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UTES (Underground Thermal Energy Storage)—Applications and Market Development in Sweden

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Abstract: The market for shallow geothermal solutions has been continuously growing in Sweden and is recognized as a cost effective and environmental sound way for space heating. In later years, UTES (underground thermal energy storage) systems have become frequently installed for combined heating and cooling of commercial and institutional buildings. After 20 years, operational experiences of these systems are proved to be energy efficient, technically safe and profitable. In this paper, the current statistics of UTES applications are given as well as market trends and technical development. The goal is to encourage designers and installers in other counties to use this promising technology.

Key words: Shallow geothermal, energy storage, ground source heat pumps, underground thermal energy storage.

1. Introduction

Utilization of GSHP (ground source heat pumps) is by far the most common way of using shallow geothermal energy in Sweden, especially for single residents. It is estimated that more than 400,000 GSHP systems have been installed by the end of 2011. These systems extract some 10-12 TWh out of the ground annually, representing approx. 13%-15% of all heat used for space heating [1], making Sweden an outstanding country using this form of space heating [2].

The market for small scale GSHP seems to have leveled out the last few years. Instead, there is a steady growth of larger systems, often for combined heating and cooling. Since these systems are defined by storage of thermal energy, they are referred to as UTES (underground thermal energy storage) systems [3].

In UTES systems, thermal energy is actively stored in the underground. In most cases, the storage of thermal energy is seasonal. Typically waste heat from cooling of a building is stored during the summer to be used for heating during the winter. Vice versa, waste cold from the heat pump evaporators is stored from winter to be used for free cooling in the summer. The two systems that, since the late 1980: ties have penetrated the Swedish energy market are ATES (aquifer thermal energy storage) and BTES (borehole thermal energy storage). These systems have step by step grown on the market and are now totally commercial alternatives on the Swedish heating and cooling market.

Currently, UTES applications are steadily growing in number, and have become strong competitive systems especially for commercial and institutional buildings. As such they represents, a powerful alternative to other forms of heating and cooling such as oil, gas, biomass electric boilers and chillers, but occasionally also district heating and cooling. UTES systems are particularly competitive for cooling since

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there are few other alternatives except conventional chillers or connections to district cooling.

This paper presents an overview of the UTES systems applied in Sweden together with statistics on efficiency and market development. Some examples of applications in different market sectors are given as well as examples of technical improvements on design and construction over the last years. Finally, the current situation concern environmental, legal issues and is overviewed as well as economic aspects.

2. ATES Applications and Development

The principal for ATES is shown in Fig. 1. Typically, these systems are heat pump supported. The temperature is often 12-16 °C on the warm side of the aquifer and 4-8 °C on the cold side. Normally the systems can cover the total cooling load, but in some applications the heat pumps are used for peak shaving. It should be noted that modern heat pumps can be applied for cooling as well by switching the mode of operation.

In the design phase of such a system, the thermal balance between the warm and the cold side has to be considered in order to avoid a long term thermal break trough. This can be studied by modeling the thermal behavior of the storage. These simulations are based on comprehensive site investigations and are used to establish the number of wells, the distance between wells in the same group, and the distance between the warm and the cold side of the aquifer. Furthermore, the simulations give input to environmental impact studies that is a part of the legal handling of any planed ATES plant. An example of such a hydrothermal simulation is given in Fig. 2.

For detailed studies on how the static head in the aquifer reacts with respect to different flow rates, a 3D simulation model (Visual MODFLOW) is used. These simulations are necessary for establish the area of influence and are the basis for the legal assessment procedure that will always be an important permit item for the development of any ATES application.

Fig. 1 The principal of ATES, an open loop concept, where heat and cold are seasonally stored in an aquifer.

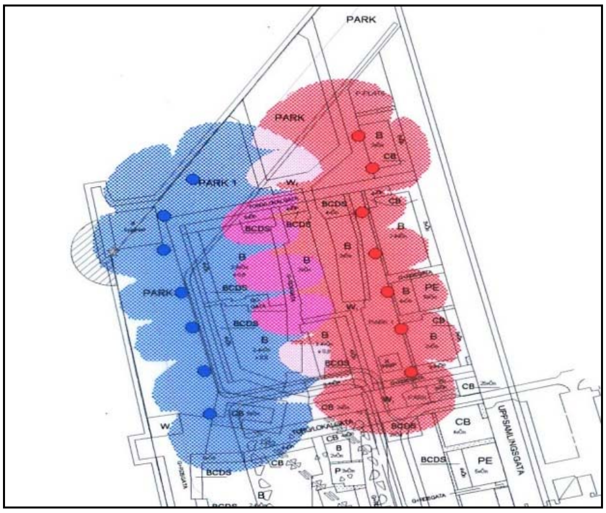

Fig. 2 A 2D CONFLOW simulation for placing the wells at the ATES plant Bo01 in Malmö [3].

The groundwater is always practically handled with a double flow direction in a separate airtight and pressurized loop. Heat and cold are transferred to the HVAC system by means of plate heat exchangers. During the winter season the warm side is pumped, heat is extracted from the loop and chilled groundwater is injected through the cold wells. During the summer season, the flow is reversed. The stored cold water is used for free cooling and the waste heat from that process is stored on the warm side of the aquifer. This type of system represents some 85% of the known Swedish applications. As seen in Table 1, the remaining 15 % are designed for storage of heat or cold only.

Table 1 Statistics for recognized Swedish ATES applications up till the end of 2011 [5].

Sectors of application	Heating/cooling	Heating only	Cooling only	Capacity (kW)
Commercial/institutional buildings	37	2	0	700
District heating/district cooling	6	2	4	4,500
Manufacturing industries	3	0	2	1,400
Telecom stations/offices	7	0	1	400
Totally	53	4	7	1,300

There is no official statistics and the 53 plants addressed in Table 1 come from the Sweco internal record of designed and realized plants, starting in the year 1983 [4]. However, a few of the older plants are known from publications originating from scientific reports (experimental and demonstration plants sponsored by the former Swedish Board for Building Research). Some of these are addressed in Ref. [5].

The largest plant is an ATES cold storage system taken into operation 1998. It is operated with connected to the district cooling in Stockholm and operated at a capacity of 14 MW. This is the only short term storage (day to day) and is used for peak shaving only. Another large and somewhat different ATES system is applied for Stockholm Arlanda Airport. It operates without heat pumps. The waste heat from cooling the airport is seasonally stored and used for preheating of ventilation air and snow melting of gates during the winter. It was taken into operation 2009 and the thermal capacity is the range of 6-7 MW [6]. In the year 2011, some 11 GWh of heat and cold respectively were produced from the system.

A rough estimate based on information from several sources such as the drilling contractors and heat pump suppliers indicates that there are at least 50 more plants in operation. However, the average size of these is less than for the ones presented in Table 1. Since these additional cases seem to be applied mainly on commercial buildings such as hotels and offices, the average capacity size has been assessed to be in the order of 600 kW. Based on this assumption, all ATES systems put together are estimated to have a thermal capacity in the order of 110 GW.

The number of ATES systems grew steadily with a couple of new plants per year up till the turn of the century. Over the last ten years, the number of ATES applications seems to have increased with 4-5 new plants per year. This is far from the growth compared to the Netherlands that have up a thousand of applications [7]. However, the exceptional market growth of ATES in the Netherlands is supported by a much higher geological potential as well as favorable incentives. In Sweden, the presence of suitable aquifers is limited to some 15% of land surface. Other important growth limiting factors are restrictions due to water supply and an extensive permit procedure that normally takes years. Furthermore, to have a project safely through the legal procedure, comprehensive and thereby costly site investigations would be an initial obstacle. For this reasons, a potential ATES user may drop the thoughts of ATES and turn over to the other UTES option instead, which is much simpler and faster to develop and realize.

3. BTES Applications and Development

The principal for BTES is illustrated in Fig. 3. These systems can be regarded as huge tube heat exchangers where a large number of densely spaced boreholes are representing the tubes. By circulating a heat carrier fluid (brine) through the boreholes, thermal energy is exchanged with the penetrated mass of soils and rocks.

The Swedish BTES boreholes have a dimension of 115-140 mm and are commonly 150-200 m deep. The BHE (borehole heat exchanger) is typically single or double U-pipes and the tubes are filled with a fluid consisting of water and bio-ethanol. The content of ethanol varies between 15%-27% that gives a freezing protection down from -10 °C to -17 °C. No solid backfill (grout) is required unless the systems are located to water protected areas, or at sites with specific

Fig. 3 The principle of BTES, a closed lope concept, where heat and cold are seasonally stored in a solid rock mass through a large number of densely spaced boreholes.

geological conditions. Instead the boreholes are filled with groundwater. The main reason for not using grout is that water filled boreholes are more thermal efficient than grouted ones. It is also more cost effective. Protection from potential groundwater contamination from the surface is obtained by installing a permanent steel casing that is sealed by grout at the bottom part according to a norm [8]. The boreholes are normally spaced in the range of 5-10 m and coupled in parallel and connected to field manifolds, from which major pipes are entering the building. The fluid is circulated to store or discharge thermal energy into or out of the underground. The storing process is mainly conductive and the temperature change of the rock will be restricted to only a few meters around each one of the boreholes. The rock temperature will typically swing between +2 ^{o}C at end of winter and +8 ^{o}C at the end of summer.

In the design of BTES systems, the load characteristics have to be fairly well established and one or several test drillings with TRT (thermal response tests) will describe the thermal properties of the underground, but to some extent also the local hydro geological conditions at site. The latter ones are of importance since flow of groundwater may have an influence on the storage efficiency.

Another important factor is the long term thermal balance. In some cases, additional heat or cold must be supplied to the storage (air or surface water).

The most common tool for designing storage is the simulation program EED (earth energy design). This program has shown to be used friendly and accurate enough for standard projects in Fig. 4. However, for larger and more complex designs, the model DST (duct storage) or TRNSYS with DST-module is sometimes used [9].

There is no official statistics on the number of BTES plants. Still, by combining several sources such as sales statistics of heat pumps, U-pipes, field manifolds, official borehole records at the Swedish Geological Survey, and verbal information from the main drilling contractors, it can be estimated that there are approx. 400 BTES systems in operation at the end of 2011 [1].

To be qualified for the statistics of the BTES applications the installation should contain at least 1,000 m of borehole length. Commonly the applications have 20-80 boreholes and 150-200 m deep. In average, the borehole length is in the order of 8,000 m. Put into applications with a heat pump, this size would generate some 350 kW of heat and 200 kW of cold. Based on these rough figures, the total thermal heat capacity of BTES installations, heat pumps included, would be in the order of 140,000 MW, while the free cooling capacity would be in the order of 80,000 MW.

The largest Swedish BTES plant so far consists of 163 boreholes with an average depth of 230 m. It was taken into operation in 2004 and serves a number of buildings connected to the University of Lund. The capacity is roughly 1,800 kW of heating and 1,100 kW of free cooling [1].

A minor fraction of BTES plants are for storage of heat only. As heat sources surface water, out-door air or exhaust ventilation air are used to be stored at a temperature of 15-20 ^{o}C during summer and recovered during the winter season. Compared to traditional GSHP solutions these applications are limiting the number of boreholes and the space between boreholes that will bring the investment cost down. For high temperature applications, there is one plant connected to solar collectors and one for storage of industrial waste heat in operation [10].

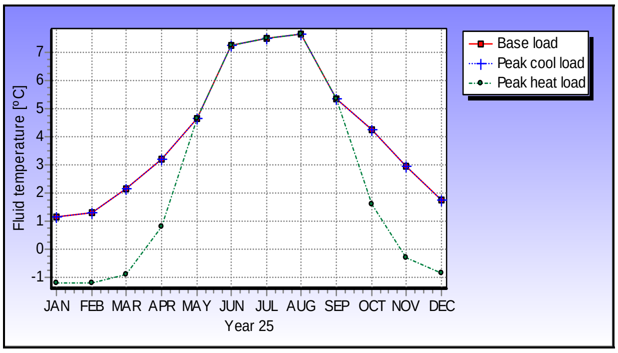

Fig. 4 In the most commonly used simulation model EED, different borehole configurations, space between boreholes, number and depth of boreholes can be simulated as a function of thermal loads and thermal properties of the underground.

Except for a large number of the BTES systems used for cooling in the telecom sector, there is so far only one system applied for industrial process cooling. This is an 850 kW free cooling system for chilling an electric generator at a cogeneration plant in Karlskrona. In this case, cold from the air is seasonally stored in BTES system with 120 boreholes, representing 21,600 m [1].

In general, applications of BTES systems are to the major part found in the commercial and institutional building sector, where it has become a natural and competitive option for the supply of heat and cold. The systems are typically installed in new buildings that are used as offices, stores, hotels, hospitals, schools and libraries. There is also an increasing utilization when older buildings in the same sector are being refurbished. Since cooling in residential buildings is rare, this section has yet only a few BTES applications. However, there is a clear tendency that new single houses have started to install air-conditioning together with GSHP system, making them turned into minor BTES concepts.

A recent frequent user of UTES for new store establishments is IKEA. Up till now there are six UTES applications in operation and two under construction. As can be seen in Table 2, the dominating system is BTES. During the upcoming four years there are far reaching plans for another 6-7 UTES installations [4].

In the IKEA stores, the need for cooling is in the same order as the need for heating. For BTES concepts the free cooling is limited to some 75%-80% of the need, while the peak load is covered by running the heat pump as a chiller. The heat pump is designed to cover some 50%-60% of the heat load, and supply the building with 80%-90% of heat demand, while the peak load is covered by an electric boiler.

4. Recent Technical Improvements

It was known early on that ATES applications are sensitive for clogging and corrosion of wells and other system component. This problem was studied in the 1990: ties within the frame of International Energy Agency, the implementing agreement for ECES (Energy Conservation through Energy Storage). The processes that cause clogging and corrosion were defined and guidelines for minimizing such problems was developed [11].

The main lesson learned is to design the wells carefully in order to avoid large draw down and hence pressure drops and to always keep the groundwater loop under pressure. By this measure stripping of gas and entrance of air to the loop is prevented and clogging by precipitation of dissolved iron minimized, as well as an enforced corrosion potential. These preventive measures have gradually been adopted by the ATES designers and installers by know-how transfer and first attempt for education of drillers and designers has been made in the EU-project Geotrainet [9, 12].

Table 2 UTES installations for IKEA stores and buildings in Sweden [5].

Name of store or building	UTES type	Start of operation	Installed capacity (kW)	Borehole length (m)
Torsvik distribution center	BTES	1999	130	1,800
IKEA office, Helsingborg	BTES	2003	370	5,200
IKEA Store, Karlstad	BTES	2007	1,000	14,000
IKEA Store, Uppsala	BTES	2008	1,300	18,000
IKEA Store, Malmö	ATES	2009	1,300	(5 + 6 wells)
IKEA Store, Helsingborg	BTES	2010	1,200	14,400

When it comes to well technology, nothing much has been developed the past decade. In most cases screened wells with formation filters are used in eskers and other glaciofluvial deposits. In consolidated sedimentary rocks simple “open hole” wells are applied. For treatment of wells the former method of using acid has totally been replaced by mechanical treatment methods. One such advanced method is using high speed rotation combined with high pressure jetting. This method, called Jet Master, and developed by Etschel Brunnenservice AS, has proven to be very efficient for development and cleaning of screened wells. An example of the treatment results of six wells at the Stockholm Arlanda Airport ATES plant is shown in Fig. 5.

The treated wells were back to their original efficiencies and in five cases even slightly better. At construction, these wells were developed by air lifting that is the most common method. It is obvious that the combination of vibration and high pressure of the water jets is more efficient than the air lift method. It should be noticed that the jetting treatment requires that the well is pumped during the process.

A substantial recent improvement of ATES is related to the rapid development of the control and monitoring systems that are applied now a day. Potentially, the UTES systems can be equipped with sensors that make it possible to closely monitor the functions from a computer screen. It is also possible to have alarms on parameters that indicate malfunctions on almost any kind. In Fig. 6, an example of a modern control and monitoring system is shown applied to an ATES system.

Frequency controlled circulation pumps are also commonly used in BTES systems. However, in this type of systems, the flow rate is more narrowly steered due to fact that the BHE always requires turbulent flow in different regimes.

A former technical problem for BTES has been to get rid of the air in the closed loop system, especially the large ones with several cubic meters of fluid. By

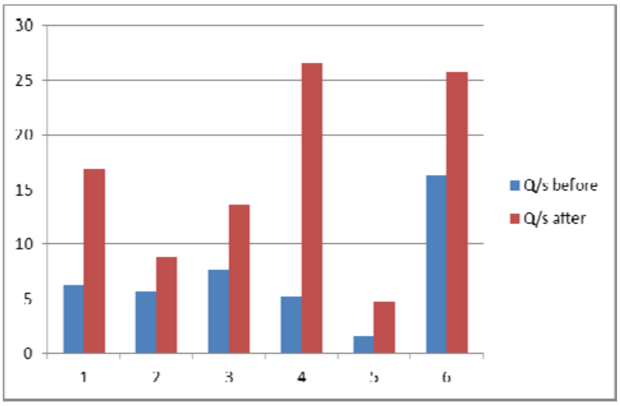

Fig. 5 Specific capacity (L/s per m draw down) before and after Jet Master treatment of six screened wells at the Stockholm Arlanda Airport ATES plant.

installing simple degassing valves, most of the air can be removed before starting the circulation. However, micro bubbles of gas will still be a part of fluid. By experiences, this will somewhat limit the system efficiency. To solve that problem, automatic vacuum gas removers are installed in recent larger BTES plants. This type of equipment works by continuously remove gas from a small portion of the flow. This method has proven to be an effective way to avoid problems with air in the BTES loops.

Water filled boreholes in which single or double U-pipes (BHE) are installed is fully accepted by the Swedish authorities. However, in special cases the authorities require tight boreholes, preferably by solid grout. Since grout limits the thermal efficiency, an alternative to grout has been developed. This BHE consists of a capsule inside which a centralized single pipe is installed (a single or double U-pipe).

By applying a hydrostatic overpressure in relation to the static level in the borehole, the capsule is pasted towards the borehole wall and effectively tightens it (Fig. 7). Field tests have shown that an overpressure of 0.3-0.5 bar is enough to keep the borehole tight [13]. It has also been shown by experiments that the thermal borehole resistance will be favorable low [14]. So far this BHE has been installed in approximate 200 boreholes. An advantage compared to grouted boreholes is that the function can be controlled and the capsule replaced if it starts to leak. Another is that the

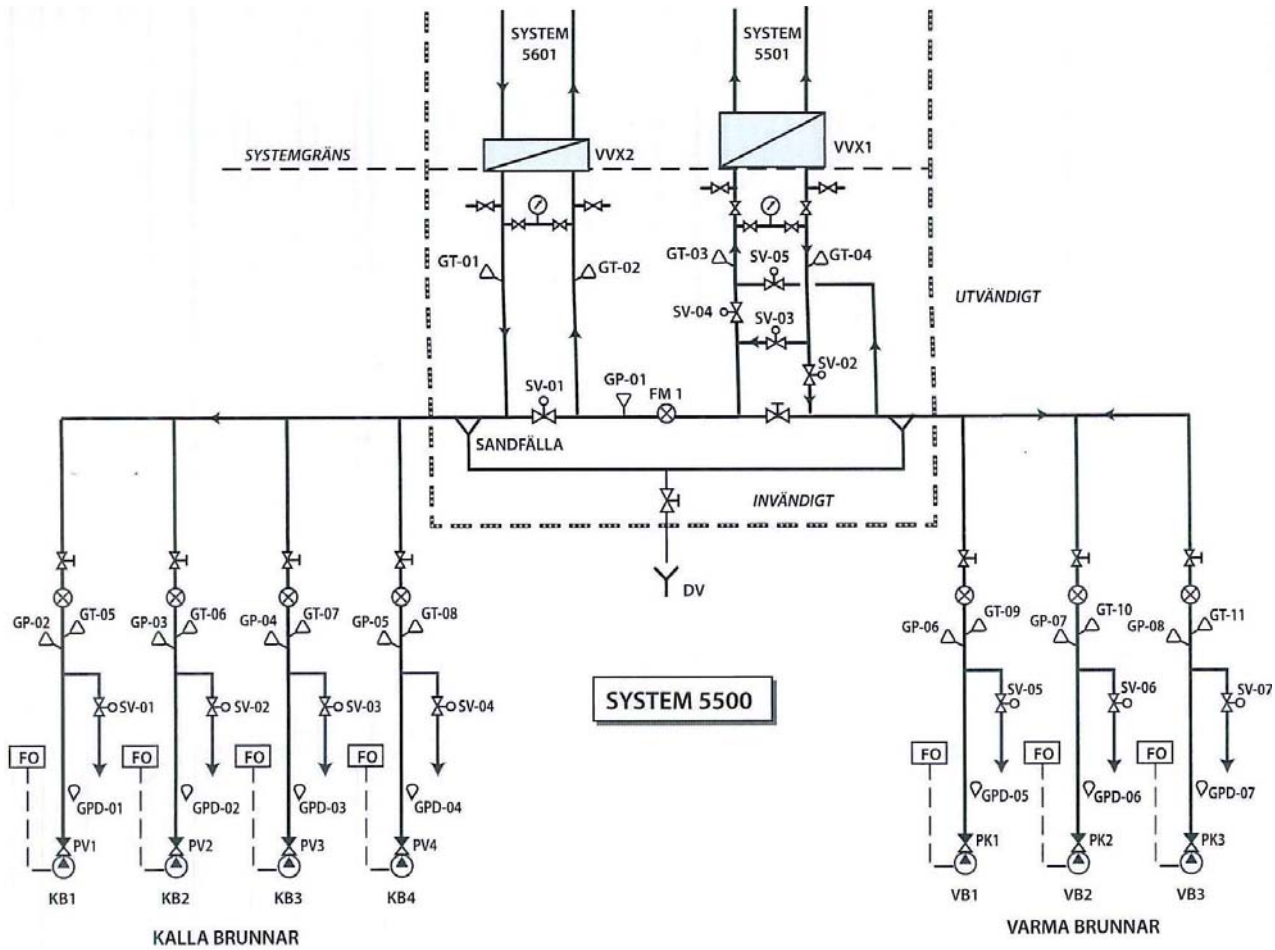

Fig. 6 An example of an ATES flow chart with controlling and monitoring equipment. In this case the pumps in wells are frequency controlled (FO) in order to save electricity (from design of The New Prison ATES plant in Helsingborg 2010).

capsule is thin and does not reduce the thermal efficiency to a detectable degree. The capsule is still under development and not yet fully accepted by authorities.

The boreholes in BTES systems are expected to have a technical life of 50-100 years. This is probably fulfilled, but one sensitive component in the system is the field manifold. The humid inside of traditional manifolds represent a corrosive environment that may cause corrosion of valves and other sensitive components. Moreover, they represent very narrow and inaccessible working places. For these reasons, a new more spacy and environmentally safer field manifold has been developed and introduced on the market (Fig. 8). It consists of a large size plastic tube in which manifold pipes are placed. Each individual borehole is connected to these pipes together with an adjustment valve and a flow deviser meter. The manifold system is placed below surface with an up sticking entrance, through which you can climb down on a ladder. Furthermore, it is heated and ventilated and has light installed.

5. Environmental, Economic and Legal Aspects

Due to a high SPF (seasonal performance factor) that will typically be in the order of 5-7 for ATES and 4-6 for BTES applications, the energy savings are substantial as shown in Table 3. This will of cause be an environmental benefit in comparison to heat and cold derived from other sources. Still, there is an ongoing discussion on the environmental value of electricity that has to be used to run the systems. At

Fig. 7 The capsule comes to the site folded and is easily installed in the borehole by help of a bottom weight.

Fig. 8 The new type of field manifold, that was first applied at IKEA Helsingborg 2010.

present there are two sides, one representing the view of the established district and heating cooling sector, and one representing the interests of the shallow geothermal sector. The former side claims that each kilowatt hour of electricity should be classified as marginal ("dirty") since it originates from coal fired plants outside Sweden. The shallow geothermal sector side claims that the environmental value of electricity shall be based on the actual production in Sweden. There are currently no official guidelines. However, a couple of court decisions state that using green electricity for peak shaving in UTES plants is acceptable [1].

From an economic point of view, most UTES systems have calculated pay-back times less than 10 years. However, for economic comparison between UTES and other alternatives, a LCC (life cycle cost) analysis is recommended as a true tool for profitability estimation. This is especially of importance for BTES applications where the boreholes with a long technical life time, represents about half the investment cost complete system for production of heat and cold. Still, the common way to analyze the profitability is by using the straight payback time method as shown in Table 3. The table is based on projects realized within the last 10 years. Direct use means heating and/or cooling in systems without heat pumps or chillers. The efficiency and energy saving values originate from calculations in the designing stage. The specific investment costs are calculated based on contractual sums.

From a legal point of view, there is a large difference between developing an ATES and BTES application. ATES applications have to be examined and proved in the Environmental Court according to the Environmental Act. Extensive technical descriptions of the system and an environmental assessment description consider all possible local impacts based on simulations have to be delivered to the Court. After consultations with potential opposite interests a final negotiation concludes the process that may take a full year to proceed and finalize.

Table 3 Ranges of efficiency, energy saving, specific investment and payback time of UTES applications in Sweden.

Type of UTES system	Efficiency (SPF)	Energy saving (%)	Spec. invest. (KSEK/kW)	Payback time (year)
Heat pump supported ATES	6-7	85-90	8-10	2-4
Direct h/c with ATES	40-60	95-98	6-8	1-3
Heat pump supported BTES	4.5-5.5	75-80	12-18	6-8
Direct h/c with BTES	20-30	95-97	9-13	4-6

A permit for BTES is much simpler due to the fact that groundwater is not a part of system. BTES projects are handled by local environmental authorities and they can deny a realization only if there is a risk for people's health and/or severe environmental damages. In areas that are protected due to water supply wells, the authority often conditions the BTES plant to have grouted or with other methods sealed boreholes. The same condition is given if there is a risk that the borehole enters fractures with fossil salt water that may be introduced to sweet groundwater at a higher level. This situation may occur close to coasts of Sweden, some parts of middle Sweden, and occasionally also specific sites with sedimentary rocks.

6. Conclusions

UTES concepts are steadily growing and have become commercially compatible alternatives for heating and cooling on the Swedish energy market. The main applications are so far connected to commercial and institutional building sector. By the end of 2011 some 250,000 MW has been installed. The current tendency indicates that BTES applications will continue growing with a rate of 10%-20% the next coming years. ATES applications expect to have a slower growth due to less geographical potential, but also to a time consuming legal procedure.

From a technical point of view, the ATES systems have gone through a continuous development of well design and well installations. This development has resulted in increased well efficiency and measures have been developed to prevent from clogging and corrosion. Development of advanced controlling and monitoring systems makes the systems easy to optimize and monitor. However, proper maintenance programs are still to be developed and standardized.

BTES applications have step by step seen a technical development as a natural part of the market growth. Failures that were common in the past are nowadays considered and the modern systems are running with a minimum of failures. However, the BTES technology is still under development, especially when it comes to drilling the procedure and different components in the systems, such as borehole heat exchangers.

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