Metro tunnels enable geothermal air-conditioning

Geothermal plants can be integrated into new tunnel structures in inner cities

When constructing new underground metro lines it is possible to integrate geothermal plants with few additional costs. That provides an excellent opportunity to use this renewable energy source in cities with densely built underground infrastructures. A test plant is in operation on Metro Line 6 at Stuttgart’s Fasanenhof underground station. Scientists at the University of Stuttgart are investigating the effects that the geothermal activation of the tunnel is having on the subsurface.

Thanks to their large amounts of surface area in contact with the ground, tunnel structures have a high geothermal potential. Newly built tunnels are situated close to possible consumers. Offices, homes and commercial businesses can be heated and cooled using geothermal energy. Only a few technical modifications are required to use a tunnel as a heating and cooling source. For example, preliminary forecasts indicate that the increased costs for the shell caused by the geothermal activation only amount to about two per cent. The absorber tubes can be mounted on the shotcrete used for the external tunnel lining and integrated into the in-situ concrete used for the inner tunnel lining. This process is suitable for new mined tunnels where the tunnel is bored or excavated. The alternative cut and cover method, in which a tunnel is built with rectangular sections like a cellar and then covered, was not investigated. Two tunnels in the city’s metro system were both equipped with absorber tubes along a length of 10 metres. The two tunnel sections are located in layers of sandstone and shale. They both have two absorber circuits. Each sub-circuit was installed with around 2x200 metres of absorber tubing across an area of approximately 90 m². Connection lines link the absorber circuits with a heat pump located in the operating room at the Europa-platz station. The scientists use the heat pump to test different load profiles for the heating and cooling operation.
As with a borehole heat exchanger, absorber fluid flows through the heat exchanger tubes. The water/monoethylene glycol mixture absorbs the heat stored in the ground and the tunnel air or releases it.

**Measurements and calculations show the influence**

Scientists from the University of Stuttgart installed a test system during the construction of the new tunnel for the city’s underground metro line at Stuttgart-Fasanenhof. The aim of the research project was to investigate the possible energy extraction in accordance with the different boundary conditions. In addition, the scientists investigated how the geothermal activation of the tunnel affected the ground. For this purpose they conducted measurements and numeric calculations.

The temperature fields in the ground, structure and tunnel air were determined using comprehensive measurement technology. In addition, the researchers have measured the flow speed of the tunnel air. They also determined the thermal properties of the rock, such as the thermal conductivity and the specific thermal capacity.

The scientists are measuring the supply and return temperature of the absorber circuits in the tunnel as well as the respective mass flows in order to determine the performance capability of the absorber system. The supply and return temperatures of the entire system are recorded in the operating room along with the volume flow for the main circuit, which is used to calculate energy balances. In order to calculate the heat transfer on the inner side of the tunnel lining, the scientists are also recording the air speed in the tunnel. Using two-dimensional, numeric thermal transport calculations they are investigating the influence of the tunnel air temperature on the performance capacity of the plant. The model is being calibrated with comprehensive measurement series.

**Ground temperature only changed in immediate vicinity**

In the project the researchers have investigated the influence of the geothermal usage on the ground temperature. The temperature in the direct vicinity has changed as a result of constructing the tunnel. The measurements show that the temperature is only influenced at a distance of up to eight metres around the tunnel. The researchers did not find any influence on the subsurface further away.

At a horizontal distance from the metro tunnel of more than eight metres, the undisturbed ground temperature at Fasanenhof is around 12 °C. The temperature of the tunnel air fluctuates as a result of the weather. This also changes the ground temperature at a distance of up to eight metres from the tunnel. The temperatures measured near the tunnel lie between 2 °C and 18 °C.

The geothermal activation of the tunnel also influences the temperatures close to the tunnel. The measurements show that the temperature close to the tunnel approaches the supply temperature when the heat pump is continually operated, whereby the specific change depends on the method of operation.

The geothermal plant is controlled via the supply temperature and the volume flow for the absorber fluid. For the test section, the supply temperature accords with the provisions stipulated by Stuttgart’s environmental protection office. According to these, the groundwater temperature near the tunnel should not be less than 0 °C. This limit applies when the geothermal plant is used for heating. If the plant is used for cooling, the heat is directed underground. In this case the groundwater temperature near the tunnel must not exceed 25 °C.

By means of heating and cooling experiments, the scientists are investigating the performance capability and the temperature behaviour of the absorber system, whereby they are maintaining the supply temperature to the absorbers and the mass flow of the system at a constant level. Depending on the time of year, the thermal output of the overall system ranges between 5 and 37 W/m².

**The tunnel air and groundwater increase the heat recovery**

With tunnel-based geothermal energy, the strongly fluctuating temperature of the tunnel air influences the thermal output. Other conditions apply to borehole heat exchangers. They are surrounded on all sides by earth, which has a relatively constant temperature. The temperature of the tunnel air depends on the external air temperature, the flow speed and further heat sources such as the metro trains.
Techniques for utilising shallow geothermal energy

For air-conditioning buildings, geothermal energy provides an almost inexhaustible heat source. Particularly suitable is shallow geothermal energy that uses boreholes up to 400 metres in depth.

Various techniques can be used in accordance with the ground conditions and the foundations for the building. The most widespread type of system used in central and northern Europe consists of borehole heat exchangers. These are mostly used with boreholes at a depth of 50 to 160 metres. A heat transfer fluid circulates in the tubes that absorbs the heat from the ground and transports it to the surface for the heat pump.

Another construction form is provided by energy piles. Here the tubing is integrated directly into the foundation piles for the building. Energy piles usually have a depth of 10 to 30 metres. Horizontal tubes can also be installed in or beneath the foundation slab. These are called ground absorbers.

Another version is provided by geothermal horizontal collectors. Here the absorber tubes are laid in roughly two- to three-metre-deep trenches, for example beneath car parks or park areas. A hybrid form results from their use in so-called geothermal energy baskets. Here they also specifically utilise the thermal potential provided by rainwater.

According to the Bundesverband Geothermie (GTV), around 290,000 shallow geothermal systems are currently in operation. Numerous new installations are added each year. In 2012 there were around 22,200 new systems.

The scientists are also investigating the influence of points where the tunnel comes into contact with flowing groundwater. The groundwater flow thermally balances out the temperature in the area surrounding the tunnel. This effect depends on the hydraulic conductivity of the rock and the hydraulic gradients. The groundwater flow increases the energy generated by the tunnel-based geothermal plant, whereby it particularly increases the extraction capacity during the cold and heating-intensive winter months.

In the follow-up project the scientists are now simulating the connection with a building. During the next two years they are running tempered fluid through the test section in order to produce a realistic extraction profile. Further research needs to be conducted on the economic feasibility of the process. In particular, a business model has been lacking until now. The geothermal activation of tunnel systems would enable their operators to become energy suppliers. However, they would already need to decide how many metres of the tunnel should be furnished with the tube systems during the construction. For this purpose the requirement provided by possible loads, such as office buildings, would have to be forecast.

Measurements made on the test section show that the tunnel air has a significant impact on the energy generated. For example, the tunnel air has a positive influence in spring: whereas the ground only heats up slowly, the air heats up very quickly. When a cold day occurs, a larger heating capacity is available for the geothermal plant as a result of the heated tunnel air.

If the air temperature increases in summer, the output of the plant for cooling a building lowers. An analogous situation applies for the conditions in autumn and winter.

In order to optimally plan the geothermal plant, it is important to know the air temperatures in the tunnel. Two critical operating conditions need to be observed in particular: when heating the tunnel air temperature can fall below the supply temperature; when cooling it can increase above the supply temperature. This considerably reduces the output of the geothermal plant.

In this case, the volume flow, for example, needs to be increased in order to be able to extract more energy.
Thermally activating tunnels

In Austria a building has already been heated with a geothermally activated tunnel. Using tunnel-based geothermal energy, the pilot system heats the municipal building yard belonging to the community of Jenbach. Along a distance of 54 metres, a 3.5-kilometre railway tunnel was furnished with absorber tubing. During the first winter the system completely met the heating requirements for the municipal building yard, which amounts to 40 kW. The system monitoring showed that it could have provided even more heat. Whereas the underground tunnel for the U6 metro line in Stuttgart was constructed using mining techniques, mechanised tunnelling was deployed in Jenbach with a tunnel boring machine. In Stuttgart the absorber tubes were installed between the shotcrete layers and the inner structural concrete lining. In Jenbach the feeder line to the Brenner Base Tunnel was built using segmental construction, whereby the concrete segments – called tubbings – were installed using a tunnel boring machine. The absorber tubing was already installed in the precast concrete segments during the manufacture. As soon as each complete segment ring was installed, the absorber tubes were connected to the recesses. This technique was jointly developed by Rehau and Züblin and has been patented as “energy tubbings”. It can also be used for constructing tunnels for trams, wastewater and supply tunnels. Depending on the ground conditions and temperature in the tunnel, an energy yield ranging between 10 and 30 W/m² can be achieved. Tunnel structures can be used as a source for heating and as an energy sink for cooling buildings, for example offices.

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