ENERGY PERFORMANCE ANALYSIS OF THE FIRST RESEARCH-ONLY GROUND COUPLED HEAT PUMP IN ROMANIA

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Abstract: - One laboratory belonging to Energy Engineering Faculty is heated with a ground-coupled heat pump (GCHP) system having two types of ground heat exchangers: a vertical one and a horizontal one. This paper presents, at first, several coefficients of performance that can be defined for heat pumps together with their usability. Then, an energy efficiency model is set specially for CGHP systems. In this paper the simulation of energy performances is done only for the vertical heat exchanger (borehole heat exchanger) having two configurations: single-U and double-U. All simulation results range between normal values and can be considered realistic.

Key-Words: - Ground coupled heat pump, energy efficiency, performance, simulation

1 Introduction

University of Oradea developed a sustained research activity in the field of renewable energy sources [1,2,3]. In this framework, a ground-coupled heat pump (GCHP) system was installed in 2008, having two types of ground heat exchangers (SCS): ***a vertical one*** - SCSV - (borehole heat exchanger) consisting of a double-U pipe inserted into a borehole of 75 m depth, and ***a horizontal one*** – SCSO - consisting of 4 pipes laid down into a 75 m long trench, on two layers (1.8 m, respectively 1.2 m depth). Because of manifold headers the system is capable to separate the individual brine circuits.

Any GCHP system has three main subsystems (Fig. 1):

- underground subsystem,
- heat pump subsystem;
- consumer subsystem.

In order to analyze the efficiency of the whole system, all component subsystems must be successively studied as in the end will result the GCHP energy performance.

2 Modeling the energy efficiency of a GCHP

Literature defines several coefficients of performance [4] for heat pumps (HP), starting with the theoretical ones and going to real ones, some of them related to power, and some related to energy.

For a monovalent GCHP the expression of seasonal performance factor (SPF) is given by equation (1):

$$SPF = \frac{Q_{cons}}{W_{PC} + W_{aux}} \tag{1}$$

Table 1 – Coeficients of performance for heat pumps

Coefficient of performance	Expression	Application factor
Theoretic of the sources	$COP_{ts} = \frac{T_2}{T_2 - T_1}$	• control value; • not practical; • theoretic;
Theoretic of the cycle	$COP_{tc} = \frac{T_c}{T_c - T_{ev}}$	• control value; • not practical; • theoretic;
Moto-compressor group	$COP_c = \frac{\dot{Q}_2}{P_c}$	• doesn't offer a clear idea about real performances; • given by some manufacturers;
Global of HP	$COP_{PC} = \frac{\dot{Q}_{2\ med\ orar}}{P_{c\ med\ orar} + P_{aux\ med\ orar}}$	• indispensable; • allows a better definition of HP qualities; • given by the manufacturer;

Table 1 – Cont.

Global of whole installation	$COP_i = \dfrac{\dot{Q}_{2\ med\ orar_{util}}}{P_{c\ med\ orar} + P_{aux\ med\ orar}}$	• found after testing; • allow to observe the behavior of HP as a function of outside temperatures;
Mean annual of compressor	$COP_{a\ c} = \dfrac{\sum n_i \cdot COP_c}{\sum n_i}$	• to avoid;
Mean annual of HP	$COP_{a\ PC} = \dfrac{\sum f_i \cdot n_i \cdot COP_{PC}}{\sum f_i \cdot n_i}$	• to avoid;
Seasonal or global annual of whole installation	$SPF = \dfrac{\text{annual heat produced}}{\text{total annual electric energy consumptio}}$	• allows to determine the economy of energy; • indispensable; • found after testing.

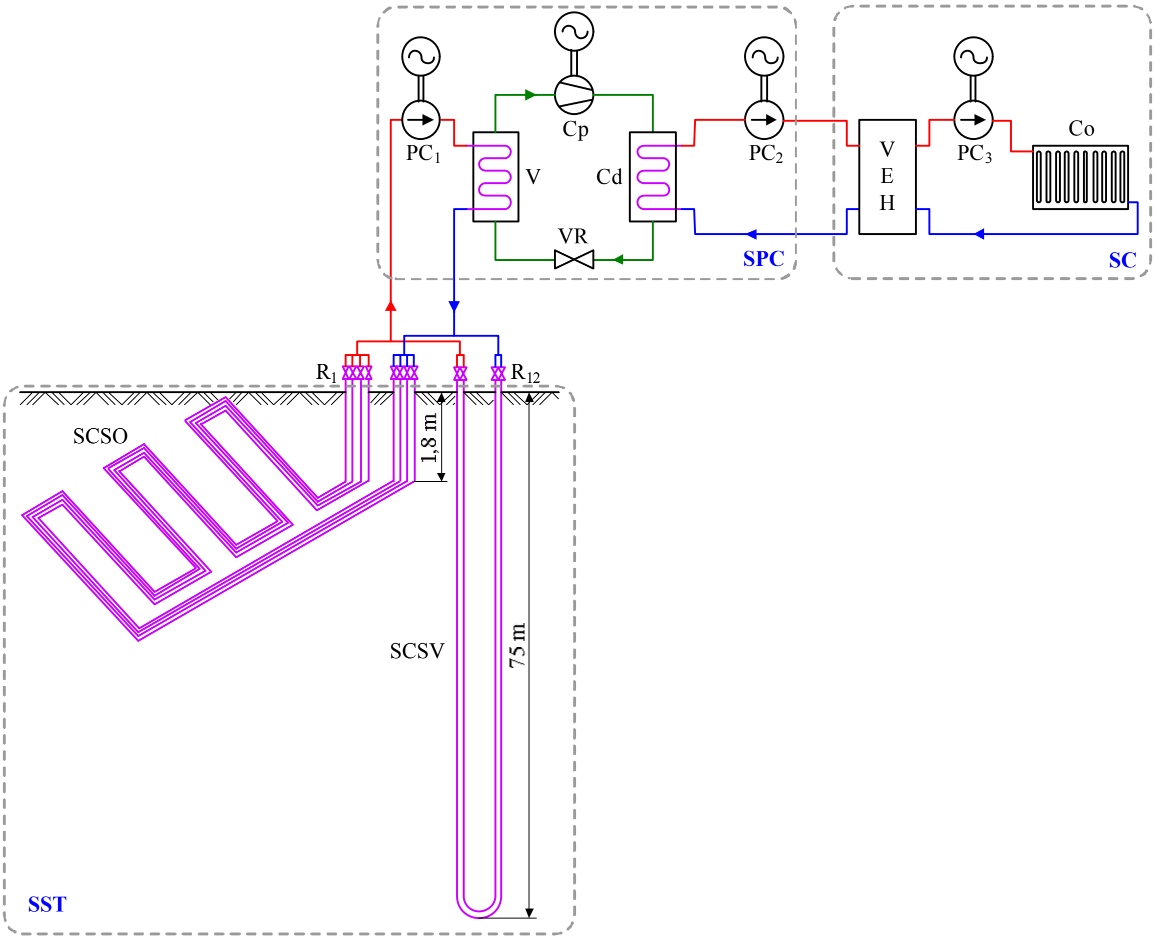

Fig. 1 – Lay-out of the experimental installation:
SST – underground subsystem; SPC – HP subsystem; SC – consumer subsystem; SCSO, SCSV – horizontal, respectively vertical ground heat exchanger; $R_1 \div R_{12}$ – valves; PC_1, PC_2, PC_3 – circulation pumps; V – evaporator; Cp – compressor; Cd – condenser; VR – expansion valve; VEH – header; Co – heat consumer

where: SPF[-] – seasonal performance factor of GCHP;
Q_{cons} [J] – heat required by the consumer;
W_{PC} [J] –electric energy absorbed by the HP;
W_{aux} [J] –electric energy for auxiliaries; is not included in COP_{PC} definition (represents the energy consumed by the circulation pump of the brine and of the water from heating system).

If GCHP works in bivalent mode, SPF of the system is:

$$SPF_{sist} = \frac{Q_{cons}}{\dfrac{\delta \cdot Q_{cons}}{SPF} + \dfrac{(1-\delta) \cdot Q_{cons}}{\eta_{rez}}} \qquad (2)$$

where: δ [-] – fraction of heat required by the consumer covered by HP;
η_{rez} [-] – efficiency of additional (back-up) heat source.

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Electric energy consumption of the compressor (W_{PC}) is calculated from total heat production of the HP related to its coefficient of performance. Total heat delivered by the HP is calculated adding to consumer requirements both heat losses because of cyclic operation of the heat pump and storage heat losses [5]:

$$Q_{tot} = Q_{cons} + Q_{ciclic} + Q_{stoc} \tag{3}$$

Therefore, daily performance factor (PF_i) is:

$$PF_i = \frac{Q_{cons\,i}}{\dfrac{Q_{cons\,i} + Q_{ciclic\,i} + Q_{stoc\,i}}{COP_i} + W_{aux\,i}} \tag{4}$$

Performance factor of GCHP system working in monovalent mode, calculated for the entire heating period, is:

$$SPF = \frac{\sum_{i=1}^{n} PF_i}{n} = \frac{\sum_{i=1}^{n} \dfrac{Q_{cons\,i}}{\dfrac{Q_{cons\,i} + Q_{ciclic\,i} + Q_{stoc\,i}}{COP_i} + W_{aux\,i}}}{n} \tag{5}$$

where i, respectively n represent the current day, respectively the total number of heating days.

3 Energy performance simulation for GCHP

Next steps have to be followed to accomplish SPF simulation:

a. simulate daily heating requirement of the consumer;
b. simulate ground heat transfer in order to determine mean brine temperature;
c. determine the available heat flow to be extracted from the ground, checking if it covers consumer requirements, setting therefore the operation mode of the HP (monovalent or bivalent);
d. calculate the parameters that characterize energy performances of GCHP, both as daily and annual values: heat delivered to consumer, electric energy consumption, COP, PF, SPF.

For the considered GCHP system, the consumer is the space itself where experimental HP was installed. This is the Thermodynamics Laboratory from Energy Engineering Faculty in Oradea.

The first step is accomplished by running CALCER computer program for this specific consumer. Daily heat flow required by the Laboratory room is calculated for an inside temperature of 20 □C, and the values are represented in Fig. 2. It must be said that even in summer time this space needs heating because it is located in the basement and external heat gains don't cover heat losses to the ground. Maximum heat flow required is 2025 W and annual energy requirement is 8636 kWh. The experimental installation has got two types of heating equipment: a radiator and a fan-coil unit, both requiring a temperature of 50 ^{O}C for inlet water.

Fig. 2 – Heat flow requirement for a calendar year

HP manufacturers provide COP_{PC} values for certain operation conditions (different temperatures of brine and outlet water from condenser). But, in practice, a heating system is not working all season between these fixed temperatures. Therefore, daily value of COP is needed in order to be able to calculate SPF. COP value strongly depends on both brine temperature and outlet water temperature at condenser side. For a brine-to-water GCHP, the analytical expressions of COP are:

$$T_{tur} = 35\ ^{\circ}C: \quad COP = \frac{0{,}0305 \cdot T_{SCS\,e} + 1}{0{,}0005 \cdot T_{SCS\,e} + 0{,}2225}$$

$$T_{tur} = 40\ ^{\circ}C: \quad COP = \frac{0{,}029 \cdot T_{SCS\,e} + 0{,}985}{0{,}001 \cdot T_{SCS\,e} + 0{,}255}$$

$$T_{tur} = 45\ ^{\circ}C: \quad COP = \frac{0{,}029 \cdot T_{SCS\,e} + 0{,}965}{0{,}002 \cdot T_{SCS\,e} + 0{,}28}$$

$$T_{tur} = 50\ ^{\circ}C: \quad COP = \frac{0{,}0275 \cdot T_{SCS\,e} + 0{,}9475}{0{,}002 \cdot T_{SCS\,e} + 0{,}31}$$

$$T_{tur} = 55\ ^{\circ}C: \quad COP = \frac{0{,}027 \cdot T_{SCS\,e} + 0{,}925}{0{,}002 \cdot T_{SCS\,e} + 0{,}34}$$

where: T_{tur} [°C] – outlet water temperature at condenser side;

T_{SCSe} [°C] – outlet brine temperature (when exiting borehole heat exchanger and entering the evaporator).

The second step is accomplished using EWS simulation program for specific conditions of experimental GCHP system, both for single-U and double-U borehole heat exchangers. Mean brine temperatures in the 5th year of simulation are shown in Fig. 3:

- for 1 circuit (single-U tube) marked 1V;
- for 2 circuits (double-U) marked 2V.

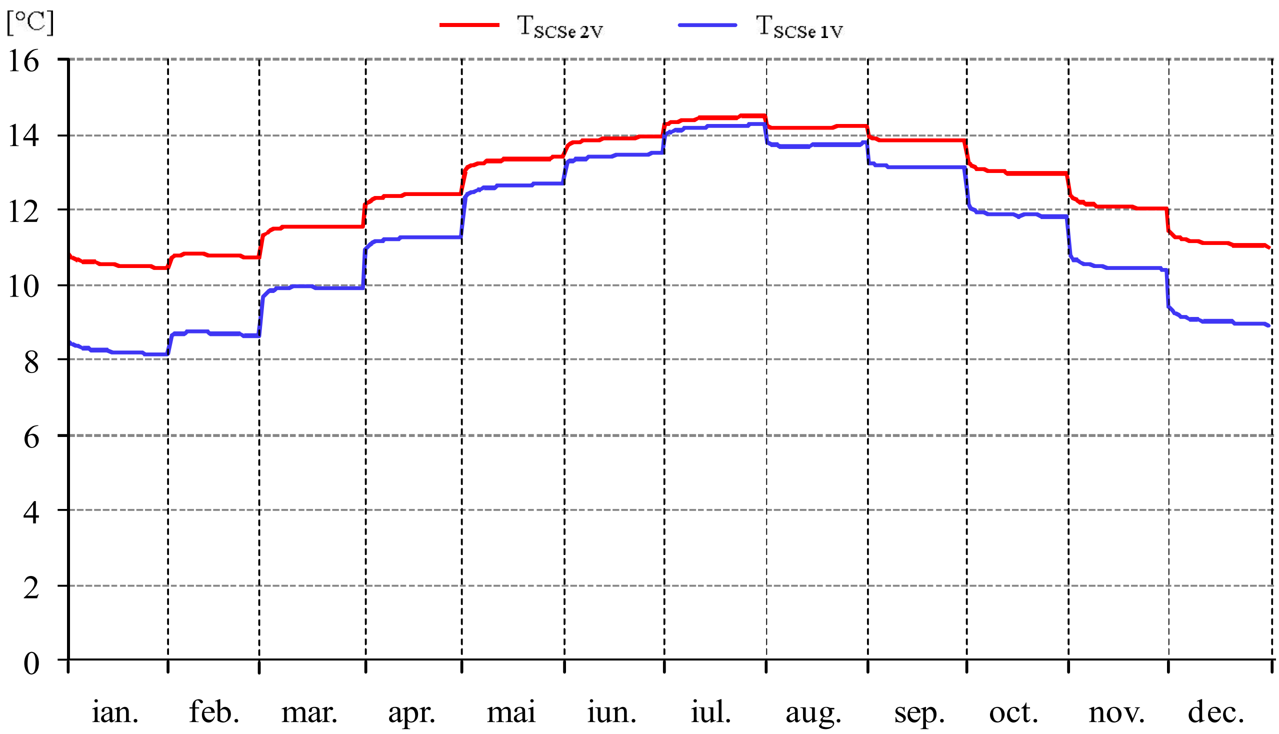

Fig. 3 – Simulated mean brine temperatures for single-U and double-U configurations, in the 5th year of operation

In order to calculate energy performance parameters, all types of heat and electricity must be known. Therefore, for the considered system, since HP and header are both located in the same environment as the consumer, storage heat losses are zero. Also, heat losses due cyclic operation are zero. Electricity consumption of auxiliaries is approx. 25 % of heat pump electricity consumption (according to performed experimental measurements). Fig. 4 shows the results of simulated daily energies. Based on equations (1) ÷ (5) energy performance parameters were calculated for a calendar year. Simulation results are graphically represented in Fig. 5.

Mean annual values of energy performance parameters of vertical GCHP system from University of Oradea are obtained by integrating the above simulated daily values over the heating period. These values are shown in Table 2.

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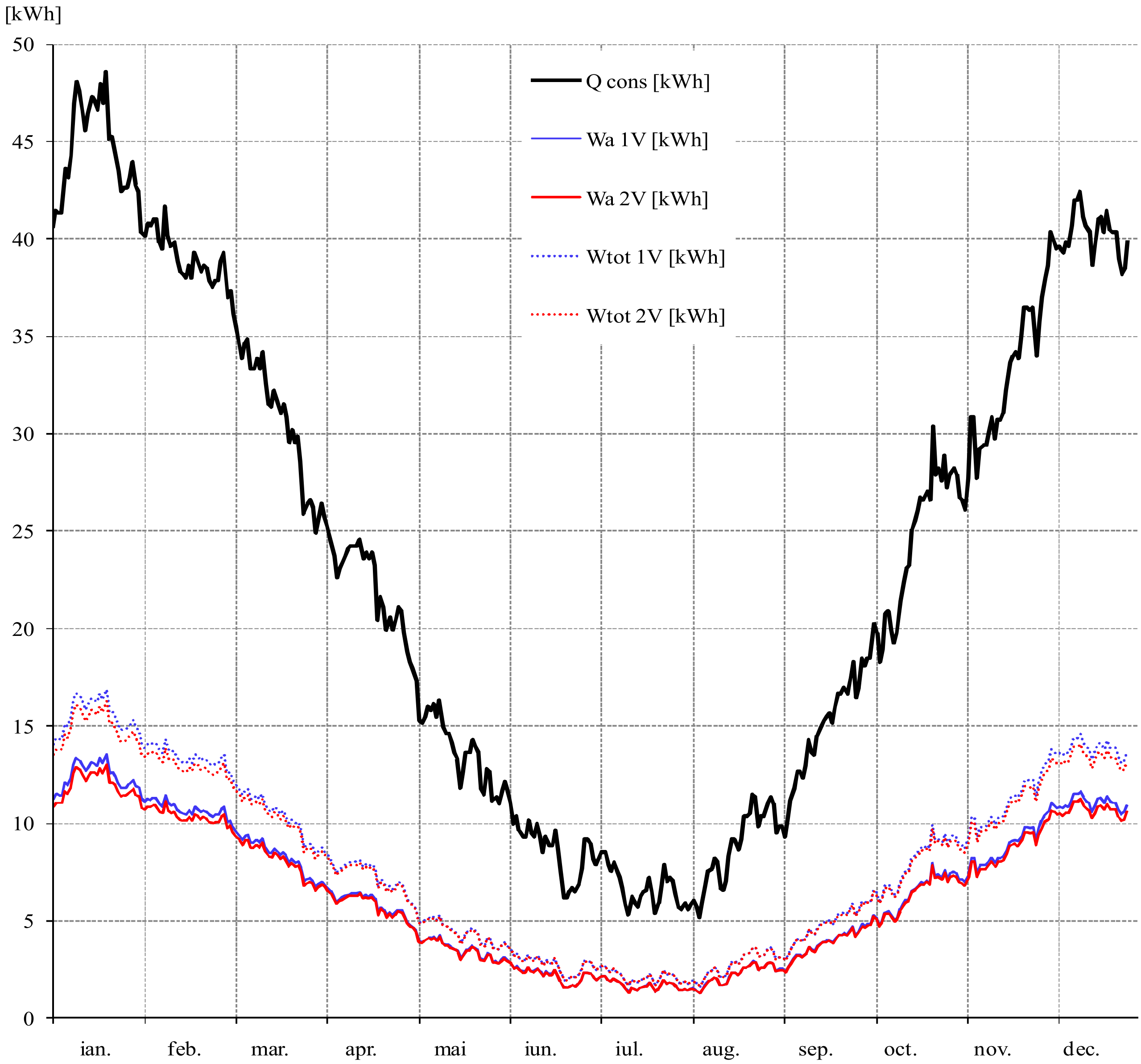

Fig. 4 – Mean daily values of heat delivered to consumer (Q_{cons}), active electric energy consumed by HP (W_a) and total electric energy (W_{tot}) consumed by experimental GCHP for both configurations (1V and 2V)

Tabel 2 – Mean annual values of energy performance parameters for vertical GCHP in Oradea

Operational configuration of SCSV	Q_{cons} [kWh/an]	W_a [kWh/an]	W_{tot} [kWh/an]	COP [-]	SPF [-]
1 V	8636.39	2321.95	2902.44	3.72	**2.98**
2 V		2262.83	2828.54	3.82	**3.05**

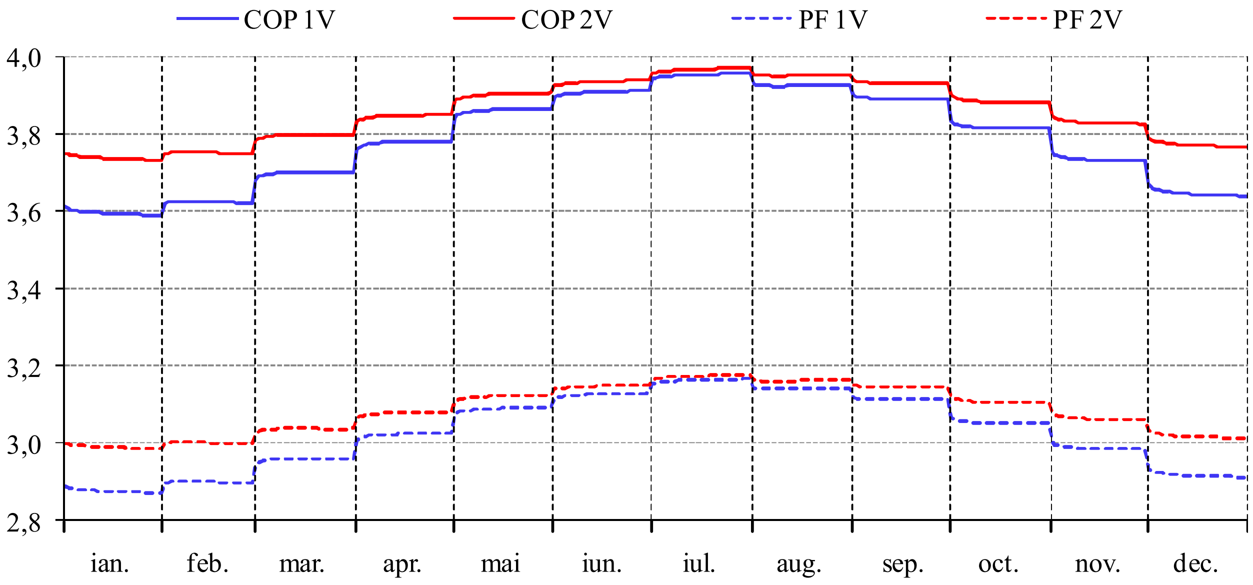

Fig. 5 – Simulated mean daily values of COP and PF for the two configurations of borehole heat exchanger

4. CONCLUSION

Analyzing the results of the simulation shown in Fig. 4, Fig. 5 and Table 2, the following conclusion can be set:

- Values of HP coefficient of performance (COP_{PC}), respectively the performance factor of the system (PF) fit into normal range, COP values are between 3.6 ÷ 4, respectively 2.8 ÷ 3.2 for PF.
- Daily electricity consumption of the heat pump is 1.3 ÷ 13.5 kWh/day, and total electricity consumption of GCHP heating system is 1.6 ÷ 16.9 kWh/day.
- Results for daily electricity consumptions are relatively close for the two borehole heat exchanger configurations.
- Annual electricity consumption ranges between 2263 kWh and 2322 kWh for heat pump and 2828 kWh and 2902 kWh for the whole system.
- Mean annual value of COP_{PC} and, respectively, of seasonal performance factor (SPF) is approximately 3.8 for COP_{PC} and 3.0 for SPF.
- Very small differences (less than 3 %) can be seen between energy performance parameters belonging to 1V and 2V operational configuration.
- Results of all simulations range between values specified into literature or recommended by manufacturers, therefore they are considered as being realistic.

References:

[1] Research Project: *Reaching the Kyoto targets by means of a wide introduction of ground coupled heat pumps (GCHP) in the built environment (GROUND-REACH),* financed by European Commission (Contract No. EIE/05/105), 2006-2009

[2] Research Project: *High Solar Fraction Heating and Cooling Systems with Combination of Innovative Components and Methods, (acronym HIGH-COMBI),* financed by European Commission (Contract No. TREN/07/FP6EN/S07.68923/038659), 2007-2011

[3] Research Project: *Advanced ground source heat pump systems for heating and cooling in Mediterranean climate (acronym GROUND-MED),* financed by European Commission (Contract No. 218895 FP7-ENERGY-2007-2-TREN, Funding scheme CP, 2009-2013

[4] Bernier, J., *La pompe a chaleur. Determiner, installer, entretenir*, PYC LIVRES, Paris, 2004

[5] Wemhoener, C., Afjei, Th., Seasonal Performance Calculation for Residential Heat Pumps with Combined Space Heating and Hot Water Production, *Final Report*, Research program heat pumping technologies, cogeneration, refrigeration, 2003

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