RENEWABLE ENERGY SYSTEMS AND STORAGE

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ABSTRACT

Renewable thermal energy is usually available with a time difference between supply and demand. This mismatch can be solved by energy storage. The most appropriate seasonal storage technologies are Underground Thermal Energy Storage (UTES) systems. The most common technologies are ATES, BTES and CTES. It is not possible, for geological or geo-hydrological reasons, to construct all these systems any place but one of them can in most cases be realised. ATES (aquifer) systems are most favourable in large-scale applications. The BTES (borehole) system is the most general system because it finds applications of all scales. CTES (rock cavern) systems are most favourable when loading and unloading powers are extremely high. This paper presents a brief summary of old and new ideas on seasonal storage of renewable thermal energy.

BACKGROUND

Renewable energy is solar energy one way or the other. The most obvious renewable energy source is solar radiation but it also occurs as wind energy, wave energy, and as thermal energy passively stored in air, water, or in the ground. Solar energy is also stored in plants and trees. Renewable energy is defined by its time of renewal. So, bio-fuel is a renewable energy but oil is not because it takes such a long time for its renewal. Because of low intensity or absence of solar energy snow and ice are accumulated during the winter. This type of natural cold storage is also a type of renewable "energy" or rather a temperature gradient that can be utilised in cooling applications. This paper deals with thermal energy only, which leaves us with the following renewable energy resources:

- Solar Energy Resources
- Biomass Energy Resources
- Geothermal Energy Resources?
- Snow/Ice Energy Resources

In most climates there is a time difference between supply and demand of renewable energy. This mismatch can be solved by energy storage. There are many technologies developed for short-term and long-term storage. In this paper seasonal storage of thermal energy is discussed. Thermal energy storage systems can be classified according to:

- Storage Purpose - Heating, cooling or combined heating or cooling
- Storage Temperature - Low < 40-50°C and High >50°C
- Storage Time – Short term (hours- weeks) or Long term (months - seasons)
- Storage Technology - ATES, BTES, CTES, DTES, Pit/Tank Storage, PCMES
- Storage Application - Residential, Commercial or Industrial

Energy Storage History

Man has used passively stored energy throughout history. Early examples are people who lived in natural or excavated caverns in rocks and soils. Such dwellings were warm in the winter and cold in the summer because the seasonal temperature variation does not penetrate deep into the ground. It is also known that the buildings of the native people of Arizona and New Mexico worked in the same way but on a diurnal basis. In this case the heat of the day did not penetrate the wall until the coldest hour of the night while the cold of the night was cooling the inner wall surface during the warmest period of the day. There are also many examples of ice cellars where ice was stored from the winter for cooling purposes during the summer.

Small-scale short-term storage of hot water and ice was early made in thermos flasks. Another example is electric water heaters in single family houses. Such heaters are motivated by power saving meaning that the heater takes many hours to produce necessary hot water while the hot water is used during shorter periods of the day.

One of the earliest types of technical energy stores were large water tanks to reduce the peak power demand. Such stores are now common in District Heating systems and also in solar applications. Storage systems are also needed in solar applications because of the diurnal variation in solar intensity. In this way solar energy is available after sunset. The variation in solar intensity also results in the need of weekly and seasonal storage.

The interest in large-scale seasonal thermal energy storage started with the oil crisis in the early seventies. At the beginning of seasonal storage research the long-term aim was to store solar heat from the summer to the winter primarily for space heating. Industrial waste heat was another heat source of great potential. This is still true but in recent years cooling has become an increasingly important issue and District Cooling (DC) systems are growing in Europe. So far, these systems have utilised passively stored cold but now we see an increasing interest in large-scale seasonal cold storage systems.

Storage of sensible heat results in an energy loss during the storage time. This loss is a function of storage time, storage temperature, storage volume, storage geometry, and thermal properties of the storage medium. Since seasonal thermal energy storage requires large inexpensive storage volumes the most promising technologies were found underground in Underground Thermal Energy Storage (UTES) systems. These most common UTES technologies are Aquifer Thermal Energy Storage (ATES), Borehole Thermal Energy Storage (BTES), Rock Cavern Thermal Energy Storage (CTES).

SEASONAL THERMAL ENERGY STORAGE

ATES - Aquifer Thermal Energy Storage

In ATES systems an aquifer is used for thermal energy storage. The thermal energy is stored in the ground water and the minerals of the aquifer. One or more wells are drilled for injection and extraction of groundwater, which is the heat carrier of the ATES system (Figure 1). For ATES two concepts are possible:

- Alternating flow for loading and unloading the store, thus switching the production and injection wells and creating "warm" wells and "cold" wells.
- Continuous flow in one direction, with varying temperatures at the injection well and mean temperatures at the production well. This is used for cooling applications.

ATES systems are used for short term and long term storage. A large number of these systems have been built in the Netherlands and Sweden. ATES is economically feasible in a lot of applications. (Bakema et.al. 1995 and 1998).

There are two major problems when considering an ATES system.

- Conflicts of interest in ground water use
- Water chemistry

There are a number of computer models to design and simulate the thermal behaviour of ATES system for different loads geological conditions. The best groups for designing and simulating ATES are found in the Netherlands, Sweden and USA.

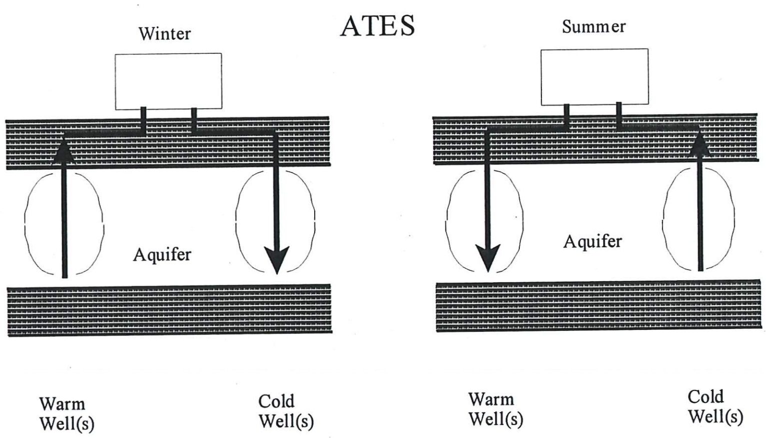

Figure 1. Outline (section) of an ATES System. The flow direction is reversed during the summer and the winter to get the highest temperature when heating and the lowest temperature when cooling.

BTES - Borehole Thermal Energy Storage

Borehole systems (BTES) are the most generally applicable UTES. In such systems bedrock is used as the storage medium. A pipe system is installed in the borehole to enable the circulation of a heat carrier. When thermal energy is injected the temperature of the storage medium is increased. The boreholes that penetrate the storage volume are the heat exchanger of the system, through which the heat carrier is pumped. The BTES system has many applications.

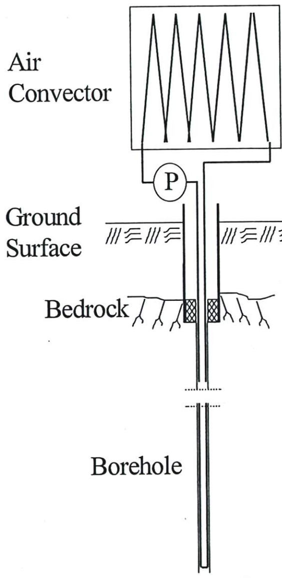

Figure 2. Section through a single borehole system.

Small-scale systems:

- Single borehole for cooling (with and without recharge)
- Single borehole for heating with heat pump (with and without recharge)
- Single borehole for heating with heat pump and direct cooling

Large-scale system:

- System of Boreholes for heat extraction with heat pump
- System of Boreholes for heat extraction with heat pump and recharge of extracted energy

Borehole Storage Systems

- Seasonal loading of thermal energy (heat or cold) for later extraction
- Seasonal loading of thermal energy for the purpose of cooling or heating of the ground

BTES systems are most suitable for base load operation, both when loading and unloading the store. It is mainly for seasonal storage.

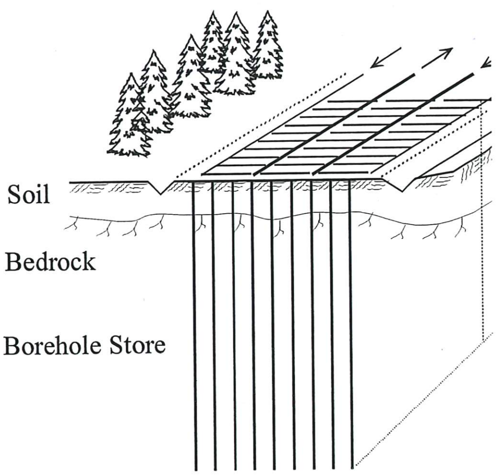

Figure 3. Section through a borehole system. This high temperature solar heated seasonal store is due to be realised during 1999 in Anneberg, Stockholm. The store consists of 99 boreholes (c/c 3 m) drilled to a depth of 65 m in granite. This is a high temperature store for low temperature space heating of buildings. (After Nordell, Hellström, 1999).

Hundreds of thousands of BTES systems have been constructed around the world. The Geothermal Heat Pump Consortium (GHPC, see WWW Ref. GHPC) estimated that 400.000 BTES systems would annually be built in US within a few years. Most of them are borehole systems of one or a few boreholes. There are however an increasing number of large-scale systems i.e. more than 10-20 boreholes.

BTES systems are most favourable for direct cooling i.e. without heat pumps, even though heat pumps sometimes are required. Another type is a high temperature store delivering heat at a low temperature. Only a few high temperature BTES have been built since the first large-scale high temperature BTES at Luleå University, Sweden, in 1982 (Nordell, 1994).

A good application of high temperature storage for a low temperature application is now being studied at Luleå University of Technology. A high temperature BTES, loaded with waste heat during the summer, will be used for de-icing of the airport runways during the winter. The runways are de-iced by hot water circulation in a plastic pipe system embedded in the paved runways. Several similar BTES are in operation in Japan for de-icing of paved areas (Iwamoto et.al. 1998). In the SERSO project in Switzerland the paved area is also used as a solar collector during the summer, which delivers the heat for charging the BTES.

Another good application suggested (but never tested) is a backup storage for industrial waste heat utilised in a DH system. The problem to solve is that when industrial waste heat is used for heating of larger districts there must be some kind of backup heat supply for standstill periods, for repair and maintenance, at the industry. So, the store would be continuously loaded, like a battery backup, and unloaded when there is a need for it. The size of the storage must be decided from the possible standstill periods. Such systems would enable an extended utilisation of waste heat.

When BTES is constructed in soils or clays it is usually called Duct Thermal Energy Storage (DTES). There are many such plants constructed in Europe - with horizontal or vertical plastic pipes in the ground. Some of them are operating at high temperatures but most of them are connected to heat pumps and thus operating close to the undisturbed ground temperature.

CTES - Rock Cavern Thermal Energy Storage

In the Rock Cavern Thermal Energy Store (CTES) energy is stored as hot water in an underground cavern. In such a system with a large volume of water it is of great importance to maintain a stratified temperature profile in the cavern. During injection hot water is injected at the top of the store while colder water is extracted from the bottom.

Two such storage systems were built in Sweden, Avesta with a volume of 15,000 m^3 and Lyckebo with a storage volume of 115,000 m^3. The Avesta CTES was built in 1981 for short-term storage of heat

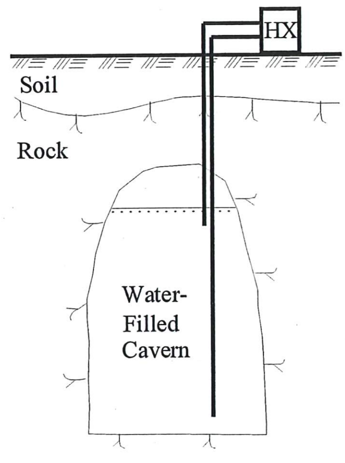

Figure 4. CTES - Rock Cavern hot water storage.

produced at an incineration plant. The Lyckebo store, which is partly heated by solar energy, has been in operation since 1983. There are a few more CTES systems built but in these cases the caverns used were not initially constructed for CTES. There are examples of shut down mines and oil storage caverns that have been reconstructed for hot water storage. (Gustafson G, 1985)

Rock caverns are very expensive to construct. CTES still have a big advantage - the powers of injection and extraction are very high. So, CTES can be used to meet very high powers.

It is also possible to use CTES as part of a system for ice/snow storage, see PCMES.

PCMES - Phase Change Material Energy Storage

Phase Change Material (PCM) melts and takes up energy corresponding to the latent heat (heat of fusion) of the material when its temperature is increased. When it is getting cooler the PCM solidifies and heat is released. For cooling purposes there will be a reversed process. (Alexandersson K., et.al 1996)

There are several types of PCM used for energy storage e.g. paraffin and water (ice). Such storage systems have high storage density. Other qualities of PCM systems are that there is no thermal loss from the storage medium and that the latent heat (when recovered) is obtained at a constant temperature i.e. at the melting point of PCM.

Paraffin has one big advantage; it is possible to select an appropriate working temperature or melting point of the paraffin at least in the range of -30°C to 115°C. The heat of fusion (latent heat) for such paraffins are about half that of water, i.e. approximately 200 kJ/kg. Consequently, there is paraffin for many different applications. Such systems are now being developed within the IEA, see International Collaboration below. One problem with these materials is that the high cost of e.g. paraffin.

For large-scale energy storage applications ice is the most common PCM. Because of the low melting point of ice such systems are mainly used in cooling applications. The historically old technique of ice storage, using sawdust as thermal insulation, is now being rediscovered. There are several seasonal snow/ice storage systems in e.g. Japan and Canada (Skogsberg, 1999).

The first "modern" large-scale seasonal snow storage in Sweden is now being constructed. The snow deposit of the city of Sundsvall will be used for cooling of a hospital during the summer (cooling demand 1000 MWh, peak power 2.5 MW).

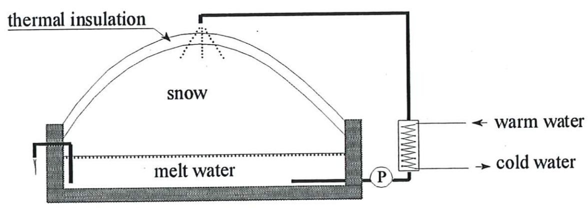

Figure 5. Principle of the snow deposit seasonal cold storage.

The snow deposit contains about 20.000 tons (30.000 m^3) or roughly 2000 MWh of cooling energy (latent heat). Calculations show that by using 0.1 m of wood chips as thermal insulation 70% of the snow will last over the summer. Wood chips are used in the heating plant of the District Heating system, so after one summer of cooling the hospital the used wood chips will be burnt. The snow is stored on a watertight floor with a surrounding vertical wall. Thus the melt water is contained under the snow surface. The melted water, with a constant temperature of 0°C, is pumped through a heat exchanger connected to the cooling system of the hospital and re-circulated to the snow deposit (Figure 5).

A similar application, a combined CTES/PCM system is now investigated at Luleå University of Technology. On ongoing pre-study investigates the feasibility of a rock cavern for the combined use as snow deposit and seasonal cold store. The start of this project was a rough cost estimate indicating one year's payback time. The cost of excavating the cavern was 150 SEK/m^3 (~20 USD/ m^3), the value of the excavated rock was about 100 SEK/m^3 (in densely populated areas) and the value of stored ice was about 50 SEK/m^3. Furthermore this CTES/PCM store means that the snow does not have to be transported away from the city which means savings in both transportation and environment.

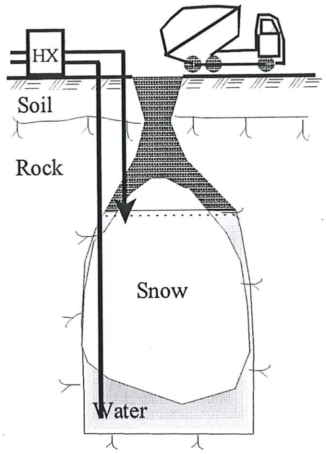

Figure 6. Rock cavern for seasonal snow storage.

For all these UTES system one of the most important external factors is the required temperature level for the heating/cooling case involved. Thermal energy storage systems become more efficient if the temperature requirement for space heating is low, about 35°C and if the temperature for cooling is about 15°C, i.e. a temperature difference of 10°C. This also explains why high temperature storage and low temperature applications are most favourable.

INTERNATIONAL COLLABORATION

A series of International Conferences in the field of Underground Thermal Energy Storage started in 1981. Since 1985 these conferences have been named "Stock" something and it has become the major international UTES conference. Next conference will be held in Germany in 2000. These conferences gather about 200-300 scientists, experts and decision-makers from 25 countries.

Table 1. UTES Conferences 1981-2000

Year	Location
1981	Seattle, USA
1983	Stockholm, Sweden
1985	Toronto, Canada (Enerstock)
1988	Versailles, France (Jigastock)
1991	Scheveningen, Netherlands (Thermastock)
1994	Helsinki, Finland (Calorstock)
1997	Sapporo, Japan (Megastock)
2000	Stuttgart, Germany (Terrastock)

International Energy Agency, IEA

Another form of international collaboration is carried out within the framework of the International Energy Agency, IEA. IEA was formed by a group of OECD member states in 1974 after the oil crisis. Collaborative effort was developed in the area of future energy. This collaboration takes place under Implementing Agreements (IA) which specify the commitments of the Contracting Parties. There are five IEA R&D Working Parties under which a number of IAs are performed. The Contracting Parties can be government organisations or private entities designated by their respective governments. Non-IEA Member countries can become Associate Contracting Parties. Today there are 25 Participating Countries in the IEA work. One of the Working Parties is Efficient Energy End-Use Technologies in which there is an IA on Energy Conservation through Energy Storage. There are thirteen annexes within this IA of which seven have been terminated. Here Annex 8 is briefly described.

Table 2.	Ongoing annexes within IEA ECES IA
Annex 8	Implementing Underground Thermal Energy Storage Systems
Annex 9	Electrical Energy Storage Technologies for Utility Network Optimization
Annex 10	Phase Change Materials and Chemical Reactions for Thermal Energy Storage
Annex 12	High-Temperature Underground Thermal Energy Storage (HT UTES)
Annex 13	Design, Construction and Maintenance of UTES Wells and Boreholes
Annex 14	Cooling in all climates with UTES

The scope of Annex 8, Implementing Underground Thermal Energy Storage Systems, is to conserve energy and to improve the environment by facilitating an extended use of UTES in the building, industrial, agricultural and aqua-culture sectors. Annex 8 disseminates UTES information on different levels depending on the target group.

1. General Information. Philosophy, UTES Potential, benefits, system. Target Group: Politicians, Decision makers
2. Engineering Information. Demonstration projects, Systems and applications, Design Tools. Target Group: Architects, Consulting Engineers, and Public Works on community level
3. Scientific Information. Theory, Teaching, Courses, Books, Detailed modelling. Target Group: Scientist, students, post graduate students

Annex 8 is encouraging energy conservation and increased sustainability of the energy resource by stimulating the expanded use of UTES in innovative, energy efficient and cost-effective projects in participating countries. The means employed to achieve the objectives are collaborative efforts based upon co-operation and task sharing arrangements with lead countries for each sub-task. Nine countries (Belgium, Canada, Germany, Netherlands, Poland, Sweden, Turkey, USA, and Japan) represented by their UTES experts are today involved in this work. New participating countries (with little experience of UTES) start to perform national potential studies but are also participating in ongoing work.

There have seen a strong UTES development in the participating countries. One recent result of the Annex 8 work was the start of Underground Thermal Storage and Utilization - A Peer Review International Journal on Energy Conservation. It is an electronic journal [WWW Ref. UTSU]. The Annex 8 experts initiated Annex 12-14.

Annex 14 has not yet formally started but a first workshop will be held in Sweden, June 1999.

Further information about IEA, ECES IA and Annex 8, see [WWW Ref. ECES].

Since several of the participating countries have found the Annex 8 work rewarding, a new similar annex will be started when the ongoing work is terminated in 1999. Then also new participants are expected to join.

CONCLUDING REMARKS

- ATES systems are feasible when the geological conditions are favourable. ATES is for large-scale cooling or heating. Still it is used for both short-term and seasonal cold and heat storage.
- BTES is the most general type of UTES system. It is feasible in a very small scale and also in large scale. The soil cover should however not be too deep. BTES is most efficient when the task is to load and unload a base load of thermal energy. Because of the pipe installations it is possible operate at below freezing degrees.
- A combination of CTES and PCM, i.e. seasonal storage of ice and snow in a rock cavern for district cooling seems to be very promising application.
- The most important external factor for efficient UTES systems is that the temperature requirement for space heating is low, about 35°C and that the temperature requirement for cooling is about 15°C, i.e. a temperature difference of 10°C.
- The most favourable UTES applications are high temperature storage with low temperature applications without heat pumps.
- The long-term aim of storing solar heat from the summer for space heating during the winter does not seem to be far away. The Anneberg project was the first Swedish solar energy - seasonal storage project that showed similar cost for both the solar system and the best conventional alternative.
- International Energy Agency results in efficient international collaboration and technology transfer. There are several ongoing projects on renewable energy and energy storage.
- The newly started Underground Thermal Storage and Utilisation - An International Peer Review Journal on Energy Conservation - has the potential to become an important forum for scientific and technical UTES information.

UTES conserves energy and improves the environment. Applications are found within the building, industrial, agricultural and aqua-culture sectors. UTES is a local technology. Local entrepreneurs preferably carry out the construction work. UTES saves money, energy and the environment. It should be utilised in many more countries throughout the world.

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[http://www.sb.luth.se/vatten/projects/iea/]

GHPC - Geothermal Heat Pump Consortium.
[http://www.ghpc.org/]

UTSU - Underground Thermal Storage and Utilization.
[http://www.geo-journal.stockton.edu/]