Underground thermal energy storage

Network "Communities of a sustainable Europe" (CoSE)

International network of RURAL villages and URBAN neighborhoods for bottom-up approach

For more information, see: http://communities-of-sustainable.eu/

Underground Thermal Energy Storage

- Significant energy savings
- Open systems or closed systems
- Cooling in summer and heating in winter
- From individual household application to neighbourhood scale

Underground thermal energy storage, what is it?

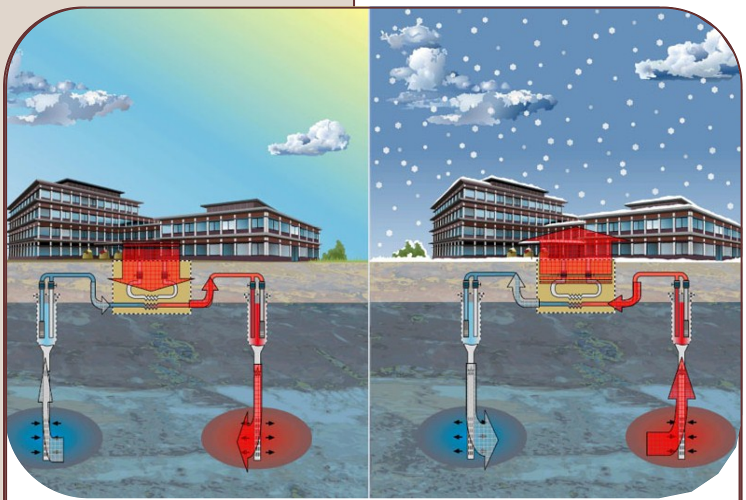
Nowadays there are numerous methods to generate renewable energy utilising infinite sources such as the sun, wind, waves or earth. Unfortunately, the supply and demand of renewable energy is frequently not simultaneous. This not only holds for renewable electricity but also for renewable heat. In terms of heat, renewable energy sources such as solar thermal are often most productive when demand is relatively low. A solution to bridge this gap is to store excess heat during summer time and extract it during the winter. This concept is referred to as Underground Thermal Energy Storage (UTES).

Technical aspects (preconditions / opportunities)

UTES systems can be classified according to storage temperature (low or high), storage purpose (heating, cooling, or a combination) and storage technology or method. In relation to the latter, there are various methods to transfer or store thermal energy towards and from the ground. The selection of a particular method and technology depends on the local geological conditions. In general two types of UTES can be distinguished: open and closed systems.

Open systems

Open systems use groundwater to store or extract heat. Aquifer Thermal Energy Storage (ATES) is the most common type op UTES that uses groundwater to store heat. Storing excess heat or cold in aquifers can be applied in various buildings like office buildings, hospitals, greenhouses as well as residents.



Operation of UTES in Summer (left) and winter (right)

To operate an ATES system one or more wells are needed. During summer when cold water is needed for cooling buildings, groundwater is extracted from at least one cold well. In the process of cooling down the building, the extracted cold water absorbs the heat and is injected in separate warm well nearby. This process is reversed during winter when the relative warm water is extracted from the warm well and used for heating the building.

Groundwater temperatures can vary between 5 and 30°C, depending on how deep the wells are. In some cases the temperature of the groundwater is not sufficient enough to solitary heat a building and is used as a low temperature heat source. In these conditions a heat pump is installed to provide additional heat.

Aquifers can be used for under ground storage under certain conditions:

- An aquifer should be in between impervious layers
- There should be no or only low natural groundwater flow
- Water filled permeable sand, gravel, sandstone or limestone layers with high hydraulic conductivity can also be used for storage.

Because all the extracted groundwater from one well is again injected in another well, there is no net extraction of groundwater from the soil. Although there is no net extraction of groundwater, extracting and injecting groundwater can affect its quality and might influence the flow patterns.

Closed systems

Closed systems, of which the most common is Borehole Thermal Energy Storage (BTES), consist of a circular network of hollow pipes fitted in the subsoil. This network of pipes can either be installed vertically using boreholes or horizontally using trenches. In comparison to using groundwater for storing or transferring energy surpluses, BTES systems rely on a coolant fluid that transfers thermal energy towards and from the ground. Similar to open systems, BTES systems are frequently equipped with a heat pump due to the relative small temperature difference between the soil and the coolant fluid.

Besides BTES, other closed systems for storing thermal energy are Tank Thermal Energy Storage (TTES) or Pit Thermal Energy Storage. Where the latter one can only be constructed under ground, the former one can be constructed above ground as well.

An advantage of a closed system is that it is less dependent on site-specific groundwater conditions on which open systems such as ATES rely heavily. Therefore closed systems provide an alternative for areas where groundwater conditions are insufficient. Furthermore, closed systems commonly operate under more extreme temperatures in relation to open systems.

Components

The main components of a UTES system are:

- The heat source. This can be solar thermal, solar absorbers or (industrial) waste heat.
- The method or technology of storing the energy. Open versus closed systems.
- The distribution of heat or cold. Heat is often distributed through a district-heating network.
- A heat exchanger. This is used to exchange energy between the building and the ground.

Scale

UTES can be applied on various scales ranging from individual households to neighbourhoods or industrial sites and greenhouses. In the recent past UTES systems are frequently applied in large-scale projects since UTES systems are usually more ideal for projects with high-energy demand. Moreover, the storage volume is mainly determined by the energy demand and hence large storage volumes are ideal.

Although large-scale projects are more ideal, it does not imply that individual systems are non-existent. However, a general rule of thumb is that costs decrease as energy demand and storage volumes of a project increase. Therefore, individual buildings can benefit from UTES systems through for example collectively use. In such conditions, participating parties have the additional advantage to exchanged energy between each other. This results in more efficient use of energy and hence lower energy costs. Furthermore, collective systems might benefit through a higher reliability.

Benefits for the community

Costs

Investments costs for an UTES system depends on several characteristics. A major aspect that affects the total investment costs is the storage volume. An optimal volume for inter-seasonal UTES systems varies between 2,000 and 20,000 m3. Within this range the investment costs are estimated to be between €40 and €250 for each cubic meter.

Besides the costs related to the storage volume, the thermal performance of the storage itself and the connected network are equally important when considering the economy of a UTES system. As a consequence each system has to be examined separately. To determine the economy of storage, the investment, maintenance and operational costs of the storage have to be related to its thermal performance.

Considering the above, the costs involved with implementing ATES and BTES systems are lower in comparison to TTES or PTES systems. On the contrary, ATES and BTES systems often require supplementary equipment for operation like buffer storages or water treatment. Furthermore, many countries have stringent requirements concerning local ground conditions that might increase the costs of realising ATES systems in particular.

Revenues (economic and ecological)

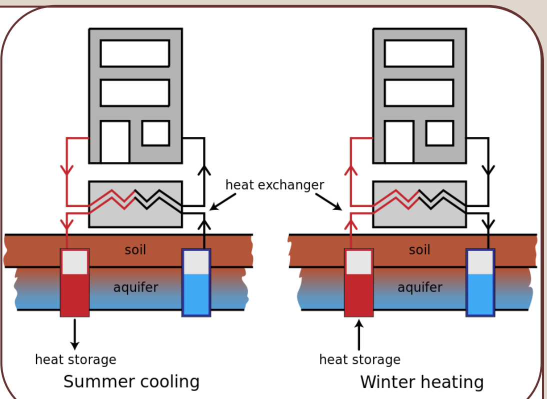
Compared to other (renewable) methods for heating buildings, the investment costs for UTES systems are generally a bit higher. But the difference in costs can be compensated through significant energy savings. UTES systems can achieve energy savings of 50 per cent and in some cases even up to 80 per cent.

The efficiency and amount of energy savings reach through UTES systems depends on the temperature difference. Low temperature heat sources with temperatures below 40°C frequently require additional heat from a heat pump. On the other hand high temperature heat sources with temperatures above 40°C not necessarily rely on heat pumps. Furthermore, open systems usually have a higher heat transfer capacity compared to closed systems and hence are more efficient.

Social aspects (cohesion)

To meet our demand for heating and cooling buildings, homes or industrial sites demands a significant quantity of fossil fuels. UTES systems provide an alternative to fossil fuels by capturing and storing excess (renewable) heat and extracting it when needed. By storing heat enables us to decline or supplement a large share of our demand for fossil fuels. Therefore UTES systems contribute substantially to reduce greenhouse gas emissions and the related adverse impacts on the environment.

Where on the one hand greenhouse gas emissions can be reduced, UTES systems might have some negative environmental impacts on the other hand. For example, with increasing storage temperatures, several hydrological, (micro) biological and geotechnical problems might arise. In addition, changes in groundwater flows or possible leakages of coolant fluids can negatively impact the environment as well.



Where has it been implemented?

Examples CoSE communities

In Reda, Poland, 2 houses benefit from geothermal energy.

In Ashton Hayes, United Kingdom, 1 house has a ground sources heat pump installed.

Success and Fail Factors for implementation

Among many different factors and parameters that determine the success of a UTES system, it is important to consider the following:

- The availability of (underground) storage in the vicinity
- The geological and hydrological conditions on location
- The thermal characteristics of the storage method as well as the distribution network
- The type of the heat source used, which determines:
  - The difference between low or high temperature heat source
  - The amount of heat (and heat flow) and its distribution in time;
- The degree of required temperature and its distribution in time,
- The amount of heat demanded and the storage volume

How to get started?

European legislation

The European Commission (EC) sets a target of 20 per cent renewables within the EU by 2020. Renewables include wind, solar, hydroelectric and tidal power as well as geothermal energy and biomass. Increasing the share of renewables in the EU will contribute in cutting down greenhouse emissions and make it less dependent on imported energy. To reach this ambitious goal the EC has presented the 2009 Renewable Energy Directive.

Besides setting a target, the Directive also improves the legal framework for promoting renewable electricity, requires national action plans that establish pathways for the development of renewable energy sources including bioenergy, creates cooperation mechanisms to help achieve the targets cost effectively and establishes the sustainability criteria for biofuels.

Each Member State has a national target, which differs between them. Annex I of the 2009 Renewable Energy Directive shows the various national targets. An annual report on the progress of each Member State is presented on the website of the EC. These reports include various aspects such as the current share of renewables, updates on national legislation, all support measures taken, system of guarantees of origin, administrative procedures and many other relevant national measures. Under further reading a link to the national reports can be found.

In regard to UTES systems, currently many are in operation in various European countries. However, in some countries UTES systems are more common and technologies more matured than others. Climatological conditions and underground conditions partly explain the observed differences European countries. But the presence of clear energy efficiency targets for buildings seem to be the major explanation.

Comprehensive regulation is in force in traditional UTES countries such as Sweden, the United Kingdom, Switzerland, Germany, and Austria. Furthermore, in many European countries permission from water authorities is a prerequisite prior to implementing UTES systems. This is necessary to ensure that no interests regarding drinking water are affected.

Local knowledge (CoSE partners)

Besides three individual examples using geothermal heat or a ground source heat pump, no UTES systems are implemented so far among the CoSE partner communities.

Finding partners (co-funding)

None of the communities currently formulated the ambitions or set goals regarding the implementation of an underground thermal energy storage system.

Building a strategy and plan

When considering the implementation of a UTES system, the following steps might be useful:

- Obtain information on local (underground) conditions and energy demand of the building in order to establish whether an UTES system is feasible or not.
  - Geothermal modelling can be useful in order to guarantee the long-term efficiency of the system and is frequently required to get an abstraction licence.
- Select a suitable storage method, which depends on several factors such as:
  - Local geological situation
  - System integration
  - Required size of the storage
  - Required temperature levels and the impact on the environment. At high charging temperatures water treatment can be necessary (chemical and biological processes can lead to deposition, corrosion and degradation in the system)
  - Legal restrictions. Aquifers near to the surface are often used for drinking water extraction
  - Economical characteristics
- Depending on the type of UTES system applied, start-up times ranging from two to five years are necessary to reach normal operation conditions. During the first years of operation heat losses of the storage are higher than during long-term operation.
- Make sound estimations regarding the return temperatures. In many installations the measured return temperatures are much higher than initially calculated, which might result in reduced heat capacity and a lower performance of the connected heat storage.

Further reading

- European legislation
  - Homepage: http://ec.europa.eu/energy/renewables/targets_en.htm
  - 2009 Renewable Energy Directive: http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2009:140:0016:01:EN:HTML
  - Summary of legislations: http://europa.eu/legislation_summaries/energy/index_en.htm
- Additional information on storing energy:
  - http://www.iea-eces.org/energy-storage/storage-techniques/underground-thermal-energy-storage.html
  - http://www.ecologyandsociety.org/vol16/iss1/art22/
  - http://www.solarthermalworld.org/content/underground-thermal-energy-storage-2011
  - http://www.icax.co.uk
  - http://www.solar-district-heating.eu/Portals/0/Factsheets/SDH-WP3_FS-7-2_Storage_version1.pdf
  - SDH-WP3_FS-7-2_Storage_version1.pdf

Network “Communities of a sustainable Europe” (CoSE)

International network of RURAL villages and URBAN neighborhoods for bottom-up approach

An initiative of the communities of:

Ashton Hayes (village in Cheshire-West, United Kingdom)
Beckerich (municipality-village in Luxemburg
Betlejem (quarter of Reda, near Gdansk, in Poland
Böcs and Bükkaranyos (municipality-villages in Bükk-Mak-Miskolc-Region, Hungary)
De Stoere Houtman (quarter of Arnhem, the Netherlands)
Measolle (village in France)
Ommerkanaal (village of Overijssel, the Netherlands)
Strem (municipality-village in Öko-Energie-Bürgerland, Austria)

Other communities invited into the network:
Blacon (quarter of Chester, United Kingdom
Feldheim (invited, village of Treuenbrietzen, Germany)
Frankenwald (invited, village near Hof, Germany)
Jühnde (invited, independent village in Germany)
Schönau (Schwarzwald, Germany)
Vauban (quarter of Freiburg, Germany)

For more information, see: http://communities-of-sustainable.eu/

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