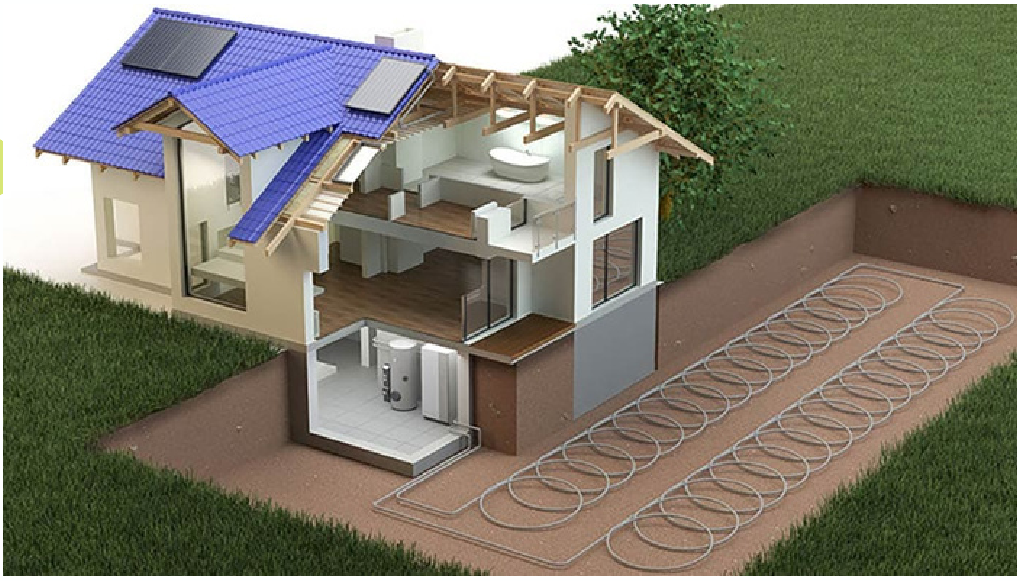

GEOTHERMAL HEAT PUMPS

CURRENT APPLICATIONS & POTENTIAL

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Table of Contents

Chapter 1: Heat Pumps

Introduction

As we live in the 21st century, we can often hear about climate change and how it affects our everyday lives. Every country and international organization is fighting climate change significantly. The Paris Agreement goals are a set of several long-term goals intended to address climate change and its impacts. To avoid climate change and meet the Paris Agreement goals, we need to develop renewable energy technologies and implement them as much as possible. Per research, the buildings sector accounts for around 3 gigatons (Gt) of direct carbon dioxide (CO2) emissions per year, with electricity use and associated fossil fuel combustion for district heating raising that figure to 10 Gt of CO_2 per year [(1)]. The cost of renewable energy power generation has fallen, especially in the wind and solar technologies. This fact has made the decarbonization of the power generation sector increasingly economical. It is to be expected that indirect emissions from buildings will decline as electrical end-uses become less carbon intensive. The devices that are expected to have a crucial role in decarbonization of space and water heating in buildings are heat pumps, highly efficient and electricity driven devices. Hence, heat pumps, more specifically Geothermal Heat Pumps, also known as Ground-Source Heat Pumps (often abbreviated throughout this paper as GHP) are the topic of discussion of this report. Their significance and potential are inevitable, and it can be said with certainty that they are the future of the renewable energy sector. Compared to the combustion of fossil fuels for the provision of heat, they are remarkably efficient, being capable of converting one unit of electrical energy into 2.5 to 5.5 units of heat (an efficiency range of 250% to 550%), depending on the heat pump technology, climate, and end-use needs [(1)].

Heat Pumps' Significance

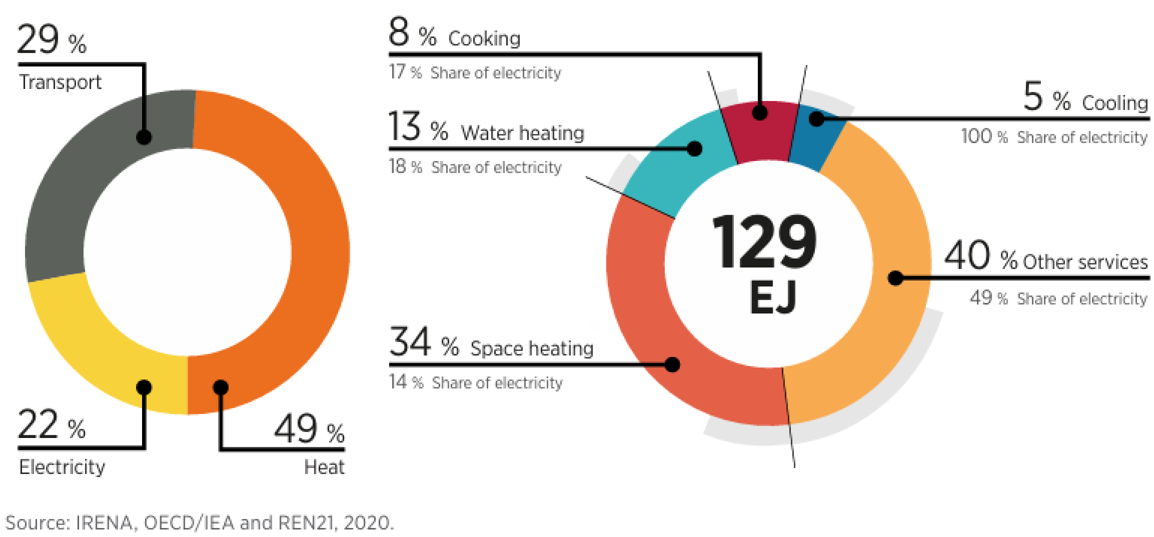


Figure 1. Share of heat in total final energy consumption and energy consumption by end-use in buildings, 2018 [(2)]

Figure 1. visually represents the share of heat in total final energy consumption. We can see that heat takes up almost one half of total final energy consumption. This fact alone emphasizes how important it is to develop a technology which will provide us with a reliable and renewable energy source. Heat pumps are a perfect device, because not only can they provide us with heat, but also air-conditioning and economically speaking, it is a far more economically acceptable option than having two separate devices for heating and air-conditioning.

Certainly, almost all of us must have heard about heat pumps and how important they are for the future of energy consumption. It is without doubt that we can state that heat pump represents a huge improvement compared to other types of energy sources for HVAC systems, both economically and environmentally. Geothermal Heat Pumps are an "eco-friendly" option, which utilizes basic principles of thermodynamics to transfer heat from and to the ground. In this chapter, we will discuss basic principles of heat pumps, types of heat pumps and operation principle of heat pumps and see how GHPs differ from other types of heat pumps.

Types of Heat Pumps

In this report, we will deal with a special type of heat pump, so-called Geothermal Heat Pumps. However, we will first discuss heat pumps in general. We will start with an explanation of different types of heat pumps and what is the actual difference between GHPs and other types of heat pumps. The following paragraphs briefly explain different types of heat pumps.

Main types of geothermal heat pumps are as follows:

- Air Source Heat Pumps: use our exhaust (ambient) outside or indoors as a heat source or heat sink to provide heating and cooling. [6]

Figure 2. The principle of Air Source Heat Pumps [6]

- Ground Source (Geothermal) Heat Pumps: main subject of our report. This type of heat pump uses heat (energy) from the ground of stable temperature and heat sink. The transfer fluid flows through pipes that can be assembled in a horizontal or vertical collector. [6]

Figure 3. The principle of Geothermal Heat Pumps [6]

- Water Source Heat Pumps: the principle is almost identical to the Ground Source Heat Pumps. The only difference is that we use water directly (open loop) instead of a closed loop heat exchanger with a transfer fluid. [(6)]

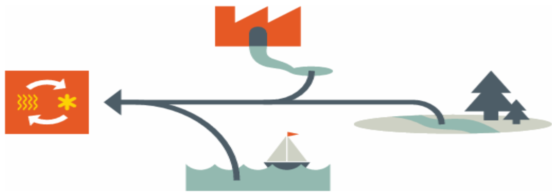


Figure 4. The principle of Air Source Heat Pumps [(6)]

Operation Principle of Heat Pumps

The scheme below very clearly and easily explains the principle of operation of Heat Pumps. The principle of operation of HPs is based on the *refrigerant cycle* in which the ambient renewable energy obtained from the water, air or ground or low-temperature waste is the dominant energy source, even though the electrical energy drives the system. Because of this, heat pumps have high efficiency. There are several heat pump technologies, however, the dominant technology is the vapor compression heat pump driven by electrical energy.

In an electric compression heat pump, heat is transported from a low-temperature energy source to an energy sink of a higher temperature through transfer fluid, also called refrigerant. This cycle is based on evaporation and compression. This installation usually consists of a heat exchanger (evaporator), a compressor, which is driven by electricity, a second heat exchanger (condenser) and an expansion valve. This system also needs the refrigerant and a control unit.

The refrigerant is exposed to the energy source in the first heat exchanger (evaporator) and evaporates. The energy source is cooled down in this process. This refrigerant vapor is then compressed, and this results in a temperature lift. The condensation of the refrigerant is a direct result of the transfer of higher temperature to the heat distribution system via the second heat exchanger (condenser). After this, the liquid, which is still under pressure, is fed into an expansion valve. Low-pressure, low-temperature heat is then ready to enter the first heat exchanger (evaporator) again and the cycle is finally closed.

What makes Heat Pumps so special is the fact that they can both cool down and heat up spaces very efficiently, all while being environmentally friendly. This is why heat pumps are used more and more every day and why we can consider them the future of energy. More advantages of heat pumps, compared to other similar devices and heating methods, is that they provide a more consistent and comfortable indoor temperature. They are also very safe and operate without combustion and when properly maintained, heat pumps tend to have a longer lifespan than other similar heating methods. It is crucial to note that regular maintenance is needed for the maximum efficiency of heat pumps, and this can lead to a long lifespan and save on costs. [2]

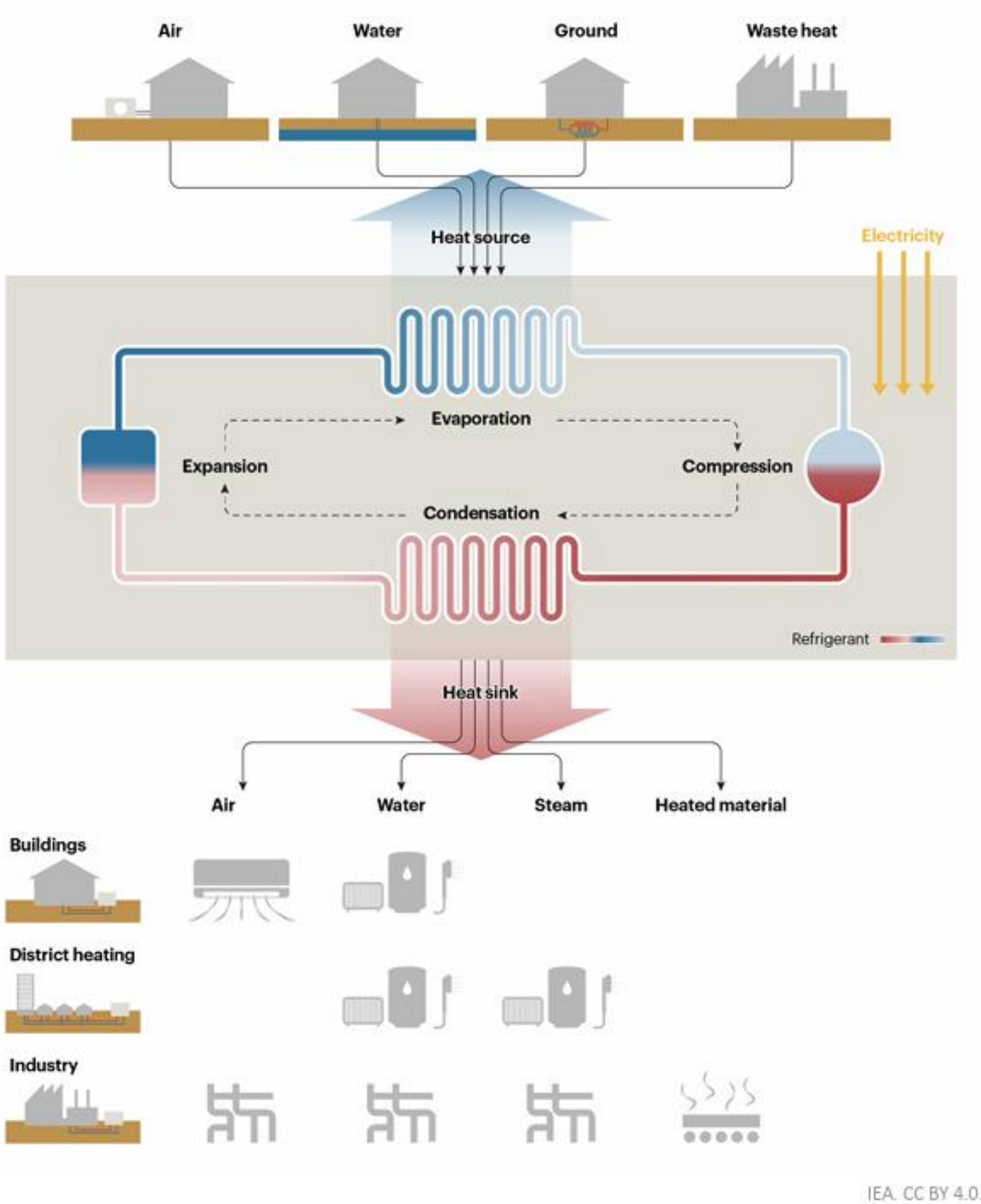


Figure 5. The operation principle of Heat Pumps [3]

Chapter 2: Geothermal Heat Pumps: Applications & Benefits

What is a Geothermal Heat Pump?

After defining and explaining the basics of heat pumps and their operation, we will now proceed to talk about the topic of our research, which is Geothermal Heat Pumps.

Geothermal heat pumps, often abbreviated as GHP and well-known as *Ground-Source Heat Pumps* (abbreviated GSHP) are a type of heat pump, whose principle of work is based on the usage of the stable temperature of the ground. In the winter, GHPs transfer heat throughout a system of underground pipes (in some cases we use underwater pipes, depending on the configuration) from the warmer earth or water source to the building. In the summer, we have the opposite case, in which the heat is discharged through the pipes from the building to the cooler ground. Heat pumps allow transformation of heat, from a lower temperature level to a higher temperature level using external energy (as an example, to drive a compressor). (10)

Types of Geothermal Heat Pumps

- Horizontal Installation

Horizontal GHPs are a type of installation of GHP. Speaking of effectiveness, this type of installation is the most effective one for residential installations, in general. It is important to note that this type of installation is particularly effective for new construction buildings, where sufficient land is available. This type of installation requires trenches at least four feet deep. The most common layouts use either two pipes, buried at six and four feet respectively, or two pipes placed side-by-side at five feet in the ground in a two-foot-wide trench. The Slinky™ method (shown in the Figure 6.) consists of a looping pipe, which allows more pipe in a shorter trench, which decreases the installation costs and allows the horizontal installation type possible to use in the areas where it would not be conventional for horizontal applications. (10)

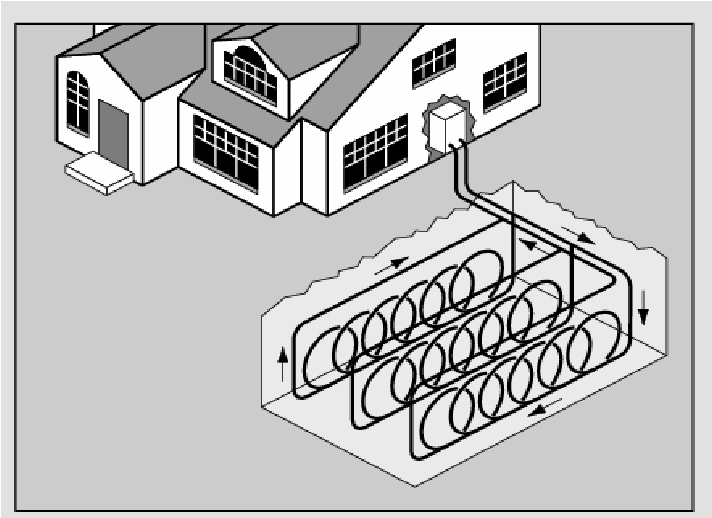


Figure 6. Horizontal Type of Geothermal Heat Pumps (10)

- Vertical Installation

Large commercial buildings, like schools, malls, factories etc. often use vertical systems because the land area required for horizontal loops would be prohibitive. Another problem which requires the usage of vertical type of installation is when the soil is too shallow for trenching, and they minimize the disturbance to existing landscaping. Holes, approximately four inches in diameter, for a vertical system are drilled about 20 feet apart and 100 to 400 feet deep. Two pipes that are connected at the bottom with a U-bend go into these holes to form a loop. The vertical loops relate to horizontal pipes placed in trenches and connected to the heat pump in the building. (10)

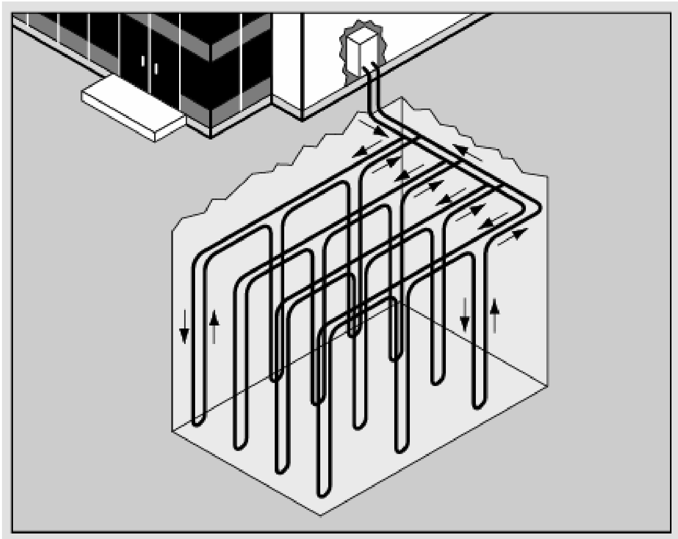


Figure 7. Vertical Type of Geothermal Heat Pumps (10)

Applications

- Heat pump deployment in residential and commercial buildings

Heat pumps, which include Geothermal Heat Pumps, are a solution to provide heating and hot water to residential buildings, including small, single-family houses and multi-family residential buildings. Depending on the local building tradition, or more particularly the specific building we're dealing with, heat can be distributed via water-based systems, like radiators and floor heating or via air-conditioning devices, like ducted or ductless systems. What makes heat pumps such an ideal technology for any building type with sufficient heat distribution surface is that they allow comfortable indoor temperatures at comparatively low temperatures of the heat distribution system. For example, for hydronic distribution systems, a good indicator is a feed temperature below 55 °C. (6)

Today's building designs include near-zero energy, 'passive' houses and energy 'plus' building designs. Moreover, heat pumps can replace boilers in the deep renovation of buildings. The biggest challenge engineers are facing nowadays is the replacement of oil and gas boilers in existing buildings. Users often do not see the added value and significance of investing in an immediate renovation of the building envelope. For that reason, it is important to emphasize the significance of such feats.

Today, it is all about comfort and reaching as low a price as possible. Commercial spaces and spaces in which humans spend time are required to have comfortable temperatures and have clean and fresh air to create a pleasant environment. All sorts of buildings, like residential houses and apartment buildings, schools, hospitals, malls etc. require clean air with the desired temperature and hot water. The solution for these requirements is large heat pumps. Boilers provided heat and air conditioning and refrigeration equipment provided cooling devices in the past. Nowadays, heat pumps are supposed to integrate both requirements, which makes them a clear choice to implement in today's installations. Large demands are often covered by geothermal drillings, which is the principle of Geothermal Heat Pumps and will be discussed in detail further in the paper. Also, the connection to the buildings foundations or via open loop systems are a viable option. (6)

Industrial applications and district heating

As per European Copper Institute (Copper Alliance), 2.388TWH of final energy is used by industry for heating and cooling purposes. industry uses 2,388 TWh of final energy for heating and cooling purposes. Most of this energy is used for process heating.

The goal of governments worldwide is to reduce fossil fuels usage because of the emissions they produce. To achieve that, we need to obtain energy in the most efficient way possible. Different branches of industry require different amounts of energy. Unfortunately, most of that energy is obtained from non-renewable sources. Processes that operate at high temperatures need to reduce fossil fuel emissions or for their design to be changed towards electrification.

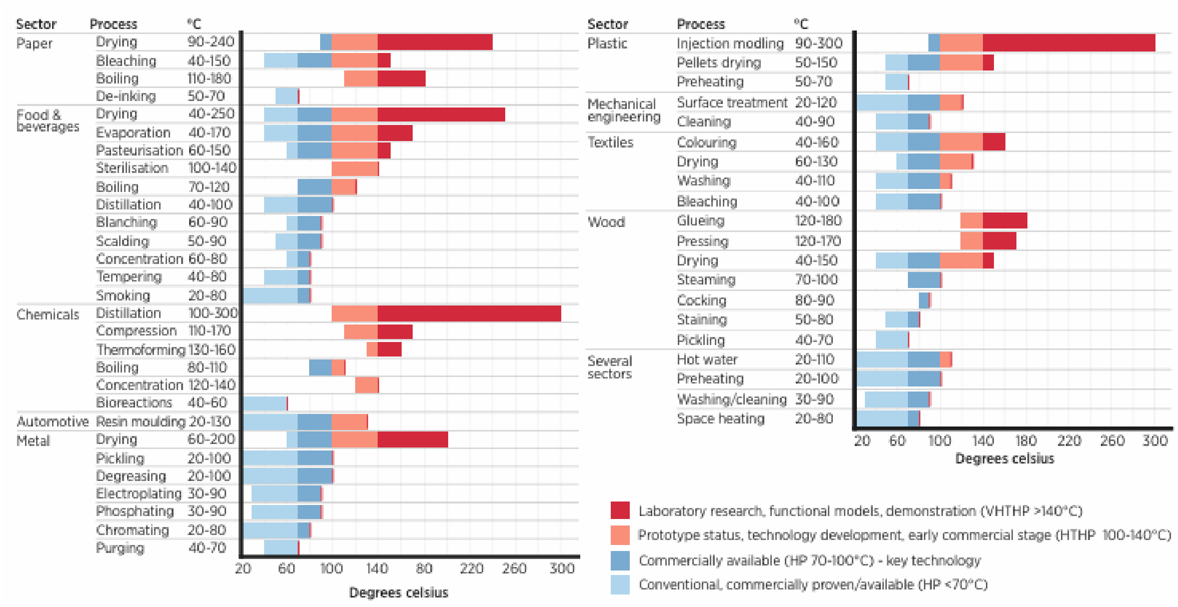
To decide whether heat pump technology is a viable option for a specific usage, it is decided regarding the temperature levels needed in production. On the other hand, after eventually deciding on the heat pump technology, it is then to opt for the type of heat pumps that should be used. To decide whether to use Geothermal heat pumps, certain factors are considered, like geological suitability, energy costs, space availability, installation costs etc.

So, technology is used according to the temperature levels needed for production. To make the decision simpler, *Eurostat distinguishes the following sectors:*

- *Iron and steel/non-ferrous metals*
- *Chemical and petroleum*
- *Non-metallic minerals*
- *Paper, pulp, and print*
- *Food and tobacco machinery*
- *Wood and wood products*
- *Transport equipment*
- *Textile and leather*
- *Others* (6)

Regular heat pumps, which are commercially available, can provide us the temperatures of up to 80°C. They can also use energy from renewable and waste sources with temperatures up to 40°C. We also have high temperature heat pumps, which are also commercially available. These pumps provide temperatures up to 100°C. They can use energy sources of temperatures up to 60°C.
On the other hand, unlike normal and high temperature heat pumps, very high temperature HP, which provide temperatures up to 150°C, are still limited to prototypes and experimental solutions.

However, experts are very optimistic regarding this type of heat pump and their market integration. (6)



Source: Arpagaus and Bless, 2017.

Figure 8. (Arpagaus et al.) Temperature ranges of different industrial processes (2)

Figure 8. shows temperature ranges of different industrial processes. According to this figure, we can deduce for which technological processes Geothermal Heat Pumps are the most viable option. We need to take different facts into account. First, the possibility of implementation of GHPs, considering the terrain, space available, political, and civilian policies etc. This comprehensive graph can be a useful asset in deciding which heat pump technology we should use, if any at all. (2)

Benefits of using geothermal heat pumps

Overview

There are many benefits of using Geothermal Heat Pumps. The following figure explains the benefits of heat pumps (accordingly Geothermal Heat Pumps). One thing from the following figure attracts the viewers' attention the most: enhance local employment. Considering that GHPs are still relatively unexplored, and their implementation is still relatively small, it only says how big their potential is.

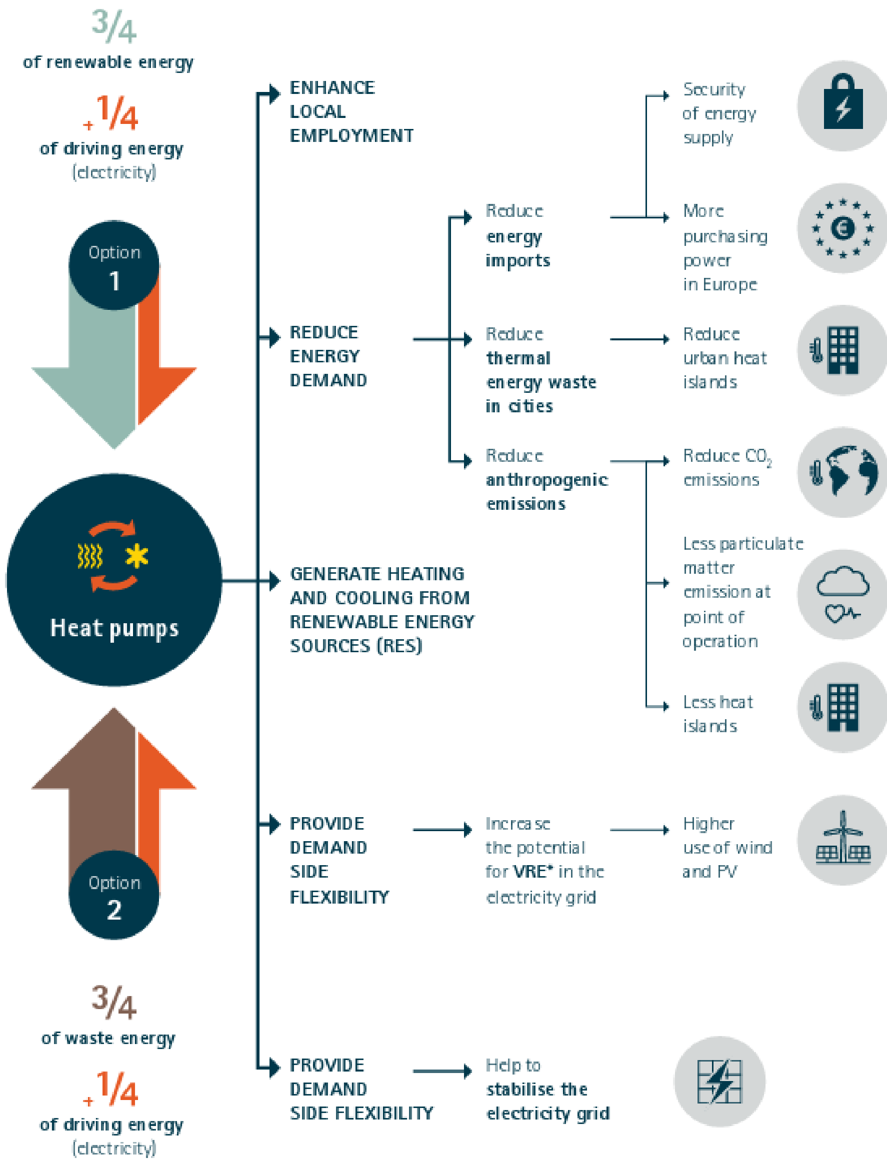


Figure 9. The added value of heat pump technologies [(6)]

Emphasis on the environmental benefits of geothermal heat pumps in reducing greenhouse gas emissions.

Geothermal heat pumps hold a great significance in today's efforts to obtain energy from renewable and sustainable sources, without toxic emissions. They are a great contributor to these efforts and are a big advantage for the environment. However, no technology is perfect, and it is still important to take some environmentally important things into account. The biggest concern is the water, as any perforation can carry a potential risk, especially regarding ground water. Since ground water is the primary source for drinking water, it is of great importance to protect it. When drilling holes in the ground for the GHPs or groundwater wells for thermal use, it is important to follow the regulations, which are already well-established in the countries with a developed GHP market. These regulations will be required in other countries too.

To achieve clean installation and operation of GHPs, we are required knowledge from all levels, both planners and installers as well as authorities. As in every other aspect, authorities show the power to regulate the installation and operation of GHPs through sets of laws. Moreover, they are mostly responsible for the development of the GHP market.

We can achieve our goals through education, training, and certification. A skilled and responsible workforce is needed to enjoy the benefits GHP technology can provide.

	CO_2 EMISSION PER KWH OF ENERGY (g $CO_{2equivalent}$/kWh)	EFFICIENCY OF TECHNOLOGY	CO_2 EMISSION PER KWH OF USEFUL HEAT (g $CO_{2equivalent}$/$kWh_{useful\ heat}$)
Gas condensing boiler	Gas: 242	eta = 95%	254
Gas non-condensing (eta = 85%)	Gas: 242	eta = 85%	284
Oil	Oil: 357	eta = 75%	476
Coal	Coal: 390	eta = 65%	612
Direct electric heating	Electricity: 400	eta = 100%	400
Heat pump (SPF 3)	Electricity: 400	eta = 300%	133
Heat Pump (SPF4)	Electricity: 400	eta = 400%	100
Heat Pump (SPF4) + electricity emission = 100	Electricity: 100	eta = 400%	25

Figure 10. Comparison of emission levels of different heating technologies and fuels [(6)]

Figure 10. explains the benefits of heat pumps compared to other heating technologies and fuels. Even though heat pumps have higher CO_2 emissions per kWh of energy, heat pumps have much larger technology efficiencies and less CO_2 emissions per kWh of useful heat.

Highlighting the energy efficiency and cost-effectiveness of geothermal heat pumps

As per IRENA's 2022 'Heat Pump Costs and Market' report and Figure 11., we have the following: "*the range of costs per country for ASHPs and GSHPs for the countries for which data were available. Wide cost ranges for ASHPs exist in countries where air-air and air-water systems are utilized, with the lower bound representing the costs of air-air systems for space heating only, while the upper bound usually represents small (3-4 kWth) air-water systems. Finland and Lithuania both have wide cost ranges for ASHPs, from under USD 332/kWth for small air-air systems in Finland, up to USD 2213/kWth for small air-water systems. However, the data for Finland are much more robust, dating from 2020, while the data for Lithuania date from 2014. Sweden, Latvia, Austria, and Switzerland all have estimates of above USD 2000/kWth, but the data date from 2014. The data for Norway and the Netherlands are for 2019, with a range of USD 945 to USD 2191/kWth in the Netherlands and USD 739 to USD 2069/kWth in Norway. The data for*

ASHPs in Denmark also span a wide range, with air-air systems at USD 296/kWth up to air-water systems at USD 1392/kWth . Data for North America suggest ASHPs in Canada cost between USD 486 and USD 1171/kWth, while in the United States, large central forced air systems cost on average USD 463/kWth. The market for GSHPs is typically smaller, given their higher specific costs (per kWth) and higher overall costs (with, on average, larger system sizes). This translates into less data generally being available, and a greater number of countries with single point estimates. A wide variation in costs exists for systems in Belgium, Denmark and Finland, with the lower end of costs for these markets being USD 934/kWth, USD 726/kWth and USD 553/kWth , respectively, up to as much as from a low of USD 1234/kWth in Bulgaria, through to Norway, where the data from the support scheme have seen costs range from USD 1117/kWth up to USD 7356/kWth. Although little data through time are available, it appears that costs have fallen for ASHPs and GSHPs in Denmark, Finland, the Netherlands, Norway, and Poland. The robustness of this result is yet to be verified with more data." [1]

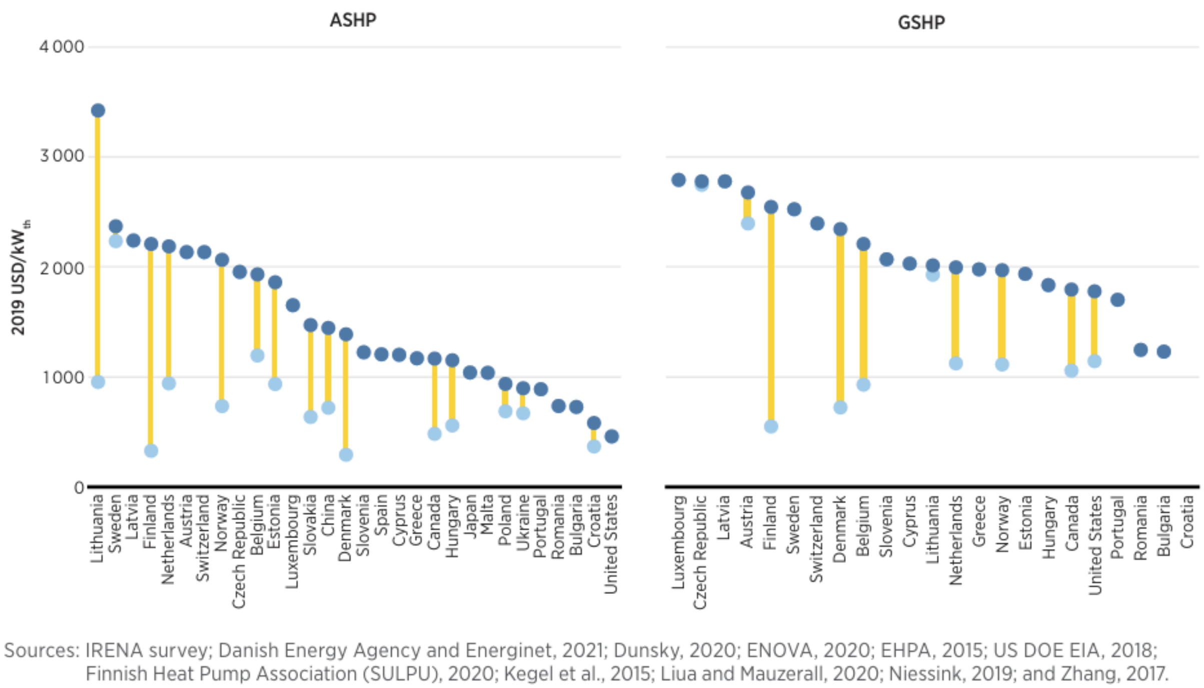
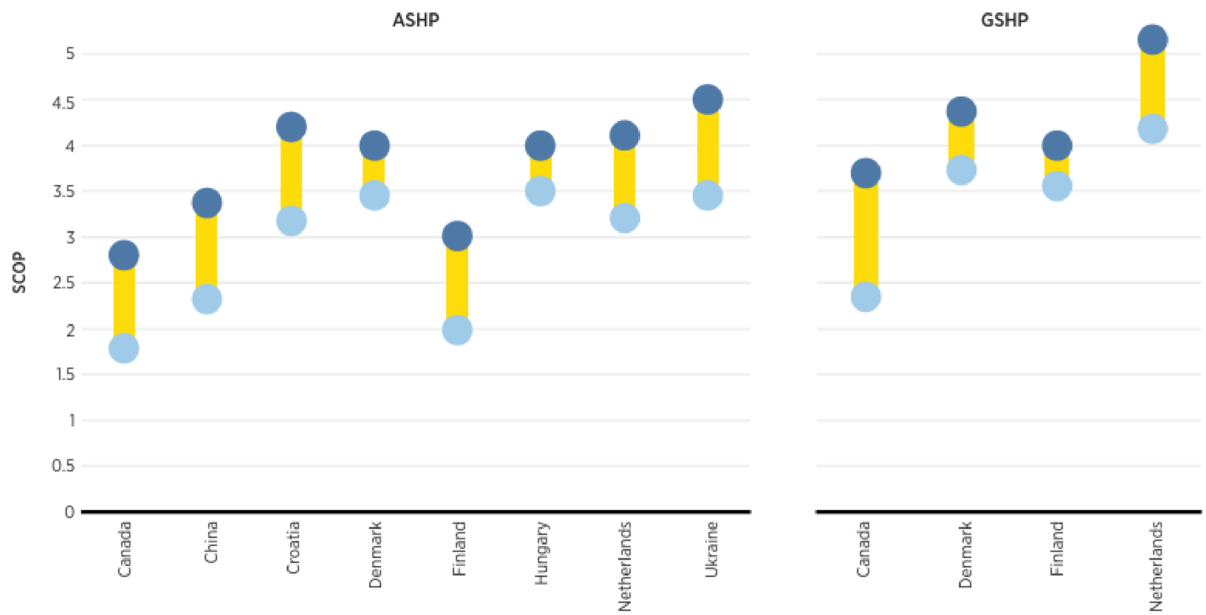


Figure 11. Heat pump system cost data range by technology for residential heat pumps by country

Figure 12. represents the countries for which a range of data for which seasonal coefficient of performance (abbreviated sCOP) is available (single point estimates excluded). Countries with milder climates achieve higher sCOPs, however, technology also plays a crucial role. On average, GHPs with access to a more stable heat source perform better than ASHPs, but with additional auxiliary loads, the benefit is not large. However, it is still noticeable and important to address. From the figure, we can see that the Netherlands had the biggest achievement regarding seasonal

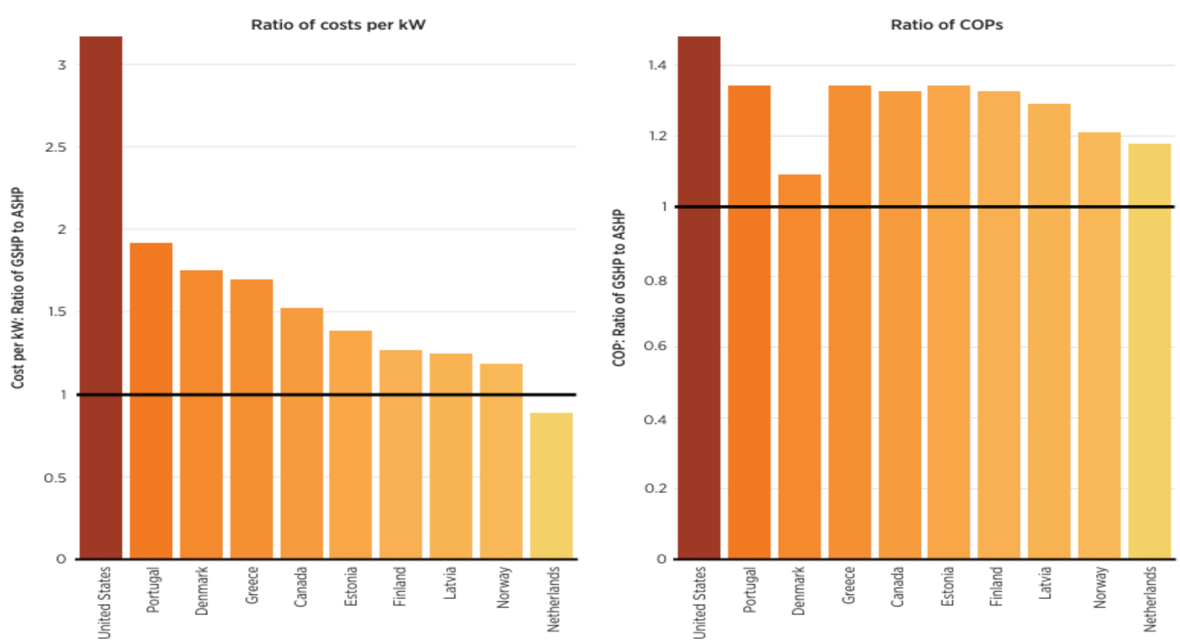
[1] IRENA (2022), *Renewable solutions in end-uses: Heat pump costs and markets*, International Renewable Energy Agency, Abu Dhabi.

coefficient of performance and if we compare it with the Netherlands' sCOP for ASHPs, there is a significant benefit of using the Geothermal heat pumps (2).



Sources: IRENA survey; Danish Energy Agency and Energinet, 2021; Dunsky, 2020; ENOVA, 2020; EHPA, 2015; US DOE EIA, 2018; Finnish Heat Pump Association (SULPU), 2020; Kegel et al., 2015; Liua and Mauzerall, 2020; Niessink, 2019; and Zhang, 2017.

Figure 12. Heat pump system sCOP ranges by technology and country for residential heat pumps



Sources: IRENA survey; Danish Energy Agency and Energinet, 2021; Dunsky, 2020; ENOVA, 2020; EHPA, 2015; US DOE EIA, 2018; Finnish Heat Pump Association (SULPU), 2020; Kegel et al., 2015; Liua and Mauzerall, 2020; Niessink, 2019; and Zhang, 2017.

Figure 13. Geothermal heat pumps costs and performance relative to Air-source heat pumps

Figure 13. shows the ratio of Geothermal heat pumps costs to Air-source heat pumps costs for individual markets and the ratio of the sCOP for the two systems. The United States is a clear outlier, given the very competitive costs of air-air central heat pump systems. What explains why GHP markets are usually smaller than ASHP markets is that the significant costs premium of Geothermal heat pumps over Air-source heat pumps and the relatively modest average increased sCOP. It is important to note that this doesn't tell the whole story because in cold climates, the performance improvement of GSHPs over ASHPs can be more pronounced than these representative ranges and avoid the need for back-up heat, particularly in buildings with poorer-performing building envelopes. (2)

THEORITICAL STUDY: The effect of different heat pump efficiency on electricity consumption

As per EGEC 2018 briefing, we got the following results which briefly explain how the heat pump technologies can have a huge impact on the electricity demand. The article states as follows:

The differences between heat pump technologies' efficiency can have huge impact on the electricity demand. The result of analysis of two scenarios for heat pump deployment: 20% Geothermal systems, 80% Ambient systems. 80% Geothermal systems, 20% Ambient systems. The assumptions include a COP of 3 for ambient systems, a COP of 4 for geothermal systems and the data on energy consumptions in the heating and cooling sector modeled by PRIMES in the current policy scenario. The results, listed in Figure 14., highlight the start difference in electricity needs compares to the current electricity demand and across scenarios.

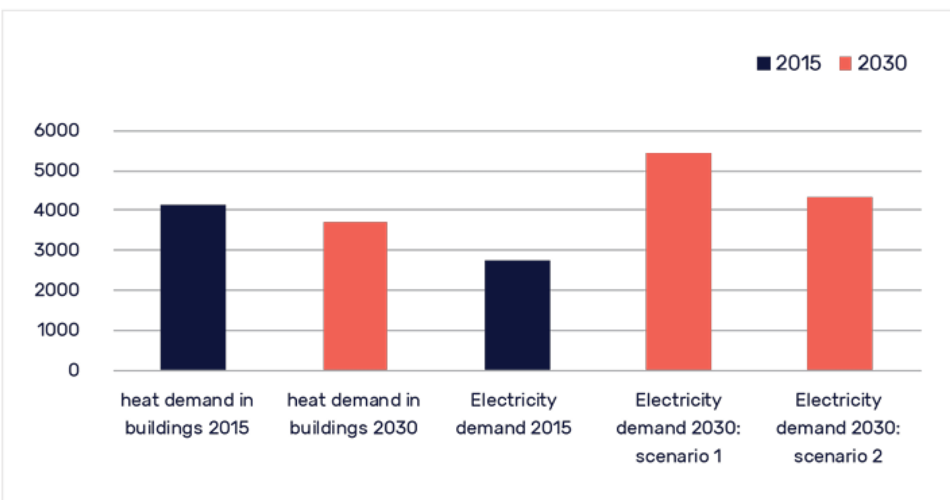


Figure 14. Electricity and H&C demand in TWh in 2015 and 2030, impact of Heat pump systems

Geothermal heat pump is so significant for decarbonization of heat and cooling consumption in the building sector, that that the development of GHPs can reduce the energy consumption by 50%, just by developing geothermal instead of air-source heat pumps. Decarbonizing the heating sector is one of the major challenges of the European Union. The objective is to completely replace the use of fossil fuels in heating and cooling sectors, as it is the one of the major contributors of CO_2

emissions nowadays. Geothermal heat pumps, as are heat pumps in general, are expected to use green, renewable sources of electricity. However, the most effective way to supply heat is to gain it from heat. The reason for this is the 2nd law of thermodynamics since there are no additional conversions of energy. [(4)]

However, as heat pumps still require electricity for work, it is important to develop them to have as high efficiency as possible and to obtain electricity from renewable sources. This combination is the optimum of today's technology.

Chapter 3: Geothermal Heat Pumps Markets

Overview

As per IRENA, more than 80 countries use geothermal energy for heating and cooling. 10 countries have at least 2 GWth of installed capacity, including GHPs (Figure 15.). China has the most installed capacity (40.6 GWth), followed by the United States (20.7 GWth), Germany (4.8 GWth), Türkiye (3.5 GWth), France (2.6 GWth), Japan (2.5 GWth), Iceland (2.4 GWth), Finland (2.3 GWth) and Switzerland (2.2 GWth). GHPs account for a large share of heating and cooling installed capacity in many of these countries (100% in Finland and Sweden, 99% in Switzerland, 98% in the United States, 92% in Germany, 78% in France and 65% in China). Other significant heating and cooling applications in leading countries include district heating in China, Iceland, and Türkiye; hot springs resorts (onsens) in Japan; and bathing in Türkiye. [2]

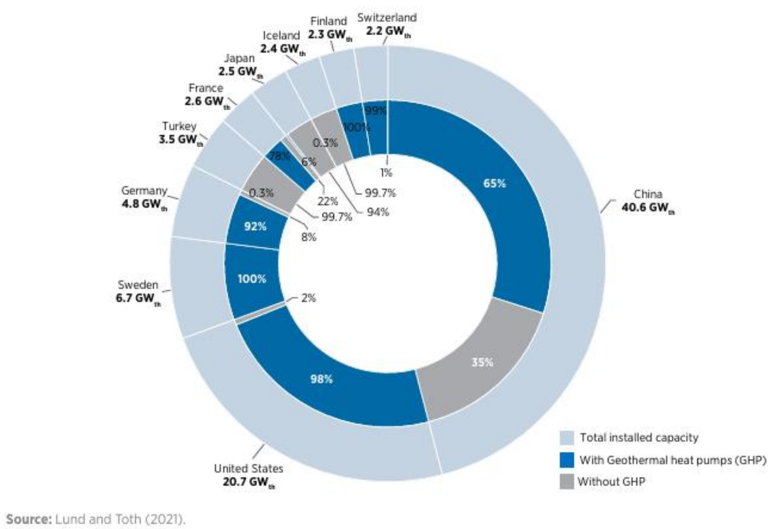


Figure 15. Top ten geothermal countries for heating and cooling, by installed thermal capacity in 2020.

Leading and Developing GHPs Markets

Geothermal heat pumps experienced record sales in 2022. In 2022, the market witnessed the largest ever volume of sales of Geothermal heat pumps. More than 141300 Geothermal heat pump systems were installed. Compared to the year 2021, which was also a record-breaking year, when 120900 systems were installed, the percentage growth was 17%. [3]

This fact stands as proof of the great potential GHPs have and the constant growth in the market. It is also important to note that the growth and sales could've been even higher if not for the

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[2] IRENA and IGA (2023), Global geothermal market and technology assessment, International Renewable Energy

[3] EGEC (2023), *EGEC Geothermal: Market Report 2022*, Brussels.

COVID outbreak in 2020 which significantly impacted the world's economy, including the heat pumps market.

To further substantiate this claim, the first trimester in Germany and Sweden in 2023 confirms the trend. It is yet to be seen the results for 2023.

Let's see a few interesting facts about the GHP market:

- 2.19 million geothermal heat pumps in Europe in 2022.
- Geothermal heat pumps provided 78TWh in 2022.
- Identification of regions with the highest prevalence of geothermal heat pump usage (regions with specific climates, etc.)

Figure 16. represents the comparison of GPH unit sales in 2021 and 2022, in European countries (Germany, Sweden, Netherlands, Finland, Switzerland and Poland). The sales growth was significant in these countries. Let's take Poland as an example. Despite having a relatively small market compared to other countries, Poland's GHP market experiences a significant growth and it is to expect for Poland to continually rise the GHP sales.

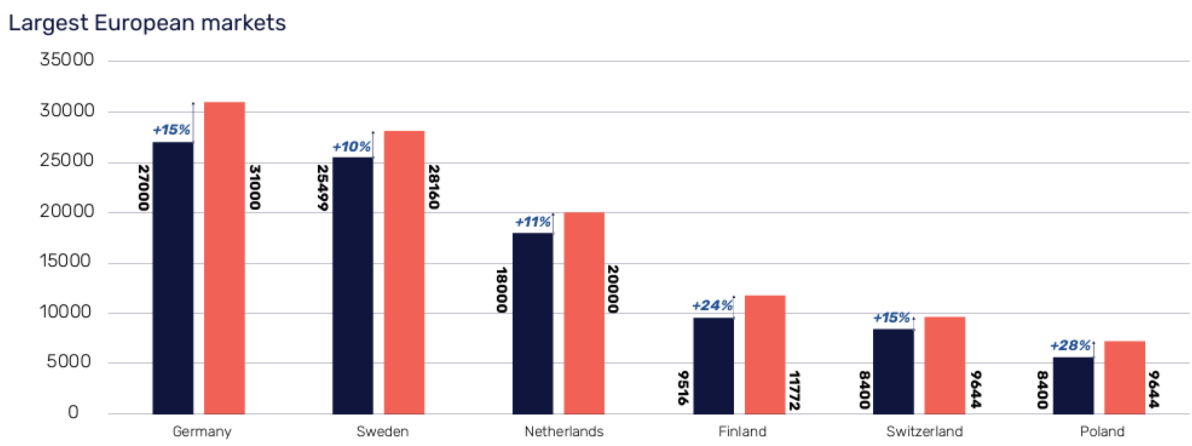

Figure 16. Sales of geothermal heat pumps in Europe (2021-2022) in selected countries, highlighting growth rate.

Figure 17. represents European GHP markets in development. Geothermal heat pumps, including large fields of boreholes and large open-loop systems, provided 78 TWh in 2022 from 35,6 GWth installed capacity. The total stock of geothermal heat pumps was 2,19 million units or 2,196,709 systems of which 2,196,100 had a capacity of 15 kWth; 600 units of large fields of boreholes with a capacity greater than 50 kWth and 200 large open-loop systems with a capacity greater 100 kWth) [4].

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[4] EGEC (2023), *EGEC Geothermal: Market Report 2022*, Brussels.

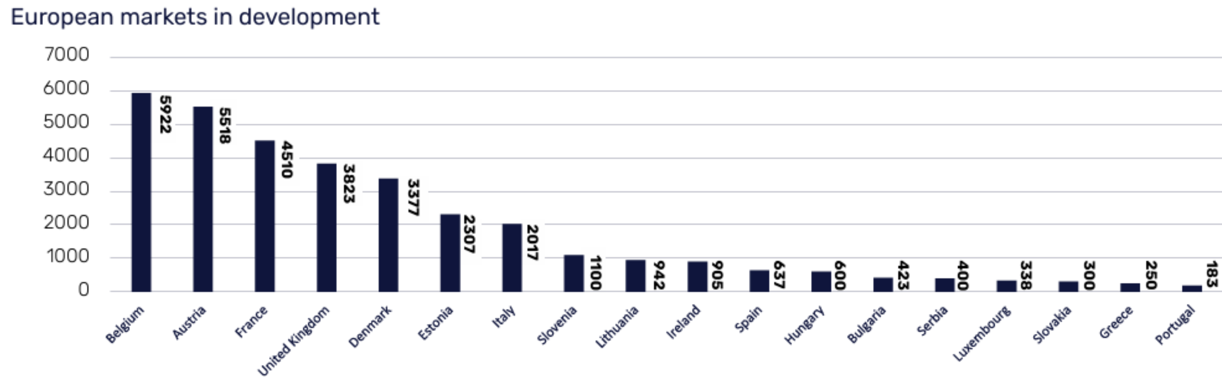


Figure 17. European GHP markets in development

The future for geothermal, particularly geothermal heat pumps, looks bright. The European Commission will launch a strategy on heat pumps in 2023 to help streamline regulations to meet its target of deploying 30,000 hydronic heat pumps by 2030.

Factor Affecting Geothermal Heat Pumps Adoption

When deciding whether it is an economically viable option to implement the installation of Geothermal heat pumps, it is important to consider several reasons. The most important GHP characteristic is its efficiency. The efficiency of an HP depends critically on the source of heat. During winter, the ground and external water sources usually remain warmer than the ambient air, which means that ground and water-source heat pumps consume less electricity that air-source heat pumps, which results in a higher COP. This particularly has a significant impact in cold climates, where defrosting outside components of air-source heat pumps requires addition energy and of course, costs. The disadvantage of geothermal heat pumps is that they are more expensive to install, since they require an underground heat exchanger, a deep vertical borehole or a large network of pipes buried at least one meter below the surface of the ground, depending on the type of geothermal heat pump installation used.

The latter is the main reason why ground-source heat pumps are generally less common than air-source heat pumps. Nowadays, almost 85% of all heat pumps sold for buildings worldwide are air-source[5]. The reason for this is that they require the least effort and costs to be installed. However, in heating-dominated regions, the air-to-water or so-called hydronic pumps are growing in prevalence. In fact, they are becoming so significant in Europe, more than in any other region, that they account for nearly half of all units sold. Although Geothermal heat pumps and hybrid heat pumps that combine a heat pump with another heating source, like a gas boiler, are a small portion of global sales today, however, they make up a substantial share of the market in some countries. For example, in Sweden, the leading market for ground-source heat pumps, every fourth house is equipped with such a model. The market for ground-source heat pumps is also growing steadily in the People's Republic of China (hereafter, "China"), where they often replace coal based heating systems, helping to reduce carbon dioxide (CO_2) emissions and improve air quality [(3)].

[5] IEA (2022), *The Future of Heat Pumps*, International Energy Agency, Paris.

Chapter 4: Future Potential & Challenges

Overview

IEA states that Geothermal heat pumps, as well as Heat pumps in general are a central technology in reducing emissions from space and water heating in the buildings sector. Globally, over 100 million households use heat pumps as a main heating source, meaning that one in ten homes that require substantial heating are served by heat pumps. As a result, heat pumps provide around 10% of the global heating needs in buildings. In the IEA's Net Zero Emissions by 2050 Scenario (NZE Scenario), this increases to 25% in 2030 and 55% in 2050. (8)

As per IEA, the heat pump market has seen a remarkable development during the last years. Global sales rose by 11% in 2022, driven by policy support and incentives amid high natural gas prices and efforts to reduce emissions. Europe experienced a record year, with sales increasing by nearly 40%, particularly for air-to-water models, which saw a 50% rise. In the United States, heat pump purchases surpassed gas furnaces in 2022, while sales in China, the largest heat pump market, remained stable, maintaining the largest overall sales worldwide.

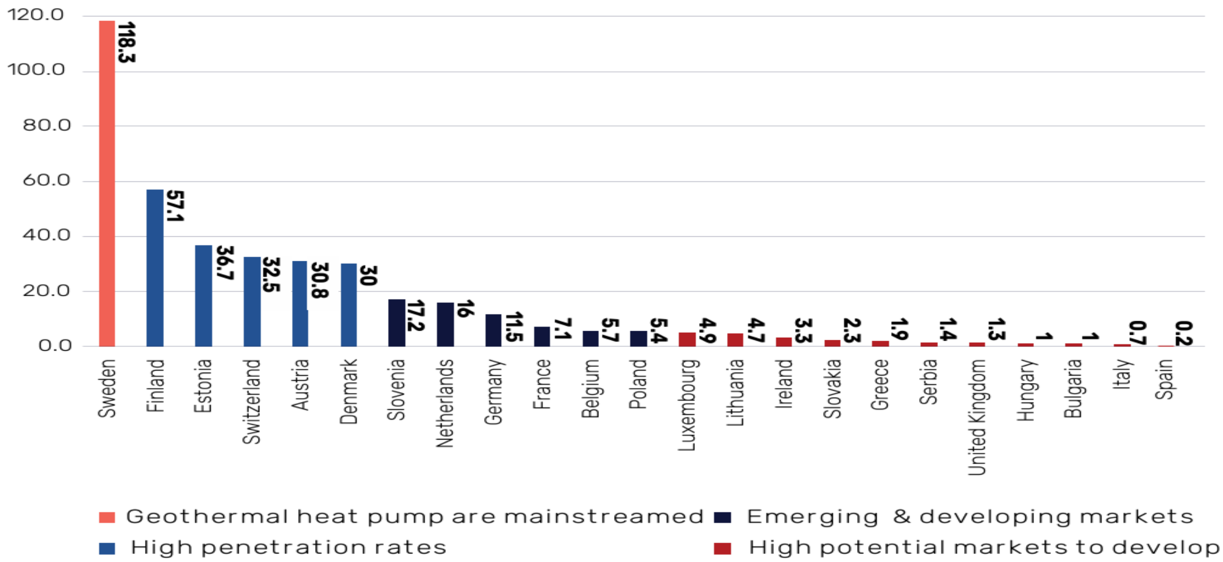
Heat pump sales have been boosted by financial incentives that are currently available in over 30 countries around the world. Collectively, these countries make up more than 70% of global heating demand for buildings. Many countries are also further strengthening existing incentives for heat pumps. In Canada, for example, a new program announced in October 2023 will make the average heat pump free by providing a grant up to almost USD 11000 in Atlantic provinces for households at or below median income. Several countries showed strong growth in the first half of 2023, with heat pump sales up 75% in Germany, the Netherlands and Sweden combined. However, heat pump sales are set to decrease in 2023 in several other countries, such as Italy, Finland, and Poland. As a result of the expected decline in sales in 2023 in some countries, the European Heat Pump Association has called for strong and consistent policies to provide certainty for investors and consumers and accelerate the residential energy transition. (7)

On the other hand, EPRS states that the announced heat pump action plan envisages at least 10 million additional heat pumps by 2027 and 30 million by 2030. The plan would encourage the use of small and large geothermal heat pumps in buildings, heating, and cooling systems, and in industry. (9)

Evaluation of the potential for further expansion of geothermal heat pump use in specific regions

To evaluate the potential for further expansion of geothermal heat pump use in specific regions, there are three trends to focus on.

- The first trend is growing national awareness to support geothermal including GHPs. Germany, Ireland, France, and Poland have shown the way through their national roadmaps.



- *Figure 18. Number of Geothermal heat pump systems per 1000 households*

- The second trend will be the impact on power systems. At present there is considerable hype around the electrification of heat. Whilst this is beneficial to geothermal heat pumps there is no differentiation between technologies, especially heat pumps. The moment this is done, we expect the full benefits of GHPs to finally come to the fore.
- The third trend is expected to be the rise of new business models. The current approach to driving GHP investment in residential and commercial buildings centers on a conventional approach to subsidies, tax rebates and other incentives to promote a transfer for new builds and refurbishments. This approach is unlikely to change. However, to better accommodate for the higher upfront capital costs for GHPs a combination of business models will be required for different stakeholders to shift the focus from niche investments to mainstream and mass deployment.

Technology Advancements

The possibility of heat pumps providing temperatures above 150°C has been shown in laboratory research - but they are not expected to be commercially available soon. High and very high temperature industrial heat pumps with large capacities are unique solutions in decarbonizing the energy demand in industry. Not only do they provide energy for heating, hot water, cooling, and dehumidification but they do this by closing energy cycles and thus reducing the need for requiring additional final energy.

The main obstacle for heat pumps in existing processes is the fact that steam is used most often for energy distribution, resulting in high temperature system designs. In smart system designs, heat pumps help to close energy cycles by using all output to a maximum, thus reducing heating/ cooling losses to a minimum. [3]

Discussion on the development of more efficient and cost-effective systems

During the past decades, Geothermal heat pump performance, as well as the heat pump performance in general have improved significantly in terms of efficiency and noise. As per *Swiss office of Energy (2020)*, COPs have increased by more than 70% since the early 1990s for air-to-water heat pumps in Switzerland. However, it is still important to focus on research and development of heat pumps. There is a lot of potential which can yield many smarter and more flexible features, like higher efficiency and reduced noise, more compact design, improved ease of installation etc. One of the most important things is to use materials and refrigerants which are environmentally friendly and don't affect living beings. The governments and researchers need to work together to get the best results possible. The IEA's Heat Pumping Technologies Technology Collaboration Program (HPT TCP) and the Innovation Community on Affordable Heating and Cooling of Buildings (a Mission Innovation initiative) are key forums for advancing RD&D collaboration on heat pumps. The HPT TCP is exploring potential improvements for system and resource efficiency by optimizing the use of heat pumps for both heating and cooling purposes, including in commercial applications with simultaneous needs. One aspect being looked at is the dual ability of a heat pump when operated in a very low-temperature thermal grid on a district or city level to be used as a heat sink and source simultaneously. Air conditioners result in large amounts of waste heat that could be recovered to produce domestic hot water in well-designed systems.

To further prove the point of the need of governments and experts to work together proves the fact that long-term RD&D efforts have made heat pumps a viable option even in cold climates. However, to efficiently apply the technology in very cold climates, the next generation of heat pumps will need to be more efficient over a larger temperature range. Progress is also needed in adapting heat pumps for the most difficult conditions for carrying out building retrofits, such as where insulation is tricky and where the heating system requires high temperatures. To achieve this, continuous research on component development and system design is necessary. The US Department of Energy recently launched the Residential Cold Climate Heat Pump Technology Challenge to accelerate the deployment of technologies in very cold climates (US DOE, 2022). Optimized heat pump solutions differentiated by climate needs could also bring down equipment costs. Stepping up research on technologies that are still far from market introduction is also needed to pave the way for leapfrogging in the development of more efficient and cost-effective heating solutions. They include non-traditional compression technologies for heat pumps such as solid-state (e.g. magnetocaloric, thermoelectric and elastocaloric) and gaseous (e.g. Brayton and Stirling cycles) ones. Early results for elastocaloric-based cooling systems are particularly promising. [(3)]

Integration of geothermal heat pumps with renewable energy sources

A promising bridge for the future of geothermal and heat pumps in general are the hybrid systems, which combine heat pumps technology with other technologies, like solar thermal, biomass, gas, oil, etc. Hybrid systems can leverage the advantages of their technologies. For example, during the largest part of a season, heat pump technology can efficiently provide heating and hot water while combustion is used to provide these services during very cold winter periods. If at a later stage the building envelope is refurbished, then a heat-pump only solution is feasible and preferable. (6)

Potential of geothermal heat pumps in achieving sustainable energy goals

Heating is a significant driver of global energy demand, both in buildings and in industry, and is an important component of energy expenditure for households, especially in colder climates. Many households use natural gas to warm their homes, provide hot water and to cook. However, high gas prices during the energy crisis - and significant policy action in response – have made the business case for electrification of heat more attractive, which is reflected in the sharp increase of residential heat pump sales in 2022. Several countries have implemented or announced plans for phaseouts of fossil fuel boilers, although these have sometimes proven controversial. Governments also introduced minimum energy performance standards requiring heat pumps to be installed. Given all these developments, the energy crisis may have accelerated the shift away from gas for residential space heating. Based on the most recent data, countries representing 50% of global residential gas consumption have seen their demand peak, stabilize or fall, while countries representing the other half are still experiencing demand growth. The IEA's Outlooks for gas markets and investment report estimates that gas demand in buildings is expected to decline by 65bcm in advanced economies from 2021 to 2030 thanks to a swift acceleration of efficiency improvements and widespread adoption of heat pumps. (7)

Challenges: What are the main reasons for the current lull in the market?

As per ReGeoCities, we can deduce a few main reasons for the current lull in the market:

1. Insufficient awareness about this technology and its advantages. Architects, the building sector, and local authorities need to be better informed.
2. High upfront investment is an issue. Because of the drilling, geothermal heat pumps can be considered as capital-intensive technology in comparison with other small-scale applications. The lifecycle analysis is not considered when comparing alternatives.
3. Quite unfavorable competition with gas. Geothermal heat technologies are heading for competitiveness, but support is still needed in certain cases, notably in emerging markets and where a level playing field does not exist. In addition, there is a need for an in-depth analysis of the heat sector, including about the best practices to promote geothermal heat, the synergies between energy efficiency and renewable heating and cooling, and barriers to competitiveness. As geothermal heat pumps can be considered a mature and competitive technology, a level playing field with fossil fuel heating systems will allow the phasing out of any subsidies for shallow geothermal in the heating sector.
4. Regulations need to be simplified further.
5. Bad publicity from problematic projects in Germany and recently in France and The Netherlands. (5)

Chapter 5: Conclusion

According to the International Energy Agency, Heating and Cooling accounts for more than 50% of the final energy consumption, however, this demand is currently being met using fossil fuels which has led to an unprecedented environmental consequence.

Geothermal heat pumps, also known as Ground-Source Heat Pumps (GHP), are positioned as a crucial technology for the decarbonization of space and water heating in buildings. Their high efficiency and ability to provide heating and cooling make them a promising solution for reducing carbon emissions, particularly in the buildings sector. Considering their potential and advantages, constant development and implementation of geothermal heat pumps will lead to meeting goals of Paris Agreement more quickly. Apart from their good environmental impact and high efficiency, there is also the social aspect of development of geothermal heat pumps.

Application of Geothermal Heat Pumps is a solution to provide heating and hot water to residential buildings, including small, single-family houses and multi-family residential buildings. In addition to residential and commercial building applications, it can also be employed to supply the process heating requirements in industry at diverse temperature ranges. However, the high-temperature applications of heat pumps are still under development stage and are subject of laboratory testing. It is important to note that the potential is great, and countries should invest in the development of this type of heat pump.

Despite their environmental, economic and efficiency advantages, the adoption of geothermal heat pumps has always remained dependent on geographical location of the country. For instance, largest geothermal heat pumps markets are usually those countries that have cold climates through the year such as Sweden, Finland & Germany, etc., while those with relatively hotter climates are more suitable for air-source heat pumps. However, prospects for geothermal heats pumps are getting better as they are subject to an ever-growing market.

In conclusion, it is still important to focus on research and development of geothermal heat pumps. There is a lot of potential which can yield many smarter and more flexible features, like higher efficiency and reduced noise, more compact design, improved ease of installation etc. One of the most important things is to use materials and refrigerants which are environmentally friendly and don’t affect living beings. The governments and researchers need to work together to resolve the following challenges related to geothermal heat pumps: insufficient awareness, high upfront cost investment, unfavorable competition with gas, regulations, and bad publicity.

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