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Heat Pumps Unleashing Flexibility and Sector Coupling

Vol.42 No.1/2024
A HEAT PUMP CENTER PRODUCT

Contents

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In this Issue

Welcome to the first edition of Heat Pumping Technologies Magazine Issue 1, 2024. This issue marks a significant shift as we embrace the digital era, transitioning from the traditional layouted and printable magazine format to a modernized complete online digital magazine. Despite this change, our commitment to delivering high-quality content remains unwavering.

This edition is dedicated to delving into the dynamic realm of "Heat Pumps Unleashing Flexibility and Sector Coupling Amidst Electric Grid Transformations and Strategic Investments." In today's rapidly evolving energy landscape, heat-pumping technologies have emerged as pivotal forces in shaping the future of sustainable and efficient energy utilization.

Our Foreword section, titled "Navigating the Grid Challenges and Solutions in the Netherlands' Energy Transition," sets the stage for insightful discussions on the complexities of modern energy grids and the innovative solutions being implemented to overcome them.

In our Column section, titled "Navigating the Path to Decarbonization: Addressing Challenges in the Absence of Regulatory Building Policies," we explore the critical role of regulatory frameworks in driving the decarbonization agenda and the challenges encountered in their absence.

Throughout this issue, our topical and non-topical articles will delve into the multifaceted aspects, challenges, and opportunities inherent in the strategic focus on heat-pumping technologies. Join us as we uncover the transformative potential of heat pumps in navigating the complexities of modern energy systems and driving forward the transition towards a sustainable future.

With rising temperatures and stringent energy-saving regulations, heat pump technology emerges as a pivotal player in Japan's quest for sustainability. The national market section explores key trends, challenges, and innovations shaping the future of heating, cooling, and hot water supply in Japan's evolving energy landscape.

Enjoy your reading!
Metkel Yebiyo, Editor
Heat Pump Centre
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Foreword

Navigating the Grid Challenges and Solutions in the Netherlands' Energy Transition

By Marion Bakker and Tom van Aalten of Netherlands Enterprise Agency

In the Netherlands, the ever-increasing rate at which additional transmission capacity is required exceeds the speed at which grid operators can expand the electricity grid. Although work on the grid is in full swing in all regions, the billions of euros invested and additional measures are unfortunately not enough. The grid operators signal that the Netherlands is entering the next phase, in which access to the electricity grid will come under further pressure. Without drastic measures, housing construction, economic growth and sustainability in the Netherlands will slow down.

There are currently more than 105 gigawatts (comparable to more than 150 times the capacity of Amsterdam) in applications for reinforcements or new connections for electricity consumption. These are, for example, applications for large-scale batteries (75GW) and industry, companies, data centres, hydrogen plants and new residential areas. All these developments add up to much faster than grid expansions can be realized. Rising energy prices and increasing climate ambitions are accelerating this considerably. Nationally, the trend is that the limits of capacity are coming into focus in more regions. The grid operators also note that the electrification of businesses and households makes the electricity grid in the district busier. This means that, unfortunately, small businesses and consumers will also have to wait longer for a connection.

The energy transition is accelerating, and the demand for renewable electricity has exploded. The grid operators currently invest 3.9 billion euros annually in the electricity grid. However, this is not enough to keep up with the pace of the transition, as the electricity grid is reaching its limits. To achieve climate goals, companies and industries are investing in sustainability, but they are hampered by a shortage of transport capacity. Priority one remains to expand the electricity grid as quickly as possible so that more and faster grid capacity becomes available, but more is needed. The National Action Programme for Grid Congestion, drawn up and endorsed by a broad representation of stakeholders, focuses on four main goals:

1. Faster construction and faster realisation of grid expansions;
2. Stronger efforts to make better use of the grid;
3. Increasing flexible capacity: public-private actions for smart solutions;

4. Smart EV charging and smart sustainable homes.

The actions are not only aimed at tackling grid congestion but also necessarily to improve the energy system. Flexible capacity could easily enlarged by a heating grid. In the Netherlands, the district heating sector does have an approximately 6% market share due to an extensive natural gas infrastructure, which is the most common heat source for buildings.

In the future, district heating will be aimed at covering around 1/3 of the energy supply. Electrical heat pumps will cover 1/3, and 1/3 will be covered with hybrid heat pumps that run on renewable gas. Supporting policies will help to achieve these national climate goals; for example, in 2023, the government opened a new subsidy scheme to reduce the CAPEX investment of new district heating grid projects.

The acceleration of hybrid heat pumps is seen as a transition technology from gas boilers to electrification in the building environment. A couple of heat pump manufacturers invested in a large-scale experiment named DACS-HW. This experiment is supported by the government and provides insight into the flexibility potential of hybrid heat pumps by peak shaving power peaks due to the large-scale use of heat pumps. The Dutch Association of national-regional Electricity and Gas Network Operators has introduced a plan to deploy up to 2 million (hybrid) heat pumps by 2030, especially in existing building stock. The plan is supported by a government subsidy scheme and will enable the installation of at least 100,000 heat pumps per year starting in 2024. Hybrid systems can easily increase the flexible capacity, not only because of the backup boiler but also to optimize the control strategy between the heat pump, gas boiler and hydraulic system.

Together with Denmark, Germany, Sweden, and Austria, we joined HPT Annex 57 Flexibility by implementation of heat pumps in multi-vector energy systems and thermal networks, which will be finalised soon. The reports will give some insights into the potential flexible capacity of heat pumps in the energy system. Hopefully, it will contribute to the discussion of how to unlock the potential flexibility because the urgency is here and now.

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Column

Navigating the Path to Decarbonization: Addressing Challenges in the Absence of Regulatory Building Policies

By Lukas Kranzl, Senior Scientist University of Technology of Vienna

Scenarios for decarbonizing the space and water heating sector show a significant increase in heat pumps, reaching levels of 30% to over 70% of buildings equipped with heat pumps across EU-27 by 2050. The remaining part is largely covered by district heating, where again, studies show significant shares (~50%) of district heating supplied by heat pumps by 2050. This high contribution of heat pumps will not only contribute to climate neutrality targets. It also opens up significant potentials for load shifting and contributing as a flexibility potential for future renewable power systems.

It needs to be understood that these scenarios are no prognoses. Rather, either they show what would be needed in order to achieve a certain target (normative scenarios), or they show what could be the outcome of certain policies in place (explorative scenarios). Most of the latter scenarios implicitly or explicitly assume a stringent set of regulatory policies to be in place.

Still, the last year has shown a significant drawback in the implementation of regulatory policies. The draft revised Energy Performance of Buildings Directive proposed by the European Commission has foreseen Minimum Energy Performance Standards requiring low-performing buildings to be renovated. The trialogue ultimately led to a much less ambitious instrument that only applies to non-residential buildings. Similar for the German "Gebäudeenergiegesetz" or the Austrian "Erneuerbare Wärmegesetz". Concerns regarding the acceptance and public perception of these mandatory instruments need to be taken seriously, and policy decisions need to be accepted. The lack of stringent regulations will require alternative measures and framework conditions to make the huge changes happen. Obviously, we by far cannot take it for granted that the heat transition will be successful.

In recent years, prices for heat pumps have risen significantly and above the average inflation rate. This is partly due to increasing material and production costs. However, it is also partly due to the absorption of subsidies and higher demand driving up prices. These price increases for heat pumps could jeopardize the transition, as they could lead to counterfactual public perception and opinion, which in turn would make it more difficult to implement regulatory requirements towards building renovation and heating system replacement in the coming years.

I draw the following conclusions from this situation:

(1) We need a rapid increase in skills and personnel and a reduction in the associated bottlenecks along the whole supply chain to ensure that supply can meet rising demand at a reasonable price.

(2) We need a broad portfolio of heat pumps. In particular, large-scale heat pumps for district heating supply and new solutions in 5th-generation energy grids could spread the risk of failure instead of focusing on individual heat pump systems alone.

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Topical Article

Fitting Large Amounts of Heat Pumps in the Energy System

DOI: 10.23697/azm1-8429

Adriaan van Eck, Flexiblepower Alliance Network – FAN

In the face of increasing electricity consumption and the need for a resilient energy system, integrating large amounts of heat pumps poses both challenges and opportunities. Adriaan van Eck from Flexiblepower Alliance Network (FAN) explores the concept of energy flexibility and its value in navigating the complexities of the modern energy landscape. By leveraging smart appliances like (hybrid) heat pumps and embracing open standards, such as the S2 communication standard, the potential for optimizing energy usage while minimizing comfort impacts becomes evident. This article sheds light on the importance of open standards in scaling up energy flexibility and shaping a sustainable energy future.

Introduction

In the next decade, millions of relatively heavy electric appliances are expected to be installed in and around homes and offices. This will cause electricity consumption to increase significantly, which will put pressure on the electricity system. At FAN, we believe that smart appliances like (hybrid) heat pumps can contribute to both relieving pressure on the electricity grid and reducing energy bills for the owner, provided they can be easily used for this purpose. We promote the use of open standards for this because that's the only way to make this feasible on a large scale.

What is Energy Flexibility, and how is it valuable

Energy flexibility is the ability to alter the use of energy without a significant impact on comfort. The latter part, 'without a significant impact on comfort', is often overlooked in discussions about the energy transition. At FAN, we believe that Energy Flexibility will help the energy transition, but it is important that we can apply energy flexibility without large adaptations in our lives and work. Of course, it's even better when there is no impact at all. The anti-legionella cleaning cycle of heat pumps is a good example: this energy-intensive process offers certain degrees of freedom to shift to moments when the national or regional energy demand is less stressed without anybody losing comfort. Of course, this needs to be executed within legal and hygienic boundaries and with the technical limitations of heat pumps in mind.

The value of energy flexibility can be demonstrated by looking forward to the future. An all-electric home may have a peak electricity consumption that is 5 times higher than compared with a classic home. [1] On top of that, the energy demand for heating is centered around the winter: In a cold winter period, many homes and buildings will have a large heat demand at the same time and for a large part of the day.

In a world with many heat pumps, this may lead to an electricity demand of 10 to 20 times the demand of today. In the Netherlands, such a scenario may take place in a period of 5 – 10 years. With this in mind, it is easy to see that both energy generation and transportation and distribution of the needed energy will be a challenge and that a more evenly distributed energy demand will be very beneficial.

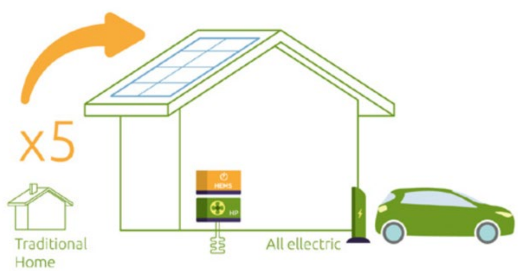

Figure 1. An all-electric home may need 5 x as much electricity as a classic home

In our 2022 study "Energy Management Opportunities for the Home", we've analyzed the value chain of energy flexibility. The most relevant benefits for the owners of heat pumps are:

1. Dynamic energy prices: use energy at cheap moments and avoid expensive moments,
2. Optimization of one's own energy generation, storage and consumption,
3. Grid connection optimization: stay within certain limits or bandwidths.

The most relevant benefits for the energy system stakeholders (grid operators, utilities, energy communities, service providers, etc) with respect to heat pumps are:

1. Portfolio optimization: Energy companies are constantly coordinating supply and demand to fulfill contractual agreements,
2. Congestion management: reduce the strain on national, regional and local grids.

Next to these, other values may come into play, for example fiscal values or sustainability values like minimizing the CO2 footprint of your energy consumption.

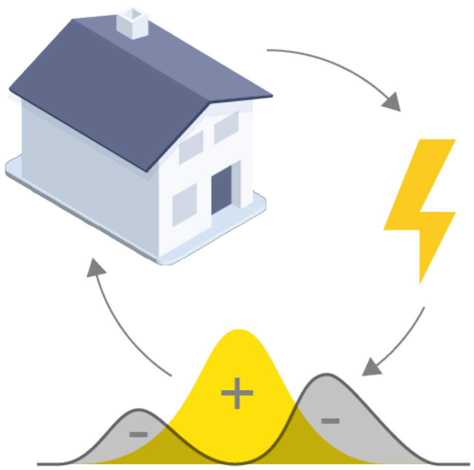

Figure 2. Reducing peaks via shifting energy demand to off-peak periods

Energy Flexibility and (hybrid) heat pumps: combining the value(s)

At FAN, we often talk about The Big 4: PV systems for solar energy, electric vehicles (EV) and their chargers, batteries, and (hybrid) heat pumps. Many companies, researchers, and service providers have developed or are developing strategies and services to optimize these devices and their use cases for congestion management, energy price optimization and other challenges.

In our vision, combining the various energy flows within the home or building is the best way to limit the impact on comfort and still get the best out of the possibilities offered by the devices. PV systems, EV chargers, batteries, and (hybrid) heat pumps are very suitable for this purpose when they are combined in a smart approach, for example, by using an Energy Management System (EMS) and the smart meter.

The rationale behind this is quite obvious: the ultimate goal of energy management is to mitigate a shortage or a surplus of energy demand; adapting the energy usage of heat pumps or EV's is only the means to it, not the goal in itself. At one moment, the heat pump offers the best opportunity to adapt to the energy demand; at another moment, an EV or a home battery may offer the best chance.

And there is another reason. In case the heat pump is optimized by an individual energy service provider and the EV by a different one, the risk occurs that the heat pump may demand more energy because the energy price is low, and at the same time, the EV is postponing it's charging due to congestion management needs. The net effect would be zero, and the energy system would be worse off.

Why do we need open standards?

Energy optimization requires a lot of information and connectivity. A wifi chip or matter implementation may make your heat pump smarter, but it's not enough. Heat pump research carried out by FAN reports that 94% of the heat pumps sold in The Netherlands in 2021 are connectable. [2]. The report also shows that a large variety of protocols and standards exist, both for control and for communications. One could think that this makes it easier to develop smart energy services since there will always be a technology that suits your needs. Yet, it is the other way around: because there are so many standards, a utility or service provider would need to implement many of them, which is very costly to develop and maintain.

Let's take a look at the functionalities someone needs to integrate if one wants to do smart things with energy usage:

- Retrieve information from the residence or building and its users. What is the current state of affairs, and what is expected during the coming period? What is the temperature in the building, will someone be at home today, and how much battery charge is needed to drive the EV tomorrow?
- Retrieve and combine information from external parties: the energy grid platforms, energy prices on markets, weather forecasts, etc.
- Retrieve information from heat pumps and other devices, for example, state of charge, the maximum power consumption and the like
- Send commands or messages to adapt the energy usage according to the optimization needs and possibilities.
- Gather and register data for settlement and billing.

Combining all these functionalities is a complex task, and it does not help if many brands and organizations have their own proprietary protocol to access them. Standards will make it easier and less expensive to use appliances for smart energy services; that's why we need them. These standards need to be open and maintained by independent bodies to prevent vendor lock-in and assure interoperability between devices and services in the energy system.

Energy flexibility and (hybrid) heat pumps: the elegant way

At FAN, one of our focus areas is energy management in homes and buildings. As already mentioned, we want to integrate the energy flows of 'the big 4', for the best result and minimal impact on comfort. From this perspective, FAN has been working with partners in the S2 consortium to promote the adoption of S2, an open communication standard for energy management.

S2 aims to simplify the combined use of energy flexibility of multiple smart devices in homes and buildings.

In S2, there are two entities that communicate with each other:

- A **Customer Energy Manager** (CEM) which orchestrates the flexibility provided by the appliances in the building.
- A **Resource Manager** communicates the energy flexibility information of an energy-smart appliance

The Customer Energy Manager and the Resource Manager communicate via the S2 standard.

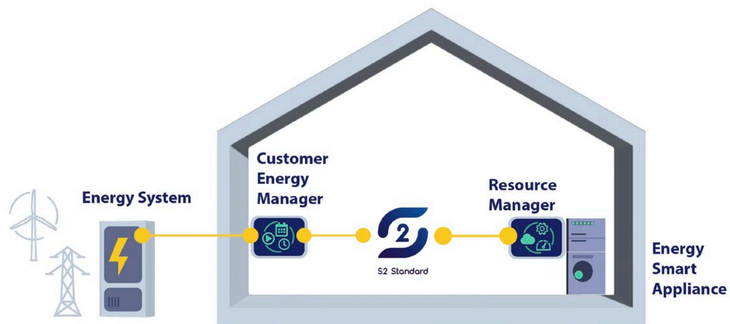

Figure 3. Concept of the S2 standard with a customer energy manager and a resource manager

Thanks to its setup, S2 does not require heavy integration with the firmware of energy smart appliances, and it respects the internal logic, safety and security limitations of devices. There is also no limitation for manufacturers: S2 can be used with cloud services and via local control.

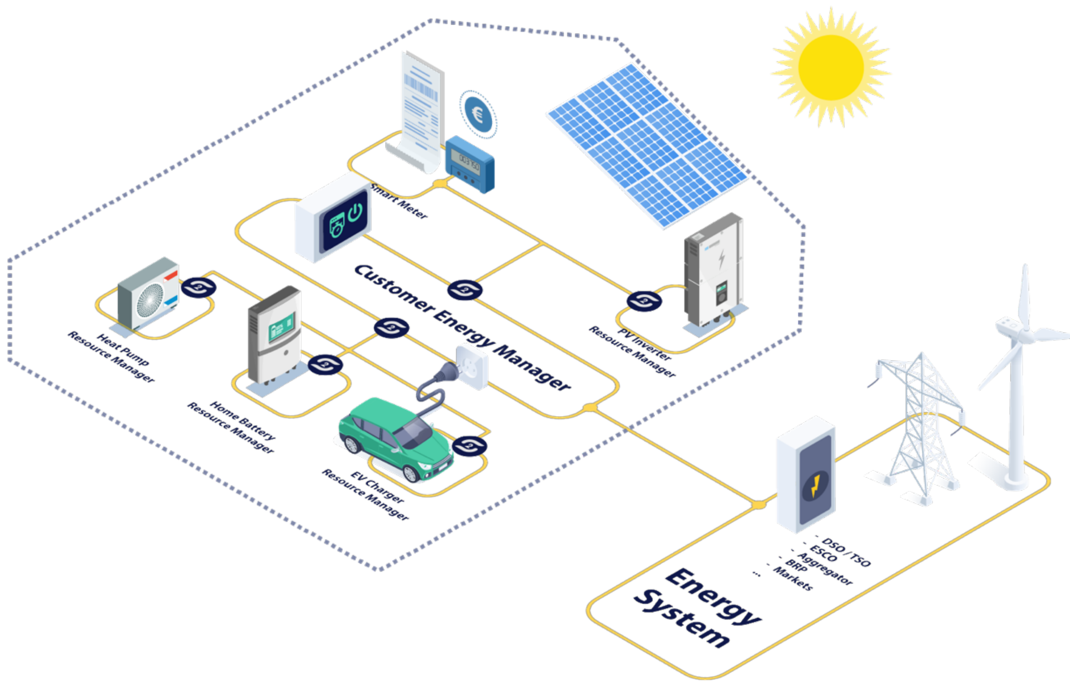

Figure 4. The S2 standard in the energy system

Final remarks

In the coming decade, we expect millions of larger appliances to be installed in the built environment. At FAN, we believe that energy flexibility will be key in assuring a resilient, sustainable energy system, and we believe that this flexibility can be used without a significant impact on comfort. Open standards will be crucial to scale up the use of energy flexibility.

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Topical Article

Flexibility Potential With Heat Pumps In Swedish Thermal Grids

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The ongoing electrification of the society, in combination with an increasing share of electricity from intermittent sources, puts pressure on the power grid and increases the need for flexibility to balance variations in electricity production and consumption. Flexibility can also help to reduce issues related to bottlenecks or capacity shortages in the power grid. One alternative is to use heat pumps in thermal grids to deliver flexibility. This has been investigated** in project within IEA HPT Annex 57 **by focusing on the Swedish energy system, and both possibilities and barriers have been identified. The thermal grids have many times alternative heat production units available, and the thermal system gives high inertia and larger storages, which increases the possibilities for a flexible operation of the heat pumps, but on the other hand, the high investment cost for the heat pump is pointed out as a barrier.

The electrification increases the need for flexibility

The transition to a low-carbon energy system requires a high penetration of renewable electricity sources, which are often intermittent and variable. This poses challenges for the power system, which needs to always balance the supply and demand of electricity. Moreover, the ongoing electrification of the society increases the demand for electricity and puts pressure on the existing grid infrastructure. Here, the need for flexibility to balance variations in electricity production and consumption will increase to achieve a resilient and efficient power system. Flexibility can also help to reduce problems with bottlenecks and shortages of capacity in the electricity grids. An advantage of using a combination of heat pumping technology and thermal networks is the larger flexibility in heat production and storage options that it entails.

According to scenarios presented in the IEA World Energy Outlook [1], the need for short-term flexibility on a global level will significantly increase in the following years. The main reason is the fast-increasing use of solar PV, while batteries and demand response are cited as crucial suppliers of short-term flexibility. Here, heat pumps can have a role to play and, together with other sources like EV´s, support the power system with demand response. Today, dispatchable thermal power plants and hydropower provide most of the flexibility to the power system, independent of the time scale, but in the future, they are foreseen to mainly provide seasonal flexibility.

There are several potential markets for flexibility, either for implicit (voluntary adjustment of electric load due to, for example, variations in electricity price) or explicit services (to get revenues to adjust the electricity load as a service). The markets for explicit flexibility put technical demands on the heat pumps regarding activation time, duration, and possibilities to measure the flexibility delivered. While implicit flexibility is more of a voluntary adjustment of the electric load to decrease the electricity costs. These implicit services are generally easier to plan for as they are known in advance, and the need for challenging fast changes in the heat pump can be avoided.

The potential endurance of the flexibility service from heat pumps increases with larger storage volumes and higher thermal inertia. Here, it is a benefit for heat pumps connected to thermal grids due to the many times higher inertia and larger storage in the system. Therefore, the heat pumps can, for example, be switched off for longer periods without any large impact on the system and, in the end, provide comfort for the end consumers. But flexibility is all about moving electric loads in time. Sooner or later, the heat pump needs to run harder to catch up with lost heat production if no other units for heat production can cover up for the lost production. Here, heat pumps in thermal grids often have an advantage compared to stand-alone heat pumps in buildings as there might be alternative heat production available. Another advantage of large heat pumps, compared to heat pumps in single-family buildings, is that they do not require aggregation to reach the minimum bid size for delivering flexibility. Additionally, they have better possibilities for monitoring their electricity consumption. However, other barriers like high power fees or a limited heat source can force the heat pumps to operate in a certain way that limits their possibility of flexible operation.

To use heat pumps for explicit flexible operation is still unusual. However, there are international examples of heat pumps in thermal grids participating in TSO's ancillary markets. One example is the heat pump in Søndre Felding, which is the first in Denmark to obtain the official qualification to deliver an FRR regulation. In Denmark, this requires a start-up time of a maximum of 5 minutes and a minimum bid size of 1MW. In Sweden, Stockholm Exergi has participated with some of its heat pumps in the newly established local flexibility market, SthlmFlex.

Heat pumps in Swedish district heating grids

In Sweden, as in many other countries, there is an ongoing electrification of the society, and political goals are being made to increase the share of electricity derived from renewable sources. Therefore, an increasing strain on the Swedish power grid can be anticipated in the future.

A heat pump connected to a thermal network can either be centrally located within the thermal network or decentralized. A typical example of central heat pumps is the larger heat pumps present in district heating networks today, used for producing district heating. Decentralized heat pumps are typically situated at the end-users' premises and are often owned by the property owner. In such cases, a combination of heat pump and district heating is normally used to heat the building. Additionally, there are examples when district heating companies have their own heat pumps located further out in the network.

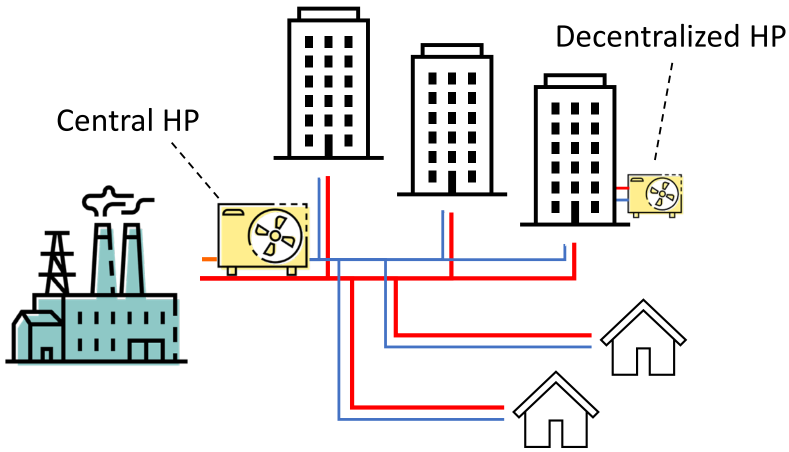

Figure 1. Schematic image of a centrally placed heat pump compared to a decentralized heat pump.

Sweden has a long tradition of centralized heat pumps in their district heating grids, with a significant installed capacity compared to other European countries. However, many of the Swedish heat pumps were installed during the 1980s and have been in operation for several years. Some of these heat pumps have been replaced by alternative heat production over the years, which is one reason for the gradual decline in the amount of heat generated from heat pumps in the Swedish district heating grids, as depicted in Figure 2.

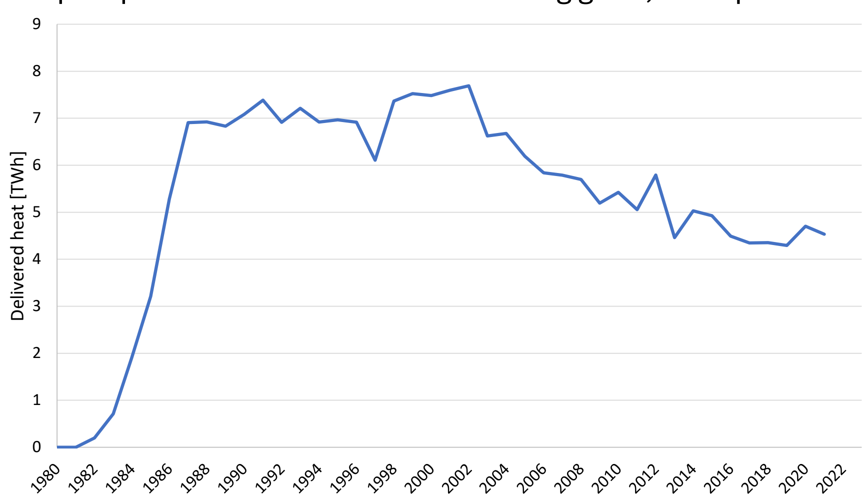

Figure 2. Delivered heat from heat pumps in Swedish district heating grids [2]

Interviews with district heating companies about heat pumps

Within the project, we conducted an interview study with district heating companies that have centrally located heat pumps in their production mix. The purpose was to identify possibilities and barriers for using heat pumps in a flexible manner, either to respond to variating electricity prices or to provide flexibility services to, e.g. TSO´s such as Svenska Kraftnät or local flexibility markets. Companies with heat pumps in their grids perceive it as

advantageous to use them flexibly when electricity prices vary. These heat pumps are also relatively easy to regulate and have shorter start-up and shutdown times compared to many other district heating production units. From a technical standpoint, it is feasible to start or stop the heat pumps almost immediately. However, in practice, the current minimum operating time is several hours, primarily to minimize wear and tear.
The study reveals that the primary barrier to increased utilization of heat pumps in the Swedish district heating grids is the high investment cost for the heat pumps. The cost makes it challenging to justify new installations compared to investments in new combustion units, which have the advantage of covering a wide range of temperatures and heat requirements. Additionally, combustion facilities often have the possibility to also produce electricity.

District heating companies routinely engage in the everyday practice of planning and producing heat at the lowest cost. They also leverage the inertia of the network and accumulator tanks to reduce peak power demand. However, there is untapped potential for more active utilization of heat pumps within thermal networks if certain barriers can be overcome. One such obstacle is the monthly power fee, which renders it uneconomical to start a heat pump if it is not planned to be used for more than a few days in a calendar month.

There is also a potential for larger flexibility, but since the operation of the older heat pumps in the Swedish grids is not automized, motivated and available personnel are required, so quick variations in electricity prices can be managed by starting or stopping the heat pump. Other identified barriers to further utilization of existing heat pumps include the need for, or regulatory requirements, to keep heat production from other sources running, such as waste incineration. Additionally, interviews revealed that limitations on the cold side of the heat pump may arise due to factors like low seawater temperatures, insufficient volumes of wastewater, or a lack of waste heat.

Figure 3. Detail from the heat pump system at Hammarbyverket, Stockholm

Results From Simulations

Within the project, we have also conducted simulations for both centrally located heat pumps and decentralized heat pumps. The purpose was to assess the economic potential of controlling heat pumps to contribute with the flexibility to the power system. The results from the simulations clearly demonstrate that there is an economic potential for delivering various types of flexibility services in both scenarios. However, this potential hinges on overcoming the remaining technical challenges. These challenges may involve issues with communication with the heat pumps or ensuring that they can adjust their power consumption rapidly enough to meet the requirements from the TSO.

About the project

This article is based on findings from IEA HPT Annex 57 Flexibility by implementation of heat pumps in multi-vector energy systems and thermal networks, focusing on flexibility from heat pumps as well as the Swedish research project "Flexibility by implementation of heat pumps in thermal networks" which has been funded by the Swedish Energy Agency. The Swedish project is a collaborative effort involving RISE Research Institutes of Sweden, Halmstad University, and Lund University. For detailed results, I recommend the conference article titled "Flexibility Potential of Heat Pumps in Swedish Thermal Grids: A Perspective for District Heating Companies and End Users" [3].

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Topical Article

Efficiency and Flexibility: A UK Perspective on Heat Pumps in the Electricity System

DOI: 10.23697/9159-2985

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This article raises the question of what the 'optimal' performance of a heat pump looks like as we transition to a decarbonised, flexible electricity system. As the system boundary is widened from heat pump efficiency to whole electricity system efficiency, we reflect on how heat pump and heating system design may evolve to result in the lowest system costs. The article is set in a UK context, but many of the issues raised are relevant to other countries with current or planned large-scale heat pump uptake.

Introduction

UK policy on building decarbonisation relies heavily on heat pump deployment - in 2021, the UK government set a target of installing 600,000 heat pumps per year by 2028. Achieving this target will require decreases in capital costs and running costs, as well as overcoming a number of other barriers [1]. Running costs depend on electricity tariffs as well as building and heat pump efficiency, leading to a drive to improve the Seasonal Coefficient Of Performance (SCOP) of heat pumps in order to increase affordability for households. To maximise SCOP, the current best practice involves running the heat pump constantly through the heating season, using weather compensation control to adjust the required flow temperature. Some installers also advocate designing out buffer vessels, as hydraulic separation between the heat pump circuit and space heating circuits reduces efficiency in principle. Our sizing calculations (and running cost predictions) tend to be based on steady-state heat loss, corresponding to constant operation[1].

[1] The heat pump design standard used in the UK, MIS3005D, also allows for intermittent operation but the authors have not encountered this option being used for sizing domestic systems.

Meanwhile, there is a growing awareness of what the future electricity system will look like. In the UK, supply will be dominated by wind power, and demand will peak in winter evenings (as it does today), but the electrification of heat, transport and industry will change the demand profile, including the potential introduction of a new winter morning peak created by heat pumps (see Figure 1). In the future, it is likely that we will operate heat pumps flexibly to manage the hourly variability of electricity demand both on a national and local scale and thus to support system operation. A national expert workshop held in 2023, which brought together stakeholders from the heat pump industry, electricity sector and other parts of the system, found there a broad consensus that heat pump flexibility will be widespread by 2035, the year by which the UK electricity system is planned to be fully decarbonised [2].

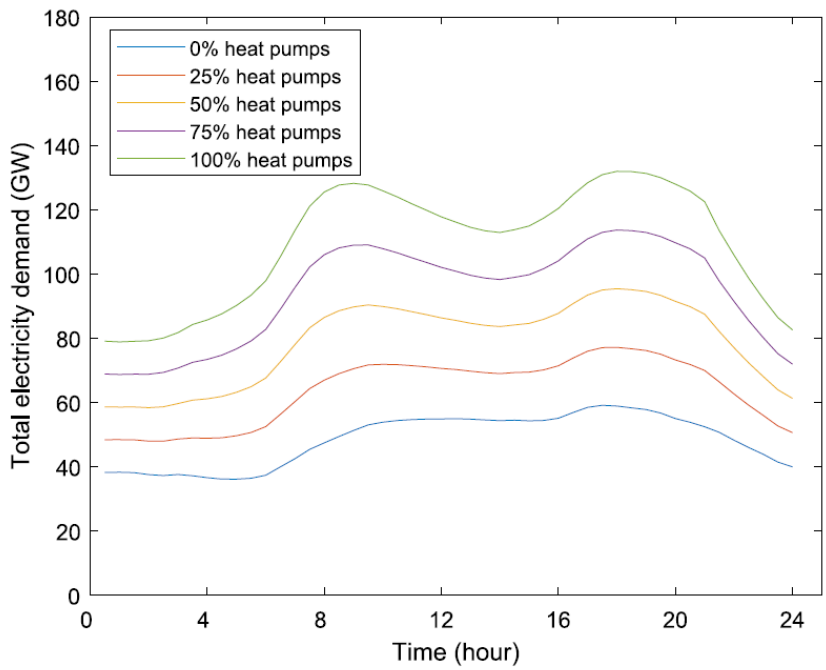

Figure 1: Predicted effect of heat pump penetration on half-hourly British electricity demand on a very cold winter day. Figure from [3].

How, therefore, do we reconcile the above two perspectives: on the one hand of, maximally efficient heat pumps running at a constant output, and on the other hand of heat pumps as part of a dynamic electricity system, turning on/off/up/down according to the requirements of the system? More specifically, what needs to change in order to move from the first way of defining ideal heat pump operation to the second?

In this article we focus on some of the technical aspects of this transition; there also exist important social, economic and governance aspects of introducing heat pump flexibility which need to be addressed.

Redefining efficiency

Historically, for good reasons, heat pump efficiency – SPF, COP, SCOP – has drawn the system boundary around the heat pump, plus backup heating. This makes sense when each unit of electricity used costs the same amount, and it is desirable to minimise the total cost by getting as much heat out of the system as possible for each unit of electricity used.

These metrics, however, will not represent the value of the heat pump's operation in the future electricity system, in which the ability of the heat pump to modify its load and to defer or front-load its operation will be worth money. For example, a recent UK trial has investigated preheating homes during periods of low-cost electricity and then switching heat pumps off during expensive periods. This will decrease heating system efficiency – requiring higher flow temperatures during the preheating times and potentially during recovery after an 'off' period. Electricity use is likely to increase, and yet within the context of the whole electricity system, the heat pump's performance is 'better' or 'more useful' than it would have been under constant operation due to the value of load shifting to the system.

Unlike other countries in which utilities carry out direct load control of heat pumps, the UK is taking a market-driven approach to flexibility. Customers will be incentivised to run their heat pumps flexibly through half-hourly electricity pricing structures. Variable half-hourly pricing will lead to a different cost-optimal way to run a heat pump than is currently the case under fixed unit pricing. It is not yet clear exactly how different the electricity price will be throughout a single day, but if the price signal is great enough, then a different set of operational characteristics will be desirable in a heat pump compared to simply running efficiently at constant output. This is discussed next.

Modifying heating system capability

A future in which electricity prices vary half hourly and heat pumps regularly translate price signals into different modes of operation may lead to heat pump and heating system designs being different from those of today. Firstly, extra storage may be needed. The UK's building stock is old and leaky compared to those in other European countries, yet most buildings are eligible for a subsidy on heat pump retrofit. Experts currently agree that space heating load can be shifted 1-3 hours in the majority of homes without thermal discomfort (and hot water up to 12 hours); it is also likely that building fabric efficiency upgrades in the years from now to 2035 will proceed much more slowly than the heat pump roll-out. Therefore, the amount of thermal storage available from building fabric alone is unlikely to increase in the coming years. The 1-3 hours of storage available in most homes is helpful for evening demand peak smoothing but is not usually long enough to match demand to variable wind supply (which varies on a timescales from daily to weekly rather than hourly). Batteries and thermal storage can significantly extend the load-shifting potential of heat pumps, and it may be that these become much more common aspects of heat pump installations as the need for flexibility increases.

Heating system responsiveness may also become more important so that when heat pumps respond to low prices and ramp up their output, or recover from a period of no/lower operation by increasing their output to restore an internal temperature, this can be done quickly. Increased responsiveness may occur by increasing flow temperature or change in component specification (e.g. size of radiators, use of fan-assisted radiators for faster heat transfer); again, the incentive structure for electricity pricing will determine what is the most cost-effective configuration of heat pump equipment and operation. This may, in turn, affect the sizing methodology and even the performance testing regime.

Enhancing heat pump control

Different heat pumps use different control logic, but in general, the control is designed to maintain a steady state internal temperature (and sufficient hot water). For example, in our previous work, one UK heat pump expert could not find a way to program an off period into their controller as the heat pump's control was set to run all winter unless the outdoor temperature exceeded a threshold - its algorithms were designed to maintain a certain flow temperature [4].

Adapting control functionality to deal with turning up/down, or off and back on, should be fairly straightforward. There are decisions to be made as to whether to constrain the flow temperature when heat pumps resume operation after an off period, in order to not create new electricity peaks. However, these could, in theory, be simply implemented in firmware updates to the heat pump.

It has also been shown in previous work that if a heat pump installation has not been carried out with flexibility in mind, it is easily possible for components in the heating system to override or negate attempted flexibility from the heat pump. We have identified buffer tanks calling for heat during high-price periods [4], and others have found thermostatic radiator valves blocking attempts to preheat spaces before high-price periods. Again, these issues might be solved by changes to the heat pump controller's software so that the heat pump or smart home controller can take into account other system components, as well as requests from the electricity system to flex its load. As our energy system becomes more complex, this simply reflects the need to think about the efficiency of the wider system and not allow the optimising of individual components to lead to wider system inefficiencies.

Conclusion

We are moving from a world in which the key performance metric, representing the lowest cost way of running heat pumps, is *heat pump* efficiency to one in which it is *whole energy system* efficiency. The latter will combine heat pump efficiency, flexibility capability, and other factors such as resilience. There will be a trade-off involved between these factors in order to reach the most efficient and, therefore least-cost solution - this trade-off will affect heating system design and operation. This article is not intended to give all the answers but to open up the debate as to how heat pumps and their associated heating system components may have to change and how heating system design and retrofit can best facilitate flexible operation.

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Non-Topical Article

Joining Forces to Encourage High-Temperature Heat Pumps in Swiss Industries

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The IEA HPT Annex 58 HTHP-CH project regroups multi-disciplinary experts around the shared objective of promoting the integration of high-temperature heat pumps (HTHP) in the Swiss industries. Available products with supply temperatures above 100 °C show a slow adoption rate despite the key role forecasted and necessary to reach international CO2 reduction roadmap targets. This study investigates the integration of HTHP applied to three industrial case studies. The assessment based on Pinch analysis is led alongside the development of supporting tools and guidelines.

Introduction

After pioneering in the development and commercialization of heat pumps (HP), Switzerland is currently lagging to uptake this technology in the industrial sector. Yet the HP market is well established in the country with a 74% share of the heat production units sold in 2023, mostly smaller capacities for domestic applications (87% of HP under 20 kW) [1]. With market-available high-temperature heat pumps (HTHP) for heat production above 100 °C and allowing for steam generation, the lack of products is no longer a barrier. There is, however, still a need to broader disseminate knowledge about HTHPs and their adequate integration.

The HTHP-CH project [2] has been launched by specialists from OST (Eastern Switzerland University of Applied Sciences), EPFL (Ecole Polytechnique Fédérale de Lausanne), HEIG-VD (Haute Ecole d'Ingénierie et de Gestion du Canton de Vaud) and CSD Engineers. The objectives are to provide tools and inform on HTHP integration. Three national case studies with industrial partners contribute as concrete examples. A solution generator for optimal HTHP integration following Pinch analysis principles and suggestions for the best heat pump design as well as a pre-assessment tool are in development. The project is involved in IEA Annex 58 on HTHP, facilitating international exchange and serving as a national relay.

Market review

The range of industrial HTHP on the market has grown steadily in recent years. Figure 1 presents 33 products with heat supply temperatures above 100 °C producing pressurized water or steam [2]. They are shown sorted by their maximum heat supply temperature and heating capacity, ranging from about 10 kW demonstrators to 70 MW units. This synthesis is based on information collected in the IEA HPT Annex 58 [3] covering closed-cycle as well as open-cycle HP for mechanical vapor recompression (MVR). Please note that suppliers provided the information without third-party validation and that the technology readiness level (TRL) varies between products.

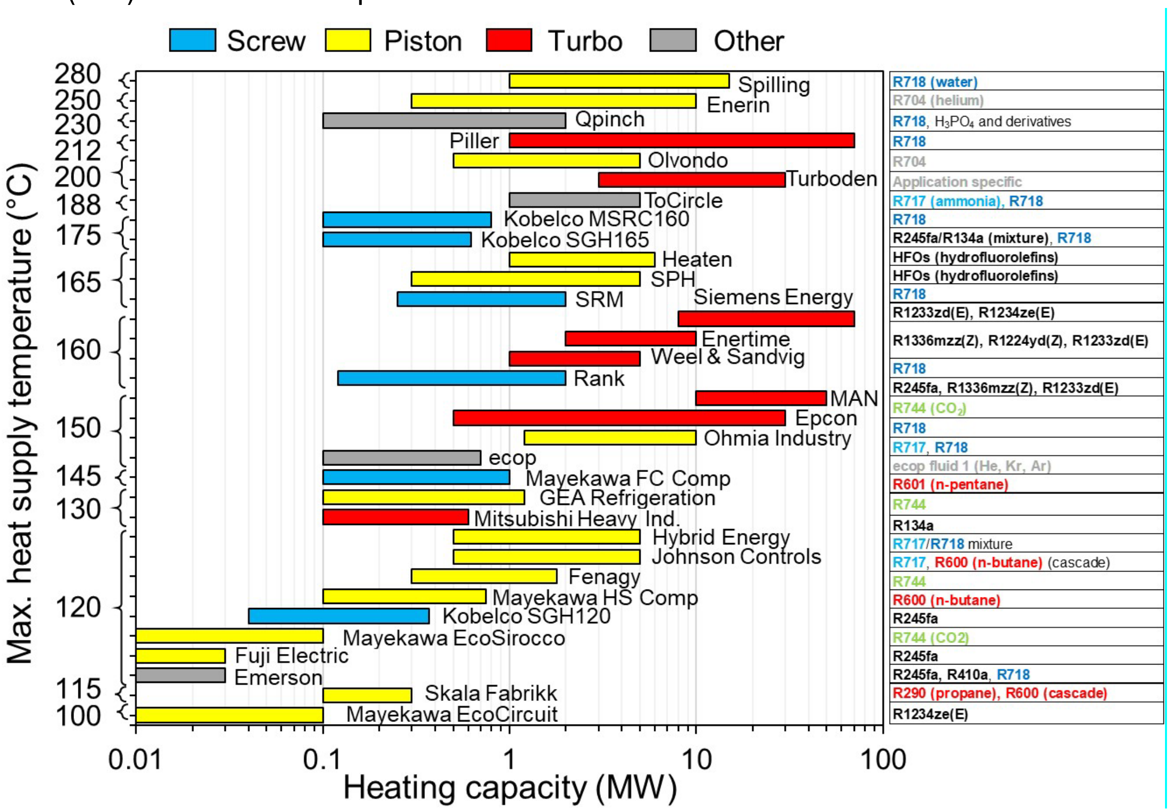

Figure 1. Industrial HTHPs products sorted by maximum heat supply temperature (>100 °C) and heating capacity. The compressor technology is color-coded. The table indicates the refrigerant [2].

Case studies

Three industrial companies support the HTHP-CH project by giving access to their process data. In a global improvement approach, and not merely by adding a heat pump according to intuition or to replace warm utilities, Pinch Analysis are being performed. The effort needed to gather the information translates into optimized heat recovery opportunities identification and adequate placement of the HTHP, hence lowering the process's overall energy need.

ELSA (Estavayer Lait SA) is Switzerland's largest dairy on a single site, processing around 260,000 t/a of milk into a wide range of dairy products. The main heat treatments are pasteurization and sterilization ranging up to 155 °C. In addition, a cleaning-in-place process requires large amounts of water and an important steam consumption at 4.5 bar(a). A wood chip boiler and natural gas boilers currently generate process steam. To save energy and water, waste heat from the ammonia chillers at 20 °C or drain water at 50 °C, could be used as a heat source for a HTHP. This solution has yet to be confirmed. The company benefits from a favourable electricity-to-gas price ratio.

Cremo SA processes milk into various dairy products. Today, heat is supplied by two 5 MW gas-fired steam boilers and a district heating network (105 °C / 80 °C). As a future reduction of the district heating operating temperatures to 80 °C / 60 °C is envisioned, a large-scale HTHP is considered to upgrade the supplied heat temperature. Another potential integration point for a HTHP has been identified in the TIXOTHERM™ drying plant, which produces milk permeate powder and consumes 10% to 15% of the total steam demand. For the latter, Figure 2 (left) shows the calculated Composite Curves of a preliminary assessment, indicating a Heat Recovery (HR) potential through direct heat transfer of about 600 kW between air flows and a Pinch temperature of around 70 °C. Furthermore, the corresponding Grand Composite Curve shows the impact of an integrated HTHP providing 940 kW of heat at 120 °C using 523 kW at 38 °C, with a COP of about 2.3. Finally, Figure 2 (right) shows the Composite Curves with integrated HTHP. The example demonstrates a potential reduction of the Hot Utility (HU) by 100% (from 940 to 0 kW) for this drying unit and 47% (from 1,204 to 634 kW) of the unused waste heat. A challenge is the low evaporation temperature (large temperature lift of 82 K), and the probably insufficient evaporation capacity if the waste heat is to be recovered exclusively from the drying process. Therefore, additional waste heat sources must be identified.

Gustav Spiess AG in Berneck (SG) produces meat products such as sausage, ham, and bacon. Today, a gas boiler provides 6 to 8 bar(a) steam to the pasteurization and cooking/smoking cabinets. Process data is currently being acquired for this site to perform a Pinch analysis and adequate dimensioning of a steam-generating heat pump using waste heat from the chillers.

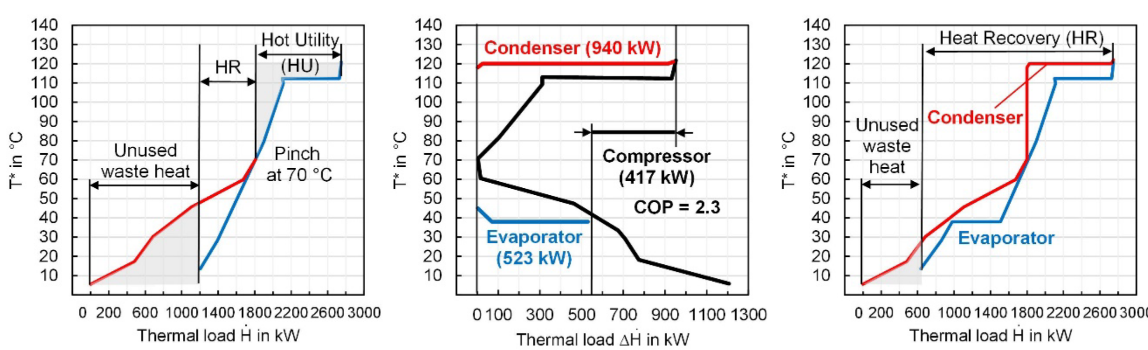

Figure 2. Composite curves (left) and Grand composite curve (center) of the current drying process from Cremo showing the potential HTHP integration. The resulting Composite curves (right) show increased heat recovery and reduced waste heat.

Preliminary evaluation tool

A preliminary economic evaluation of the case studies was performed with a calculation tool developed in MS Excel, illustrated in Figure 3. It assumes that the gas boilers' investment is depreciated and that it remains for production redundancy or other use (start-up, peak loads). The tool helps to quickly evaluate the economic feasibility as a "go/no-go" decision to further evaluate a potential HTHP project:

- First, the efficiency of the HTHP is estimated using the temperature lift and a COP correlation.
- Next, the investment costs of the HTHP are evaluated based on specific investment costs, the heating capacity and a cost multiplication factor accounting for planning and integration (typically between 1.5 to 4.0 depending on the complexity of integration).
- Then, the annual cost savings are calculated considering the electricity cost to operate the HTHP, the maintenance costs of the HTHP using a multiplication factor on capital cost, saved fuel costs, and possible refunds of CO_2 reduction.
- After that, the payback period of the investment is evaluated using the investment costs and the expected annual cost savings resulting from the investment.
- Finally, the discounted payback periods (DPP) is computed.

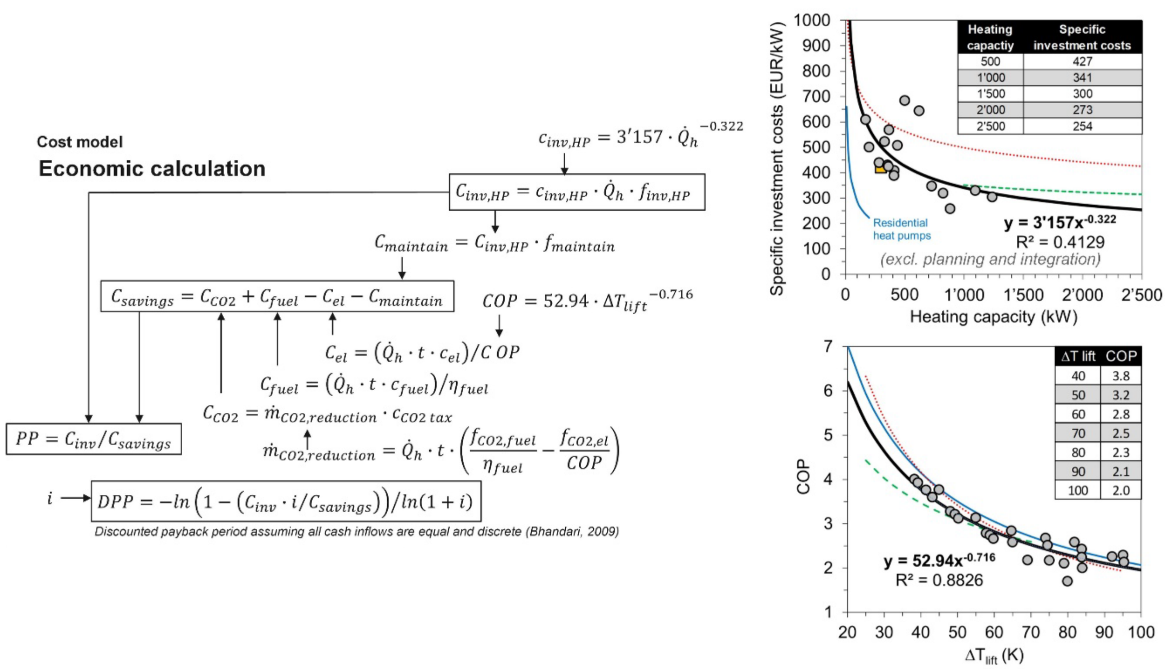

Figure 3. Economic calculation, COP, and specific investment costs to derive the payback period for HTHP integration.

Preliminary calculations from 2022 using the simplified evaluation tool led to payback periods of 2.0, 3.7, and 3.3 years [2] and a non-definitive HTHP point of integration. The cost multiplication factor for planning & implementation, which depends on the complexity of the HTHP integration, leads to significant uncertainty. Overall, the concerned processes analysed showed important annual energy savings of 55%, 60%, and 66%, and CO_2 emission reductions of 71%, 75%, and 98%, respectively, given the Swiss electrical mix CO_2 emission factor. The estimated COP varies between 2.0 and 2.7. Favourable conditions are lower electricity prices, higher fuel prices, longer operating time, and to a lesser extent CO_2 tax and increasing capacity.

Solution generation tool

EPFL is developing a web-based tool for optimal integration of HP into industrial processes [4]. The ROSMOSE platform determines the minimum energy requirements and operating costs of a process based on the Pinch Analysis methodology. Inputs needed are the hot and cold heating demand profiles, mass and electricity flows, and economic data. Outputs are delivered in a formatted report, including the integration and sizing of utilities (HP and competing technologies, for example biomass boiler or natural gas) and comparison of optimized solutions. The tool computes the evaporation and condensation temperature levels, compressor technology and best thermodynamically suited refrigerant for the HP generating the most economically competitive solution. Relevant KPIs such as cost, CO_2 emissions or efficiency can be also determined.

National workshop

A successful event was organized by the project team to raise awareness and knowledge on HTHP and get insight from the Swiss stakeholders. Around 70 participants from the industry, planners, manufacturers, academics and administration took part on site. A half-day of presentations was followed by four workshop roundtables [5].

The main conclusions on financial aspects were that the investment cost of the machine alone is less relevant (as are the funding opportunities) than payback time, ROI or total cost of energy production. A list of points of attention was generated on various technical aspects. As for HTHP products capacities, the range from 500 kW to 10 MW has been regarded as adequate, and steam-producing machines would be preferred a priori. Companies with a strong sustainability motivation and/or under customer pressure for low-carbon products are a lead market for HTHP. The perceived risks by end-users are linked to the suitability of installed HTHP to modified operating conditions, compliance risk to future policy changes and reliability.

Proposed key actions to push the implementation of HTHPs were:

- Increase knowledge and trust about HTHP by giving examples of running systems,
- Increase the availability of products (standardized / with natural refrigerants),
- Increase in CO_2 tax or restrict fossil fuels, and
- Decarbonize the electricity supply.

Conclusions

There is an urge to decarbonize the Swiss and international industrial heat production, and high-temperature heat pumps (HTHP) constitute an adequate and efficient solution. HTHPs provide heat by upgrading thermal energy at lower temperature levels, hence simultaneously reducing the cooling needs.

The objectives of the HTHP-CH project are to provide tools and communicate knowledge and visibility to promote the insightful integration of HTHP helped by 3 industrial case studies.

The Swiss project team gratefully acknowledges the Swiss Federal Office of Energy (SFOE) for the financial support of the R&D project Annex 58 HTHP-CH as well as the industrial partners for their collaboration.

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Non-Topical Article

Are Rules of Thumb Misleading? The Complexity of Borefield Sizing and the Importance of Design Software

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Engineering firms, architects, drilling companies: everyone works with rules of thumb. We have simple rules for pressure drops in pipes, water usage in residential buildings and the sizing of geothermal borefields. Although all rules of thumb are a simplification of reality, the sizing of borefields is way too complex to be put into one rule. This article demonstrates that relying on rules of thumb for borefield sizing can easily result in a 50% over- or under-sizing of the borefield, potentially leading to infeasible projects, non-functioning systems, or even environmental harm.

Introduction

The building sector is responsible for 26% of the global CO2 emissions related to energy usage, mainly due to heating and cooling demand [1]. In order to decarbonise this sector, ground source heat pumps (GSHP) have gained a lot of attention over the years since they have a high efficiency, can provide free/passive cooling and require little maintenance. On the other hand, geothermal systems carry a high investment cost, so a correct sizing is important. When talking about closed geothermal systems (borefields) there are multiple ways to size them, ranging from using detailed geothermal design software (like GHEtool, EED, GLHEPro) to using a simple rule of thumb. This last option, however, although often used, requires some caution.

The importance of correct borefield sizing

Geothermal systems are not sustainable by nature but by design. It is, therefore, important that the borefield is sized in such a way that, over time, the ground temperature stays between certain temperature limits. This is important for the system itself, as too low temperatures can cause system failures, but also for the environment, as microbiological life in the underground can be impacted due to temperature fluctuations. On the other hand, borefields are rather expensive to drill, so in order to keep them economically attractive, you don't want to oversize them. So, how do you size them?

The blindness of rules of thumb

Within the field of engineering, rules of thumb are used everywhere, from pressure drops in pipes to water usage in residential buildings. They simplify and speed up the design process, but they give no insight into all the physics that lies underneath a certain rule. Such general guidelines are oftentimes created based on a certain scientific correlation or an extrapolation of some practical experience. But after time, we lose track of the exact assumptions behind a specific rule, and these rules become a truth in and of itself.

In the field of shallow geothermal borefields, such rules of thumb come in the form of the 'specific heat extraction x W/m borehole', making abstraction of all the parameters that determine the required size of a borefield: the building heating and cooling demand profile, the fluid regime and borehole internals, temperature limits.

In the next paragraphs, these design parameters are varied in order to show the sensitivity of the borefield size (expressed in total borehole length, i.e. the depth of the borehole multiplied by the number of boreholes in a borefield) and the correctness of a specific rule of thumb, for three different building cases: an office, an auditorium and a residential building complex. These three cases are based on real projects and were simulated on an hourly basis. Some characteristics of the heating and cooling profiles are given in Table 1. All buildings use rather slow emission systems (concrete core activation (CCA) and floor heating) but use the ventilation system for cooling, hence the small heating peak in comparison to the cooling peak.

Sensitivity to building demand

Figure 1 shows the required total borehole length of the three cases calculated using a rule of thumb of 30W/m applied to both the peak heating and peak cooling. This sizing is compared to an hourly sizing with GHEtool [2]. The relative difference between both rule-of-thumb sizings and the reference sizing is shown in Figure 2.

One can see that applying the rule of thumb of 30W/m to the peak heating value leads to under-sizing the borefield for all cases, even for the heating-dominated buildings like the auditorium and residential buildings. This can be explained by the fact that using slow emission systems requires only small peak powers and, hence, a smaller sizing, underestimating the effect of the yearly load imbalance.

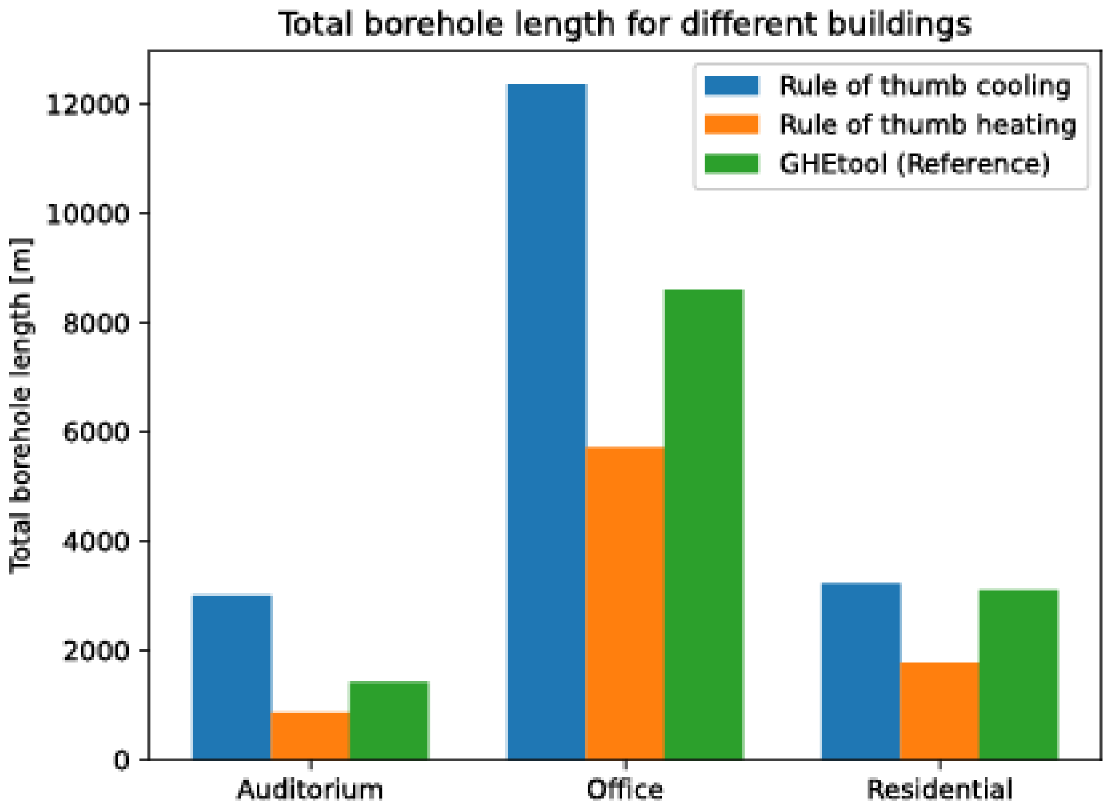

Figure 1: The total borehole length for three different buildings using a rule of thumb of 30W/m for both peak cooling and peak heating in reference to a borefield sized with GHEtool.

On the other hand, sizing according to a rule of thumb for peak cooling can give a very significant oversizing up to a factor of 2 in the case of the auditorium. This is due to the fact that the auditorium has a high peak cooling, but the yearly cooling demand is rather small. The effect of the peak is hence overestimated using the rule of thumb for cooling here. Rather coincidentally, sizing for peak cooling gives a very good result for the residential case.

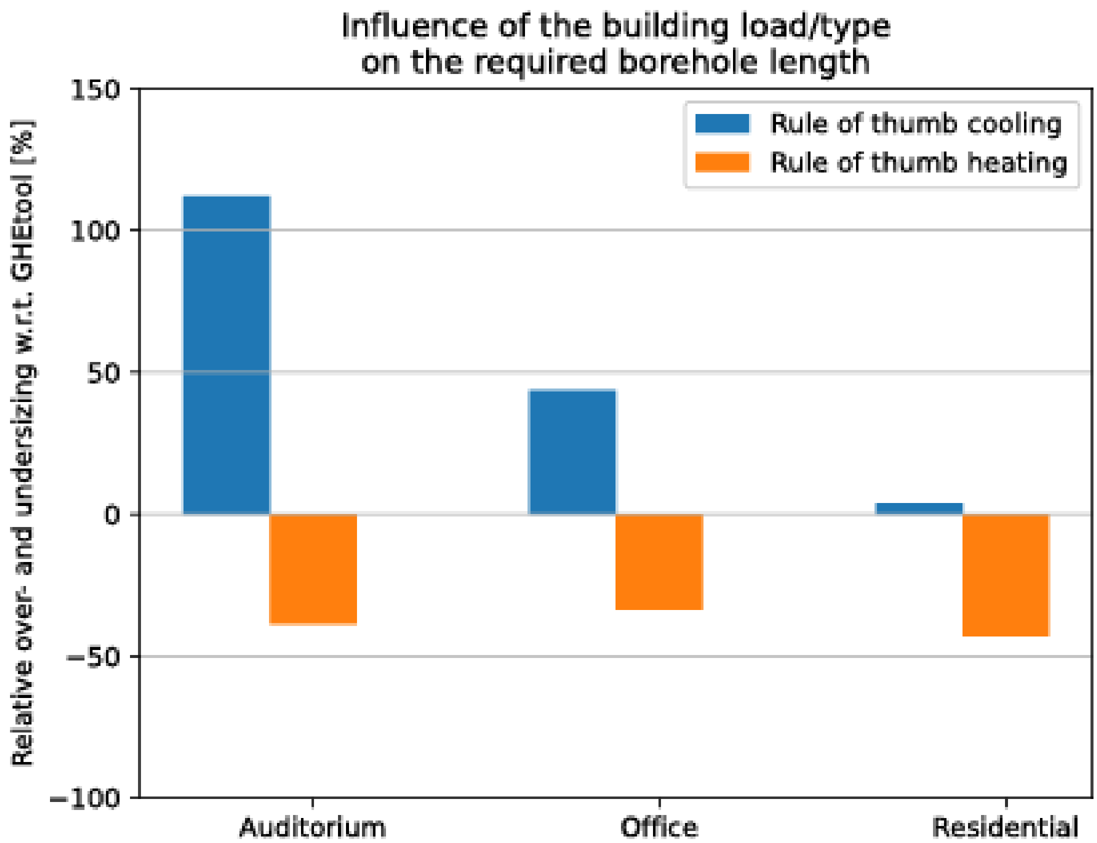

Figure 2: Relative over and undersizing when using rule of thumb sizing in reference to a borefield sizing with GHEtool.

Sensitivity to fluid regime and number of pipes

Not only can the building loads lead to significant under- and oversizing, but the internal design of the boreholes themselves can also be of great importance. In designing the borehole itself, typically, two parameters can be varied: the type of tubing (single or double U-pipes or even coaxial) and the fluid regime (laminar or turbulent). All these parameters have an effect on the equivalent borehole thermal resistance and, hence also the required total borehole length.

Figure 3 shows the influence of these design parameters in the over- and under-sizing of the borefield in reference to a sizing with GHEtool for the auditorium. The oversizing of Figure 2 (which was calculated with a turbulent flow and double U-pipe borehole) disappears when working with a single U-pipe, laminar flow borehole. This can be understood since the turbulent flow and double U-pipe case give the best borehole thermal resistance, making the influence of the peak power smaller, whereas a single U-pipe, laminar flow case, stresses the influence of the peak power. Therefore, the oversizing when using a rule of thumb for cooling is smaller in this latter case.

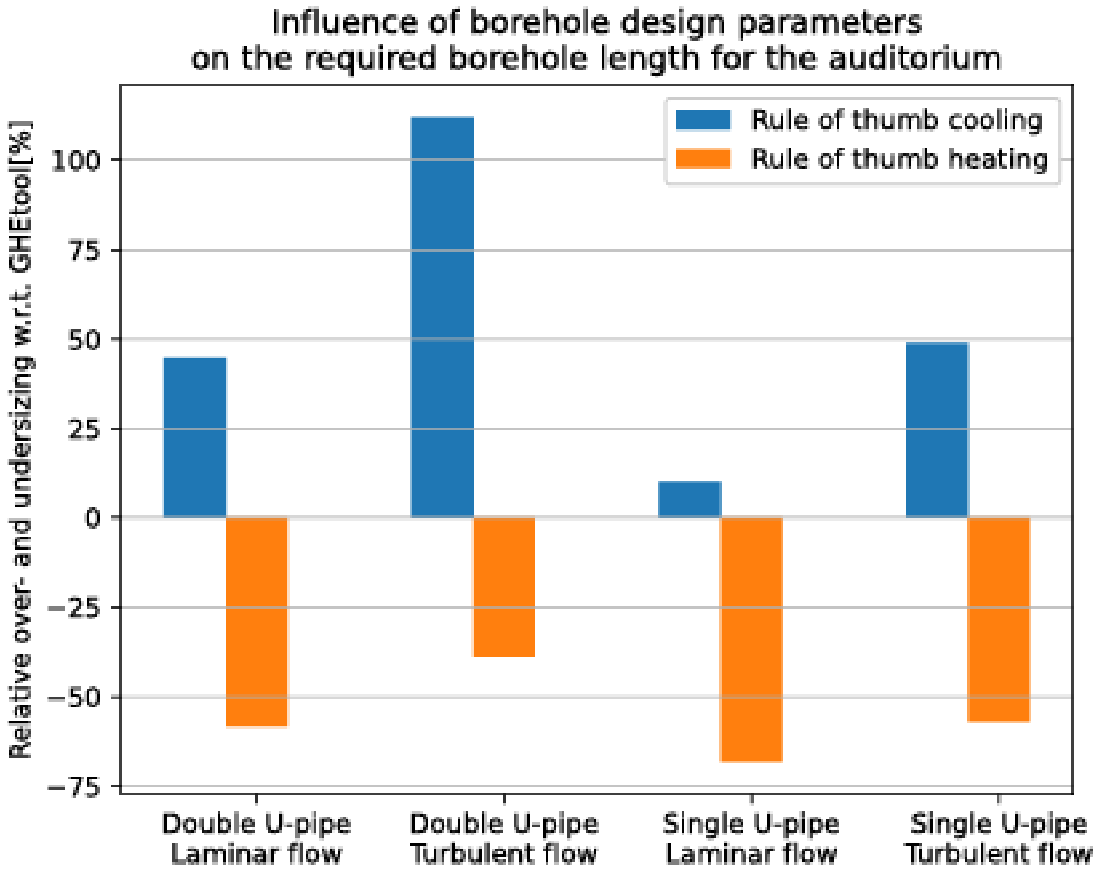

Figure 3: Influence of the fluid regime and the number of U-pipes in the borehole on the relative over- and under-sizing of the borefield in reference to a borefield sizing with GHEtool.

Sensitivity to temperature limits

Depending on the system design, other temperature limits can be set for the borefield. For example, when working with passive cooling, a maximum average fluid temperature of 17°C is typically used, which requires larger borefields for buildings with high cooling demand. When using a system with active cooling, 25°C can be used as a maximum temperature limit, relaxing the required total boreholelength. However, on the minimum temperature side, one can also work with different safety margins. 3°C for the average fluid temperature can be used as a safe margin to never get to negative fluid temperatures. This can, in practice, lead to oversizing; therefore, some people suggest using 1°C as a minimum average fluid temperature bound. This is a less safe solution, but it increases the economic viability of the borefield design. The effect of these temperatures on the relative over- and under-sizing is shown in Figure 4.

When going to active cooling (and using a maximum average fluid temperature limit of 25°C), sizing with a rule of thumb for cooling gives an extreme oversizing with a factor of 3 to 4. This is due to the fact that the borefield is now limited by the heating load, and hence, the peak cooling does not matter that much [3]. Notice how moving to active cooling also makes sizing with a rule of thumb for heating shift from under- to oversizing. This can be understood since the field is now limited by the heating peak, and therefore, this rule of thumb gives a more accurate estimation.

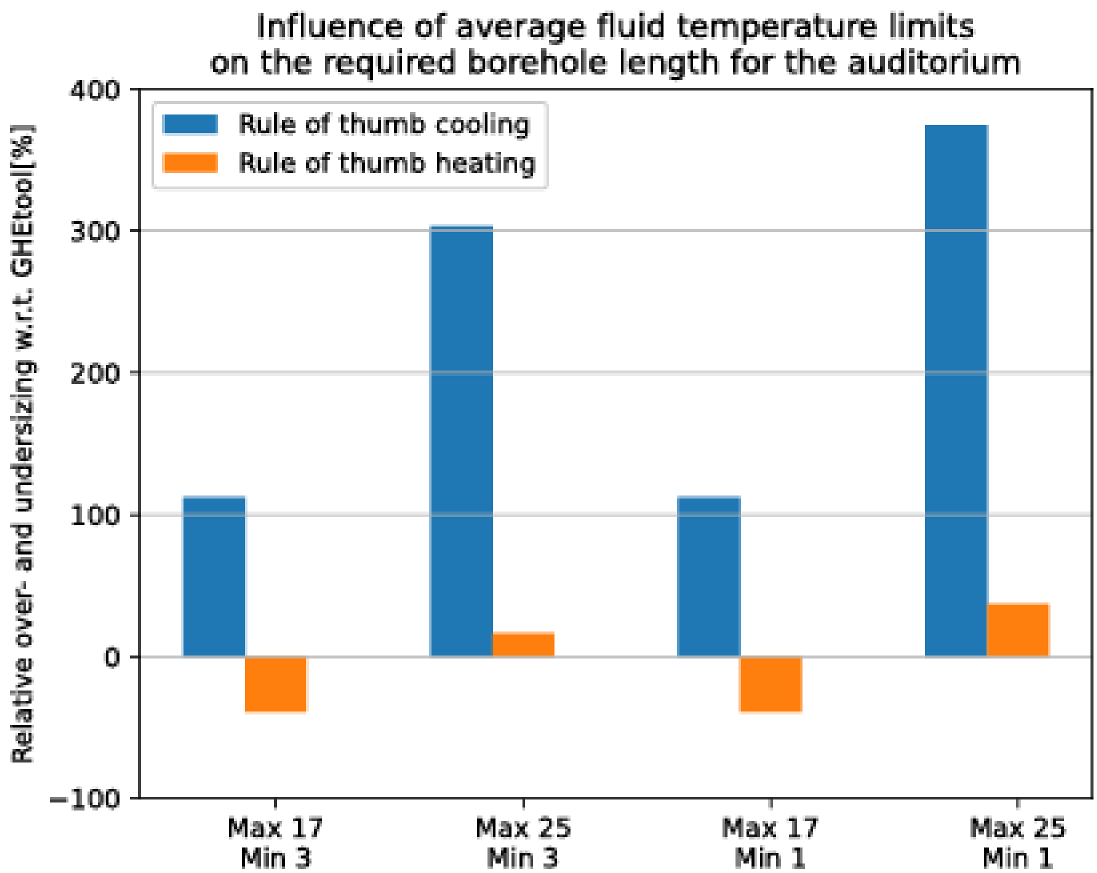

Figure 4: Influence of the average fluid temperature limits on the required borehole length in reference to a borefield sizing with GHEtool.

Overall sensitivity

The previous three paragraphs only showed a couple of parameters that influence the required total borehole length. The length/width ratio of the borefield, the simulation period (being 20 to 40 years), the ground thermal conductivity, the ground temperature gradient, the grout thermal conductivity, the peak duration, etc., all influence the required total borehole length. Figure 5 shows the total spread in the required total borehole length when varying all these parameters using a boxplot. It is clear that the one rule of thumb is nowhere near capable of capturing all variations in the required total borehole length when varying all the abovementioned parameters. The same conclusion can be drawn from Figure 6, where the rule of thumb value was reverse-engineered based on the calculated borefield size and the peak power. There is no one good and clear rule of thumb for all these cases and their variations.

The (non)sense of rules of thumb in borefield sizing

By now, it should be clear that there is a lot of diversity in the required borefield size that is not captured with a simple rule of thumb, but we don't necessarily need to throw them all away. For very specific buildings with similar designs, in a similar region and for borefields constructed in the same way, the spread in Figures 5 and 6 can for sure be smaller, and hence, a rule of thumb can be found in that case. However, it is not easy (to near impossible) to predict when one will deviate from it. In general, therefore, it is better to double-check the calculated borefield size with specialized software like GHEtool, EED, GLHEPro, EWS. By doing so, one can be more certain of a correct borefield size and, hence, a more robust, durable, economical and viable system.

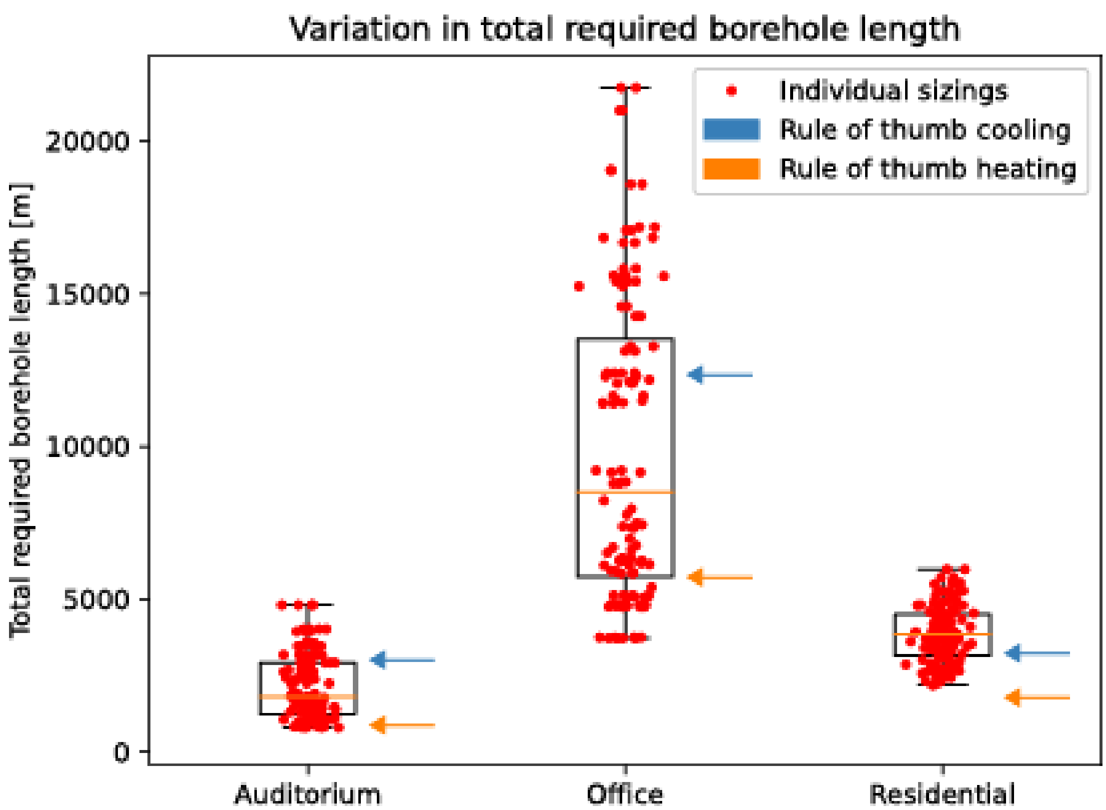

Figure 5: Variation in total required borehole length for three different buildings when varying the ground properties, grout properties, average fluid temperature limits, fluid regime, number of U-pipes and simulation period. The variation is shown in a box plot per building, indicating the sizings according to a rule of thumb.

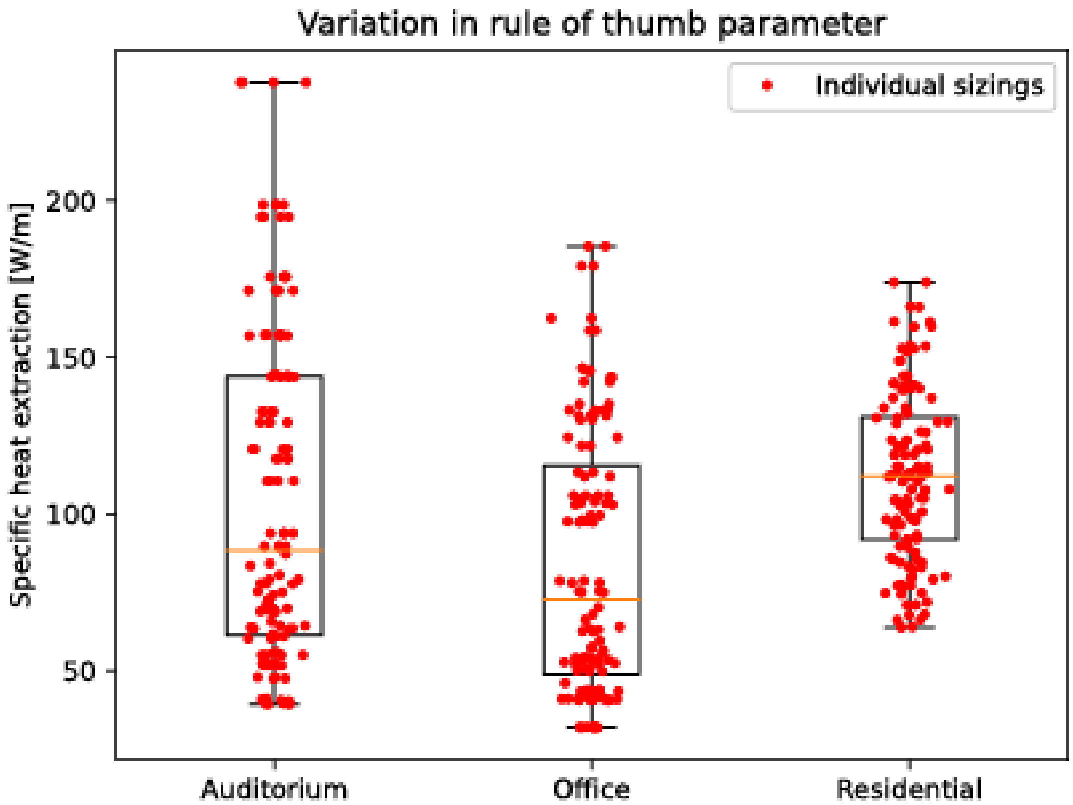

Figure 5: Variation in total required borehole length for three different buildings when varying the ground properties, grout properties, average fluid temperature limits, fluid regime, number of U-pipes and simulation period. The variation is shown in a box plot per building, indicating the sizings according to a rule of thumb.

Conclusions

This article shows the potential danger of using rules of thumb for borefield sizing. For three different buildings, it was shown that a simple rule of thumb can sometimes undersize the borefield or oversize it by up to 400%. The results from these simple rules are not, by definition, wrong, but they are covered with uncertainty. One cannot know for sure when these results can be trusted and therefore, the use of detailed borefield sizing tools is to be recommended in order to design borefields in such a way that they are both robust and financially viable.

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Table 1: Geothermal loads for the three building cases.

Building	Peak heating	Yearly heating demand	Peak cooling	Yearly cooling demand
Auditorium	26,0 kW	30,6 MWh	90,2 kW	3,86 MWh
Office	171 kW	94,0 MWh	370 kW	118 MWh
Residential	53,2 kW	122 MWh	96,7 kW	24,0 MWh

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National Market

Japan: Heat Pump Market Report

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By Hirofumi Sano

Given Japan's hot and humid summers, heat pumps, particularly inverter air conditioners for both cooling and heating, have been extensively adopted since early on. Heating usage is prevalent across the country, barring the colder northern regions where combustion heating remains prevalent. Moreover, stringent energy-saving regulations for heat pump equipment have consistently driven down power consumption for air conditioning and domestic/commercial hot water supply.

Introduction

Figure 1 illustrates the average temperature deviation in Japan [1]. In 2023, the deviation from the reference value (a 30-year average from 1991 to 2020) for Japan's average temperature was +1.29°C, marking the highest recorded since statistics began in 1898, surpassing the figures of 2020. Over time, Japan's annual average temperature has shown an upward trend, albeit with fluctuations. Long-term data indicates a rise of 1.35°C per century, with a notable increase observed since the 1990s, marked by several years of elevated temperatures.

In Japan, eight regional classifications are defined, as shown in Figure 2. Generally, regions 1 to 4 are often defined as cold regions. [2], [3]

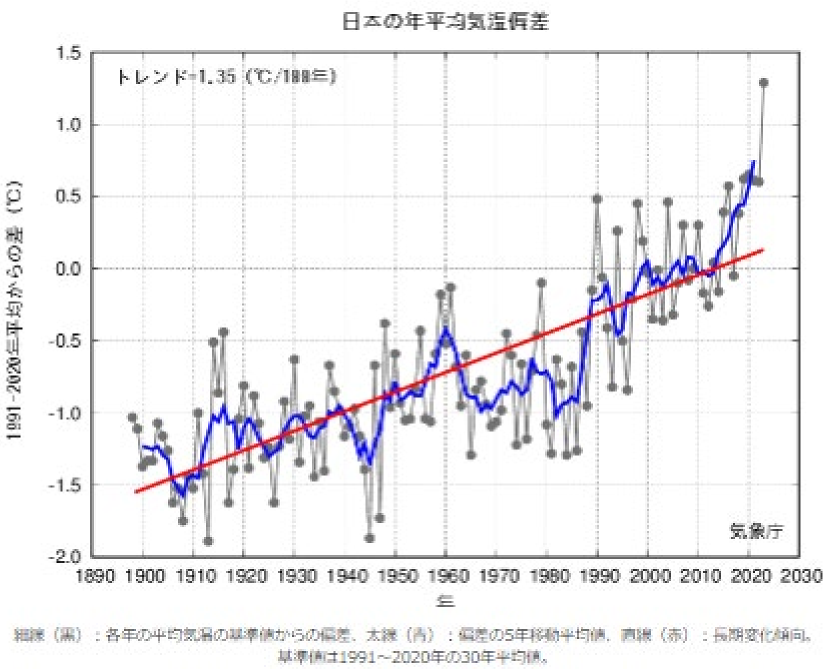

Figure 1: Average temperature deviation in Japan

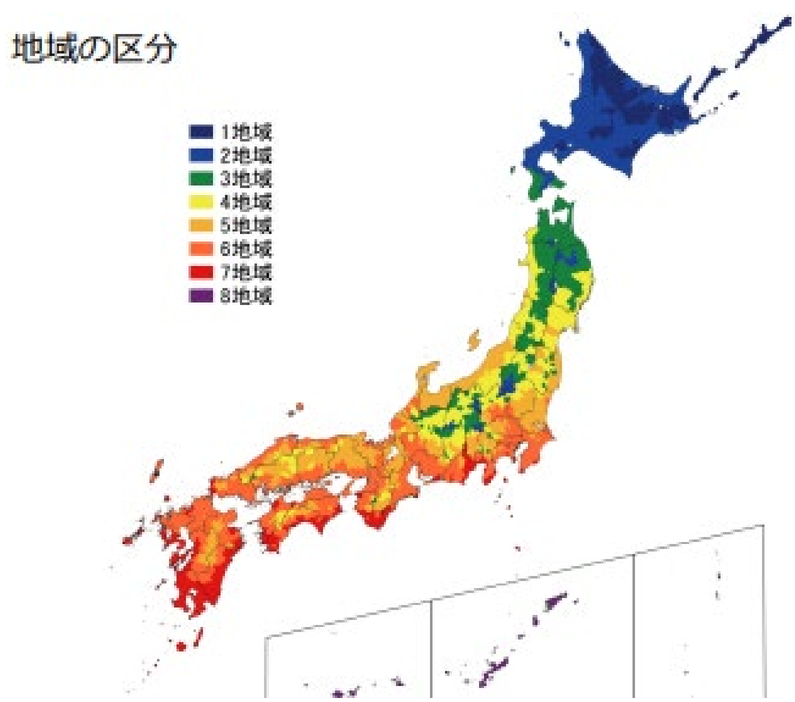

Figure 2: Definitions of Regions in Japan

In accordance with the Japanese climate of high temperature and humidity, the spread of heat pumps as cooling equipment was preceded. In the Japanese residential market, inverter air conditioners, which can switch between heating and cooling, account for almost 100% of the market. However, the ratio of combustion-type heating is still high in cold regions. The heating performance and defrosting control of air conditioning equipment continue to improve thanks to the technological development efforts of manufacturers.

For domestic hot water supply, the government subsidy policy and electric power companies have cooperated to promote the popularization of heat pump by domestic hot water supply equipment "EcoCute". It is a domestic hot water heat pump using a CO_2 refrigerant. It is characterized by a large hot water storage tank that stores hot water at night using inexpensive late-night electricity and is suited to Japanese bath conditions.

In order to reduce power consumption, the government has been eliminating low-efficiency heat pump equipment from the market by establishing energy-saving regulations based on APF: Annual Performance Factor for residential air conditioners, commercial air conditioners, and hot water supply equipments.This energy-saving measure has greatly improved the energy efficiency of heat pump equipment in Japan over the past decade.

Room air conditioner and package air conditioner

As shown in Figure 3 and Figure 4, the shipment volumes of room air conditioners and package air conditioners are almost flat, and the Japanese market is mainly driven by replacement demand. [4]. As mentioned above, heat pump technology spread mainly in cooling equipment in Japan and was later applied to heating. Air-conditioning equipment manufacturers are working on the development of equipment specialized for improving heating efficiency for cold regions, and are also making efforts to popularize heat pump equipment in cold regions, including hot water supply.

In cold regions where the outside temperature is below freezing, the heating efficiency of heat pumps is certainly lower, but they are still two to three times more efficient than oil or gas heating systems. On the other hand, regarding low-GWP refrigerants, the heat pump industry is cautious about selecting standard refrigerants because the optimum refrigerant selection has a significant impact on the energy efficiency of equipment and its cost.

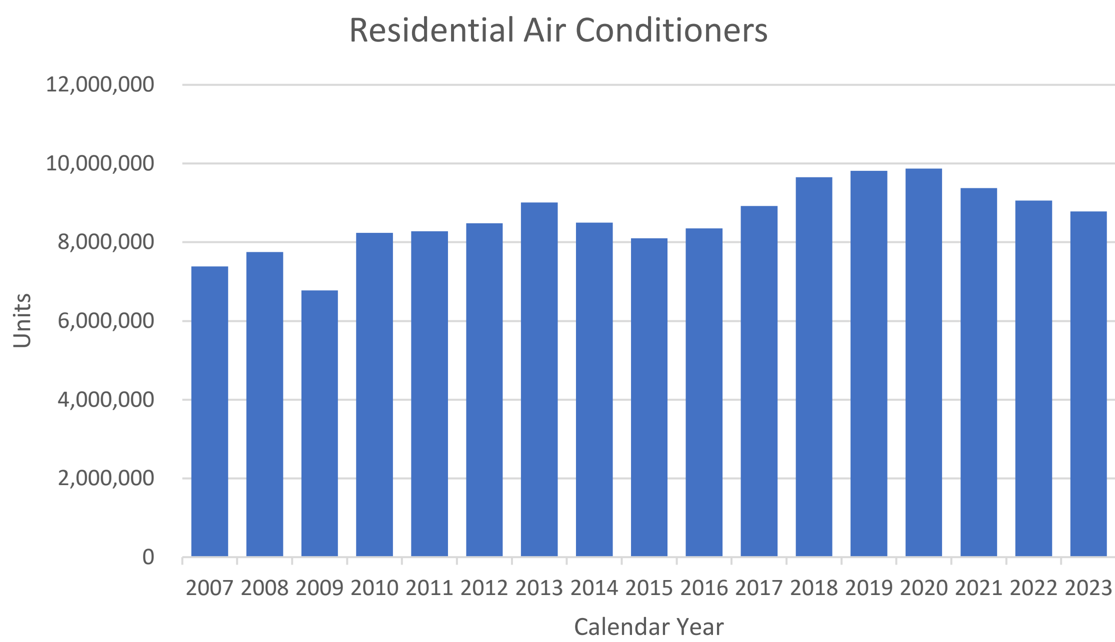

Figure 3: Shipment volumes of Room Air Conditioners

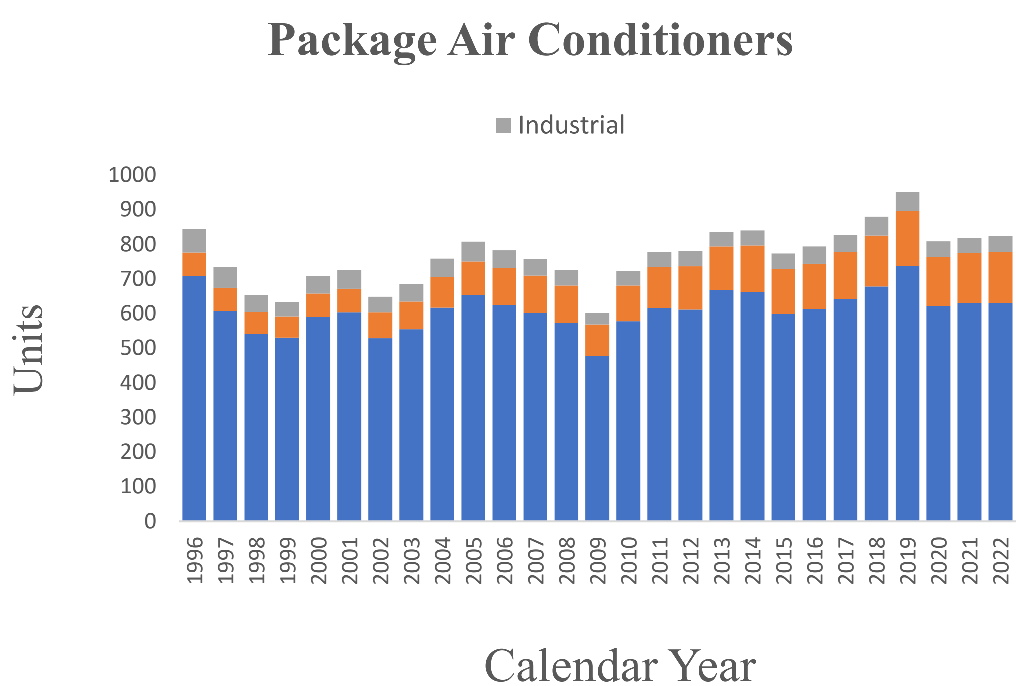

Figure 4: Shipment volumes of Package Air Conditioners

Domestic hot water heatpump “EcoCute”

Japan's CO_2 hot water supply technology, which can raise the water temperature from 10 ℃ to 90 ℃ at once, can contribute to the European market depending on how it is used. On the other hand, the refrigerant pressure is high, and the installation cost of the equipment is much higher than that of combustion equipment. Therefore, it is needless to say that the introduction support of the government is an issue. In addition, there is a problem in terms of reliability related to water quality when expanding overseas.

Figure 5 shows the number of units shipped from EcoCute [4].

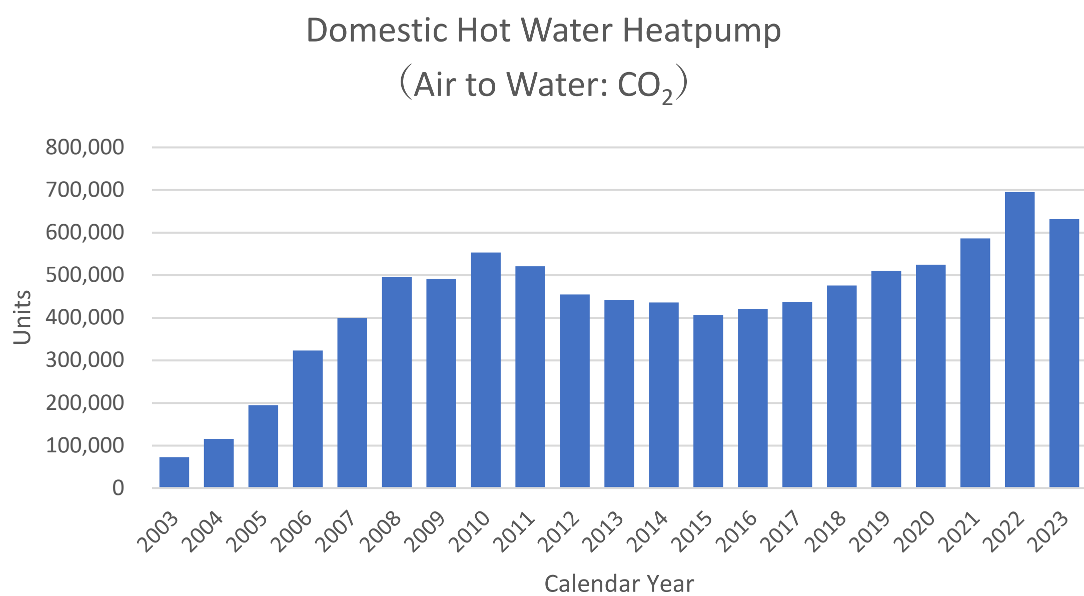

Figure 5: Shipment volumes of Domestic Hot Water Heat Pump "EcoCute"

Central air conditioning

Air-cooled chillers and water-cooled chillers

In Japan, air-cooled modular chillers, which are modular types capable of generating cold and hot water, have variable connection capacities and are equipped with inverter-driven compressors, are becoming increasingly popular. In addition to the ability to control the number of operating units, the compressor is inverter-driven on a module-by-module basis, making it possible to realize efficient operation of the entire system. Although the initial investment for the equipment is somewhat large, the system is superior in terms of energy saving and maintenance cost, and each manufacturer is gradually expanding the system to overseas markets.

Figure 6 shows the statistical data of chiller shipments excluding centrifugal chiller and absorption-type chillers [4]. Compared to 10 years ago, the market estimates that the total capacity of refrigeration tons has increased, as the number of units shipped has leveled off while the refrigeration capacity per unit of module chiller has increased.

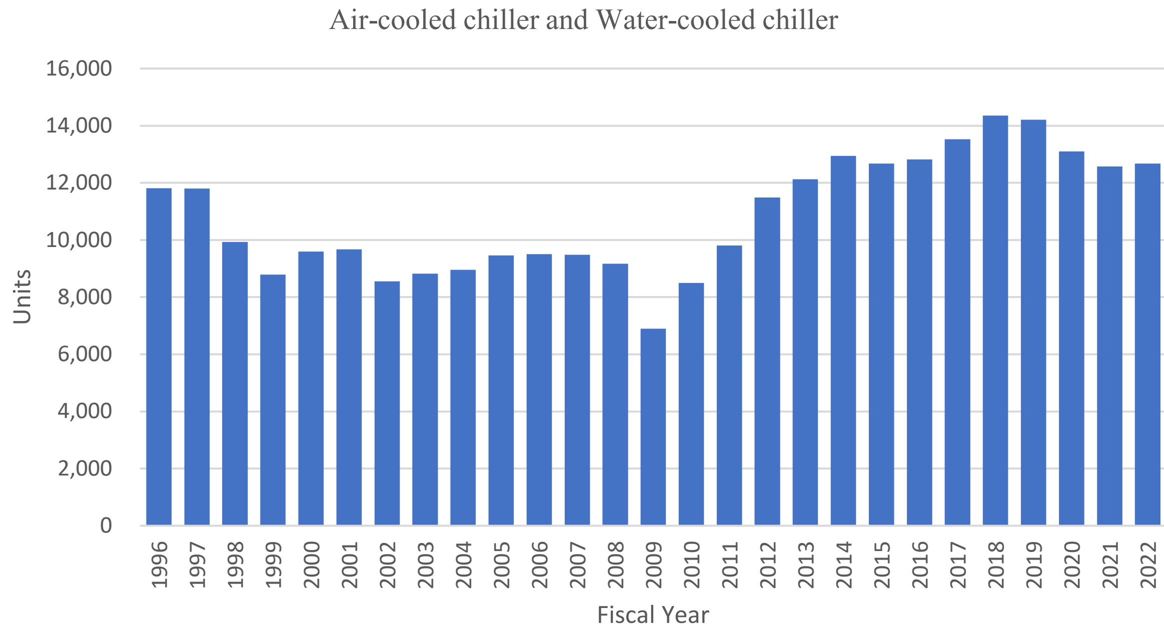

Figure 6: Shipment volumes of Air-cooled chillers and Water-cooled chillers

Central air conditioning, centrifugal chiller and absorption chillers
As shown in Figure 7, while shipments of centrifugal chillers have been flat, shipments of absorption-type chillers, regardless of type, have decreased by more than half from 20 years ago [4].

These data suggest that small-scale absorption-type chillers have replaced high-efficiency chillers, given the flat market size.

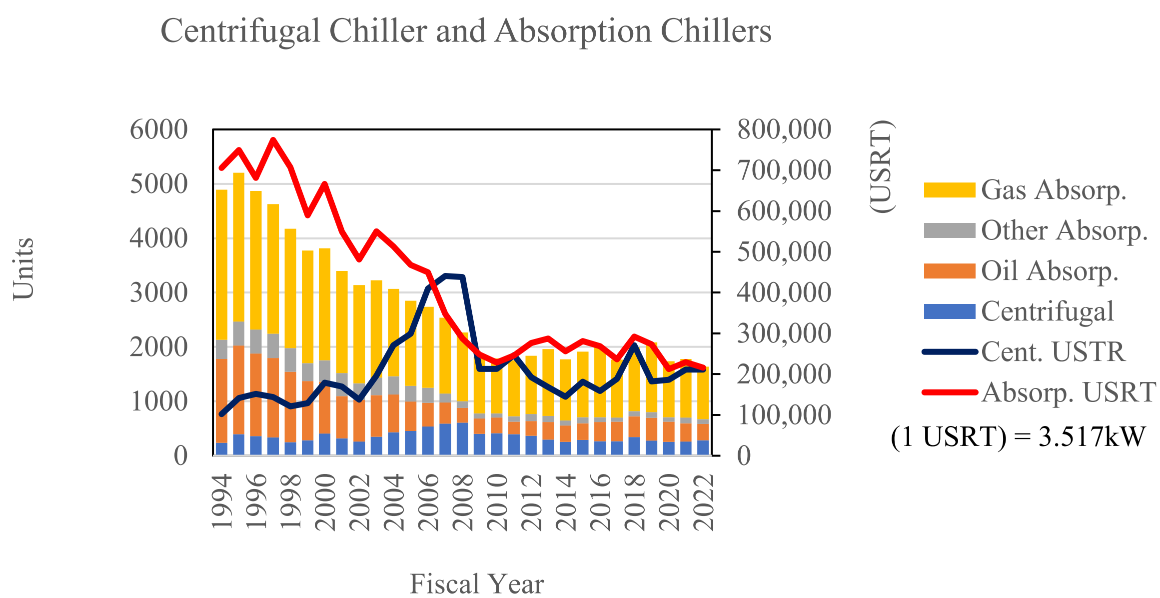

Figure 7: Centrifugal Chiller and Absorption Chillers

Industrial waste heat recovery

In industrial applications, the development of heat pump application systems that can recover waste heat from various industrial processes and waste heat recovery technology has been progressing in response to the need to reduce energy consumption. These systems will play an important role in supporting Japan's future renewable energy. At the same time, in industrial applications, there are great expectations for high-temperature heat pump technology, but there are still many problems with refrigerants and compressors, and we are still on the way.

Issue of heat pumps as a renewable energy source

As described above, the diffusion of heat pump air conditioning systems, mainly cooling systems, and the adoption of inverters are extremely high in Japan, and energy-saving regulations are also advancing. On the other hand, unlike in Europe, the government is cautious about including heat pumps in the statistics as renewable energy.

However, according to the actual energy supply and demand in Japan, the amount of renewable energy used by heat pumps is estimated to be about 16% of the total amount of final energy consumption in the consumer and industrial sectors [5]. Here, the amount of atmospheric heat for cooling in this trial calculation is calculated on the assumption that 100% of the heat supplied for cooling is atmospheric heat. Therefore, it is also a numerical value to raise the energy self-sufficiency rate, and the effect of the popularization of heat pumps on the energy supply is very large.

In Japan, policy decisions to support the diffusion of heat pump equipment are made on a policy-by-policy basis in light of the objectives of the policy. In some cases, heat pumps, including atmospheric heat, are supported as "low-carbon products." On the other hand, in some cases, atmospheric heat pumps are excluded from the measures to support the introduction of natural heat utilization facilities. Along with the reduction of resource energy and the improvement of the renewable energy rate, the energy policy is discussed from the viewpoints of the high-efficiency utilization of energy and the efficiency of final energy utilization equipment.

In discussions on the definition of renewable energy and decarbonization, renewable energy and energy conservation should be pursued in tandem to bring about fruitful results.

Conclusions

The heat pump technology stands as both an energy-saving and renewable energy utilization innovation, contributing to heat recycling efficiency. Now is the opportune moment for industry and government collaboration to position Japan as a global leader in heating, cooling, and hot water supply through its advanced heat pump technology.

While concerns have been raised about the potential increase in total energy consumption from widespread heat pump adoption without careful consideration, it's important to recognize that higher utilization rates of heat pumps in essential energy consumption sectors lead to reduced fossil fuel consumption. Our ongoing efforts focus on advancing decarbonization through the widespread adoption of heat pumps.

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