ATES and ground-source heat pumps in The Netherlands

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In the last twenty years aquifer thermal energy storage (ATES) and heat pump technology have been developed independently. However, the combination of these technologies has recently shown good prospects in offices and commercial buildings. One of the projects where heating and cooling is provided by ATES and a heat pump is a new multipurpose soccer stadium (Gelredome) in Arnhem, the Netherlands. The stadium is equipped with several other novel facilities such as a mobile playing field, solar collectors and a sliding roof.

This article describes the developments in the Netherlands and gives more details on the application in Arnhem.

Thermal storage

The development of ATES in the Netherlands started in the early 1980s. Initially, seasonal heat storage was considered a suitable method for storing solar energy to be used for space heating in winter. It soon became apparent that seasonal storage in aquifers is also very useful for storing waste heat and cold. During the second half of the decade the first projects of thermal energy storage in aquifers were realised. The projects included the storage of solar energy for an office block (30°C), storage of winter cold for a printing industry (6°C) and storage of waste heat from a cogeneration installation for a university building (90°C). Better understanding of the economic aspects and environmental advantages of ATES, plus the success of the first projects, resulted in rapid development of energy storage technology early in the 1990s.

Nowadays, 60 storage projects have been realised or are in progress (see **Figure 1**), of which 90% provide cold storage or the combination of cold storage and low-temperature heat storage. Approximately 80% of the applications are found in the building sector, mainly office blocks, hospitals and shopping centres. The remaining applications are for industrial cooling and cooling in the agricultural sector. A relatively small number of cold storage projects use a heat pump.

Economic aspects

Payback periods for the use of cold storage or combined heat and cold storage in the building sector are favourable. The simple payback period of 50% is less than five years, whereas 90% are less then ten years. This is explained by the fact that traditionally the cooling in this sector was achieved by compression chillers. The investment costs for these machines are avoided by using cold storage and balancing the investment costs for a cold storage system. In several cases, the investment required for cold storage appears to be even lower than for chillers.

Cold storage as well as combined cold and heat storage use natural energy in the form of heat or cold. Utilising this energy source therefore requires only a limited amount of auxiliary energy (for submersible pumps etc.). For this reason, cold storage can be considered a renewable energy technology, the use of which is encouraged by the Dutch government. The potential contribution from cold storage to the energy production in the Netherlands in the year 2020 has been stipulated in the Third Energy Review by the Ministry of Economic Affairs. The annual contribution is estimated at 15 PJ, which corresponds to approximately 500 million m^3 of natural gas savings per year.

Success factors

The main reasons for the success of ATES on the Dutch market are:

- aquifers are available under every major city;
- the government has responded positively towards ATES, by subsidising feasibility and market studies;
- the relatively high price of electricity compared to natural gas;
- the increasing environmental consciousness of private companies;
- the prohibition of CFCs;
- the positive attitude of licensing authorities.

▼ *Figure 1: Status of ATES projects in the Netherlands.*

At present, cold-energy storage is considered a proven technology. In the years to come, the number of cold-storage projects will increase further, partly because of an increasing environmental awareness. The expected growth rate is between 20 and 30 new projects per year.

Ground-source heat pumps

Since the discovery in 1960 of one of the world's largest natural gas fields, space and water heating in the Netherlands is mainly obtained via gas-fired boilers. Recently, however, the monopoly of natural gas been threatened by the re-introduction of electric heat pumps.

Several reasons can be mentioned for the renewed interest in heat pumps. First of all, technological developments have brought about improvements in the efficiency of heat pumps. Secondly, the newest power plants generate electricity with an increased efficiency up to a remarkable 56%. Furthermore, for electric power utilities heat pump technology can be a way to strengthen their control of the heating market, which to date mainly meant control of the gas industry. Finally, in its attempts to maximise the efficient use of non-renewable energy sources, the government is also interested in heat pumps. The electricity utilities expect approximately 200,000 heat pumps to be installed by the year 2005 in new houses in the Netherlands.

Use of ground water

Heat can be extracted from the subsoil using ground water or ground heat exchangers. In the Netherlands, 95% of the shallow subsoil (<200 m below surface level) consists of aquifers. It is relatively easy and inexpensive to extract ground water from these layers. Because of its relatively high temperature (approximately 11-12°C), this ground water makes an excellent heat source for a heat pump. Ground water systems are also more economic than ground heat exchangers, except for small systems (<100 kW_{th}).

The cheapest way of using ground water is to discharge it into the sewer after it has been used by the heat pump. However, the Dutch government does not grant licences for such systems, mainly because good quality ground water is relatively scarce. Re-injection of ground water dispels the authorities' main objection. To achieve "sustainable utilisation" of ground water (i.e. present utilisation should not form a barrier to future utilisation) restoration of the thermal equilibrium in the subsoil is preferred. For a ground water heat pump system, this can be achieved by extracting ground water from the extraction well in summer and heating it using outside air (dry heaters), the sun (solar collectors), surface water or surplus heat from buildings. The warmed ground water is then re-injected into the subsoil where it mixes with the cold ground water from the previous winter season. However, a better way to restore the thermal balance in the subsoil is to utilise the cold energy which is injected in winter in a combined ATES and heat pump system.

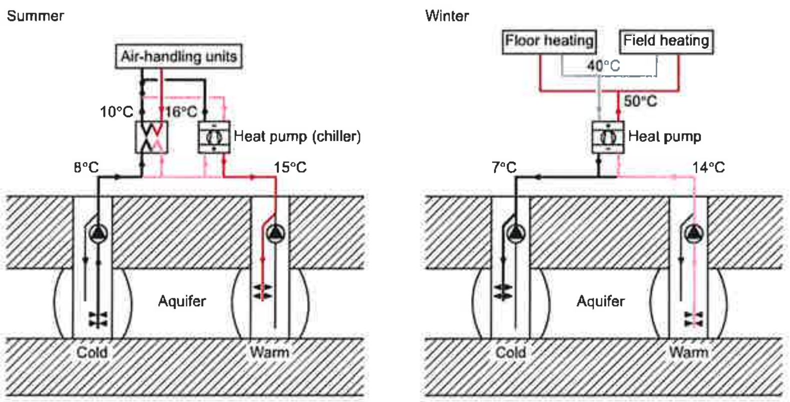
A heat pump with a coefficient of performance (COP) of 3-4 uses less energy than a gas-fired boiler with 90% efficiency. The overall COP may be adversely affected, if warm tap water is prepared by the heat pump. In addition to energy efficiency, the success of heat pumps will largely depend on the connection to the subsoil. If contractors and heat pump suppliers have inadequate knowledge of the hydrological and thermal behaviour of the subsoil, there is a risk that poorly functioning systems are built. For the moment, research into systems with ground water source heat pumps, as well as the realisation of such systems, will continue in the Netherlands. In a few year's time results will show whether these systems really contribute to a sustainable energy supply.

Heat pumps and ATES

The Gelredome stadium is one of the projects using a combination of ATES and heat pump. The Gelredome stadium - a USD 70 million project - will

▼ *Figure 2: Photo of the Gelredome stadium - installation of ATES.*

▼ *Figure 3: Energy storage with heat pump at Gelredome.*



accommodate 27,000 spectators (see **Figure 2**). Apart from soccer matches other sporting events and concerts will take place in the stadium. In winter, the soccer pitch and base floor will need heating, while in summer the stadium will need cooling for offices and congress facilities.

In winter, the heat pump (with a heating capacity of 410 kW) will supply 70% of the required heat. The remainder is provided by a gas-fired boiler. Ground water is used as the heat source for the heat pump and is extracted via two wells (see **Figure 3**). Once the ground water has given off its heat, it is re-injected into the subsoil via a cold well. In summer, cold is supplied either directly (without heat pump) or indirectly (with heat pump). The cold-storage system can provide a direct cooling capacity of approximately 2,800 kW. This is achieved by extracting ground water at a rate of 0.069 m^3/s from the cold well and, after supplying its cold energy via the air-handling unit, injecting it into the warm wells.

Under very extreme summer weather conditions, the stadium may demand an extra 10% more cold energy. In this case, the heat pump (which is connected to the supply line of the air handling unit) will be used as a chiller, the condenser of which is also cooled by the cold storage. It should be noted that in summer this system supplies cold 95% of the time without using the heat pump. If the cold ground water was only used to cool the condenser of the chiller (heat pump), a considerable part of the energy saving that could be achieved with the system, would not be realised.

Advantages

Compared with a conventional installation using chillers for cooling and a gas-fired boiler for heating, the combined system of energy storage with a heat pump results in a 45% energy saving. In summer, in cooling mode, the only energy consumer is the submersible pump in the cold well. The number of cold-storage systems with heat pumps is increasing. A major reason for this is that the supply temperature of the heating systems in modern office buildings is less than 50°C. Additionally, an important aspect is that the heat pump produces cold energy as a by-product of heating. With this cold energy the cold-storage system can be charged in a relatively simple way with low energy requirements. A further advantage is the fact that heat injected into the subsoil in summer, can improve the heat pump COP in winter. Finally, the heat pump has the option of serving as a chiller when there is insufficient cold-energy supply from the subsoil.

Conclusion

ATES has proven to be a reliable and sustainable way of cooling and heating buildings and industrial processes. The ground water heat pump shows good prospects for heating in residential areas and commercial buildings. The combination of both systems has even more advantages. The system is especially suitable for situations where there is a balance between the heating and cooling demand. For the Netherlands, this means that a combined system of ground water heat pumps and ATES can be very suitable for commercial buildings and offices, but less feasible for residential buildings.

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