and to develop new strategies for energy flexibility.

Conclusions

The energy transition leads to the gradual replacement of fossil-fired appliances by heat pumps, while the volatility of renewable energy resources requires more energy flexibility. In this context, new heat pump control strategies for energy flexibility provision are investigated. A preliminary step is to obtain an accurate knowledge of the heat pump's internal control strategies, already implemented by the manufacturer, as these control rules can generally not be bypassed. Also, energy trading by end-users in microgrids requires an accurate estimation of the heat pump behavior and energy flexibility potential during the trading interval. Again, the internal control strategies change the operational behavior and can affect the estimated flexibility potential. Hence, developing smart heat pump control strategies requires an accurate knowledge of the real heat pump behavior.

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INFORMATION

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Germany: Heat Pump Market Report

Dr Rainer M. Jakobs, Germany

Heat pump sales in Germany are again showing strong growth following the record year of 2020, according to sales statistics on the heating market. In 2021, heat pump sales growth was 28%. The industry is delivering – now it is up to the new German government to step up the heat turnaround in line with its announcements. The sustained positive market trend shows the high level of acceptance of heat pumps among consumers.

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Since 2000, the volume of heat pump sales in Germany has increased significantly. In 2020, more than twelve times as many heat pumps were sold as in 2000.

Germany at a glance [1]

It has an area of 357,578 km². Germany is a federation. The federation and the 16 states each have areas of responsibility of their own.

Figure 1. States of Germany [1].

With 83.1 million inhabitants, Germany is the most populous country in the EU and one of the most densely populated; around 77% of its inhabitants live in densely and highly populated areas. Around 30% of the population resides in big cities with more than 100,000 inhabitants, of which there are 80 in Germany, four with more than one million inhabitants, Berlin, Hamburg, Munich and Cologne. Munich has 4,713 people per square kilometer, Berlin 4,012. Experts believe the ongoing trend of growth and innovation is reflected in the renaissance of cities – with considerable consequences for the housing market, inner-city mobility, and infrastructure.

Households by types of households:
42.3% 1-person, 33.2% 2-persons,
11.9% 3-persons, 9.1% 4-persons, 3.5% 5+ persons

Almost 50% of people in Germany live in rented accommodation, which is the highest level on a European comparison, and for this reason, many people are affected by rising rents. People who have moved into a new apartment since 2015 pay on average 7.70 € per m² without heating and other running costs. That is around 12% more than the average. The trend is particularly acute in cities like Berlin, Munich, and Frankfurt/Main. In Berlin, the average rent, excluding heating and running costs for apartments recently leased, has come to 9.10 € per square meter. This urbanization makes Germany part of a global trend.

Germany enjoys a moderate climate. In July, the mean temperature is 16.9°C, and in January -0.5°C. The most recent winters in Germany were particularly mild and the summers particularly hot. With a mean temperature of 10.5°C, 2018 was the warmest year in Germany since records began back in 1881. 2019 placed alongside 2014 as the second warmest. The highest temperature since the records began was recorded on 25 July 2019 in Lingen in Lower Saxony, namely 42.6°C.

Heating energy for a cozy home [2]

For now, most Germans still use gas to heat their homes see Figure 2. But renewables are catching up. If you're thinking about switching your heating for a system based on renewables, there are a number of new funding options and advisory services. The 10-year overview shows that there is a clear trend towards renewables, with heat pumps and district heating each gaining 10% and natural

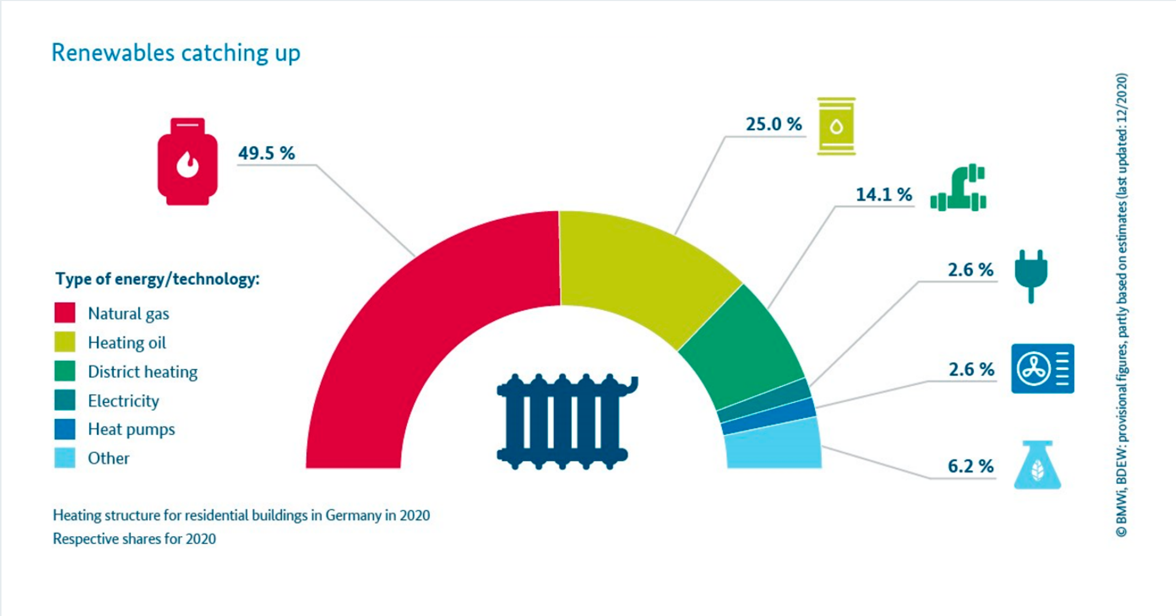

Figure 2. Heating energy for cosy homes [2].

gas/ bio-methane losing roughly 15% over the last decade. No heating is built for eternity, and a regular replacement is a good opportunity to switch over to renewables. Those making this decision can benefit from various efficiency programs for buildings, such as the new federal funding programs for efficient buildings [3].

Market for Heat Pumps [4]

Since 2000, the volume of heat pump sales in Germany has increased significantly. In 2020, more than twelve times as many heat pumps were sold as in 2000. Heat pump sales in Germany are again showing strong growth following the record year of 2020, according to sales statistics on the heating market. In 2021, heat pump sales growth was 28%.

54,000 heat pumps were sold in Germany in 2021. Air-to-water heat pumps experienced the greatest growth: 127,000 units (+ 33%) were sold in total, of which around 83,500 were monobloc units (+ 48%) and 43,500 split units (+ 12%).

Brine-water heat pumps grew by 12%, with 27,000 ground-coupled systems.

Air-water systems were able to slightly increase their market share again in 2021 to 82 % (2020: 79 %), while ground-coupled systems had a market share of 18%.

The sales of domestic hot water heat pumps rose by 15% compared to the previous year. The number of units sold was 23,500 units.

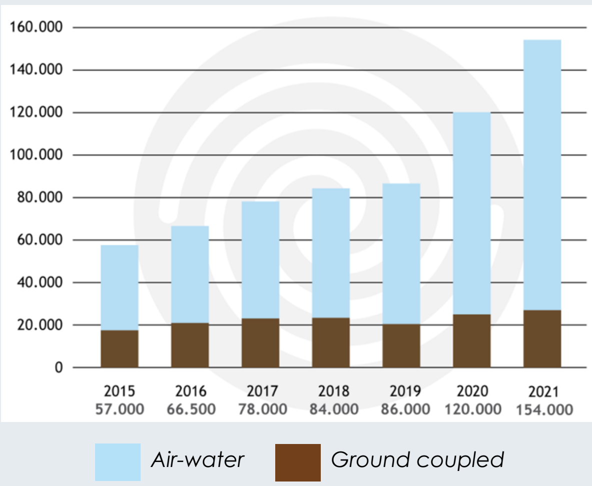

Figure 3. Sales of heat pumps [4].

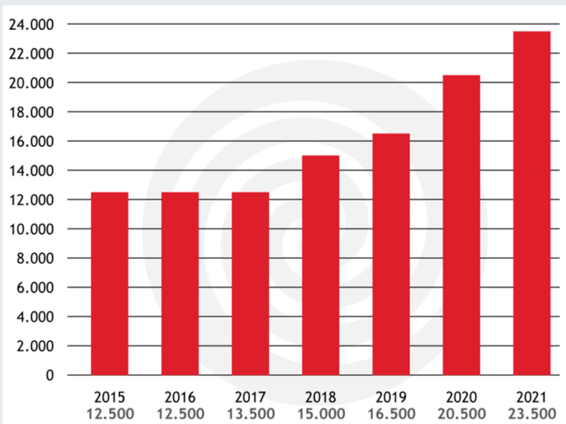

Figure 4. Sales of domestic hot water heat pumps [4].

The positive market trend is thus proving to be extremely stable despite Corona-related restrictions and global supply-chain complications. This is also reflected in the high demand for the new federal subsidy for efficient buildings, which replaced the market incentive programme this year.

The continuing positive market trend is indicative of the high level of consumer acceptance that heat pumps now enjoy. Heat pumps are on the way to become the standard heating system in the country.

Challenge

One of the main barriers for the successful rollout of heat pumps is the electricity price. It cost on average 23.8 cent/kWh in 2021. This makes it significantly more expensive than fossil fuels (heating oil, natural gas) or pellets. This is mainly due to state-regulated price components, which are not charged for most other heating energy sources, and which account for almost 60% of the price [4].

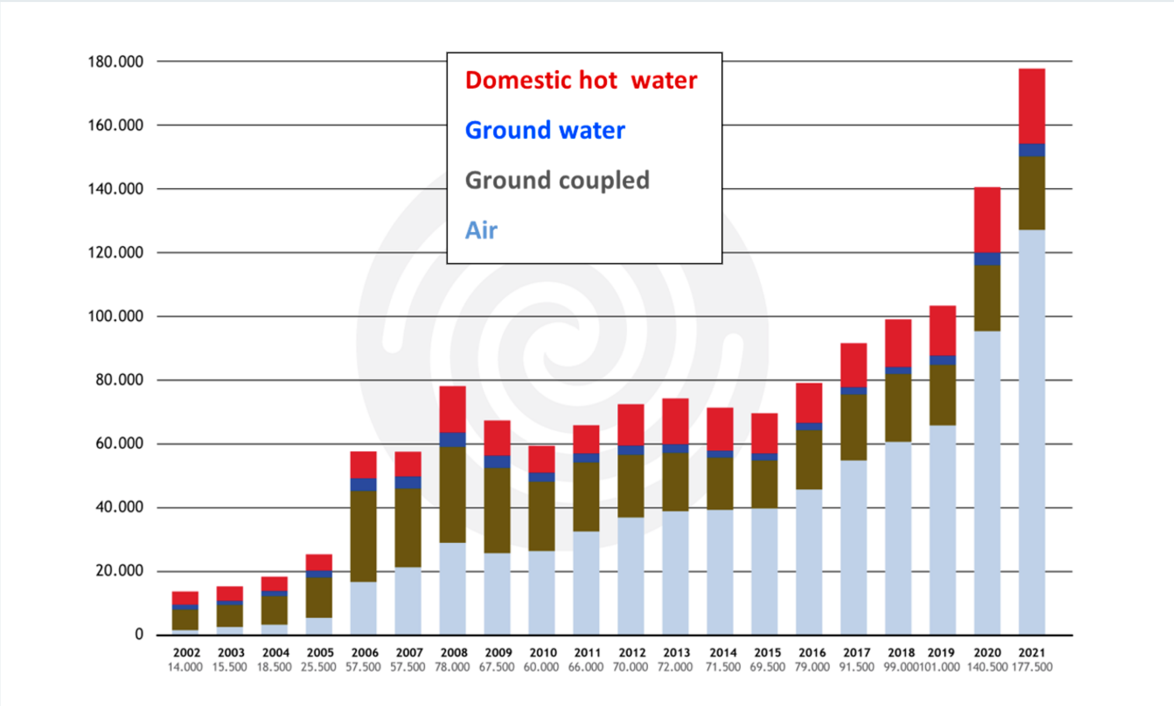

Figure 5. Total sales of heat pumps 2002–2021 [4].

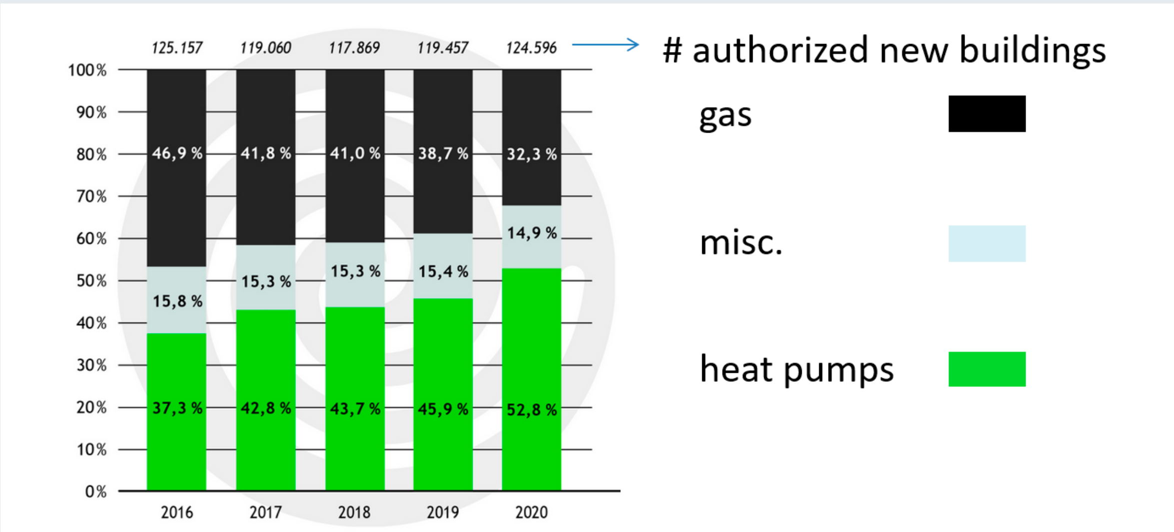

Figure 6. House building permission [5].

House-building permission [5]
According to the Federal Statistical Office, a total of 124,596 residential buildings were approved for construction in 2020. Of these, 55,544 are to be heated with environmental heat and 10,257 buildings with geothermal heat - a total of 52.8% of approved residential buildings. So more and more building owners are opting for climate-friendly heating systems, which is good news.

Gross electricity consumption [6]
Development of gross electricity consumption until 2030: The consortium of Prognos, Öko-Institute and Fraunhofer ISI, on behalf of the Economic Affairs Ministry, carried out an ad-hoc (Nov. 2021) estimate of the development of gross electricity consumption up to the year 2030. The continuing positive market trend shows the high acceptance of heat pumps among consumers. Electric heat pumps are becoming increasingly important in the heating sector. In this scenario, the number of installed heat pumps increases from nearly 1 million in 2018 to 5.5 million in 2030. This does not take into account small uncoupled hot water heat pumps. The majority of heat pumps are in residential buildings, with a small proportion in non-residential buildings. The non-residential buildings are usually larger buildings with more powerful heat pumps. The 5.5 million heat pumps are associated with electricity consumption of around 33 TWh (in 2018, under 7 TWh). At the same time, the use of large heat pumps in district heating is also increasing (+ 9 TWh). Overall the electricity consumption of heat pumps increases by 35 TWh to around 42 TWh between 2018 and 2030 in the scenario. If the small uncoupled hot-water heat pumps are also included, the electricity are added, the electricity consumption of heat pumps increases by an additional 3 TWh to a total of 45 TWh.

The German government has now a clear understanding of the significance of heat pumps and about the size of ~6 million heat pumps and the associated additional electricity consumption in 2030.

Research [7]
The German government is aiming for a climate-neutral building stock by 2045. In order to achieve this goal, it is necessary to reduce the heat demand on the one hand and achieve a climate-neutral heat supply on the other. The German government is, therefore, funding projects in the areas of research, development and demonstration as a part, e.g. of the 7^{th} Energy Research Programme. The Energy Research Programme is a strategic element of the Federal Government's energy policy that aims to support this continuous research and innovation process [7].

Since 2010, research projects in the fields of heat pump and refrigeration technology have been funded with more than **71 million €**. In the past few years, development has focused mainly on heat pumps for buildings (single-family houses, multi-family houses, non-residential buildings), and the main areas of development are refrigerants, components, integration and demonstration. There are also some projects addressing heat pumps for the industry.

Currently, another main topic is the generation of cold at temperatures below 0°C by water-based absorption and adsorption processes.

In addition, a major project on the topic of heat pumps in district heating networks, "Reallabor GWP", has been started as of 01.04.2021. The Federal Ministry of Economic Affairs and Energy is funding this project with **21 Mio. €.** [8]

A large number of universities, research institutes and industrial companies are working on heat pump technologies in Germany.

In particular, the Fraunhofer Institute for Solar Energy Systems ISE, the Technical University of Dresden and the E.ON Energy Research Center at RWTH Aachen University on the research side and Vaillant, Viessmann, Stiebel Eltron and Bosch-Thermotechnik on the industry side are to be mentioned.

New Institutes for large energy systems:
- German Aerospace Center's (DLR) Institute of Low-Carbon Industrial Processes
- Fraunhofer Research Institution for Energy
- Infrastructures and Geothermal Systems (IEG)

(This enumeration is not intended to be complete or definitive)

Conclusion
- Heat pumps as heating systems are dominant in new buildings.
- There is further a great potential in the building stock.
- A government scheme rewards property owners for replacing older oil-fired central heating.
- Air to water heat pumps have ~80% market share.
- Great potential also in commercial + industrial applications
- High electricity prices in comparison to gas and oil are a strong barrier for Heat Pumps.

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Events 2022/2023

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

2022

28 August – 1 September
10th IIR Conference on Caloric Cooling and Applications of Caloric Materials
Ljubljana, Slovenia
https://www.thermagx2022.si/

22 September
Inspiration, innovation and policy measures to solve the heat challenge - a side event on the CEM13/MI7 meeting
Pittsburg, USA
https://heatpumpingtechnologies.org/activities/1/57650/

28 September
Heat Pump Forum
Brusseles, Belgium
https://www.ehpa.org/events/#/event-details:67

3–6 October
INTERCLIMA
Paris, France
https://www.interclima.com/en-gb.html

4 October
HPT TCP National Experts meeting
Online

11–13 October
Chillventa 2022 - Refrigeration, AC & Ventilation, Heat Pumps Exhibition
Nürnberg, Germany
https://www.chillventa.de/en

18–22 October
23rd China Conference on Heating Ventilation, Air-conditioning & Refrigeration
Jiangsu Province, China
https://hvacr2022.scimeeting.cn/cn/web/index/

2–4 November
2022 China International Air conditioning, Ventilation, Refrigeration and Cold Chain Expo(RACC)
Hangzhou International Expo Center, Zhejiang, China
https://www.raccexpo.com/

10–12 November
HPT TCP Executive Committee meeting (Only for delegates, operating agents, and invited guests)
United Kingdom

2023

4–8 February
ASHRAE's Winter Conference 2023
Omni Hotel at CNN Center and Georgia World Congress Center
https://www.ashrae.org/conferences/2023-winter-conference-atlanta

4–6 April
3rd IIR Conference on HFO Refrigerants and Low GWP Blends
Shanghai, China
https://iifiir.org/en/events/3rd-iir-conference-on-hfo-refrigerants-and-low-gwp-blends-f026669c-85d4-4f22-900e-6d6e04e5adaa

24–28 April
17th CRYOGENICS 2023 IIR Conference
Dresden, Germany
https://www.cryogenics-conference.eu/cryogenics2023

27–29 April
10th IIR Conference on Ammonia and CO_2 Refrigeration Technologies
Ohrid, R. Macedonia
https://iifiir.org/en/events/10th-iir-conference-on-ammonia-and-co2-refrigeration-technologies

15–18 May
The 14th IEA Heat Pump Conference in Chicago (HPC2023)
Chicago, Illinois, United States
https://www.hpc2023.org/

8–9 June
20th European Conference
Milan, Italy
https://www.centrogalileo.it/

21–25 August
26th IIR International Congress of Refrigeration
Paris, France
https://www.icr2023.org/

11–13 September 2023
13th International Conference on Compressors and their Systems
London, United Kingdom
https://citycompressorsconference.london/

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

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

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

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

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

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

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

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