Proceedings World Geothermal Congress 2005
Antalya, Turkey, 24-29 April 2005

Comparative Study 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

G. Romero[1], J.F. Urchueguía[1], H. Witte[2], W. Cambien[1], T. Magraner[1]

[1] Instituto de Ingeniería Energética - IIE / Universidad Politécnica de Valencia -UPV / Camino de Vera, 14, 46022 Valencia, Spain

☎: (+34) 96 387 98 95, email addr. ✉: jfurchueguia@fis.upv.es

[2] Groenholland B.V., Valschermkade 26, 1059 CD, ☎: (+31) (0)20 6159050, Amsterdam, The Netherlands

Keywords: Cooling, Heating, Heat Pump, Ground Coupled Heat Exchanger, Performance.

ABSTRACT

To make a overall assessment of a Ground Coupled Heat Exchanger (GCHE) it is not only important to understand the behaviour of the GCHE, but also to consider the system in which it will operate: its loads and utilization factors (as a function of climate conditions and application), efficiency (which also depends on the heat pump) and other system parameters, such as pumping requirements, long term soil heat imbalance, etc.

As part of the European project GEOCOOL [1], this paper shows the results of applying a methodology developed for the comparative study between a system combining a water-to-water reversible heat pump of commercial size with a vertical GCHE and an equivalent air-to-water heat pump system in typical conditions of the European Mediterranean rim (of great importance for cooling). For this purpose, the seasonal system performance factors for heating and cooling, and the temperature profiles of the water in the GCHE for a 25 year period were calculated for different borehole configurations and for different backfill materials. In addition, an extensive study of relevant climatological parameters of Valencia-Spain was made. These results were transformed into bin-hour data which are used for calculating the seasonal system performance factors for heating and cooling for the air-to-water heat pump system. The heat pump properties have been calculated using the IMST Group's ART software [2]. Finally, a comparison was made between the GCHE-system and an air-to-water heat pump showing the efficiency improvement obtained for various grouting materials, and for different GCHE geometries.

1. INTRODUCTION

In many applications, the ground temperature in winter can be up to 15-20 degrees higher than the air temperature [3], this increases the capacity and the efficiency of a heat pump system. Depending on the geographic localization, heat pump systems with a ground heat exchanger can show an improvement in the efficiency of the system of 35% in heating mode compared to the conventional air source heat pumps systems. This value reaches up to 40-60% in cooling performance. As a consequence of this, the IMST team of UPV, have been developing this relatively new technology which contributes towards energy efficiency. The IMST works in association with other national and European institutions, and it is the main member in the European project GEOCOOL, whose main aim is to show the advantages of using Ground Heat Exchangers as an energy saving technology in Mediterranean Europe.

2. PRE-DESIGN PARAMETERS

Based on the energy demand of the GEOCOOL prototype facility at the UPV, the performance data of the heat pump and the local geology and geo-hydrology, have resulted in a pre-design consisting of six boreholes in a rectangular 3 x 2 configuration , to a depth of 50 meters. When we consider the application of the GEOCOOL concept for the whole region, it is obvious that the size and construction of the borehole heat exchanger may differ between regions, e.g. due to the need to use an anti-freeze solution or due to legislation requiring specific backfill materials. To be able to define proper sizing rules and to extend the theoretical work it has been decided to construct different borehole configurations for the GEOCOOL experiment. The following alternative borehole completions will be implemented:

backfill with coarse sand with spacers

backfill with fine sand without spacers,

backfill with fine sand with spacers,

backfill with 10% bentonite in water with spacers

backfill with 12% bentonite mixed with fine sand with spacers.

Other parameters used in the pre-design process are:

GROUND (test IN-SITU):

Ground thermal conductivity: 1.6 W/m K,

Volumetric heat capacity: 2.4MJ/m3·K

Ground surface temperature: 18.5 °C.

BOREHOLE:

Configuration: 6 : 3 x 2, rectangle,

Borehole depth: 50 m, Borehole spacing: 3 m,

Borehole diameter: 0.14 m,

U-pipe diameter: Polyethylene PE100, DN 1 ¼",PN 10.

HEAT CARRIER FLUID: Water,

HEAT PUMP: IZE70 (Ciatesa) [4],

CIRCULATION PUMP: CH 4-20 (Grundfos).

Additionally, a study of heating and cooling loads for the GEOCOOL building was done (Figure 1). It is important to realize that the load calculated for the month of August is zero corresponding to the vacation period of the university.

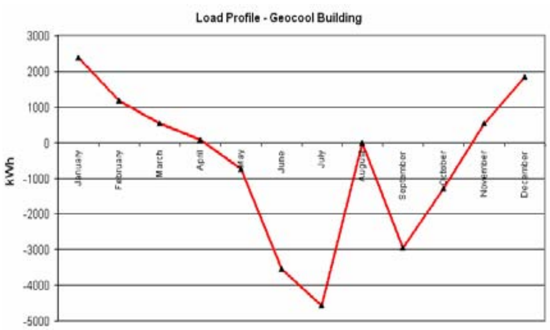

Figure1: Load Profile Geocool Building

It can be seen in Figure 1 that the values of the thermal loads are given in kWh, being positive for heating requirements and negative for cooling requirements. The software used for the evaluation of the heating and cooling load profile is CALENER [5].

3. RESULTS AND DISCUSSION

3.1 Water temperature profile in the GCHE

3.1.1 Evolution of the water temperature for different backfill materials

To investigate how the different backfill materials influence the evolution of the temperature of the water, calculations have been made of the temperature response of the system to a steady peak load. The results are presented in Figures 2 & 3).

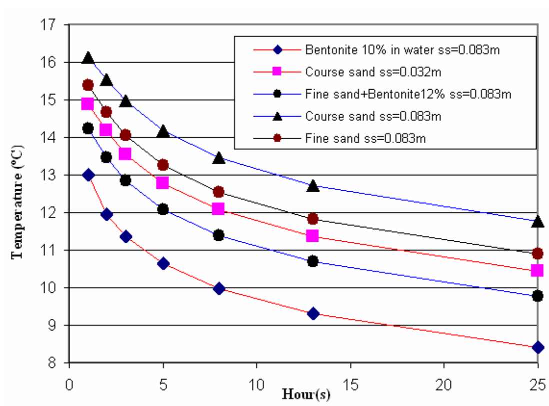

Figure 2: Modelling results for five different vertical borehole configurations in heating conditions.

Figures 2 and 3 shows the sensitivity of temperature evolution to the type of grouting used and its associated thermal conductivity in heating and cooling respectively.. A 10% bentonite in water grout gives a poor thermal conductivity compared to the coarse sand grout.

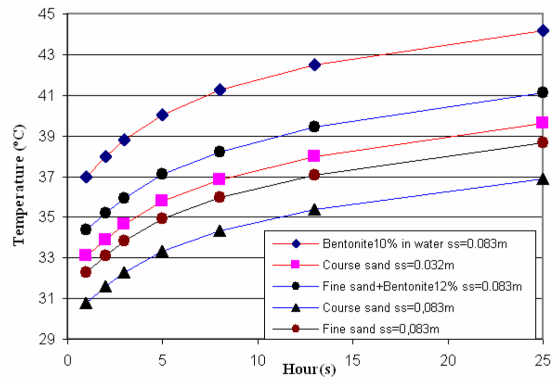

Figure3: Modelling results for five different vertical borehole configurations in cooling conditions.

As is evident from the graphs, the main effect is the temperature difference needed to overcome the thermal resistance of the borehole given a specific heat flux. The thermal conductivity varies from 0.7 W/m.K for the 10% bentonite in water filled borehole with 0.083m spacers to 2.4 W/m.K for the borehole filled with coarse sand. This gives a temperature difference of 3.49 ºC during heating of the building (12.8 kW net load) and of 6.95 ºC during the cooling load (17.6 kW net load). The differences are very pronounced for the system using coarse sand as backfill material and the system using 10% bentonite in water as backfill material. The use of spacers is especially useful in a borehole backfilled with bentonite, in which case the distance between the up- and down legs has a big influence. The boreholes with intermediate conductivities show only small effects of thermal resistance and spacers. These differences in temperature will probably be difficult to measure adequately as there will be other perturbations in the data which may, mask the effect of filling material and spacers. It will be very interesting to see if these theoretical calculations are reproduced by the experimental data.

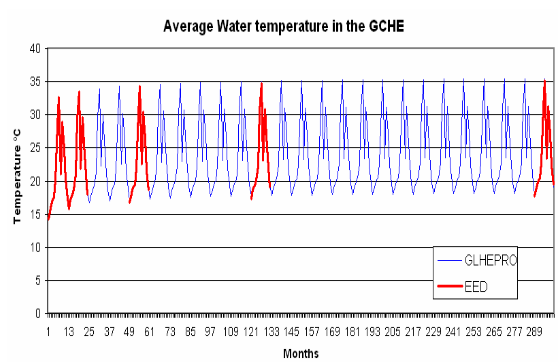

Figure 4: Average temperature profile of the water in the GCHE

Figure 4 shows the average temperature profile of the water inside the ground heat exchanger for a 25 years period. . The design parameters given above are used to do this analysis, using 10% bentonite in water as the backfill material. Results shown here were obtained using two different software packages, EED [6] and GLHEPRO [7]. It can be seen that the average temperature of the water over the years is increased by 2.6 ºC at the end of the 25 year period because the annual cooling load is higher than the annual heating load.

As an example, Figure 5 shows the peak temperature profile for the 5 different backfill materials considered for the 24 and 25th year, when the highest temperatures are reached.

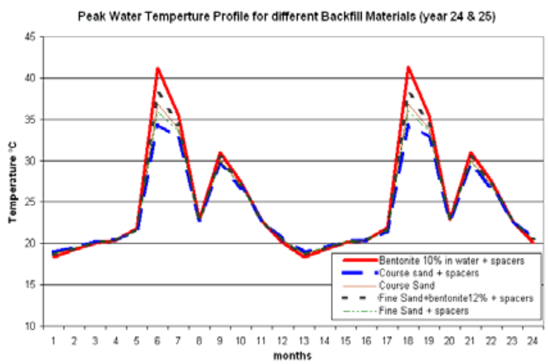

Figure 5: Peak temperature profile for the water in the GCHE for 5 kinds of backfill materials.

Figure 6 showsn that 10% bentonite in water is the backfill material which results in the highest temperatures, reaching 41.27ºC in the 25th year supposing an 8 hour peak load. The analysis shows that the best behaviour with respect to the highest temperature of the water is achieved with coarse sand with spacers (SS=0.083m) as a backfill material where the temperature reaches the maximum of 34.22ºC in the 25th year. This demonstrates the importance of the thermal conductivity of the backfill material in the installation design. The thermal conductivity of the 10% bentonite in water is 0.7 W/mK while this value rises to 2.1 W/mK for the sand.

It is also observed that intermediate values among those mentioned above are obtained with other backfill materials for the same design conditions. Another very important factor is the use of spacers; for example, the maximum temperature reaches 36.86ºC for coarse sand without spacers in the 25th year, which is 2.54ºC higher than the temperature obtained with the same backfill material but using spacers (Shank Spacing = 0.083m).

<u>3.1.2 Effect of different borehole configurations on the water temperature</u>

Once the effect of different backfill materials on the water temperature was known, the effect of different borehole configurations was studied. Five configurations were compared: 2 in line (5x1 and 6x1) and 3 in rectangle (2x2, 3x2, 4x2). The same design parameters were assumed for all of them using the worst backfill material (10% bentonite in water) and a total heat exchanger length of 600 meters.

Results shown in the next graph were obtained using EED and GLHEPRO software, with a difference between them of only 0.4ºC for the values of the water temperature.

As we can see in Figure 6, the behaviour of the minimum temperature of the water in the GCHE is similar among the rectangular configurations 2x2 and 3x2, reaching the value 9.43ºC in the 13th month out of the whole 25 years period of analysis. The maximum value of the minimum temperature is 10.21ºC in the 13th month for the 4x2 borehole configuration. The rest of the borehole configurations show a similar behaviour with the water temperatures staying within the range of values obtained with the borehole configurations 2x2 and 4x2 presenting a maximum difference of 0.78ºC.

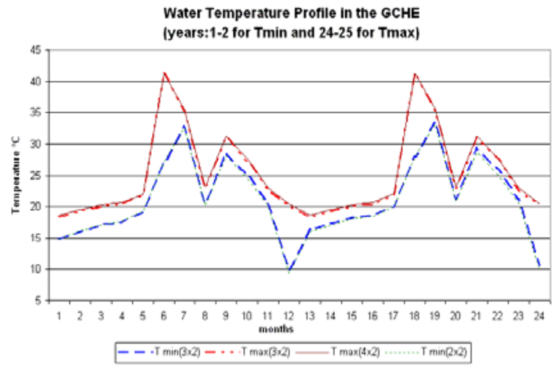

Figure 6: Maximum and minimum temperature profile of the water in the GCHE for some borehole configurations.

3.2 Estimation of seasonal system performances for the GCHE of the Geocool system

The Seasonal Performance Factor is the ratio between the thermal energy provided to/extracted from the building (heating/cooling thermal load) and the supplied electrical energy used for heating or cooling in a determined season. We distinguish between the HSPF – Heating Seasonal Performance Factor, as the performance factor of the system in winter, and the CSPF – Cooling Seasonal Performance Factor for the summer.

In the calculation of the SPF all energy inputs of the system must be taken into account, such as heat pump consumption, circulation pumps, blowers, etc. In this section the results obtained for the GEOCOOL project will be described, and HSPF and CSPF will be calculated for different borehole configurations and for different backfill materials. Moreover the study will compare the performance of the GCHE system with an equivalent air-to-water heat pump system, calculating HSPF and CSPF and showing the enhancements of the GCHE system compared to the air-to-water heat pump system.

A sensitivity analysis of the different options in the design of the GEOCOOL GCHE system has been done with the help of CALENDER, EED, GLHEPRO, ART, and other software tools. The parameters used for this analysis are those given in section 2. Also the heat pump and circulation pump properties are taken in account.

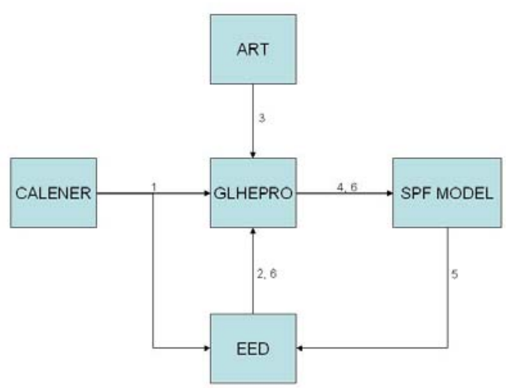

Figure 7: Interaction between the different software packages

Figure 7 shows the interaction between the different software packages that were used to model the global GEOCOOL system.

Figure 7 shows that the first step in the modelling process is to calculate the GEOCOOL building's load profile (1). To make this calculation the software package CALENER was used, entering the thermal load data of the building and the design parameters mentioned in section 1.2.1. EED calculates the effective thermal resistance of the borehole (2), and ART is used to model the heat pump (3). The electricity consumption is calculated using GLHEPRO (4), and finally the SPF model calculates the SPF both for heating and for cooling for a period of 25 years (5). This result is introduced into EED again as one of the design parameters, in order to recalculate the effective thermal resistance of the borehole; this iterative process leads to a higher precision in the final result. EED and GLHEPRO calculate the water temperature in the GCHE for a period of 25 years (6).

Heat Pump (IZE70)

As was mentioned before, the selected heat pump is CIATESA's IZE70, which is a reversible water-to-water heat pump equipped with a scroll compressor and using R-407c refrigerant. Thermal capacity and power curves are shown below.

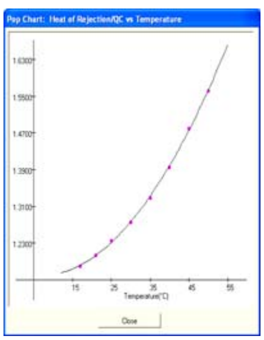

Figure 8: Cooling capacity of the HP/Cooling Load vs entering water temperature at the HP.

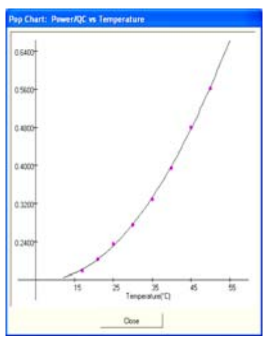

Figure 9: Electrical power consumed by the HP/Cooling Load vs entering temperature at the HP.

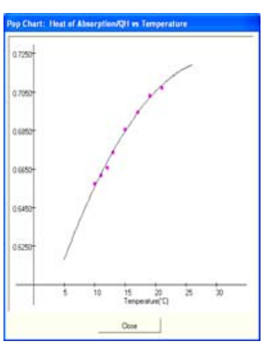

Figure 10: Heating capacity of the HP/Heating Load vs entering water temperature at the HP.

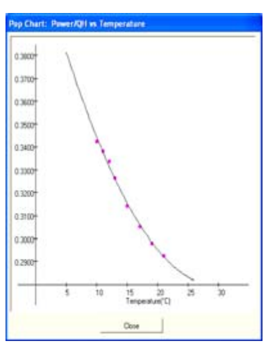

Figure 11: Electrical power consumed by the HP/Heating Load vs entering temperature at the HP.

Data used in the curves below (see figures 8, 9, 10 & 11) are taken from the manufacturer's catalogue. The team of researchers also made their own measurements of these properties and checked them with the catalogue information. Additional data were calculated with ART (Advanced Refrigeration Technologies, of IMST-group, IIE, UPV) software.

The characteristic curves for the HP are given for a water flow rate of 2.9 m^3/h and specific temperature conditions in the interior circuit in the building, therefore:

For summer (cooling):

Hot Temperature = load side entering water temperature at heat pump = 12 ºC

Cold Temperature = load side temperature of the water leaving the heat pump = 7 ºC

For winter (heating):

Hot Temperature = load side temperature of the water leaving the heat pump = 50 ºC

Cold Temperature = load side entering water temperature at heat pump = 45 ºC

The circulation pump

For the design of the GCHE system a Grundfos' CH 4-20 centrifugal circulating pump was selected based on a hydraulic study of the system. Its pump curve is shown below:

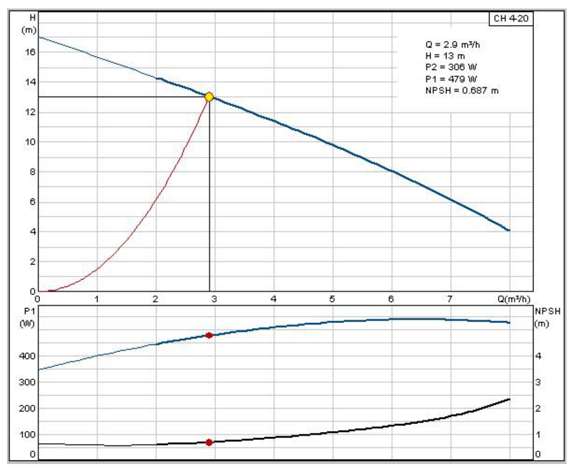

Figure 12: H-Q Curve for Grundfos CH 4-20 pump.

Figure 12 shows that the electrical power consumption of the pump for a 2.9 m^3/h water flow is 0.479 kW, which must be added to the electrical consumption of the heat pump in order to obtain the total consumption of the system.

SPF calculation for the GCHE system

Once the design parameters are defined and introduced in the corresponding software EED and GLHEPRO, the average, minimum and maximum temperature profiles of the water in the GCHE for a 25 years period are obtained, as well as the monthly average value of the heating/cooling energy (winter/summer) and the consumed energy of the system (heat pump + circulating pump) for the same period of time.

The Heating Seasonal Performance Factor, HSPF [kWh/kWh], is defined as:

$$HSPF = \frac{\sum_{i=1}^{n} \dot{Q}H_i}{\sum_{i=1}^{n} \dot{E}H_i} \qquad [1]$$

where:

$\dot{Q}H_i$ is the heating thermal load for the month i (in kWh)

n is the amount of heating months per year

$\dot{E}H_i$ is the electrical power consumed by the system in the month i (in kWh)

Similarly, the Cooling Seasonal Performance Factor, CSPF [kWh/kWh], is determined by:

$$CSPF = \frac{\sum_{i=1}^{n} \dot{Q}C_i}{\sum_{i=1}^{n} \dot{E}C_i} \qquad [2]$$

where:

$\dot{Q}C_i$ is the cooling thermal load for the month i (in kWh)

n is the amount of cooling months per year

$\dot{E}C_i$ is the electrical power consumed by the system in the month i (in kWh)

3.2.1 Modelled values for HSPF and CSPF for a system with a GCHE with different grouting materials

In this section we will comment on the HSPF and CSPF values found for the GEOCOOL concept; we will compare these parameters for 5 different grouting materials, in order to show which grout is more favourable. (Total borehole length = 300 m)

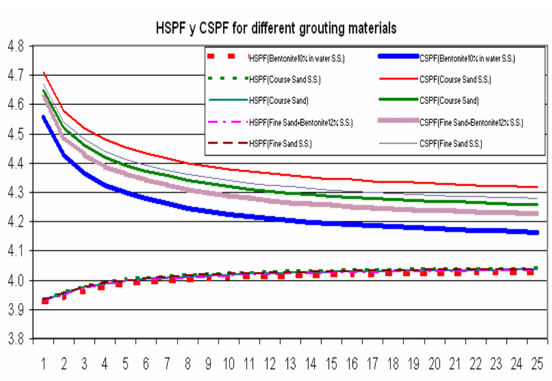

Figure 13: HSPF and CSPF for different grouting materials in a rectangular configuration (3x2)

Figure 13 shows that 10% bentonite in water gives the lowest HSPF, while coarse sand with spacers gives the best. The difference between both is 0.0154 after 25 years. Figure 13 also shows that 10% bentonite in water gives the lowest CSPF again, while coarse sand with spacers gives the best. The difference between both is more pronounced than in the case of the HSPF, being 0.1541 after 25 years.

The values of CSPF are higher than those of HSPF, this is a consequence of the fact that the heat pump in heating mode works in hot water conditions of 45/50ºC

3.2.2 HSPF and CSPF for different GCHE geometries

In this section we compare the HSPF and CSPF for 5 variants of the GEOCOOL concept with different borehole configurations

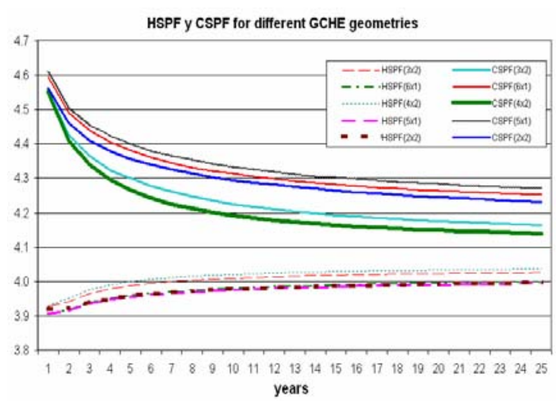

Figure 14: HSPF and CSPF for different borehole geometries

As shown in Figure 14 the highest HSPF is obtained with a 4x2 configuration, rising to 4.035 in year 25. The lowest HSPF is found for a 5x1 configuration, giving a difference of 1% compared to the former geometry. Configurations 6x1 and 2x2 behave very similarly to 4x2, while configuration 3x2 gives a better yield.

These values were calculated using the same total GCHE length (300m). Therefore the borehole depths may vary between different configurations. In practice the geometric configuration will depend on construction considerations, such as available space, drilling equipment, cost per meter of borehole length, etc.

In the same way the CSPF was calculated for different geometric arrangements of the boreholes. The best performance is found for configuration 5x1, being 4.27 after 25 years, followed by configuration 3x2 and finally configuration 4x2 with a CSPF of 4.14. So different geometric configurations will be ideal in summer than in winter. (Figure 6)

3.3 Seasonal Performance Factor (SPF) for the Air-to-Water Heat Pump

The Seasonal Performance Factor for the air to water heat pump is the ratio between the thermal energy supplied to or extracted from the building (heating or cooling load), and the electrical energy consumed, in a certain season. In this case the devices that use energy are the heat pump's compressor and the axial fan.

In this section we will describe the different elements in the air to water heat pump, the computing methodology and the results obtained for the GEOCOOL project.

3.3.1 The Air to Water Heat Pump

The selected heat pump is a reversible IWD 80s, manufactured by CIATESA, featuring a scroll compressor and using R-407c as refrigerant with a cooling capacity of 15.9 kW and heating capacity of 18 kW. The calculations below are based on data from the manufacturer's catalogue, which have been checked using ART software and found reliable.

The main nominal characteristics of this heat pump are:

Series IWD	80s
evaporator capacity (1) (kW)	15.9
electrical power demand (C)(3) (kW)	6.9
condenser capacity (2) (kW)	18
electrical power demand (H)(4) (kW)	6.6

(1) evaporator capacity for water leaving the heat pump at 7 ºC and an exterior air temperature of 35 ºC
(2) condenser capacity for water leaving the heat pump at 50 ºC and an exterior air temperature of 6 ºC
(3) compressor's and fan's joint electrical power demand in nominal cooling conditions
(4) compressor's and fan's joint electrical power demand in nominal heating conditions

3.3.2 Climate Data

A method to represent the temperature profile for a certain area in a certain period is the bin-hours method. It consists of adding up the number of hours that the outside temperature lies within a certain range, and repeating this calculation for all temperature ranges that may occur. In this way a temperature histogram is obtained. The information needed to make this histogram is a database of hourly temperature observations in the study area. In the case of Valencia, *the Instituto Nacional de Meteorología* (Spanish National Meteorological Institute) supplied the raw data for the years 2000, 2001 and 2002.

Documentation

The data furnished by the INM were compared with data gathered in the Climatic Atlas of Valencia (Atlas Climático de la Comunidad Valenciana). This book contains tables with absolute minimum temperatures, means of minima, means, absolute maximum temperatures and means of maximums for each month in the period 1961-1990. A period of 30 years is considered as a statistically representative period, therefore these values can be considered as the expected values for Valencia.

On the other hand data were available for the INM website (http://www.inm.es), where means of minima, means and means of maximums are shown for the period 1971-2000, for each month.

Histogram Analysis

40 Temperature intervals were defined, from 0ºC to 40ºC with steps of 1 ºC, in which the values observed in the city of Valencia were classified.

Figures 15 and 16 show the histograms for the months of January and July in the period 2000-2001-2002. The mean temperatures in these months have been calculated using the formula:

$$\overline{T} = \frac{1}{n}\sum_i m_i b_i \qquad [3]$$

where $\overline{T}$ the mean temperature

n the total number of hours (744)

m the mean of each interval

b the number of bin-hours corresponding to each interval

The data variance was calculated by means of the formula:

$$s = \frac{1}{n}\sum_i \left| m_i - \overline{T} \right| b_i \qquad [4]$$

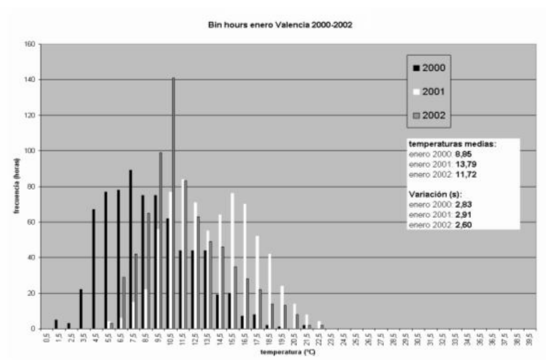

Figure 15: Histogram of temperatures in Valencia in January (2000-2001-2002)

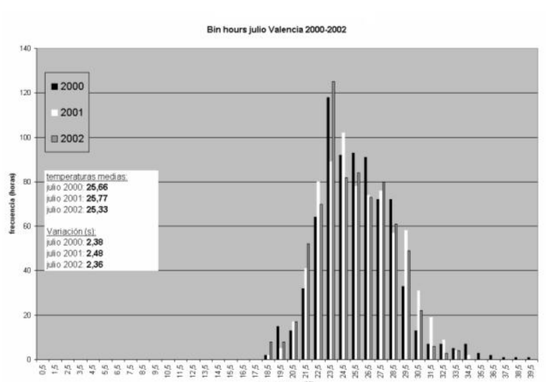

Figure 16: Histogram of temperatures in Valencia in July (2000-2001-2002)

As can be observed the histograms are not perfectly symmetrical: they have a “tail” to the right, i.e. towards the higher temperatures.

Comparison with data gathered in the Climatic Atlas of Valencia

The “*Atlas Climático de la Comunidad Valenciana*” unfortunately doesn’t give data variance. It does however give information about the mean values, but the mean is defined as follows:

> “The annual mean is normally calculated on basis of daily means, which are the average values of the daily maximums and minimums. Other methods to estimate the mean daily temperature exist as well, based on a continuous record of temperatures during the day or regular temperature measurements during the day.”

This way of calculating the mean daily temperature, and therefore the mean monthly temperature, does not correspond to the method explained in the previous chapter. Since the histograms are not symmetrical, the average of the minimum and maximum temperatures (*Tmed*) will be higher than the mean temperature based on 24 daily observations. Indeed, for the period 2000-2001-2002 we find important differences, especially in the months of January:

Table 1: Comparison with data from the Atlas Climático de Valencia

	T	$\overline{T_{min}}$	$\overline{T_{max}}$	T_{med}
January 2000	8.85	4.43	14.94	9.68
July 2000	25.66	21.06	30.61	25.83
January 2001	13.79	9.88	18.31	14.10
July 2001	25.77	21.23	30.50	25.86
January 2002	11.72	7.57	16.68	12.13
July 2002	25.33	20.94	29.51	25.22
Means January	11.45	7.29	16.64	11.97
Means July	25.58	21.08	30.20	25.64

The question is: Do *Tmed*, $\overline{T_{min}}$ and $\overline{T_{max}}$ for the period 2000-2002 correspond to the equivalent values for the period 1961-1990?

According to the atlas *Tmed* for January is 11.5ºC. The mean minimum and maximum temperatures are respectively 7 and 15.9ºC. The average value of the *Tmed* for 2000, 2001 and 2002 is the value that comes closer to 11.5ºC than any *Tmed* in these three years. Therefore the best way to model the temperatures in January in Valencia is taking the average values for these three years.

According to the atlas *Tmed* for July is 24.3ºC. The mean minimum and maximum temperatures are respectively 20.5 and 28.7 ºC. However the months of July during 2000, 2001 and 2002 were all warmer; the most similar year was 2002. Therefore the best way to model the temperatures in July in Valencia is taking the values of the year 2002.

Comparison with data provided by INM-website

We compare our hourly observations with the INM data for the period 1971-2000.

According to the data found on the INM website $\overline{T}$ for January is 11.5ºC. The mean minimum and mean maximum temperatures are respectively 7 and 16.1 ºC. The average value of the *Tmed* for 2000, 2001 and 2002 is the value that comes closer to 11,5ºC than any *Tmed* in these three years.

According to the data found on the INM website $\overline{T}$ for July is 24.9ºC. The mean minimum and mean maximum temperatures are respectively 20.8 y 29.1 ºC. However the months of July during 2000, 2001 and 2002 were all warmer; the most similar year was 2002.

<u>3.3.3 Calculated HSPF and CSPF for the IWD 80s heat pump in the GEOCOOL Concept</u>

After having analysed all climatic information, calculated the bin-hours for Valencia, modelled the IWD 80s heat pump with ART, calculated the heating and cooling load for the building of the GEOCOOL project and applying the methodology proposed in the Standard ANSI/ASHRAE 116-1995[8] and ARI Standard 210/240-2003[9], the following results were obtained:

Table 2: SPF values for CIATESA´s IWD 80s heat pump

Year	*HSPF*	*CSPF*
2000	2.96	2.81
2001	2.96	2.81
2002	2.96	2.83
Average	2.96	2.82

The HSPF values are very similar for the three years, having an average value of 2.97. The CSPF the 2002 has a slightly higher value than the other two years. According to the climatic study of Valencia, 2002 was the most representative year if you compare it with the last 25 years [10], while the most representative value for HSPF is the average of all three years.

3.4 Comparison between GCHE-system and Air-to-Water Heat Pump

This study compares two equivalent systems: the GCHE-system and an Air-to-Water Heat Pump with similar capacities in heating (18 kW) and cooling (16 kW). The heat pumps where selected because they use similar technology, both have a vapour compression cycle using R-407c as a refrigerant, a Scroll compressor and plate heat exchangers at the application side. The main difference between the two heat pumps is the normal working temperature of the outside circuit. In summer, the water in the external circuit will have a lower temperature than the air that cools the air-to-water heat pump, while in winter it is warmer than the air used to carry heat to the air-to water heat pump. Therefore the COP of the water-to-water heat pump will be higher in both modes of operation

With the SPF calculated for the GCHE system (see 3.2) and for the Air-to-water Heat Pump (see 3.3), the results can be compared to quantify the efficiency gain obtained compared to a conventional air-to-water system.

3.4.1 Efficiency improvement obtained for various grouting materials

In order to quantify the improvement of the GCHE versus a conventional air-to-water heat pump, heating and cooling SPF values of several years were calculated. The results are shown below:

Figure 7 shows the percentage efficiency gain in heating mode of a GCHE system vs. an Air-to-Water Heat Pump, for various grouting materials. The grout that gives the highest improvement is coarse sand, followed by fine sand mixed with 12% bentonite; while 10% bentonite10% in water gives the least improvement. The average improvement over time of the GEOCOOL concept using coarse sand with spacers as grouting material is 35.4%.

Also Figure 19 shows the percentage efficiency gain in cooling mode of a GCHE system vs. an Air-to-Water Heat Pump, for various grouting materials. The grout that gives the highest improvement is coarse sand, followed by fine sand mixed with 12% bentonite; while 10% bentonite in water gives the least improvement. The average improvement over time of the GEOCOOL concept using coarse sand with spacers as grouting material is 52.6%.

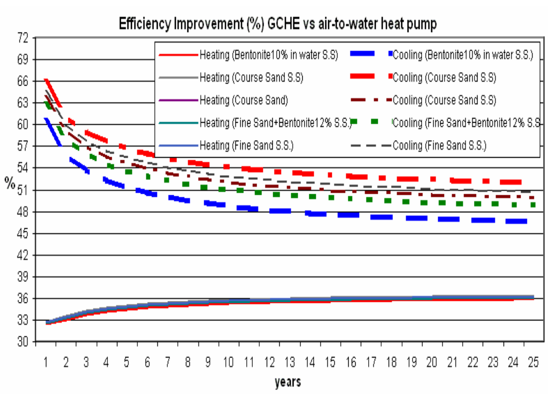

Figure 17: Heating and Cooling Efficiency Improvement GCHE vs. air-to-water Heat Pump for various Grouting Materials

3.4.2 Efficiency improvement obtained for various borehole configurations

Figure 20 shows the percentage efficiency gain in heating mode of a GCHE system vs. an Air-to-Water Heat Pump, for various borehole configurations. The geometric configuration that gives the highest improvement is 4x2 boreholes with 36.15%, while the 5x1 in-line configuration gives the least improvement (34.7%).

Also Figure 8 shows the percentage efficiency gain in cooling mode of a GCHE system vs. an Air-to-Water Heat Pump, for various borehole configurations. The geometrical configuration that gives the highest improvement is 5x1 boreholes with 50.4%, followed by 6x1 with 49.8%, while the 4x2 configuration gives the least improvement (45.8%).

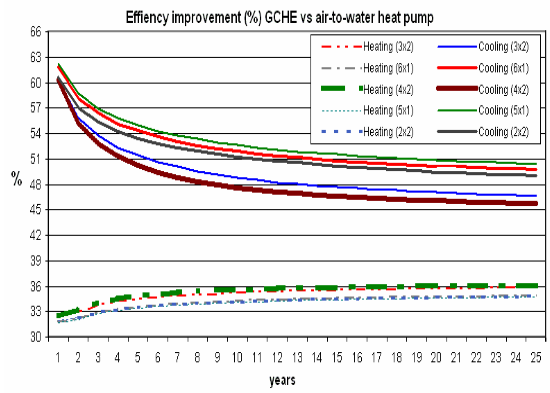

Figure 20: Heating and Cooling Efficiency Improvement GCHE vs. air-to-water Heat Pump for various borehole configurations

A possible explanation for the opposite results in heating and in cooling mode is that due to the imbalance between annual heating load and annual cooling load (the former being smaller than the latter), more and more heat is stored in the ground over time. This leads to an increasing improvement of the heating efficiency, but a loss of cooling efficiency over time. When a relatively "compact" geometrical borehole configuration is chosen, such as a 4x2 rectangle, this storage effect is enhanced; therefore this configuration gives a higher improvement in heating and a lower improvement in cooling. A linear configuration however, such as a 5x1, will favour heat dissipation and therefore leads to a higher yield in cooling, but lower in heating.

Note that in heating mode, the difference between efficiency gain in the best (4x2) and in the worst configuration (5x1) is 1.4%, while in cooling the difference is 4.6%.

As was mentioned before, the modelling helps to choose the best grouting material and geometrical configuration as far as the system efficiency is concerned. However, construction limitations, costs, etc are not taken into account here.

4. CONCLUSIONS

The advantages of the use of ground coupled heat pumps compared to conventional air source heat pumps were shown to be an energy saving technology in the European Mediterranean area.

In particular the theoretical improvement in the seasonal coefficient of performance for the heating season has been shown to be about 32-36%, and the improvement in the seasonal coefficient of performance for the cooling season to be 50-60% over a 25 year period of operation.

Other advantages of GCHE system compared to air source in a costal region are primarily that the ground source heat pumps will not be affected by salt corrosion, the lower noise level, the lower maintenance cost because the heat pump is placed indoors, the lower visual impact and the reduction in peak electrical requirements.

REFERENCES

[1] Geocool "Geothermal Heat Pump for Cooling-and Heating along South European Coastal Areas", NNE5-2001-

00847, Financed by European Commission. – FP6 Sixth Framework Programme (2002-2005).

[2] J.M. Corberán, J. Gonzálvez, P. Montes, R. Blasco. “ART: A computer code to assist the design of refrigeration and A/C equipment”, 8th International Refrigeration Conference at Purdue University, West Lafayette, IN, USA., (2000) p. 217-224.

[3] Closed-Loop/Ground-Source Heat Pump Systems, Installation Guide, International Ground Source Heat Pump Association, Oklahoma State University, 1988.

[4] CIATESA Noticia Técnica Nº 7100 A, Diciembre 2001. Equipos agua-agua con compresor Scroll, serie IZE. Catálogo de fabricante.

[5] CALENER. Manual de Usuario Versión 2.0. Grupo de Termotecnia, Escuela Superior de Ingenieros, Universidad de Sevilla. (2001).

[6] EED - Earth Energy Designer, User manual, Version 2.0. Dept. of Mathematical Physics, Lund University, October 30, 2000

[7] Spitler, J.D. GLHEPRO - A Design Tool for Commercial Building Ground Loop Heat Exchangers. - Proceedings of the Fourth International Heat Pumps in Cold Climates Conference, Aylmer, Québec. August 17-18, 2000.

[8] ANSI/ASHRAE 116-1995, Methods of Testing for Rating Seasonal Efficiency of Unitary Air Conditioners and Heat Pumps. American Society of Heating, Refrigerating, and Air-Conditioning Engineers, Inc. Atlanta, GA, 1995 p23-35.

[9] ARI Standard 210/240-2003, Unitary Air-Conditioning and Air-Source Heat Pump Equipment. Air-Conditioning & refrigeration Institute. Arlington, Virginia, sect. 5.1, p20-27.

[10] INM–Instituto Nacional de Meteorología, Datos climáticos. 1961-1990. *htpp://www.inm.es*