ENERGETIKA. 2023
T. 69. Nr. 1. P. 49–64

ISSN 0235-7208 eISSN 1822-8836
DOI: https://doi.org/10.6001/energetika.2023.69.1.4

Analysis of the Wider Potential for Heat Pump and Geothermal Energy Integration in Traditional Systems and Grids

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The current energy security crisis is primarily a heating crisis. Space and water heating accounts for almost one-third of the EU's final energy consumption, and unfortunately, around 62% of this demand is still met by fossil fuels. In this context, heat pumps, geothermal energy, and other renewable energy sources emerge as crucial technologies offering effective solutions to enhance energy efficiency and decrease dependence on fossil fuels as well as to achieve the EU energy and climate goals.

This article focuses on the analysis of the potential and opportunities of using heat pumps and geothermal energy in conventional heating systems and district heating networks. This topic requires an in-depth analysis of the current state, challenges, benefits, and prospects of these technologies in the EU market. By examining the possibilities for wider adoption and discussing the associated factors, the article aims to provide valuable insights into and recommendations for the advancement of heat pumps and geothermal energy in the EU, along with the presentation of some case studies in this field.

Keywords: renewable energy; heat pump; geothermal energy; district heating; district cooling

INTRODUCTION

Recent discussions on climate change mitigation and geopolitical developments necessitate new approaches for decarbonising the heating and cooling sector that covers almost half of final energy consumption in the EU and is heavily reliant on energy imports, primarily fossil fuels [1]. Furthermore, the COVID-19 pandemic and the geopolitical events since February 2022, with Russia's war against Ukraine, underscore the urgency of deploying local energy sources to enhance the resilience of the energy sector in terms of energy security and political autonomy.

Space and water heating constitute almost one-third of EU final energy consumption, and, unfortunately, around 62% of this demand is still met by fossil fuels [2]. In the EU, 85% of buildings were built before 2000, and among those, 75% have poor energy performance. However, even though about 75% of buildings in the EU are not energy-efficient, only 1% of them are renovated every year. This means that 85–95% of the building stock will still be functional in 2050. Additionally, the rate of new buildings in the EU is also low – between 1% and 3% per year [3, 4].

Different types of heat pumps (HP) and geothermal energy for both direct and indirect use have been well-known technologies for many years. However, they have not received sufficient attention compared to traditional energy sources that are cheap and easily accessible. On the other hand, the efficiency of HPs has increased in the last decade [5, 6], along with better large-scale HPs integration [7–9] and advancements in drilling and exploitation technologies for geothermal energy usage [4, 10, 11].

Several case studies have shown promising results in the transition from traditional heating systems to HPs and combining various renewable energy sources, including HPs, solar energy, common storage facilities, and similar synergies. These efforts aim to improve heating efficiency in both individual and district heating (DH) solutions [12–19].

New technologies, such as energy geostructures (a special type of ground heat exchanger installed within ground-contact structures like retaining walls, piles, tunnels, and other underground infrastructures) are emerging in the market and hold great promise. However, technical and non-technical obstacles still prevent their large-scale implementation [22–22].

It is evident that saving energy in buildings and reducing the demand for fossil fuels are crucial. However, for efficient use of most renewable energy sources, energy-efficient buildings are a must. It is well-known that HPs, solar thermal systems, etc. are more efficient in low-temperature heating systems. Changing the heating systems to lower temperatures is a simpler task when dealing with a single building or complex renovations. The challenge becomes more complex when dealing with large scale DH systems with different types of buildings and needs. In such cases, the integration of geothermal energy, HPs, or other low-temperature heat supply systems becomes more complicated [23].

This paper aims to review and analyse the opportunities and challenges, demonstrating the potential of medium- and large-scale HP technologies through the presentation of some case studies. Additionally, the utilisation of geothermal energy for the EU market is explored. The paper primarily focuses on third or fourth generation (3G or 4G) networks, with supply temperatures below 100°C and return temperatures below 60°C, as well as traditional heating systems with supply temperatures up to 80°C. Fifth generation (5G) networks and integration of geothermal cooling into district cooling (DC) networks are reviewed as well.

REVIEW OF DISTRICT HEATING SYSTEMS IN THE EU

The majority of DH systems in the EU were developed during the twentieth century, even though the first DH system at Chaudes-Aigues (France) dates to the fourteenth century. District heating and cooling (DHC) systems have undergone substantial evolution from the first generation DH (1 GDH), predominantly composed of steam-based systems supplied by coal-fired boilers with DH flow temperatures reaching up to 200°C, to the fourth generation DH (4 GDH). The 4 GDH is distinguished by extensive integration of local renewable energy sources and waste heating and cooling technologies, functioning at lower temperatures (DH flow below 60°C), and promoting increased interaction between consumers and producers within an intelligent local energy network [24].

The new fifth generation district heating and cooling (5 GDHC) network is based on the thermal energy exchange between buildings that have different needs, such as industrial, residential, office buildings, shopping malls, data centres, and electrical transformers. The great advantages of 5 GDHC, including integration of low-temperature sources, bi-directional operation, decentralised energy flows, and possible energy sharing, are analysed and described in a series of articles [25–29]. However, the practical implementation of 5 GDHC systems is still challenging. In most of the EU countries, the weighted average specific heat consumption exceeds the suitable 4 GDH threshold of 50 to 150 kWh/m^2/year, which varies depending on climate conditions and other factors. This impedes the reduction of the DH supply temperature and obstructs the development of advanced heating and cooling systems [24].

Today, DH networks in Europe are predominantly owned and operated by public entities. DH market situations in the EU countries vary significantly, especially in DHC deployment and energy mix. In the EU residential sector, the highest DH market shares are observed in the Nordic (around 50% in Sweden, 46% in Denmark, and 46% in Finland) and the Baltic countries (around 65% in Latvia, 62% in Estonia, and 57% in Lithuania). Conversely, several EU countries (including Belgium, Ireland, and Spain) have a DH market share below 1%. In the EU, DH production primarily originates from cogeneration plants (63%). Approximately two-thirds of the district heating supply is generated using fossil fuels, predominantly natural gas, while biomass, biofuels, and renewable waste that are the primary low-carbon fuels, account for around 27%. Remarkably, Nordic and Baltic countries, with a high share of district heating and cooling (DHC) in the heating and cooling sector, along with a significant proportion of low-carbon fuels in DHC, are currently leading in heating and cooling decarbonisation in Europe. They boast more than 45% renewable energy sources in the heating and cooling share [9, 24].

REVIEW OF GEOTHERMAL ENERGY AND HEAT PUMP MARKET IN THE EU

Although geothermal development in Europe has a history spanning over a century, the European market entered the fast-growing phase only in recent years and must triple by the end of the decade. The status of geothermal energy in Europe varies by region, depending on the geothermal technology that aligns with the available natural resources. The spectrum ranges from power generation using high enthalpy resources (observed in countries like Iceland, Italy, Greece, and Turkey) to the direct use of hydrothermal energy. Shallow geothermal energy is available universally and is predominantly harnessed through ground source heat pump (GSHP) installations [30–32].

As of the end of 2022, there were 395 operational geothermal heating and cooling systems, with 14 new systems becoming operational in that year. Within the EU, 261 systems are in operation, including 12 commissioned in 2022. This growth trend is expected to persist, with 316 projects currently under investigation. These projects have the potential to add over 700 MW of capacity to the existing 5608 MW. Additionally, 16 projects were in the initial drilling phase at the end of 2022, aiming to facilitate large-scale heating and cooling production. As of the end of 2022, geothermal heating and cooling systems were installed in 29 countries across Europe, with 21 of them the EU member states. This coverage is expected to increase to 34, with projects of the pipeline for Bosnia, Ireland, Latvia, Luxembourg, and Malta [33].

The year 2022 witnessed a record-setting period for GSHP, with more than 141300 systems installed. The positive trend is evident in the numbers of the first trimester of 2023, especially in Germany and Sweden, the leading countries in terms of GSHP sales in Europe [33].

In 2018, the European Commission launched the revised Renewable Energy Directive [34], which includes new targets for renewables in heating and cooling. The directive calls for better integration of heating with the power grid and additional support to replace fossil fuel boilers. The Commission is also preparing the EU action plan to accelerate the deployment of HPs [35].

According to the European Heat Pump Association (EHPA), there were 19.79 million HPs primarily used for heating and cooling to around 16% of Europe's residential and commercial buildings, replacing around 4 billion cubic meters of natural gas. HP sales grew by 38.9% in 2022 to reach 3 million units, of which around 2.5 million were air source HPs. This attributed to lower investment and easier installation compared to other types of HPs. The strongest relative gains were achieved in Belgium (+118%), Poland (+112%), and the Czech Republic (+106%) [36].

According to the POTENCIA model of the Joint Research Centre (JRC), the number of individual HPs primarily used for heating in the EU (13 million in 2020) is planned to grow 2.5-fold by 2030 and almost 10-fold by 2050. The HP capacity is expected to double by 2050, aligning with the ambition of the REPowerEU plan to install 30 million or more HPs by 2030 [35].

DH might be the favoured heating solution in densely populated urban areas where large HPs can harvest energy from geothermal and solar sources or excess heat from industrial or urban processes. The Heat Roadmap Europe project estimates a potential 50% market share for DH by 2050, which approximately covers up to 38% of all DH production in the EU [35]. In the Baltic countries, the baseline scenario shows that in 2050, 54% of heat will be generated by large HPs and 33% by biomass boilers and CHPs [9].

The technical potential for industrial HPs (maximum sink temperature of 200°C) varies by sector, from around 65% of process heat in the paper industry to 40% in the food industry and 25% in the chemical industry [35]. The potential of cumulative heating capacity of industrial HPs in the EU is very promising at 23.0 GW, consisting of 4174 HP units which can cover 641 PJ/a of the process heat demand [37].

CASE STUDIES

Klaipėda Geothermal Plant

The research on geothermal energy in Lithuania began more than 30 years ago. It revealed the high energy potential of the geothermal anomaly at the greater depths in Western Lithuania. In comparison to the background geothermal field intensity of 40–50 mW/m^2, the intensity of the anomalous field in Western Lithuania measures 90–100 mW/m^2. Surveys conducted at the end of the twentieth century indicated that geothermal waters in the southwestern part of Lithuania are located at a depth of about 1200 m, with temperatures reaching approximately 50°C [38–40].

The construction of the geothermal plant in Klaipėda was launched in 1997, marking the inception of the first geothermal heating plant in the Baltic countries (Fig. 1). In the Klaipėda Geothermal Plant, circulation pumps were used to pump 38°C geothermal water through four wells from the Devonian layer at a depth of 1135 metres. Up to 700 m^3 of water could be obtained from the two wells per hour, but the ground only absorbed 450 m^3 of water. In summer, the plant supplied heat for approximately half of Klaipėda. In winter, it generated enough energy to supply about 10% of the city. The capacity of the geothermal plant ranged from 10 to 35 MW, with a geothermal loop flow rate varying between 160–210 m^3/h [39, 41, 42].

The commissioning of the geothermal plant lowered the workload of conventional boilers, reducing the burning of fossil fuels. While the geothermal plant served as a commendable example of utilising geothermal water for heating purposes, finding the most suitable management model for the company posed challenges in balancing the expansion of alternative energy sources against ensuring their economic viability. During the first years without price regulation, it was difficult for a loss-making company to repay its loans. The managers of the geothermal plant company proposed using part of the pumped water for other purposes, including medical treatment, fish breeding, road irrigation, and heating of swimming pools [5].

Operation of the geothermal plant was suspended in 2017, primarily due to high liabilities. Additionally, the cost of energy production using traditional sources such as biomass and waste heat dropped. Investors had been sought to lease the heating plant, but having failed to do so the company was declared bankrupt in early 2019 [40]. Currently, the geothermal plant is in

Fig. 1. Klaipėda Geothermal Plant

the state of conservation and is not monitored. It is unclear what the cost of relaunching the operation of the geothermal plant would be [5].

Since 2022, the company Klaipėdos Energija has had a working connection to the Klaipėda Geothermal Plant and is currently conducting active R&D as well as investment planning for the future of the DH network in Klaipėda. The aim is to achieve 90% renewable energy production by 2030 in accordance to the national and EU development strategy.

The Klaipėdos Energija is therefore actively seeking partners to work on possible solutions for the grid, in particular for the renewal of the existing geothermal plant or considering a new one.

Hybrid Heat Pump System of Kaunas University of Technology

In 2019, Kaunas University of Technology (KTU), Lithuania, installed a hybrid solar, ground, and waste heat energy system that supplies electricity for cooling the server premises and thermal energy for heating the university building (Fig. 2). The system combines a solar power plant, an underground energy storage tank, and HPs. The solar power plant is installed on the flat roofs of the buildings, maintaining a 25° inclination angle and using a metal frame and concrete ballast to avoid damaging the waterproofing properties of the roof covering. The underground energy storage facility is constructed using non-thermally insulated monolithic reinforced concrete structures (wall thickness 20 cm), the storage facility is fully buried at a depth of 1 m with the storage tank bottom elevation of 3.4 m. The heat exchanger of the storage facility consists of plastic piping with total length of 2640 m, which is connected to the data centre cooling/building heating system chain in series. The HPs are installed in the basement of the heated building adjacent to the existing building heat point to have the shortest possible thermal paths between the different heat sources and thus to obtain the most efficient management of the heat supply system.

As the system has a strong seasonality, a full year cycle is evaluated to determine its efficiency. The summer season produces maximum solar electricity generation, maximum energy use for cooling of the server room, a large amount of waste heat which is stored in the underground sensible heat storage tank and in the surrounding soil, but there is no need for heating the building. The efficiency of summer is positively influenced by the fact that the cooling the server rooms by directing the excess thermal energy to the underground storage is much more efficient than using a traditional steam compression cycle, and even more efficient than using free-cooling. During the autumn season, solar electricity generation decreases, the electricity demand for cooling the server room decreases, the amount of waste heat decreases, and the demand for thermal energy for heating the buildings increases. In autumn, the waste heat energy stored in the storage and in the soil surrounding the storage is used, which is also still supplied by the server room cooling system. During the winter season, minimal electricity is generated, with minimal electricity needs for server cooling, but with increased electricity needs for HPs. In winter, the HPs operate as long as the thermal energy stored in the storage medium is available and the temperature of the storage tank medium (water) does not drop below 1°C. During the spring season, the heating needs of the building decrease, there is no energy left in the energy store, the cooling needs of the server room (and thus the amount of waste heat) are not significant. The principal scheme of the system energy flows is shown in Fig. 2. In most cases, though, these flows do not all occur simultaneously and in the same volume but are activated depending on the environment, the needs of the engineering systems, and the circumstances of their settings.

The building is heated by an old heating system with cast iron radiators. However, the building is renovated (by an insulating building

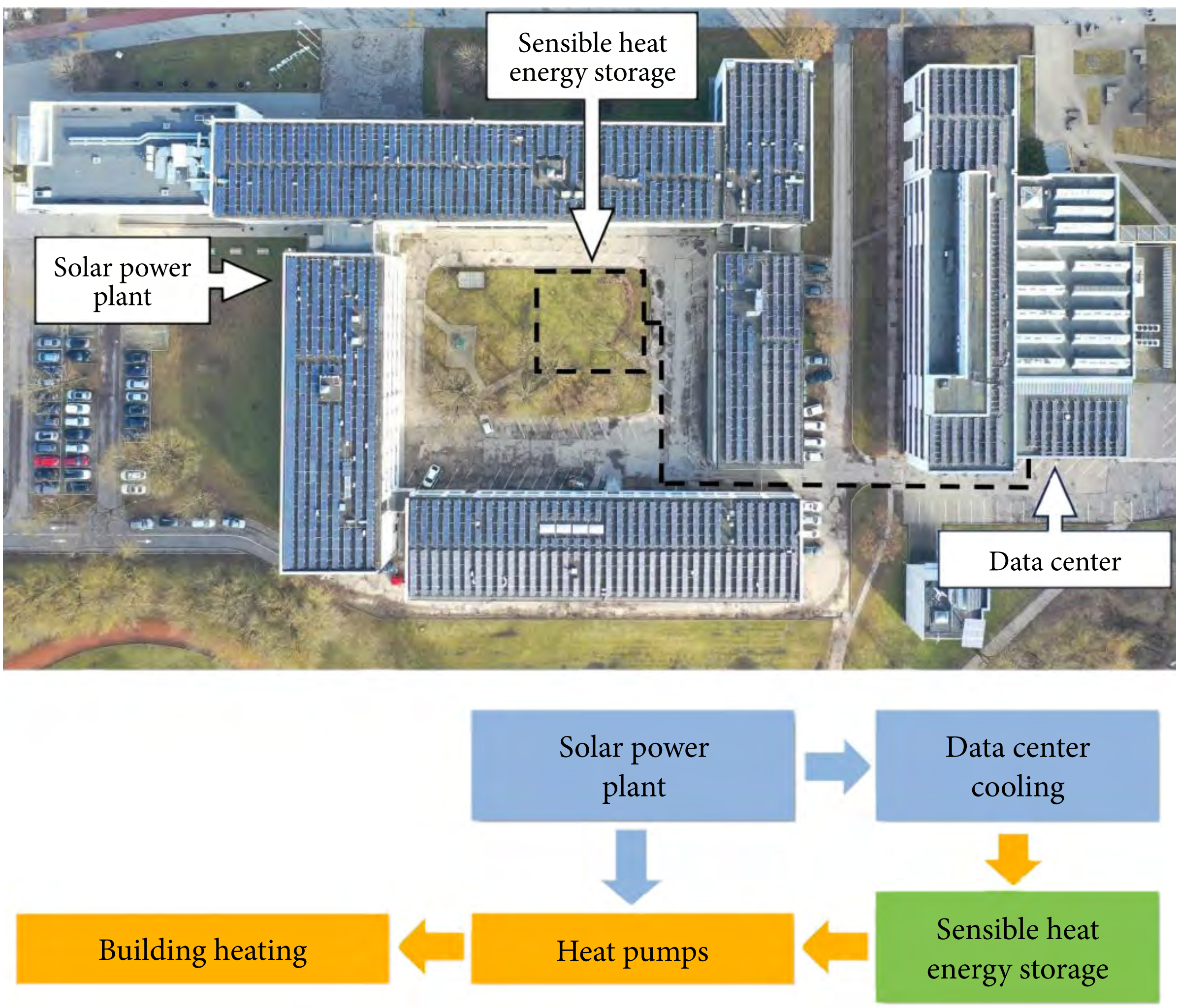

Fig. 2. The schematic diagram of the energy flows of the hybrid renewable energy system with sensible thermal energy storage (KTU case) (yellow arrows – thermal energy flows, blue arrows – electrical energy flows)

envelope), the temperature of the heat carrier does not exceed 55°C and is fully compatible with optimal working regimes of HPs. The building is still connected to the DH network of the city and the heat energy supplied by the DH network is used at times when the hybrid system becomes energetically or operationally inefficient or impossible to operate. The aim of operating this hybrid system is not to freeze the underground energy storage, although there are other practices for operating similar storage systems where the water in the energy storage is partially frozen.

Table 1. **Technical parameters of the KTU hybrid HP system**

Solar power plant capacity	300 kW
HPs capacity	170 kW
Underground thermal energy storage capacity (13 × 13 × 3.4 m)	500 m^3

The installation of the underground thermal energy storage was one of the biggest challenges for the designers and contractors, as there were no projects of this type in Lithuania before. Considering the technological aspect of the construction work, it was decided to install a rectangular reinforced concrete tank (Fig. 3) instead of the initially planned round tank.

The installed hybrid system is also equipped with a monitoring system that is capable of monitoring various technical indicators: the amount of thermal energy delivered to the building, the amount of thermal energy delivered from the HPs, the temperature of the coolant flowing from the server room cooling system to the storage tank, the temperature of the coolant flowing from the storage tank to the HPs, the temperature of water in the tank, etc. In addition, measurements of the soil temperature around the tank are planned to analyse the thermal energy storage potential of surrounding soil around the tank. Measurements of energy quantities over several years show that the installed system has led to a reduction in CO_2 emissions of around 440 t/year, as the building complex now needs to purchase an average of 1400 MWh of electricity and 460 MWh of heat per year from energy suppliers instead of the previous 1800 MWh of electricity and 1300 MWh of heat.

Lendava Town Geothermal District Heating System

The geothermal DH in Lendava, Slovenia has been in operation since the mid-1990s when a 1.5-km-deep production well Le-2g was drilled predominately in the regional and transboundary Upper Pannonian geothermal aquifer, producing thermal water of up to 66°C [43]. A 1.2-km-deep reinjection well Le-3g was drilled in 2007 and launched in 2009. The wells are vertical, and the distance between them is about 700 m. Produced thermal water is the Na-HCO_3 hydrogeochemical type Pleistocene rainwater and contains 1.1 g/l of total dissolved solids, including 31 mg/l silica, and low concentrations of calcium, magnesium, and chloride. The major scaling or corrosion processes are not observed [44]. Waste thermal water of approximately 45°C is injected back into the aquifer at a rate below 25 l/s and at

Fig. 3. Sensible thermal energy storage of a hybrid renewable energy system

the wellhead pressure of 2–4 bars. The injection is preceded by three-stage mechanical filtering of suspended solids; sand and two microfiber filters are used to remove particles of the diameter exceeding 10 μm. If the injection pressure increases, the flow through sand filters is reversed and the 20 μm and 10 μm microfiber filters are changed. Additionally, the well is cleaned once or twice per year. The 20-bar compressor reverses the flow direction and activates the well to produce thermal water (backwashing) [45].

The system's total installed heat power is 6.65 MWth and it is operated by the Petrol Geoterm Co. It provides heat for an area of 65,000 m^2, including 612 residential apartments, four public buildings (a health centre, a theatre, a primary and a secondary school with gyms), and three business buildings (a business and a shopping mall, a hotel).

The innovative part of this system is the use of high-temperature HP (>250 kW, COP > 7), developed within the EUREKA project. It uses the heat of waste geothermal water (40°C) to rise temperatures in the primary circuit plate heat exchangers. Natural gas boilers are traditionally used to provide additional heat in the secondary circuit at peak loads or at end-locations. In 2021, an upgrade of the system was made at a 600 m^2 cultural heritage building. Its insulation was not possible due to protection measures, and oil-boilers were used to heat it. As the library is at the endpoint of the DH network, another innovative solution was applied. Oil boilers were replaced by two 1000 L tanks filed with paraffin wax (i.e., phase change material PCM) balls [46]. The temperature is absorbed at 45/30°C, so energy is accumulated during the day and distributed overnight and in the morning.

The latest concession contract was signed for ten years in 2015. The DH system uses predominately geothermal heat, its annual heat consumption is approximately 5400 MWh. The total amount of heat sold in 2022 was 6192 MWh, 88% of it was geothermal heat and 12% heat from fossil fuels [47]. The DH network has a primary circuit that operates at 62–65°C and two bars with ± 3°C tolerance at consumer. Where floor heating is applied, the provided temperature is 50°C. The secondary circuit, in the worst case, can be expected only at 45°C. Energy efficiency reached 87% in the last five years, and periodical washing of heat exchangers is performed to keep efficiency high. Due to full capacity, the extent to new users is currently not possible [48].

Concession fee summed to approximately 8500 EUR, so the cost of geothermal production is negligible. Fixed costs represent 70% (amortisation of investment). The variable part covers electricity costs for operating the pumps etc. and natural gas supply. The heat price for consumers was constant from 2018 but increased in autumn 2023 due to the increased price of the variable part [47]. However, the system remains one of the most cost-effective DH systems in Slovenia, with the estimated price of about 91.9 EUR/MWh. The weighted average monthly heat price for household heating in November 2023 in Slovenia, including all contributions and VAT, was 142.74 EUR/MWh.

Integration of Heat Pumps into 5 GDHC Networks in Europe

With the development and the advancement of DHC networks into fourth and fifth generations (discussed above in the review of district heating systems in the EU), there is a clearly high potential of low-grade temperature sources available to be incorporated into. Such sources can be found in shallow geothermal elements.

Many cases related to DHC exist in the EU, with the incorporation of geothermal energy in the form of either shallow thermal or medium geothermal (direct use) applications. The available cases can be categorised into the 'retrofitting' or upgrading of the existing networks, new hybrid networks incorporating many sources [49], or geothermal only DHC networks. A specific European cost action project (Geothermal-DHC CA18219) addresses and promotes these cases where a web GIS tool has been developed to record as many cases as possible. More information about other European DHC network case studies that integrate geothermal energy can be accessed at [50]. Additionally, identification and classification of networks in different categories, including such sources as geothermal, of current 5 GDHC networks (Fig. 4) were recorded in the survey study [51]. Selected case studies of 5 GDHC networks that use multisource for both heating and cooling, as reported by Buffa et al. [51], are presented in the following Table 2.

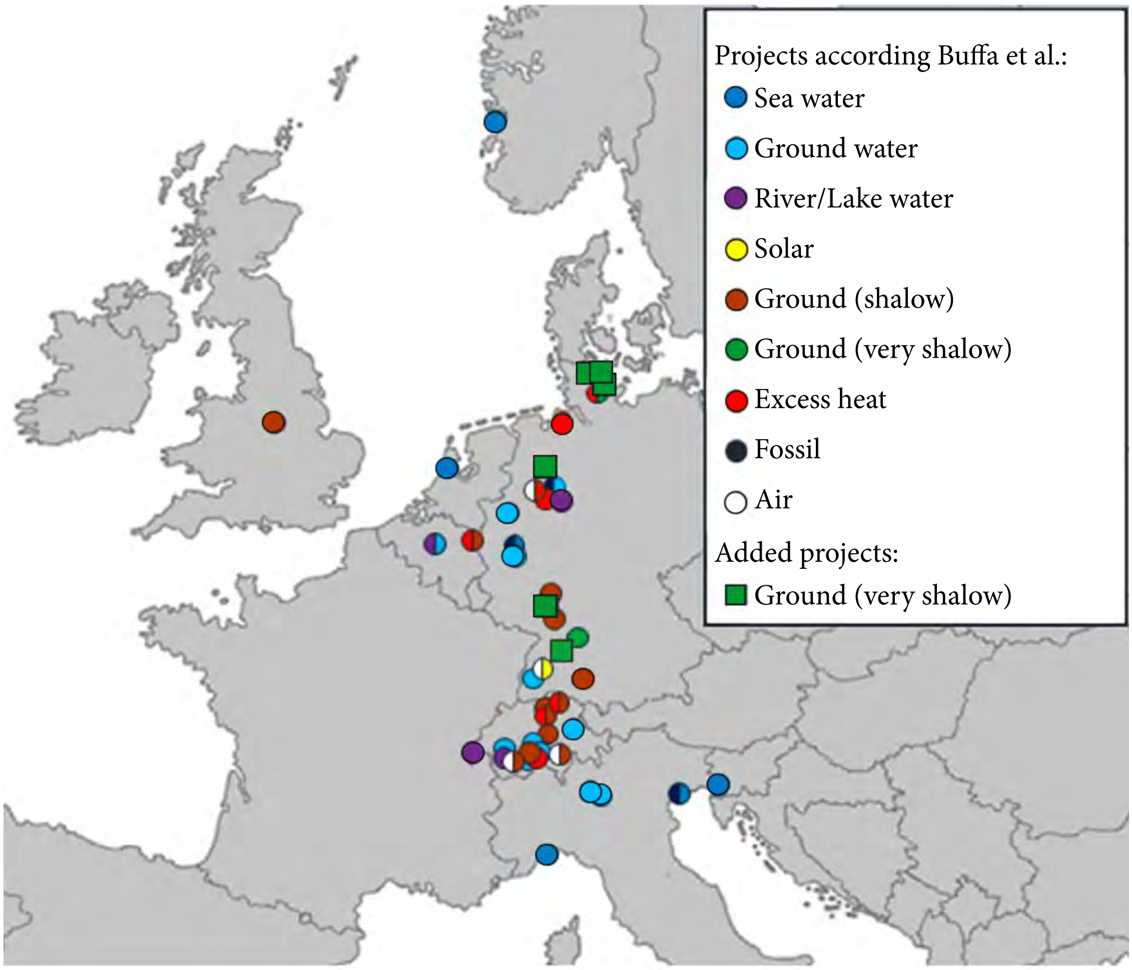

Fig. 4. 5 GDHC networks in Europe, as reported by [51] and presented by [58]

Table 2. **Selected 5 GDHC cases that include geothermal energy as a source, selected and modified from [50] and [51]**

Location/Country	**Since**	**Source(s)**	**T supply Min-Max (°C)**	**SCOP**	**Capacity (MW)**	**Network length (km)**
Oberwald/Obergoms, Switzerland [52, 53]	1994	Abandoned Tunnel (~Geo-Structure)	15–16	–	1.337 [kW]	2.2
Obstanger area, Herford, Germany	2000	Air & Vertical GHEs (19 boreholes × 100 m)	15–15	4.7	–	0.7
Nymøllevej, Nibe, Denmark	2002	Shallow/Ambient Geothermal 60–70% share (1 km horizontal)	–	–	Heating <1 Cooling 0.2	–
Genève-Lac-Nations, Switzerland [54]	2008	Ground Water (Lake/Surface Water)	5–17	2.5	2.9	6
Küferweg district, Mainz, Germany	2011	Vertical GHEs (4 boreholes × 300 m)	8–9	3.85	0.112	–
Wüstenrot, Germany [55]	2012	Horizontal GHE	5–15	4.45	0.32	–

Table 2. **(Continued)**

Location/Country	Since	Source(s)	T supply Min-Max (°C)	SCOP	Capacity (MW)	Network length (km)
Suurstoffi district-Risch Rotkreuz, Switzerland [56]	2012	Vertical GHEs (215 boreholes × 150 m + 180 boreholes × 280 m)	8–25	3.8	5.431	–
Koper, Slovenia	2012	Shallow/Ambient Geothermal 90% share (Depth range 32–40)	8–55	–	Heating <1 Cooling 0.2–1.0	–
ETH Campus Hönggerberg, Zürich, Switzerland	2013	Vertical GHEs (431 boreholes × 200 m)	8–24	5.8	5.5	1.5
Familienheimgenossenschaft District, Zürich (FGZ), Switzerland [57]	2014	Excess heat & Vertical GHEs (332 boreholes × 250 m)	8–28	4.1	3.93	1.5
Hochvogelstraße area, Biberach, Germany	2016	Vertical GHE (34 Boreholes × 200 m)	0–20	–	–	–
Sohnius-Weide district, Nümbrecht, Germany	2017	Solar & Horizontal GHE	4–21	4.23	–	0.45
Max-Ernst-Straße area, Schifferstadt, Germany	2017	Vertical GHE (28 boreholes × 100 m)	12–12	–	0.23	–
Rendebjergvænget – Tune, Denmark	2021	Shallow/Ambient Geothermal	<20	–	<1	–

Integration of Geothermal Cooling into District Cooling Networks

Although cooling demand (cooling loads) are conventionally higher in southern Europe, in recent years there has been an increasing demand for cooling from central to even northern Europe as an evident effect of climate change. As noted by IEA [59], cooling demand presents the fastest growing use of energy in dwellings in the share of global electricity demand growth to 2050. There is a recorded increase in space cooling by approximately 4% per year globally, and with the 5% increase from 2021 to 2022. Kranzl et al. [60] determined that by 2050, the proportion of energy consumed for cooling purposes in both residential and non-residential buildings might range from 8% to 9%, a significant increase from the 2% recorded in 2012.

The need for cooling in the southern countries of the EU will experience the highest increase in the future. The Mediterranean countries (Greece, Italy, Portugal, and Spain) could potentially have the highest share (estimated at 71%) for the residential sector energy depend over the total average annual energy use in the Europe [61]. In the cases where higher or close to the recorded high temperatures or concurrent days with high temperatures close to the record high are noted, , there will be theoretically a higher demand from the electricity grid, with a potential risks of power outage.

The integration of HPs, with the use of 5 GDHC networks, offers the benefit of reversibility. The HPs integrated in the network could operate for both heating and cooling applications, which is an advantage over conventional (up to 3G) DHC networks. Although this is associated with high performance values (higher than heating mode for HPs), it comes with potential challenges. One major challenge is the current infrastructure of most dwellings in Europe, where the HVAC (Heating, Ventilation, and Air Conditioning) system of dwellings used to be – and some currently are – developed with heating in mind. This impacts the selection of the 'heat exchangers' where conventionally the standard radiators or under floor pipes are typically installed. For cooling applications however, these units would form condensation on the dwelling floor, making them impractical for cooling applications, and therefore different units, e.g., fan-coil units, are required to be installed.

Another major challenge associated with the high risk of condensation is insufficient insulation. It may cause the formation of condensation on pipes and can subsequently lead to water damage in the nearby elements/structure. Furthermore, this can be extended with the risk of water damage when connected to the network, where leaks originating from the connecting pipes may result in gradual yet substantial harm and therefore necessitate expensive repairs. In addition to the initial water damage, there may be subsequent complications such as mould growth, electrical issues, and structural damage, which further complicate and increase the costs of repairs. System pressure variations may prove to have a potential harmful effect on the connection of the HPs, where pressure needs to be regulated. Further information on the challenges, limitations, and best practices are available in the literature, for example [62].

Only few DC networks exists in Europe, but with the introduction of 5 GDHC networks, both heating and cooling can be provided by the same network. With the integration of DC, there is a potential of 'free cooling' sources, where this is achieved by using natural low temperature sources, such as lakes, seas, or similar. The free cooling method is the most efficient (with COP values of approximately 10 or higher) and economical [63, 64], but since it is constrained by environmental and geographical limitations, compression cooling is the conventionally used method.

To the authors' knowledge, there are no DC-only networks using only geothermal energy in the EU. Somewell-known DC networks using aquifers and/or seawater in the EU also deserve to be mentioned.

One example of existing DC network in Europe is the CLIMESPACE in Paris, France (Fraicheur de Paris), which is considered the first in Europe (since 1991). The network has a capacity of 269 MW, with more than 700 customers, and an 89 km network length under the streets of Paris. The network uses surface water from the Seine River via three plants, seven cooling tower plants, and four energy storage sites. The majority of the customers are office buildings with offices and retails, department stores, hotels, etc. Similarly, the DISTRICLIMA (Poble Nou district, Barcelona, Spain) followed the 22@ project DC networ which is expanded to a DHC network [65]. There are 41 buildings connected to the network, including 24 office buildings and hotels, 12 equipment buildings, and five residential buildings, with a total covered area of 390,000 m^2, approximately 10,000 users, and a length of 13 km. The cooling production comes from two power plants, the Forum Central and the Tanger Central, where the former has two absorption systems with a capacity of 4.5 MW each (indirectly refrigerated with sea water), two electric chillers with a capacity of 4 MW (indirectly refrigerated with seawater), two electric chillers with a capacity of 7 MW each (directly refrigerated with seawater), and one cold water storage tank of 5000 m^3. The latter, on the other hand, has two compression chillers at 6.7 MW each (second phase). The Milan Tecnocity (Milan, Italy) DC network is another example of urban DC [66]. The network has a cooling capacity of 17.5 MW, uses absorption chillers and electric chillers, and its cooling network length is 11 km serves the area of 80,000 m^2. The heating network, however, is of a much larger scale, with a network length of 136 km and a heat production of 622 MW. Another example of a DC system in northern Europe, Norrenergi AB, is in Sweden and operates in Solna and Sundbyberg municipalities. Norrenergi AB utilises three production plants: the Sundbybergsverket in Sundbyberg, Frösundaverket in Frösunda, and Solnaverket in Solna Strand. The network provides heating and cooling to over 100,000 residents, including dwellings, offices, malls, data centres and hospitals. Renewable energy is used for both heating (99%) and cooling (100%) production. The production mix in these plants consists of three components: free cooling, compression chillers, and cold from HPs. Specifically, sea water (low temperature) is also incorporated in the production. The cooling network is approximately 37 km in length. Additionally, the Solna Strand production plant has a cold-water storage capacity of 6500 m^3 (equivalent to 10 MW). The entire nominal installed capacity of the DC system of Norrenergi AB is 73 MW, including the peak-shaving and load-shifting contributions from the existing 10 MW Cold Storage in Solna Strand facility.

DISCUSION AND CONCLUSIONS

This paper presents case studies from several countries and a broader European perspective, highlighting the crucial role that HP technology can play in transition to green energy. The slow uptake of HPs and their integration within district heating and cooling networks can be attributed to substantial initial costs, a general lack of awareness, and a range of technical and non-technical obstacles to implementation. The current DH sector in Europe still relies significantly on fossil fuels, and the building renovation speed is low.

The main barriers and challenges:

1. Technical and financial challenges, including the need for significant upfront investment in HPs and geothermal systems, and the adaptation of existing buildings and infrastructure to utilise these technologies efficiently. Early phases of exploration are of higher risk.

2. Regulatory and policy barriers, including inconsistent support and incentives across the member states, hinder the widespread adoption of renewable heating and cooling solutions.

3. Market and societal challenges, such as the lack of consumer awareness about the benefits of HPs and geothermal energy, and resistance from traditional energy industries.

Recommendations for wider implementation:

1. Strengthening EU-wide policies and regulations that encourage the adoption of renewable heating and cooling technologies, including financial incentives, subsidies, and favourable financing conditions for both new installations and renovations.

2. Increase investment in R & D to further improve efficiency and reduce the costs of HPs and geothermal systems. This includes advancements in drilling technologies, HP efficiency, and integrating renewable energy sources into existing infrastructures.

3. Implementing programmes to raise awareness among consumers, businesses, and local governments about the benefits and possibilities of using HPs and geothermal energy for heating and cooling, thereby increasing demand and acceptance.

4. Supporting the development of infrastructure necessary for the widespread use of HPs and geothermal energy, such as geothermal plants, and the retrofitting of buildings to be more energy-efficient and compatible with low-temperature heating systems. HPs are more efficient in renovated buildings and neighbourhoods.

5. Encouraging collaboration between public and private sectors and research institutions to share knowledge, best practices, and innovative solutions for the challenges of deploying HPs and geothermal energy on a large scale. In the EU, there is a clear market for HP manufacturers, designers, suppliers, and installers.

The utilisation of heat pumps and geothermal energy is anticipated to experience rapid growth in the coming decades. This is due to the abundance, ubiquity, versatility, low-carbon nature, and non-intermittent characteristics of this energy resource. The EU should utilise this potential to accelerate the transition towards a more sustainable, efficient, and secure heating and cooling sector, contributing to its goals of climate change mitigation, and enhancing energy security.

ACKNOWLEDGEMENTS

This article is based upon work from COST Action CA18219 – Research network for including geothermal technologies into decarbonised heating and cooling grids (Geothermal-DHC), supported by COST (European Cooperation in Science and Technology).

Received 22 December 2023
Accepted 5 March 2024

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ŠILUMOS SIURBLIŲ IR GEOTERMINĖS ENERGIJOS INTEGRAVIMO Į TRADICINES SISTEMAS IR TINKLUS DIDESNIO POTENCIALO ANALIZĖ

Santrauka

Esama energijos saugumo krizė pirmiausia yra šildymo krizė. Patalpų ir vandens šildymas sudaro beveik trečdalį Europos Sąjungos (ES) galutinės energijos poreikio, ir, deja, apie 62 % šio poreikio vis dar padengiama deginant iškastinį kurą. Šiame kontekste šilumos siurblių, geoterminės energijos ir kitų atsinaujinančių energijos išteklių panaudojimas yra esminės technologijos, galinčios padėti padidinti energijos naudojimo efektyvumą, sumažinti priklausomybę nuo iškastinio kuro bei pasiekti ES energijos taupymo ir klimato kaitos stabdymo tikslus.

Šiame straipsnyje daugiausia dėmesio skiriama šilumos siurblių ir geoterminės energijos potencialo ir galimybių analizei tradicinėse šildymo sistemose ir centralizuotuose šilumos tiekimo tinkluose. Nagrinėjant šią temą reikia detaliai analizuoti šių technologijų esamą būklę, iššūkius, naudą ir perspektyvas ES rinkoje. Straipsnio tikslas yra išnagrinėti galimybes plačiau naudoti šias technologijas ir aptarti su tuo susijusius veiksnius. Taip pat pateikti vertingų įžvalgų ir rekomendacijų šilumos siurblių ir geoterminės energijos plėtrai ES, kartu pristatant keletą šios srities atvejų analizių.

Raktažodžiai: energija iš atsinaujinančių energijos išteklių, šilumos siurblys, geoterminė energija, centralizuotas šilumos tiekimas, centralizuotas šalčio tiekimas