GEOTHERMAL HEATING AND COOLING OF BUILDINGS

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Abstract: Aspects of environmental protection and an economical extraction or storage of energy led to the development of “geothermal foundations”. In such cases neither deep boreholes nor hot springs are necessary. Structural elements, which are required for the building and being in direct contact with the soil (“geothermal absorbers”) are directly used. This refers mainly to structural elements of concrete (piles, diaphragm walls), but also shallow foundations and even basement walls or retaining walls can be utilized.

This innovative technology provides not only substantial long-term cost savings in relation to conventional energy systems but also a valuable contribution to environmental protection by reducing fossil energy utilisation. The paper describes the principles, illustrates case histories, and reports on the results of in-situ measurements.

Special applications are “energy tunnels”, heating or cooling of road surfaces/pavements, “energy wells” etc. There are systems with or without heat pumps, both providing clean and renewable energy for an economical heating and/or cooling of buildings.

1. INTRODUCTION

Subsurface geothermal resources represent a great potential of direct use energy, especially in connection with (deep) foundations and heat pumps. The heat pump for the extraction of geothermal energy from the ground was invented about 140 years ago by the Austrian, Peter Ritter von Rittinger. Geothermal energy can also be obtained by means of flat collectors, trench collectors, or borehole heat exchangers (up to 300 m depth; standard diameter = 32 to 120 mm). These systems have been widely used since many years in Austria. Presently, nearly 100,000 heat pumps are operating there.

Since the beginning of the Eighties, geothermal energy has also been increasingly obtained from foundation elements in Austria and Switzerland; at first from rafts, then from piles (1985) and diaphragm walls (1996). This innovation makes use of the high thermal storage capacity of concrete. Moreover, these concrete members are required already for structural reasons and need not be installed as additional elements like conventional thermal energy utilisation systems.

With combined geothermal cooling/heating systems heat energy is fed into and withdrawn from the ground via “energy foundations”. This innovative method is significantly more cost effective than conventional systems and it is environmentally friendly because it uses clean, renewable energy.

2. PRINCIPLE OF GEOTHERMAL UTILISATION OF FOUNDATIONS (“ENERGY FOUNDATIONS”)

Energy foundations may be raft foundations, piles, barrettes, slurry trench systems (single elements or continuous diaphragm walls). Combinations with surface-near earth collectors or retaining structures are also possible. Energy foundations can be used for heating and/or cooling buildings of all sizes (Fig. 1) as well as road pavements or bridge decks, etc.

Energy piles may be driven, bored or augered piles of reinforced concrete. The piles contain plastic pipes (HDPE) carrying a heat transfer medium (brine or water). In case of
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1 = energy piles (570)
2 = absorber pipes
3 = collectors
4 = main pipe
5 = heating / cooling centre

Fig. 1 Scheme of heating/cooling an industrial building with energy piles. The same concept is applicable for energy diaphragm walls or barrettes.

pre-fabricated or in-situ cast concrete piles, the pipes are mounted along the reinforcement cages. Fig. 2 shows the scheme of an energy pile, and Fig. 3 illustrates the installation of the absorber pipes. From the pile heads the pipes are leading to a distributor where they are collected. Fig. 4 gives a partial view of the laving system of absorber pipes on the sub-concrete of a piled raft foundation. Connected to this primary circuit is the secondary circuit within the building where the thermal energy is distributed. The energy can be utilised for classical cooling- and heating systems too.

In case of heating, the energy carrier coming from the ground is compressed by a heat pump, thus generating heat which is transmitted through the heating circuit of the building. All low-temperature heating systems can be thus employed, including floor-heating. As a useful side-effect, the fluid in the energy piles (also “absorber piles”) works as a coolant in the summer. Whilst cold energy is stored in the ground during the winter, the process is reversed in the summer, with cold energy extracted from the ground for cooling purposes. The cooled subsoil then heats up in time for heat extraction during the next winter. Such combined heating/cooling systems require a reversible ground-source heat pump or in the case of free cooling a circulation pump only for cooling.

Heat can be extracted by means of a heat pump from brine or water which circulates in the primary circuit and regenerates itself in the subsoil or the massive absorber. All that is required for this process is a low application of electrical energy for raising the originally non-useable heat resources to a higher, usable temperature. The principle of a heat pump is similar to that of a reverse refrigerator. In case of the heat pump, however, both the heat absorption in the evaporator and the heat emission in the condenser occur at a higher temperature, whereby the heating and not the cooling effect is utilised. The effect of a heat pump is defined by an efficiency factor, for instance an efficiency factor of four means that from one portion of electrical energy and three portions of environmental energy (from the ground) four portions of usable energy are derived Fig. 5.
Experience has shown that this cooling/heating system may save up to two thirds of conventional heating costs. Moreover, it represents an effective contribution to environmental protection by providing clean and self-renewable energy.

In Central Europe, ground temperatures remain relatively stable all year round below a depth of 5 to 10 m. Values between T = 10° and 15°C predominate. Such temperatures permit economical heating as well as cooling and represent an ideal condition for heat pumps. In tropical countries, the groundwater temperature varies between T = 20° and 25°C (locally even 28°C) in a depth of ≥ 5 to 10 m below surface. This provides the possibility of transferring the heat from cooling machines into the subsoil.

Water saturated, highly permeable soil is best suitable, but the system works also economically in over- or under-consolidated clays. Dry sand or gravel makes deeper piles and a larger area of absorbers necessary. Depending on soil properties and the installation depth of the absorbers, 1 kW heating needs between 20 m² (saturated soil) to 50 m² (dry sand) of surface of concrete structures in contact with soil or ground water.

There is no limitation to the depth of piles or diaphragm walls as far as the installation of energy absorber systems is concerned. The energy potential increases with depth, hence deeper foundations are advantageous. The economically minimum length of piles etc. is about 6 m.
3. THERMODYNAMIC PRINCIPLES AND THERMAL SOIL PROPERTIES

Heat transport occurs in different ways (Fig. 6):
- Conduction (in solid, liquid, and gaseous media);
- Convection (in liquid and gaseous media);
- Radiation (not bound to medium; also in vacuum).

Conduction means energy transfer by molecules (from a higher to a lower energy level), whereby molecules in liquids or gases need to move convectively. Convection is based on energy transfer by a (relative) movement of a medium in the thermodynamic system; hence convection cannot occur in a solid medium. Closely related to convection is dispersion which also influences heat transfer. Heat transfer by radiation is based on electromagnetic waves.
Fig. 6 Heat transport and geothermal situation for deep foundations (schematic). Ground temperature at depth rather constant (Europe: $T = 10^\circ - 15^\circ$C; Tropics: $T = 20^\circ - 25^\circ$C, locally $28^\circ$C).

The thermal properties of a medium are described by heat conductivity $\lambda$ (in W/m$^\circ$K) and thermal storage capacity, i.e. heat capacity $c$ (in J/m$^3$K) or C (in J/kgK). Both parameters depend widely on soil, density, water content and temperature. The influence of temperature is relatively small, unless freezing occurs. Figures 7, 8 and Table 1 show some data for $T = 20^\circ$C and isotropic ground. Anisotropic layers may exhibit different heat conductivities depending on the direction. Generally, the heat conductivity varies to a greater extent than the heat capacity, but both values increase with density and water content. Water saturated soils, therefore, have the greatest heat storage capacity, unless strong groundwater flow occurs.

The temperature of water bearing zones in the ground can be determined by geothermal measurements and temperature modelling. This requires the use of high-precise temperature logging with temperature measuring chains and detailed knowledge about the hydrogeological ground characteristics, especially the transmissivity (product of hydraulic conductivity and thickness of water bearing zone).

When lowering the temperature, the thermal conductivity of the ground water decreases slightly, e.g. from $\lambda = 0.600$ at $T = 20^\circ$C to $\lambda = 0.572$ W/m$\circ$K at $T = 5^\circ$C. But freezing causes a significant increase of the thermal conductivity of a soil because the thermal conductivity of water then rises to $\lambda = 2.2$ W/m$\circ$K, whereas the specific heat capacity drops from $C = 4.18$ to 1.93 J/kg$\circ$K. Simultaneously, a loosening of the soil structure occurs in case of frost-susceptible soil. In total, the thermal capacity of the ground decreases during freezing. The lower the natural water content and the suction forces in a soil are, the lower is the influence of freezing on the thermal properties. The freezing-thawing behaviour of the soil depends not only on grain size distribution but also on the mineralogical composition of the fines (Brandl, 1998). Initial density, void ratio, and degree of water saturation are also influential. The most reliable results can be obtained from freezing-thawing tests in an open system, i.e. with sufficient supply of groundwater.

The available energy potential in the ground is rather high as a simple calculation demonstrates. In case of an one-family house of only 100 m$^2$ and a pile length of 12 m, the soil body would be 1200 m$^3$. When cooling down this mass by only $\Delta T = 1^\circ$C, a geothermal energy of more than 1000 kWh can be obtained.

<table>
<thead>
<tr>
<th>Soil</th>
<th>$c$ [J/m$^3$K]</th>
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<tbody>
<tr>
<td>peat – dry</td>
<td>0.7</td>
</tr>
<tr>
<td>gravel – dry</td>
<td>1.3</td>
</tr>
<tr>
<td>silty clay – dry</td>
<td>3.0</td>
</tr>
<tr>
<td>peat – saturated</td>
<td>4.0</td>
</tr>
<tr>
<td>Water</td>
<td>4.25</td>
</tr>
</tbody>
</table>

Table 1
Thermal storage capacity (heat capacity per volume, $c$) for some soils and water at 20$^\circ$C.
Figs. 7, 8  Average thermal conductivity, $\lambda$, of unfrozen soils as a function of water content and dry density (Andersland & Anderson, 1978).

4. DESIGN PARAMETERS

A proper design of energy foundations requires detailed ground investigation and a numerical simulation of the entire system, also including the secondary energy system within the building. Accordingly, the following data should be determined, unless sufficient local knowledge of some parameters already exists:

- Geotechnical soil properties, especially
  - water content,
  - density and void ratio,
  - permeability,
  - swelling-shrinking behaviour,
  - freezing-thawing behaviour (if intensive heat extraction is required),
  - shear parameters and stress-strain behaviour (for foundation design).

- Geothermal soil properties, especially
  - thermal conductivity and capacity at specific temperature levels,
  - in-situ ground temperature,
  - thermal gradient.

- Hydrogeological ground properties, especially
  - depth and seasonal fluctuation of the groundwater table,
  - flow direction and velocity of ground water.

- Mineralogical and geochemical soil properties

- System, dimensions, spacing pattern, way of installation, and concrete properties of the foundation elements.
Fig. 9
Temperature curves in the soil around an energy pile utilised for heating or cooling. Schematic; constant thermal flow stream assumed.

Fig. 10
Detail of temperature distribution around four energy piles which are part of a piled raft foundation (see Fig. 25). Result of numerical calculation.

- Climatic conditions.
- Energy concept
  - heating/cooling requirements within the building,
  - temperature conditions in primary and secondary energy circuits,
  - velocity of the circulating fluid (brine or water) within the energy system,
  - heating-cooling intervals, operation plan.

Heat transfer in the subsoil occurs predominantly due to conduction, convection, and dispersion. This leads to the following differential equation (Sauty; Katzenbach):

\[
\nabla \cdot (\lambda \nabla T) - (\rho c)_s \nabla \cdot (\mathbf{v} T) + \nabla \cdot (D_\lambda \nabla T) + \dot{Q}_i = \rho c \frac{\partial T}{\partial t}
\]

\[
\nabla \cdot ((\lambda + (\rho c)_s) \nabla T) - (\rho c)_s \nabla \cdot (\mathbf{v} T) + \dot{Q}_i = \rho c \frac{\partial T}{\partial t}
\]

where \( \rho c = n(\rho c)_f + (1 - n)(\rho c)_m \)

\( \rho c = \) volumetric heat capacity of the soil

\( n = \) porosity

\( (\rho c)_f = \) volumetric heat capacity of the fluid

\( (\rho c)_m = \) volumetric heat capacity of the solid particles
The heat flow ($d\dot{Q}$) through an arbitrary area ($dA$) at a steady state temperature distribution is defined as:

$$d\dot{Q} = -\lambda \cdot dA \cdot dT/dr \ [W]$$  \hspace{1cm} (2)

$dT/dr$ is the temperature gradient in the normal direction of $dA$. If the thermal conductivity and the temperature gradient are constant over the area and in its normal direction, respectively, an integration of the formula gives:

$$\dot{Q}/A = \lambda \cdot dT/dr \ [W/m^2].$$  \hspace{1cm} (3)

This is indicated in Fig.9 for an energy pile utilised for cooling (= heat transfer into the ground) or heating (= heat extraction from the ground).

Complex ground properties and pile groups require a numerical modelling of the geothermal heating/cooling system. Fig. 10 shows an example for a group of four piles of the foundation system in Fig. 25.
5. INSTALLATION SCHEMES FOR HEATING/COOLING

Fig. 11 shows the installation scheme for heating with energy foundations (piles or diaphragm wall elements) and a heat pump comprising the primary energy circuit (in the ground) and the secondary energy circuit (in the building). Reversible heat pumps can achieve heating and cooling.

Fig. 12 illustrates the installation scheme for “free cooling”. In this case the necessary energy input is limited to the electricity required to operate a circulation pump, whereby about 1 kWh of electricity is needed to obtain up to 50 kWh of cooling energy. The same fluid which cools as it passes through the absorber loops in the foundation is pumped through the cooling system of the building. Coolness can be transferred into the building and distributed there either by a ceiling-, floor-, or wall cooling system (see Figs. 17, 21, 22).

Cooling with chiller (Fig. 13) is another proved geothermal technology making use of energy piles or diaphragm walls: In a geothermal cooling system, the chiller is connected to the building by a distribution system – mostly air ducts in the case of fluid-based systems. The chiller is connected to the soil by PE-pipe loops filled with fluid and integrated into the foundation. This transfers the heat into the subsoil, thus avoiding noisy or unsightly outdoor
cooling towers. As the temperature of the out-flowing fluid from a chiller is around 40° C, this technology has also proved suitable in tropical countries with high underground temperatures (up to 28° C). It can avoid the problems associated with cooling towers in hot and humid air. Likewise, process energy, e.g. from industrial machines, can be transferred into the ground.

6. CASE HISTORIES

6.1 Heating and Cooling of a Multi-purpose Hall

A multi-purpose hall with a capacity of 8000 persons was designed for exhibitions, fairs, and as a sports hall, especially as an ice rink. The latter required intensive cooling and temporary heating. The complex energy management could be solved with energy piles, because piles were already needed for a deep foundation of the structure resting on weak clays (Fig. 14).

The deep foundation comprises 320 cast in situ concrete piles (bored piles, $\varnothing = 50$ cm) of 18 m length. The piles contain in total about 65 km absorber pipes (HDPE; $\varnothing = 25$ mm). This cooling/heating system provides an annual saving of 85,000 m³ of natural gas which is equivalent to an environmental relief of 73 tons CO₂.
6.2 Cooling of an Industrial Building

Fig. 15 shows an example for cooling an industrial building with energy piles ("absorber piles"). In the production rooms significant waste heat is created causing room temperatures of 35°C and more during the summer. This would have significantly reduced the production output by the employees. Therefore, a refrigerant system involving an energy pile system was designed.

If the surplus energy cannot be used for heating, it is transferred to the absorber system and the energy piles respectively. This makes the cooling of the rooms possible by using a brine pump with 2.6 kW capacity. Fig. 16 shows the temperature fluctuation in the absorber...
6.3 Heating and Cooling of an Arts Centre

This case history refers to an example with energy diaphragm walls, required as retaining walls for the 11 m deep excavation pit and for the foundation of an Arts Centre (Fig. 17). The building comprises a structural volume of 28,000 m$^3$ and an area of 33,500 m$^2$. The foundation elements comprised a perimeter diaphragm wall of 0.5 m, 0.9 m, and 1.2 m thickness around the excavation pit and piles of 1.2 m diameter within the cut-off. The wall depth reached up to 28 m, the pile depth varied between 17 m and 25 m.

The subsoil consisted of 3.5 m surface-near gravel layer covering loose sands and weak clays to a depth of about 21 m below ground. These under-consolidated young sediments were underlain by a moraine and finally by rock. Hence, the foundations were designed as end-bearing elements. The groundwater level was about 1 m below surface.

The building is a cast concrete structure, incorporating absorber pipes for heating in the winter and cooling in the summer to provide a comfortable room climate. The allowable variations in daily and long-term temperature and humidity are very small, namely $\pm 2^\circ$C and 3%, respectively.
The building is isolated from external weather conditions in order to minimise geothermal energy utilisation. This provides for optimum operation conditions during the heating period. Any heat flow which penetrates the insulation is absorbed by the piping system installed between the structural fabric of the building and the outer insulation - for either heating or cooling purposes.

The thermal energy for conditioning is extracted from the concrete absorber system integrated in the diaphragm walls which serve as retaining structure for the excavation pit and as perimeter foundation of the building. The scheme of an energy diaphragm wall panel is illustrated in Fig. 18. It comprises in total 24,000 m of DN 25/2.3 mm PE pipes installed.
within 4,500 m$^3$ of concrete, forming 249 units, each approximately 100 m in length, which are connected to flow and return circuits placed around the building next to the diaphragm wall. The absorber units were mounted in loops within the reinforcing cages of the diaphragm wall panels (similar to Fig. 19) and were then lowered into the slurry trenches before the concrete was cast. Throughout the construction phase, the absorber units were pressurised at 8 bar and monitored, so that any pipe failure could have been detected immediately (Fig. 20).

A total water volume of 26 m$^3$ circulates in the absorber system and provides a maximum cooling capacity of 120 kW, due to the heat exchange between the absorber units in the diaphragm walls and the ground (i.e. primary circuit). The secondary circuit within the building comprises some 30 km of 16/2 mm piping positioned in the concrete floors and walls. Fig. 21 shows absorber pipes entering the thermo-active slabs in the first floor. The loops are running from the diaphragm walls up along the outer walls of the building and are distributed then within the slabs as illustrated in Fig. 22 (i.e. secondary circuit).

The benefits of this energy concept for an Austrian Arts Centre are both environmental and economical. The saving in investment costs was US$ 2 mill., and the annual savings in operation costs are US$ 0.33 mill. compared to a conventional air-conditioning system. Furthermore, excessive energy can be temporarily stored in the ground for short periods.
Fig. 22
Absorber pipes placed in loops within the reinforcement of the thermo-active concrete slab in the fourth floor. Detail to Fig. 17 (secondary circuit).

Fig. 23 Partial cross section of a large rehabilitation centre in an unstable slope. Foundation and retaining structure include energy piles.

6.4 Foundation Piles and Pile Walls for Heating and Cooling a Rehabilitation Centre

A large rehabilitation centre with an indoor swimming pool had to be constructed in an unstable slope (Fig.23). The excavation pit required a 14 m deep slope cut in tertiary fissured silt and clay. Groundwater was found 4 - 5 m below original surface, though not as a continuous aquifer but locally in sandy inter-layers and joints.

The ground plan of the building is given in Fig. 24, and Fig. 25 shows the energy piles and the energy systems comprising 175 bored piles ($\varnothing = 1.2$ m) which had three functions:
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Fig. 24
Ground plan of the rehabilitation centre Bad Schallerbach/Austria with foundation areas A to J and part of the retaining walls, fitted with energy piles. Area F rests on a piled raft foundation, the other areas are founded only on rafts.

Fig. 25 Detail to Fig. 24 with piles and energy transfer system.

- foundation of the statically critical area F,
- retaining structures for the slide-prone slope,
- retaining walls for the 14 m deep excavation pit.

Due to the sloped surface of the building area and the deep-seated collector galleries, the piles had to be installed at rather different levels (e.g. Fig. 26). The pile depth varied according to static requirements and local soil characteristics: 9 - 11 m for foundation piles and 9 - 18 m (mean value 14 m) for the retaining piles. Most of the retaining structures had to be tied back with prestressed anchors. 143 piles are fitted with heat exchangers. The optimisation of the geothermal heating and cooling system required detailed parametric studies with numerical modelling (e.g. Fig. 10).

Some 40,000 meters of polyethylene piping were attached to the reinforcement cages of the piles. Throughout the construction period, the absorber units were pressurised at 8 bar so that any defects could have been detected immediately. The pipes leading from the piles to the distributors were placed beneath the raft of the building and behind the pile walls.
The (long-term) stability of the retaining structures has been monitored since the initial construction period by inclinometers in piles and by pressure cells on anchor heads. The pipes of the absorber system have been monitored with pressure gauges. One load bearing pile of the piled raft foundation was fitted with the following measuring devices:

- pressure cells on pile toe and head,
- fissuremeters in three levels,
- thermo-elements in five levels.

The aim of the measuring pile was to investigate the effects of temperature changes within an energy pile on its bearing capacity, especially on its shaft resistance during hydration and subsequent energy extraction. Moreover, the influence of natural temperature fluctuation in the ground should be monitored.

Fig. 27 shows the load changes on head and toe of the measuring pile versus time. The rough structure of the building was completed in autumn of 1996 providing about 85 to 90% of the dead load. The initial results illustrate that residual stresses were imposed on the pile before any static loading, caused by the heat development in the fresh pile concrete due to hydration. Thermal contraction after peak temperature caused a temporary reduction of the base pressure in the pile toe. To a certain extent this continued for a short period and simultaneously, shaft friction was increasingly mobilised. Over a long-term period of more than three years the point load in the base of the pile, \( Q_b \), has remained constant now - independently of the increase in total load and of the temperature variations within and around the energy pile. This proves conclusively that a proper operating of energy piles has no relevant influence on the shaft resistance.

In Fig. 28 the temperature fluctuations are plotted versus pile depth. The "zero"-measurement (which is not plotted in Fig. 28) was performed during the hydration phase of the pile concrete and showed a temperature of up to 60° C. The first follow-up measurement (27.9.1995) provided typical summer results and the second one winter results, whereby the measuring pile was already loaded by four floors. At that time, only the concrete structure was under construction and no temperature insulation had been installed. This explains the
Fig. 27 Loads on head and toe of the measuring energy pile versus time at different construction stages. Permanent, full operation of the energy pile system since autumn 1997. Previously, only temporary test runs of the energy system.

Fig. 28 Temperature versus pile depth at different construction stages and since the energy system has been fully operated (see Fig. 27).

0°C - value on the pile head. Measurement No. 3 was taken during a test phase of operating the energy piles, after the structure was finished at that time. The last two measurements provided the data under full operation of the energy piles (since autumn 1997). The different winter results of 9.2.1998 and 29.1.1999 correspond very well with the different weather conditions in these two years: the last winter was significantly milder, and therefore less geothermal energy was extracted from the ground. The shape of the temperature-depth curves has remained rather similar since the energy system has been fully operated: It exhibits a relatively high value on top (due to the heat flow from the building), a minimum in the central zone of the pile depth, and again increasing values towards the pile toe due to the temperature field of the undisturbed groundwater beneath the piles.

6.5 Keble College in Oxford

The first energy pile project in the United Kingdom started in 2001, based on Austrian knowledge and technology: A new building of the Keble Colleges in Oxford comprising a lecture hall and residences. According to Figures 29, 30 foundation piles (Ø 0.75 m and
0.45 m) and secant piles (Ø 0.6 m) of the retaining wall for the excavation pit were fitted with absorber pipes.

The heating load of the building is 85 kW and the cooling load 65 W. The monthly costs for heating and cooling can be fully covered by this geothermal system (Fig. 31).

Fig. 29 Energy piles for the foundation and pit retaining wall for the new building of the Keble Colleges in Oxford.

Fig. 30 Cross section to Fig. 29.
7. SPECIAL APPLICATIONS

7.1 Overview

Subsurface geothermal resources can be used widely for heating and/or cooling traffic areas by using structural elements for energy extraction or storing (Brandl 1998; Brandl, Adam & Kopf 1999).

- Piles, barrettes, and diaphragm walls as foundation elements of bridges;
- Shallow foundations;
- Retaining walls;
- Embankments;
- Tunnel linings (especially near to the portals).

Special applications are

- Heating/cooling of multi-purpose buildings (e.g. Fig. 14);
- Heating/cooling of bridge decks;
- Heating/cooling of road pavements, parking places;
- Heating of airport runways;
- “Energy tunnels” for heating/cooling of buildings near to the tunnel portals;
- “Energy wells” for heating/cooling of buildings near groundwater extraction wells (e.g. for temporary or permanent groundwater lowering).
7.2 Heating/cooling of bridge decks

In countries with cold winters and hot summers the heating and cooling of bridge decks (Fig. 32) provides numerous environmental, technical, and economical advantages:
- Keeping the pavement free from ice and snow, and thus significantly reducing traffic hazards for road users;
- Substituting gritting and the use of de-icing salt by a clean and renewable energy;
- Reduction of temperature-induced rutting of asphalt pavements caused by heavy, dense traffic;
- Reduction of temperature constraints in bridge decks which increases the service lifetime of the superstructure and the pavement;
- Reduction of maintenance costs;
- Reduction of environmental impacts.

![CROSS SECTION](image)

Fig. 32 Heating/cooling of a bridge deck: watertight passage of absorber pipes through the substructure.

7.3 Heating/cooling of road pavements

Geothermal technology in road engineering refers mainly to the heating of pavements during the winter months – comprising the following goals:
- Road surface free from ice, hence higher traffic safety;
- Reduction of winter road clearance;
- Increased environmental protection because salt or grit for icy roads is not necessary;
- Increase of the lifetime of the road pavement/surface;
- Increase of traffic comfort (no mounting of snow chains);
- Minimisation of freezing-thawing damages to the road structure, especially in the case of frost susceptible subbases;
- Cost savings for the road authorities/owners.

In order to keep a road surface free from ice, its temperature should be higher than +2° C. The critical range of air temperature lies between 0° and –10° C. Lower temperatures allow an intermittent operation or even a turning off, because commonly there is no snow fall then.

Presently a long-term research project is running in Austria in order to determine the optimal position of absorber pipes from thermal, energetic and structural points of views (Fig. 33). Partly, these aspects exhibit contrary optima which requires certain compromises.
7.4 Energy tunnels

Until recently geothermal heating from tunnels was used only in connection with hot waters, mostly without heat pumps. But the heat potential along a tunnel can also be utilized by using the tunnel support and lining as energy absorbers. These may be anchors, rock/soil nails, geosynthetics and secondary concrete lining. Anchors or nails reaching deeply into the surrounding ground can activate a relatively large mass for geothermal utilisation.

“Energy tunnel” may be excavated as closed systems, e.g. after the NATM (Fig. 34) or after the cut and cover method (Fig. 35).

Near the portals of transportation tunnels with geothermal equipment the following groups may take the available energy:
- The owner or operator of the tunnel;
- Private users (especially large residential blocks, but also one-family houses);
- Commercial, industrial users;
- Public users (municipal, federal).

An example from a railway tunnel in Vienna underlines these advantages: About 1200 private flats can be supplied with geothermal energy, but also large public buildings.

Energy tunnels are an exciting challenge to geotechnical engineering and the optimisation of energy extraction or storage, transfer and distribution requires a multi-disciplinary cooperation. Ground investigation and geotechnical design should incorporate geothermal aspects already at an early stage. The main advantages of this innovative technology are:
- Commonly, tunnels are situated in a depth, where the seasonal ground temperature is widely constant.
- Tunnels exhibit large interfaces between structure and ground, thus favouring the extraction/storage of geothermal energy.
- Very deep-seated mountain tunnels can make use of great geothermal gradients.
- Long tunnels exhibit significant inner heat, mainly due to the waste heat of transportation. In metro-tunnels, for instance, temperatures of more than +20° C are possible even during the winter months.
- Utilizing clean and self-renewable energy from tunnels is environmentally friendly and economical. Therefore energy tunnels have a high public acceptance and political support which makes the approval procedures easier.
8. RECOMMENDATIONS FOR PRACTICE

Detailed soil investigation is essential for optimising an absorber system for thermal energy extraction/storage. This comprises not only geotechnical and hydrogeological characteristics but also geothermal conductivity and heat capacity of the ground at specific temperature levels. The mineral composition of the fines is also important as it influences
the soil behaviour under temperature fluctuation (shrinkage, swelling, freezing). Moreover, chemical and biological properties of the groundwater may be of interest.

Usually, temperature fluctuations caused by energy foundation have no relevant effect on the surrounding soil, assuming its temperature remains higher than +2°C. However, cooling below 0°C, as a result of improper operation, should be avoided, as it may cause freezing-thawing impacts in the soil, hence affecting the load-bearing behaviour of the piles, barrettes, or diaphragm walls. Moreover, thermal conductivity increases and thermal storage capacity decreases with freezing, especially in soil with high water content. Freezing is avoided at any rate if the absorber system is operated only with water and not with brine. But experience has shown that this reduces the efficiency of the energy system significantly. Therefore it has proved suitable to use brine and limit the freezing temperature in the core of piles or diaphragm walls to about -1°C.

Commonly, a temperature difference of about $\Delta T = 2^\circ$ C between absorber entry and exit is sufficient for an economical operation of the energy system (e.g. Fig. 16). Operational fluctuation of the groundwater temperature should be kept as low as possible ($\Delta T \leq 5^\circ$ C). Lowering the groundwater temperature causes an increase in viscosity, hence a decrease of the hydraulic conductivity. In case of $\Delta T \leq 5^\circ$C this influence is practically negligible.

Too intensive cooling of the groundwater increases the pH value, reduces calcium solubility, and raises the solubility of gaseous substances such as CO$_2$. Too intensive heating results in a relatively large reduction in oxygen solubility which may make the groundwater unfit for drinking. Furthermore, temperature is one of the most important environmental factors for the micro-organisms in water. Many of them can only exist within a very limited temperature range. Especially the activity of bacteria eating micro-organisms drops significantly at temperatures below 10°C.

The influence of excessive heat extraction from the ground could be clearly observed along some sections of the piled retaining structure (Fig. 26). Operational temperatures between -2°C to -3°C (temporarily even -5°C) caused the formation of ice lenses in the ground and thus a frost heave, $H$, of the surface behind the piles. A maximum of $H = 15$ cm was observed, and it decreased with distance from the heat extraction sources analogously to Fig. 9. After stopping this improper test run of the energy system, the temperatures increased again, also favoured by warmer weather.

If there is sufficient heat supply from the ground, an intermittent operation of the heating/cooling system is possible. This means, for instance, one to two days of operation and turn off, alternately.

In the case of a piled raft foundation, the raft should be properly isolated in order to minimise heat loss in the winter and cooling reduction in the summer. Geothermal utilisation of concrete retaining walls is also possible: gravity walls, cantilever walls, pile walls, diaphragm walls, etc.). In this case, a proper design of the absorber system has to take into consideration the natural temperature fluctuations along the free-standing front face of „energy walls“, which differ widely from those in the fully embedded zone beneath surface (see Brandl 1998).

9. CONCLUSIONS

Utilisation of geothermal energy for heating/cooling purposes of buildings represents a promising alternative to (fossil) fuels and electric energy with respect to costs and environmental protection aspects. This technology makes use of renewable “clean” energy and can be adapted to nearly all ground conditions. Deep foundations, incorporating concrete piles, barrettes, or diaphragm walls but also shallow foundations and even
retaining walls (below and above ground) can be used directly for the installation of heat exchangers. This innovation is an essential improvement over the conventional methods like borehole heat exchangers (borehole heat pumps) or earth collectors. Monitoring of several sites has disclosed that the investment-return period for this new heating/cooling system with reversible ground-source heat pumps is roughly 3 to 8 years, depending on ground properties, foundation system, building characteristics and energy prices.

The shaft resistance of energy piles, barrettes or diaphragm walls is not affected by the heat absorption process in a statically relevant magnitude. This could be found from detailed site measurements (Brandl, 1998). But the exposure of the skin of deep foundations to temperatures below freezing must be avoided. Fine grained soils with a high content of active clay minerals (e.g. montmorillonite) are especially critical.

Energy foundations for buildings exhibit numerous advantages:

- Environmentally friendly.
- Economical, at least in the long-term.
- Increase of personal comfort in indoor rooms. The temperature personally felt there consists of air and radiation temperature, which are influenced by wall and floor temperatures. Comfort is favoured by low temperature heating of walls and floor exhibiting a large heat radiating surface.
- Geothermal cooling may replace conventional air conditioning which is frequently felt to be loud and unhygienic.
- Reduction of energy imports, hence lower dependency on external situations.

The utilisation of geothermal energy can be widely promoted by public support. This refers not only to public buildings but also to private ones, especially one-family houses. In most regions of Austria the local authorities encourage geothermal heating/cooling systems by financial subventions. This is considered a political contribution to environmental protection.

REFERENCES