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Analysis of the energy performance of a Ground Source Heat Pump system after five years of operation

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ABSTRACT

GeoCool plant was the result of a EU project whose main purpose was to adapt ground coupled heat pump technology to cooling dominated areas. The execution of this experimental plant was completed at the end of year 2004, starting on February 2005 the regular operation of the air conditioning system. Since then, GeoCool facility has been monitored by a network of sensors characterizing its most relevant parameters. Several aspects of the performance and behaviour of the system during its first operation year were presented on a previous paper. This paper presents the energy performance measurements of GeoCool ground coupled heat pump system acquired during five years of operation as well as the evolution of the return water temperature from the ground as a representative of the ground temperature. The analysis of the experimental results shows that the system energy performance is maintained through the years with no appreciable impact on ground thermal response.

Keywords: Heating and cooling systems, ground coupled heat pump, energy efficiency.

1. INTRODUCTION

The Spanish heating, cooling and ventilation (HVAC) market is dominated by the traditional use of reversible air-source heat pump equipment. There is, since, very little documented experience with regard of the use of heat pumps coupled to other sources, such as the ground. In 2001, a group of researchers at the Universidad Politécnica de Valencia (UPV) started a new research line on the development and adaptation of ground coupled heat pump systems, well known in northern European heating dominated areas, to situations in which cooling is a major need. Their research activity included the construction, operation and analysis of several demonstration facilities, such as the European FP6 project based GEOCOOL system, the adaptation of design and analysis software to the special characteristics of mixed climate conditions and an intense interest in questions related with Thermal Response Tests (TRT), including the development of new analytical models that aim to substantially improve the existing state of the art in that field.

GeoCool plant is a ground coupled heat pump air conditioning system designed and constructed in the context of a European Union Project (*Geothermal Heat Pump for Cooling and Heating along European Areas*, contract NNE5-2001-00847) whose main objective was 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. The construction of this experimental system was completed at the end of 2004, starting on february 2005 its regular operation [1].

Ground coupled heat pumps are recognised as a good alternative system for heating and cooling buildings [2-8]. Some international agencies, such as the U.S. Environmental Protection Agency consider these systems as being among the most efficient and comfortable heating and cooling systems available today [9]. By comparison with standard air source heat pump equipement, these ground source systems offer competitive levels of comfort, reduced noise levels, lower greenhouse gas emissions and reasonable environmental safety. Their electrical consumption and maintenance requirements are lower than those required by these conventional air source systems and, therefore, have lower annual operating cost [10-12]. Since 2001, the adaptation and behaviour of this promising technolgy to cooling dominated areas has been studied by our research group.

GeoCool experiment was designed to allow a fair comparison between a ground coupled heat pump system and an air source heat pump system [1,13]. The results of this experiment after comparing the efficiency of both systems during its first operation year were that the ground coupled system saves, in terms of primary energy consumption, a 43.17% of the energy consumed by the air source one in heating operation, and a 37.18% in cooling operation. After this succesful results several aspects concerning the design, characterization and optimization of ground coupled heat pump systems have been developed.

A crucial point for an accurate design of a ground coupled heat pump air conditioning system is a proper knowledge of ground thermal properties. In situ thermal response tests are carried out to have a measurement at site of ground properties. This technique can be improved by refining the model describing the borehole heat exchanger to include effects not taken into account. In [14], finite length effects were incorporated in the analysis procedure of test in situ outputs. In [15], a filtering technique of the undesired effect produced in temperature measurements by the ambient temperature was designed to improve the estimating of ground thermal properties. Another approach to improve the in situ estimation of ground thermal properties is the development of new devices able to measure relevant quantities characterizing heat transfer between the fluid and the ground. This characterization could be done if the evolution of the fluid temperature along the heat exchanger is known. In [16] a sensor probe including a temperature sensor, an acquisition system, temporary storage and wireless communication has been developed to obtain these measurements.

Optimizing the energy performance of a ground coupled air conditioning system can be faced by managing its operation. Note that, in the standard design of an air conditioning system, the references taken to estimate the heating and cooling capacity of the heat pump to be installed are usually based on the coldest and the warmest day along the year. Therefore, the thermal energy required by the thermal load is under the design point of the air conditioning system during most part of the time. In this context, the development of strategies for the operation of the air conditioning system based on the ground coupled heat pumps, allowing to adapt the thermal energy generated by the system with the thermal load is a good way to improve the system energy efficiency while satisfying the thermal comfort. In [17], a new management strategy is designed to diminish the consumption of the system while keeping the comfort requirements. In [18], an approach based on combining the ground source system with other production system, and decoupling energy production from energy distribution using a thermal storage device was studied. In both cases substantial energy savings, of the order of the 30%, were achieved.

Following the same idea of energy performance optimization, in [19] the development of a mathematical model capable of describing the quasisteady state performance of GeoCool ground coupled heat pump system was presented. This model was validated against the experimental data adquired from the sensor network that monitors GeoCool plant. Then, the validated model was used to examine system capacity and performance sensitivity to different control optimisation strategies, including set-point control of room air temperature, room air bandwidth temperature, building loop return water temperature and building loop return bandwidth temperature.

Maintaining the energy performance of the ground coupled heat pump air conditioning system through the years is a relevant question for the success of this technology. Decreasing energy performances will produce an increase in the time needed to recover the higher initial capital investment demanded by this kind of systems. An accurate design of the system, that guarantees a high energy performance maintained through the years and with no appreciable impact in ground thermal response will be desirable. This paper is focused on discussing long term energy performance of GeoCool experimental plant. For this purpose, energy performance measurements are presented for the data available from its starting operation date in February 2005 until April 2010. Performances of the system for these years are compared with the purpose of determining if the system suffers of performance degradation. In addition, an estimation of the impact of GeoCool plant in ground thermal response is provided. This estimation is performed by analysing the data available for the temperature of the water entering to and returning from GeoCool ground heat exchanger. These data are analysed to infer if GeoCool system is producing a net heating or cooling effect in the ground surrounding the heat exchanger.

This paper is organised as follows. Section 2, *geothermal experimental plant*, describes GeoCool experimental plant. Section 3, *methodology*, presents the methodology used to calculate energy performances. Section 4, *analysis and results*, presents and analyses the experimental measurements for energy performances and temperatures of the heat carrier fluid. And finally, section 5, *conclusions*, summarizes the results obtained in this research work.

Nomenclature	
COP	Coefficient of performance
Cp	Specific heat at constant pressure
cp	Circulation pump
DPF	Daily performance factor
$\dot{h}$	Enthalpy flow
$\dot{m}$	Mass flow
PF	Performance factor
Q	Thermal loads
$\dot{Q}$	Instantaneous thermal loads
SPF	Seasonal performance factor
T	Temperature
W	Energy consumption
$\dot{W}$	Power consumption
Subscripts	
EC	External circuit (ground loop)
IC	Internal circuit (building)
in	Input
out	Output
max	Maximum
ww	Water to water heat pump
1	Considering heat pump consumption
2	Considering heat pump and external pump consumption

2. GEOTHERMAL EXPERIMENTAL PLANT

GeoCool plant air-conditions a set of spaces in the Department of Applied Thermodynamics at the Polytechnic University of Valencia, Spain, with a total surface of approximately 250 m^2. This area includes nine offices, a computer classroom, an auxiliary room and a corridor. All rooms, except the corridor, are equipped with fan coils supplied by the experimental system: an air to water heat pump and a ground coupled heat pump working alternately (Figure 1). The geothermal system consists of a reversible water to water heat pump (15.9 kW of nominal cooling capacity and 19.3 kW of nominal heating capacity), a vertical borehole heat exchanger and a hydraulic group. The water to water heat pump is a commercial unit (IZE-70 model manufactured by CIATESA) optimized using propane as refrigerant. The vertical heat exchanger is made up of 6 boreholes of 50 m. depth in a rectangular configuration, with two boreholes in the short side of the rectangle and three in the large side, being 3 m. the shorter inter-borehole distance. All boreholes are filled with sand and finished with a bentonite layer at the top to avoid intrusion of pollutants in the aquifers.

A network of sensors was set up to allow monitoring the most relevant parameters of these systems (Figure 1). These sensors measure temperature, mass flow and power consumption. The temperature sensors are four wire PT100 with accuracy ±0.1 ºC. The mass flow meters are Danfoss Coriolli meters, model massflo MASS 6000 with signal converter Compact IP 67 and accuracy <0.1%. The power meters are multifunctional power meters from Gossen Metrawatt, model A2000 with accuracy ±0.5% of the nominal value. Data from this sensor network is collected by a data acquisition unit Agilent HP34970A with plug-in modules HP34901A.

3. METHODOLOGY

In order to better understand the performance of the installation, a typical day in July will be analysed. Figure 2 shows the evolution of the inlet and outlet temperatures in the indoor and outdoor circuits. As can be seen, the water temperature sent to the outer loop, TinEC (ground source heat exchanger) reaches a maximum value of 32 ° C. The ground return temperature to the condenser, ToutEC, takes values around 27 º C. This is typical in cooling season during the summer when the soil has warmed up during the month of May and June, and the daily thermal load is very high especially at noon. As can be observed, the heat pump is supplying the chilled water to the system at a temperature, TinIC, around 7 ° C. The heat pump switches off when the return temperature ToutIC takes values around 9 º C, and starts up when the return temperature is around 12 º C.

It should be pointed out that the operation of the heat pump is governed by a conventional thermostat which, depending on the building water return temperature, switches on/off the heat pump compressor. The default values for the building circuit return temperatures are between 37ºC and 43ºC for heating mode and 9ºC and 12ºC for cooling mode. The ground circulation pump is controlled by the heat pump controller, which activates the external pump 60 seconds before compressor activation. When the compressor switches off, the external pump continues to operate for a further period of one minute. A timer controls the overall system operation, which is programmed to operate between 06:00 and 21:00 hrs in winter and between 07:00 and 22:00 hrs in summer, 5 days per week. The internal circulation pump is continuously working during the 15 hours of the system operation.

The system energy efficiency is calculated from the power consumption readings and the values of the internal thermal loads calculated from experimental measurements. These thermal loads are calculated with the values of T_{in}, T_{out} and $\dot{m}$ showed in Figure 1 (measured with four wire PT100 temperature sensors and a Coriolis meter). Instantaneous thermal loads are obtained by means of the following expression:

$$\dot{Q}(t) = \dot{h}_{out}(t) - \dot{h}_{in}(t) , \qquad (1)$$

where,

$$\dot{h}_{in}(t) = \dot{m}CpT_{in}(t) \quad ; \quad \dot{h}_{out}(t) = \dot{m}CpT_{out}(t) \qquad (2)$$

are the input and output enthalpy flows at the circuit connecting the fan coils and the heat pump. Because of all the measures are taken in one minute intervals, the internal thermal load is defined as the integral of expression (1). It represents the cooling or heating load demanded by the building during the time period Δt starting at T_0 time.

$$Q = \int_{T_0}^{T_0+\Delta t} \dot{Q}(t)dt \qquad (3)$$

Likewise, the system energy consumption is calculated by numerically integrating the power consumption, $\dot{W}$, measured by the power meter located on the right of Figure 1, corresponding to the consumption of the water to water heat pump, $\dot{W}_{ww}$, plus the consumption of the circulation pump, $\dot{W}_{cp}$.

$$W = \int_{T_0}^{T_0+\Delta t} \dot{W}(t)dt \qquad ; \qquad \dot{W}(t) = \dot{W}_{ww}(t) + \dot{W}_{cp}(t) \tag{4}$$

The system energy efficiency is characterized by the energy performance factor, defined as the ratio between the thermal load and the electric energy consumption during a time interval:

$$PF = \frac{Q}{W} \tag{5}$$

Depending on the duration of the integration period, the energy performance factor can be seasonal, monthly, daily, etc. The most representative one is the seasonal performance factor (SPF) that estimates the system performance on each working mode (heating or cooling).

The data acquisition system is programmed, such that the power consumption of each individual component, i.e., the consumption of the internal circulation pump, the external circulation pump, the fan coils and the heat pump compressor unit, can be calculated from the data collected by the two power consumption meters shown on Fig. 1.Two different performance factors will be defined as: heat pump daily performance factor (DPF_1) and outdoor loop daily performance factor (DPF_2). These factors will be calculated using expressions (6) and (7) for a typical day in cooling and heating mode.

$$DPF_1 = \frac{\int_0^{t=24hr} \dot{Q}(t) \cdot dt}{\int_0^{t=24hr} \dot{W}_{ww}(t) \cdot dt} \tag{6}$$

$$DPF_2 = \frac{\int_0^{t=24hr} \dot{Q}(t) \cdot switch_{cp} \cdot dt}{\int_0^{t=24hr} \left(\dot{W}_{ww}(t) + \dot{W}_{cp}(t) \right) \cdot switch_{cp} dt} \tag{7}$$

where, $switch_{cp}$ is the control signal of the external circulation pump and takes a value of 0 when it is switched off and a value of 1 when it is turned on.

The main difference between DPF_1 and DPF_2 is that the first one just takes into account the energy consumption of the compressor, whereas the second considers both the consumption of the compressor and the external circulation pump. In order to properly analyze the daily performance factor of the outdoor loop (DPF_2), the thermal load and the power consumption will be only integrated when the external circulation pump is working. This is calculated as shown on expression (7), by multiplying the values of the thermal load and the power consumption by the external circulation pump control signal.

4. ANALYSIS AND RESULTS

The system has been in operation and fully monitored along several years up to now and experimental measurements have been collected since 2005.

In order to evaluate the system performance evolution along the years, registered data was collected and analysed from January of 2005 to April of 2010.

Two different studies were carried out. First, an analysis of the impact of the ground source heat pump system in the ground thermal response. Second, an evaluation of the system energy performance along five years of operation was done from two different points of view: on one hand, the mean monthly values for the heat pump daily performance factor (DPF_1) and outdoor loop daily performance factor (DPF_2) for every month along the 5 years of operation were calculated. On the other hand, integrated and instantaneous values for the DPF_1 were analyzed for one typical day at cooling and heating mode.

4.1 Five years water temperature measurements in the external circuit

In order to evaluate the impact of the system in the ground thermal response during its operation, it is necessary to identify a parameter that properly characterizes the behaviour of the ground and its response to the injected and extracted heat. Measurements of the ground temperature were undertaken at Geocool plant and the registered values were very close to the water temperature coming from the ground loop. So, for the purpose of this paper, it is considered that the parameter that better represents the impact of the system in the ground thermal response is the outlet water temperature from the borehole heat exchanger (BHE), in such a way that an increase in the ground temperature due to an imbalance of thermal loads, would make the outlet water temperature from the BHE be higher, leading to a performance degradation of the unit.

Values of the outlet water temperature in the borehole heat exchanger (BHE) were calculated from measurements for each day of the year, as the average water temperature when the external circulation pump is working. Figure 3 shows the mean monthly values for the outlet water temperature from the BHE calculated as the average of the mean daily values for each month. Therefore, the values presented on Figure 3 stand for a typical day of each month. The same process was undertaken in order to calculate the mean monthly values of DPF_1 and DPF_2 in Figures 8 and 9.

It can be noticed in Figure 3 that there are some months where no data was available due to maintenance operations, some problems with the data acquisition system and some periods where the installation was stopped in order to carry out other research activities such as the tune up of a thermal response test mobile facility. As it can be observed in Figure 3, the first month of the year 2005, no data was registered because the system wasn't monitored yet. During the next months of 2005, several comparison studies were carried out in which the air to water heat pump was working instead of the ground source heat pump and it was concluded that there was a 40% energy savings compared to the conventional air to water heat pump system [13]; during the year 2006 some tests in situ took place and very little data was available; finally, in the summer of 2007 maintenance operations and the tune up of a test in situ mobile facility were undertaken in the installation and no data was collected. During the year 2009 and 2010 optimization strategies were carried out where temperature settings were changed for cooling and heating mode.

The water return temperature from the BHE, ToutEC, is a good representative of the ground temperature, and this is why the mean daily values tend to be the same as the ground mean daily temperature. Taking a look at year 2008, it can be noticed that the water temperature starts at 17.44ºC approximately in January and decreases a little until March which means that the ground has been cooled down during heating operation. Then, due to a lower amount of extraction heat, it increases from March until May. This is typical in Mediterranean climates like in Valencia, where the heating energy demand is very low at spring time, leading to a smaller amount of heat extracted from the ground and allowing the ground to recover. In May the heat pump is switched to cooling mode. Water return temperature increases along the cooling season until September because the ground is being heated up during cooling mode operation. It must be pointed out that at university, summer holidays take place mainly in August and this is why, during this month, the ground recovers due to a lower energy demand. In October it decreases a little due to a lower cooling load in the building. Finally, the heat pump is switched to heating mode again in November and water return temperature starts decreasing. All in all, it can be observed from Figure 3 that the return water temperature from the BHE starts taking values of 17 ºC at February 2005 and after 5 years of operation, February 2010, the value is the same. Looking at the maximum water temperatures coming from the ground in July, it can be noticed that the variation is very low from year to year. So, it is concluded that the balance between the amount of extracted heat during winter, the injected heat during summer and the periods where the ground recovers due to a lower energy demand in spring time, August holidays and in autumn, let the ground reach a balanced state which can be observed in the last three years of operation. It can be observed that the mean water return temperature remains constant along the five years of operation at 20ºC approximately. This means that in this unbalanced case (cooling dominated) the BHE is well designed in such a way that the ground thermal response is not affected.

A study was done using GLHEPRO [20] software to compare measured values with numerical predictions. GLHEPRO is a software tool developed as an aid in the design of vertical borehole-type ground loop heat exchangers used in geothermal heat pump systems and has been validated experimentally and against more detailed models as presented in [21].Using GLHEPRO, the mean monthly values for the water return temperature from the ground were calculated for 25 years of operation. In order to do so, the design characteristics of the ground heat exchanger, ground thermal properties and the monthly energy load extracted/injected to the ground calculated from experimental measurements were introduced into GLHEPRO. Values for ground thermal properties (conductivity of 1.6 W/mK and volumetric heat capacity of 2.25 MJ/m^{3}K) were estimated with a Thermal Response Test performed at GeoCool heat exchanger. These values are compatible with laboratory analysis performed on soil samples although in both cases a high uncertainty (around 20%) in the estimation of the ground thermal conductivity was observed. Simulation results from GLHEPRO software showed that during the first five years of operation, the water temperature coming from the ground would increase around 0.7K, reaching a 1.12K increase after 25 years of operation, which was considered admissible during the design phase, but as it has been observed in practice, the ground has a stronger recovery capability than expected which allows the water temperature coming from the ground present a periodic evolution along the years. Figure 4 presents the energy loads injected/extracted from the ground and Figure 5 shows the predicted results obtained in GLHEPRO.

As already mentioned, simulation results differ a little from reality. Two influences arise from the observation of experimental measurements: the underground water effect and the ground recovery due to holiday periods. On the first place, it must be pointed out that the underground water level in Valencia is around 3.5m depth, which means that the ground is practically saturated of water and there is a strong possibility of having induced convection heat transfer currents. The high uncertainty observed when determining ground thermal conductivity can also be understood from this underground water effect. On the other hand, during the weekends, the installation is stopped letting the ground recover from Friday until Monday every week.

4.2 Five years energy performance results

In order to evaluate the energy performance of the system, two different performance factors were defined as: heat pump daily performance factor (DPF_1) and outdoor loop daily performance factor (DPF_2). These factors were calculated using expressions (6) and (7) for a typical day in cooling and heating mode. Figures 6 and 7 show the calculation results for a typical day in heating and cooling mode respectively, where it can be observed the instantaneous DPF_1 calculated for every minute, and the integrated DPF_1 calculated along the day. The mean daily values for the water temperature sent to the building when the compressor is working are 45ºC for heating mode and 10ºC for cooling mode, being the outlet water temperature coming from the ground around 17.4ºC for heating mode and 26ºC for cooling mode; this means that the temperature lift that has to overcome the compressor in winter is almost double than in summer. Therefore, the daily heat pump performance factor for heating mode is lower (3.8) than for cooling mode (4.8), as can be observed in Figure 6 where DPF_1 takes around 25% greater values at summer.

Instantaneous DPF_1 has been calculated for each cycle of the compressor using expression (5) from measurements registered every minute. Looking at Figures 6 and 7 it can be noticed that the first cycle in the morning gets very high values of DPF_1 due to a lower temperature lift that has to overcome the compressor because water temperature in the internal hydraulic loop has been cooling down during the night reaching a stationary value around 19ºC, and the same for the water temperature coming from the ground which gets a stationary value around 18ºC. However, the rest of the cycles present approximately the same DPF_1 values around 4.8 for cooling and 3.8 for heating, which make the integrated DPF_1 remain more or less constant until the end of the day.

Figures 8 and 9 show the typical daily performance factors of the heat pump DPF_1 and the outer loop DPF_2 for each month, which have been calculated as the mean values of the daily integrated performance factors for each month. In can be checked that the performance results previously shown on Figures 6 and 7, corresponding to year 2008, are consistent with the typical daily performance factors presented in Figures 8 and 9.

It can be observed from Figure 8, that, as the building supply water temperature is approximately constant for cooling and heating operation, DPF_1 will be mainly a function of the return water temperature from the BHE, taking maximum values around 5 in summer and minimum values around 4 in winter, it is to say, DPF_1 is a 20% lower approximately during the winter season. It should also be noticed that DPF_1 has a 0.85% variation during the cooling season, getting higher values at the beginning of the season at May because the ground has been cooled down during the winter and the return water temperature is cooler than in July when the ground has been heated up. As stated before, during August, because of the lower energy demand due to summer vacations, the ground recovers and the value of DPF_1 increases a little until October which is the end of the cooling season. The analysis for winter season is analogue, presenting greater DPF_1 values at the beginning of the season in November when the ground has been heated up during the cooling season and, as the ground cools down over the heating period, the DPF_1 gets lower values presenting a total 0.9% variation over the duration of the season.

It can be noticed in Figure 8 that for the year 2008, DPF_1 takes lower values during the cooling season. After monitoring it, it was concluded that it was lower than expected and a refrigerant leakage was detected in the heat pump. It was fixed and from that moment, the heat pump performance improved and the DPF_1 values were as expected.

It can also be noticed in Figure 8 that from May of 2009 to April of 2010, DPF_1 takes greater values for both cooling and heating mode. This is because, the heat pump control settings were changed and the mean supply water temperature to the building increased from 10ºC to 11ºC approximately for cooling mode; the same happened for heating mode, hot water was sent to the building at 43ºC instead of 45ºC, leading to a DPF_1 improvement of 4% for cooling mode and a 3.7% for heating mode per each degree variation in the water temperature setting . The influence of the water temperature setting was deeply analyzed in [19] where a mathematical model capable of describing the quasisteady state performance of GeoCool ground coupled heat pump system was presented and validated against the experimental data adquired from the sensor network that monitors GeoCool plant. The experimental results are consistent with the conclusions drawn in [19].

It can be observed by comparing the DPF_1 values presented in Figure 8 to the DPF_2 values shown on Figure 9, that the DPF_2 decreases a 10% on average for both cooling and heating mode except for the beginning of year 2005 where the DPF_2 is much lower compared to the rest of the years, with a maximum decrease of 30% in May. This is because this was the first year of operation of the Geocool plant, and the external circulation pump wasn't cycling with the compressor leading to much greater energy consumption along the day and causing even lower DPF_2 values. This was fixed during the summer making the circulation pump switch ON/OFF at every compressor cycle by means of a thermostat, which improved the DPF_2 values from September until November of 2005 as shown in Figure 9. An important conclusion that can be drawn from this experience is that there is a strong influence of the external circulation pump consumption that should be minimized. It was found that the external circulation pump consumption stands for a 10% of the compressor consumption, due to the high pressure losses introduced by the accessories existing in the outdoor hydraulic loop. As Geocool plant is a research demonstration site, there was a strong need of having precise instrumentation such as a coriolis flow meter to measure the flow rate circulating in the BHE, as well as several PT100 sensors that were placed in elbows in order to measure inlet and outlet water temperatures at each borehole. All this instrumentation, specially the coriolis flow meter, resulted in much higher pressure losses than in a commercial installation. Several optimization strategies are being undertaken at Geocool plant at the moment, in order to diminish the energy consumption of the circulation pumps and some preliminary results are presented in [22].

Finally, it can be concluded that thanks to monitored data, which is essential in order to keep the system in good operation, it is possible to detect and repair failures and develop optimization strategies such as changing the temperature setting.

It can also be concluded from experimental measurements and calculations of DPF_1 and DPF_2 that, after five years of operation, the installation performance keeps being satisfactory with minor maintenance operations needed such as air purging operations and some galvanic corrosion problems at the indoor hydraulic system due to the chemical interaction between a carbon steel buffer tank and the copper existing in the fan coils.

5. CONCLUSIONS

This paper presents the evaluation of the performance of a ground source heat pump system, providing heating/cooling to an office building. The system has been fully monitored along several years up to now and experimental measurements have been collected since 2005.

The impact of the GSHP system in the ground response was analysed. Mean return water temperature from the BHE was chosen as the parameter that best represents the impact of the system in ground thermal response and its evolution along the five years operation of the system was studied. It was concluded that the water temperature at the beginning of each year remained constant and equal to 17ºC approximately. A study was done using GLHEPRO software where the mean monthly values for the water return temperature from the ground were calculated for 25 years of operation. The results showed that during the first five years of operation, the water temperature coming from the ground would increase around 0.7K, reaching a 1.12K increase after 25 years of operation; however, it has been observed from experimental measurements that the ground has a stronger recovery capability than expected which allows the water temperature coming from BHE present a periodic evolution along the years, being the mean water return temperature of the BHE equal to 20ºC for every year of operation and confirming well designed and balanced GSHP systems as a good alternative . Otherwise, if the system were highly unbalanced, and the ground loop weren't well designed, the water temperature coming from the BHE would be higher every year and the system performance would degrade making the GSHP not so advantageous when compared to conventional systems.

In order to evaluate the energy performance evolution along several years of operation, two different performance factors were defined as: heat pump daily performance factor (DPF_1) and outdoor loop daily performance factor (DPF_2), and mean monthly values were analysed for each year. Figures 8 and 9 led to the conclusion that the efficiency of the installation remains practically constant from year to year and it doesn't degrade, needing minor maintenance operations.

It was observed in Figure 8 that changing the water supply temperature to the building, sending it cooler in winter and hotter in summer, has an influence on the DPF_1 , leading to a DPF_1 improvement of 4% for cooling mode and 3.7% for heating mode per each degree variation in the water temperature setting. This was noticed from May of 2009 to April of 2010, in which DPF_1 takes greater values for both cooling and heating mode. So, monitored data made it possible to keep the system in good operation and develop optimization strategies such as changing the temperature setting along the year and sending it cooler in winter, and hotter in summer.

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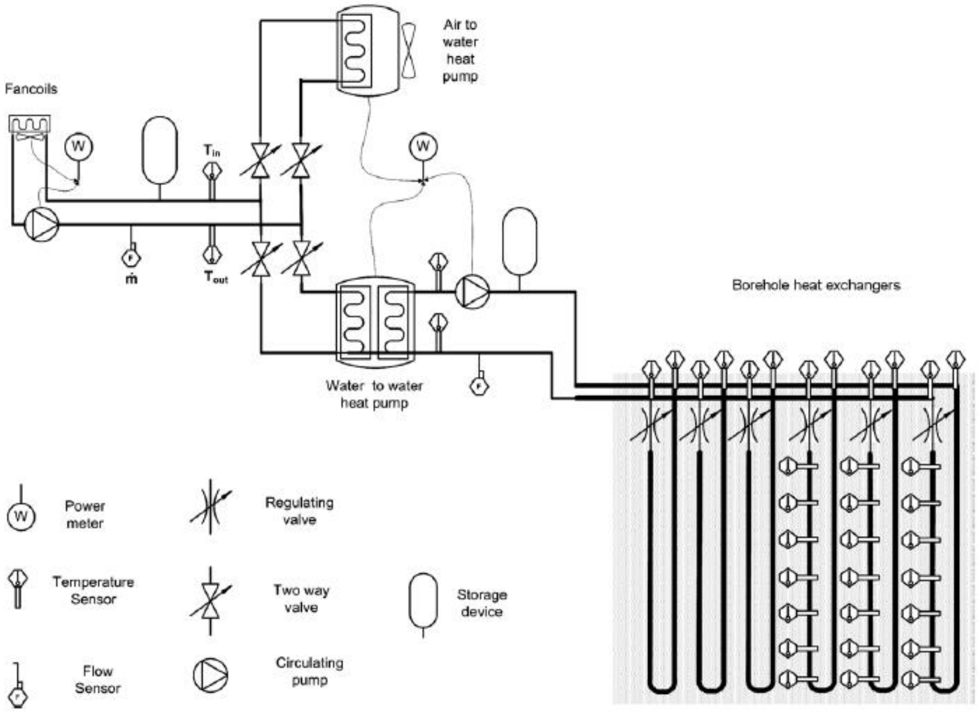


Figure 1. GeoCool schematic diagram. The air to water heat pump and the ground source heat pump are linked in parallel to the internal hydraulic group that transfers the energy to fan-coils.

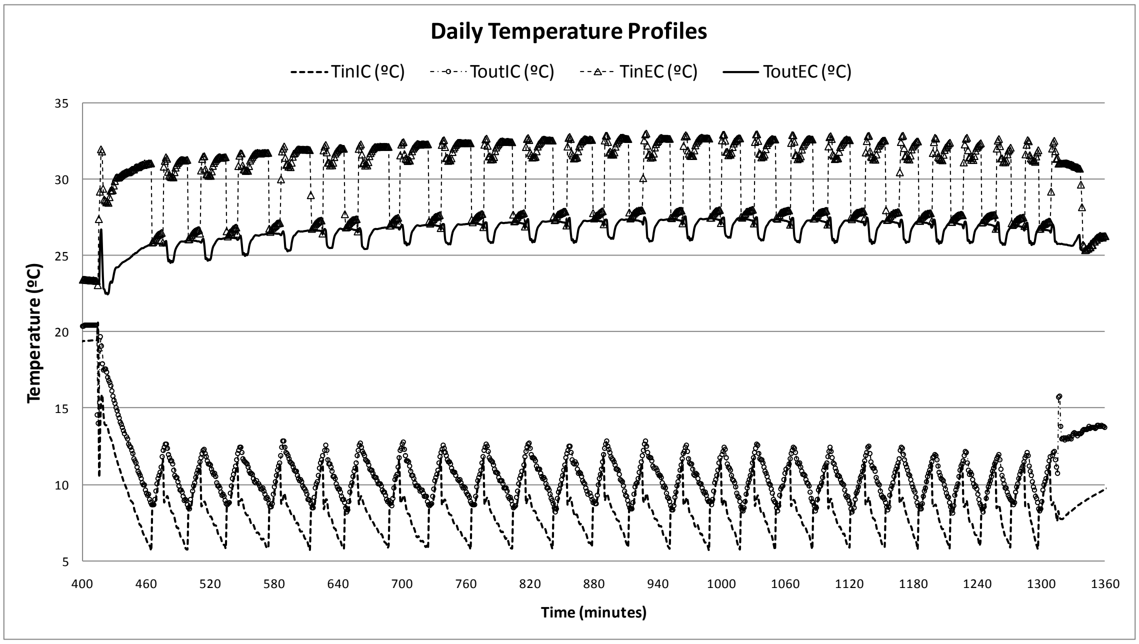


Figure 2. Daily temperature evolution at the internal and external circuits.

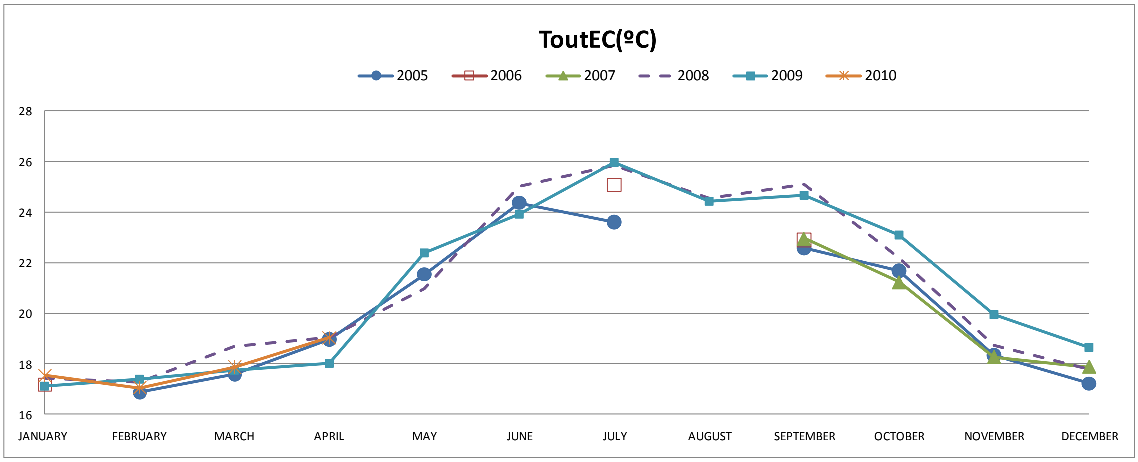


Figure 3: 2005-2010 temperature measurements at the outlet of the external circuit.

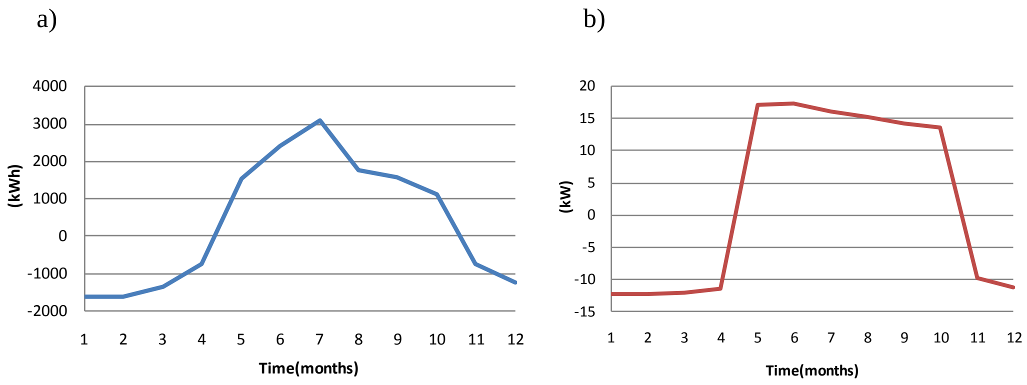


Figure 4: Monthly energy load profile exchanged with the BHE: a) Base loads b) Peak loads.

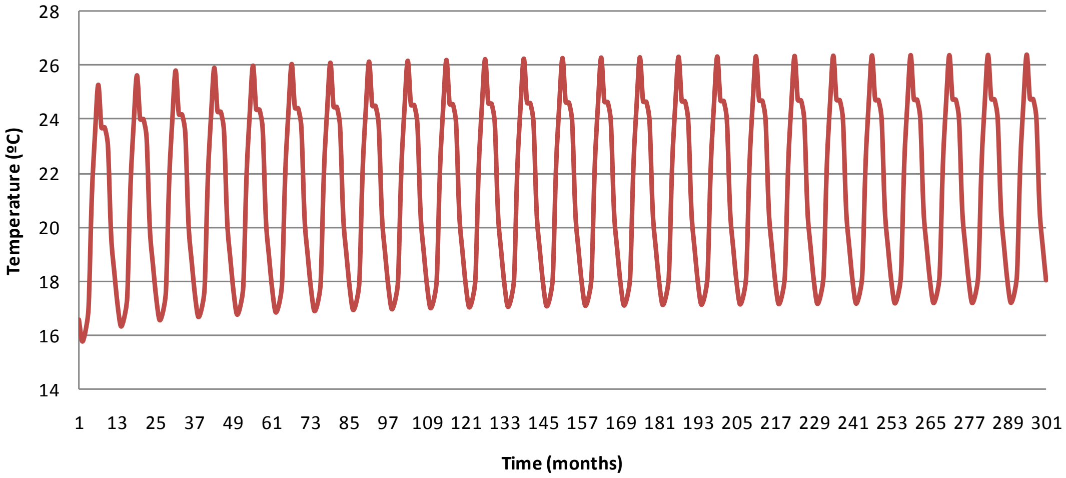


Figure 5: GLHEPRO 25 years of simulation results: mean monthly BHE outlet water temperature.

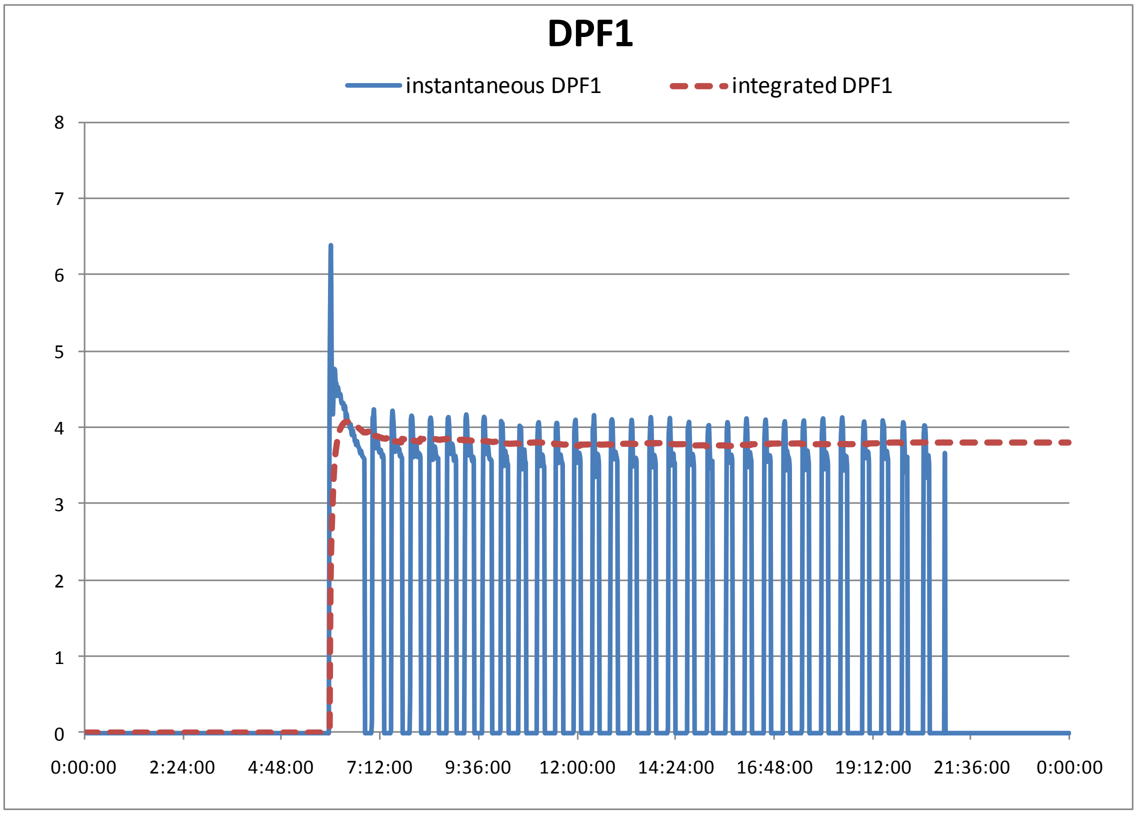


Figure 6: DPF_1analysis for a typical heating day in 2008.

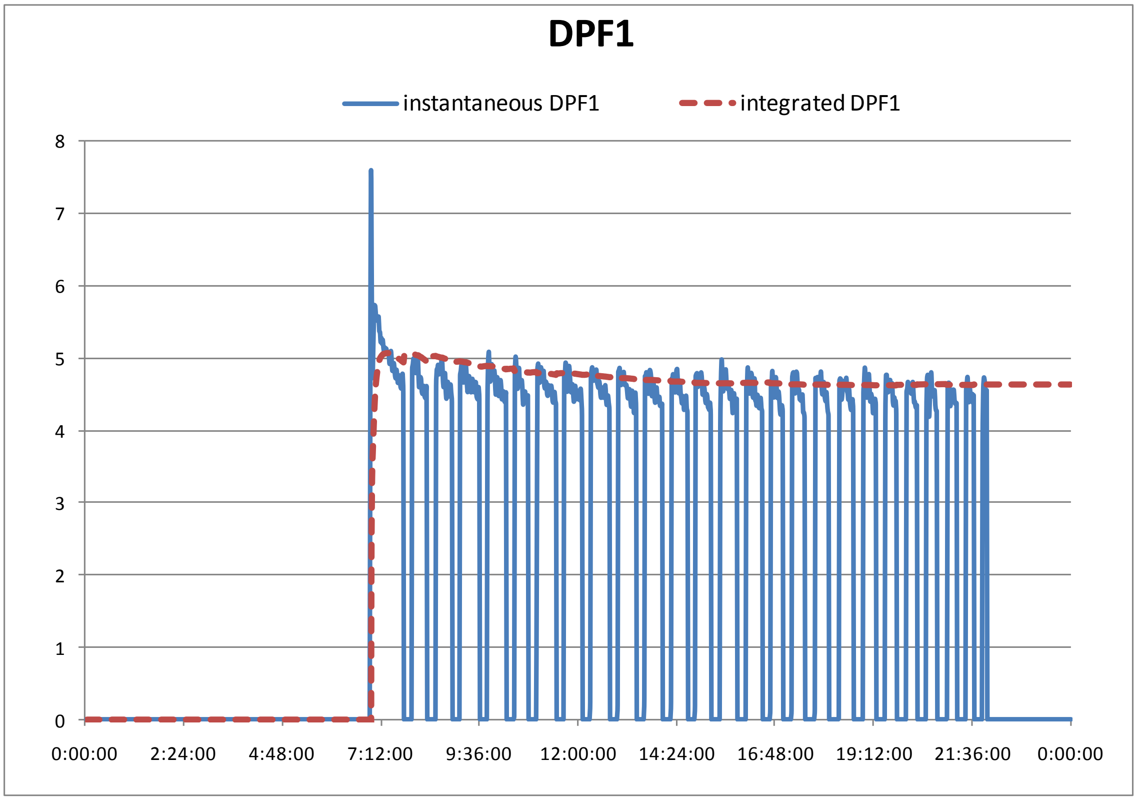


Figure 7: DPF_1analysis for a typical cooling day in 2008.

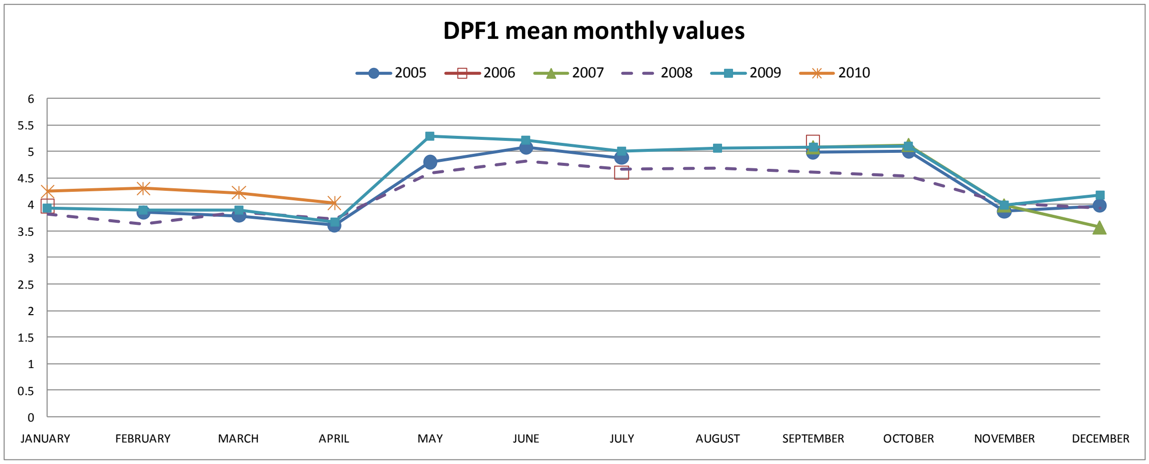


Figure 8: 2005-2010 energy performance results: DPF$_1$ mean monthly values.

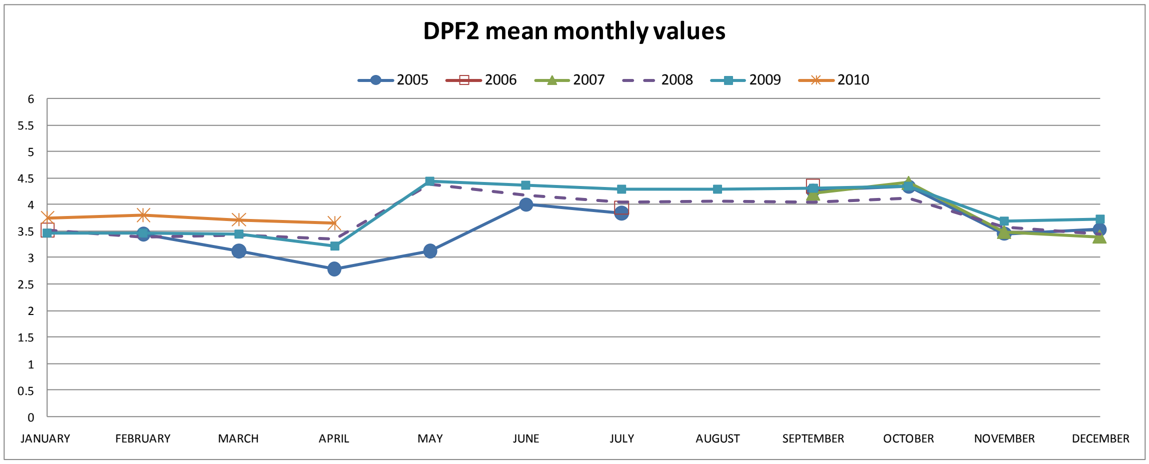
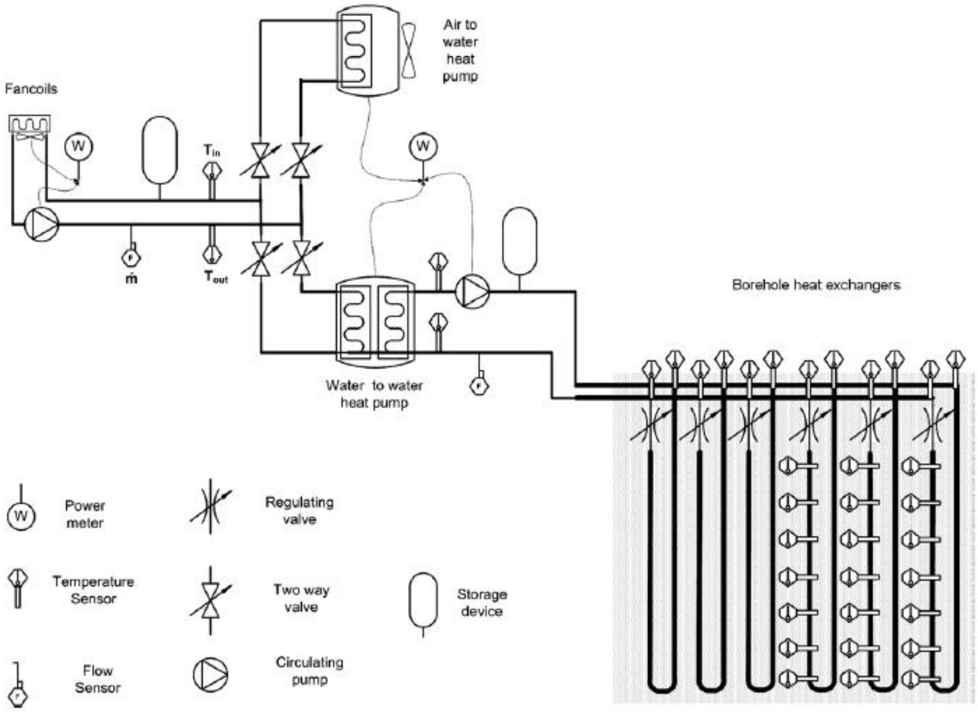


Figure 9: 2005-2010 energy performance results: DPF_2 mean monthly values.



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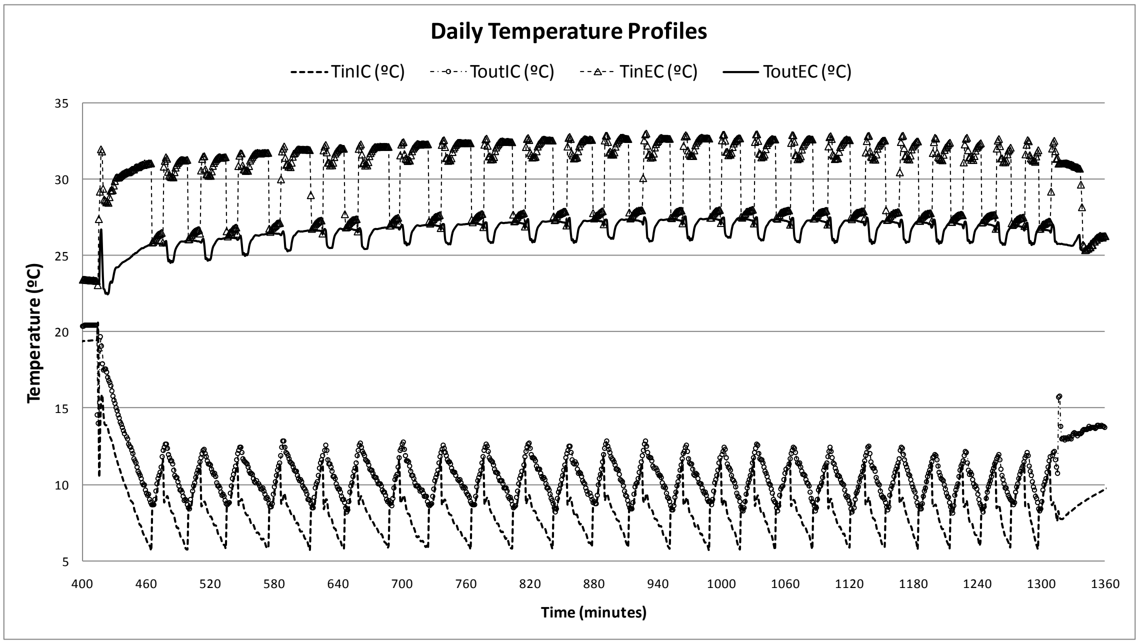

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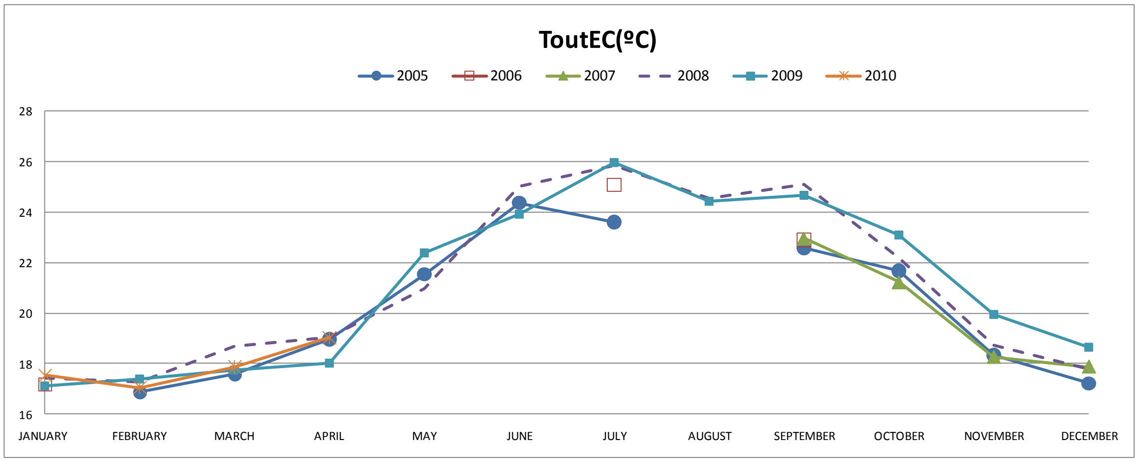

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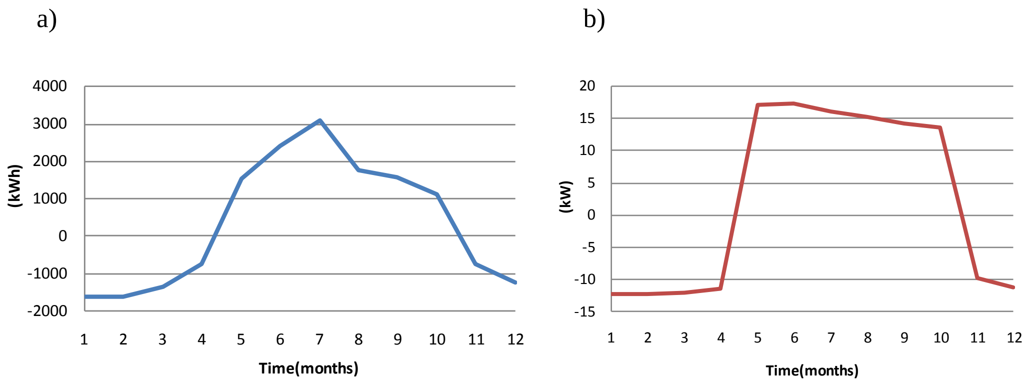

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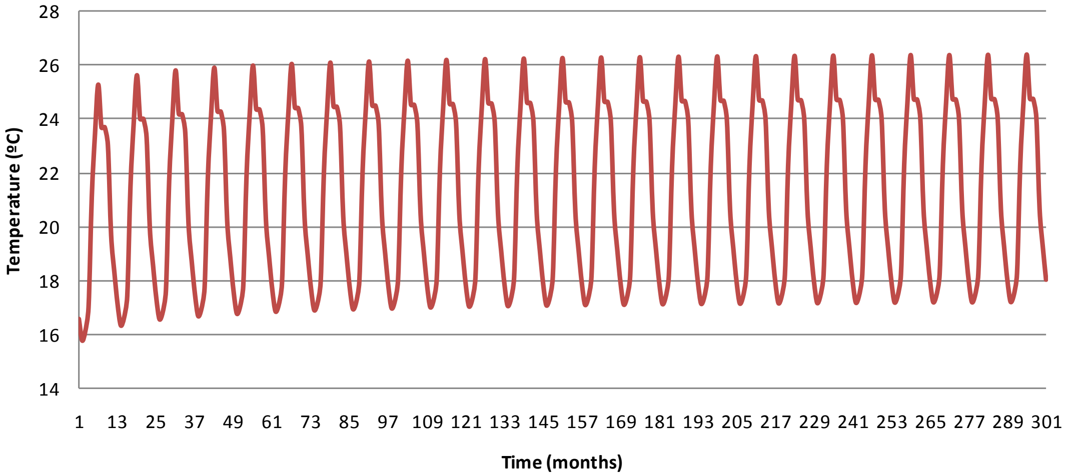

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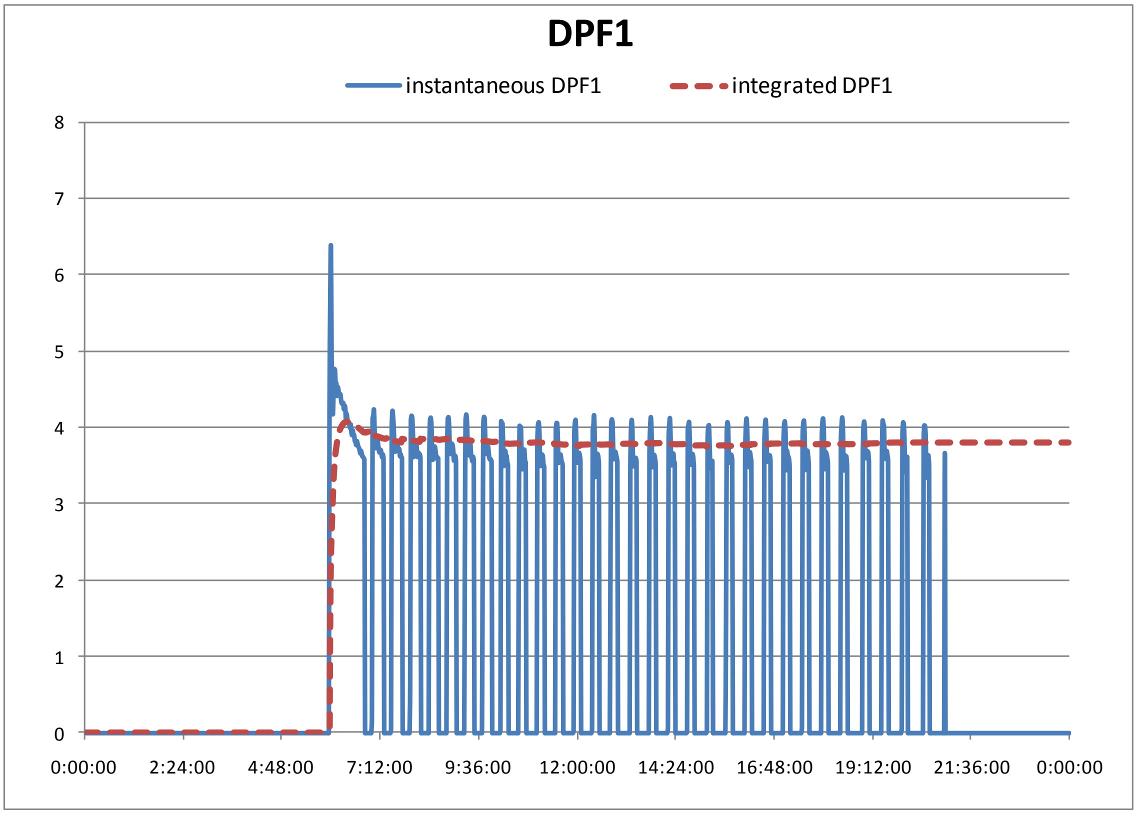

Figure 6: DPF_1analysis for a typical heating day in 2008.

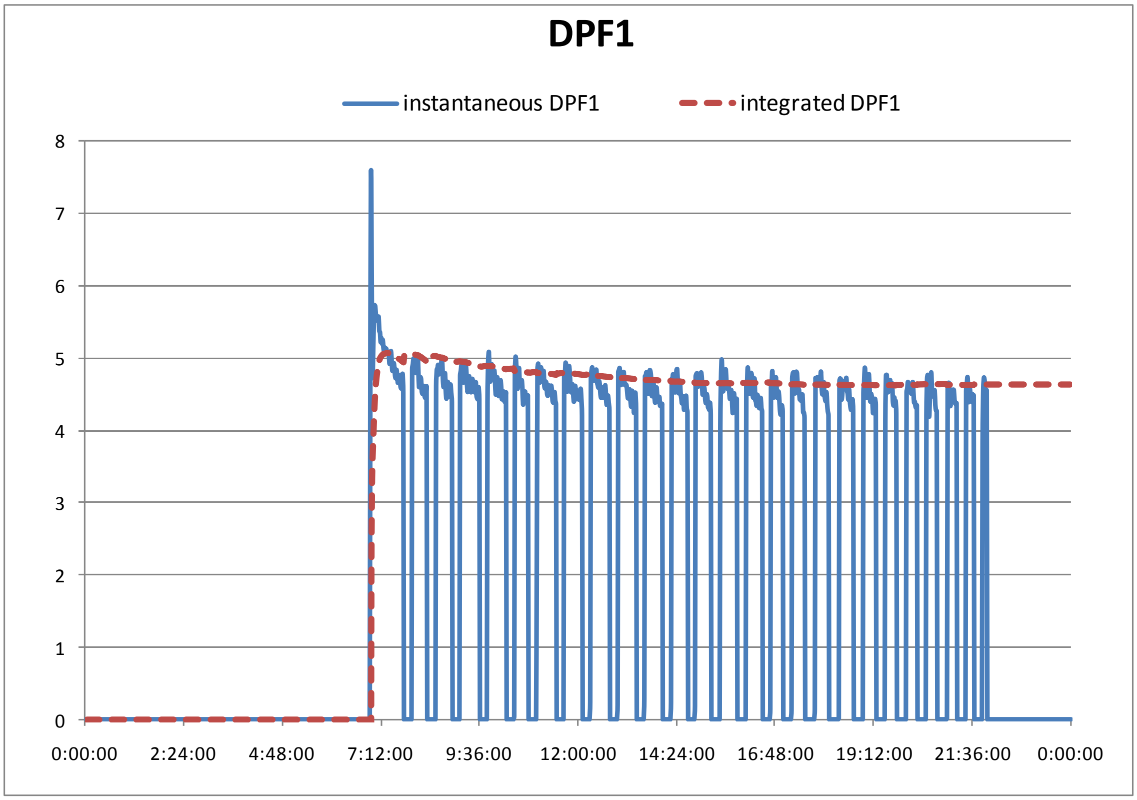

Figure 7: DPF_1analysis for a typical cooling day in 2008.

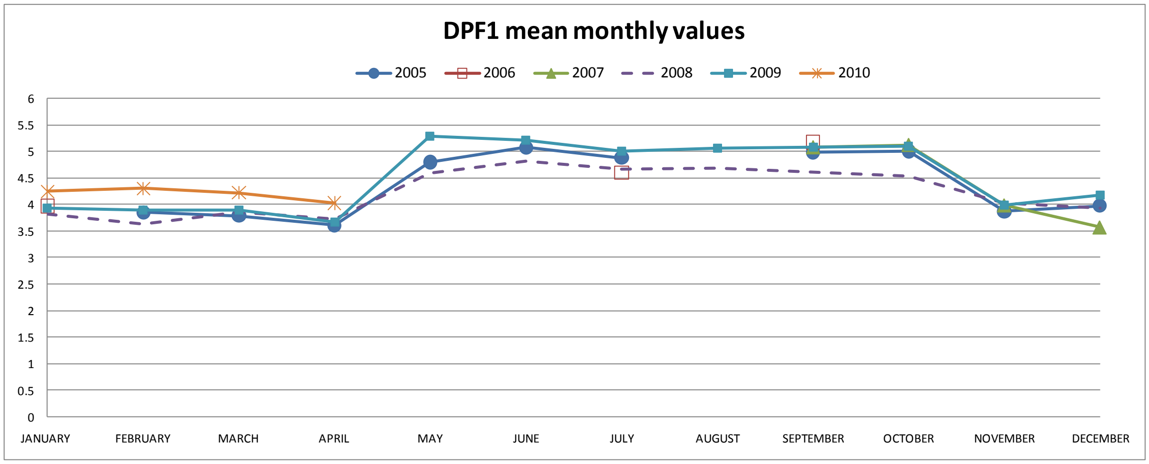

Figure 8: 2005-2010 energy performance results: DPF_1 mean monthly values.

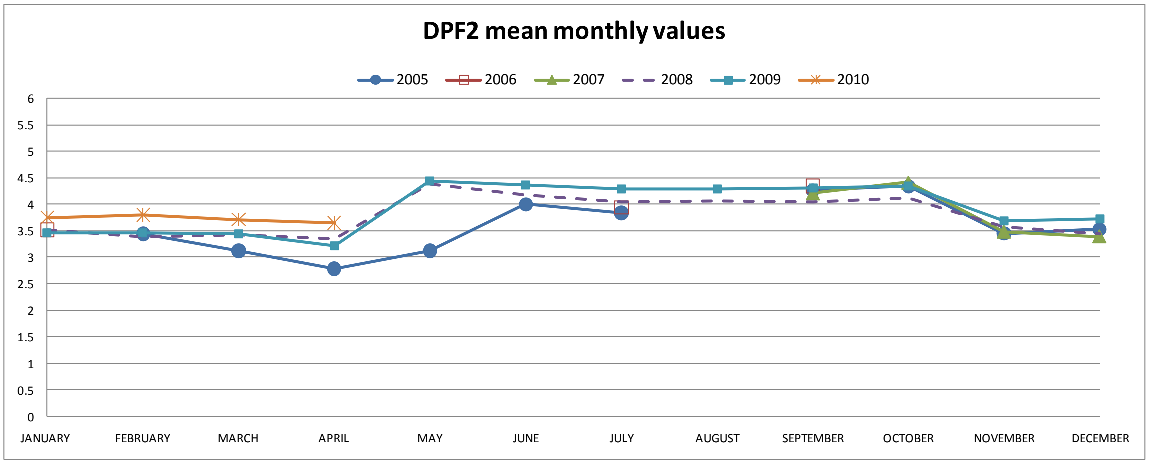

Figure 9: 2005-2010 energy performance results: DPF_2 mean monthly values.

***Highlights**

>Five years energy performance measurements of a GSHP system are analyzed. > System energy performance is maintained through the years. >No impact on ground thermal response is detected.> Monitored data allow to keep the system in good operation and optimize it.