Thermal Analysis of UTES for Efficient Heating and Cooling of Building- A Review

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Abstract— The building sector accounts for about 40% of the total energy use. However, at the same time the building sector has a cost-effective saving potential of up to 80%, which can be effected over the next 40 years. A variety of TES techniques for heating and cooling applications have been done. To overcome this problem, we can use underground reservoir such as aquifer thermal energy storage and borehole thermal energy storage. The use of Thermal Energy Storage (TES) in buildings in combination with space heating, domestic hot water and space cooling has recently received much attention. Underground Thermal Energy Storage (UTES) systems allow the direct application of the earth energy in a form of heat that can be recovered and exploited by humans. As they are both economically competitive and environmentally friendly, UTES systems have gained increasing acceptance. So far, most UTES systems have been applied in cold and temperate regions for both heating and cooling. The aim of this study to propose an advantageous operation mode for the underground thermal energy storage (UTES) by reformatting the ground temperature distribution, and clarify the effects of an actual application. In general there were four typical operation modes, such as uniform mode, concentrative mode, intermittent mode and heat shield mode, which based on the different load allotment. Considering the heat treatment mode that usually give rise of temperature on the area apron and will shape an isothermal vertical wall to block heat flowing.

Key words: Underground Temperature, Soil Surface Treatment, Heat Transfer

I. Introduction

It was observed that the ground temperature was often very different from the air temperature. It was found out that the underground could serve as protection not only from enemies, but also from the coldest days of the winter and the hottest days of the summer. The ground temperature at a certain depth below ground surface (10-15 m), which is not influenced by the season temperature variation at the surface, is equal to the annual mean air temperature. It is well known that underground temperature varies with depth that it is not the same as the ambient air temperature, and that this difference can be used for heating or cooling purposes. Cooling with groundwater at around 18ºC instead of utilizing outside summer air at 30–35ºC decreases consumption of electrical energy significantly. [1]

In summer, underground temperature is lower than the ambient temperature, and in winter it is higher than the ambient temperature. Generally in winter, atmosphere temperature is approximately about 14-19 ºC, and the underground temperature is 25-30 ºC [1]. Soil can thus be used as heat reservoir for heating (in winter) or cooling (in summer). Air taken from the ambient flows along a tube installed underground, and its temperature changes in the useful sense, both in winter and in summer. This air, with the so modified temperature, is introduced in the building, whose internal temperature is mainly conditioned by that of the entering air and by the heat exchanged with the exterior ambient surrounding it, through the roof and through the walls. This can be used to reach better comfort conditions in small rooms, small greenhouses, office buildings and residential buildings. Depending mainly on the ambient air temperature, soil could be the unique heat source or sink needed for heating or cooling purposes, respectively, during considerable periods of time along a year. These demands can be matched with the help of Underground Thermal Energy Storage (UTES) refers to the use of the ground for storage and exchange of heat and cold, for the purpose of providing efficient heating and cooling for buildings. It has been demonstrated as a viable heating and cooling system for residential, commercial and institutional buildings. However, because of the need for energy saving and reduction in CO_2 emissions the interest is growing, resulting in the realization of the first projects in these countries. [1]

A. *Underground TES concepts*

Underground Thermal Energy Storage (UTES) system is one of the principal systems for direct application of geothermal energy. There are several types of UTES systems commercially available in the market worldwide, but only three of them are commonly used: the Aquifer Thermal Energy Storage (ATES) system, the Borehole Thermal Energy Storage (BTES) system, and the Energy piles Thermal Energy Storage (ETES) system. These systems are usually used in combination with heat pumps to form what are called Geothermal Heat Pump (GHP) systems, for providing space heating and cooling. [1, 7]

Underground Thermal Energy Storage (UTES) has been used to store large quantities of thermal energy to supply space cooling/heating, and ventilation air preheating. Energy sources include winter ambient air, heat-pump reject water, solar energy, process heat, etc. The most common UTES technologies are aquifer storage (ATES) and borehole storage (BTES). There are a number of such technologies summarized by the UTES (Underground Thermal Energy Storage). [1, 11]

- Ground Source Heat Pump (GSHP)
- Aquifer Thermal Energy Storage (ATES)
- Borehole Thermal Energy Storage (BTES)

B. *Motivation*

The discrepancy between supply and demand is too high. There is need to meet this discrepancy. If there is intermittent source of energy, it will help to reduce the input power requirement, which will help to save the energy, but keeping the appliances in use, we need to generate power from freely available resources. So thermal energy storage (TES) is one of the way by which we can store the energy and use it when required.

II. Literature survey

The technology of underground thermal energy storage (UTES) has evolved considerably over the past 25 years. UTES is widely used for cold storage and combined cold and heat storage, particularly in Sweden, Canada and the Benelux countries (i.e. Belgium, Netherlands). It was begun with cold storage in aquifers in China. Outside China, the idea of UTES started with more theoretical work in the early 1970s. According to Kazmann, he describes various uses of aquifers and states after dealing with heat pumps. This would utilize the aquifer for the storage of heat on a cyclic basis and would improve the thermodynamic efficiency of the process by salvaging waste heat. In the 1980s interest in UTES, several pilot and demonstration plants were built, in combination with solar thermal energy, with waste heat or heat pumps.

After that, B. Givoni [1], he describes different options for long-term storage of solar energy, as well as thermal energy from other sources. The various options are analyzed from the viewpoint of their applicability under different climatic and soil conditions. Several approaches can be contemplated for designing systems of long-term storage of thermal energy. Not all of the possible options are applicable under different climatic and soil conditions. He found some of the possible design approaches and mentions briefly the conditions under which they are applicable.

S Hasnain [2] develops the technologies for available thermal energy storage for space and water heating applications. Traditionally, available heat has been stored in the form of sensible heat (typically by raising the temperature of water, rocks, etc.) for later use. In most of the low temperature applications, water is being used as a storage medium. Latent heat storage on the other hand, is a young and developing technology which has found considerable interest in recent times due to its operational advantages of smaller temperature swing, smaller size and lower weight per unit of storage capacity. It has been demonstrated that, for the development of a latent heat thermal energy storage system, the choice of the phase change material (PCM) plays an important role in addition to heat transfer mechanisms in the PCM. He found that in the development of latent heat storage systems, research is underway in two directions, namely the investigation of phase change materials and of heat exchangers. In spite of the fact that PCMs have been investigated by several researchers, their (especially technical grade PCM) thermo physical properties such as density, specific heat and thermal conductivity in the solid and liquid phases are lacking.

After two years, O. Anderson et al. [3] designed a system, using solar energy in combination with Aquifer Thermal Energy Storage (ATES) that will conserve a major part of the oil and electricity used for heating or cooling.

A. Khudhair et al. [4] do some work related to investigation and analysis of thermal energy storage systems incorporating PCMs for use in building applications and they found that energy storage in the walls, ceiling and floor of buildings may be enhanced by encapsulating suitable phase change materials (PCMs) within these surfaces to capture solar energy directly and increase human comfort by decreasing the frequency of internal air temperature swings and maintaining the temperature closer to the desired temperature for a longer period of time.

After a long time G.Watzlaf [5] use a heat pump for underground heating and cooling. By using of underground mine water in geothermal heat pumps could be extremely cost effective, particularly at existing mine water treatment sites where the mine water is already being pumped and treated. Operational costs are much lower than that of conventional heating and cooling options. Costs per unit of heat for geothermal heat pumps using underground mine water are only 33%, 34%, and 21% of the costs incurred using fuel oil, natural gas, or propane, respectively. Cooling costs using mine water and geothermal heat pumps should be less than 50% of the costs associated with conventional air conditioning systems. But it has some limitations that it should be utilize only in coal region because there is a availability of mine water.

H. Wang [6] did a study to analyze the performance of underground thermal storage in a solar-ground coupled heat pump system (SGCHPS) for residential building. The results show that the performance of underground thermal storage of SGCHPS depends strongly on the intensity of solar radiation and the matching between the water tank volume and the area of solar collectors. Compared with the solar radiation, the variations of the water tank.

III. Working

For the efficient cooling and heating of buildings underground water is utilized and this underground water is pumped with the help of heat pump and the process continues, but with increase in population the humidity increases, also there is a power curtailment, it becomes difficult to survive, so it is today need we can change the existing technology with new ones keeping the basic application same. So we coupled the heat pump with the aquifer.

A. *Ground source Heat Pumps*

A ground source heat pump (GSHP) is a heat pump that uses the ground as either a heat source, when operating in heating mode, or a heat sink, when operating in cooling mode. For the exchange of thermal energy the GSHP is connected to the ground with a loop. The most common connection is a closed loop, existing of U-tubes of high density polyethylene inserted into boreholes of 50 to 200 meters deep. A less common design is the direct use of water from an aquifer (often called an open-loop system). One or several wells supply the water necessary for a GSHP application, a similar number of wells would be used to inject the water. The application of a GSHP system is based on the natural ground temperature. The GSHP extracts heat from the ground in winter and injects heat into the ground in summer. [7]

1) *Limitations of Ground Source Heat Pump*

- Depth required is large, so it becomes hazardous for soil fertility.
- Cost required will be more.
- Net gain is very less compared to cost involved.

B. *Aquifer Thermal Energy Storage*

An aquifer is a groundwater reservoir. The word aquifer derives from the Latin words “aqua “meaning water and “ferre” meaning to carry. The material in an aquifer is highly permeable to water, and the boundary layer consists of more impermeable materials such as clay or rock. An ATES system is a large open-loop system optimized and operated to realize seasonal thermal storage, i.e. by reversing extraction and injection wells seasonally. An aquifer is a groundwater reservoir. The amount of energy that can be stored in an aquifer depends on local conditions, such as

– Allowable temperature change
– Thermal conductivity
– Natural groundwater flows.

ATES or groundwater energy systems utilize groundwater, and do not necessarily deplete nonrenewable resources. In some systems, external thermal energy is stored in an ATES. In others, the natural groundwater temperatures are used. In the latter case, the system requires production wells to supply groundwater to a series of heat exchangers. In winter, heat from underground is used to preheat outside building air. In summer, direct cooling is achieved by transferring heat from buildings to the groundwater using the same principle in reverse. In both cases, the groundwater is returned to the subsurface aquifer through reinjection wells without having been exposed to any form of contamination. Over time, a thermal balance is maintained in the aquifer. [3, 6]

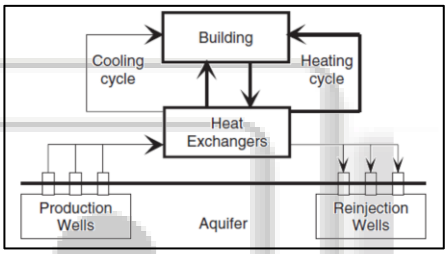

Fig. 1: Schematic of Aquifer thermal energy storage [6]

With ATES no groundwater is discharged. All the water extracted from one well is re- injected in another well. This means that there is no net extraction of groundwater from the soil, which minimizes negative impacts on the environment. ATES systems require that relatively high well yields can be obtained on site. Because of this the applicability depends strongly on site-specific hydro geological conditions.

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 [6].

Aquifers can be used for underground 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.

1) ATES using Heat Pumps

The concept of TES in an aquifer combined with a heat pump is relatively simple. During the summer, cold water is extracted from a cold well and warmed by cooling a building, and then returned to a warm well in the aquifer. A heat pump can be used to chill the cold water further, if necessary. The warmed water diffuses out from the warm well, gradually raising the temperature of the aquifer. During the winter the process is reversed, with heat drawn from the warm well and the temperature boosted with the heat pump, if necessary. The schematic is as shown in fig.3.

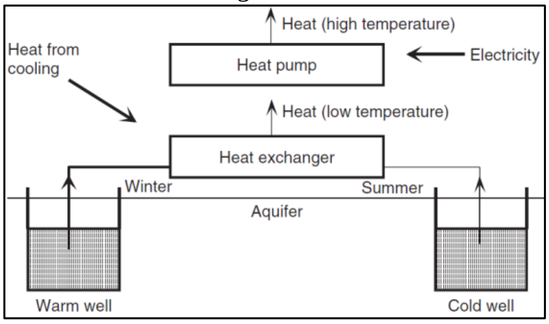

Fig. 3: A schematic of ATES system combined with a heat pump [6]

The basic operational scheme of a ground-coupled heat pump with seasonal cold storage is shown in Fig.4. During heating, the ground or groundwater is cooled, while heat is supplied to the building. At the end of the heating season, enough cold is stored to run cooling system directly (mode 1), with cold groundwater from the injection well or cold brine from earth heat exchangers. [6]

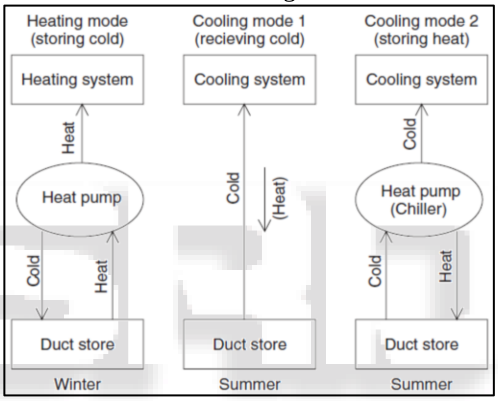

Fig. 4: Operational principles for ATES systems using heat pumps [6]

For peak cooling loads, a backup system using the heat pump in reversed mode can be operated (mode 2). After continuously running the heat pump for space cooling for more than a few hours, temperatures in the ground may be too high for mode 1 cooling. The system should then be operated only as a conventional heat pump plant, storing heat in the ground until the beginning of the next heating season. The most cost-effective and efficient energy performance can usually be obtained by running the system in heating mode and cooling mode 1 only.

C. Requirement of building for UTES installation

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

1) Obtain information on local (underground) conditions and energy demand of the building in order to establish whether an UTES system is feasible or not.
2) 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 (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.

3) 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.

IV. THERMAL ANALYSIS

A. Energy Analysis

The energy to drive the heat pumps is electric energy. This needs to be produced, with an average efficiency of 0.4. In this way heat pumps are not much more efficient than conventional heating, with a COP of 0.95. However, if the electric energy is produced with sustainable technologies like wind, sun and hydropower, heat pumps can save a lot of CO2. Also, what is not taken into account here, is that during the productions of heat by the heat pump, cold water is produced, which is stored and can be used for cooling of the building later on without the use of the heat pump. So to use this cold energy only water pumps are needed to transport it to the surface, and the COP of cooling will be very high. This is the reason ATES is more interesting for buildings that have a high cooling demand. The benefits of thermal heat storage can be explained by an analysis of energy quality as well. For conventional heating the energy is generated by fossil fuels. This form of energy has a high quality, as it can be recovered as work to almost 100% and can be used for many activities. When this form is used to heat a building in a conventional way, water with a temperature of about 80 to 90^{0}C is produced to eventually heat a building to 20^{0}C. So the energy is transferred to very low quality in two steps, first from fossil fuel to water of 80-150^{0}C, and then to a room temperature of 20^{0}C. A similar process takes place for cooling a building. With ATES and heat pumps it is possible to use low quality energy to heat or cool a building. Water with a temperature of 13-16^{0}C is upgraded to 35-45^{0}C, which is used to heat the building. [5] There are some parameters which influence the thermal performance of ATES. [4,9]

– Density differences of warm and cold water do not seem to have any relevant influence on the performance of an ATES system in the temperature range between 6 to 18^{0}C.
– Viscosity differences only have an influence of 0.3% on the performance in this temperature range. However, the model on which the results are based, did not take heterogeneities of the subsoil into account.
– The capacity of the well depends on the hydraulic conductivity, but if the capacity is not a constraint, the hydraulic conductivity does not influence the performance of an ATES, as long as the subsurface is homogeneous.
– If the distance between the wells of a double or its screen length increases, so does the performance, until an asymptotic value has been reached, which, according to the model, was about 90^{0}C.
– The higher the temperature difference is, the greater the energy performance. This might seem a strange result, but is explained by the fact that a smaller amount of water has to be pumped in the wells, and so the water will flow less fast and far. Therefore, dispersion is smaller and less energy is lost. However, the model does not incorporate any ambient groundwater flow, so a very small cold or warm bubble will not flow away from the well. This might not be a realistic case. [4,9]

B. Exergy Analysis

Thermodynamics permits the behavior, performance, and efficiency to be described for systems for the conversion of energy from one form to another. Conventional thermodynamic analysis is based primarily on the first law of thermodynamics, which states the principle of conservation of energy. An energy analysis of an energy-conversion system is essentially an accounting of the energies entering and exiting. The exiting energy can be broken down into products and wastes. Efficiencies are often evaluated as ratios of energy quantities and are often used to assess and compare various systems. [4, 9]

Conventional thermal storages, for example, are often compared on the basis of their energy efficiencies. Exergy analysis helps to overcome many of the shortcomings of energy analysis. Exergy analysis is based on the second law of thermodynamics and is useful in identifying the causes, locations, and magnitudes of process inefficiencies. The exergy associated with an energy quantity is a quantitative assessment of its usefulness or quality. Exergy analysis acknowledges that, although energy cannot be created or destroyed, it can be degraded in quality, eventually reaching a state in which it is in complete equilibrium with the surroundings and hence of no further use for performing tasks. This statement is of particular importance to TES systems in that, from a thermodynamic perspective, one would wish to recover as much thermal energy as is reasonably possible after the input energy is stored, with little or no degradation of temperature toward the environmental state. [9]

For TES systems, exergy analysis allows one to determine the maximum potential associated with the incoming thermal energy. This maximum is retained and recovered only if the thermal energy undergoes processes in a reversible manner. No further useful thermal energy or exergy can be extracted by allowing a system and its environment to interact if they are in equilibrium. Losses in the potential for exergy recovery occur in the real world because actual processes are always irreversible.

The exergy flow rate of a flowing commodity is the maximum rate at which work may be obtained from it as it passes reversibly to the environmental state, exchanging heat and materials only with the surroundings. In essence, exergy analysis states the theoretical limitations imposed upon a TES system, clearly pointing out that no real system can conserve thermal exergy and that only a portion of the input thermal exergy can be recovered. Also, exergy analysis quantitatively specifies practical TES limitations by providing losses in a form in which they are a direct measure of lost thermal exergy.[9]

V. COST ANALYSIS OF BUILDING

A reduction in carbon emissions and lower running costs for buildings are a worldwide concern with many government policies implementing schemes to bring emissions and costs to a lower level. Groups such as the International Energy Agency (IEA) or the Intergovernmental Panel On Climate

Change (IPCC) provide information leading to potential policies which have a high priority in many global energy supply initiatives which will involve significant increases in the uptake of small-scale energy efficient (EE). One such technology is known as Thermal Energy Storage (TES). This technology solves a problem, common to most other RES systems whereby it acts as a buffer between the mismatch in supply and demand of energy.

One of the disadvantages to any EE system is that it increases the initial capital cost of the building. However by increasing the energy efficient technologies in a building, the running costs over the life of the system are expected to decrease when compared to a more conventional non EE system thus justifying a higher initial cost. Capital costs can be decreased by integrating the building design and EE system to lower the loads of the system, hence reducing the capacity of the building services system. [10] There are some factors on which a cost analysis depends:

- Valuable floor area is not needed.
- The ground is able to hold energy relatively constant all year round compared to other systems such as above ground tanks.
- They are usually unobtrusive.

A. *Financial Model*

A Life cycle cost (LCC) analyses of a project is used to determine if there is a future operational savings which will justify the initial capital cost. The capital and operating costs of a number of different BTES systems were therefore estimated for a large-scale mixed development, assumed cash flows determined and net present values (NPV) determined.

1) *Capital costs*

These are costs that are incurred at the initial stages of the project. They are the highest and biggest barrier to any EE system. For a BTES the capital costs include some of the following:

- Site investigation and testing
- Design
- Site preparation and set up
- Drilling
- Pipe work installation

B. *Running Cost*

These are the costs that are associated to with the day to day operation of the plant. For the BTES system, electrical energy is needed for pumping power to deliver and recover energy from the storage area. The pumping power required was calculated by obtaining the total equivalent length of pipe and calculated pressure drop in each system. An average industrial tariff for electricity of Rs.8.36 per kWh has been used to calculate the total running costs for the pumps. A fixed costs for maintaining the system included repairs, cleaning and controls. The controls of these systems are the highest cost associated with maintenance.

C. *Advantages of ATES system*

- Groundwater energy systems provide an efficient and reliable supply of low-cost energy that can complement conventional heating and cooling systems
- The groundwater systems are environmentally being technology and can reduce stack emissions (e.g., carbon dioxide) and the use of chlorofluorocarbon CFCs.
- It can also reduce electrical usage during peak demand periods.

D. *Application*

These groundwater systems can be applied to new and existing heating and cooling systems in

1) Government buildings
2) Business parks
3) Residential complexes
4) Educational institutions
5) Hospitals
6) Industrial complexes.

In addition, groundwater systems can be integrated into industrial process plants such as paper and textile mills, and pharmaceutical manufacturing, mining, and food processing facilities.

VI. CONCLUSION FROM RESULTS

An aquifer storage system can be used for storage periods ranging from long to short, including daily, weekly, seasonal, or mixed cycles. Also by implementing this system in metro politician cities where continuous supply of electricity is needed, we can save electricity simultaneously we can also use our application. Based on current energy prices, ATES system could reduce annual costs for heating by 57% and cooling by 35% over conventional methods. The system consists of simple components and has the advantage of easy handling.

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