

# COMPARATIVE ENERGY PERFORMANCE BETWEEN A GEOTHERMAL HEAT PUMP SYSTEM AND AN AIR-TO-WATER HEAT PUMP SYSTEM FOR HEATING AND COOLING IN TYPICAL CONDITIONS OF THE EUROPEAN MEDITERRANEAN COAST

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## 1. INTRODUCTION

Ground Coupled Heat Pump (GCHP) is a well-known technology that has been used for over 50 years. However its market penetration, in particular in Europe, is still small. In those European countries in which GCHP are most popular, climatic conditions are such that by far most of the demand is for space heating, whereas air conditioning is rarely required. Therefore experience with GCHP in Europe refers mostly to heat pumps operating in heating mode. However with the ongoing proliferation of GCHP technology into southern Europe, in particular in Italy and Western Turkey, the double use for heating and cooling is becoming increasingly important. In this sense, implementation of this technology to cooling dominated applications in mild and hot climates is still in the early stages.

The aim of this work is to gain an insight into the experimental viability of the GCHP technology for coastal applications in the South European region. In this direction, we present the performance analysis of a closed loop vertical ground source heat pump system installed in Valencia (Spain) operating in both heating and cooling modes. In order to establish the efficiency improvement and energy savings, the GCHP was compared with a conventional air-source heat pump system linked to the same building and operating under similar climatic conditions. Both systems were fully monitored throughout one year. Although different features of the system performance were analysed including the ground thermal response, the work we report here will restrict to the comparative energy performance analysis.

All this work has been done in the framework of the European Project GeoCool. Its main objective is the development of a commercial size, economic, energy efficient and environmentally friendly, fully integrated turnkey ground source heat pump system for cooling and heating, targeted specifically at coastal applications in the South European region.

## 2. EXPERIMENTAL SETUP

The experimental implementation of a GCHP system is aimed to make a quantitative assessment of profits, from the energy efficiency point of view, with respect to a conventional system. An air source heat pump was chosen as a reference system since it is widely used in typical low and mid power applications in the South European region. In order to compare both systems we have established analogous operating conditions on both systems, linking them to the same building (see figure 1) and thus to the same heating and cooling load conditions. Our experimental design allows to easily switch from the air-water heat pump to the ground-coupled heat pump.

The measurement and analysis period started in February of 2005 and lasted throughout one year. During this time, both systems were operating alternately. The geothermal system worked from Tuesday to Friday while the conventional system was working only on Mondays. This choice of the running schedule is related to the fact that in

the sizing of the geothermal system the whole base load of the building was taken into account. The difference in GCHP system performance due to the missing day is considered to be small.

Both systems were fully monitored by means of a sensor network connected to a data acquisition system that provided a large experimental database at the end of the season. Technical features of system design will be described in more detail in the next sections.

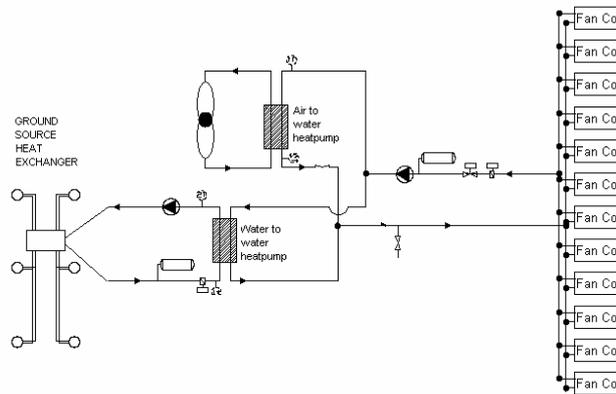


Figure 1: Geocool scheme. An external hydraulic group connects the ground heat exchangers with the water-water heat pump. The heat pumps are linked in parallel to the internal hydraulic group that transfers the energy to fan-coils.

## Building

Both systems have been installed in an academic building at the Universidad Politécnica de Valencia, Valencia, Spain. The total air-conditioned area is 250 m<sup>2</sup> and it is distributed among a corridor, nine offices, a computer classroom, a room with photocopiers and a coffee dispenser. All rooms are equipped with one or two fan coils except the corridor. Loads were calculated with standard software (based on the BLAST load calculation approach) taking into account the load profile variations during the whole season in heating and cooling mode. Load peak values in heating and cooling modes were sized at 15 kW and 17 kW respectively.

## Conventional system

The conventional system consists of an air-to-water heat pump located on the building roof. The experimental unit was a reversible air to water heat pump of CIATESA (model IWA-80) with 17.1 kW and 15.7 kW of cooling and heating capacity respectively.

## Geothermal system

The ground-coupled heat pump system consists of six ground heat exchangers of 50 m depth distributed in a rectangular (2x3) configuration.. All boreholes were finished with a bentonite layer at the top to avoid intrusion of pollutants into the aquifers.

A secondary goal of the GeoCool project was the design of a specifically optimized heat pump using propane (R290) as refrigerant. The use of this refrigerant implies an efficiency improvement and high benefits in terms of capacity and COP. This prototype was tested and incorporated to the GeoCool installation. The unit from which the design of the propane heat pump was developed was a reversible water to water heat pump of CIATESA (model IZE-70) with 15,9 kW and 19,3 kW of cooling and heating capacity respectively. The ground-coupled heat pump was placed on the groundfloor of the building next to the internal hydraulic group.

## Data acquisition system

System performance has been characterized by means of the measurements of different system parameters like water

temperature, mass flow and power consumption. A network of forty four probes distributed in strategic points was used to monitor them.

Two temperature probes were placed in the internal hydraulic group (see figure 2). These probes measure the going/returning water temperature to/from fan-coils. Heating and cooling capacity supplied by both systems is calculated from these measurements. Likewise, the heat capacity absorbed/transferred from/to the ground is calculated by means of the temperatures measurements of two probes placed in the external hydraulic circuit at the inlet and outlet of the geothermal heat pump. In addition, two temperature probes were placed at each borehole to measure the inlet and outlet water temperature. Ground temperature was also recorded in three of the six boreholes by means of seven temperature probes uniformly distributed at different depths. Two Coriolis meters registered the mass flow at the internal and external hydraulic groups.

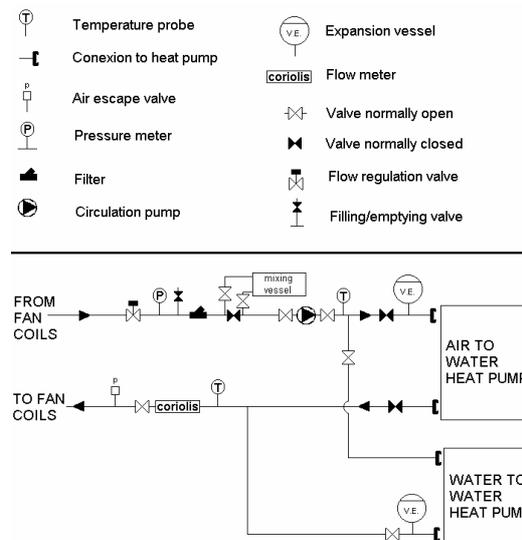


Figure 2: Scheme of the internal hydraulic group.

To evaluate the energy performance it is necessary to measure the power consumption of different elements of the system. The acquisition system recorded the power consumption of the circulation pumps (internal and external group), heat pumps and fan coils. All measurements were taken at one minute intervals. Besides the measurements of system performance parameters, climatic data were available coming from a meteorological station placed on the building roof near to the air-source unit. It records twenty four parameters like temperature, humidity, wind speed or irradiation at five minute intervals.

Data acquisition system generates a daily file with 1440 registers of 44 probes. To process systematically this considerable amount of data, a specific analysis software tool was designed. This code performs automatically the necessary database reading and the statistical analysis.

### 3. THEORETICAL REMARKS

Energy system performance may be analysed from the instantaneous measurements of temperature, flow and power consumption. For this purpose several characteristic magnitudes derived from the experimental measurements has been calculated:

#### Heating/Cooling capacity

This parameter is calculated from the going/returning water temperature from/to the fan-coils and the mass flow in the internal hydraulic group:

$$\dot{Q}(t) = \dot{h}_{out}(t) - \dot{h}_{in}(t) = \dot{m} c_p (T_{out}(t) - T_{in}(t)) \quad (1)$$

It's important to stress the physical meaning of  $\dot{Q}(t)$  keeping in mind the scheme of figure 3. Air-conditioning systems are represented as a black box linked to the building. Function  $\dot{Q}(t)$  represents the difference between the input and output enthalpy flux at the connection point between the building and the heat pump systems. This station was chosen at the groundfloor, next to the internal hydraulic group and the water-water heat pump, far from the air-source heat pump unit located on the building roof (see figure 2). As a consequence of this, the instantaneous values of  $\dot{Q}(t)$  take into account not only dynamic effects due to the thermal inertias involved in the system, but also all losses to the ambient upstream from the measurement station. What we are characterizing is the dynamic response of the air-source system vs. the geothermal water-source system, which sometimes will substantially differ from the nominal stationary heat pump unit heating/cooling capacities provided by the manufacturers. Nevertheless and to the extent that we consider the design and layout of both systems as typical and representative, the obtain results shall give a realistic idea of the comparative energetic performance of both types of systems.

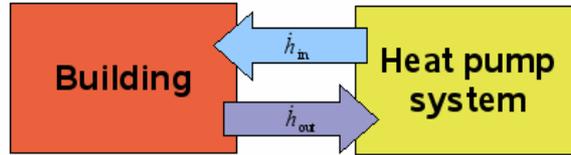


Figure 3: System scheme.

### Heating/Cooling load

This parameter is defined as the integral of  $\dot{Q}(t)$  in the  $\Delta t$  interval.

$$Q = \int_0^{\Delta t} \dot{Q}(t) dt \quad (2)$$

Due to the experimental setup this quantity is always larger for the conventional system. The air to water system configuration involves an additional piping from the groundfloor to the roof. Therefore this system has larger thermal inertia due to the extra water volume of the additional piping that has to be cool or heat at the system startup.

### Electrical load

This parameter has been calculated integrating numerically power consumption  $\dot{W}(t)$  of different components (heat pumps, circulation pumps and fancoils) in the  $\Delta t$  interval.

$$W = \int_0^{\Delta t} \dot{W}(t) dt \quad (3)$$

### Coefficient of performance (COP)

This parameter is defined as the ratio between the flux of enthalpy and the power consumption:

$$COP = \frac{\dot{Q}}{\dot{W}} \quad (4)$$

Note that it has been only taken into account the power consumption of the heat pumps. The power consumption for the external circulation pump has been also included in the geothermal system calculations.

### Seasonal performance factor (SPF)

This parameter is defined as:

$$SPF = \frac{Q}{W} \quad (5)$$

Again, note that it has been only taken into account the power consumption of the heat pumps. External circulation pump has been also included in the geothermal system calculations.

### Energy savings

From the SPF values it is possible to estimate the energy savings that may be obtained when switching to GCHP technology assuming that the heating/cooling load is the same for both systems. Under this hypothesis, the energy savings can be theoretically evaluated as:

$$\frac{W_{aw} - W_{ww}}{W_{aw}} \cdot 100 = \left( 1 - \frac{SPF_{aw}}{SPF_{ww}} \right) 100 \quad (6)$$

## 4. RESULTS

### Heating season

Figure 4 shows the SPF evolution. The red line corresponds to the air-water system and the blue line to the water-water system. Each point of the curve has been calculated considering the period comprised from the beginning of the season (1<sup>st</sup> of February) to the day considered. Therefore, the last point of the curve is the quotient between the total heating load and the total electrical energy consumption. These values are very meaningful since they provide an estimation of the global energy performance. Final SPF at the end of the heating season was **3.46** for the geothermal system and **2.00** for the conventional system. These results involve an efficiency improvement of **73 %**. In terms of energy savings, system based on ground coupled heat exchangers consumes **41 %** less energy than the conventional.

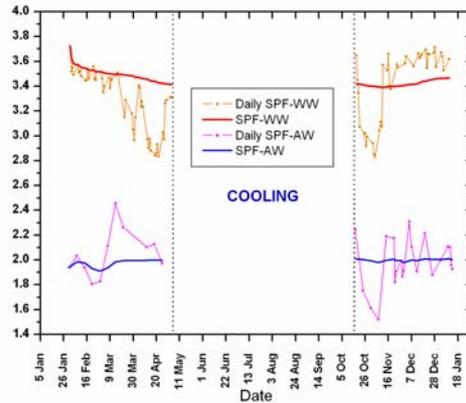


Figure 4: SPF evolution in heating mode

Daily evolution of SPF is also represented in figure 4. In this case, SPF is calculated from the integrated values throughout one single day. Periods corresponding from the middle of March to the beginning of May and from October to the middle of November attract attention due to the decreasing trend of the SPF. It is easily understood if we take into account that these periods are characterized by mild temperatures and a low use of the heat pump (with short and low frequency cycles). In fact, probably natural ventilation would be enough to cope with the loads at these conditions. Consequently the system is heavily oversized and losses are predominant.

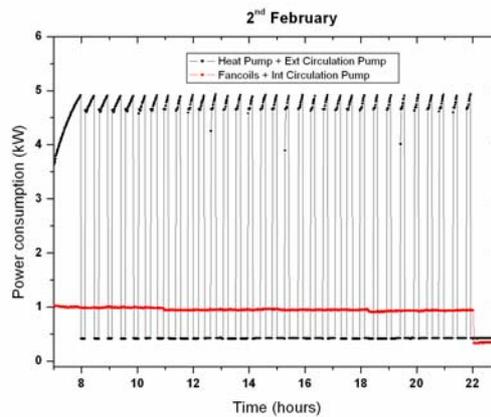


Figure 5: Daily evolution of power consumption

Up to this point we have only taken into account the electrical consumption of the heat pumps and the external circulation pump, whereas in figure 5 the power consumption of the water-water heat pump and the external circulation pump (black line) and the power consumption of the circulation pump and fan-coils (red line) is compared. Notice that the power consumed by the auxiliary components is low, although, as they operate permanently, their impact in the overall energy consumption is proportionally larger. In order to evaluate the impact of these elements in the global energy balance, in figure 6 the monthly electrical consumption - separating the contribution corresponding to the energy transport components from the energy production (heat pumps and external circulation pump) – is shown. The results are quite meaningful as the weight of the secondary components is systematically above 30% and, during warmer periods, when the system use is low, reaches up to 50%. Percentages of secondary components for the air-water heat pump are lower due the higher electrical consumption of the heat pump. In any case they are larger than 20%. Our analysis points especially to the need of more intelligent control strategies to attenuate the energy demand of the auxiliary components (here the usual thermostatic control of the indoor entering water temperature was used).

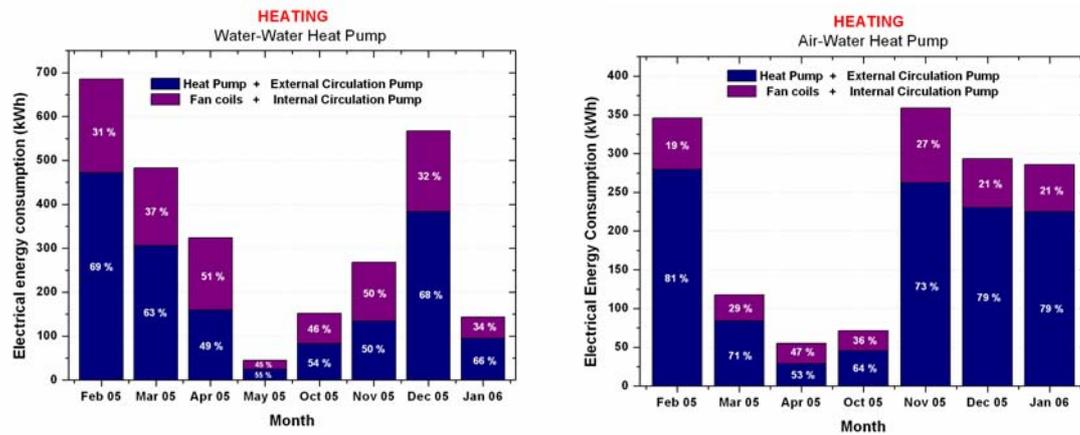


Figure 6: Monthly electrical energy consumption in heating mode.

### Cooling season

A similar analysis has been carried out for the cooling season. Figure 7 represents the SPF evolution. In this case, SPF final values were **4.36** for the geothermal system and **2.72** for the conventional system. These results involve an efficiency improvement of **60 %**. In terms of energy savings, results reveal that system based on ground coupled heat exchangers consumes **38%** less energy than the conventional system. These results show that use of the ground as a heat sink allows to achieve important energy savings in cooling mode.

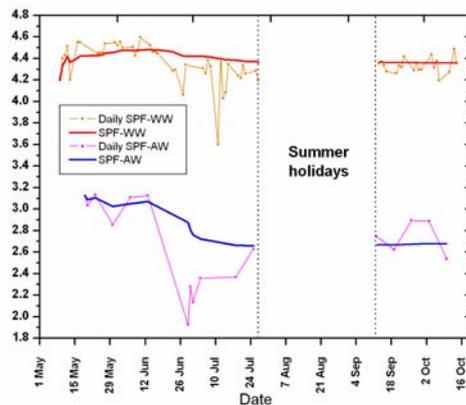


Figure 7: SPF evolution in cooling mode

The power consumption analysis of secondary elements reveals the same trend observed in heating mode. Figure 8 represents the monthly power consumption itemizing the power consumption of each component apart. Again, the weight of the transport components (circulation pump and fan-coils) is unexpectedly large making clear the need of a new control strategy.

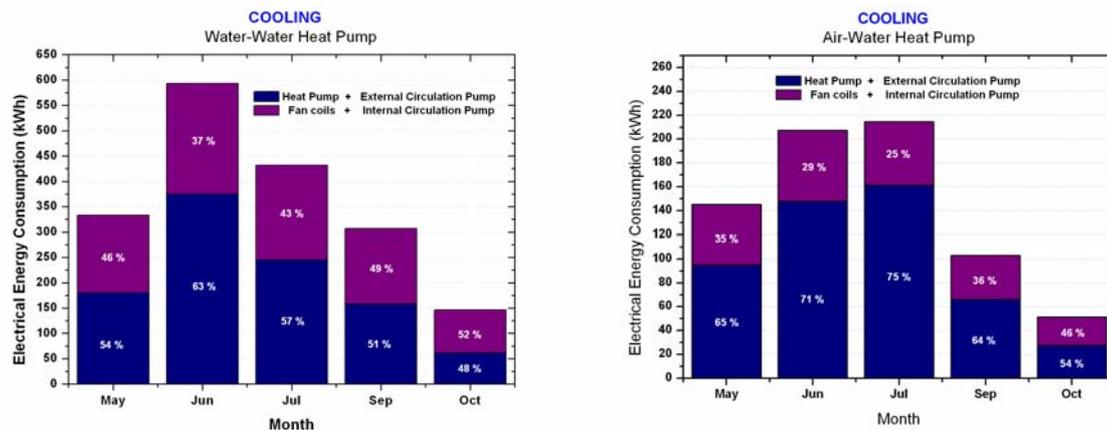


Figure 8: Monthly electrical energy consumption in heating mode.

#### 4. CONCLUSIONS

Experimental measurements at the GeoCool facility throughout one year have provided considerable information about the system performance. Particularly in this work we have focused on the evaluation of the energy efficiency of an air conditioning system based on GCHE faced to the conventional one in heating and cooling modes. The results have allowed us to obtain some conclusions about the operation of both systems which can be summarized as follows:

In heating mode, the geothermal system saves, in terms of primary energy consumption, a 41% compared to the conventional one. In cooling mode the saving obtained was 38%. These results demonstrate that ground source heat pump system is a viable alternative to conventional systems for heating and cooling applications in the South European regions.

It has been detected that air-conditioning systems in heating mode were oversized during warmer periods causing an efficiency drop. For these periods a capacity adaptation strategy would be advisable.

The impact in electricity consumption of the auxiliary elements of the air-conditioning system such as circulation pumps and fan-coils was found to be large and should be taken into account to improve the system efficiency, pointing to the necessity of improved control strategies.

#### ACKNOWLEDGMENTS

This work was financially supported by projects GEOCOOL (EU 5<sup>o</sup> Framework Programme, NNE5 – 2001 – 00847) and GEOCARE (co-financed by Ministerio de Educación y Ciencia, ENE2004- 04551/ALT and FEDER funds).

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