State-of-the-Art: Sweden

Ground Source De-Icing and Snow Melting Systems for Infrastructure

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“Ground Source De-Icing and Snow Melting Systems for Infrastructure”

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PREFACE

This State-of-the-art report is a work document compiled within the framework of the 2021-2024 IEA ES Task 38 “Ground Source De-Icing and Snow Melting Systems for Infrastructure”. The report is a summary of the Swedish state of the art concerning technology, applications and market for de-icing and snow melting systems.

The authors gratefully acknowledge the financial support for their work from the Swedish Energy Agency, Grant 51491-1, and from their employers.

This state-of-the art report deals with Swedish applications and conditions only. However, International overviews are found in the reference literature, e.g. Trafikverket 2014a, Johnsson 2019 and Person 2008.

The report covers a large field of technologies and applications and may not be easy to read. As a readers guide an overview of the report structure and contents is given below.

Chapter 1 points out general reasons and justifications for using de-icing systems and gives a short general overview of Swedish applications.

Chapter 2 deals with applications of electrical supplied de-icing systems and shall be looked upon as rough overview of this technology in order to find market spots for conversion to geothermal systems.

Chapter 3-4 deals with applications of hydronic de-icing systems supplied by district heating followed by a description of configurations and components.

Chapter 5-7 deals with the potential to use geothermal hydronic de-icing systems, the current applications, and experimental studies. The latter one includes parameter studies.

Chapter 8 deals with the basis for design of hydronic de-icing systems, including examples of different models being used.

Chapter 9 gives an overview of the main actors in the field of hydronic de-icing systems, in terms of main suppliers, users and owners.

Chapter 10 deals with information on how much thermal energy the existing hydronic de-icing systems are using.

Chapter 11 deals with economics related to investment and energy cost using district heating versus geothermal heat sources.

Chapter 12 deals with environmental and legal aspects, mainly in the form of differences using district heating versus geothermal heat sources, and laws/ legislations applied for geothermal drilling.

Chapter 13 gives an overview of laws and legislations applied for drilling of geothermal boreholes and wells.

Chapter 14, finally, is a short list of conclusions based on findings of this report. A more extensive summary is given below.

SUMMARY

To prevent from fall-related injuries and even fatalities among pedestrians several city centers are equipped with Hydronic Heated Pavement (HHP) systems, preferably on pedestrian streets and sidewalks. Apart from personal tragedy and human pain, the society cost for fall-related accidents is estimated to billions SEK annually. However, specific fall-related accident statistics are missing and should be a subject for more research.

The HHP systems in Sweden cover a total area of approximately 600 000 m^2 and are all using district heating (DH) as a heat source. The heat is typically supplied from the return pipe of DH systems that are connected to cogeneration plants.

Another large user of HHP systems is football fields with artificial turf. According to a survey by the Swedish Football Association (SvFF), approximately 8 % of these fields have HHP systems representing a heated surface area of some 500 000 m^2. The reason is to prevent injuries, but also for prolonging the playing season. The main heat source is also in these cases district heating.

Most of the plants appear to be sized for a power capacity of 250-350 W/m^2. The annual use of heat varies greatly depending on the winter climate, the type of application and the way in which they are operated. However, occasional data indicate an annual energy consumption of 300-350 kWh/m^2 for busy city applications and approximately 150-200 kWh/m^2 on average for football fields.

There is an unclear picture when it comes to the energy cost. However, the average market price for district heating in the year 2023 is about 950 SEK/MWh. This indicates an energy cost of 170-200 million SEK annually for HHP systems in busy city areas and some 70-95 million SEK for the heating of football fields.

There are only a few Swedish examples in which geothermal energy is used in HHP systems - a couple of football fields, one airport and one minor experimental road section. However, there are many commercial and institutional buildings that use geothermal systems for space heating and cooling, of which some also use HHP systems at entrances and ramps, etc.

The potential for using geothermal HHP systems is promising, even if it may mean an additional initial investment. The strength with geothermal systems lies in the low operating cost, and that geothermal heat is completely renewable.

Compared to systems heated by DH, a geothermal GSHP system is estimated to use 70-80% of renewable heat from the ground and 80-90% or more renewable heat from the ground when using Underground Thermal Energy Storage (UTES) systems. With environmental terms this means a drastic cut of the CO2 emissions, 85-95 %, compared to DH.

Major users of HHP systems are municipalities that usually also own the HHP systems but may share the investment and the operational cost with owners of properties next to the systems.

There are several suppliers of HHP system components on the Swedish market These commonly undertake the entire construction and installation of a HHP system, the system design included.

Parameters that affect the design of HHP systems are fairly well researched and manuals are available from both suppliers and a couple of municipalities. There are also several simulation models available.

For the construction of geothermal HHP systems there is a large capacity and solid knowledge and experience in the Swedish drilling industry. There is also an established engineering tradition associated with this industry in terms of sizing and design. As a matter of fact, shallow geothermal heat already contributes significantly to the Swedish supply of space heating (approximately 20 TWh annually).

Finally, it should be noted that there are also electrical surface heating systems (electric heating cables and mats) that have previously been widely used to keep paved areas free from snow and ice. An increasingly high electricity price and thus high operating cost have led to a gradual phasing out of these systems being. However, electric systems are used for railroad switches, and that may be a potential market for geothermal applications in Sweden.

Table of Contents

List of abbreviations

ATES	Aquifer Thermal Energy Storage
BHE	Borehole heat exchanger (includes the boreholes if grouted)
BTES	Borehole Thermal Energy Storage
COMSOL	A heat flow simulation model
CTES	Cavern Thermal Energy Storage
DH	District Heating
EHP	Electric Heated Pavement
EED	Earth Energy Designer (a simulation tool for boreholes)
GSHP	Ground Source Heat Pump
GWHE	Ground-Water Heat Extraction
GWHP	Groundwater Heat Pump
HEX	Heat Exchanger
HP	Heated Pavement
HHP	Hydronic Heated Pavement
HVAC	Heating, Ventilation and Air-Conditioning, internal system for heating and cooling in buildings
OCM	Overall Control and Monitoring
ORC	Outdoor Recreation Canters
PE	Polyethene (as in plastic pipes)
PTES	Pit Thermal Energy Storage
PEX	Cross-linked polyethylene (for hot water)
SCW	Standing Column Well
SFA	The Swedish Football Association
SPF	Seasonal Performance Factor
UTES	Underground Thermal Energy Storage

List of Figures and Tables

TABLES

1 Introduction

The basic function of Hydronic Heated Pavements (HHP) is to warm an outdoor surface to a temperature above freezing, allowing snow and ice to melt and drain away safely. That surface might be e.g. busy walkways, entrances of commercial or institutional buildings, pathway for bicycles, or streets for vehicles in the center of a city.

The number of fall-related deaths among pedestrians amounts to 100–300 per year. The number of injuries is not statistically known but can be estimated to be several thousand annually. Among pedestrians, approximately 25% of the falls lead to permanent harm in the form of at least 30% disability (Trafikverket 2012).

Most of the pedestrian falls occur in urban areas and in other areas with a lot of pedestrian traffic, most of which occur on sidewalks, pedestrian, and bicycle paths. The largest concentration of casualties occur in city centers, especially around the shopping streets (Ahnlund 2008; Adolfsson 2011).

Almost two out of three falls involving seriously injured pedestrians occur during the winter (December–March), i.e. twice as many pedestrians are seriously injured during these four months compared to the other eight months of the year (Wallqvist 2018).

The cost for society of these fall accidents can be counted in the billions of SEK, with the preventive measures only being in the order of millions of SEK (Trafikverket 2018 a). This is an economic aspect that has not yet received much attention.

To justify the HP applications Carlsson et al 2016 showed that fall accidents on pedestrian streets were 67-100 % lower for heated compared to unheated pedestrian streets in four cities placed in different climate zones in Sweden, Helsingborg in the south, Göteborg on the mid-west coast, Stockholm in the mid-east coast, and Umeå in the north (FIG 1).

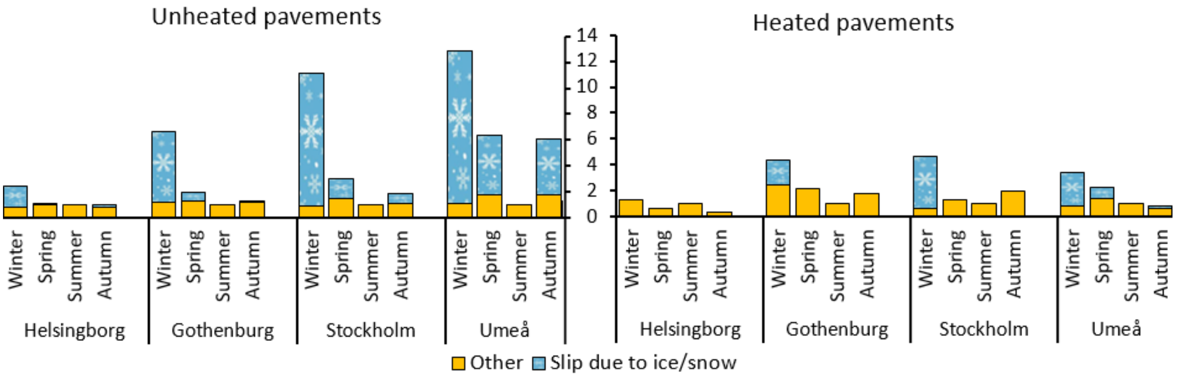


Figure 1: Number of pedestrian slip accidents in four cities with heated pedestrian streets compared to unheated (Carlsson et al 2016).

Less accidents may be the strongest factor for using HHP systems in busy inner cities and other busy places. Other advantages pointed out by Carlsson et al are:

- Increased comfort & safety
- Increased mobility & reduced insulation for vulnerable groups
- Simplified snow removal in "furnished" places
- Reduced wear and tear on sensitive materials in the substrate (marble)
- Reduced use of sand / salt = > Reduced wear in stores and escalators = > Reduced costs for cleaning, service & maintenance

In sports facilities, heating of football fields are the most common application. A strong reason in this case is to prevent the players from injuries caused by a frozen ground. However, a larger factor is to prolong the playing season to also cover most of the winter months.

As the benefits of surface heating are significant, the systems are expected to be commonly used also in the future. It is also expected that there will be an expansion in cities that are already users. An increased energy cost may restrain further market growth. However, the energy cost should be valued compared to the cost of injuries due to fall accidents

Public roads occasionally have curves, slopes and bridge decks that are prone to accidents under slippery conditions. These locations are normally located outside urban areas and are generally not available for conventional heat sources, such as district heating (DH). For this reason, geothermal applications are of special interest.

There are two basic commercial types of surface heating systems: electric (EHP), and hydronic (HHP). Electric systems use resistance wires or mats to generate heat, while hydronic systems use a fluid circulated through pipes.

Large EHP systems are nowadays rarely used in Sweden, and the ones still existing tend to be replaced by hydronic systems. However, there are smaller electric applications on roofs and for railway switches still in use. The latter ones are under technical development and there is an opportunity to combine these modern electric systems with geothermal hydronic solutions.

The existing HHP systems are practically all heated with district heat, supplied mainly from the return pipe. The potential to convert to geothermal solutions exists at many of these places, also in busy city environments.

2 Systems supplied by electric cables

The use of electricity for snow and ice melting was popular back in the time when the electricity price was much lower than today (FIG 2)

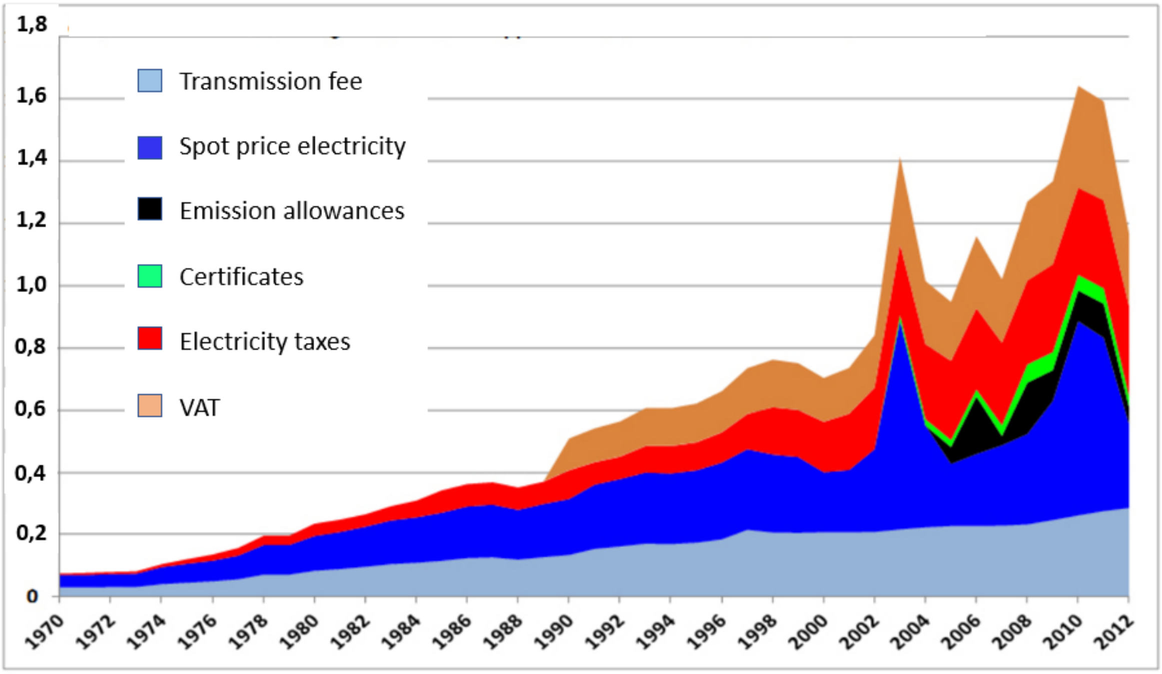


Figure 2. The historical price for electricity in Sweden, with different fees and taxes included. (Energiutskottet 2013)

Despite the high cost there are still specific EHP applications that cannot easily be replaced by hydronic systems. One such example is for snow melting on roofs.

Another special EHP application is for railway switches. However, in this case it seems to be a possibility to use a combination of hydronic and electric systems.

The low electricity prices in Sweden from the 70s up to the 90s made it economical favorable to install electric cables and mats for snow and ice melting.

Today EHP solutions are mainly used for parking lots, stairs, ramps, and similar surfaces, normally in a small scale. However, in former days there were also larger installations made for pedestrian streets and sidewalks in inner city environments, e.g. in Västerås and Stockholm. Due to the lack of statistics, it is unclear to what extent this was applied. Most of these larger systems have now been shut down or replaced by hydronic systems.

2.1 Components and design

An EHP system in general consists of two main components:

- Heating cable, mat or plate
- Thermostat with temperature sensor, or a regulator/controller with temperature and humidity sensors

The systems are intended primarily for installation in concrete structures, under stone plates, in asphalt, or even in sand.

Normally, the top layer of concrete or asphalt in an outdoor application is at least five centimeters thick.

Most cables and mats are manufactured as installation-ready heating elements with a fixed length from a few meters up to about 200 m as a maximum and with a connecting cable to the power supply (cold wire), as well as sealed joints (with sleeves or conductor termination).

The linear output power of heating cables intended for ground applications is usually 18–30 W/m. The cables are 5-9 mm in diameter, and the c-c distance is commonly 5-10 cm, where 10 cm represents a heating power of approx. 300 W/m^2.

Heating mats are available with the widths of 0,5 -1 m and an output power of around 300 W/m^2. Premanufactured mats can be bought in Swedish stores for coverage of 1 up to 20 m^2.

For detailed description of components, the design and installation of electric systems see Devi (2022).

2.2 Roof applications

At present, electrical cables and mats are still marketed for applications of smaller surfaces such as entrances to villas and for snow melting on roofs, so-called "roof heating". The latter application is mainly used for the purpose of reducing the snow load on the roofs, as well as to reduce the risk of injury due to falling lumps of snow or icicles.

Furthermore, water accumulation that remains on the roof due to plugging in the dewatering system often cause leaks and resulting water and moisture damage to the building. By installing heating cables in the roof's gutters, cornice gutters, gutter valleys, downpipes and other structural details, the risk of damage caused by frozen dewatering systems can be eliminated (FIG 3).

Figure 3. Electric cables are commonly used for snow and ice on roofs and roof dewatering systems (Photo: Värmekabel Stockholm AB 2023).

According to reference lists of a Swedish supplier of electric systems, roof heating is nowadays the dominating application for snow and ice melting application in urban areas (Värmekabelspecialisten 2022).

Larger EHP systems for snow and ice melting are rarely installed in Sweden today and, where they are used, they tend to be shut down or replaced by hydronic systems.

It is expected that the further market for EHP systems will mainly be left for roof heating applications and minor surfaces in which hydronic systems hardly are compatible.

2.3 Railway switches

In Sweden the dominating railway tracks, some 15 000 km in total length, are electrified. To avoid snow and ice problems with the switches, many of these have been equipped with electric heating. Out of about 12 300 switches, of which 7 000 are electrically heated (Bakgrund/Idé - Vertex Sweden AB). A typical railway switch under winter snow conditions is illustrated in FIG 4.

Figure 4. An electrically heated railway switch under winter conditions (SVT Nyheter 2019-02-09)

A conventional switch heater has electric heating cable loops along the entire length of the switchboard. Experiences have shown that these systems not always are capable to melt snow and ice at heavy weather conditions. Especially lumps of ice create problems. Hence, manual deicing has often been carried out.

In later years new systems have been developed that, according to the suppliers of these systems, are more effective. These are concentrated to sensitive parts of the switch system, the area between the rail and the moving tongue. In these systems plates are used for so called “point heating”. The plates have the power of some 100 W each and should prevent the snow from settling and forming ice. They are attached to the rail with springs (Vertex Sweden AB 2022).

The goal of Trafikverket is not to replace old cable heaters, but to supplement them with point heating from one or several suppliers. This will make it possible to turn on the cable heaters at zero degrees instead of plus 6-8 degrees as is common today. For the time being the point heating systems are tested at several places (Elinstallatören 2018).

The electric energy consumption for the total amount of switches is estimated to be 100-130 GWh per year (Vertex 2022)

Heating plates are as far as known only applied for railway switches in order to increase the melting capacity locally.

The concept of using geothermal systems for heating of switches has not yet been tried in Sweden. Regarding railway switches there may be a potential for replacing electric cable loops with hydronic systems and perhaps combine that with electric plates for point heating.

3 Systems supplied by district heating

Larger HHP system are mainly to be found in busy city areas and football fields with artificial turfs.

Most of the cities in Sweden have district heating (DH), thus, the needed heat for the HHP systems can be provided by a DH grid net.

The HHP system is normally fed by heat from the return pipe that commonly carries a temperature that fits well for melting purposes.

3.1 In busy city areas

Several cities with district heating use HHP systems in busy parts of the city centers. Typically, pedestrian streets, sidewalks, squares, parking lots and public transport stops use these systems.

The city of Västerås is the largest user by serving some 182 000 m^2 (2020). The first installation in Västerås was installed in 1964 and then expanded rapidly to reach 320 000 m^2 in 1985. In the late 1980s and in the 1990s, the municipality undertook saving measures when the price of energy increased. Large parts that were not co-financed by property owners were then shut off. The use of HHP has since then recovered in the last years and is still increasing. Currently, there are 11 substations for pavement heating in operating from October 15th to April 15th. All substations are connected to the district heating network, mostly to the return pipe. Some use the supply pipe, and some can be operated both ways. The ambition is to use the return heat as much as possible (Calderon 2020). Also, a few streets outside the actual city center are heated (FIG 5)

Figure 5: A few sidewalks and bicycle tracks outside the city center are heated in Västerås (Photo: Per G Norén).

The second largest user of snow melting systems is Stockholm with some 100 000 m^2 served, mainly on pedestrian streets, sidewalks, terminals, and squares.

Stockholm was an early user of HHP systems at Sergels Torg and nearby areas from the mid-1960s. It has since then expanded to the current size (FIG 6).

An example of a later user is the city of Lund that recently installed snow melting systems along a tram line in 2021. This system covers nine stops with platforms and a square at the tram station and was installed together with the tram track construction. The covered area is approximately 4 000 m^2. In Lund also the railroad station platforms are heated by another 1 000 m^2. The heat source is district heating connected to a cogeneration plant. The sources to the DH net also contain waste heat from the research facilities MAX IV and ESS as well as geothermal heat from a geothermal plant in Värpinge (Ottosson 2022).

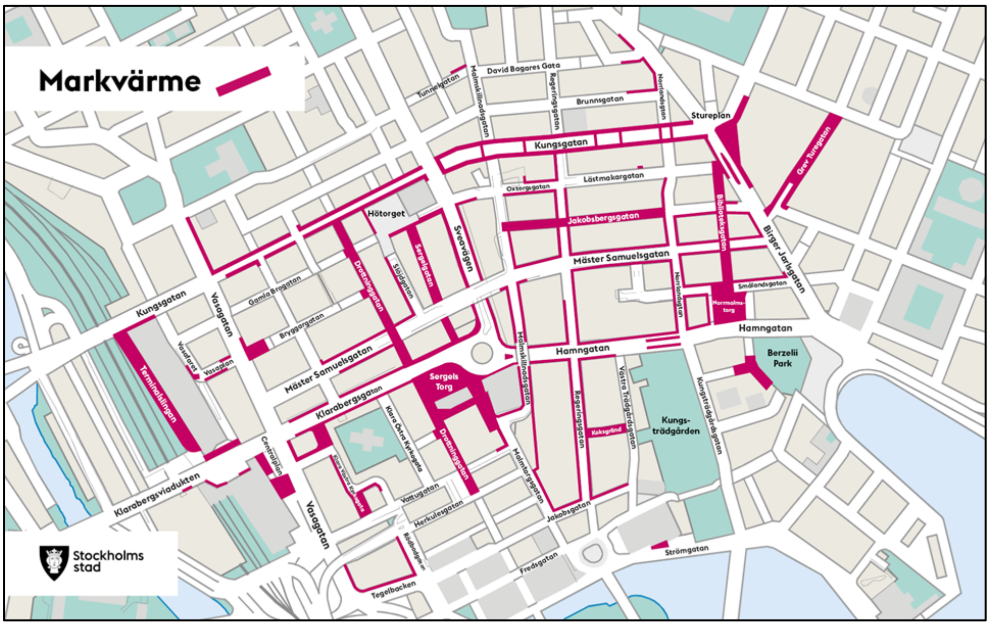


Figure 6: HHP systems in the central city of Stockholm (Snö och halka - Stockholms stad (trafik.stockholm)

Another example of a late starter is the city of Växjö. The first installation was at the central pedestrian street and has recently extended the heated surface with 8 500 m^2 outside the railway station (FIG 7). The heat source is a cogeneration plant that uses biomass combustion Nya stationsområdet får markvärme (veab.se)

Figure 7: The HHP system outside the railway station in Växjö (Photo: VEAB.se).

Other cities with snow melting systems larger than 3 000 m^2 in city centers, mainly on pedestrian streets, sidewalks, and squares, are shown in TABLE 1.

The table is originally derived from a survey performed at Chalmers university in Gothenburg, investigating how the systems prevent accidents caused by slippery conditions (Carlsson et al 2016). In this study some new users have been added based on information found on the internet or by mail correspondence. The systems are under expansion and smaller systems, not included in the table, are found in more cities. Hence, the heated surface in inner cities is currently estimated to be at least 600 000 m^2.

Table 1: Swedish cities with snow melting systems at 3 000 m^2 or more installed on busy inner-city environments obtained by different sources from 2016-2022.

Name of city	**Surface (m^2)**	**First installation**	**Source**
Boden	5 000	1997	Gustafsson/Hålsten 2006
Borås	38 000	Na	Carlsson et al 2016
Eskilstuna	11 000	1969	Carlsson et al 2016
Falun	8 500	2019	Thermotech/references
Gävle	50 000	Na	Sandanger 2022
Göteborg	32 000	1969	Rockström 2022
Helsingborg	*7 000*[1)]	2007	Carlsson et al 2016
Jönköping	4 500	2010	Carlsson et al 2016
Karlstad	*4 000*[1)]	1995	Carlsson et al 2016
Linköping	33 000	1970	Carlsson et al 2016
Lund	5 000	2020	Ottoson 2022
Malmö	*3 000*[1)]	2015	LK Systems reference
Mölndal	6 000	2019	Thermotech reference
Piteå	3 000	Na	Pite Energi 2019
Stockholm	100 000	1965	Carlsson et al 2016
Sundsvall	11 000	Na	Ossèen 2022
Södertälje	3 000	Na	Carlsson et al 2016
Umeå	22 500	1998	Carlsson et al 2016
Uppsala	41 000	Na	Eriksson 2022
Växjö	11 500	2018	VEAB 2021
Västerås	184 000	1964	Calderon 2020
Örebro	*3 500*[1)]	Na	Carlsson et al 2016
In total	**586 500**		

[1)] Estimated by using Global Earth surface calculator

All systems in Table 1 are using DH as heat source, normally from the return pipe. This is seen as an advantage when the heat is generated by a cogeneration plant, because of the lower return temperature to the plant.

The systems are usually automatically controlled by the surface temperature. In later years also weather forecasts are used for control. There are also many manually operated systems.

The systems are commonly owned and operated by the city municipally and the cost is often shared between the municipally and property owners around the HHP heated areas.

3.2 Suburb areas

In the outer urban environments, it is mainly entrances to commercial and institutional buildings that use HHP systems, mostly at entrances and sensitive ramps. Commonly these systems cover relatively small surfaces, estimated to be 100-300 m^2.

Example of users are shopping centers and hotels. In the industrial sector HHP systems may be found at e.g. loading decks. It is not known how common these systems are. These are typically supplied with heat from the internal HVAC system at the property, through a separate loop. Hence, the source of heat is the same as for the building, including geothermal systems such as ground source heat pumps (GSHP).

Airports are of particular interest for HHP systems. In Sweden, Stockholm Arlanda Airport has a geothermal HHP system installed at the gates covering some 75 000 m^2 (FIG 8). In this system waste heat from cooling of the terminal buildings is stored in an ATES system to be used as a heat source during winter, see further in chapter 5.2 and 6.1.

Figure 8: Snow melting at the gates at Stockholm Arlanda airport (Persson, 2007)

3.3 Sport facilities

There are many outdoor sport facilities in Sweden dominated by football fields of natural grass or artificial turf. It is mainly artificial turf fields that utilize snow melting systems (FIG 9). Although sports fields are admittedly not transporting infrastructure, design criteria for these systems are similar to those for de-icing systems for transport infrastructure, hence they provide useful information and experience of equipment, installation, operation, cost and energy loads for de-icing and snow-melting. Sports field applications also indicate an expanded market for HHP system with or without the ground as a heat source.

Figure 9: A football field with HHP system (Lappsport AB)

According to the Swedish Football Association there are approx. 1 100 fields with artificial turf, of which at least 80 are winter heated (SvFF 2023).

The field surface area varies between 6 000- 8 000 m^2 with elite arenas as the largest. Assuming that the average area is 7 000 m^2 the total heated football field area with artificial turf is then around 580 000 m^2.

An artificial turf is made up of several layers with granules at the top. The top layers are often wet and freezes to ice at sub-zero temperatures. This may cause accidents with resulting injuries for the players. For this reason, but also to prolong the play season there is an increasing interest for HHP heating of these fields.

Practically all heated football fields are using DH as heat source, preferably from the DH return pipe.

A few other HHP sports facility applications have been found, such as a water park, a few outdoor gyms, a facility for spontaneous sports, an ORC track, and courts for padel and tennis. These are all heated by DH, except for one that uses industrial waste heat (Sport och anläggningskonsult AB).

3.4 Roads and bridge decks

As an alternative to traditional salt and sand, HHP systems offer a promising solution, especially for bridge decks, steep slopes, and slip-sensitive curves (Trafikverket 2014a).

In Sweden there is so far only one installation in operation, "Göteborgsbacken" in Jönköping (FIG 10). This is a steep section of the road that was provided with a ground heated lane in 2007. In total, about 30 km of heating pipes were installed in the 1500 m slope. The heat source is DH return, and the experience is that the system has worked as intended (Trafikverket 2014b).

Figur:10: “Göteborgsbacken” prior to installation of the HHP system (Tidningen Energi 2020-03-19)

There is also a HHP test facility outside Östersund where the pipe system in the road acts as a solar collector during the summer and the heat is stored in boreholes in the rock (BTES) to be used during the winter (Johnsson 2019), see further in chapter 7.2.

In Umeå there is a 150 m long bridge deck with a slope of 7%. It was constructed in 2005 and the roadway has embedded heating pipes in the wear layer. The glycol-filled heating coils provide a heating power of 350 W/m² and the heating is controlled by temperature sensors in the pavement. The heat source is DH (Trafikverket 2014 b).

4 System configuration and components

An HHP system is not very different from other heat production and distribution systems.

Even the heating pipe systems can be compared with floor heating for buildings, but the outdoor systems are exposed to significantly greater thermal as well as physical loads.

The traditional HHP system lay-out has been developed by the district heating industry. In principle, the internal system lay-out and components are the same as for the sub-centrals of a district heating network. The out-door system with pipes and couplings, however, seems to have been developed by the companies that supply these types of components.

4.1 Lay-out

The basic lay-out is more or less the same for all applications but may differ in detail. One or several heating loops in parallel are placed beneath the heated surface. The loop consists of densely placed plastic pipe loops, in which the heat carrier is circulated using a circulation pump.

The source heat is commonly transferred to the ground heating loop through a heat exchanger. The heat source may be different as well as the size of each plant, but schematically as shown in FIG 11.

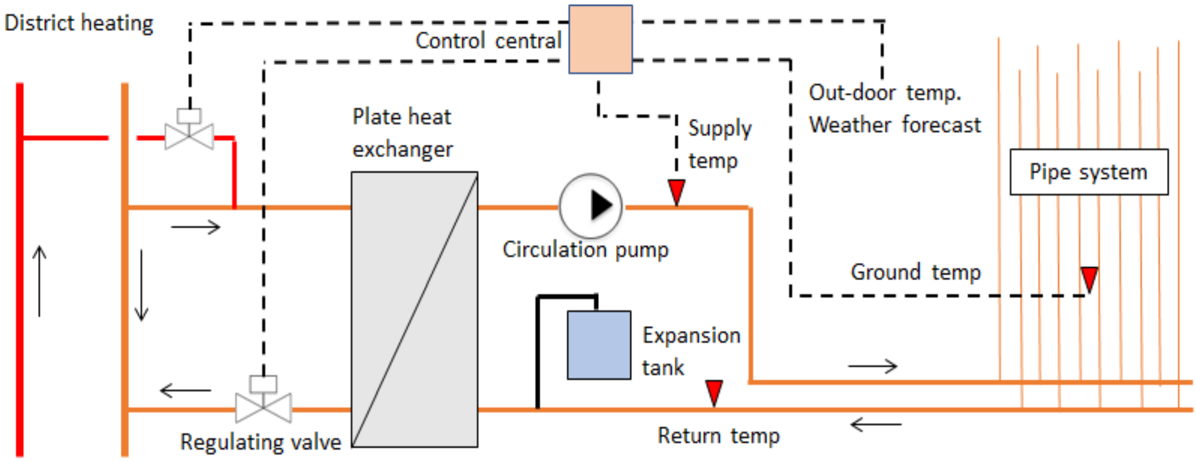


Figure 11: Basic concept layout for HHP systems supplied by district heating.

In order to melt snow quickly, these systems are recommended to allow for a heating power of 350 W/m^2 at a temperature of 35/20°C (Uponor 2020). In practice this is site specific and an item for analyzes for each place, with respect to several parameters and considerations.

4.2 Main components

4.2.1 Melting pipes and couplings

The pipe system for melting is commonly made of plastic piping, such as PEX or PE-RT that can withstand temperatures up to +40°C. These are also flexible enough to manage the required u-bends.

The size is commonly 20 or 25 mm with a wall thickness of 2 and 2,3 mm respectively.

The c/c-distance would typically be 200-250 mm and the depth below surface often 10-20 cm. However, if cast into a concrete bed an even smaller depth can be applied (FIG12)

Figure 12: Part of a surface with PEX pipes fixed to a mesh of rebar and ready to be cast into concrete (Uponor)

The length of each loop is recommended to be in the order of 200 m to limit the flow resistance. Furthermore, the lengths for each loop should be equal for an evenly spread of heat to the surface (LK Systems 2017).

If placed directly on the ground the pipes are kept at place by a guide as shown in FIG 13.

Figure 13: PE pipes placed directly on the ground and fixed by specially made guides (LK Systems)

The loops are connected in parallel to manifolds for supply and return of the system. These pipes (often HDPE) have a much larger diameter, depending on the total system flow rate from the loops connected in parallel (FIG 14).

Figure 14: Example of manifolds for flow distribution to many loops in parallel (LK Systems)

There are several types of couplings between the melting pipes and manifolds, mechanical or welded. In FIG 14 an example with electric welding sleeves is shown. This type of coupling may be the safest alternative when it comes to risk for leakage.

There are two types of mechanical couplings, with or without metals. The latter ones are used in the “Melt-a-way system” and consist of two clamping rings and a splice sleeve with prefabricated O-rings and cutting rings.

4.2.2 Indoor components

Except for conventional pipes and fittings, valves and sensors, the main components indoor are a heat exchanger (HEX), an expansion vessel (EV) and a heat carrier mixing and filling vessel (MFV). The types of heat exchangers used are illustrated in FIG 15.

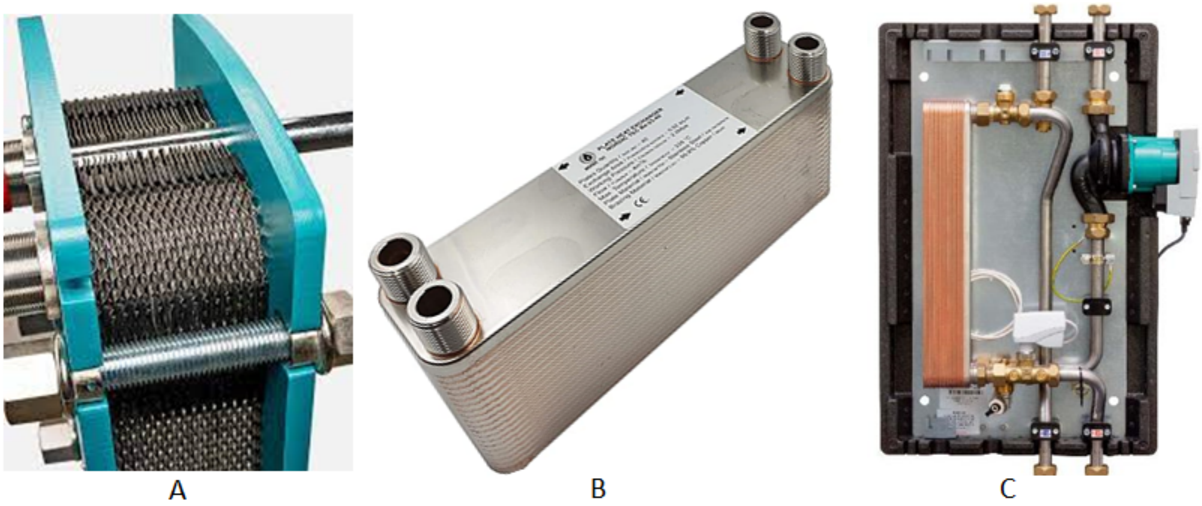


Figure 15: The types of plate heat exchangers used in the systems. (A) in large systems, (B) in medium large, and (C) in small systems

The HEX is commonly a plate type that is also most efficient. In the plate type the temperature drop at the heat exchange is relatively small, commonly just a few degrees. They are mainly made of stainless steel.

For large systems a type with a flexible number of plates is sometimes used (A in FIG 15). These can be inspected and cleaned, and plates can be added if required. However, the most common type is a

HEX with fixed plates (B). This type consists of a fixed number of plates that are welded together and cannot be inspected. In type (C), the HEX is built into a shunt, which can be directly connected to a snow melting system. This has been developed for small systems up to about 300 m^2 (Uponor 2020).

Expansion vessel (EV) is used to maintain a stable hydraulic overpressure in the system (FIG 16).

Figure 16: Examples of (left) an expansion vessel and (right) a mixing and refilling vessel.

It will also show if the system starts to leak. It is normally set at about 1 bar. A sudden drop of pressure would indicate a severe leakage. A minor but continuous pressure drop would indicate minor leaking conditions.

In systems that are using anti-freeze in the heat carrier (commonly glycol) a mixing- and filling vessel is needed (MFV), except when it has a pump connected to the main pipe (FIG 16 right).

4.3 Control

The key to successful operation of any mechanical system is the means to control it. In principle, a hydronic snow melting system uses the controls to turn on and off and to regulate the pumps, valves, etc.

The system is commonly turned on at a certain date in the late autumn and turned off at a certain date in the spring. This does not mean that the fluid is circulated throughout this period. Instead, circulation is turned on at a certain temperature in the ground, for instance when it sinks below +3°C, and turns off when the temperature increases above that set-point. This may for instance be the case for a football field aiming at just keeping the ground unfrozen.

Set points may be changed depending on the weather condition. Reasons for changing would be high snow fall intensity, wind speed and drastic change of air temperature. For this reason, these systems are often manually controlled, and operated according to expectations by weather forecasts.

A control board is used to operate the system, commonly placed in a technical room. The control board is typically a small box mounted on the wall. Since control boards are connected to essentially all electronic devices, they can take advantage of interfacing with overall control and monitoring system (OCM) using BAC net or Modbus. This allows for alert notifications, remote monitoring, and full adjustment capability to be carried out through the OCM.

The means for providing input to the control panel are to use automatic sensors that detect moisture and temperature. Commonly in-ground sensors are used to automatically monitor the pavement temperature. However, there are sensors that can also detect snow or ice on a driveway or walkway. In some cases, also aerial sensors are used, especially if the use of in-ground sensors is impractical.

Complete control systems for snow-melt systems are available by the major suppliers on the Swedish market, e.g. Uponor and LK-Systems.

5 Potential for geothermal systems

There are several geothermal systems that can potentially be used for snow- and ice melting. These systems are today commonly used for space heating and cooling. As a matter of fact some 20 TWh of heat and 1-2 TWh of cold is today generated from geothermal systems (Gehlin et al 2022)

The most promising geothermal systems HHP melting would be the ones designed for seasonal storage of heat in which solar heat is stored during the summer season and withdrawn during the winter season. These are named UTES (Underground Thermal Energy Storage) and are supported by heat pumps that will certainly be largely used for BTES and less for ATES applications (FIG 17).

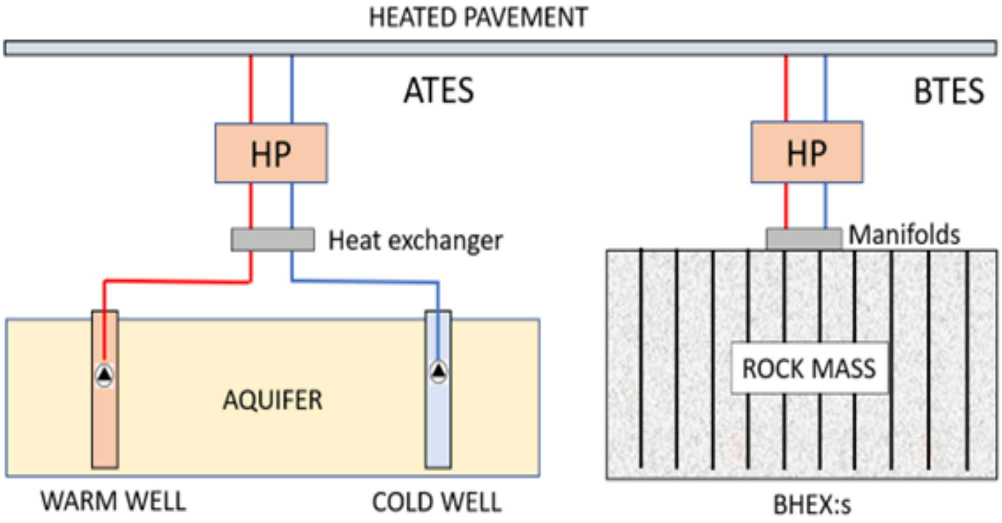


Figure 17: Swedish basic concepts of using UTES systems with heat pumps for HHP systems .

These systems will charge in summer by the use of the HHP system as a solar collector for seasonal storage of heat.

The geothermal systems will most certainly be favorable when it comes to the operational cost of snow- and ice melting and will also have less emissions of carbon dioxide and other environmental harmful gases and particles.

5.1 Geothermal system definitions

There are potentially several established shallow geothermal systems that could be used for HHP applications. These systems have been developed over a period of 50 years, and Sweden is one of the largest users of shallow geothermal energy in the world.

Shallow geothermal applications can be divided into “open loop” and “closed loop” systems. Open loop systems indicate that groundwater is used as a heat carrier, while closed loop systems circulate a fluid (brine) in a closed pipe system to extract heat from the ground. The systems with best potential for HHP applications and their abbreviations are shown in FIG 18.

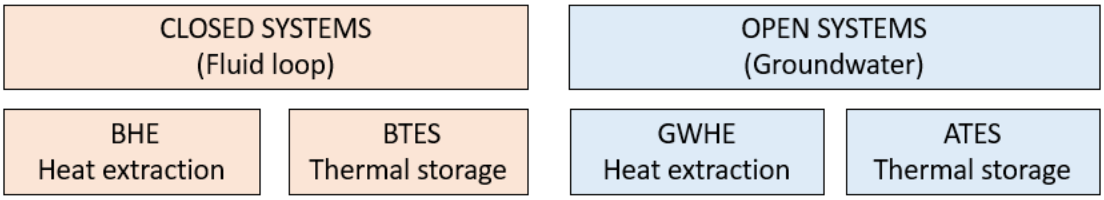


Figure 18: Shallow geothermal systems and their abbreviations.

For heat extraction the term GSHP (Ground Source Heat Pump) is commonly used since a heat pump is needed to make the heat from shallow geothermal sources useful. This term incorporates several other sources such as coil systems in the topsoil or on the bottom of lakes, dams, streams and bays (sometimes called surface water heat pump systems, SWHP). When groundwater is the heat source the term GWHP is sometimes used.

To distinguish shallow geothermal from heat extraction in deep boreholes and wells, the term Deep Geothermal is commonly used for the latter. From a drilling point of view the depth limit of shallow geothermal systems is approximately 600 m with conventional drill rigs.

BTES and ATES may store heat at a much higher temperature than in the common applications, in which case the abbreviation HT (High Temperature) is used as prefix to ATES and BTES, e.g. HT-BTES.

Heat storage may also take place in rock caverns, old mines, etc. In this case the term CTES (Cavern Thermal Energy Storage) is commonly used. In some countries also man-made pits are used as heat storage, referred to as PTES (Pit Thermal Energy Storage).

Finally, the term UTES (Underground Thermal Energy Storage) is used for all systems in which thermal energy is stored below the ground surface.

5.2 Closed loop systems

5.2.1 BHE

The abbreviation BHE (Borehole Heat Exchanger) denotes a borehole that is drilled in rock and fitted with a borehole heat exchanger, commonly a plastic U-pipe. If more than one borehole is used, these are connected in parallel by using a manifold. Supply and return pipes are connected to a central heat pump. Thermal energy is transported by a fluid with anti-freeze (typically water-ethanol of 20-27% concentration) that circulates through the entire pipe system.

The average BHE depth is today 200 m, with boreholes to a depth of 500 m occurring. The latter ones use DN50 U-pipes, while the common U-pipe size is DN40.

Extracted heat is naturally recharged with solar heat during the summer season. A minor contribution also comes from the geothermal heat flow.

In 2021, approx. 18,5 TWh of renewable geothermal heat was produced in Sweden. The vast majority of this energy is provided by BHE installations (Gehlin et al 2022).

Potentially also so called “energy piles”, i.e. foundation piles fitted with plastic pipes as heat exchangers, could be used as a heat source to heat pumps.

5.2.2 Standing column well

A Standing Column Well (SCW) system uses one or more groundwater filled boreholes to extract heat at larger depths and at higher temperatures compared to more shallow systems. These boreholes will typically be 400 m deep or more and use the geothermal gradient to exploit an elevated ground temperature.

The geothermal gradient in the Archean rock in Sweden is about 15-17°C/km and in the sedimentary rock in southern Sweden some 25-30°C (Rosberg and Erlström 2021)

There are several drill rigs on the Scandinavian drilling market that are capable of drilling to depths of at least 1500 m with the hammer drilling methods. At this depth the rock temperature would be around 25-30°C in the Archean rock. An insulated coaxial heat exchanger is preferably used to extract heat a higher temperature level or alternately at higher extraction rate per meter borehole (FIG 19).

Due to increasing flow resistance with depth, the coaxial pipe standing column may be a suitable solution already at more shallow depths.

Even though there are single experimental boreholes being drilled to some 1 000 m depth, the deep SCW technology is not commonly applied in Sweden.

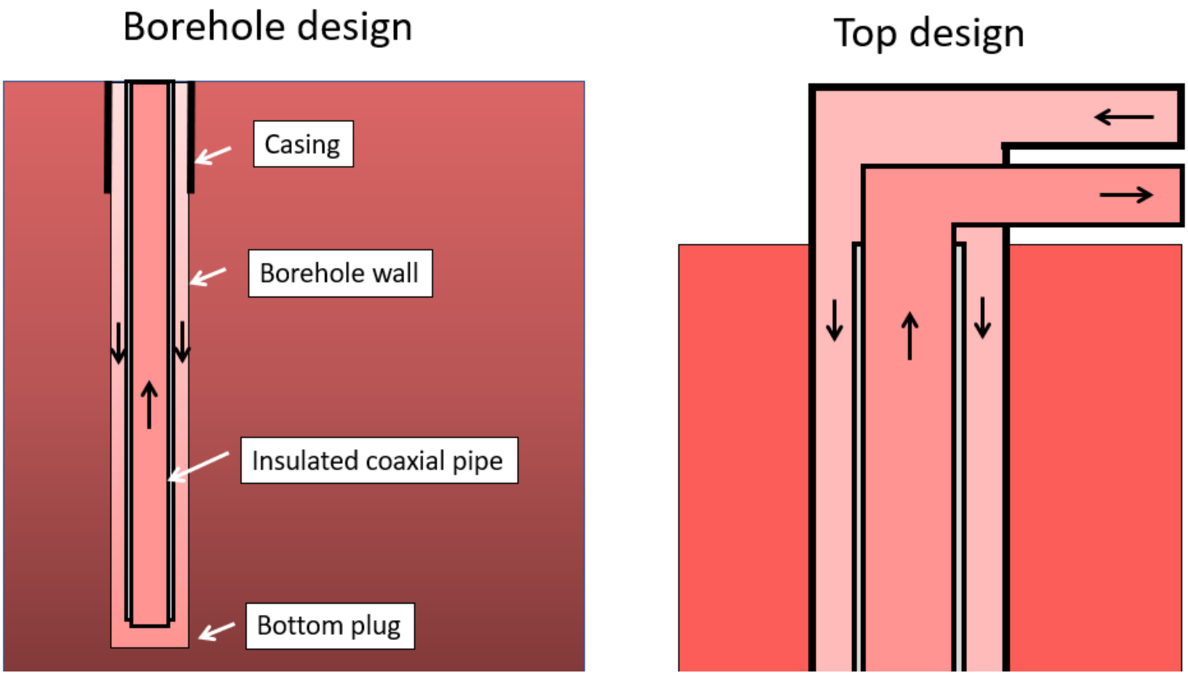


Figure 19: Principal design of a Standing Column Well solution for deep boreholes

5.2.3 BTES

In systems designed for seasonal storage of heat and cold, the boreholes are placed closer to each other, often at 5-8 m distance, with the purpose to create a thermal interaction between the boreholes. In this way heat and cold is seasonally stored in a defined rock volume.

In winter the rock volume is cooled down by extracting heat as a source to heat pumps. In summer the cold rock is used to provide free cooling.

BTES is commonly used for commercial and institutional buildings with air condition. They often contain 10-50 boreholes drilled to a depth of 150-300 m. In the statistics it is difficult to distinguish the BTES from larger BHE systems with heat extraction only. However, put together they represent more than 2 000 sites that have 10 boreholes or more, and at least 100 sites have 100 boreholes or more (Gehlin et al 2022).

In Sweden both BHE and BTES typically have groundwater-filled boreholes, as is the case also in Finland and Norway. In many parts of the world grouted boreholes are mandatory due to the local geological conditions.

5.2.4 HT-BTES

A conventional BTES system may not be capable of producing high enough temperatures throughout the winter season, even when heat is stored at 15-20°C during the summer. The reason is the temperature loss due to heat transfer to and from the rock. The temperature drop can be as much as 10°C. This means that BTES must be overcharged in temperature to meet required high extraction temperatures.

In Sweden there are a couple of HT-BTES of which Xylem Emmaboda has been a subject for long-term monitoring. In this storage, 140 boreholes of 150 m depth deliver approximately 1 MW of heat with a delta-T of 10°C and with a temperature above 20°C throughout the winter season. The storage temperature is around +50°C and consists of industrial waste heat (Andersson et al 2021).

In HT applications a considerable amount of stored heat disappears as losses. In Emmaboda the losses are estimated to 20 % of stored heat. Heat losses increase with increasing temperature and the relative losses decrease with increasing storage volume.

There is growing interest of using HT-BTES in Sweden, primarily connected to DH with cogeneration plants.

As a possible solution a thermally active foundation utilizing piles (energy piles) may be used as a heat source. Such applications could be a part of GSHP system.

5.3 Open systems

5.3.1 GWHP

In GWHP systems water wells that are installed in an aquifer are used. The circulation of the water is carried out by drainable pumps. Heat from or the groundwater is transferred over to a heat pump by using a plate Heat Exchanger (HEX).

In systems designed for heat extraction only, there are pumping wells, and the chilled water is reinjected in injection wells. The distance between pumping wells and injection wells should be such that thermal break through is avoided, i.e. the chilled water should not reach the pumping wells.

Water chemistry must be taken into consideration in early project phase since it may cause corrosion and precipitation problems.

The temperature of the groundwater is practically constant over the year, roughly representing the average air temperature at the site. This makes groundwater an excellent heat source for heat pumps

The number of GWHP systems in Sweden is not known but restricted to places where useful aquifers are available and not occupied for drinking water supply.

5.3.2 ATES

Conventionally ATES (aquifer thermal energy storage) is divided into two well fields with one warm and one cold side. The wells are equipped with pumps on both sides. This means that the flow direction can be reversed, and heat stored during summer has a high temperature quality as well as the cold side.

Typically, and applied for heating and cooling of buildings, the temperature on the warm side would be 12-15°C and some 4-8°C on the cold side. This makes ATES an excellent candidate for HHP without using heat pumps.

On the other hand, proper aquifers may be hard to find. Furthermore, the permit procedure ominous and has a considerable cost.

There were approximately 200 ATES systems with a capacity of 100 kW or more in operation by the end of 2021 (Gehlin et al 2022).

6 Existing HHP geothermal applications

In Sweden there is limited experience of using geothermal systems for snow- and ice melting. However, the few ones in operation work well and may be of interest as references for a future technical and economic development.

6.1 GSHP systems

Since some of the district heating grids also have a geothermal baseload for heat generation, snow melting systems are partly geothermal. One such example is the city of Lund, where a significant portion of heat is generated by a geothermal plant (Aldelius 2017)

Buildings or facilities that already use GSHP systems for space heating, indirectly also use geothermal heat for any HHP system connected to the building (FIG 20).

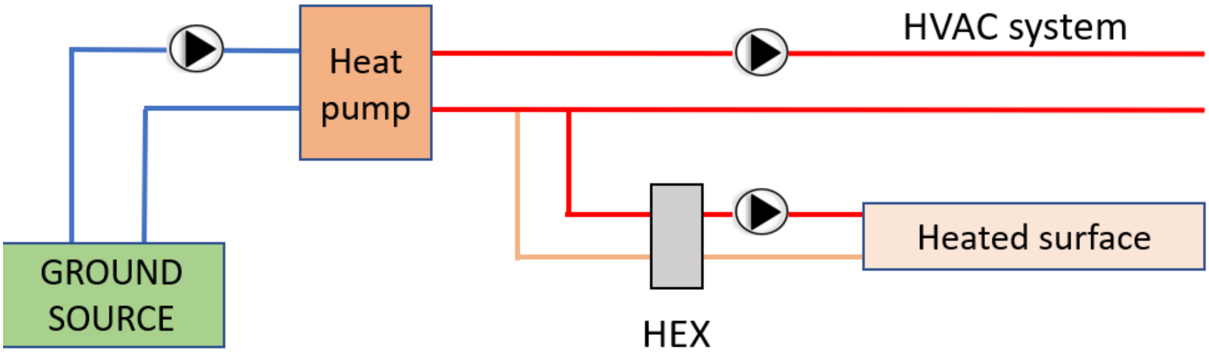


Figure 20: Basic concept for geothermal HHP connected to HVAC using GSHP.

There are thousands of GSHP systems in Sweden, but there are no records on how many of these are connected to HHP systems at entrances and other outdoor surfaces. However, it is well known that several shopping centers keep their entrances dry and free of snow to avoid bringing dirty slush into the stores.

It is also well known that several other commercial and institutional buildings have ramps, entrances, loading bays, etc. equipped with snow melting systems connected to the building heating system.

A couple of known examples taken from tender documents are:

- The new administrative building in Lund (Kristallen), constructed in 2013. It has a steep pedestrian/bicycle ramp from the railway station to the building kept heated under slippery conditions with the use of heat from a BTES system
- The prison in Helsingborg, constructed 2012, which has a 60 m^2 rest area on the roof deck and another 40 m^2 ramp to the garage heated by an ATES system.
- The entrances of several newly constructed IKEA that are supplied by BTES systems at a size of approximately 1 MW.

6.2 ATES and BTES systems

An ATES example is the Stockholm Arlanda Airport that is directly supplied by heat and cold from an aquifer with a warm and a cold side. In winter the heat is directly used for preheating of ventilation air as well as for keeping the gates free of snow and ice.

The temperature from the aquifer is on the order of 20-25°C, while the return temperature to the cold wells is about 2-5°C. In the summer the stored cold is used for air conditioning. By using the gates as solar collectors the temperature to the warm wells can be increased up to around +30°C. The flow rate of groundwater is 200 l/s and the supply of heat and cold is about 10 GWh/a respectively

(Andersson 2009). The system has been operational since 2009. The basic concept of ATES is illustrated in FIG 21.

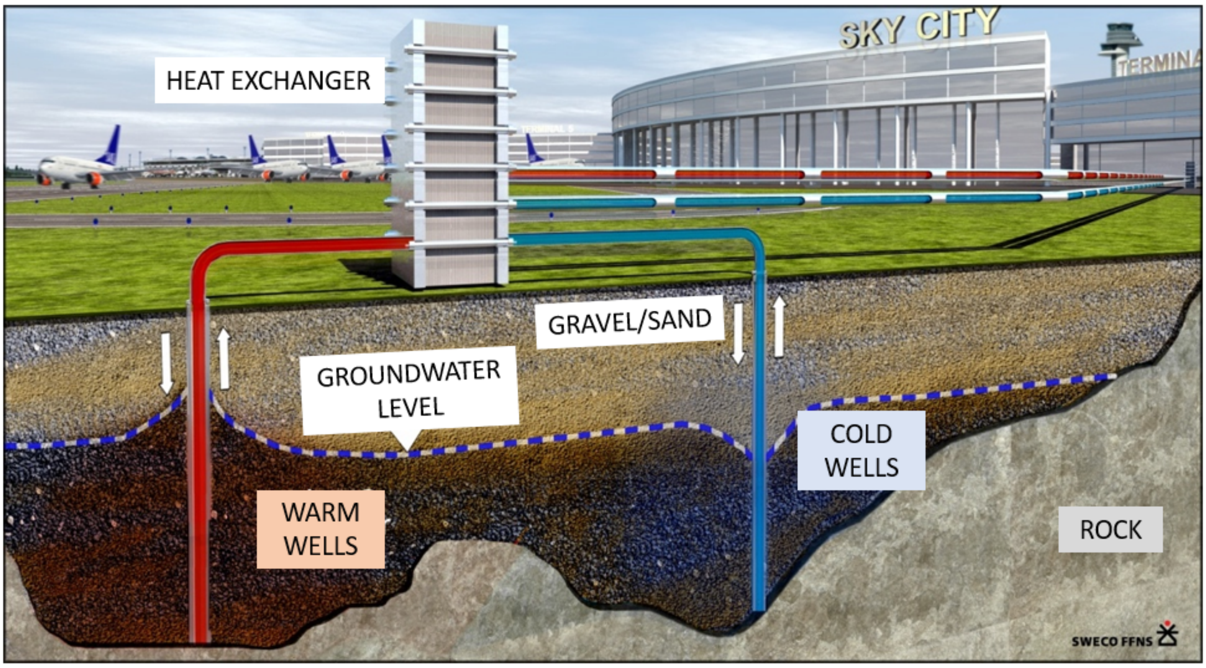


Figure 21: The ATES system used for heating and cooling of Stockholm Arlanda Airport (Sweco FFNS 2010).

The HHP system, in which heat from the aquifer is used, covers an area of 100 000 m^2 of which some 75 000 m^2 are gates at Terminal 2 and 5. The rest is used for entrances, etc. Previously, the heat was supplied by a local district heating system (Swedavia 2016).

Examples of BTES applications are heating of football fields with artificial turf. One of these is Backavallen in Katrineholm that has a BTES system with 91 boreholes of 180 m depth installed in 2009. The storage capacity is about 1 700 MWh of which some 400 MWh is harvested from the field when used as a solar collector, while the other part comes from waste heat when making indoor ice for ice hockey, curling, and outdoor ice bandy (FIG 22).

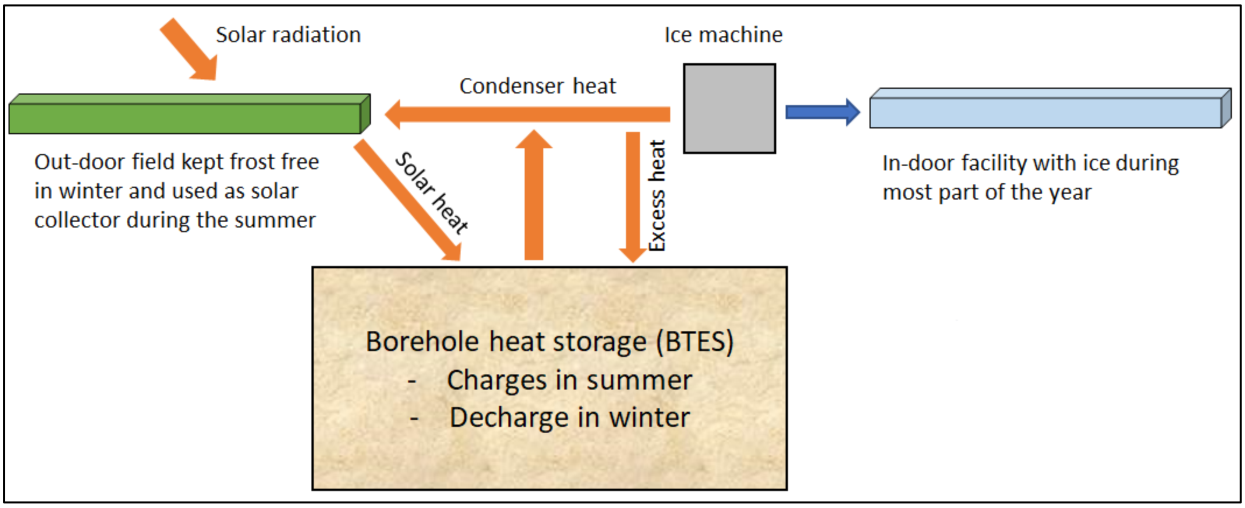


Figure 22: Basic concept for using condenser waste heat and solar heat stored in BTES for heating of football fields

A similar system is also used at Kungsängen sports center, where 40 boreholes, 180m deep are used with waste heat from indoor ice-making, Other known applications of BTES are, Täby football arena, with 90 boreholes, 300 m deep, and Torvalla arena with 91 boreholes, 230 m deep (Svensk Geoenergi 2018).

6.3 Groundwater

In the city of Hallsberg in middle Sweden a football field is heated by groundwater obtained from wells that drain the sport facility area. The groundwater is pumped from three wells throughout the year at a maximum flow rate of 35 l/s and disposed in a small river. The temperature of the groundwater is constant at about +8ºC (Olsson 2010).

The groundwater is occasionally picking up condenser heat from the chiller to an ice hockey rink that increases the temperature to +14°C. The maximum supply temperature to the football field is +14°C and the lowest return temperature is +3,5°C (FIG 23). This indicates a maximum heating capacity in the range of 1 500 kW and the system is said to be capable to keep the turf unfrozen at an outdoor temperature of -12ºC (Olsson 2010).

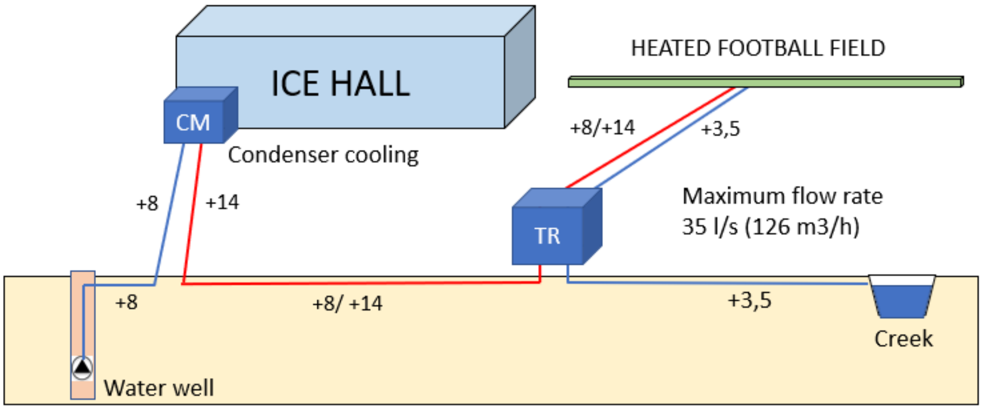


Figure 23. Simplified flow chart for the groundwater HHP system (after Olsson 2010)

7 Experimental geothermal HHP studies

Even though there are only a few Swedish applications, several experimental studies have been performed on both existing and planned applications. The results of these may serve as important knowledge for the further market development.

7.1 Gates at Stockholm Arlanda Airport

In an experimental study at Stockholm Arlanda Airport the influence of several variables was studied at one of the heated gates (Persson 2007). The objective was to find out to what extent heat from an ATES system could be practically used.

It was shown that the aquifer temperature at +20°C could efficiently be utilized to keep the ground at +3°C by simply increasing the flow rate (FIG 24 and 25). However, at a high-capacity demand, the fluid had to be run under turbulent flow conditions.

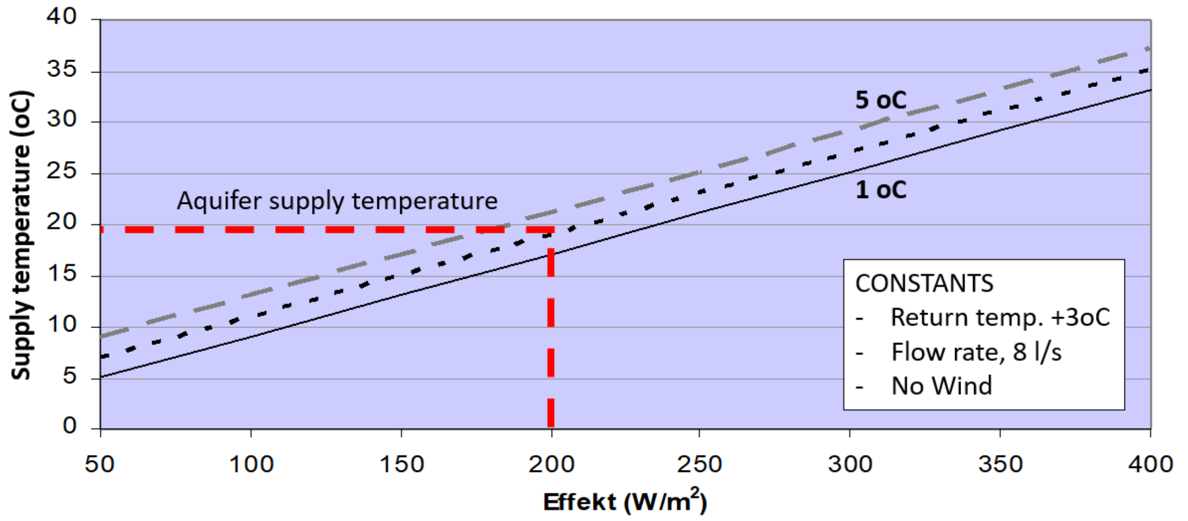


Figure 24: Aquifer supply temperature for having the gate kept warm at 3°C with the designed flow rate (Reworked after Persson 2007)

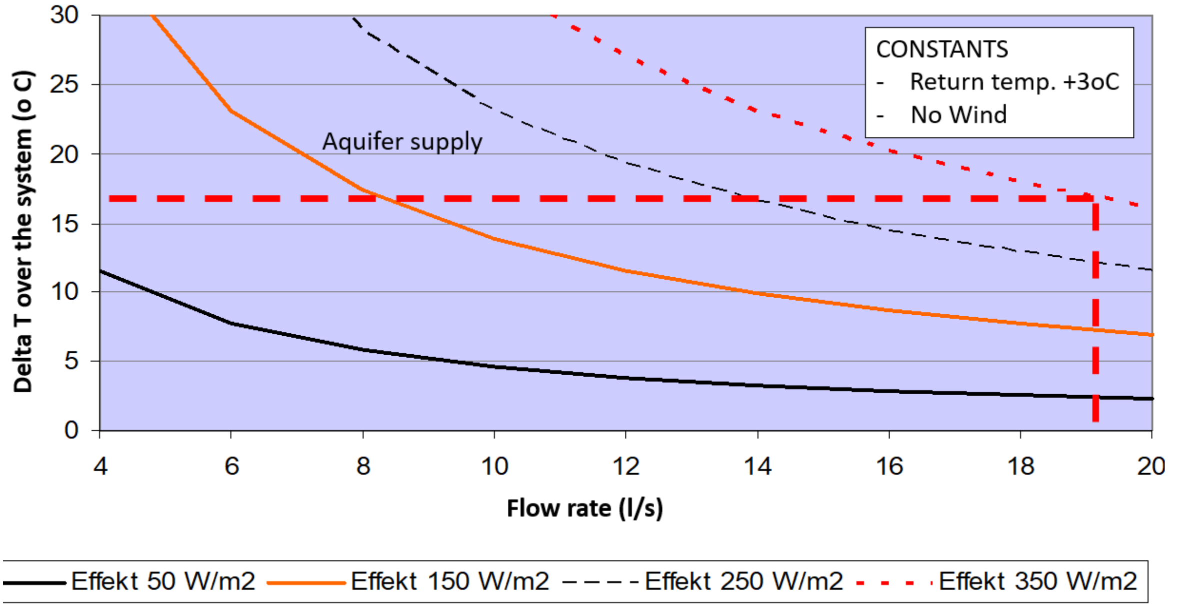


Figure 25: Aquifer supply temperature for having the gate kept warm at +3°C using variable flow rates (Reworked after Persson 2007)

Several other parameters were analyzed, e.g. the wind speed had a significant effect on the capacity demand. The heating capacity needed to keep the surface constantly heated at +3 °C at different wind speeds is shown in FIG 26

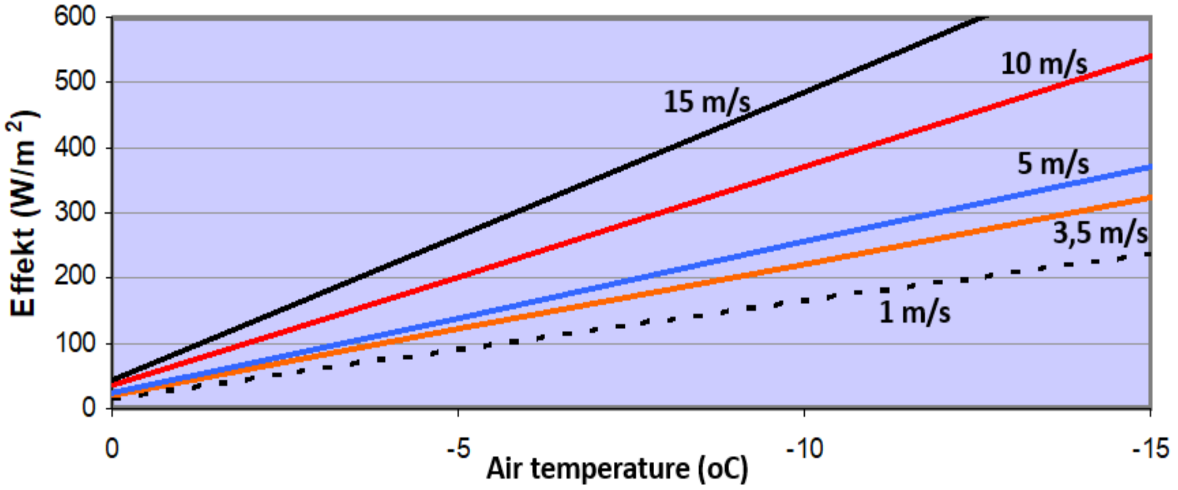


Figure 26: Power demand as a function of wind speed and air temperature to keep the surface warm at +3°C (Persson 2007)

Only some 6 % of the heat consumed was used to melt snow (average for the years 2002-2006). Still, it was shown that the intensity of snowfall is an important design factor if the ambition is to melt the snow immediately as it falls (FIG 27).

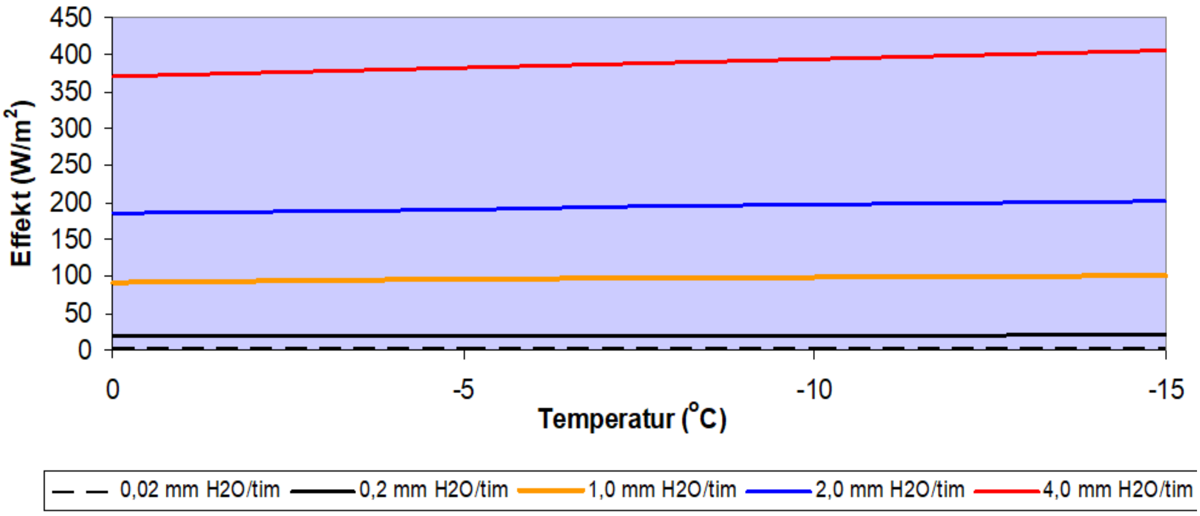


Figure 27: Load demand as a function of snow intensity and air temperature (Persson 2007)

Persson (2007) also studied how the gates could be used as solar collectors charging the warm side of ATES system with solar heat. (FIG 28).

If the supply temperature to the gate during summer is +20°C (waste heat temperature from the airport cooling system) it was found that temperatures up to +35°C could be stored in the ATES system during the summer months. Furthermore, the total extracted solar heat would be approx. 50 % of heat used to keep the gates heated during the winter season.

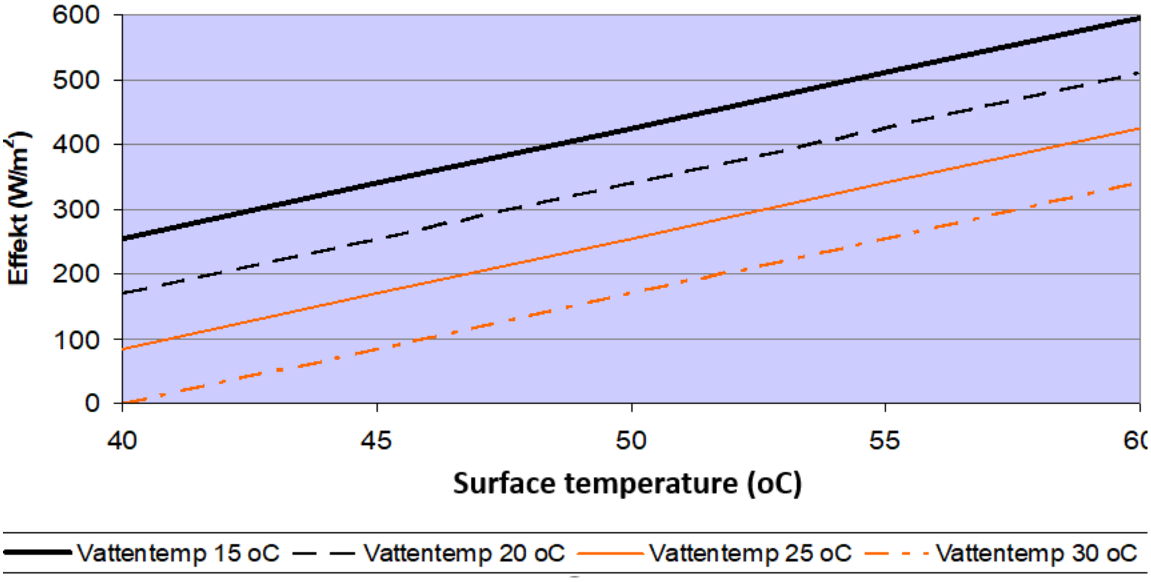


Figure 28: Solar power uptake as a function of surface temperature and fluid inlet temperature (Persson 2007).

7.2 The HERO experimental site outside Östersund

This experimental plant is part of a project named HERO (Heating Road with Stored Solar Energy) and was constructed 2017. The concept is to use solar energy for heating a section of a paved road with a concept principally shown in FIG 29 (Johnsson 2019).

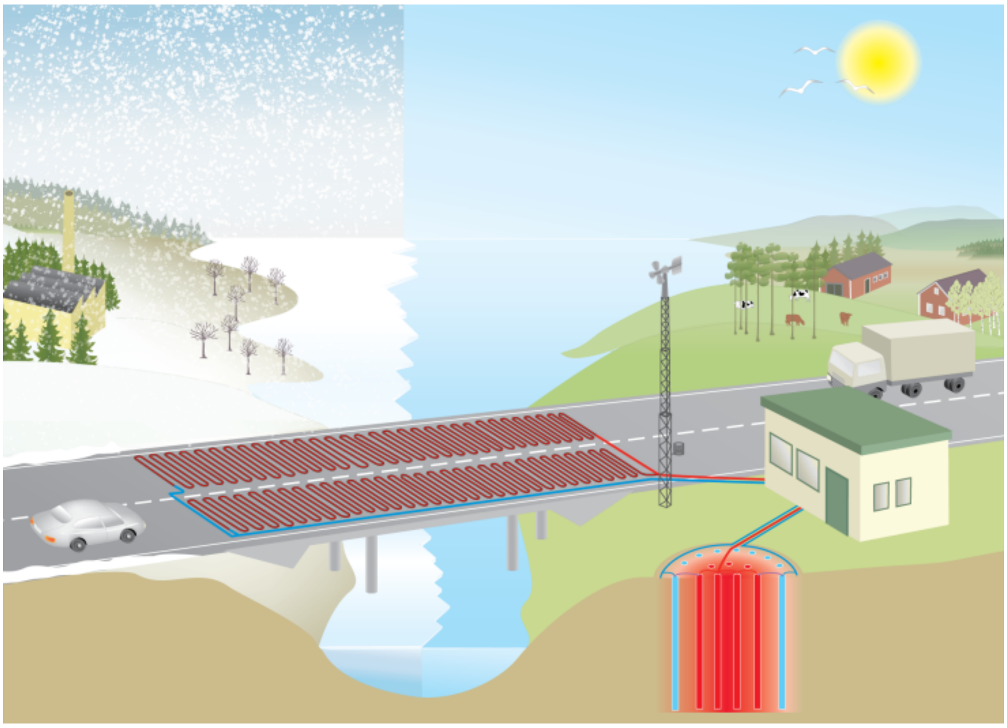


Figure 29: A hydronic pavement connected to a BTES system keeping the harvested solar energy stored into the winter. (Illustration: Karin Holmgren)

In the HERO project a 20 m long and 3,5 wide section of a minor road is heated by solar energy stored in a BTES with four boreholes of 210 m depth (FIG 30).

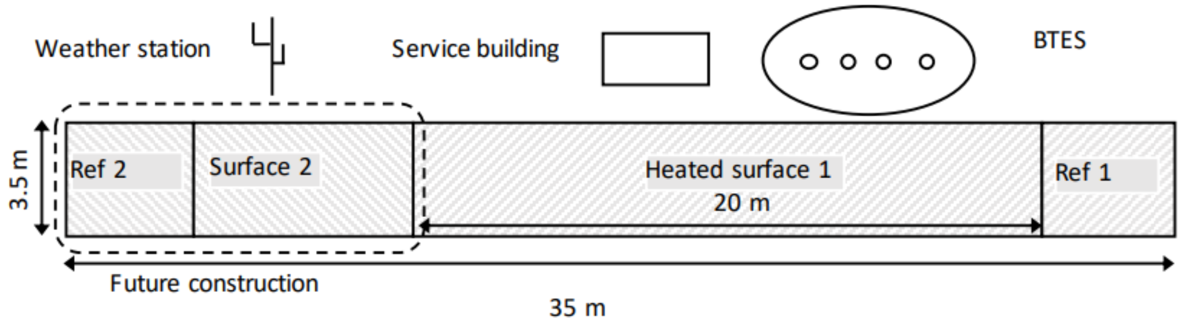


Figure 30: Layout of the HERO field station (Johnsson 2019)

The objective of the test plant was to collect data for verification of a simulation model that was developed prior to the tests.

The results indicate that it is possible to harvest more solar energy in the summer than needed during the winter if the system is controlled in an efficient way.

The energy demand measured at the test field in the winter was consistent with the simulated energy demand. However, only half of the energy supplied to the system originated from the BTES since the supply temperature from the boreholes was lower than required.

7.3 Snow dump melting at Arlanda airport

Some airports have large snow masses to take care of and it must be melted in a controlled way for environmental reasons. For this reason, they have snow dumps from which melted snow water is led to a treatment plant. Some winters with heavy snow the dumps are filled to the brim and therefore it may be of interest to artificially melt some of the snow.

At Stockholm Arlanda Airport an experiment was performed in 2008 (Hägg and Andersson 2009) to melt snow by using the snow dump floor as a solar collector in the summer to store heat in a BTES (FIG 31).

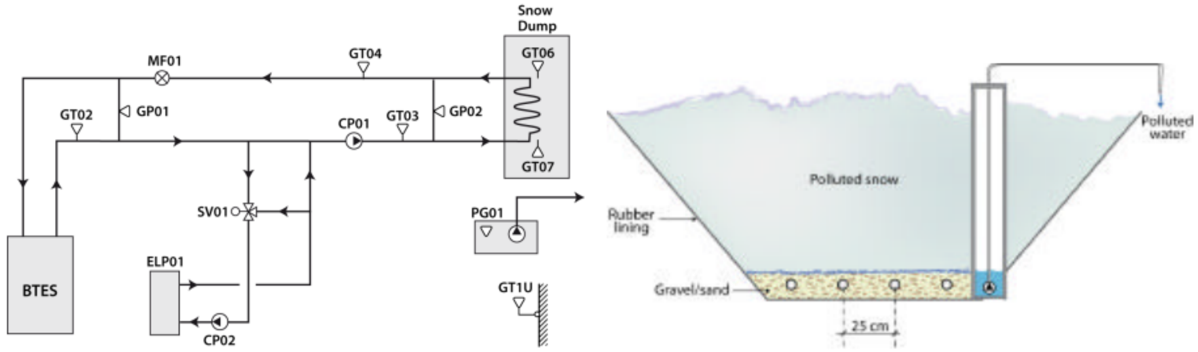


Figure 31: Experimental set up for enforced snow dump melting at Arlanda airport (Hägg and Andersson 2009)

To simulate the existence of a thermally charged BTES, an electrical heater was used to increase the temperature delivered by the BTES by +3°C. The system was run over three winter months. During the operation the impact of different parameters was tested such as varying circulation flows, higher water level in the snow dump and using the uncharged BTES (10 boreholes á 200 m) as the only heat source.

The supply temperature to the pit was kept at 7- 8°C during most of the time and the return temperature from the pit to BTES was at this mode of operation 2-3°C (FIG 32).

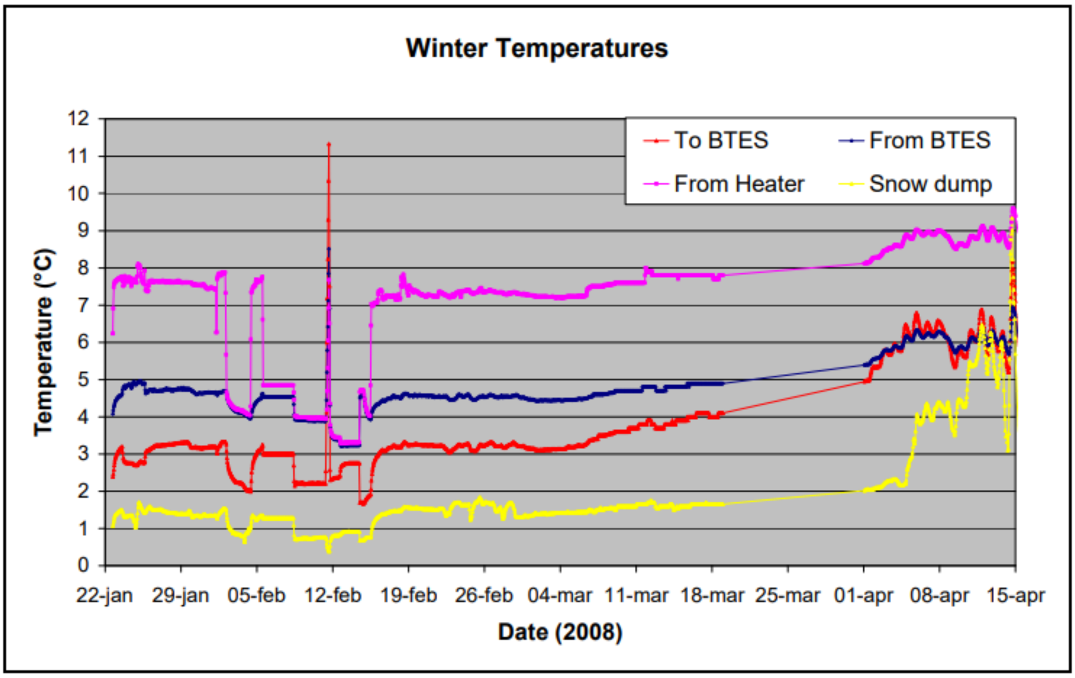


Figure 32: Recorded system temperatures for the snow melting system (Hägg and Andersson 2009)

Altogether 55 MWh of heat that was supplied to the snow dump equals to melting about 600 tons of snow (ice).

The following summer a test was conducted where the tubes on the bottom of the pit were used as a solar collector to store heat in BTES (FIG 33).

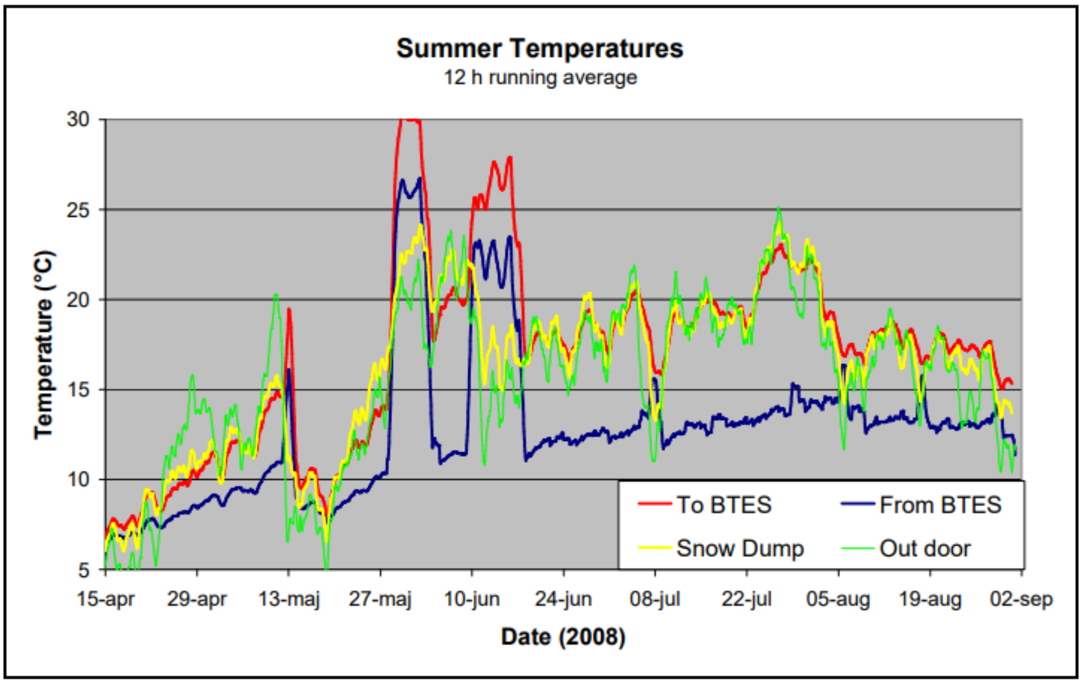


Figure 33: Recorded system temperature at charging the BTES with solar heat (Hägg and Andersson 2009).

The BTES was recharged with 90 MWh of heat during the summer operation, with an average power of about 35 kW,

It was concluded that both modes of operation would be significantly more effective using a better control system than the one used in the experimental set up.

8 Basis for design

There are many parameters and factors to consider in the design of snow- and ice melting system, such as the type of surface, climate conditions and the operational strategy.

The parameters affecting the design are fairly well known and several models have been developed in order to design the heating capacity.

8.1 Type of surface

In an optimal design, pavement in a material with high thermal conductivity combined with high mechanical strength allows the heating pipes to be placed close to the pavement surface. An example of a material with such properties is walking slabs without heavy vehicle traffic.

Stone-plates have generally a favorable thermal conductivity, so that the pipes can be placed at a relatively shallow depth. Stone covered surfaces are usually thicker and has often traffic by cars or even heavy vehicles. The heating pipes in such cases must be placed deeper in order to not suffer damage. The same applies to asphalt on busy roads, but asphalt also has poorer thermal conductivity. Common pavements for snow melting systems are illustrated in FIG 34.

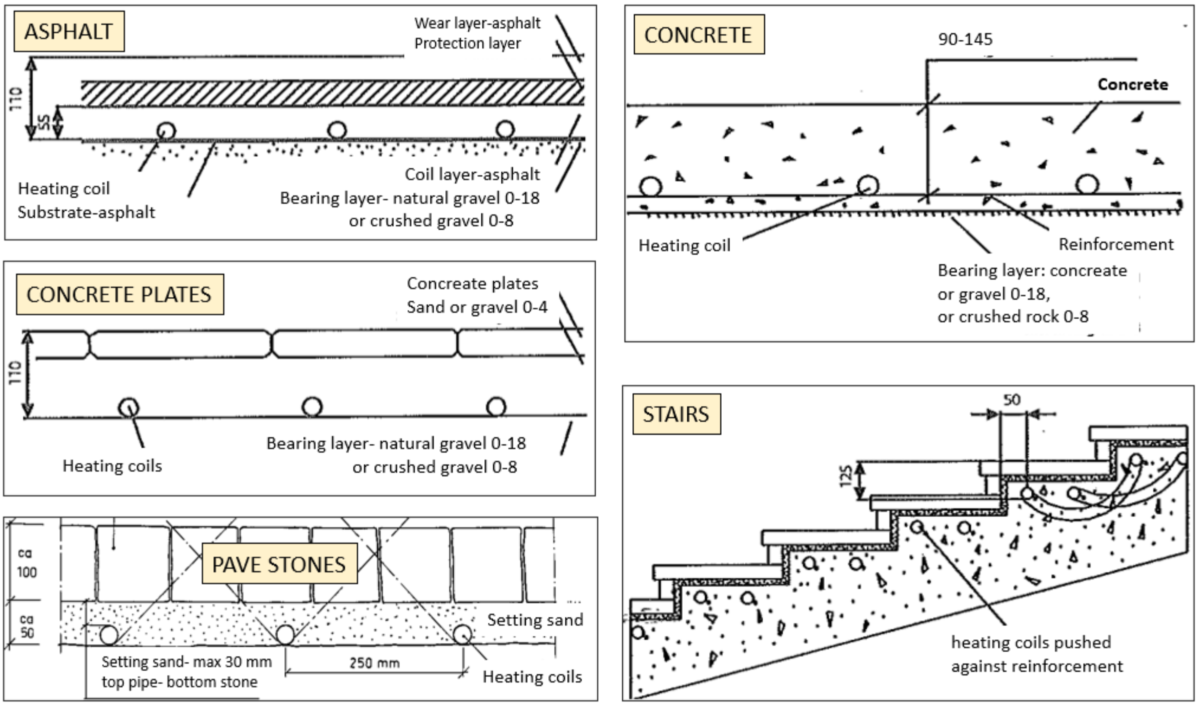
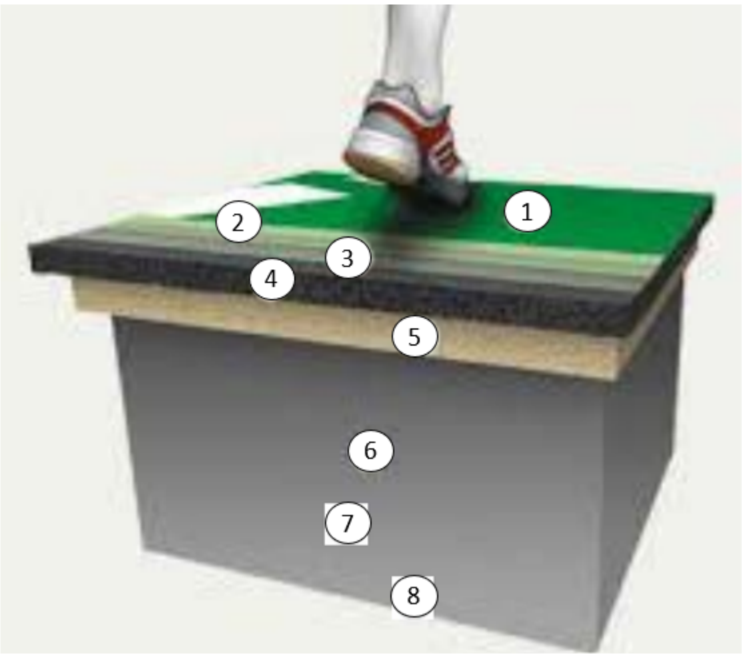


Figure 34: Different pavements for HHP systems (after Stockholm stad 2012)

If a pavement consists of concrete, it is advisable to cast the heating coils directly into the lower part of concrete. In general, concrete has relatively high heat conduction compared to asphalt, and is also more durable.

In grassy areas, there is a zone of roots that extend into organic soil. The thermal conductivity is therefore low and less suitable for heating coils if the goal is to melt snow on top. However, such a system can be used to keep the surface frost-free and even green during the winter season.

Surfaces with artificial grass (turf) for football fields are built up with a failing pad under thin layers of granulate and sand (FIG 35). The thickness of layer 2-3 would typically be 5-8 cm and the pad 2-4 cm, while the packed fine sand would be 5-10 cm. Normally heating pipes are placed in the sand beneath the pad. Sand as well as the granulate and grass, have a considerably high thermal resistance.



1. Artificial grass
2. Granulate
3. Sand
4. Failing pad
5. Fine sand
6. Draining layer
7. Strength layer
8. Draining pipes

Figure 35: Layers for a football field with artificial turf (Svenska FF 2017)

8.2 Climate conditions

Out-door temperature, precipitation of snow, solar radiation, exposure, and wind speed are the main conditions affecting the design. In general, regional statistic data are used (FIG 36).

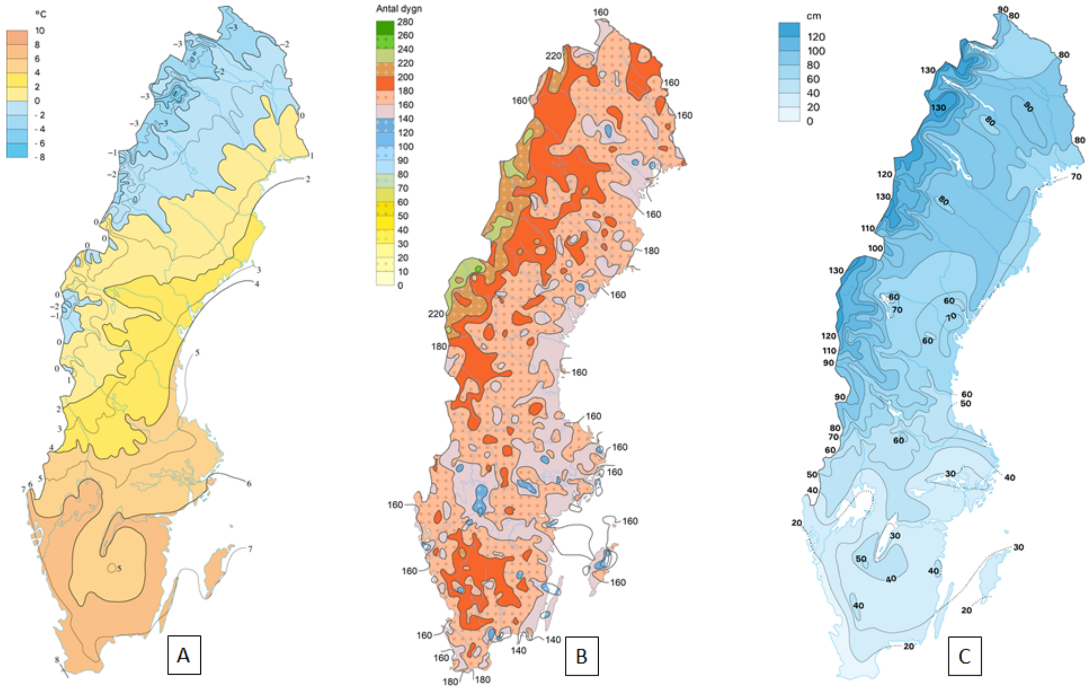


Figure 36: Main weather conditions in Sweden as mean values for (A) temperature, (B) hours of precipitation > 0,1 mm (as water), and (C) snow depth (SMHI 2022).

8.3 Operational strategy

An important prerequisite when designing a system with ground source heat is the goal you plan to achieve. This affects not only the capacity of the system, but also to a large extent the energy consumption.

In principle, the following operational strategies are at hand:

- Keeping the surface free of frost, e.g. applied for football fields with artificial turf. In this type of system, the ground is warmed up to keep the field frost free down to a certain air temperature below zero, e.g. -10ºC. These systems are characterized by a long period of operation, but at a low heating capacity.
- Avoid frost and to melt snow, typically applied in a central urban environment. In this type of system, the surface is kept sufficiently heated to avoid frost buildup at temperatures below zero. To melt snow the heating rate is increased. Hence, this mode of operation is characterized by intermittent use with varying capacity.
- Continuously running systems to keep the surface preheated and dry throughout the winter to melt high-intensity snowfall. Such an operation is applied, e.g. at airports that are vulnerable to sudden heavy snowfall or snowstorms.

The choice of operation mode is governed not only by function, but also considering the energy cost. For this reason, a manual control with an intermittent operational strategy may be an optimized way of operation for most applications.

8.4 Influencing parameters

In designing a system several parameters should be considered (FIG 37). These have all an influence on the system design and how it will operate.

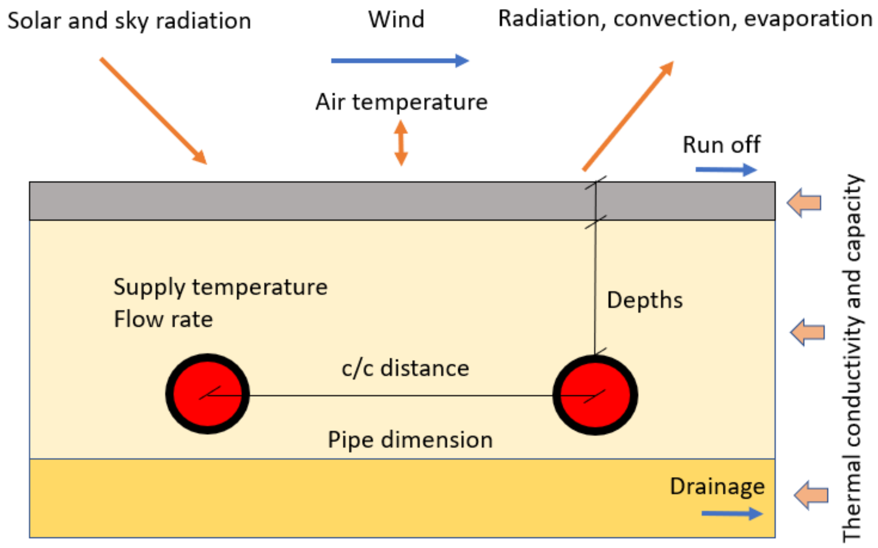


Figure 37: Main parameters influencing the design of a HHP system

In some applications, especially for roads and bridge decks, also factors such as moisture, dewpoint and the albedo effect are of importance (Johansson 2019).

If the system is designed to melt snow as it falls, the snowfall intensity should be added to the list of parameters. In this case also the runoff of melted snow is of great importance.

To keep a surface warm, the dominating factors are the ambient temperature, the wind speed, and the thermal conductivity of the layers above the pipe system.

8.5 Simulation models

For design of systems with respect to all necessary parameters there are several simulation models used.

Johnsson (2019) used HyRoSim (Hydronic Road Simulation) for simulations of the HERO test plant, see next chapter. This model was developed as a model for HHP and is a modification of Bridgesim, that is used for simulation of HHP systems for bridges elsewhere in the world.

The model consists of two modules, the HHP module and the storage module Pygfunction. The latter module is an open-source software that calculates fluid and borehole wall temperatures for a borehole field (BTES), based on the heat load applied to the storage.

By combining Pygfunction with the HHP module a model for total HHP concept that also can handle surface moisture and a BTES system (FIG 38).

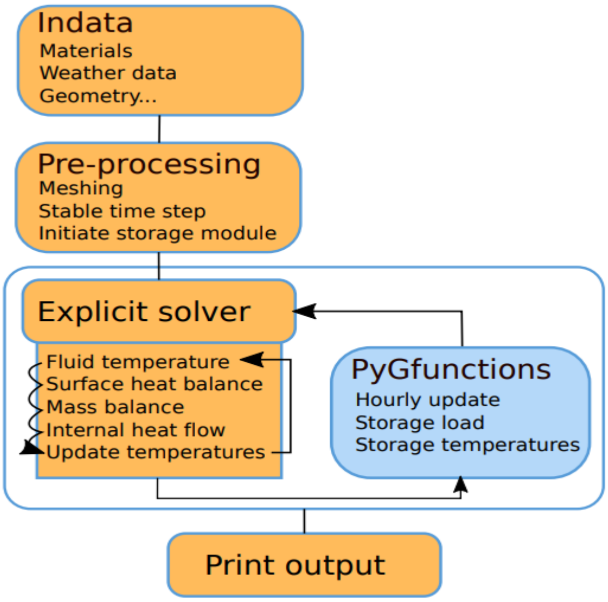


Figure 38: Flow chart for the model HyRoSim developed in project HERO (Johnsson 2019)

A model in a Swedish feasibility study (Matteusson 2022*)* used for pavements and artificial football fields is the 2D simulation model COMSOL Multiphysics. In this model the thermal property of each layer is inserted, and the heat flow can be studied at different heat power supply levels (FIG 39).

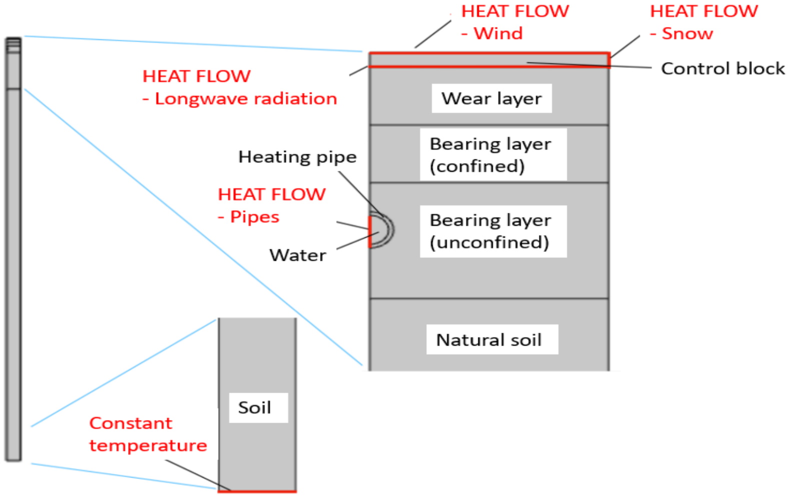


Figure 39. The principle for using COMSOL for heat flow simulation (Matteusson 2022)

This type of model has also been used in several other studies (Dijar 2013, Gewert 2013 and Umas 2014), the latter ones for study heating of artificial football fields.

One climate model was developed at Linköping University to study how some of the existing systems could be more effectively operated with respect to energy and cost saving. This unnamed model is a ground cross-section, representing the surface heating system design, control system, and weather conditions that affect the ground surface temperature. The model is run in the FEM-program ANSYS Workbench and its CFX calculator. It was found that the use of heat could be significantly lowered (some 50 %) by using an improved control system (Blomqvist och Nyberg 2014).

In 2014 a massive car accident on a bridge (Tranarpsbron) occurred, due to slippery road conditions. In a study (Togård 2014) of the feasibility of providing heat to the bridge to prevent future accidents, the simulation tool CoupModel was used. This model is a program that calculates the heat and mass transfer between soil, plants, and atmosphere. In this study the program was also adapted to bridges. As such it was used for calculations of how much heat was needed to prevent from this type accidents. In this study a large BTES system provided the heat. However, it was found not be economically feasible at the time of the study .

In the study by Togård (2014) a commonly used simulation program called EED was used to calculate the fluid temperatures entering and exiting the BTES (FIG 40).

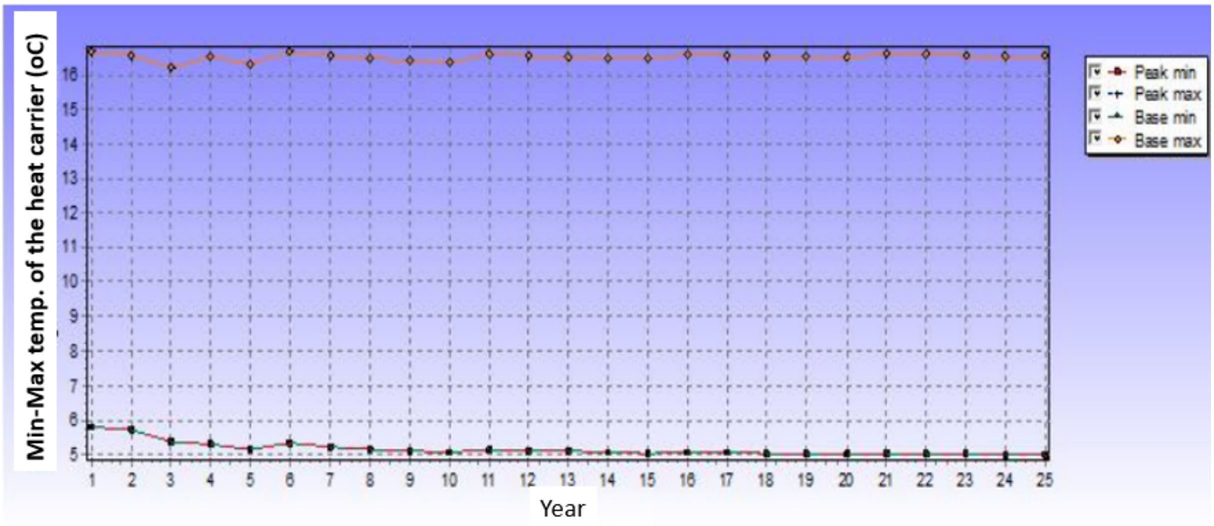


Figure 40: EED simulation of yearly peak fluid temperatures at charging (red) and discharging (green) (Togård 2014)

The CoupModel was also used in a case study to investigate the cost for heating a bridge (Halvors länk) in Gothenburg (Trafikverket 2014b). In this case three options for keeping the bridge heated, combined with traditional snow clearance, were simulated, analyzed, and cost calculated

9 Market actors

The most common customer for snow- and ice meting systems is municipalities that use these systems to prevent slip accidents and to avoid costs for manual clearance of snow and salt for melting.

The municipalities are also responsible for the maintenance of football fields or other outdoor sports facilities.

The provider of heat is commonly the local district heating company that also design and construct the systems. There are several suppliers of components that sometimes also design and install the systems.

9.1 Customers and heat providers

By far the most common customer of snow- and ice-melting systems in Sweden is municipalities that, for various reasons, choose to install these systems in central urban environments and on football fields with artificial turf.

Regarding sports facilities, the Swedish Football Association (SFF) has shown a special interest in the use of heated football fields to prolong the season and to prevent injuries caused by a frosty and hard turf.

Another common client is property owners who, for example, want slip-free entrances and ramps, and also face regulatory demands to keep sidewalks at non-slip conditions. For larger systems in a central urban environment, co-financing often takes place between the municipality and the property owners. Organizations responsible for public transport may also be included in such constellations.

When it comes to tender documents there are no formal guidelines such as are available for a large number of other constructions (AMA publications). However, a few municipalities, e.g. Stockholm Stad (2012) and Göteborgs Stad (2022), have issued special guidelines.

The Swedish Transport Administration is another actor that has initiated research and development of ground heating systems for particularly vulnerable road sections and bridges (Trafikverket 2014a).

Outside city centers there are several commercial and institutional properties as well as industries that use heated surfaces. These are often systems for entrances, loading docks, etc. Systems adjacent to shopping centers are particularly common applications.

The heat supply side is dominated by energy companies with cogeneration plants that provide for district heating in most Swedish cities. They commonly also produce electricity and are interested in low return temperatures for their plants. Others may have access to waste heat suitable for low-cost heat supply.

9.2 Component suppliers, designers, and installers

There are several companies on the Swedish market that supply components and also install ground heat systems on a turn-key basis. Examples of such companies are Uponor, LK Systems, and Thermotech. These companies also provide handbooks that describe the system components and system lay-outs.

In the case of geothermally based ground heat systems the drilling industry, in particular drilling companies and suppliers of borehole heat exchangers and well installations, are also part of the supply chain. Most of these companies are organized through an industry association Borrföretagen (borrföretagen.se). A liaison to Borrföretagen is the Swedish Geoenergy Center (Svenskt Geoenergicentrum) which has, among other things, published several guidelines or manuals for geothermal applications (geoenergicentrum.se)

The drilling companies have valuable expertise in construction of larger GSHP systems for heat extraction as well as Aquifer thermal energy storage (ATES) and borehole thermal energy storage (BTES) systems för seasonal storage of heat.

On the design side there are several engineering companies with long experience in design of HVAC systems as well as geothermal systems, commonly with heat pumps involved.

10 Use of heat

The annual heat consumption in various HHP applications is uncertain and the variation seems to be high. However, there are some information available that could be of great interest in comparing the operational cost for conventional solutions with geothermal systems.

10.1 Busy city center applications

In this sector of HHP applications there is only sporadic information about design and energy load to be found in literature.

The heating capacity would be different depending on which climate zone the installation is located, but also with respect to the subject and the goal. According to figures given in several references, the systems commonly have a specific heating capacity of 250 - 350 W/m^2.

The energy load is governed by using a setpoint for the ground temperature in order to keep the surface frost free. This setpoint is the governing factor for the energy load (FIG 41)

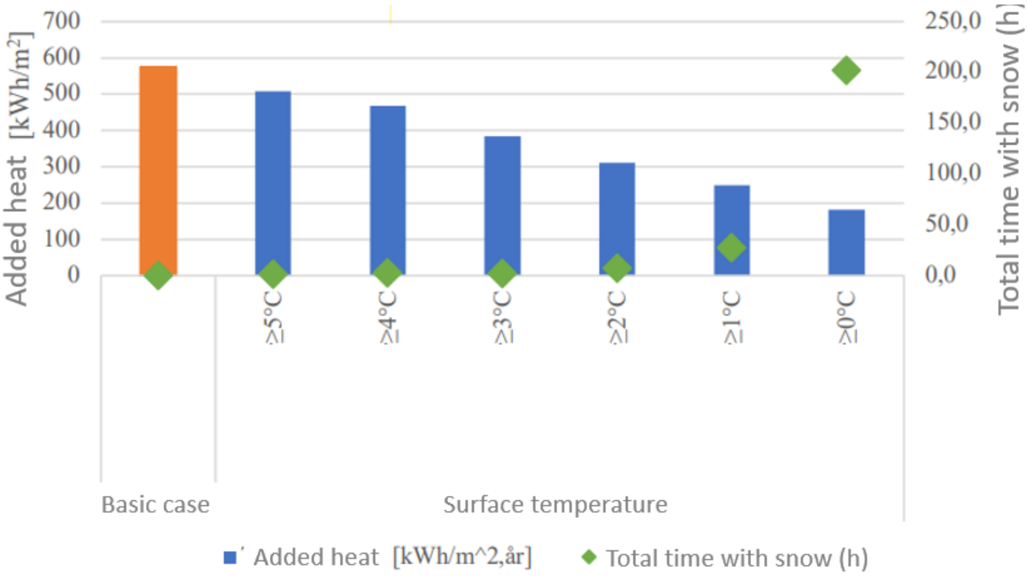


Figure 41: Heat load as function of set point for ground temperature and hours with snow on the surface applied for the city of Karlstad, middle Sweden. In "Basic case" the system is run constantly during the winter with an inlet temperature of +23°C (Matteusson 2022)

The target for e.g. Karlstad, in the middle of Sweden, would be intermittent operation with practically all snow melting. This target is achieved by turning the temperature on at +1°C and off at +4°C, using approx. 300 kWh/m^2 annually. Measured use of heat for some completed ground heating systems are shown in TABLE 2. An average value for Sweden would typically be 300-350 kWh/m^2.

Table 2: Measured annual heat consumption for some existing HHP systems

Location and heat source	**System size (m^2)**	**Annual heat (kWh/m^2)**	**Reference**
City of Skellefteå (DH)	1 700	386	Gustafsson och Hålsten 2006
City of Boden (DH)	5 000	486	Gustafsson och Hålsten 2006
Göteborgsbacken (DH)	6 600	125-250	Trafikverket 2014a
Linköping (DH)	30 600	320-420	Blomqvist and Nyberg 2022
Arlanda airport Pir F (Geo)	40 000	240	Persson 2007

10.2 Football fields

The only detailed Swedish study that we have found regarding use of heat to keep football fields free from frost is a survey made by Södertälje FC (Wedlund 2010).

For the Södertälje arena the heat consumption had at the time been recorded for six years showing mean value of approx. 800 MWh/year (FIG 42).

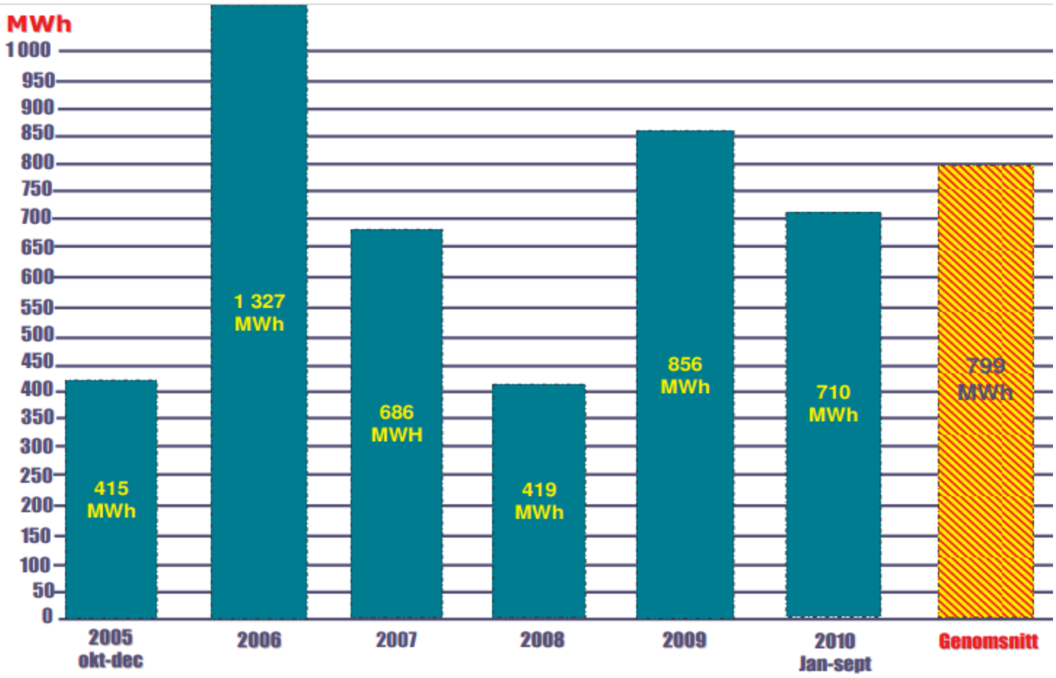


Figure 42: Use of district heat to keep the Södertälje football arena frost free during the period 2005-2010. The yellow bar is mean value (Wedlund 2010)

The field has artificial turf with the pipes placed at 60 mm below the pad. There were five temperature sensors in the field and also a reference sensor outside the field (FIG 43).

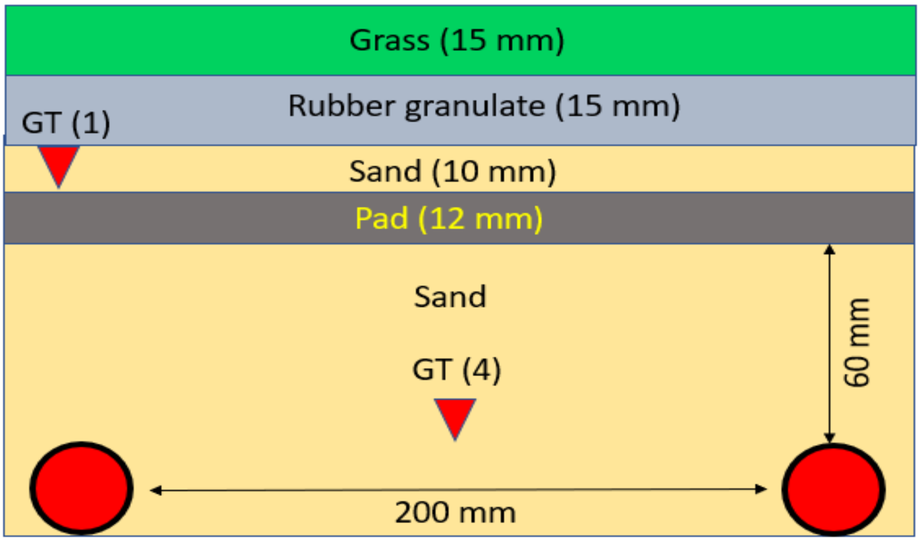


Figure 43: Layers and placement of pipes and sensors (after Wedlund 2010)

The system is controlled by temperature and precipitation setpoints but can also be manually operated. It is automatically run if the temperature is less than +3,5°C.

The heat is supplied by district heating and the supply temperature is controlled by the return temperature. The operating temperatures on a cold day in January 2010 at -11°C air temperature is shown in FIG 44.

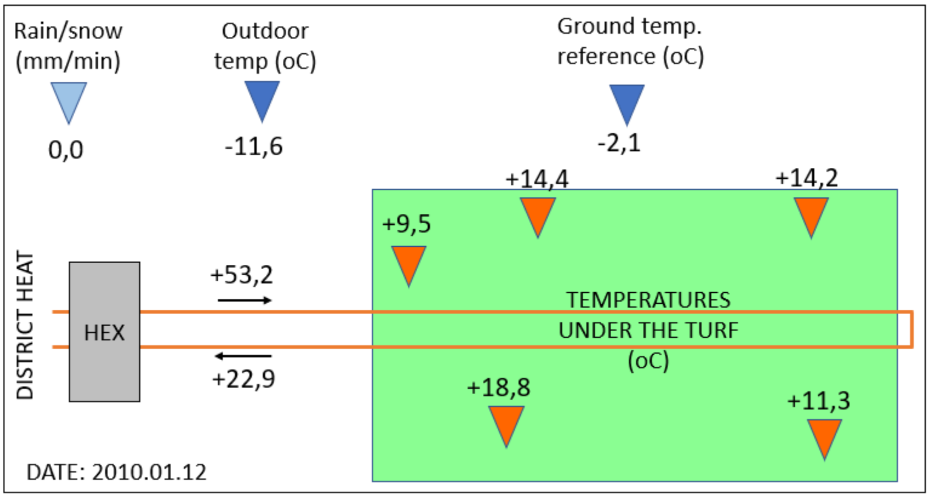


Figure 44: System temperatures at -11°C outdoor temperature (simplified after Wedlund 2010)

At this occasion the temperature above the rubber pad is +9,5 while the four sensors at pipe level is about +15, while the reference sensor shows -2,1°C.

The heating energy demand is in general related to the number of days with frost temperatures. These vary but are typically 200-250 days in the North, less than 100 days in the middle part of Sweden and even less than 50 in Southernmost parts of Sweden (SMHI 2023). For this reason, the energy demand is expected to be much higher in the North than in the South. The annual heating demand for the Swedish soccer fields ranges between 500 and 2,300 MWh (Lindgren 2013).

In a detailed study of a soccer field in Uppsala in the middle part of Sweden the energy demand was investigated for a period of two full years (Ericson et al 2016). The heat loads for 2014 and 2015 were found to be 760 and 820 MWh/year respectively. The heated area was 6 830 m^2 and the specific use of heat then becomes approximately 120 kWh/m^2. These winters were milder than usually which may have reduced the heat consumption somewhat. In this pitch the heating coils are placed in the shock pad and the supply temperature is +20°C as lowest and +35°C as highest. The system is manually operated with the on-off method and only used to prevent frost. The maximum heating capacity was in this case just above 300 kW (42 W/m^2) at minus 20°C outdoor temperature.

The heated football field in Södertälje the years 2008 2010 (Figure 42) ends up with an average consumption of 800 MWh, or about 100 kWh/m^2. However the variation is large, from 415-1 327 MWh annually (Wedlund 2010). This variation may indicate that the annual winter climate affects the use of heat to a large extent. However, also other factors are important, such as the frequency of important games during winter conditions and operational strategy.

Wedlund 2010 also presents the results from a survey on heat consumption from other football clubs with heated turfs. This study represents data from 15 football fields in different parts of Sweden is shown in TABLE 3. The obtained data cover January-March, in 2010.

All fields are supplied by district heating with a total consumption of approx. 13,3 GWh and a mean value of 890 MWh/field covering three winter months. The variation is quite large and is probably reflecting different weather conditions in different parts of the country, but also the way the systems are operated according to different demands. It shall be noted that the winter 2009-10 was colder than an average Swedish winter. For this reason, the consumption may be much lower for an average winter. Still, the football field is using a considerable amount of heat.

Table 3. Monthly heat consumption (MWh) for 15 football fields in January-Mars 2010

City	Jan	Feb	March	Sum

Borås	487	334	170	991
Borlänge	256	144	114	514
Tidaholm	545	350	214	1 109
Gävle	237	274	207	718
Södertälje	316	211	155	682
Sundsvall	(500)	(350)	260	1 110
Umeå	(300)	255	689	1 244
Örebro	310	403	315	1 028
Boden	79	304	576	959
Norrköping	514	295	183	992
Solna A+B+C	1 291	1 102	378	2 771
Eskilstuna	265	154	114	533
Göteborg	410	283	10	703
Sum	**5 510**	**4 459**	**3 385**	**13 354**

(- - -) Estimated value

If assumed that the average heated surface is about 7 000 m^2, the total heated surface is 100 000 m^2 for the 15 fields in the survey. The specific energy use for the three winter months covered by the survey would then be around 135 kWh/m^2. However, there are at least two more winter months to be added, and for this reason the annual heat consumption is estimated to be 150-200 kWh/m^2.

11 Economics

Knowing the investment cost and the operational cost for a system makes it possible to compare different systems. However, this study does not include such a comparison, due to the lack of public statistics, the varying energy prices and variation of local climate and geological conditions in Sweden Still, it can be anticipated that the investment cost is quite high regardless of which system is chosen and that the energy cost of a system supplied with district heating can be unacceptably high. This suggests that geothermal energy systems, which decreases the amount of bought energy compared to DH, have a fair economic potential in the future.

11.1 Investment cost

11.1.1 District heat supplied systems

The investment cost for HHP systems consists of several cost factors that differs depending on size and other site-specific circumstances. The investment can be subdivided into the following cost items:

HHP pipe system

The pipe system has a specific cost expressed in SEK/m^2 but is partly dependent on the number of loops and how close the pipes are placed. This cost item includes both material and labor cost for installation. References suggest costs in the order of 130-200 SEK/m^2.

Space for indoor equipment

The investment is influenced by the type of space needed in each case. Sometimes it may be necessary to build a completely new technical room, while in other cases an existing one can be used. The cost for this is in the range zero to 70 000 SEK.

Indoor equipment

The indoor equipment according to FIG11, with a control system included, mostly depends on the size of the system. This cost is rarely specified in references but may double the cost for the HHP pipe system.

Additional cost for reconstruction

In the case of a reconstruction there is a significant extra cost for first tearing up the top layer, and then restoring it. The same applies to football fields. This investment is "site specific" and therefore difficult to assess.

Design and procurement

In general, there is a cost for design and procurement. This can be part of a turnkey project in which the contractor does the design. It can also be a consulting cost for the customer in the form of tender documents, etc. Either way, experience shows that this cost is approximately 5-10 % of the total sum. In TABLE 4, some investment examples taken from literature data are compiled.

Table 4: Examples on investment costs for ground heating systems using district heating

Location and construction year and source of heat	Investment (SEK/m^2)	Covered area and type of application	Reference
Boden,1997 (DH)	1 010	4950 m^2, inner city	Gustafsson et al 2006
Skellefteå, 2000 (DH)	1 300	1 700 m^2, ped. street	Gustafsson et al 2006
Göteborgsbacken, 2006 (DH)	1 600	6800 m^2 road pavement	Trafikverket 2014a
Piteå, 2006 (DH)	956	3 734 m^2, ped. street$^{1)}$	Gustafsson et al 2006

$^{1)}$ From tender documents

Considering then time factor it is likely that the total investment cost for new installations in a busy city environment would be in the order of 1500-2000 SEK/m^2 as of today. This includes tearing up an existing surface and replacing an old system with a new one.

11.1.2 Geothermal supplied systems

These systems can be divided into two categories, (1) those using GSHP:s in HVAC systems, and (2) those specifically constructed for the HHP system.

In category (1) there is an additional cost for the ground heating loop, in-door equipment and control system included. However, this is part of the HVAC investment cost of the building itself. Assuming that HHP system will only be run under slippery conditions it will typically not have an influence on the design and size of the GSHP system.

In category (2) there is an additional cost for drilling boreholes or wells to supply the systems with heat. This cost will include heat pumps to increase the temperature to a usable level. In the case of BTES the heat pump will typically cover the maximum power demand, while in ATES the heat pump would be used for peak shaving. The cost for boreholes and wells is dependent on site specific geological conditions and rock temperature, while the cost for wells is dependent on the type of aquifer and the groundwater temperature.

In TABLE 5 the design and cost estimates of an ATES and a BTES system is shown as an indicator for a system with the power of 500 kW.

Table 5. Estimated investment costs for geothermal HHP systems designed for 500 kW

UTES system	Flow rate (l/s)	Delta T Fluid (oC)	No. Wells/ Boreholes	GS Capacity (kW)	HP size (kW)	Investment cost (KSEK)
ATES	20	6	2+2	500	240	3 000
BTES	40	3	50	400	500	6 300

The table reflects the design and cost differences by using ATES systems compared to BTES. In the estimate the specific following specific costs has been used for ATES.

- Cost per well (lost filter completion, depth 40 m) well pump, sensors and well shelter included, 300 KSEK/well (1200 SEK)
- Cost for piping (300 m) shafts included 650 SEK/m (200 SEK)
- Cost for HP system (4 x 60 kW for peak shaving), pipe system and control system included 4000 SEK/kW (1000 KSEK)
- Cost for permit according to Environmental Law regulations, site investigations included, 600 KSEK

For the cost estimate of the BTES system the following specific costs has been used.

- Cost per borehole (depth 260 m), U-pipes included, 80 SEK/ borehole (4000 SEK)
- Horizontal pipe system (400 m), manifolds chambers included, 200 SEK/m (800 SEK)
- Cost for HP system (one unit 500 kW), pipe system and control system included 2500 SEK/kW (1500 KSEK)
- Cost for permit is negligible

The specific cost used above shall only be used as indicators and are values obtained from several contract offers of equal sized ATES and BTES systems the latest two years.

11.2 Energy cost

11.2.1 District heat supplied systems

Most district heating suppliers have tariffs consisting of several cost components. For energy companies that use cogeneration and/or waste heat in their networks, the energy fee typically varies over the seasons with significantly higher winter tariff and lower summer tariff.

According to statistics from Energiföretagen Sverige 2023 the average cost for larger clients is approximately 950 SEK/MWh, VAT included (Energiföretagen 2023).

District heating suppliers do not distinguish between the heat being used for heating streets or homes. However, a few suppliers may, e.g. lower the capacity fees. Only one company has set a fixed tariff for ground heating (Stockholm Exergi 2023), but this tariff only applies for plants connected to the return pipes.

The annual use of heat will naturally vary from year to year. Also the location (climate) affects the energy use. E.g. in the inner center of Linköping with an average use of 360 kWh/m^2 (see former Table 2) and a heated surface of approximately 30 000 m^2, results in an annual cost of approximately 10 Million SEK.

Based on the mean heat consumption (300-350 kWh/m^2) it can be estimated that the system for city centers all together are using district heating to a value of 170-200 million SEK annually using the price for district heating in 2023. The variation seems to be high, and more statistics are needed for a better understanding of how it varies in different climate conditions and with various operational strategies.

As shown in chapter 10.2.2 football fields are a large users of district heating. A normal winter the average heat load is estimated to be some 800 MWh, resulting in an annual cost of 760 000 SEK per field. Altogether, the heated football fields, covering an area of 500 000 m^2 and a specific average usage of 150-200 kWh/m^2, would result in an annual energy cost of 70-95 million SEK. However, there are indications in the obtained data that placement of the heating pipes in turf pad will lead to less specific energy cost, even below 100 kWh/m^2, but that still has to be shown in future studies.

The cost for ground heating of Göteborgsbacken, with 6 600 m^2 á 200 kWh/m^2, would be 1,25 Million SEK in the 2023 price level.

11.2.2 Geothermal heat supplied systems

Since geothermal energy is free to use, the additional cost for systems already supplied with GSHPs is only the cost for the additional electricity used to run the HHP system. In an HVAC system with heat pumps, an SPF of 3-4 can be expected. Assuming that the price for electricity and district heating are the same, the operational cost for such HHP systems is 3-4 times lower than for systems heated by district heating.

For HHP systems directly supplied by GSHP, the SPF would be around 4 or more. The SPF is related to the supply temperature from the system can be kept at low temperature (+35°C). This means that at least 25 % of the supplied heat will be electricity while 75 % consists of geothermal heat free of charge.

In cases where groundwater is used as heat source to the heat pump system, even better SPF can be expected, due to the constant temperature of groundwater the year around. In these cases an SPF of 5 can be expected, hence 80% of geothermal heat.

One promising concept is the use of solar or waste heat that is seasonally stored in an ATES or BTES system. The SPF for BTES systems would probably be in the range 5-6, since it normally takes a full-sized heat pump at the heating mode. ATES is much more effective since the stored temperature can be directly used to a large extent and the heat pump would only be used for peak shaving. For this reason the SPF is expected to be on the order of 10.

It can be concluded that the electricity price together with the SPF determines the energy cost for operating geothermally supported HHP systems. From being extremely high in 2021-22 the spot electricity price in Sweden has decreased to be on the order 600 SEK /MWh in 2023. With all fees and taxes included this sums up to 1300 SEK/MWh (Nils Holgerson-gruppen 2023). Looking at the term prices for the next two years the spot price seems to stabilize at the same level as 2023, based on term trading in November 2023 (FIG 45),

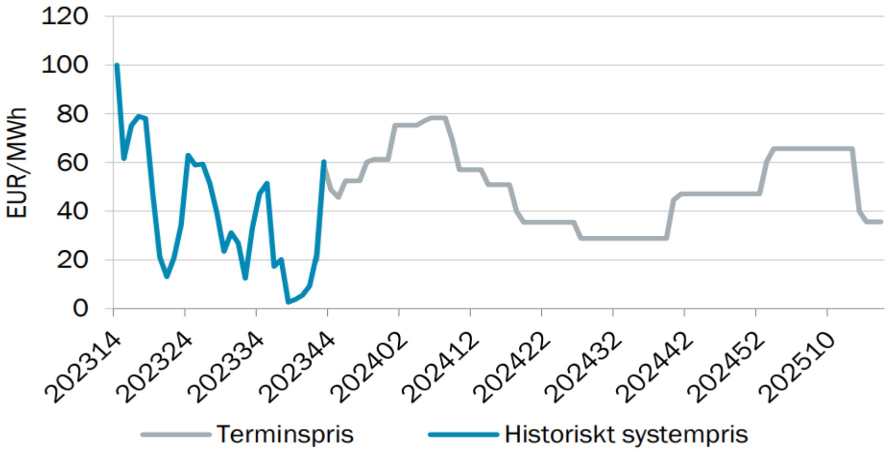
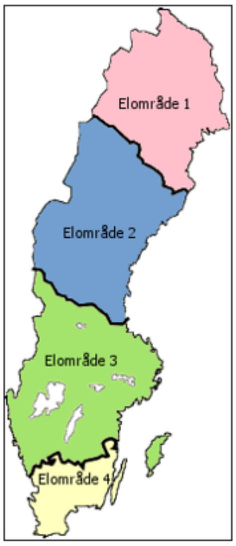


Figure 45: Current and predicted electricity North pole spot prices for electricity based on term trading (Elpris Prognos för 2023 och 2024 - Samt terminspriser (elpriser24.se)

However, in addition to the spot price, there is a network fee and various taxes, which all together sum up to more than twice the spot price. On top of this, there is also a price difference between four different price zones in Sweden. This has a large influence the operational cost depending on in what zone the HHP-system is operated in, FIG 46.



Price zone and representing city	**Term price 2024 (SEK/MWh)**	**Term price 2025 (SEK/MWh)**
SE1. Luleå	270	310
SE2. Sundsvall	270	279
SE 3. Stockholm	476	490
SE 4. Malmö	723	790
Mean value	**511**	**723**

FIG 46. Prognosis for electricity spot price for different zones 2024-2025 based om term trading (Elpris Prognos för 2023 och 2024 - Samt terminspriser (elpriser24.se)

As shown in the figure the spot price the next coming two years seems to be fairly stable in the northern and central part of Sweden, in which the HHP systems are most frequently used. Only the southern zone deviate with a large increase. This is due to several expected reasons, such as a shortage of local electricity production, shortage of distribution capacity from the north and price setting by import from European countries.

Based on the spot price for the zone 3, the prognosed spot price during the coming two years would be in the order of 485 SEK/MWh. By adding governmental taxes, network fee, and VAT the price for larger customers will remain practically the same as in 2023.

It is evident that there is currently a gap between the price for electricity and district heat in favor for the latter option. However, the history of energy prices has shown that there is a leveling out over time.

Below is a general example of energy use for geothermal systems with district heating as the reference system. The HHP area covers 1 000 m^2 with an annual heat demand of 325 MWh /325 W/m^2). It is assumed that the UTES concepts are charged by solar collection of heat and that the circulation of fluid in solar energy collection is included in the SPF. It is also conservatively assumed that the BTES concept has no direct heating at all, while the ATES concept has 50 % direct heating. The maximum supply temperature is in this case +35°C, even if the system can provide at least 50°C if required. The result of the calculation is presented in TABLE 6 .

Table 6. Estimated energy cost using geothermal alternatives with district heating as a reference system for a HHP area of 1000 m^2

HHP heating system	SPF (-)	Bought Energy (MWh)	Energy saving (MWh)	Energy cost (SEK/year)	Cost savings (SEK/year)
District heating	-	325	-	295 000	-
ATES	10	33	292	42 900	252 100
BTES	5	65	260	84 500	210 500
GSHP	4	82	243	106 600	188 400

The table indicates that the savings of using different forms of geothermal systems for heating would be in the order of 75-90 % compared to conventional heating with district heating. From a cost saving point of view these figures are 70-85 % using the price difference of today (2023).

Such a system would typically be designed for a power of 300 kW (300 W/m^2). Using a BTES system, which would be the most common alternative, the cost would in this case be on the order 3.8 million SEK, leading to pay-off time of approximately 18 years. Using an ATES system, which would be a rare possibility, would take an investment of an investment of 1,8 million SEK with a payback time of approximately 7 years. These figures indicate that conversion to geothermal heating systems may be an interesting alternative also for existing HHP systems, today heated with DH.

12 Environmental aspects

In this chapter environmental issues of importance are considered. These are focused on the greenhouse gas emissions caused by different HHP systems and the usage of salt to prevent slippery conditions. However, there may be other issues as well, not foreseen in this report.

The distribution systems are practically the same for any HHP application. The main difference is the way the heat is generated. For "conventional" systems the heat comes from district heating, for geothermal systems the heat is a mixture of geothermal heat from the ground and electricity from the grid. Of course, for electric systems it is electricity only.

12.1 Greenhouse gas emission

12.1.1 Swedish electric power mix

Swedish electricity production is a mixture of different sources (FIG 48). In total some 170 TWh is currently produced (2022). Of this, 30-35 TWh is exported, mainly to countries with fossil fuels in their own mix. The import in later years is some 10 TWh, mainly from Norway (Energimyndigheten 2022).

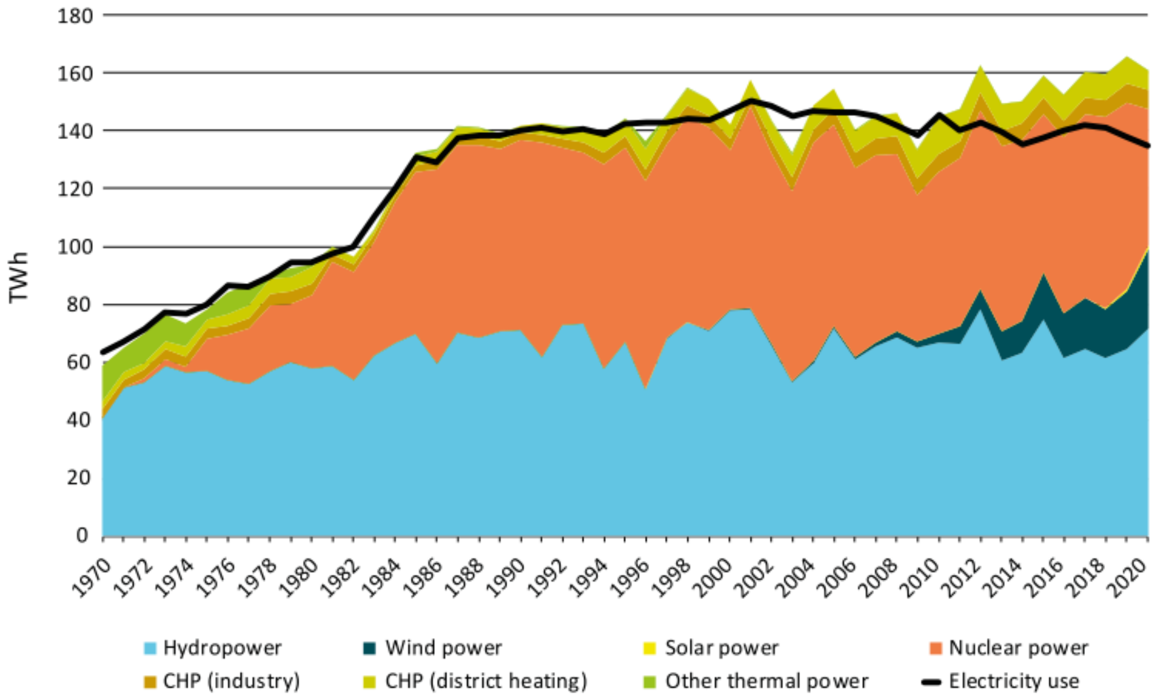


Figure 47: Net electricity production and electricity use 1970-2020 (Energimyndigheten 2022)

The figure indicates a slight increase of production over the latest 10 years, but also a decrease in usage due to the introduction of wind power. During the same period the use of electricity within Sweden is slightly decreased.

Roughly, the mix 2020 consists of hydropower (40%), nuclear power (35%) wind power (15%) and thermal power (10%). Solar is still a minor fraction but is rapidly growing to reach 1% in 2022-23 (Energiföretagen 2023).

Sweden is a net exporter of electricity with some 25 TWh annually over the latest three years (FIG 48). The main import comes from Norway (80%) and Denmark (20%) while the import contribution from other countries is negligible. Practically all Norwegian electricity is renewable (98%), while

Denmark has a more complex mix, dominated by 48% wind and with a fossil free part accounting for 67% (Statista 2023).

Figure 48 also shows that export is dominated by the other Nordic countries (some 80%), while a fraction of some 20% is exported through the Baltic transmission cables to Poland, Lithuania, and Germany.

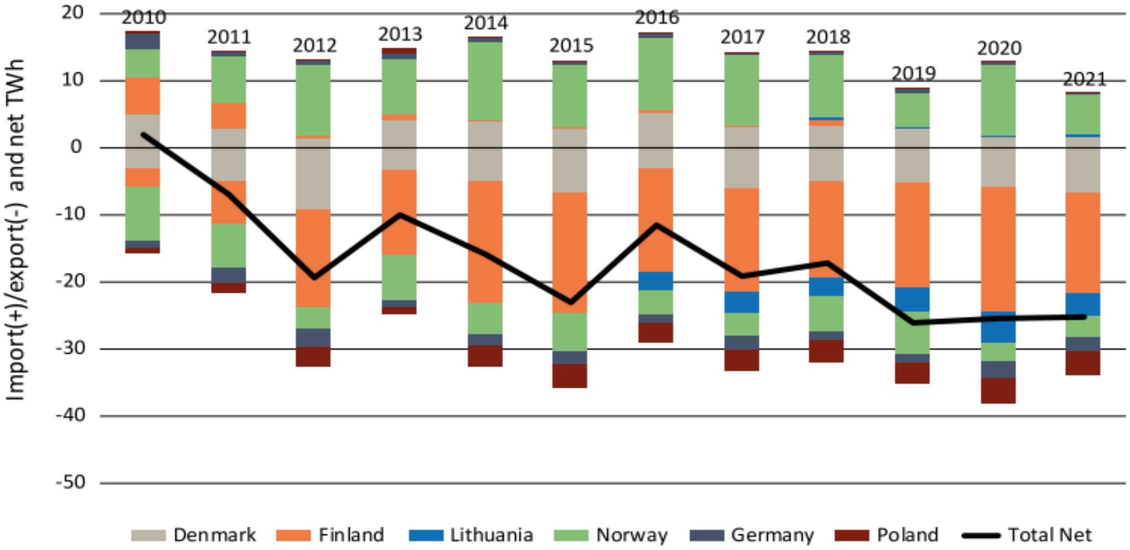


Figure 48. Electricity trade with other countries 2010–2021 (Energimyndigheten 2022)

It is not obvious how the Swedish mix should be evaluated in terms of greenhouse gas emissions. However, there are some older estimations that indicate 10 g/kWh (Energiforsk 2014 and SABO 2013). These were estimates without an LCC perspective. With LCC analyses included, the emission was estimated to be around 20 g/kWh (Message 2016) and 13 g/kWh (Energiföretagen 2017).

The latest information is an evaluation of the “fossil free” mix, stated as 4 g/kWh (Vattenfall 2023). This figure includes hydro, wind, nuclear and solar, and is said to be based on LCC analyses. This is also figures used in the political discussions (Sveriges Riksdag 2021)

The largest CHP (Combined Heat and Power) fraction comes from cogeneration plants that often use combustible waste as a heat source. This resource consists of approximately 67% non-fossil free products, such as plastic materials (Energiföretagen 2023). Based on the total CO2 emission (52 g/kWh) this means that the CHP emission from wastes is in the order of 35 g/kWh.

The emissions from the production of electricity imported to Sweden have already been accounted for in these countries respectively. For this reason it should not be a part of the Swedish mix. However, some authorities argue that the Nordic mix should be used at least for imported electricity.

By using specific CO2 emissions for the actual sources used in the Swedish mix the value has been estimated to 8,6 g/kWh (TABLE 7).

Table 7. Estimated annual CO2 emission from electricity production in Sweden 2020-2022

Energy Source	Fraction of production (%)	Specific CO2 emission (g/kWh)	CO2 Emission (g/kWh)	Source
Hydro	40	4,0	1,6	Sveriges Riksdag 2021
Nuclear	30	2,4	0,7	Sveriges Riksdag 2021
Wind	20	12	2,4	Sveriges Riksdag 2021
Biomass	9	35	3,6	Energiföretagen 2022
Solar	1	29	0,3	Vattenfall 2023
SUM			**8,6**	

Corrected for the import using the Nordic mix, 90 g/kWh (IVL 2017) the CO2 emission will increase to 14 g/kWh. This value is based on an estimated 6% of the electricity used in Sweden is imported (2020-2022). Considering that a minor part of this import is fossil free, an approximately value of 10 g/kWh has been used for the Swedish electric power mix in this report.

12.1.2 Systems supplied by district heating

Swedish district heating plants have greatly varying emissions of greenhouse gas depending on the fuel used for the production of hot water. In any case, a major source of emissions is the burning of waste.

The industry organization (Energiföretagen) has chosen to regard biofuel as renewable and waste as 33% renewable. According to this view the Swedish average CO2 emission for district heating is 52 g/kWh (FIG 49).

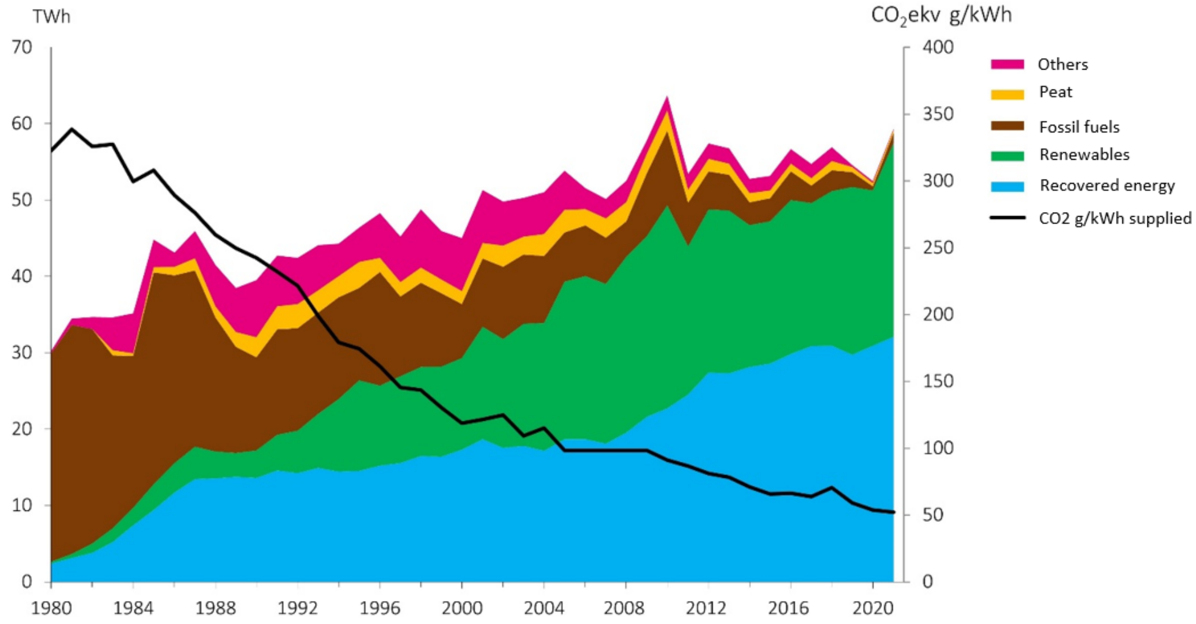


Figure 49. Energy input for district heat production 1980-2021 (Energiföretagen 2022)

To understand the diagram, “Recovered energy” is a mixture of fluid gas condensation, waste heat, heat from heat pumps, waste gases/residual gases and waste. “Renewables” are forest fuel, bio-oil/tall oil, while “Others” are electricity for heat pumps, electric boilers, and auxiliary electricity.

Even if there are different opinions of how the resulting CO2 emissions are calculated, a value of 50 g/kWh has been used for environmental assessment in this report.

12.1.3 Systems supplied by geothermal sources

According to the EU Directive on renewable energy (2007), heat extracted from the ground is renewable and can be assessed to have zero emission of greenhouse gases. However, to run such a system some electricity must be used.

From an LCC perspective, however, shallow geothermal borehole systems certainly have emissions caused by drilling of boreholes, manufacturing of drilling equipment and components used in the systems. On the other hand a geothermal borehole system has a very long lifetime, >40. For this reason the LCC emissions can be considered as very low and in practice very close to zero.

The use of electricity in the systems varies with the type of system being used. GSHP systems using geothermal boreholes as a source of heat will in most applications have SPF around 4-5 considering that the supply temperature is maximum +35°C. This means that 20-25 % of the heat comes from electric power.

In UTES systems with storage of solar heat or waste heat the SPF can roughly be estimated to have a considerably higher SPF. Using the same reference area as in Chapter 11.2.2 the CO2 emissions using district heat compared to geothermal systems is shown in TABLE 8.

Table 8. Estimated annual CO2 emissions using geothermal alternatives with district heating as a reference system for a HHP area of 1000 m^2

HHP heating system	SPF (-)	Energy use (MWh)	Spec. CO2 emission (kg/MWh)	Annual CO2 emission (kg)
District heating	-	325	50	16 500
ATES	10	33	10	330
BTES	5	65	10	650
GSHP	4	82	10	820

Regardless of assessment method, it is obvious that he CO2-eviquvalent emissions from geothermal systems are a small fraction of the emissions compared to district heating supplied systems.

Moreover, the same thing is true for several other environmentally harmful substances that are generated from combustion of different kind of fuels.

12.2 Usage of salt

A traditional way to prevent slipping is to use road-salt, mainly in the form of sodium chloride (NaCl).

In Sweden, the road network consists of about 100,000 km of state roads and about 42,000 km of municipal streets and roads (Trafikverket 2018).

About 200,000 tons of salt is spread annually on about 25% of the state road network. Approximately the same amount of salt is used by municipalities for their streets and roads (Eco Concept 2021). The salt is commonly spread as wet granules or as a liquid brine.

The salt forms a salty meltwater that is run off to stormwater, infiltrates into the groundwater, or flows directly into creeks, rivers, and lakes. This leads to locally elevated salinity levels that may affect both the fauna and the flora (SGU 2004).

In addition to a negative biological impact, road salt also leads to increased corrosion of metals, especially on cars, that come into contact with the salt. The same also applies to concrete pipes in stormwater systems (www.sverigesmiljomal.se). For the same reason, Trafikverket is concerned by the use of salt for snow and ice melting on railway platforms, railway crossings or railway switches.

Road salt is also considered to increase the risk of traffic accidents as some animals are drawn to salted roadways to lick salt. This has mainly been noted in northern Sweden, where about 2000 reindeer per year are lost in traffic accidents. However, it is unclear what proportion is due to road salt (www.Sametinget.se)

The alternative to salt is sand, but on busy roads the sand does not last very long and requires large quantities. Using sand requires extensive transport and thus is a source for larger emissions than for using salt (Trafikverket 2018).

In this chapter environmental issues of importance are considered. These are focused on the greenhouse gas emissions caused by different HHP systems and the usage of salt to prevent slippery conditions. However, there may be other issues as well, not foreseen in this report.

The distribution systems are practically the same for any HHP application. The main difference is the way the heat is generated. For “conventional” systems the heat comes from district heating, for geothermal systems the heat is a mixture of geothermal heat from the ground and electricity from the grid. Of course, for electric systems it is electricity only.

13 Legal aspects

There is currently no legislation prohibiting the construction of HHP systems within self-owned property. However, there may be obstacles within the framework of municipal planning, which in that case are written into the municipal comprehensive plans and later into individual detailed plans.

For the construction of geothermal energy systems, the legislation differs considerably depending on whether the system is closed or open.

13.1 Closed loop systems

Closed loop systems refer to boreholes for energy use, equipped with borehole heat exchangers (usually PE plastic U-pipes).

Closed loop systems must be reported to the municipality's environmental authority, which then examines whether the facility violates the Provisions of Ordinance on environmentally hazardous activities and health protection §17.

Usually, the municipality provides the permit for the facility within a maximum of five weeks. However, the permit is subject to certain conditions relating to the preventive protection of groundwater and its impact on the surrounding environment, the handling of drill cuttings and drilling wastewater. The permit usually also stipulates that drilling must be carried out by certified drilling personnel.

In inner protection zones for groundwater sources, permits for drilling boreholes are generally denied. In the outer protection zones, it is common for the municipality to prescribe backfilling of the boreholes in the same way as is mandatory in most Central European countries, for instance in Germany.

The permit also examines the so-called resourcefulness, namely that the energy boreholes are constructed within the owner’s property.

Exploratory boreholes drilled for design purposes do not normally require any permit at all.

13.2 Open loop systems

Open loop systems refer to the construction of geothermal wells for the extraction and reinjection of groundwater for thermal energy extraction/seasonal storage purposes. The wells are often less than 100 m deep.

The construction of groundwater wells generally requires a permit in accordance with Chapter 11, Section 1 of the Environmental Code. The permit covers both the extraction and the reinjection of groundwater in terms of quantities and hydraulic radius of impact arising from the operation of the plant.

Before an application can be written, extensive hydrogeological surveys must be made to describe the hydraulic properties of the aquifer. This includes, among other things, test wells and a longer period of test pumping. Based on the results, a hydraulic simulation model is used to define the hydraulic impact area. Finally, an environmental impact assessment is compiled, and this plays a central role in the permit application. The representatives for owned properties located within the influence area are given the opportunity to speak in the Environment Court where the case is decided at a hearing.

The permit process is both time-consuming (1-2 year) and costly, which is one reason that open loop systems are significantly less common than closed loop systems. Another reason is that the open systems have a restricted geographical potential. Still, they may be of interest to larger geothermal plants where available aquifers exist, and where they are not already used for drinking water supply.

14 Conclusions

There is no doubt that HHP systems prevent fall-related injuries and even deaths among pedestrians and this way save a considerable costs for the society. However, the actual numbers are not known since there is a lack of statistics of accidents with no vehicles involved.

The HHP applications using district heating as a source is significant. More than 1 million square meters are heated this way for different applications. The energy cost for the HHP systems is hundreds of million SEK annually. These facts open up a market for geothermally heated HHP systems of various kind.

The strength in systems using geothermal heat is the lower energy cost compared to systems supplied with district heating. Moreover, geothermal heat is 100% renewable. Another advantage is that geothermal systems are less sensitive to changes in energy price compared to the systems using district heating. Geothermal systems may also be applied in areas where district heating is not available as heat source.

GSHP systems specifically designed for HHP applications will use 75-80 % thermal energy that is cost free and still produces the same heating capacity as a system supplied by district heating. Hence, an additional investment in a GSHP system may be paid back in a reasonable number of years.

UTES systems with storage of heat from summer to winter will be even more favorable, even if a heat pump must be used. Such systems would preferably be applied for football fields, airports, and other open surfaces available for solar energy collection in the summer.

The lifetime of geothermal boreholes is 40 years or more for closed loop systems. Such boreholes can be drilled in almost any environment and geological conditions. The Swedish drilling companies have developed methods and ways to overcome most drilling obstacles that occur in dense urban areas. For this reason new establishments with HHP systems seem technically feasible. So will conversion to geothermal systems with already existing HHP applications.

From an environmental point of view a geothermal HHP system will have a fraction of greenhouse emissions compared to a similar installation using district heating. This is an advantage that is estimated to grow in importance over the next coming years.

From a technical point of view a geothermal HHP system is designed in the same way as any other hydronic system. The main difference is the geothermal heating source is 100% renewable and, in addition, free of taxes.

There are strong reasons to believe that geothermal HHP systems can be applied almost anywhere and used for new installations, as well as for conversion of existing district heating supplied systems, that are now too costly to operate.

From an energy cost perspective geothermal systems may initiate further growth of HHP installations on the traditional market but may also find new market segments for application, such as a supporting technology for deicing of railway switches and a broader use in the sports sector.

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