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Large-scale Utilisation of Renewable Energy Requires Energy Storage

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Abstract

Most types of renewable energy are available when the demand is low. So, summer heat is available during the warm season, when heating demand is low, and winter cold is available when the cooling demand is low. Therefore, seasonal storage of thermal energy is important for the large-scale utilisation of thermal energy. Large-scale storage systems require large storage volumes. Such systems are therefore often constructed as Underground Thermal Energy Storage (UTES) systems. The UTES includes ATES, BTES and CTES i.e. thermal energy storage in aquifers, boreholes, and caverns. UTES systems have been developed during the last three decades and are now found all over the world. Sweden is one of the leading countries in this technology. This is underlined by the fact that borehole systems cover almost 20% of the Swedish heating demand. During the last decade it has been a UTES development towards larger systems for both heating and cooling. Here, different UTES applications are presented.

1. Introduction

Energy storage is necessary for the large-scale utilization of renewable energy. The reason is that renewable energy is abundantly available when the demand is low. So, heat is available in air, ground, and water during the warm season while the heating demand mainly occurs during the cold season. In a similar way the cold of the winter would be useful during the summer. Systems for seasonal storage of thermal energy are therefore used to balance the mismatch in supply and demand. Such systems could are also used to store industrial waste heat between the seasons. Since large volumes are needed for large storage volumes Underground Thermal Energy Storage (UTES) are commonly used.

Nature itself provides such storage systems between the seasons since thermal energy is passively stored into the ground and groundwater by the seasonal climate changes. Below a depth 10-15 m, however, the ground temperature is not influenced and equals the annual mean air temperature. So, mean temperature of the ground is greater than the ambient air during the winter and colder than the air during the summer.

Consequently, the ground and also groundwater are suitable for heat extraction during the winter and cold extraction during the summer. Such extraction systems are often used both ways; for heating during the winter and for cooling during the summer. This means that the extracted heat is recharged during the summer and it becomes a storage system. If the system is unbalanced, i.e. if the heat demand is less or greater than the cooling demand, additional storage might be needed.

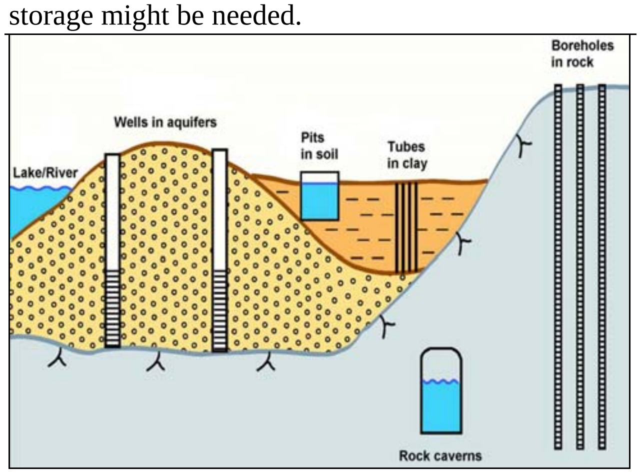

Fig. 1. Outline of the most common UTES systems, ATES, BTES and CTES.

The most common thermal storage systems used are ATES, BTES, and CTES (Fig.1); where TES means Thermal Energy Storage systems; while A, B, and C stand for Aquifer, Borehole, and Cavern. Another type of storage with a great potential is seasonal storage of snow. In this case snow is stored from the winter to the summer when it is used for space or process cooling.

UTES systems could to be used to save energy and environment in many more countries. One reason that this technology has not been promoted is probably that it is too simple. It can be constructed by local labour and companies, which means that this is not a product for export and thus no economic incentive [**1**]. Ground heating/cooling systems are almost unknown in North Africa though the local conditions in many areas are more favourable than in Sweden.

Luleå University has ongoing collaboration with Sebha University and Al Fateh University (Libya) in which where the possibility of using the ground as a source for heating and cooling is studied. Another ongoing research collaboration concerns season heat storage of solar heat at Tlemcen University, Algeria.

1.1 ATES

In an ATES system thermal energy is stored in the groundwater and the porous matrix through which the groundwater flows. Heat is transferred to the ground by the groundwater, which is pump from/to a number of extraction and injection wells. In the heating charging mode, extracted water (from the cold wells) is pumped to a heat exchanger where it is heated before injected into the warm wells. The groundwater flows through the ground towards the extraction while warming up the matrix. The temperature velocity is half of that of the water velocity which means that the water volume of the aquifer is pumped twice before the aquifer is fully charged. When extracting the heat the pumping is reversed and the heat is extracted from the warm wells. Also in this case a heat exchanger is used to transfer the heat to the heat distribution system. ATES systems mean large scale storage mainly for seasonal storage, but also for short term storage, are common in many countries. Most ATES are used for cooling though more recent systems are used for both heating and cooling. Such systems usually include a heat pump, which delivers the heat while the cooling often is by free cooling (direct use of groundwater).

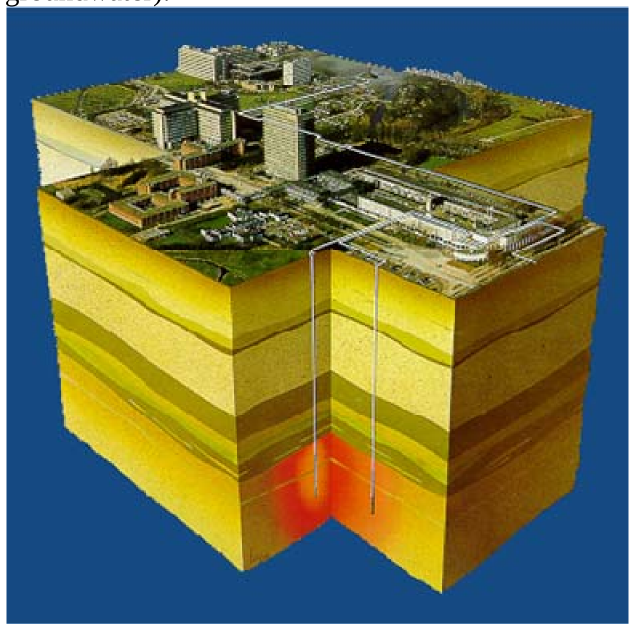

Fig. 2. ATES in Utrecht, the Netherlands.

In some parts of Sweden the number of systems fill up the whole underground of e.g. the city of Malmö.

ATES systems require suitable geology (permeable soils/sands) and favourable groundwater conditions. Occurring problems are usually related to water chemistry problems.

1.2 BTES

Sweden is one of the leading countries in using the BTES for heating and cooling. Heat pumps are usually part of such systems that supplies about 20% (20 TWh) of all space heating in Sweden [**2**]. There are about 300.000 heating systems in operation for single-family houses, with an increase of 35-40.000 systems, annually. During the last decade more than 1000 larger systems have also been constructed. These are usually for both heating and cooling though there are large plants for heating only or cooling only. This energy efficient technology is environmentally benign since extracted heat is renewable energy that is passively stored from ground surface. These systems are most efficient if low-temperature heat distribution systems are used.

Heating systems by using the ground for heat extraction have been increasingly popular during the last decades. Typical payoff times are 10-15 years but the rising energy cost improves the economy considerably. Another fact is that the value of the house increases at least with the investment. For larger systems >1000-3000 MWh the economy is considerably better with typical payoff times of 2-6 years.

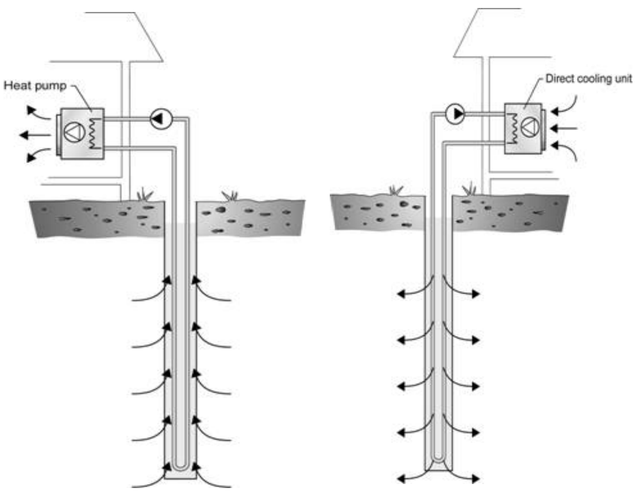

Fig. 3. Typical BTES system for a single family house. R/Heat extraction mode. L/ Heat injection mode.

Table 1. Typical data for BTES heat extraction system for a single-family house in Sweden.

- Drilling Depth: ca 100-150 m
- Borehole Diameter: ca 110 mm
- COP: 3-4
- Extracted energy: 25000 kWh of which ~¼ is driving energy for the heat pump.
- Investment Cost: 10,000€
- Pay-off: 10%, Interest rate: 5%

Large-scale BTES are mainly used for seasonal heat storage. Typical heat sources are industrial waste heat or solar heat. The most favourable system is high temperature storage for low temperature applications, where no heat pump or additional heating is required. The solar system in Anneberg, Stockholm, is a good example of how solar heat is stored and used for space heating. In this case about 1000 MWh is stored from the summer and used for heating of 60 single-family houses during the winter [**3**]. Stored heat is used at a temperature of 32^{o}C, for heating of tap water and space heating through the low-temperature floor heat distribution system (Fig.3.)

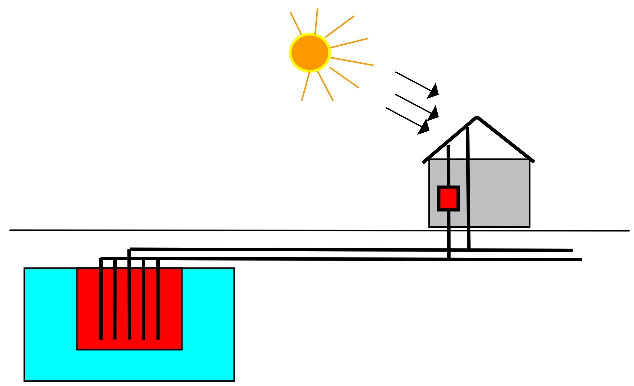

Fig. 4. In the Anneberg project, some solar heat is used directly while the rest is stored in the BTES at a temperature of 40-50^{o}C. During the winter the heat is used for space heating at a temperature of 32^{o}C.

Storage temperatures up to about 80-90C are used in BTES though low temperature systems are most common. Occurring heat losses from such systems depends on the bedrock properties, temperature, geometry, and volume. The first high temperature BTES (82C), with a volume of 120,000 m^3, was constructed in Luleå, Sweden. Its heat loss was about 40%. In larger (few hundred thousand m^3) heat temperature BTES systems the annual loss is about 10-15% [**4**].

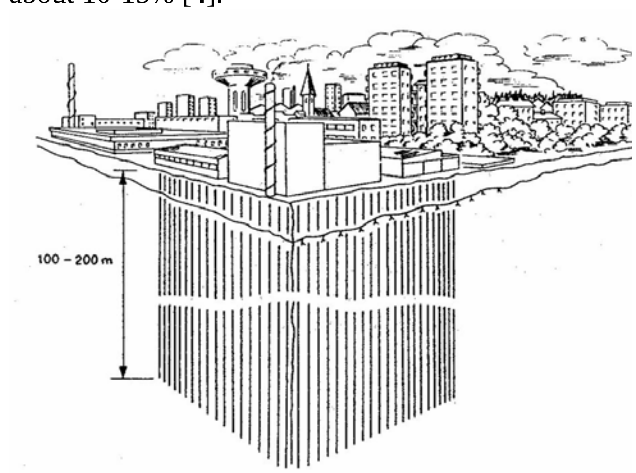

Fig. 5. Outline of large scale BTES system. The surface area on top of the storage can be used as parking lots, parks, and even for constructions.

1.3 Shallow extraction systems

In areas where the larger land areas are available, horizontal pipe systems are used for the extraction of heat and cold. The main idea is the same, to extract or dissipate heat into the ground for space heating and cooling. In colder climates heat pumps are used to extract the heat during the winter while the ground is used for direct cooling (no cooling machines) during the summer. In a warmer climate the situation would be the opposite, the heat of the cooling machines is dumped into the ground and this heat is used for direct heating during the winter season. In the most favorable case the ground could be used for both direct cooling and direct heating. This means that the heat and cold is extracted by circulating water through a buried pipe system. Fig 6 shows a space heating/cooling system for a building.

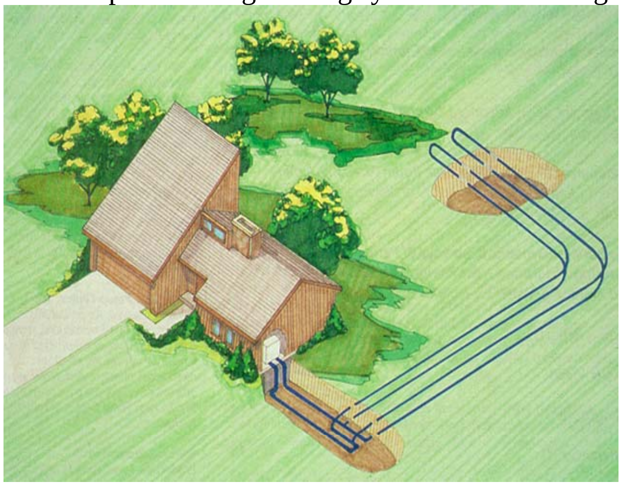

Fig. 6 Example of horizontal ground coupled pipe system for space heating and cooling.

The horizontal pipe system in the ground is placed in many different ways (Fig.7). If large land areas are available the pipes are normally placed in lines with a few m spacing over the area. If smaller areas are available the pipe is placed in a more compact manner. Different types of collectors are available. One example is the Fence Collector (Fig.8), another is coils of pipes (Slinky) mainly used in the USA (Fig. 9). The idea with more compact forms of ground heat collectors is to reduce the land area use. Several pipes in the same ditch means that the total pipe length is increased, while the length of the ditch is reduced. Typical heat/cold extracation powers are 10-15 W/m of pipe.

Fig. 7. Ditch collectors - horizontal pipes for extraction heat and cold in Austria.

Fig. 8. Fence collector and its installation.

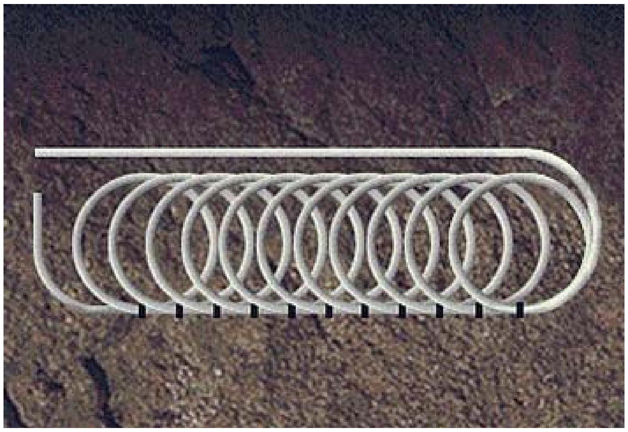

Fig. 9. Compact slinky.

1.4 CTES

The rock cavern heat storage (CTES) has the advantage of very high injection and extraction powers (just a matter of pump capacity), while the disadvantage is its high construction cost. There are some examples of how old rock caverns, previously used for oil storage, has been converted for high temperature water storage.
The first large-scale high-temperature CTES was constructed in 1983 in Uppsala, Sweden. The storage volume of 115.000 m^3 had maximum water temperature of 90^oC and 5500 MWh of heat was stored between the seasons, see Fig. 6.

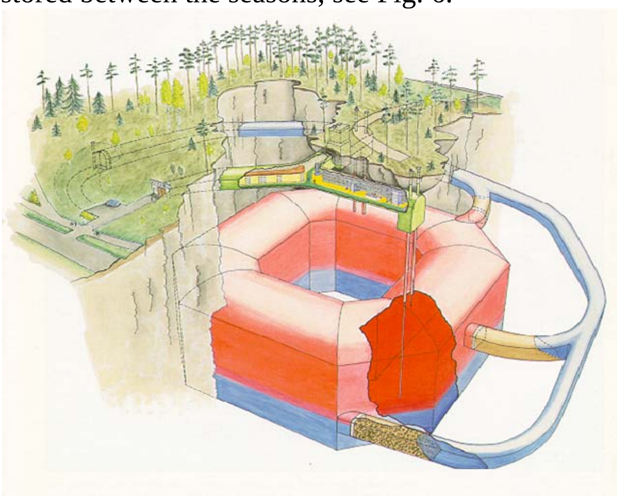

Fig. 10. The Uppsala rock cavern heat storage (CTES).

This storage, which was connected to the district heating net of Uppsala, was used for both short term and seasonal storage of heat. It was partly heated by solar collectors and used to meet the power peaks in the mornings and evenings.

1.5 Snow Storage

Seasonal snow storage has a great potential for cooling in colder areas. Its thermal properties mean that the storage itself has no limit in cooling power. The value of snow for space cooling during the summer is about 10€/ton. Another advantage is that occurring pollutants are confined in the cavern, which means that the sediments and meltwater can be treated.

Stored snow could be natural or produced by snow guns. Snow can be stored in buildings, on ground, in pits, or underground (Fig.7). The storage building prevents the snow from melting while storage systems on ground have to be thermally insulated.

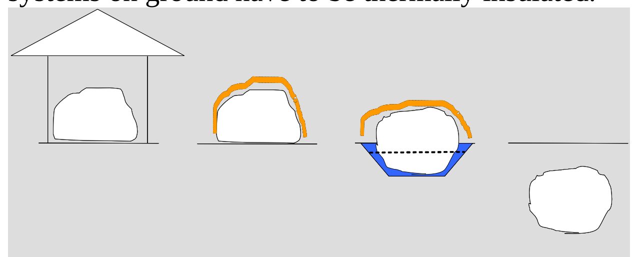

Fig. 11. Principle methods of snow storage. be

The thermal insulation could be of many different types; though sawdust and woodchips have proved to be excellent materials. Natural snow would be used where snow anyhow has to be removed from streets and roads. Snow can also be produced by snow guns, which efficiently produce snow at an air temperature below -2^oC. The efficiency of snow production varies from 1:100-1:200 depending on the air humidity and air temperature.

Fig. 12. Trucks unloading snow at the Sundsvall snow storage, in Sweden.

About 100 snow storage systems (in buildings) are in operation in Japan. In Sweden one pit storage has been in operation since 2000 for cooling of the Sundsvall regional hospital during the May to Sept. This snow storage contains 40,000 m^3 of snow and covers about 2000 MWh of cooling with cooling peaks of 2000 kW. The very successful storage system delivers cooling at considerably lower cost than conventional cooling systems [**5**]. Several new plants are presently planned.

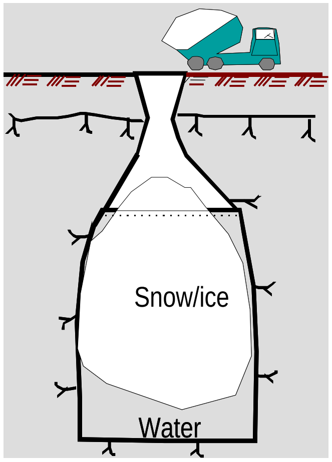

Fig. 13. Snow cavern.

The best method, for snow storage would be to use snow caverns. In such no thermal insulation is required and the cavern would be constructed where the cooling demand is high, i.e. the centre of a city. This type of snow storage has not yet been tested,

2 Summary and Conclusions

This UTES overview shows a variety of systems for heating and cooling. Such systems can be made in different climates and very different scales. Swedish has a vast experience of a large number of systems that have been in operation for decades. Our conclusion is that UTES is a reliable technology that saves energy, money and the environment. Storage of thermal energy plays an important role in future sustainable energy system.

There are many factors influencing the development of renewable energy systems, such as agreements made by the international community to reduce the effects of global warming. Increasing energy prices, which are often determined by politicians, will also be a driving force.

For Sweden, we foresee a continuous annual increase of about 40,000 BTES systems for single family houses. For larger BTES systems (1000-3000 MWh) heating and cooling commercial buildings the strong development during the last decade will accelerate.

Snow storage for space and process cooling, which can be used in most European countries, is also expected to grow rapidly, starting in the Nordic countries, and reaching most European countries within some decades.

References

[1] Nordell, B (2000). Final Report. Annex 8, IEA ECES IA: www.ltu.se/staff/b/bon

[2] EHPA (2001). European Heat Pump Assoc. Strategy for Heat Pumps. www.geothermie.de/egec-geothernet/ehpaindex.htm

[3] Nordell B, Hellström G. High Temperature Solar Heated Seasonal Storage System for Low Temperature Heating of Buildings. Solar Energy, Vol. 69:6, pp: 511-523, 2000.

[4] Nordell B (1994). Borehole Heat Store Design Optimization, PhD 1994:137D. Div. Water Res. Eng, Luleå Univ. of Tech. pp.250.

[5] Nordell B, Skogsberg K (2006). The Sundsvall snow storage - six years of operation. pp. 349-366. NATO Science Series, Series II: Mathematics, Physics and Chemistry - Vol. 234. ISBN-10 1-4020-5288-X (HB).