Measured thermal performances of the Dock Midfield energy pile system at Zürich airport

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Zusammenfassung

Das Dock Midfield ist der neue Terminal E des Flughafens von Zürich. In Anbetracht schlechter geologischer Bedingungen musste das Gebäude auf 440 Fundationspfählen gebaut werden. Mit dem Ziel, Energie zur Heizung und zum Kühlen des Gebäudes zu gewinnen, werden mehr als 300 Pfähle als Energiepfähle benutzt.

Die Messungen der Energienutzung mit den Pfählen haben im Oktober 2004 für eine Dauer von 2 Jahren begonnen. Die Resultate des ersten Jahres der Messungen werden hier präsentiert. Die Energiebilanz des Systems und insbesondere der jährliche Bedarf an Heiz- und Kühlenergie sind nahe den Werten, die während der Planungsphase berechnet wurden. Ebenfalls ist die Effizienz des Systems sehr gut. Dies bestätigt die Notwendigkeit und den Nutzen einer detaillierten und sorgfältigen Planung dieser Art von Energiesystemen und eines Auslegeverfahrens, das detaillierte Studien sowie zwei geothermische Respond-Tests umfasste und auf dynamischen thermischen Simulationen des Gebäudes und des Systems mit den Energiepfählen basiert.

Die Energiebilanz der Pfähle zeigt, dass 39% der entzogenen jährlichen Wärme durch Direktkühlung wieder an das Erdreich abgegeben wird. Dieser Wert stimmt mit der Vorhersage überein, die während der Planung des Systems gemacht wurde.

Ein Verbesserungspotential besteht beim Verteil-Kreislauf der internen Kühlung. Es könnte im Idealfall die globale Wirksamkeit des Systems von 4,9 auf 5,4 steigen.

Summary

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 first year 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. 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.

The pile heat balance indicates that 39% of the annual extracted energy is injected by geocooling. This ratio is compatible and conform to the system design predictions.

An improving potential lies in the cooling distribution. It could increase the global annual system efficiency from 4.9 to 5.4.

1. Dock Midfield

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 30 kWh/(m^2y). The total electric energy index, estimated to 400 MJ/(m^2y), 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
- optimise system operation

This paper contains the results of the first measurement year of the system.

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 [1,2,3]. 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 (the thermal loads collected by the cooling distribution are injected directly in the ground through the piles) 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 3.

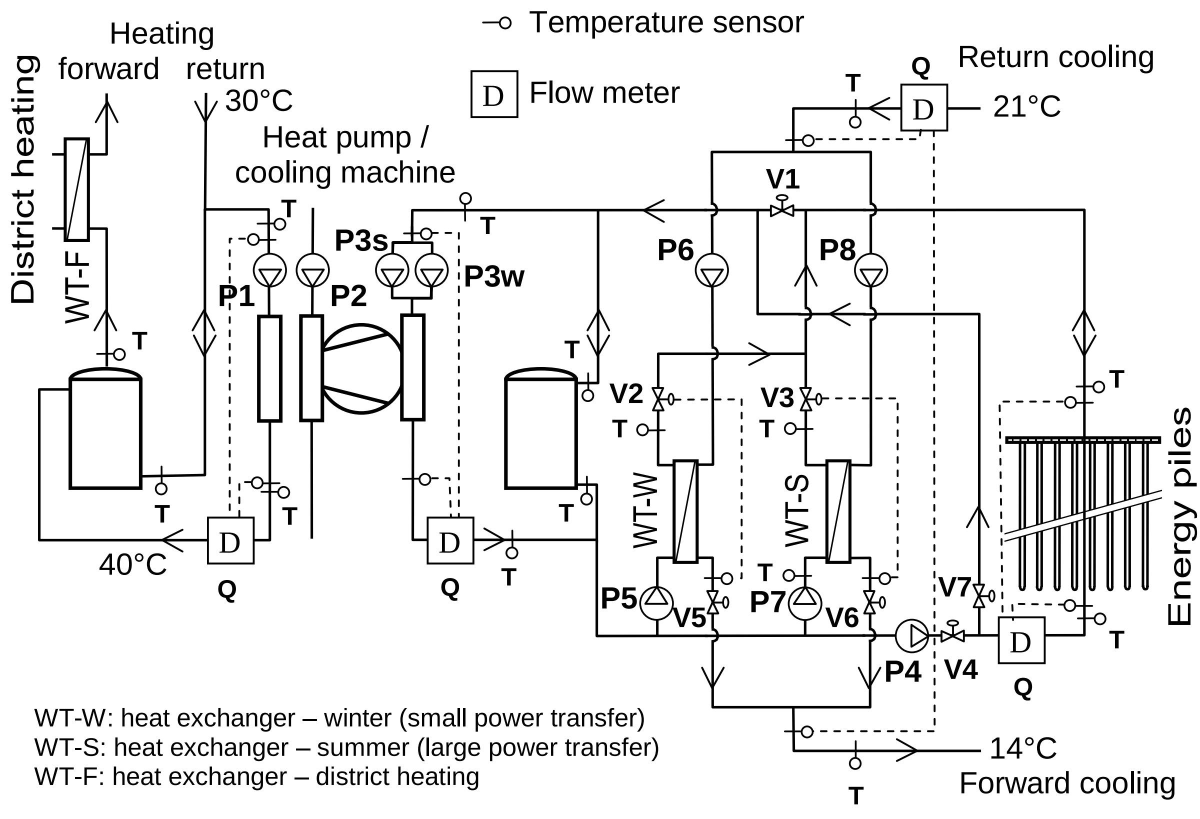

Figure 2: System layout and measurements points

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 first measured year can be found in [4].

3. Heating production

The measured monthly thermal performances of the heat pump are shown in figure 4 from October 2004 until September 2005.

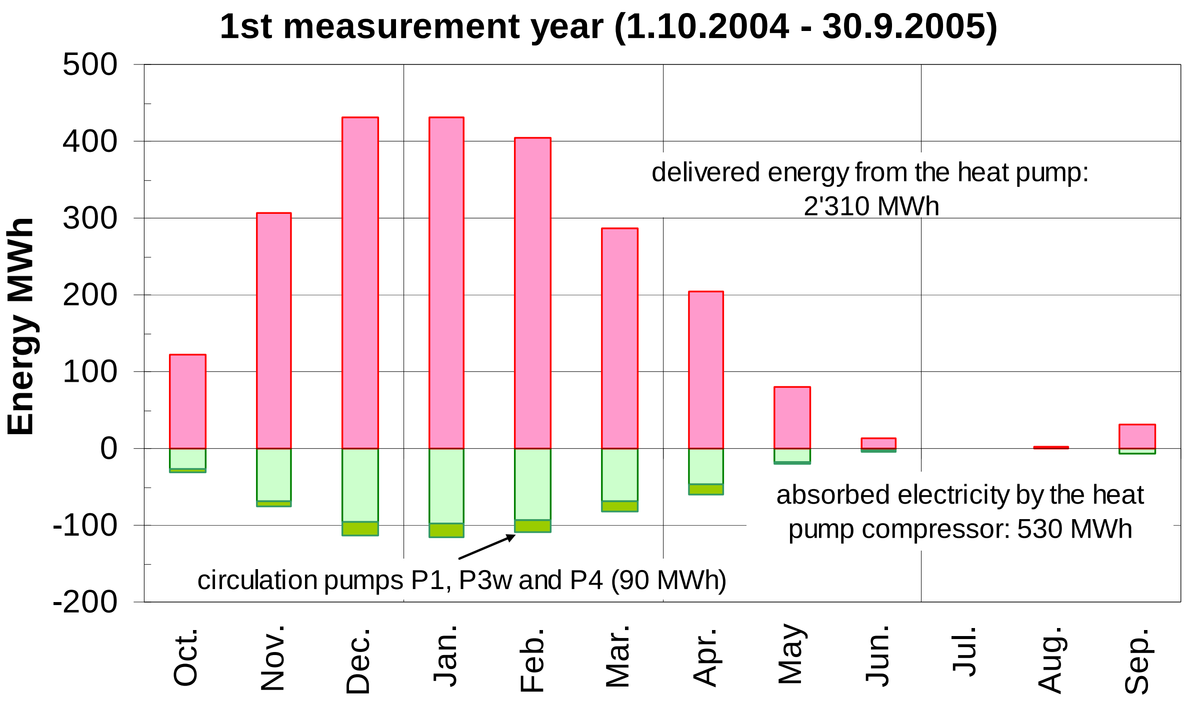

Figure 3: Monthly thermal performances of the heat pump

The heating energy delivered by the heat pump is measured to 2’310 MWh. With a district heating contribution of 740 MWh, the annual thermal energy is measured to 3’050 MWh. The annual thermal performance coefficient of the heat pump (COPA) is established to 3.7, 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 40°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 9°C. The lowest monthly value is observed in February with a value of 6.9°C.

4. Cooling production

The measured monthly cooling energies of the cooling distribution network are shown in figure 5 from October 2004 until September 2005.

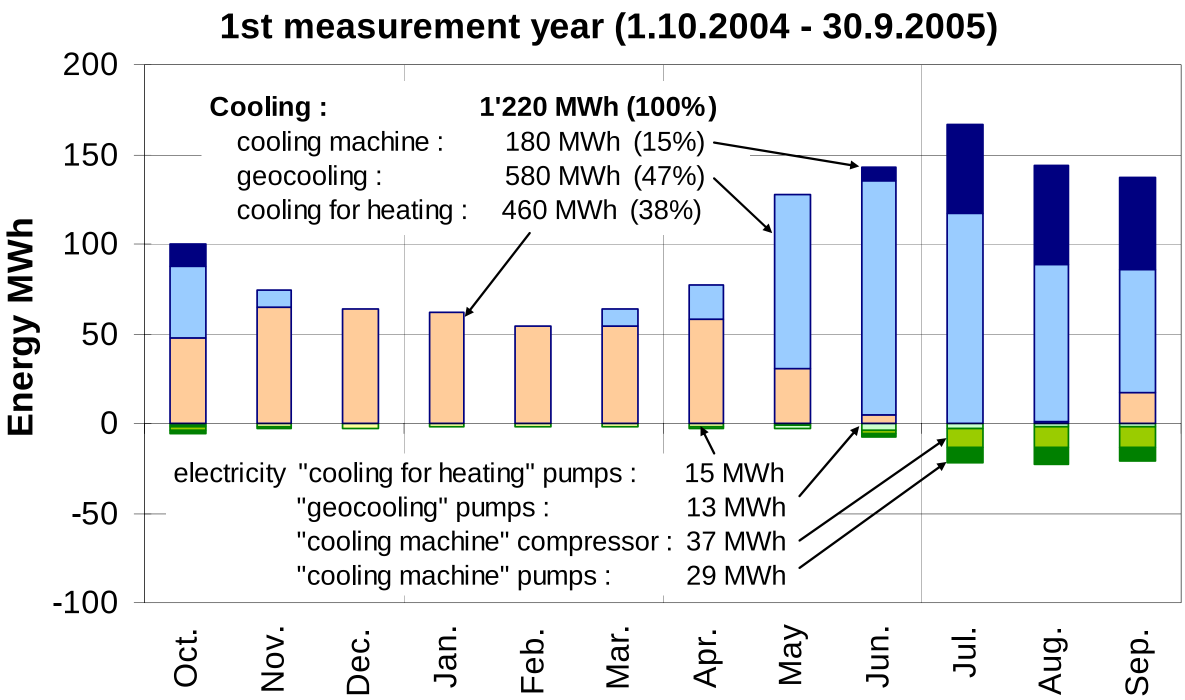

Figure 4: Monthly cooling energies delivered in the cooling distribution network

The electric energy for the circulation pumps and the cooling machine is measured to 94 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 (44). The cooling machine efficiency, established to 2.7, is heavily penalised by the electric consumption of the circulation pumps. It represents nearly 80% 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 penalises 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 580 MWh, it represents 39% 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.

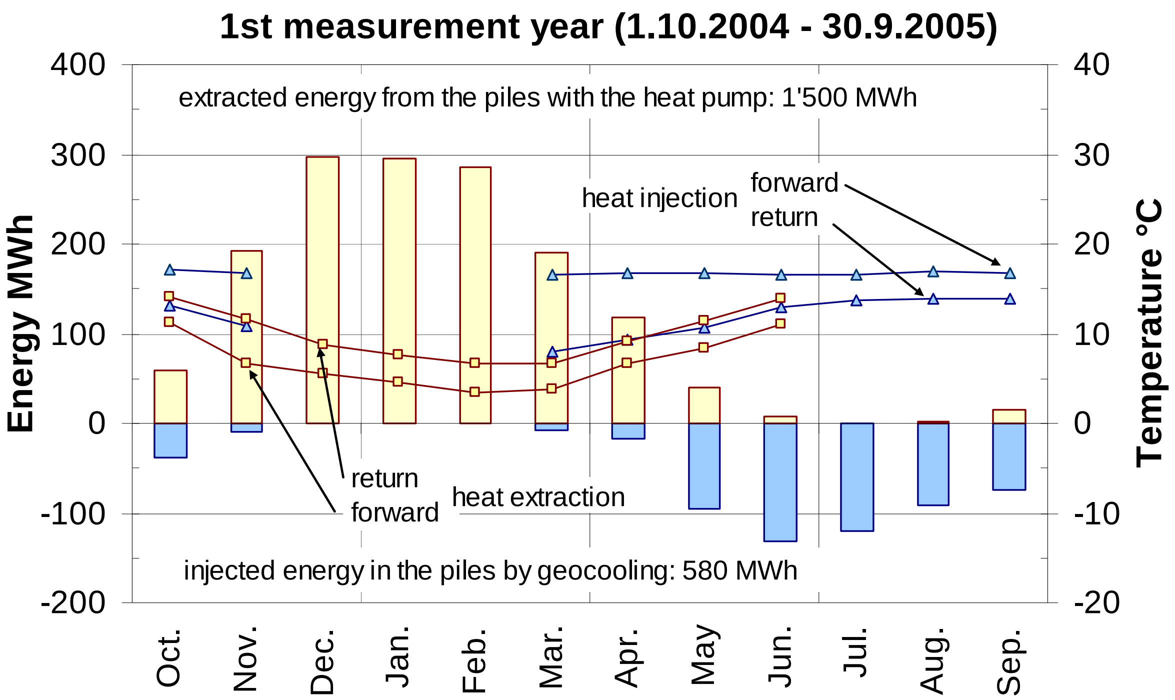

Figure 5: Monthly extracted and injected energies in the piles. The monthly temperature levels of the heat carrier fluid in the pile circuit are shown for both the extraction and injection operation modes

The ground temperatures measured in pile A are shown in figure 6. The fluid temperature levels at the inlet and outlet of the pile circuit are now shown with daily values for the extraction and injection operation modes.

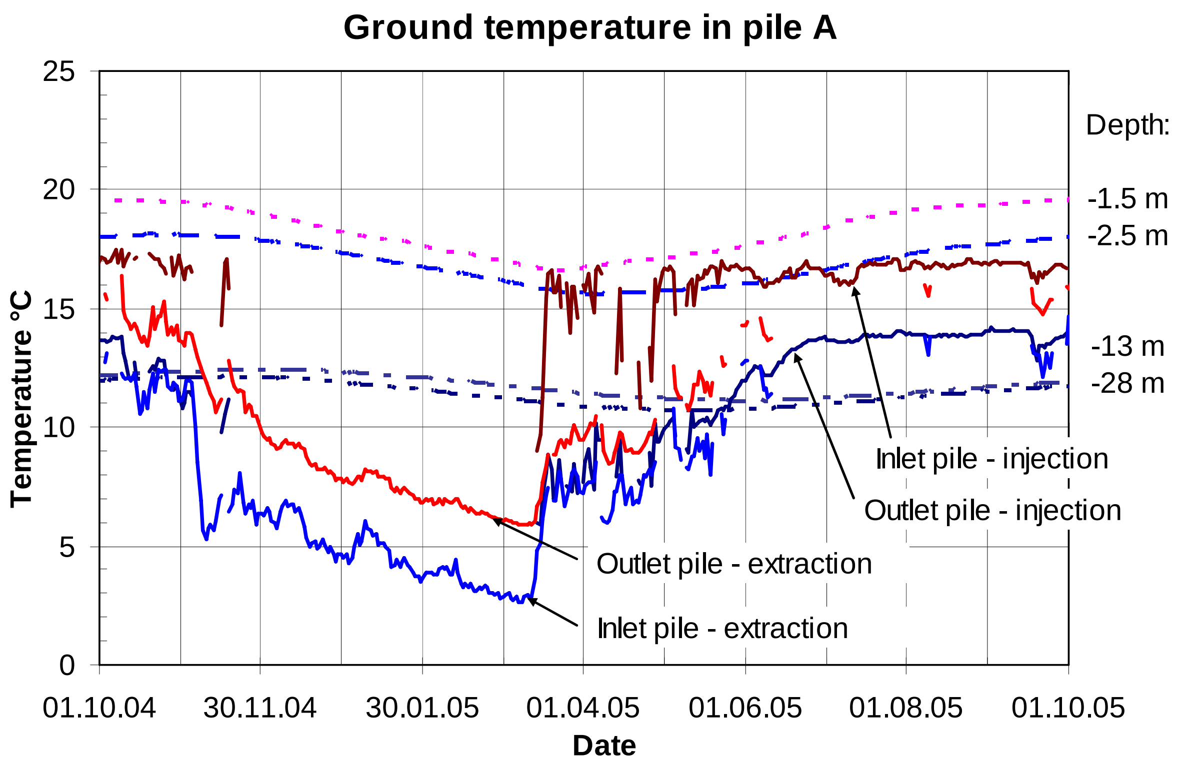

Figure 6: Ground temperatures in pile A at various depths. Daily temperature levels of the heat carrier fluid in the pile circuit are shown for both the extraction and injection operation modes

The minimum inlet fluid temperature in the piles is measured to 2.4°C the 8th of March. 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 [5].

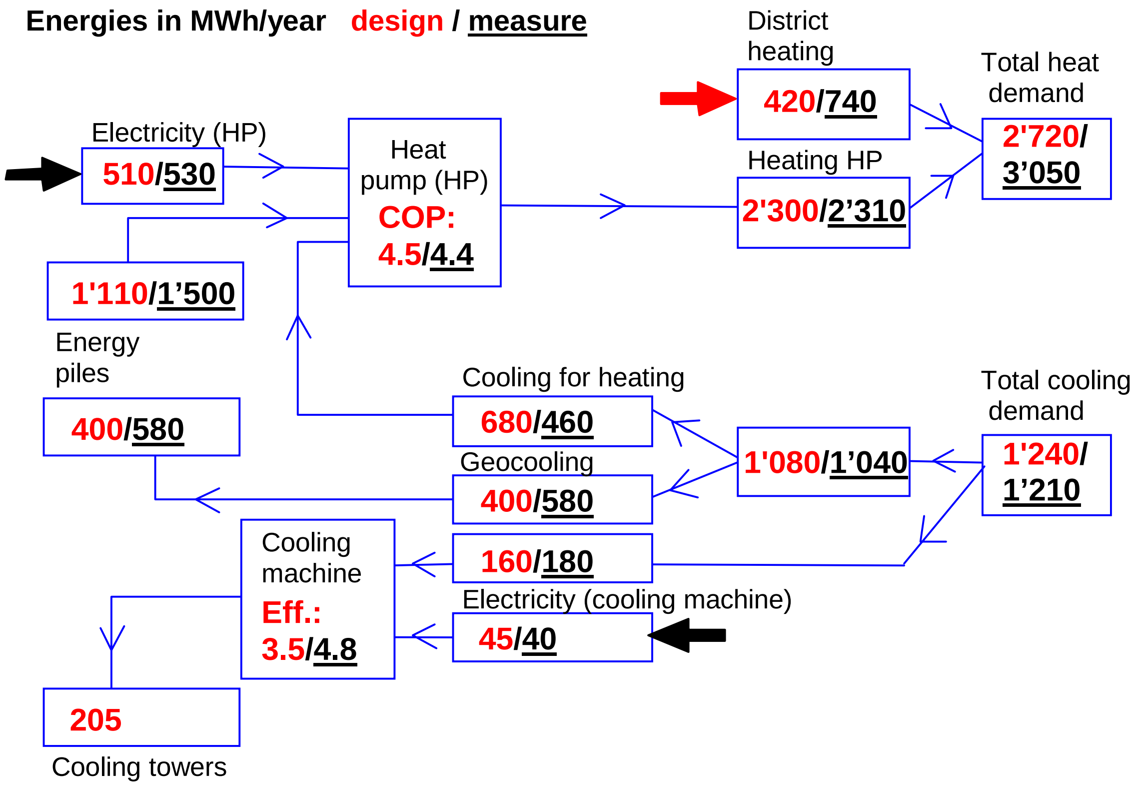

Figure 7: Pile system heat balance, comparison measured – predicted values with PILESIM

The measured values correspond astonishingly well to the predicted ones. The good accuracy of the simulated heating and cooling demands [6] 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 by the active pile length	Design	Measure (Oct. 04 – Sep. 05)	
Maximum pile heat extraction rate	49 W/m	66 W/m	(+35%)
Pile annual heat extraction	135 kWh/(m y)	183 kWh/(m y)	(+36%)
Maximum pile heat injection rate	49 W/m	35 W/m	(-29%)
Pile annual heat injection	48 kWh/(m y)	71 kWh/(m y)	(+48%)
Ratio injected over extracted	36%	39%	(+8%)

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

The piles are actually used more intensively that 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.

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

Annual heat pump performance coefficient	3.7	fraction of “heating+cooling” energy:	66%
“Cooling for heating” efficiency	30		13%
Geocooling efficiency	44		16%
Annual cooling machine efficiency	2.7		5%
Overall system efficiency	4.9		100%

Table 3: Annual thermal performance indexes related to the energy 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 4.9. It could potentially increase to 5.4 if the cooling machine wouldn’t need to operate after a temperature level optimisation in the cooling distribution.

7. 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, a thermal response test [1], dynamic building simulations for the determination of the energy requirements [6] and pile system thermal simulations [2].

The measured overall system efficiency is close to 5. Measurements have shown an optimisation potential in the cooling production which could further increase the overall system efficiency.

8. Acknowledgement

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9. References

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