

# Heating and Cooling with UTES in Sweden - Current Situation and Potential Market Development

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## KEY-WORDS

UTES, applications, market position, economy, legislation

## ABSTRACT

Underground Thermal Energy Storage (UTES) applications have slowly gained acceptance on the Swedish energy market. Two UTES concepts are successfully implemented; the ATES (aquifer storage) and the BTES (borehole storage) systems. Also snow storage in pits or caverns has reached a commercial status. The number of ATES has steadily grown to 40 large-scale plants at the end of 2002. The systems are usually designed for cold storage in district cooling application, but industrial process cooling is also common. The economical potential in terms of straight payback time is usually very favourable. However, there is still a certain risk for operational problems that might jeopardize the calculated profit. Well clogging problems and system control remain as R&D issues to be solved. From a legislation point of view any ATES application needs a permit. The process of obtaining a permit has become complex and time-consuming since a new act on environmental assessment was put into effect in 1999.

BTES systems are normally used in smaller applications. At the end of 2002 there were more than 200 installations comprising more than 10 boreholes. The majority of these are applied for space cooling of commercial or institutional buildings and for process cooling within the telecommunication sector. From a technical point of view, BTES are much simpler to construct and operate than ATES. Furthermore, they can be applied in almost any kind of geology. Another advantage compared to ATES is that the permitting procedure is much simpler. The major market obstacle is that the profitability is not always acceptable if calculated as a straight payback time. To increase the market potential, there is a need for further R&D on improvement of borehole heat exchangers and of more effective drilling methods.

Snow storage is still a new technology though the Sundsvall snow storage plant has been operated successfully for several years. This good example has inspired several pre-studies of new snow storage plants. These have shown that snow storage is feasible in various sizes and in different applications.

## 1. INTRODUCTION

The Swedish Council for Building Research (BFR; until 2000) and the Swedish Research Council for Environment, Agricultural Sciences and Spatial Planning (FORMAS, from 2001) has supported the development of different techniques for energy conservation since the oil crisis in mid 1970's. Within this research program for Underground Thermal Energy Storage (UTES), a number of different concepts have been experimentally and theoretically tested and evaluated [1]. All of these options use soil or rock for storage of thermal energy (Fig. 1). In recent years another storage technology has been developed namely storage of snow or ice in caverns or pits for cooling purposes [2]. Today, storage in aquifers (ATES) and boreholes (BTES) have reached a broad acceptance for heating and cooling on the Swedish energy market.

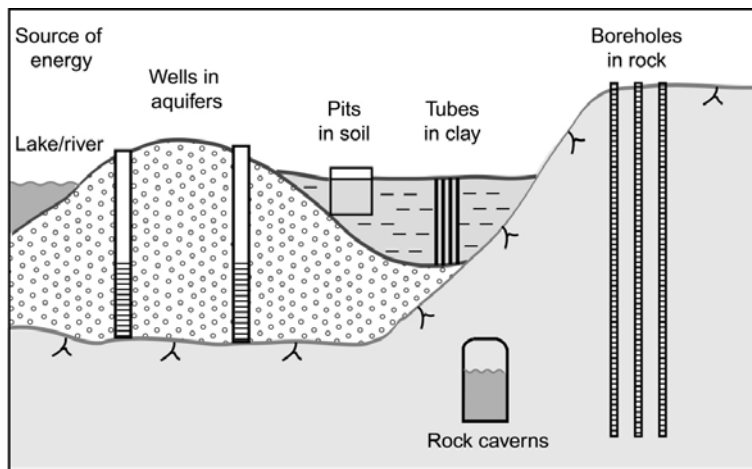


Figure 1: Different options for UTES systems that have been tested and evaluated in Sweden

## 2. ATES APPLICATIONS

The ATES systems being used in Sweden can be divided into four basic configurations (Fig. 2). In the simplest system (A), ground water is directly used for preheating of ventilation air during the winter and for cooling during the summer season. In this case heat and cold from ambient air is seasonally stored in the aquifer at a temperature level of approx. +5 °C (winter) and +15 °C (summer). More commonly used is the heat pump supported system (B) that works the same way as system A. However, the production of heat is much larger and the temperature change is somewhat greater. System C represents an early type of ATES applications where surface water is used as a source of energy for the heat pump. This heat, at a temperature of 15-20 °C, is stored during the summer and used during the heating season. The fourth system (D) is similar, but in this case cold from the winter is stored to be used for district cooling.

Of these systems, heat pump supported combined heating and cooling applications (system B) are dominating (65 %). However, in recent years, there is a growing interest for storage of natural cold (system D), which is used for district cooling applications or for industrial cooling.

In table 1 the recent statistics of ATES utilisation are presented. It is seen that the technology is preferably used for commercial and institutional buildings from small scale applications to large scale utilisation in district heating and cooling. In the industry sector only a couple of systems is applied for manufacturing industries. The rest represents cooling of telecommunication installations.

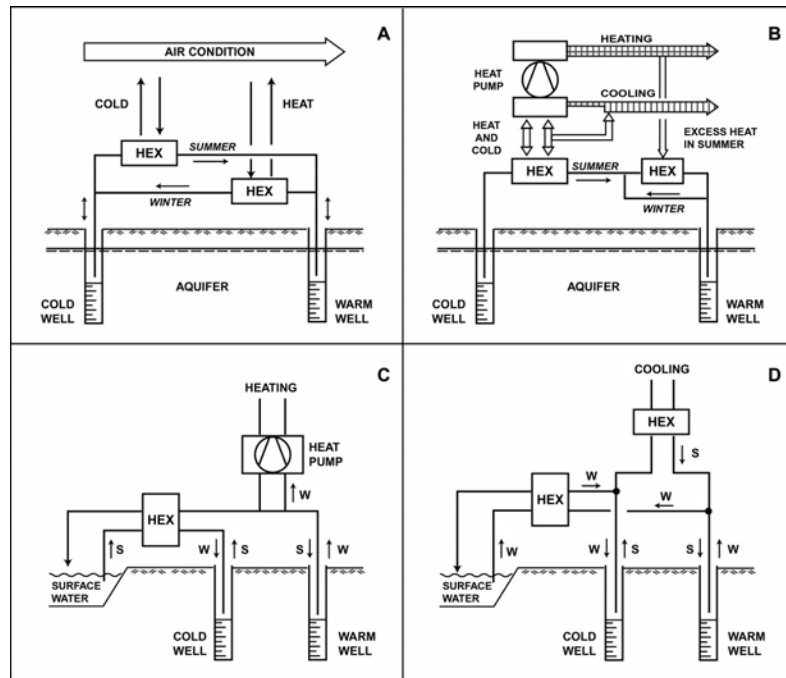


Figure 2: The different ATES systems currently being used in Sweden. (A) Direct heating and cooling without heat pump (B) Heat pump supported heating and cooling (C) Heat pump supported heating only and (D) Storage of natural cold for cooling only

The currently designed total storage capacities are in the order of 40 MW for heating and 70 MW for cooling. A rough calculation on the yearly energy turnover, based on designed values, indicates a storage heat utilisation of 120 GWh while the utilisation of cold is about 80 GWh.

Still, high temperature ATES projects are lacking in Sweden. However, recent feasibility studies of two large-scale applications have yielded promising results. In both cases these projects are related to storage of waste heat.

A survey within Annex 13 of IEA ECES IA revealed that 40 % of the plants have had or have operational problems or failures [3]. The major part of these has been solved by fairly simple measures. However, approximately 15 % have continued difficulties with well capacities. The dominating reason is clogging of the wells mainly caused by iron precipitation. These wells have to be treated from time to time. Other common problems are corrosion and malfunctioning control systems. In general, these types

Table 1. Updated statistics of ATES plants in Sweden (January 2003)

UTES system For illustration, see Fig. 2	Number of plants	Average storage capacity (MW)		Utilisation sector (Number of plants)				
		Heat	Cold	Com/Ins building	District heating	Combined DC/DH	District cooling	Industry <sup>1)</sup>
A. Direct heating and cooling	1	0.3	0.3	1	-	-	-	-
B. Heat pump supported heating and cooling	25	1.30	1.45	15		4		6
C. Heat pump supported heating only	5	1.9	-	1	4	-	-	-
D. Cooling only	7	-	6.9	-	-	-	4	3
Total	38	-	-	17	4	4	4	9

1) Process cooling of telecommunication stations included

of problems are now clearly identified and understood, and are therefore less common in newer plants. The research in Sweden has been focused on geodata collection by test drilling as one important part for proper well and system design. The objective with this work, which was carried out at the Lund Institute of Technology, was to create guidelines for site investigations related to ATES design [4]. These guidelines are part of a more extensive work with UTES guidelines that takes place within Annex 13 of IEA ECES IA. These cover all aspects of design, construction and maintenance of UTES wells and boreholes and will be published during the autumn 2003.

From 1999, a new legislation (The New Act of Environment) was applied. This Act has complicated the ATES permit procedures in Sweden and it has become an obstacle for some potential ATES projects. However, the environmental benefits in terms of energy conservation and economics (see Table 2) will probably still favour a further growth of ATES projects in Sweden, especially for large-scale systems.

Table 2. Performance Factor (PF), energy saving and pay back time for ATES installations in Sweden

<i>System application (see figure 2)</i>	<i>PF</i>	<i>Energy Saving (%)</i>	<i>Pay Back (years)</i>
A. Direct heating and cooling	20-40	90-95	0-2
B. Heat pump supp.heating and cooling	5-7	80-87	1-3
C. Heat pump supported heating only	3-4	60-75	4-8
D. Direct cooling only	20-60	90-97	0-2

### 3. BTES APPLICATIONS

The BTES systems in Sweden originate from the older ground-source heat pump systems where heat is simply extracted from deep boreholes in the rock. The waste cold generated in the rock during the winter season can be used for direct cooling (without a mechanical refrigeration cycle) during the summer season. This system, type A in figure 3, has become fairly common. In the mid 1990's there were about 20 installations. At present time the number of installations is estimated to approx. 200 plants.

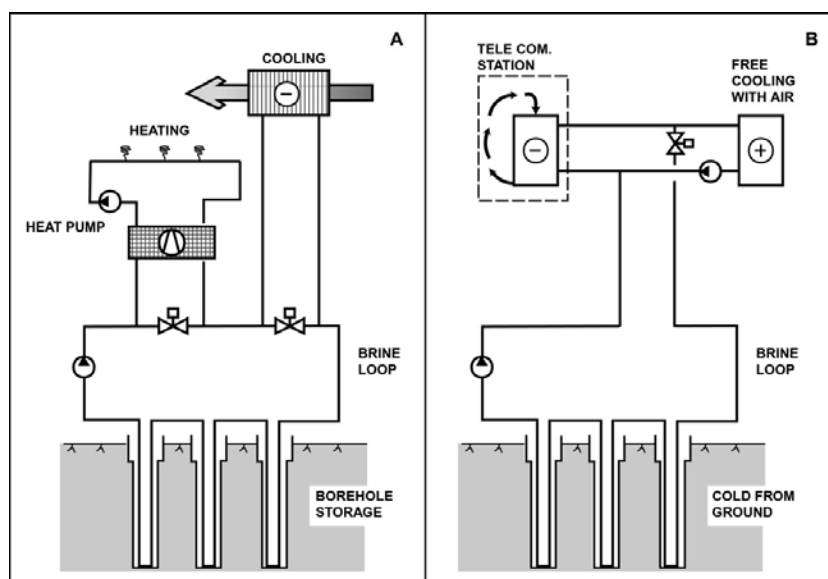


Figure 3: The dominating BTES systems in Sweden (A) Heat pump supported combined heating and cooling, and (B) Dumping of heat with passive recharging (for telecommunication installations).

The typical heating and cooling capacity is 50-250 kW using 10-50 boreholes drilled to a depth of 100-200 m. The applications are mostly for commercial buildings (offices, hotels, supermarkets, schools etc). The market potential for type A is tremendous. Approximately 20,000 new ground-source heat pumps with boreholes are installed each year and these can quite simply be designed as small-scale BTES applications. In addition, the older ground-source heat pumps can in many cases be converted to utilize direct cooling in the summer.

It should be recognised that the "European" system for ground-source heat pumps with combined heating and cooling differs from the "American" system in the sense that the heat pump systems are not installed to be reversible, so that the heat pump can operate as a cooling machine during the summer. Instead, the cooling capacity relies on the waste cold that has been accumulated in the rock during the heating season. This cold is extracted as direct cooling during the summer with an energy factor of approx. 20-30.

In recent years BTES has become a standard system for cooling of telecommunication installations (type B in figure 3). The heat of the cooling process is transferred into the rock during the whole year or part of the year. This application is both technically and economically favourable [5]. Low operational energy consumption, low maintenance costs and high reliability are considered to be important advantages. So far, at least 25 stations have been equipped with BTES. Installed cooling capacities vary from 25 to 300 kW with a maximum supply of 20 °C from the boreholes. A couple of these systems have active charging of cold during the winter. There are approx. 1200 telephone switching stations in Sweden and many thousands of radio base stations (RBS) for mobile telecommunication systems. Based on the experiences so far, the market is judged to be huge, not only in Sweden but also globally

A similar application concerns TV broadcasting systems. These systems are to a large extent located to hills in remote areas and are cooled by electrically driven compressors to a considerable investment and operational cost. It is believed that cooling with BTES would not only take less investment and operational costs, but also increase the operational reliability compared to compressor cooling. The range of cooling demand is about 25-34 kW per antenna with a maximum supply temperature of 35 °C. There are currently 35 stations in operation with a total of 144 antennas and about 400 boreholes.

Combined cooling and heating with BTES as well as ordinary ground-source heat pumps have very few reported technical failures. The borehole heat exchangers are practically all of the single U-pipe type with groundwater-filled boreholes. These installations have, with a few exceptions, proved to work without any severe leaks or collapses. There are some reported cases with undersized systems where the active borehole length is too short. In these cases, the fluid temperature becomes too low for proper performance and may also lead to a completely frozen borehole, which has been observed to obstruct the fluid flow due to squeezing of the plastic pipes.

An important issue in the design of systems using borehole heat exchangers (BHE) is to find cost-effective methods to construct the borehole heat exchanger so that heat can be injected or extracted from the ground without excessive temperature differences between the heat carrier fluid and the surrounding ground. The heat transfer between the heat carrier fluid and the surrounding ground depends on the arrangement of the flow channels, the convective heat transfer in the ducts, and the thermal properties of the materials (pipes, filling materials, etc) involved in the thermal process. The current status of different designs, test experiences and theoretical studies of borehole heat exchangers are reported in [6], where areas for further research and development are suggested. Open coaxial borehole heat exchangers where the heat carrier fluid is in direct contact with the borehole wall gives the best heat transfer but may be unsuitable due to geochemical effects, environmental concerns (contamination path along the borehole) and unstable borehole walls. In the case of closed loops, the lowest thermal resistance between the heat carrier fluid and the borehole wall is found for borehole heat exchangers using multiple pipes (such as multiple small-diameter U-pipes or multiple peripheral pipes for downwards flow with common central pipe for upwards flow) and coaxial arrangements with soft liner.

Luleå University of Technology performs research on in-situ testing of thermal properties, Thermal Response Tests (TRT), of the rock mass, thus making it possible to design BTES systems with accurate number of holes, active depth and spacing [7]. As a matter of fact, TRT has recently become a standard procedure for design of larger BTES projects in Sweden. In addition, also the influence of groundwater on the performance of the system has been studied [8].

Since the BTES systems utilise closed loops in a limited region of the underground for the storage, they have a limited impact on the surrounding environment. Hence, in the New Act of Environment no permit is required. However, the regulations require a notification to be sent to the local environmental authority, which has the power to reject the proposal. In a few cases projects have been denied due to the risk of contamination of aquifers that are used for drinking water supply. A couple of communities are not allowing any BTES at all before they know more about the risks. These legislators relate their concerns to possible health effects due contamination of groundwater from the heat carrier fluid. Hence, the type of fluid to be used in the systems is currently a topic of discussion. Meanwhile, ethanol mixed with water is accepted by a majority of authorities.

The most common hesitation for BTES realisations is that the profitability is on the edge of being acceptable. In these cases the less favourable economics are either related to restricted supply cooling temperatures or poor thermal conductivity of the underground. As a consequence of that, too many borehole meters are required. However, there is a tendency that the customer values the long term environmental benefits more and more and also considers the long technical life of the boreholes and the low maintenance cost into the final calculation. The result of this way of thinking is that lately there are a number of cases in which BTES applications have been realised even if the straight payback time is more than 8-10 years. Under normal conditions, large scaled BTES applications for combined heating and cooling commonly will be paid back within 6-8 years.

#### **4. SNOW STORAGE SYSTEMS**

There is still only one large-scale snow cooling plant in operation in Sweden. It is located at the Sundsvall regional hospital and has now been in operation since 1999/2000. The stored snow volume has increased from 18,800 m<sup>3</sup> (2000) to 40,700 m<sup>3</sup> (2002). The utilised cooling energy in 2002 was 1126 MWh with a maximum cooling power of 1873 kW. During this year the snow storage covered 84% of the cooling demand and the total COP was 26.6. Several pre-studies for snow storage projects in Sweden have been carried out during the last few years. In most of these studies a combination of different cold sources are included. This means that e.g. surface water or cold night air is partly used to meet the cooling demand [9].

Two studies were made for comfort cooling of paper mills, ASSI, Piteå (6000 MWh during the summer, cooling power 2500 kW, snow storage volume 100,000 m<sup>3</sup>, and SCA, Obbola (1400 MWh, 1650 kW, 80,000 m<sup>3</sup>). Four studies were made for district cooling (DC) applications: Luleå/Porsön DC (cooling demand 15,000 MWh, power 2 MW (winter) and 6 MW (summer), snow storage volume 300,000 m<sup>3</sup>), Sundsvall DC (8000 MWh, 7 MW; 125,000 m<sup>3</sup>), Gävle DC (4 MW, 150,000 m<sup>3</sup>), and Hudiksvalls DC (7400 MWh, 3 MW, 180,000 m<sup>3</sup>). In the Hudiksvall system it was planned to store the snow in two rock caverns of 90,000 m<sup>3</sup>. A different system was made for cooling of ventilation air in the Kiruna mine (3200 MWh, 870 kW, 61,500 m<sup>3</sup>). Another study was made for process cooling of SSAB Hardtech, Luleå, 5350 MWh, 3 MW 121,000 m<sup>3</sup>.

The snow storage in Offer for cooling of root fruits showed that it was possible to build such systems in a small scale (6200 kWh, 13.5 kW, 400 m<sup>3</sup>)

The largest system designed so far is for a cogeneration plant in Luleå. The cogeneration plant is connected to the DH. During the summer the heat load is small while the cooling temperature gets higher. Here the electricity generation would increase by 2.4 MW per °C of lower cooling temperature. By decreasing the cooling temperature 13°C another 50,000 MWh of electricity would be produced during five months of the summer. This means 84 MW of cooling power from the snow storage and a

total cooling demand of 175,000 MWh. A snow storage volume of 3,200,000 m<sup>3</sup> would be required to meet this cooling load.

The Sundsvall plant has inspired to most of the performed studies but so far no decision has been made to construct a new snow cooling plant in Sweden. Most of the systems studied have been feasible from an economical, environmental and energy conservation point of view.

## 5. CONCLUSIONS

Two UTES concepts have reached a commercial breakthrough on the Swedish energy market, aquifer thermal energy storage (ATES) and borehole thermal energy storage (BTES) systems. Snow storage applications for cooling are under commercial progress.

ATES systems, realised in later years, are mainly related to large-scale projects, either for district cooling or for combined cooling and heating of commercial buildings. Operational failures are still quite common. The two main causes are clogging of wells and badly functioning control systems. However, new plants show a lower frequency of failures than older ones. This indicates an ongoing learning process. A new legislation, the Act of Environment, has proven to make it more difficult to obtain permits for ATES projects. This has led to a decline of ATES installations. On the other hand, the high efficiency and the environmental benefits from large savings of fossil fuel and electricity, combined with substantial profit expectations are in favour for a further growth on the market, especially for large-scale applications.

The number BTES installations are currently growing very fast. The applications are mainly related to combined cooling and heating of commercial buildings and cooling within the telecommunication sector. The potential for further market growth is expected to be very high in both sectors. In later years also the industrial sector has shown an increased interest for using these type of system for process cooling and for waste heat utilisation. Operationally, BTES systems are very reliable and take a minimum of maintenance. However, especially for cooling at low temperatures, the systems suffer from an ineffective thermal performance of the borehole heat exchangers. A further development of these will strengthen the economics of BTES and extend the range of applications to also cover cooling at lower temperature demands.

Snow storage is still a new technology though the Sundsvall snow storage plant has been successfully in operation for several years. This good example has inspired to several pre-studies of new snow storage plants. These have shown that snow storage is feasible in various sizes and in different applications.

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