1999 Final report on the study:

Heat Exchanger Pile System for Heating and Cooling at Zürich Airport

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Summary

The Dock Midfield, a new building terminal planned at Zürich airport, will be constructed on foundation piles. Equipped with a pipe system, the piles will serve as a heat exchanger with the ground. A heat pump coupled to the piles will be used for heating purposes. During the summer, cooling will be performed with the piles, by transferring part of the thermal loads of the building directly into the ground.

The Dock Midfield

In the framework of the 5th construction phase of Zürich airport, Switzerland, a new terminal for 26 planes, the Dock Midfield, is planned. This building, 500 m long and 30 m wide, will be built on 350 foundation piles, as the upper layer of the ground, composed by lake deposits, is too soft to support the loads of the building. The piles will stand on moraine, which lies at a depth of about 30 m. With a diameter of 1 to 1.5 meters, the piles will be concrete and cast-in-place. In Fig. 1, a cross section of the building is shown.

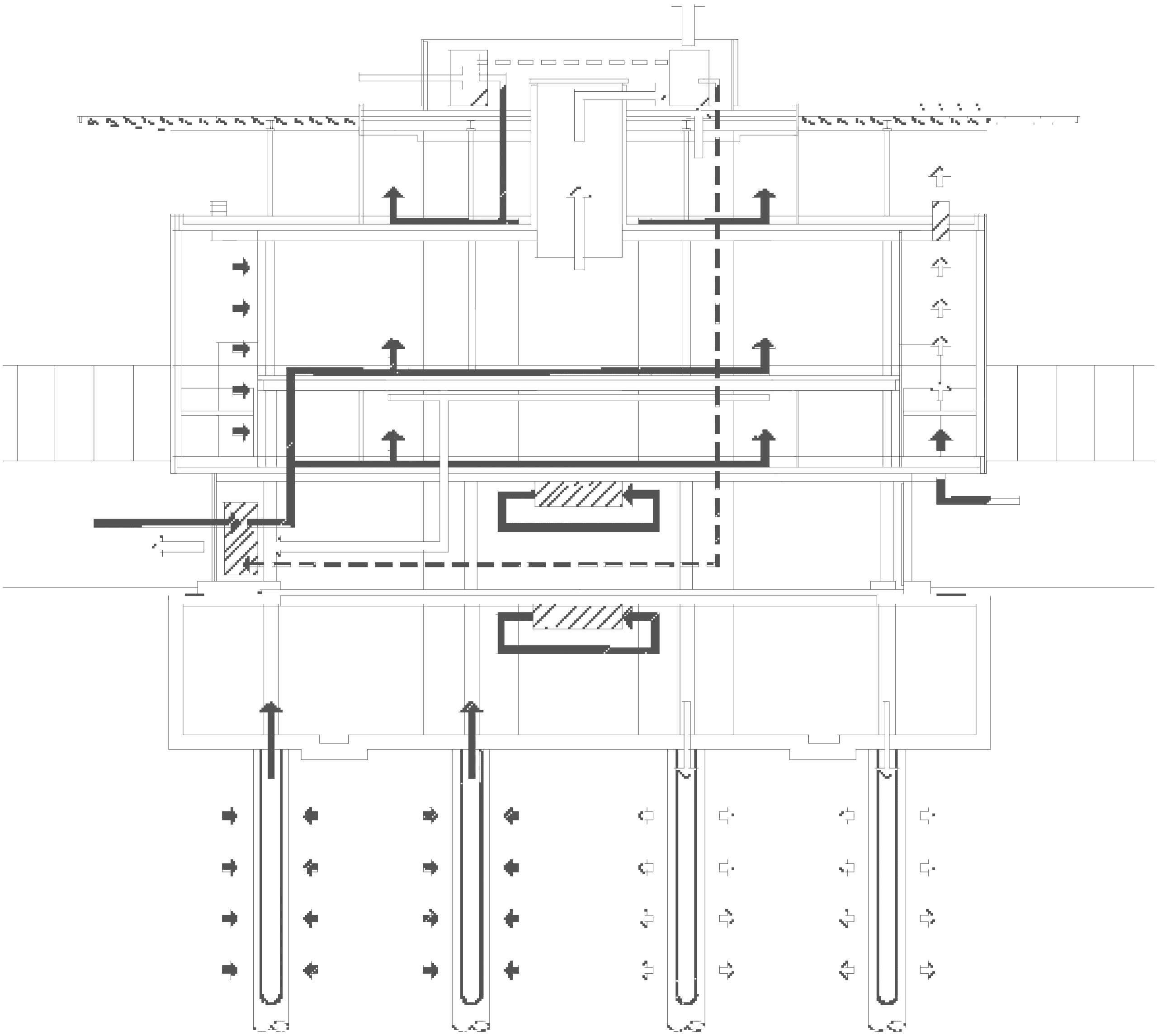

Fig. 1 Cross section of the planned Dock Midfield at Zürich airport.

The consortium ARGE ZAYETTA[1] has been mandated by the Zurich Airport Real-Estate Company (FIG) to plan the Dock Midfield. Apart from the outstanding architectural features of the building, extensive use of renewable energies has been promoted. They are expected to cover respectively 65% and 75% of the heating and cooling requirements. In this framework, the foundation piles contribute to this task being used as heat exchanger piles. The remaining energy purchased for heating is very small. The associated heating energy index (auxiliary energy and electricity for the heat pump), defined by the ratio of the annual energy by the total heated floor area, is about 30 MJ/m^{2}y. The total electric energy index, estimated to 400 MJ/m^{2}year, is also low for a fully air controlled building which will be used 18 hours a day. The construction of the Dock Midfield should start in 1999 and last about 4 years.

[1] Marin Spühler, Architekt BSA SIA, Zürich; Angélil/Graham/Pfenninger/Scholl Architecture Ltd. Zürich and Los Angeles; Heyer Kaufmann Partner Bauingenieure AG, Zürich; Nicolet, Chartrand, Knoll Ltd, Montreal; Electrowatt Engineering AG, Zürich; Amstein + Walthert AG, Zürich.

The Heat Exchanger Pile System

The heat exchanger piles are foundation piles equipped with a pipe system, in which a heat carrier fluid can be circulated so as to exchange heat with the surrounding ground. The two main functions of the heat exchanger piles are thus to support the loads of the building and to serve as a heat exchanger with the ground. The heat exchanger piles are connected together hydraulically and coupled to an electric heat pump. During the winter, the heat pump extracts thermal energy from the ground and provides heat to the building. As a result part of the heating requirement is covered by energy that originates from the ground. No significant regional ground water movement is expected at this site, which would, if large enough, provide a thermal regeneration of the ground volume which contains the piles from year to year. Cooling of the ground takes place, which is actually an advantage during the summer when the heat exchanger piles are used for direct cooling[2]. In other terms, part of the thermal loads generated in the building are directly injected in the ground through the heat exchanger piles. Direct cooling enables a thermal regeneration of the ground and is beneficial to heating the next winter. In Fig. 2, a schematic view of the heat exchanger pile system is shown.

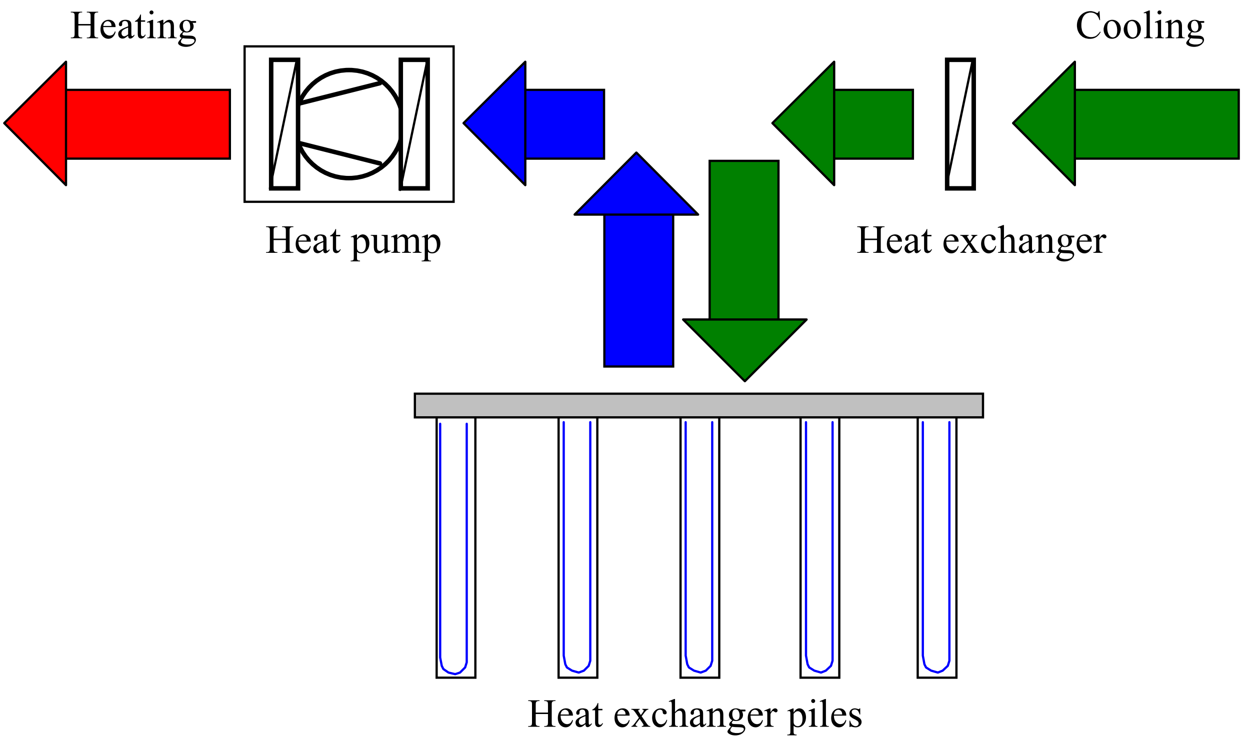

Fig. 2 Schematic view of the heat exchanger pile system.

The principal constraint on the system is that the thermal solicitations withstood by the piles must not deteriorate their mechanical properties, i.e., their ability to support the loads of the

[2] Direct cooling is realised by connecting the pile flow circuit to the cold distribution without a cooling machine in between.

building. In particular, freezing of the piles must be avoided. In a safely sized heat exchanger pile system, the fluid temperature in the piles never drops below 0 °C for a long period of time.

This temperature constraint influences the size of the heat pump, which, in turn, affects the heating potential provided by the heat exchanger piles. When direct cooling is performed, the cooling potential also depends directly on the temperature level of the fluid in the cooling system (maximum 20 °C for the Dock Midfield). The annual extracted and injected thermal energy through the piles determines the evolution of the ground temperature year after year, which, in turn, may affect the thermal performances of the system. An accurate assessment of the heating and cooling potential offered by heat exchanger piles requests a dynamic simulation of the system, which takes into account both short-term and long-term thermal performances. It requires a good knowledge of the system's thermal characteristics, the local ground conditions and the use of an accurate system simulation tool.

The PILESIM Simulation Tool

Simulation tools of heat exchanger pile systems have been developed in the Laboratory of Energy Systems (LASEN), at the Swiss Federal Institute of Technology in Lausanne (EPFL) (see Fromentin et al., 1997). Their development has been performed with the help of measurements of existing systems for comparison and validation purposes. The well-known transient system simulation programme TRNSYS was used (Klein et al., 1996). A non-standard simulation model, devised for heat storage in the ground with borehole heat exchangers (Pahud et. al, 1996a), has been adapted for heat exchanger piles (Pahud et. al, 1996b).

In the framework of the Dock Midfield project, the experience gained in the simulation of heat exchanger pile systems is used to create PILESIM (Pahud, 1998). PILESIM is based on TRNSYS but can be used without prior knowledge of it. The system's thermal performances, the thermal potential of heat exchanger piles and a variety of system designs can be assessed.

The Simulated Thermal Performances

The net space heating and cooling energy requirements of the building were simulated in hourly values for one year (Koschenz and Weber, 1997), and used as input data to PILESIM. The net heating and cooling requirements take into account passive solar gains, internal gains, heat recovery units on exhaust air, free cooling with outside air and cooling for heating purposes. At this stage of the project, a constant performance coefficient of 3.5 is assumed for the heat pump. The piles will be equipped with 4 U-pipes fixed on the inner side of their reinforcing steel: four plastic pipes drive the heat carrier fluid (a glycol-water mixture) down to the bottom of the pile and four others bring it back up. Even with such thick piles (1 to 1.5 meters in diameter), more U-pipes do not significantly improve the steady state heat transfer from the fluid to the ground in the immediate vicinity of the pile. A laminar flow regime in the piles is also recommended, when 4 U-pipes or more are used. Simulations have shown that the supplementary pumping energy needed to make the flow non-laminar is not compensated by the improvement of the thermal performances. About 300 piles will be converted into heat exchanger piles, each with a heat transfer length of about 25 m.

Detailed simulations have shown that an undersized heat pump, in relation to the total length of heat exchanger piles, does not greatly improve the performance coefficient of the heat pump (Fromentin et al., 1997). As the heat exchanger piles do significantly contribute to the investment cost, it has a negative effect on the heating cost. On the other hand, an oversized heat pump may lead to a critical situation, as the risk of the piles freezing exists. Freezing can be avoided by reducing the heat pump power. For the Dock Midfield, the heat pump is sized so that a power reduction of a maximum of 10% is accepted. In Fig. 3, the classified hourly heat and cold energy demands are shown, together with the corresponding energy rate provided by the heat exchanger pile system. A heat pump of 800 kW at the condenser will cover 90% of the 4'600 GJ (1'280 MWh) of net annual heat demand. The rest, 470 GJ (130 MWh), is covered by district heating, with a maximum peak load of 1'500 kW. Nearly the totality of the net annual cold demand, estimated to 2'230 GJ (620 MWh), can be covered by direct cooling with the pile system. However, an auxiliary cold unit with a cooling peak power of 110 kW should be available if the temperature level of the cold distribution has to be satisfied.

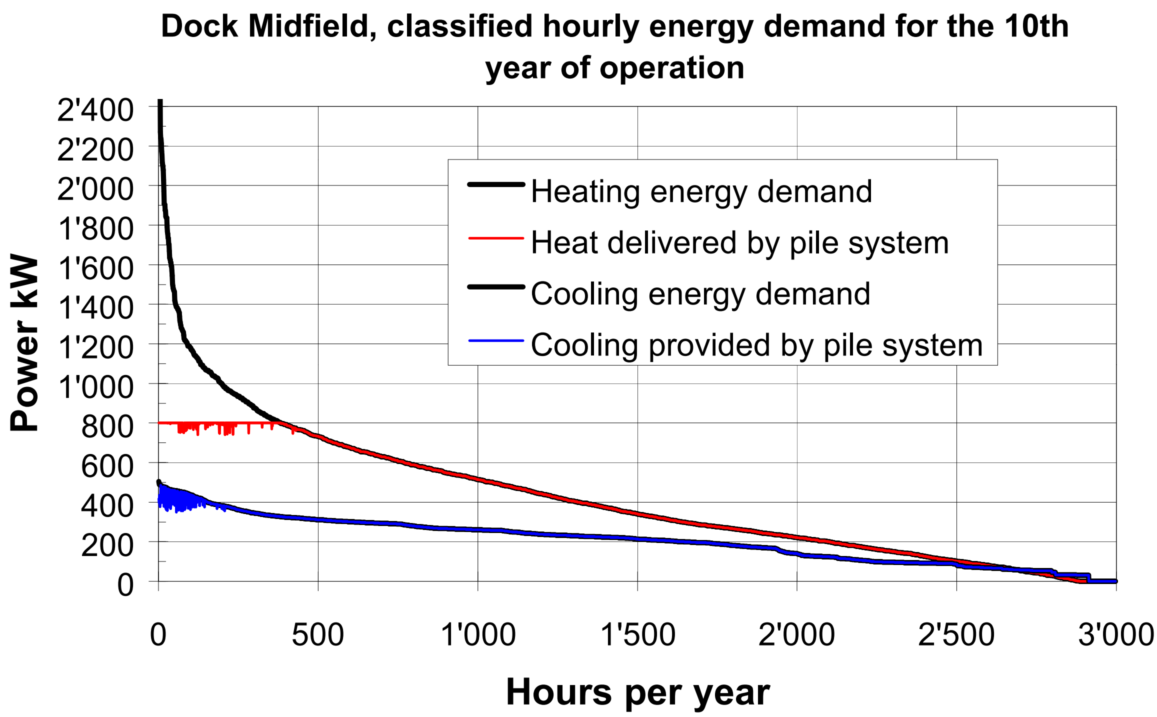

Fig. 3 Simulated classified hourly values of the net energy demands for heating and cooling the Dock Midfield. The corresponding energy rates satisfied by the heat exchanger pile system are also shown.

A higher ground temperature results in less cooling energy provided by the piles. In consequence, an increase of the ground temperature year after year should be avoided. In order to prevent such an increase, the annual extracted heat (2'950 GJ or 820 MWh) must be greater than the injected one (2'200 GJ or 610 MWh). The difference is mainly due to the thermal influence of the building. Expressed per meter of pile, the annual energies and maximum thermal powers extracted and injected by the piles are relatively high, due mainly to the large pile diameter:

Heat extraction (heating):	75 W/m	400 MJ/m per year	(110 kWh/m per year)
Heat injection (direct cooling):	60 W/m	290 MJ/m per year	(80 kWh/m per year)

The economy of the heat exchanger pile system shows a figure similar to conventional heating and cooling. The positive point is the reduction of fossil fuel required for heating. Direct cooling on the piles requires less electricity than a cooling machine. The electricity saved during the summer for cooling compensates the electricity needed by the heat pump during the winter.

Concluding Remarks

Foundation piles offer an interesting alternative for providing heating and cooling energy to a building, especially when they can combine the two. Solely heating or cooling requires a thermal regeneration of the ground from year to year, which can be performed naturally if a regional ground water flow is large enough. Heat exchanger piles are best integrated in a bivalent system; the peak power loads are covered by an auxiliary energy. The Dock Midfield presents good conditions for an optimal use of heat exchanger piles. A reduction of the fossil fuel consumption will be realised, without increasing the overall electric energy demand.

Acknowledgement

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