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Measured Thermal Performances of the Energy Pile System of the Dock Midfield at Zürich Airport

Daniel Pahud[1)] and Markus Hubbuch[2)]

[1)] ISAAC-DACD-SUPSI, CH-6952 Canobbio [2)] Abt. Facility Management, Hochschule Wädenswil, CH-8820 Wädenswil

[1)] daniel.pahud@supsi.ch [2)] m.hubbuch@hsw.ch

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ABSTRACT

The Dock Midfield is the new terminal E of the Zürich airport. As the upper ground layer is too soft to support the loads of the building, 440 foundation piles have been built. More than 300 piles have been converted into energy piles in order to contribute to the heating and cooling of the building.

Measurements of the energy pile system begun in October 2004 for a 2 years period. The results of the measurement campaign are presented. The measured system heat balance, and in particular the annual heating and cooling demands are close to the design values. Furthermore the thermal performances of the system are very good. The global system efficiency is over 5. It confirms the necessity and the suitability of a detailed and careful design process for this type of system. The design procedure has been based on detailed studies, involving response test analysis, thermal dynamic simulations of the building and the energy pile system.

Thanks to the detailed measurements of the system, the elaboration of PILESIM2, version 2 of PILESIM, has been realised. The geocooling mode is better taken into account in the calculation. The comparison of the calculations with measurements is very satisfactory. PILESIM2 calculations show that if cooling energy could be delivered at 16 – 17°C, the cooling machine would not need to be used. The global system efficiency would increase from 5.1 to 5.7.

From an economical point of view, the pile system is more convenient than a conventional system. The additional investment of the pile system is paid back in about 8 years.

1. INTRODUCTION

Dock Midfield is the new terminal E of the Zürich airport. Designed for 26 planes, the building (500 m long and 30 m wide) is built on 440 foundation piles as the upper ground layer, which is composed of lake deposits, is too soft to support the loads of the building. The piles stand on moraine, which lies at a depth of about 30 m. With a diameter of 0.9 to 1.5 meters, the concrete piles were cast in place. An image of the building is shown in figure 1.

Figure 1: The Dock Midfield of the Zürich airport has been built on 440 foundation piles of 30m.

Renewable energies are used extensively throughout this building. Renewables are expected to meet 65% and 70% of the heating and cooling requirements respectively. The foundation piles contribute by being used as energy piles: about 300 piles have been equipped with 5 U-pipe fixed on the metallic reinforcement to use them as a heat exchanger with the ground. The additional amount of energy purchased for heating is very small. The associated heating energy index, defined by the ratio of the annual purchased energy (district heating energy and electricity for the heat pump) per the total heated floor area (85'200 m^2 with height correction), is about 15 kWh/(m^{2}y). The total electric energy index, estimated to 110 kWh/(m^{2}y), is also low for a fully air conditioned building which is used 18 hours a day.

Construction of the Dock Midfield started in 1999 and was completed in 2003. In September 2004, the measurement of the pile system started for a two years period.

The main objectives of the measurement project, whose purpose concentrates on the pile system, are to:

- determine the system thermal performances
- check the validity of the design procedures
- optimize system operation

The measurements were used to improve the simulation tool PILESIM. The new version, called PILESIM2 (Pahud, 2007), better takes into account geocoling calculations in a system. Geocooling is cooling energy from the ground covered without a cooling machine. It is realized by coupling the building cooling distribution directly to the pile hydraulic circuit through a conventional heat exchanger.

2. THE ENERGY PILE SYSTEM

The heat pump coupled to the piles has been sized so that the fluid temperature in the pile circuit never drops below 0°C, both for short term and long term system operation (Pahud and al., 1998, 1999; Documentation SIA D0190, 2005). It delivers a heating power of 630 kW at the temperature conditions B4W40. Peak power loads are met with district heating used in complement to the heat pump. 85% of the annual heating demand, which was established to 2’720 MWh/y, should be covered by the heat pump. The cooling requirements are met by a cooling distribution network coupled to the pile system (1’240 MWh/y) and the building ventilation system with conventional cooling machines (510 MWh/a). Cooling energy covered by the pile system is either made by geocooling or for heating purposes, if the heat pump is in operation. The return fluid temperature in the cooling distribution is expected to be 21°C. The forward one is set to 14°C. If geocooling is not sufficient to meet the cooling demand, the heat pump is used as a cooling machine. Its waste heat is dumped in cooling towers placed on the roof of the building. Table 1 contains the main characteristics of the piles.

Type of foundation pile	cast in place, in concrete
Number of energy piles	306
Pile diameter	90 – 150 cm
Average active length per pile	26.8 m
Number of U-pipes per pile	5 (10 pipes in a pile cross-section)
Ground volume thermally activated by the piles	660’000 m^3
Flow rate per pile	max. 860 litres/h

Table 1: Main characteristics of the energy piles.

The system layout of the pile system and the measurement points are shown in figure 2.

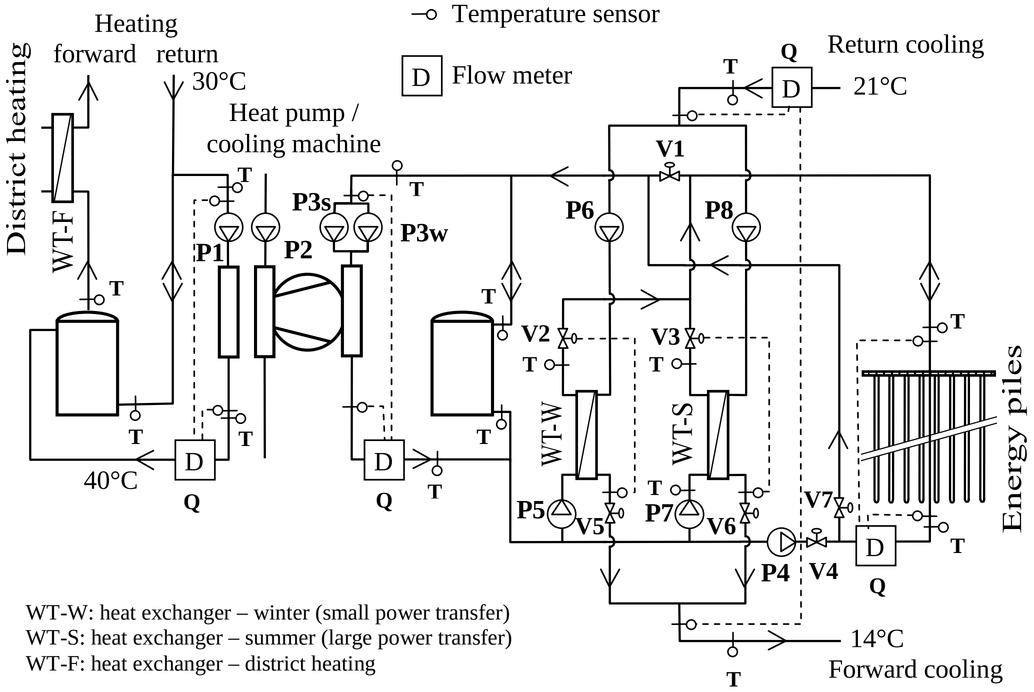

Figure 2: System layout and measurement points.

Cooling energy is transferred in the pile system through a heat exchanger (either WT-W or WT-S). The forward fluid temperature of 14°C in the cooling distribution is controlled with a variable flow rate in the pile circuit, controlled with either valve V2 or V3. As flow rate cannot be decreased below a given value, a smaller heat exchanger (WT-W) takes over the large one (WT-S) when the fluid temperature in the pile circuit is too low (normally in winter), in order to create a large temperature difference through the heat exchanger.

The system operation mode is controlled by the on/off valves V1, V4 and V7. Heat extraction from the pile requires V1 and V4 open, V7 closed and P4 switched on. Geocooling or heat injection in the pile is achieved with V1 and V4 closed, V7 open and P4 switched off.

The pile system monitoring is performed with measurements of 15 fluid temperatures, 11 operation status for the circulation pumps and the heat pump, 5 heat meters including district heating contribution, 15 ground temperatures in four piles which were not used as energy pile and the outside air temperature. These measures are recorded by the building automation system every 5 minutes. Separate dataloggers are also installed to record the electric consumptions of the circulation pumps and the heat pump / cooling machine. The results of the monitoring campaign can be found in Pahud and Hubbuch (2007).

3. HEATING PRODUCTION

The measured monthly thermal performances of the heat pump are shown in figure 3 from October 2005 until September 2006.

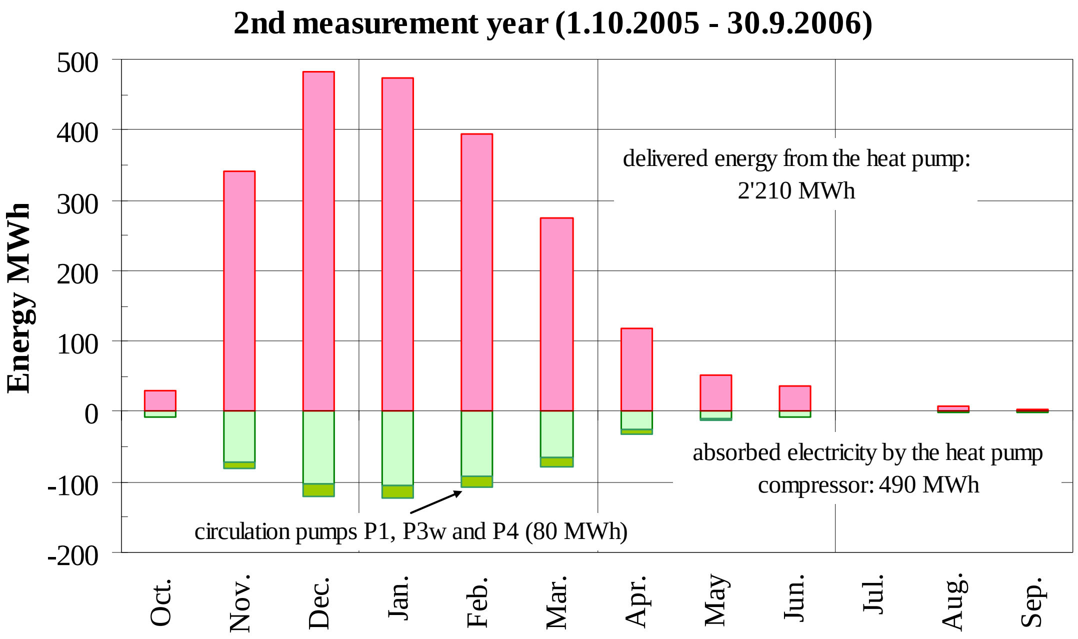

Figure 3: Monthly thermal performances of the heat pump.

Heating energy delivered by the heat pump is measured to 2’210 MWh. With a district heating contribution of 810 MWh, the annual thermal energy is measured to 3’020 MWh. The annual thermal performance coefficient of the heat pump (COPA) is established to 3.9, including the electric energy for the circulation pumps P1 (condenser), P3w (evaporator) and P4 (energy piles). The mean annual temperature level of the outlet fluid from the heat pump condenser is 39°C and is rather constant throughout the heating period. The mean annual temperature level of the inlet fluid in the heat pump evaporator is established to 8.3°C. The lowest monthly value is observed in February with a value of 6.4°C.

4. COOLING PRODUCTION

The measured monthly cooling energies of the cooling distribution network are shown in figure 4 from October 2005 until September 2006.

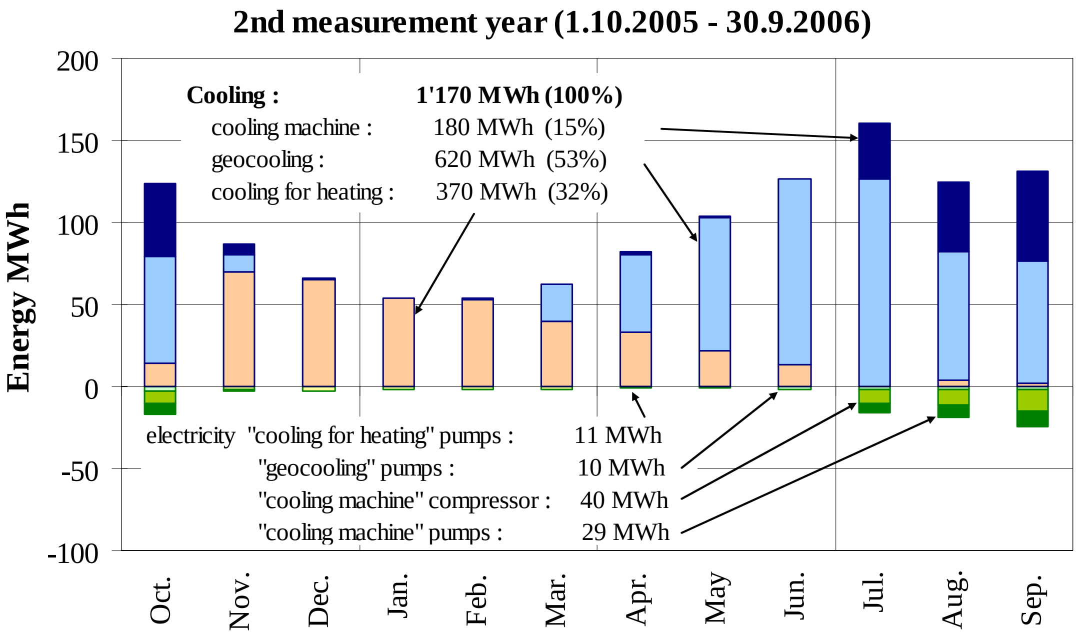

Figure 4: Monthly cooling energies delivered in the cooling distribution network.

The electric energy for the circulation pumps and the cooling machine is measured to 90 MWh. The overall cooling efficiency, defined by the ratio between the delivered cooling energy and the electric energy used to operate the system for the cooling production, is established to 13. This large value is also due to the particularly high geocooling efficiency (61). The cooling machine efficiency, established to 2.7, is heavily penalized by the electric consumption of the circulation pumps. It represents more than 70% of the compressor electric consumption of the cooling machine.

The return fluid temperature from the cooling distribution network is rather constant throughout the summer and is measured to 17°C. This value is much lower than the expected 21°C. It considerably penalizes the geocooling production, which has to be compensated for by the cooling machine one.

5. ENERGY PILES

In figure 5, the monthly extracted and injected energies in the piles are shown. The injected energy is in fact the geocooling production. Measured to 620 MWh, it represents 41% of the 1'500 MWh extracted by the heat pump. Monthly temperature levels of the fluid temperature at the inlet and outlet of the pile circuit are also shown for the extraction and injection operation modes.

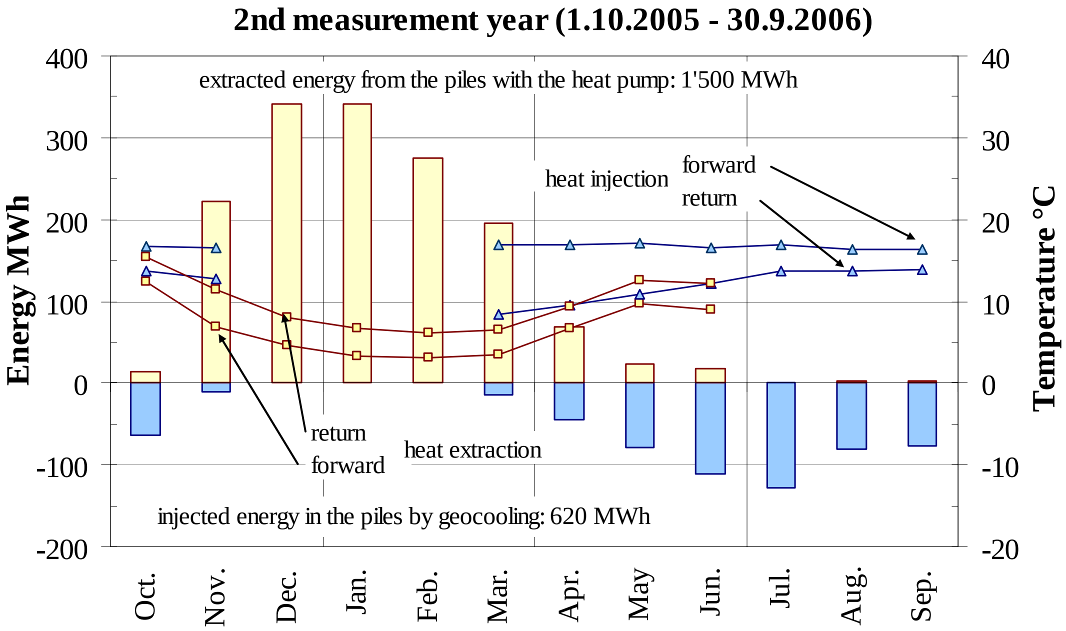

Figure 5: Monthly extracted and injected energies in the piles. The monthly temperature levels of the heat carrier fluid in the pile circuit are shown for both the extraction and injection operation modes.

The ground temperatures are measured in a pile which is not used as an energy pile (see figure 6). The fluid temperature levels at the inlet and outlet of the pile flow circuit are now shown with daily values for the extraction and injection operation modes.

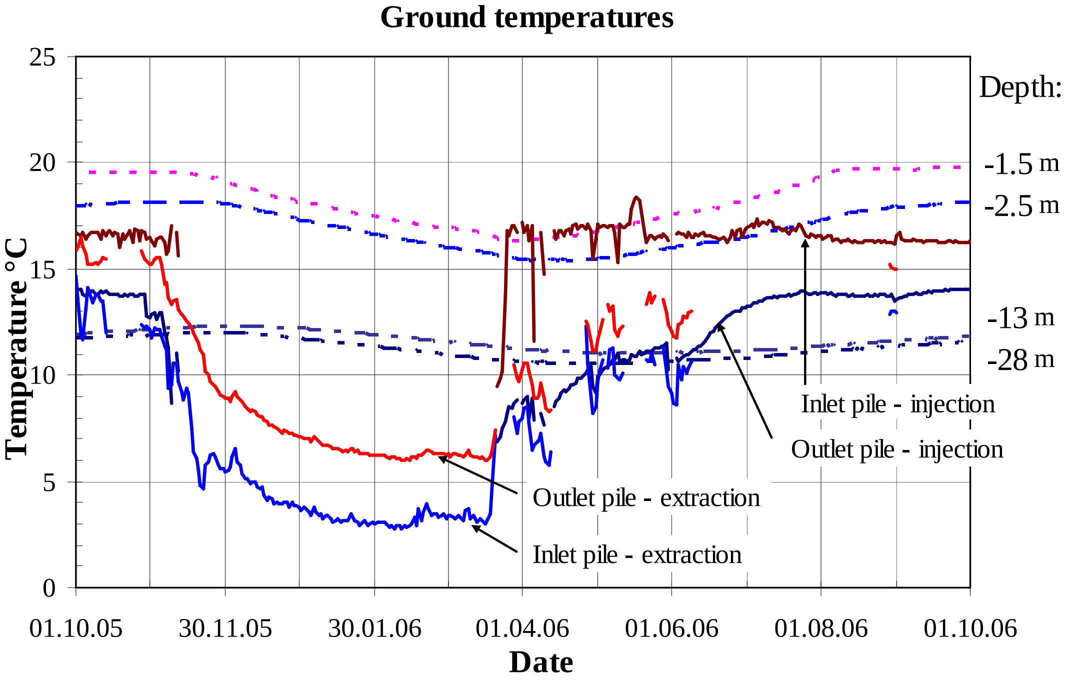

Figure 6: Ground temperatures at various depths. Daily temperature levels of the heat carrier fluid in the pile flow circuit are shown for both extraction and injection operation modes.

The minimum inlet fluid temperature in the piles is measured to 2.4°C the first measurement year and 2.5°C the second one. The ground temperature, below the thermal influence of the surface, exhibits seasonal but small variations, due to the large ground volume involved.

6. SYSTEM HEAT BALANCE

The heat balance of the pile system is shown in figure 7. The measured values are compared to the design value established with PILESIM (Pahud, 1998).

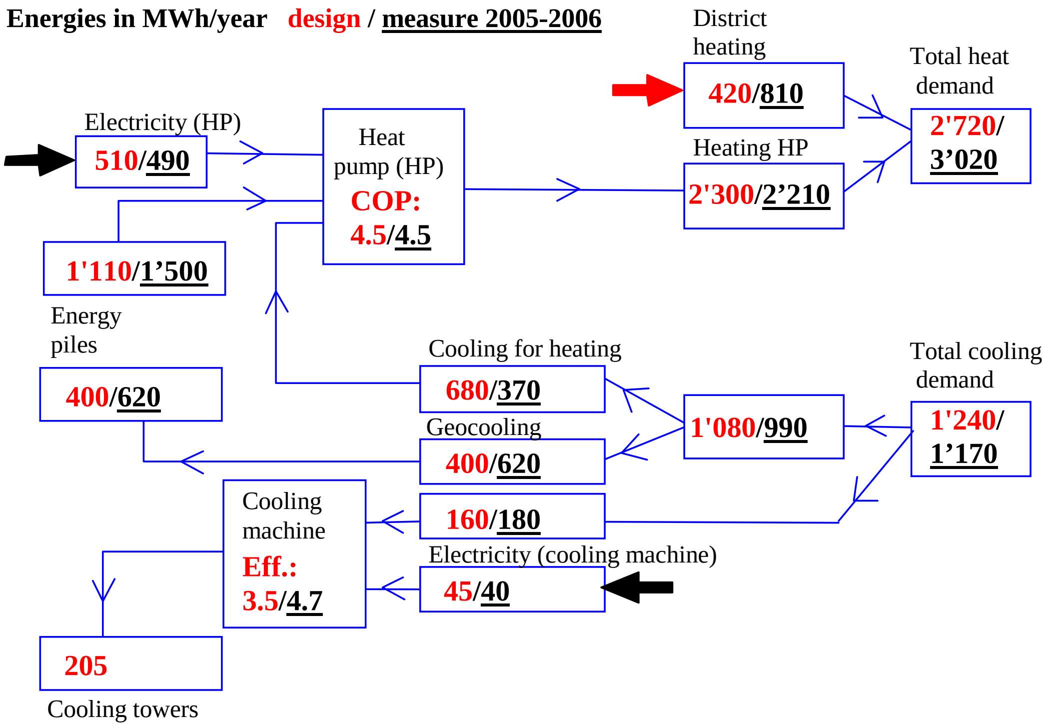

Figure 7: Pile system heat balance, comparison measured – predicted values with PILESIM.

The measured values correspond astonishingly well to the predicted ones. The good accuracy of the simulated heating and cooling demands (Koschenz and Weber, 1998) can be noticed. This confirms the pertinence of the design procedures adopted and the simulation tools used for the sizing of the system. In table 2, a comparison of the design and measured thermal characteristics of the piles is shown.

The values are referred to the active pile length	Design	Measurement
Pile heat extraction rate		
maximum (W/m)	49	72 (+47%)
average (W/m)		45
Pile annual heat extraction		
(kWh/(m y))	135	183 (+36%)
Pile heat injection rate		
maximum (W/m)	49	33 (-33%)
average (W/m)		16
Pile annual heat injection		
(kWh/(m y))	48	74 (+54%)
Ratio injected over extracted	36%	41% (+14%)

Table 2: Key values associated with the thermal use of the piles; comparison design – measure 2005-2006.

The piles are actually used more intensively than expected, apart from the maximum heat injection rate, which is lower due to a low return fluid temperature from the cooling distribution. However the ground ratio is close enough to the design one, so that a long term operation of the system is guaranteed.

The thermal performance indexes of the pile system are shown in table 3.

Performance index	Measured	Energy fraction
Annual heat pump performance coefficient	3.9	65%
"Cooling for heating" efficiency	33	11%
Geocooling efficiency	61	18%
Annual cooling machine efficiency	2.7	5%
Overall system efficiency	5.1	100%

Table 3: Annual thermal performance indexes related to the pile system for the second measurement year. The energy fraction is referred to the total heating and cooling energy supplied by the pile system.

The overall system efficiency, defined by the ratio of the thermal energy delivered by the system (heating and cooling) over the total electric energy required to run it (all the circulation pumps and the heat pump / cooling machine), is established to 5.1.

7. PILESIM2 AND GEOCOOLING

Thanks to the detailed measurements of the system, the PILESIM program has been improved to better take into account geocooling calculation. PILESIM2 (Pahud, 2007), the version 2 of PILESIM, has been developed in margin of this project and successfully calibrated to the measured thermal performances (Pahud and Hubbuch, 2007).

The calibrated input data to PILESIM2 were used to analyze the geocooling energy sensitivity to the various design parameters. The two most important parameters are the temperature levels of the fluid in the cooling distribution and the heat transfer of the horizontal pipe connections between the piles. The heat transfer takes place between the pipes and the ground at the surface, whose temperature is influenced by the building itself. The lower the cooling forward fluid temperature is, the lesser the geocooling energy and the greater the negative influence of the heat transfer of the horizontal pipe connections are. These effects are shown in figure 8 for the case of Dock Midfield.

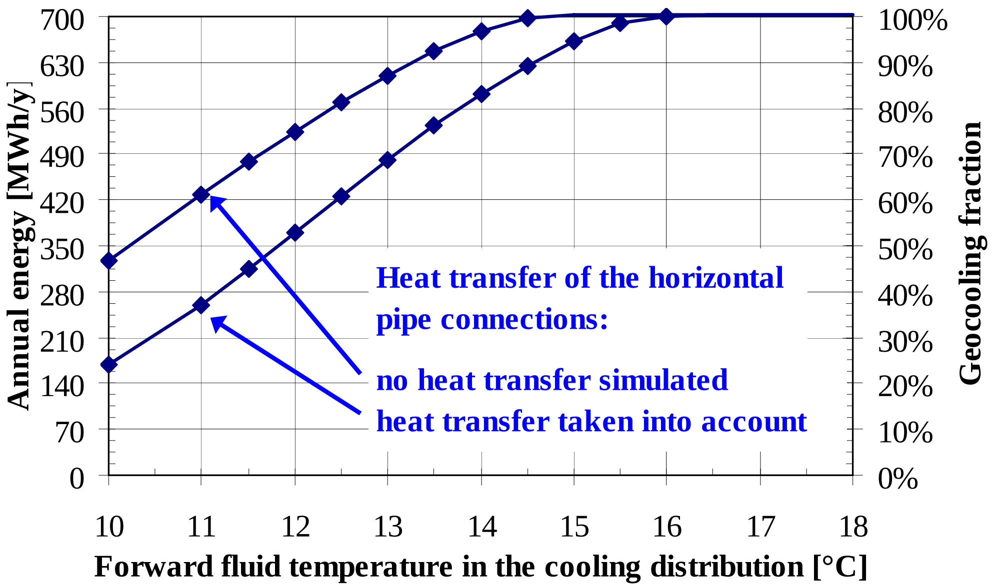

Figure 8: Sensitivity of the geocooling potential to the fluid temperature level in the cooling distribution and the importance of the heat transfer of the horizontal pipe connections with the ground.

If cooling energy could be delivered at 16 – 17°C in the cooling distribution, with a return fluid temperature of 19 – 20°C, the totality of the cooling energy could be delivered by geocooling and the cooling machine would not be used. The global system efficiency would rise from 5.1 to 5.7.

7. ECONOMICAL ASPECTS

The investment for the use of the energy piles amounts to 670’000 €. The pile system provides a saving of 80’000 €, due to the non installation of cooling units in the luggage handling rooms (Unique, 2003). Relative to a conventional system, the major investment of the pile system is 590’000 €. On the basis of the measured energies, the cost of the purchased final energy and the maintenance cost, an economical comparison of the pile system with a conventional one is shown in table 4.

System	energy piles	conventional	difference
Investment	670’000 €	80’000 €	590’000 €
Annual cost			
capital	46’170 €	5’450 €	+40’720 €
maintenance	10’070 €	3’170 €	+6’900 €
energy	71’660 €	156’180 €	- 84’520 €
Total annual cost	127’900 €	164’800 €	- 36’900 €
Thermal energy cost	0.04 €/kWh	0.05 €/kWh	

Table 3: Economical aspect of the pile system and comparison with a conventional system.

Relative to a conventional system, the pile system supplementary investment is paid back in 8 years, if the interests of the invested capital is not taken into account.

CONCLUSION

The thermal performances of the pile system are very satisfactory. They are close to the design values. It confirms the rightness and necessity of the important effort invested in the design phase of the system, which included, for the pile system, two thermal response tests, dynamic building simulations for the determination of the energy requirements and pile system thermal simulations.

Measurements were used to validate the development of PILESIM2, the version 2 of PILESIM. The new version better takes into account geocooling calculations. Calculations showed that the cooling machine would not be used if cooling energy can be distributed at 16 – 17°C instead of 14°C. The overall system efficiency, measured to 5.1, would rise to 5.7. This high efficiency is due to the geocooling efficiency, which has been measured to the exceptionally high value of 61.

Economical evaluations confirm the good thermal performances of the system. The pile system is economically more convenient than a conventional system.

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