ANALYSIS OF A GROUND COUPLED HEAT PUMP HEATING AND COOLING SYSTEM FOR A MULTI-STORY OFFICE BUILDING

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ABSTRACT

In the last few years, high energy consumption due to heating and cooling encouraged interest in the efficient use of energy in buildings and highlighted the need for new configurations and strategies for heating, ventilation and air conditioning systems of buildings. Simulation has always been a main tool for analyzing energy balances in buildings, even though the reliability of the results is often compromised by a lack of certainty that the simulations reflect real conditions.

The aim of this monitoring is to analyse the energy supply system based on a ground coupled heat pump heating and cooling system installed in a multi storey office building in Vienna, Austria.

The results showed a seasonal performance factor of 2.5 for the total energy supply system in the first year of operation; however the special conditions especially during summer in a consequence of system adaptations have affected adversely the performance of the system. The ongoing monitoring of the second year of operation of the system will bring conclusions of the system performance under normal operating conditions.

Key Words: ***heat pump, ground coupling, heating and cooling, building energy system, monitoring.***

1 INTRODUCTION

As one of the most essential guidance for the decisions to use a technology are examples of best practice proofing the capability of the technology, a monitoring of the energy supply system based on a ground coupled heat pump heating and cooling system for a multi storey office building was accomplished, to be able to offer alternative energy supply systems for future building projects.

The growing interest in the efficient use of energy in buildings has highlighted the need for new configurations and strategies for heating, ventilation and air conditioning systems (HVAC). Buildings represent one of the dominating energy-consuming sectors in industrialised societies. In Europe about 40% of primary energy consumption is due to services in buildings and the heating and air conditioning systems are basically responsible for this consumption (EC 2001).

To reduce this level of consumption and to optimize the utilisation of resources, numerous simulation tools have been developed in the last few years for energy management in buildings. Current studies for analysis of the use of energy in buildings continue to rely on the development tools that allow simulating energy management systems in buildings. However, these simulations are not always validated with measured data. The cost and work required collecting and monitoring information about typical variables in HVAC installations make it difficult to analyse real situations.

Nowadays, there exist many HVAC systems in which temperatures and internal conditions are measured and stored for control purposes, but rarely to calculate the energy efficiency of the system or the real energy consumption of buildings. It is necessary to carry out and implement this second option for energy saving and detecting possible deviations on previous calculations. The current position of Europe is to work towards this trend by implementing energy certification of buildings.

Our main objective in this work is to collect and to analyse real data dealing with the operation of the energy supply. As a result of the energy balance it is also possible to give information about the seasonal performance of the system installed and the behaviour of the ground collector system. In addition the system is compared from an ecological point of view with conventional heating and cooling systems using natural gas, fuel oil or based on district heating.

2 DESCRIPTION OF THE BUILDING

The STRABAG HOUSE was constructed as a multifunctional office property. The 21000 m^2 area of the 50 m high building is divided in 13 floors with about 18000 m^2 office area and 3000 m^2 for shops and commerce. The STRABAG HOUSE is heated by floor convectors built in along the prefabricated facade. Cooling is effected through micro perforated sheet-metal cooling ceilings. Exhaust is realised at the ceiling, and between the façade and the sun shades. Particular attention was paid to avoid the “sick building syndrome”; aside from the usual common zone regulation provided for the building technology, also room air quality can be individually controlled with the help of conventionally opening façade windows.

3 DESCRIPTION OF THE ENERGY SUPPLY SYSTEM

In Central Europe the ground temperature at a depth of 10-20 metres averages around 11-12 °C. In the soil layers above this, the temperature depends on weather conditions. Every square meter of ground surface is irradiated by approximately 1100 kW of solar energy on an annual basis. In the lower layers of the ground, geothermal influences predominate.

The basic idea is to extract the thermal energy from the ground via the foundations (near-surface geothermal energy) and to provide the appropriate systems which allow this energy to be used in buildings. Conversely, this principle can also be used for cooling by dissipating excess heat into the ground. Providing that the ground conditions permit, this means that cooling and heating energy can be stored on a seasonal basis.

Energy supply needed for heating and cooling is effected through a ground coupled heat pump system with an installed cooling capacity of 3*693 kW. The heat pumps are linked to a closed loop heat exchanger comprising of cast-in-situ driven piles integrated into the foundation were the heat transfer medium is circulated through to transport the thermal energy to the central building services control system. In total 68000 m of PE-pipes were furnished partly in the foundation of the building and partly in 250 17m long cast-in-situ driven piles; the thermal energy is exchanged in 800 circuits.

For heating purpose the heat pump can be used on the primary circuit side to extract thermal energy from the ground via the foundation structures, which is then raised to a higher temperature level (heating mode). In many cases the building can be cooled virtually without any costs through the direct use of the temperatures available in the ground. Here the heat transfer medium which circulates through the energy supply system is used directly for cooling purpose (free cooling mode). If the underground temperatures do not allow free cooling, the installed heat pumps are used as refrigerator units and the ground is deployed as the heat sink for the heat pump system (cooling mode).

The system was designed in a way that the office and retail space require no additional power supply – apart from the electric power needed for the operation of the energy supply system. In our case the four different operational modes have been distinguished: heating (Fig. 1), heating + free cooling (Fig. 2), cooling + free cooling (Fig. 3) and cooling (Fig. 4).

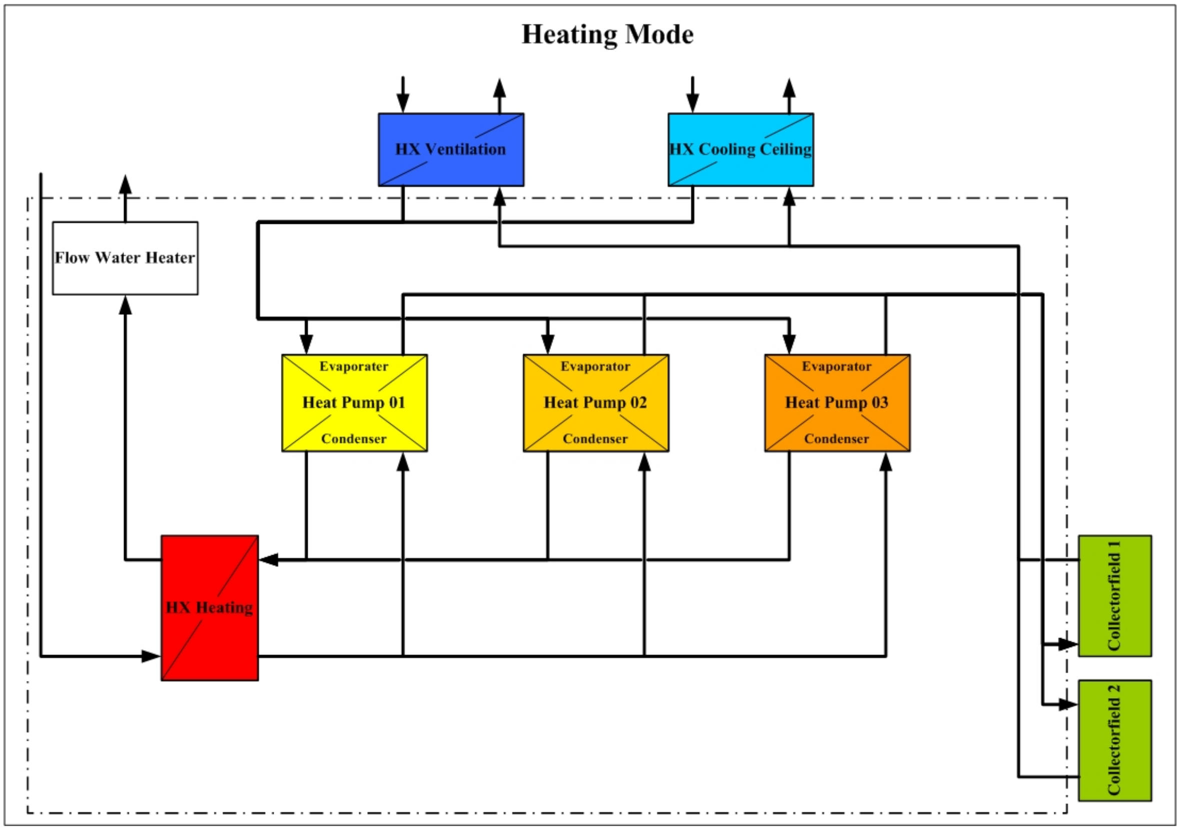

Fig. 1. Schematic of heating mode

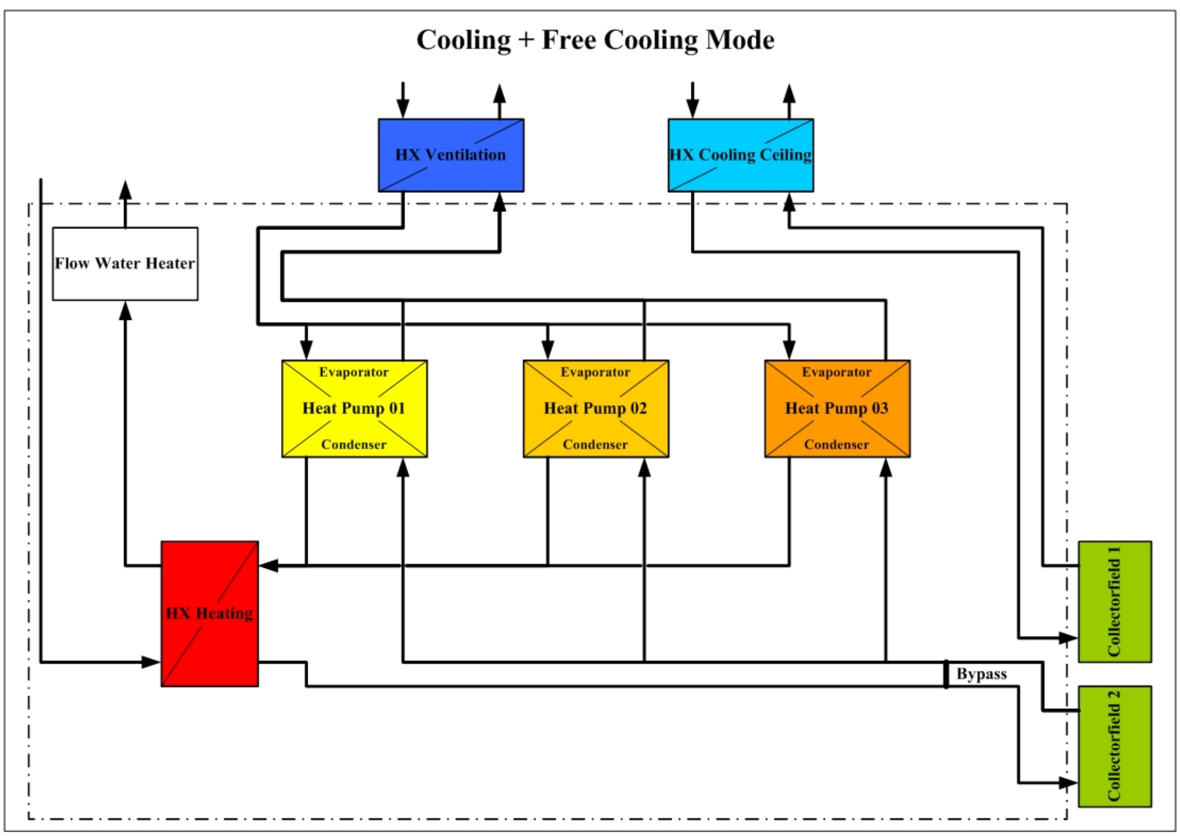

Fig. 2. Schematic of heating + free cooling mode

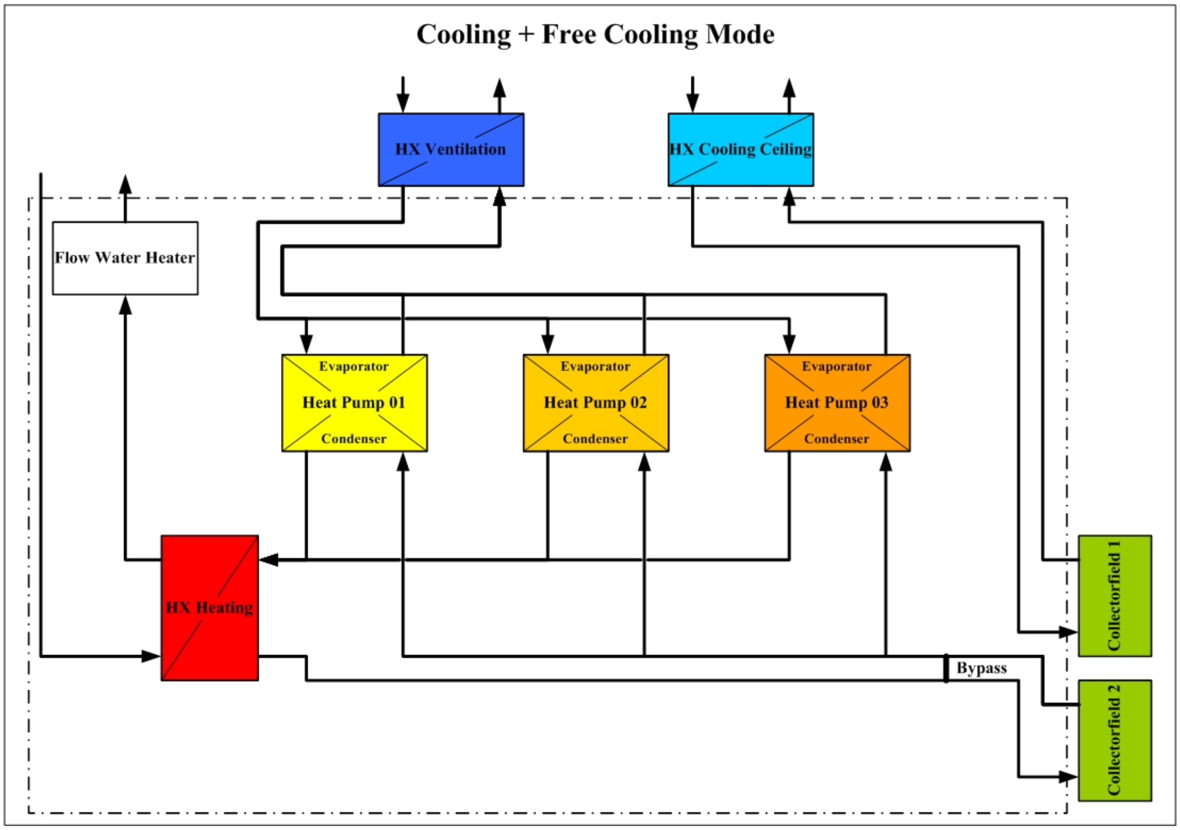

Fig. 3. Schematic of cooling + free cooling mode

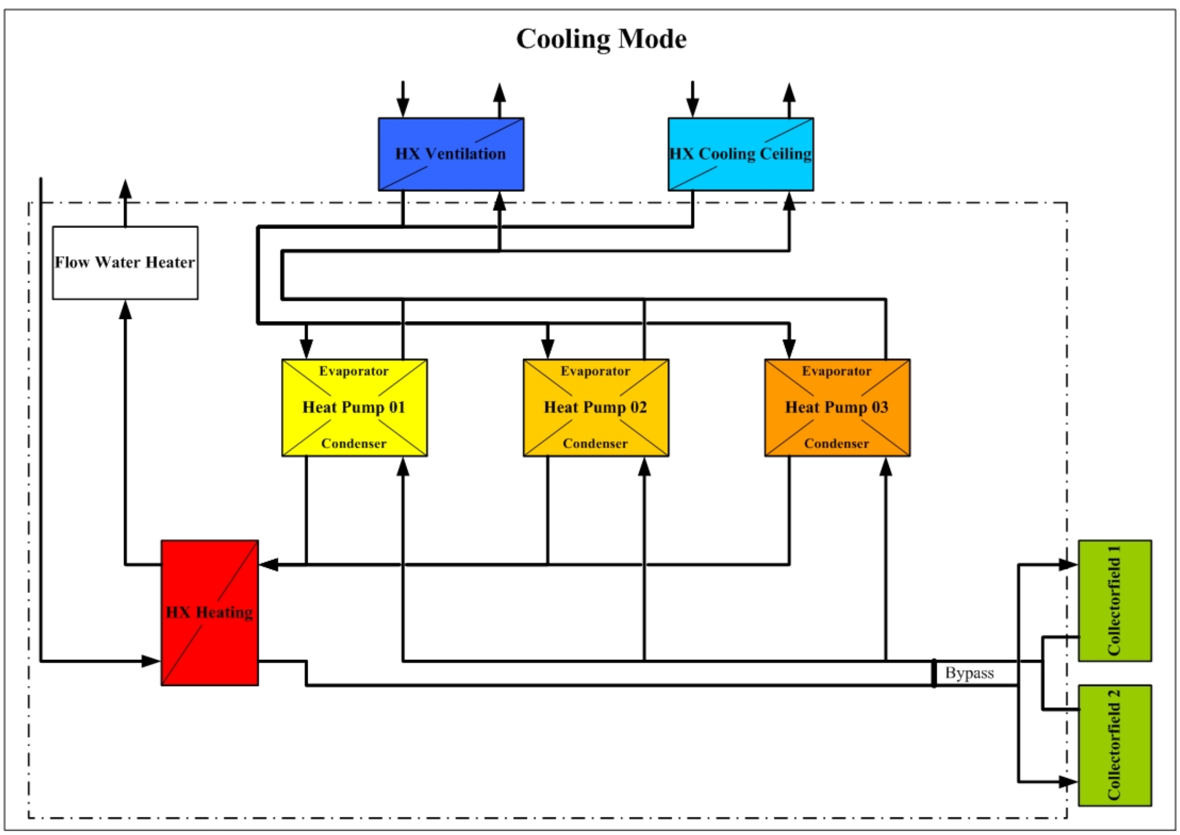

Fig. 4. Schematic of cooling mode

4 ENERGY BALANCE OF THE ENERGY SUPPLY SYSTEM

The use of energy and the related costs in a building depend on complex interactions between a large number of variables. Our main objective in this work is to collect and to analyse real data dealing with the operation of the energy supply. To ensure detailed information the monitoring data was also analysed for the different operational modes: heating, heating & free cooling, cooling & free cooling and cooling. The energy balance was drawn as indicated in Fig.1 –Fig.4. The equations of the energy balance of the energy supply system are summarized in the following:

The instantaneous heating/cooling capacity of the heat pump units (Eq. (1)) is obtained by multiplying the flow rate of the heated/chilled secondary fluid (water/antifreeze solution) of the primary circuit by the specific heat of the secondary fluid and by its difference temperature between the inlet and outlet of the condenser/evaporator.

$$\dot{Q} = \rho \cdot \dot{V} \cdot c_P \cdot \Delta T \tag{1}$$

The energy (cold and heat) supplied by one heat pump unit is calculated from the cooling-/heating capacity and the measuring period of the data storage (Eq.(2)).

$$Q = \rho \cdot \dot{V} \cdot c_P \cdot \Delta T \cdot t \tag{2}$$

4.1 Coefficient of Performance (COP)

The coefficient of performance of a heat pump is defined as the quotient of the useful heat (heating mode) or cold (cooling mode) transferred by condenser/evaporator to the heated/chilled secondary fluid to the power consumption of the heat pump under designated operating conditions (Eq. (3)).

$$COP = \frac{Q}{P_{in}} \tag{3}$$

4.2 Seasonal Performance Factor (SPF)

Seasonal performance calculation is done to asses the time-dependent performance of the energy supply system under changing operation conditions over a certain time span, usually a year. Input data are normally steady state values, which are valid for operation conditions or a certain range of operation conditions. By accumulating the operation conditions over the year the efficiency can be calculated. An addition of these instantaneous values over the whole time span thus delivers the seasonal performance.

A formulation of the SPF is given in Eq. 4 were ϕ_{used} stands for all forms of useful energy (heat and cold) transferred by the respective heat exchangers to the heat and cold distribution systems as output of the system and P_{in} represents the sum of all power input (heat pumps + secondary fluid circulation pumps) required to produce the useful energy. dt is the time step.

$$SPF = \frac{\int_{t=0}^{t_{end}} \phi_{used}\, dt}{\int_{t=0}^{t_{end}} P_{in}\, dt} \tag{4}$$

5 RESULTS AND DISCUSSION

The energy supply system, of the STRABAG HOUSE in Vienna, Austria has been monitored and analysed during its first year of operation in the period from the 29th of December 2003 to the 26th of December 2004.

The energy balance for the whole energy supply system and the three heat pump units has been carried out. Therefore the necessary measurement points have been defined and were measured as five minutes average values for the stated time period.

The results presented in this paragraph show the operation of the energy supply system in terms of daily, weekly heat and cold supply and seasonal performance factor , and energy consumption once it is submitted to the buildings thermal load.

5.1 Evaluation of the operation of the energy supply system

Figures 5–7 show weekly monitoring results of the energy supply system for the year 2004. Fig. 5 show calendar week 52 when the system was running in heating mode with a system performance of 2,6 providing an average flow temperature of the heating system of 51°C. It is shown that the heating demand is decreasing along with a lift of the outside temperature.

Within Fig. 6 the results of the monitoring of calendar week 20 are shown. It can be seen that the installed system can cover the demand of heating and cooling with a system performance of 3.8. During this week the system operated in all four modes. The performance of the system in the different modes of operation has been calculated based on the measured data as follows: heating: 3.8; heating + free cooling: 6.0, cooling + free cooling: 4.5 and cooling: 3.7.

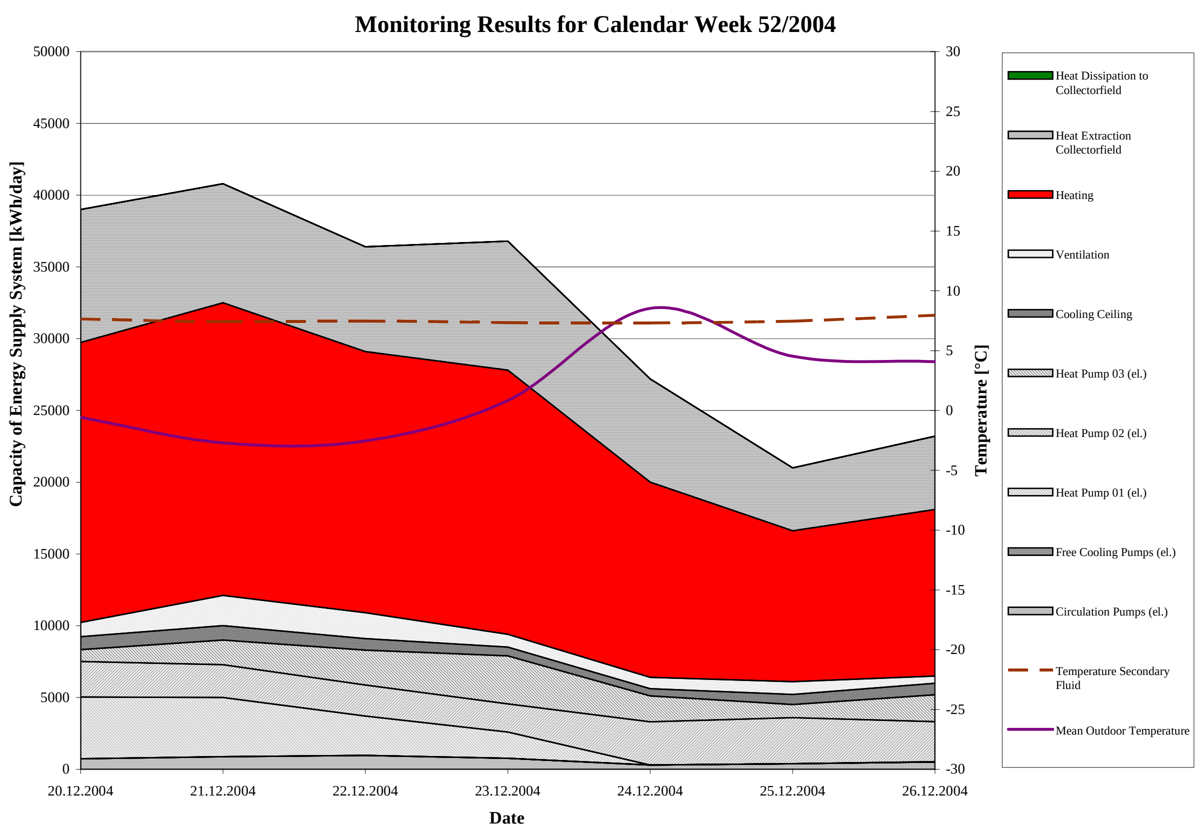

Fig. 5. Monitoring results of the Energy supply system for calendar week 52/2004 (heating mode)

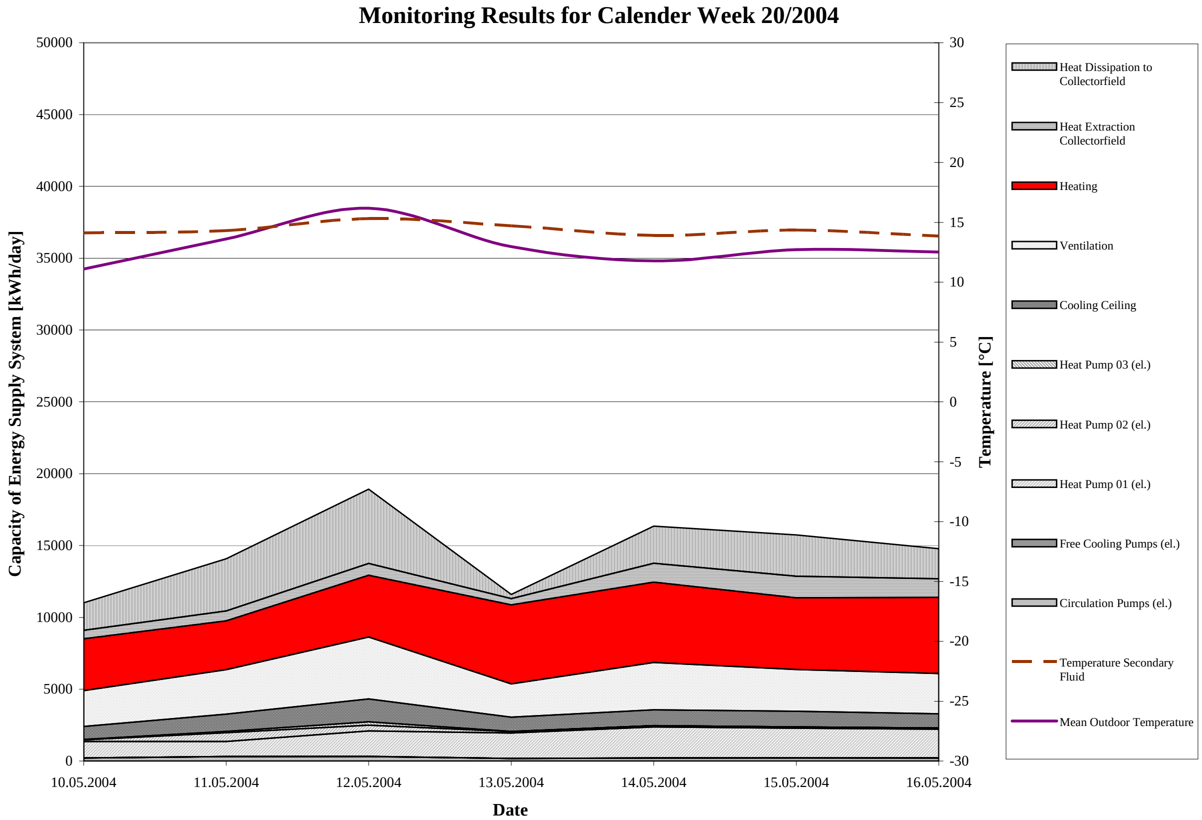

Fig. 6. Monitoring results of the Energy supply system for calendar week 20/2004

In Fig. 7 the results of one week during summer is presented. The calculation of the system performance for calendar week 36 arrived to 2.7. The high demand on energy for the system in the calendar weeks 31-34 were a consequence of system adaptations which resulted in a deterioration of the performance of the system and caused high temperatures in the collector fields for the following weeks and hence affected adversely the performance of the system
(see Fig. 8).

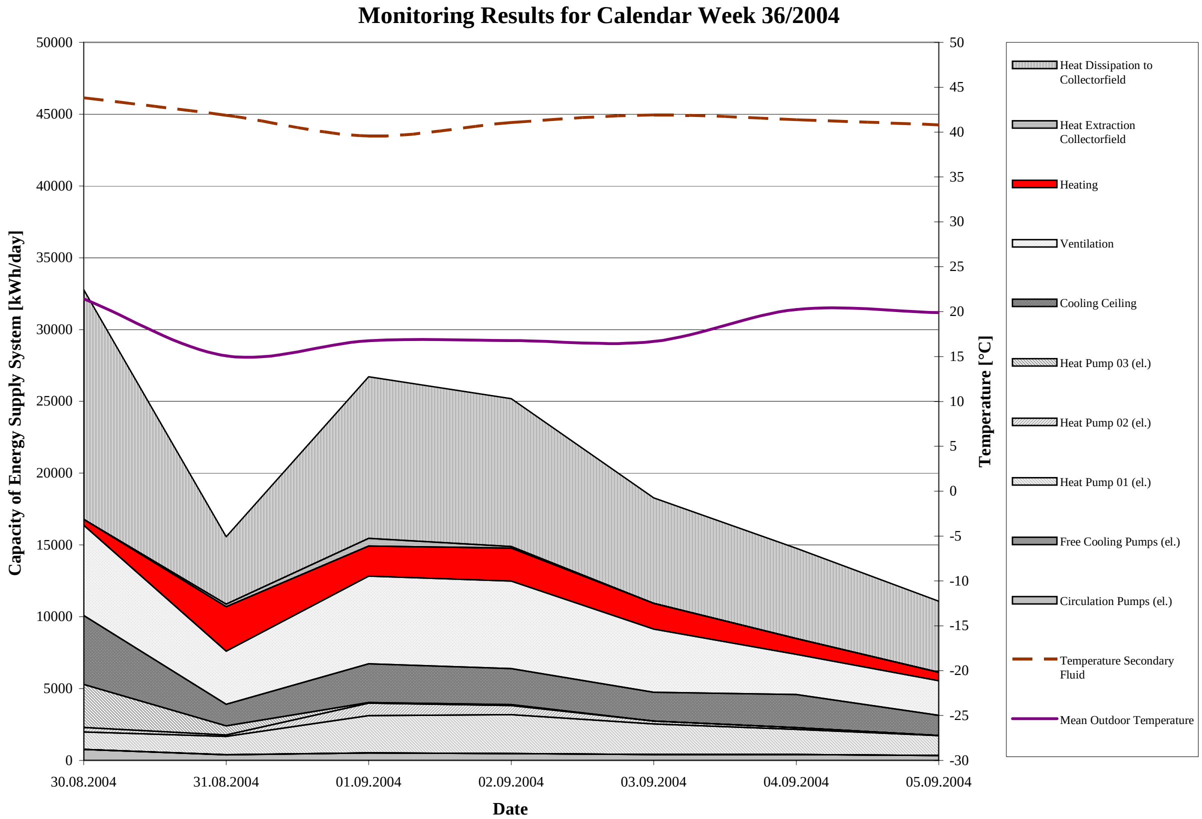

Fig. 7. Monitoring results of the Energy supply system for calendar week 36/2004

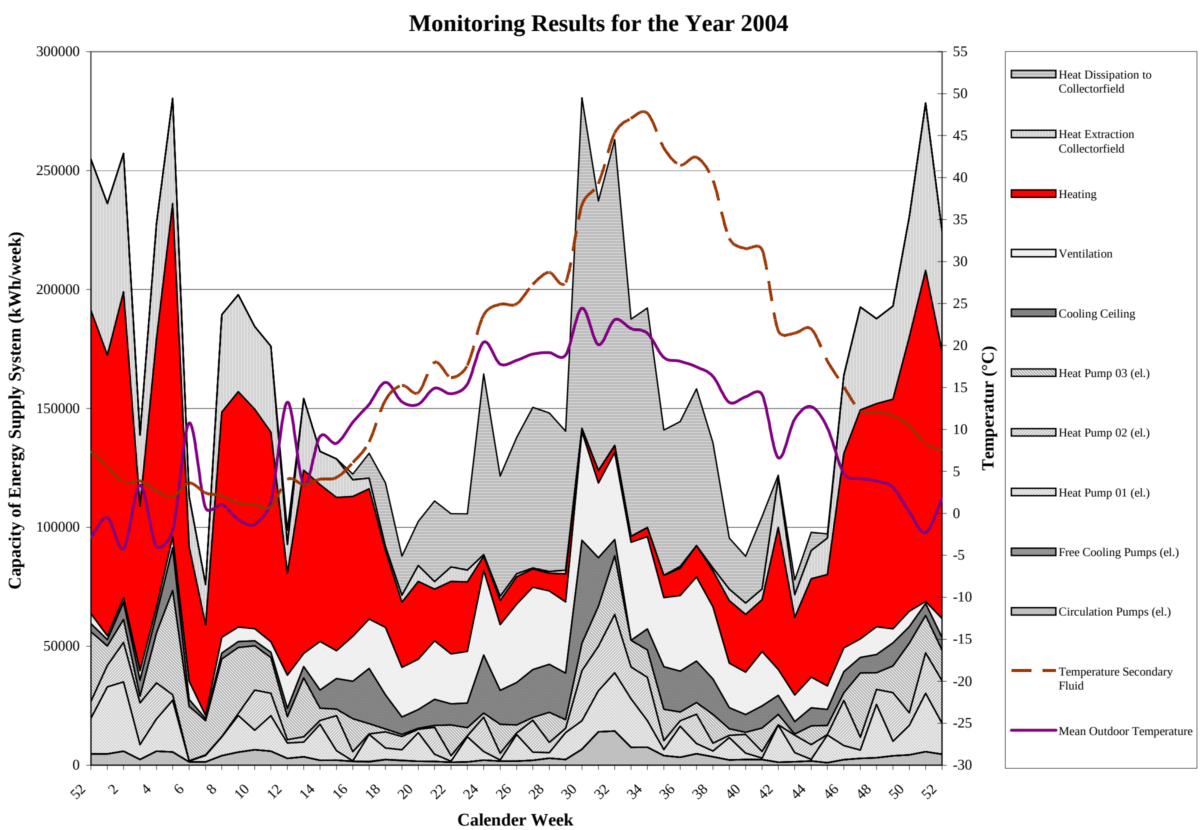

Fig. 8. Monitoring results of the Energy supply system for the year 2004

6 CONCLUSIONS

The monitoring of the energy supply system based on a ground coupled heat pump heating and cooling system installed in the STRABAG HOUSE has shown that the system can accomplish the requirements with respect to the heating and cooling demand of the building. Less than one percent of the heating demand was supplied by the electric flow water heater. The total heating demand of the building for the year 2004 was 2.7 MWh which is 64% of the total energy demand. The 1.5 MWh of cooling demand of the building represent 36% of the total energy demand for heating and cooling.

Less than two percent of the heating and cooling demand of the building was provided in the two free cooling modes. The utilisation of free cooling might be increased by the adaptation of the control set points of the energy supply system. The measured value for the electricity consumption for running the system in the year 2004 was: 1.7 MWh.

The results have shown a seasonal performance factor of 2.5 for the total energy supply system in the first year of operation; however the conditions especially during summer in a consequence of the final system adaptations have affected adversely the performance of the system. The ongoing monitoring of the second year of operation of the energy supply system will enable conclusions of the system performance under normal operating conditions.

For future implementation of such a system it is recommended to decrease the flow temperature of the heating system to improve the performance of the energy supply system.

From an ecological point of view the installed system shows a favourable CO_2 balance compared to conventional heating and cooling systems based on natural gas, fuel oil or on the usage of district heating.

7 NOMENCLATURE

COP	Coefficient of performance
c_P	Specific heat (kWh/kg K)
P_{in}	Power consumption (kWh)
Q	Heat / Cold (kWh)
$\dot{Q}$	Heating / Cooling capacity (kW)
SPF	Seasonal performance factor
ΔT	Difference temperature (K)
t	Measuring period of the data storage (s)
$\dot{V}$	Volume flow (m^3/s)
ρ	Density (kg/m^3)
ϕ_{used}	Output of Useful energy (kWh)

REFERENCES

Commission of European Communities (2001), Green Paper - Towards a European strategy for the security of energy supply. Brussels/Belgium, p. 13.