International Scientific Conference CIBv - Civil Engineering and Building Services
5^{th}-6^{th} November 2020

Multi-criteria optimization for a residential horizontal ground heat exchanger

A. M. Bulmez, V. Ciofoaia, C. Pleșcan, S. I. Bolocan and A. Șerban

1. INTRODUCTION

Energy demand continues to increase as the population grows, with an undesirable effect on the Earth's climate. Around 81% of the electrical energy generated on Earth is obtained from fossil fuels [1]. Renewable energy sources are commonly used today, especially from sources that store energy more efficient [2]. Ground-coupled heat pumps are considered efficient systems that use geothermal energy. Their usage has increased especially in the residential and commercial building sectors [3]. Recently several optimization researches have been performed for horizontal geothermal heat exchangers [4], which focused on the optimization using a single criteria. The purpose of this study is a multi-criteria optimization for HGHEs.

2. MATERIALS AND METHODS

To solve these problems for heat pump systems, a multicriteria optimization is required. Establishing the parameters that have the most impact on the performances of the HGHE is required. Thus, three types of parameters were considered: physical, operational, and energetic. Limit intervals were set for this to narrow the results as can be seen in Table 1.

Table 1 – Parameters considered for multi-criteria optimization

Type	Parameter	Limit
Physical	HGHE Surface	20÷100 [m^2]
	Pipe depth	-1 ÷ -3 [m]
	Pipe step	0,3 ÷ 1 [m]
	Pipe length	50 ÷ 200 [m]
	Pipe diameter	0,02 ÷ 0,032 [m]
Operational	Soil thermal conductivity	0,5 ÷ 2,5 [W/mK]
	Fluid flow	0,1 ÷ 1 [kg/s]
	Soil temperature with depth	-10 ÷ 30 [°C]
	Exterior temperature	-30 ÷ 30 [°C]
	Fluid temperature	-5 ÷ 40 [°C]
Energetic	Thermal energy extracted/supplied/restored	variable [kWh]

Optimization problems that consider multiple criteria simultaneously provide reliable results. However, not even this optimization strategy can offer the best optimization solution, because some criteria usually cannot be compared. Vilfredo Pareto's research [5] shows us that it is impossible to optimize all parameters simultaneously, because the improvement of one parameter will lead to the worsening of another. By using several optimization criteria, a set of solutions is searched, that provides a reasonable compromise for several parameters, including the best solution of each parameter. The solutions can be found on the curve called the Pareto Front, among which the best solution resides. To obtain reliable results, in this study two criteria were used. Firstly, the Entropy Generation Number criteria (EGN) that determines the entropy of the system. Secondly, the Coefficient of Performance (COP) was used as a criteria to consider as many parameters as possible.

3. ENTROPY GENERATION NUMBER CRITERIA

Geothermal heat exchangers use the soil as a source of renewable energy. Thermodynamic irreversibility is an important criteria when regarding the operation of the heat pump system. Assuming this, the calculation of the entropy according to the average temperature of the fluid inside it and the cost in operation offers a perspective on the energy optimization that can be achieved. This optimization criteria is characterized by the function with the same name and is calculated with the formula:

$$N_S=\frac{S_{gen}\times T_{f,a}}{Q} \quad (1)$$

In which, S_{gen} represents the generated entropy, $T_{f,a}$ represents the average fluid temperature and Q represents the energy provided by the HGHE. The average temperature of the thermal fluid is directly influenced by the soil temperature, which is approximately equal to the outlet temperature. To increase this temperature external energy must be used. The cost for the electricity needed to increase the fluid temperature based on the monthly cost in Romania was calculated using the formula:

$$W_e=Q_c\times w_1\times n_h \quad (2)$$

In which, W represents the electricity cost, w_1 the cost for 1 kWh of electricity, Qc represents the heat flux needed to increase the fluid temperature and n_h represents the average monthly operating hours. Based on that, in Figure 1, the results of EGN Pareto front are illustrated and the optimum point is located for this criteria.

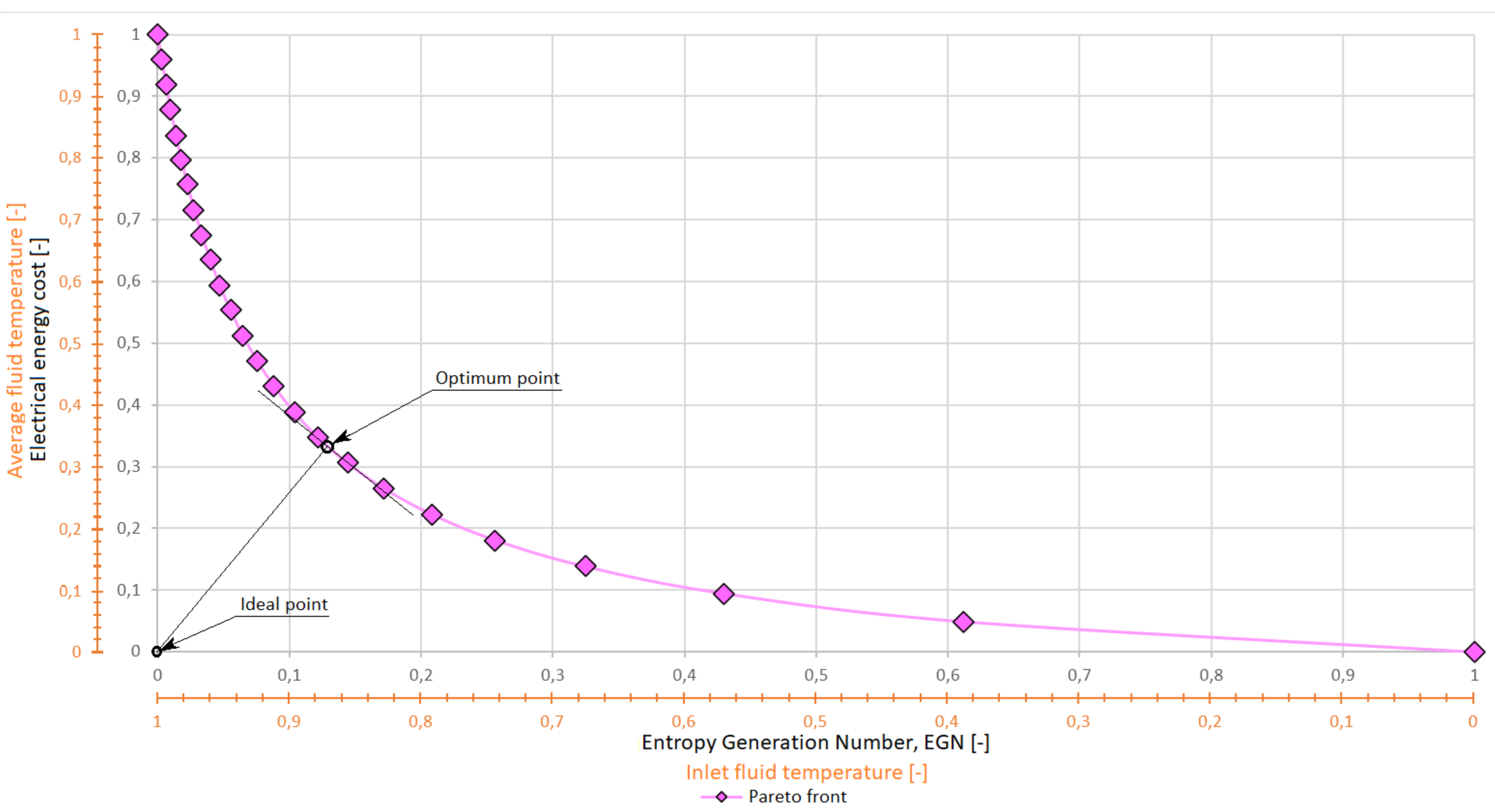

Figure 1 – Pareto front of the Entropy Generation Number for HGHE

4. COEFFICIENT OF PERFORMANCE CRITERIA

In use, the heat pump system has the COP as indicator of its overall performance. This criteria is based on its comparison according to thermal performances generated by a large set of HGHE configurations. For the calculation, the set of configurations were simulated using GLHEPro Software, on three different diameters at multiple pipe steps and HGHE surfaces.

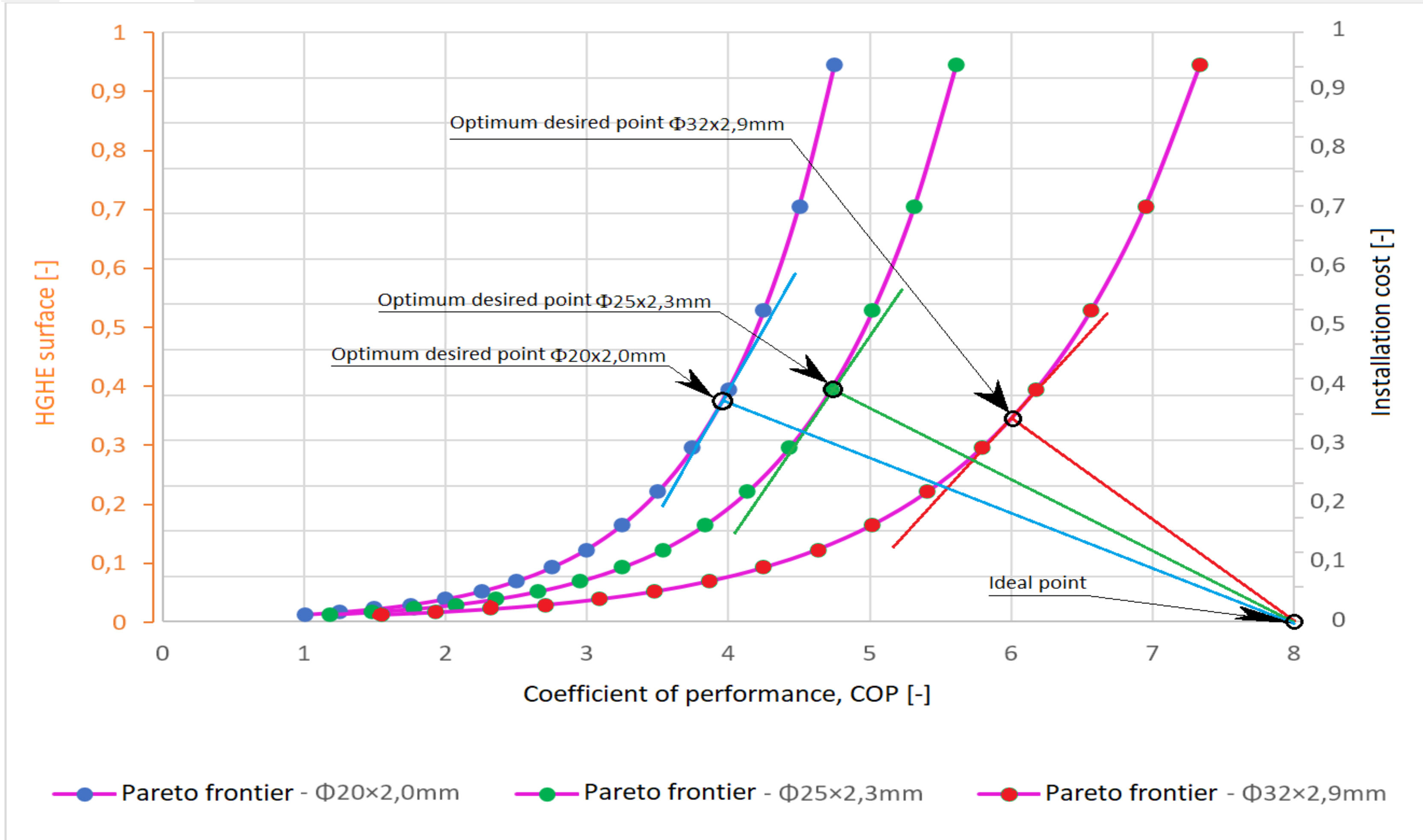

Figure 2 – Pareto fronts of the Coefficient of Performance criteria for HGHE with 3 pipe sizes

In Figure 2 the results obtained and the Pareto fronts for all three pipe sizes is illustrated. The pipe step that gave the best results is 30cm.

5. DISCUSSION

The first criteria, EGN, provides excellent results for reducing thermal irreversibility and maintaining thermal equilibrium in the HGHE. It does not consider the whole system and the thermal loads variation during the year. The second criteria, COP, provides very good results for choosing the optimal physical configuration, but does not consider both the thermal irreversibility and available HGHE install space. Therefore, analyzing the results from the two criteria used, as illustrated in Figure 3, shows what parameters can be efficiently improved. From this point of view, the optimal points of the physical configuration of the heat exchanger can be achieved, while maintaining the optimal entropy generation by providing external energy. This can be achieved by combining the geothermal energy source with another energy source such as solar energy.

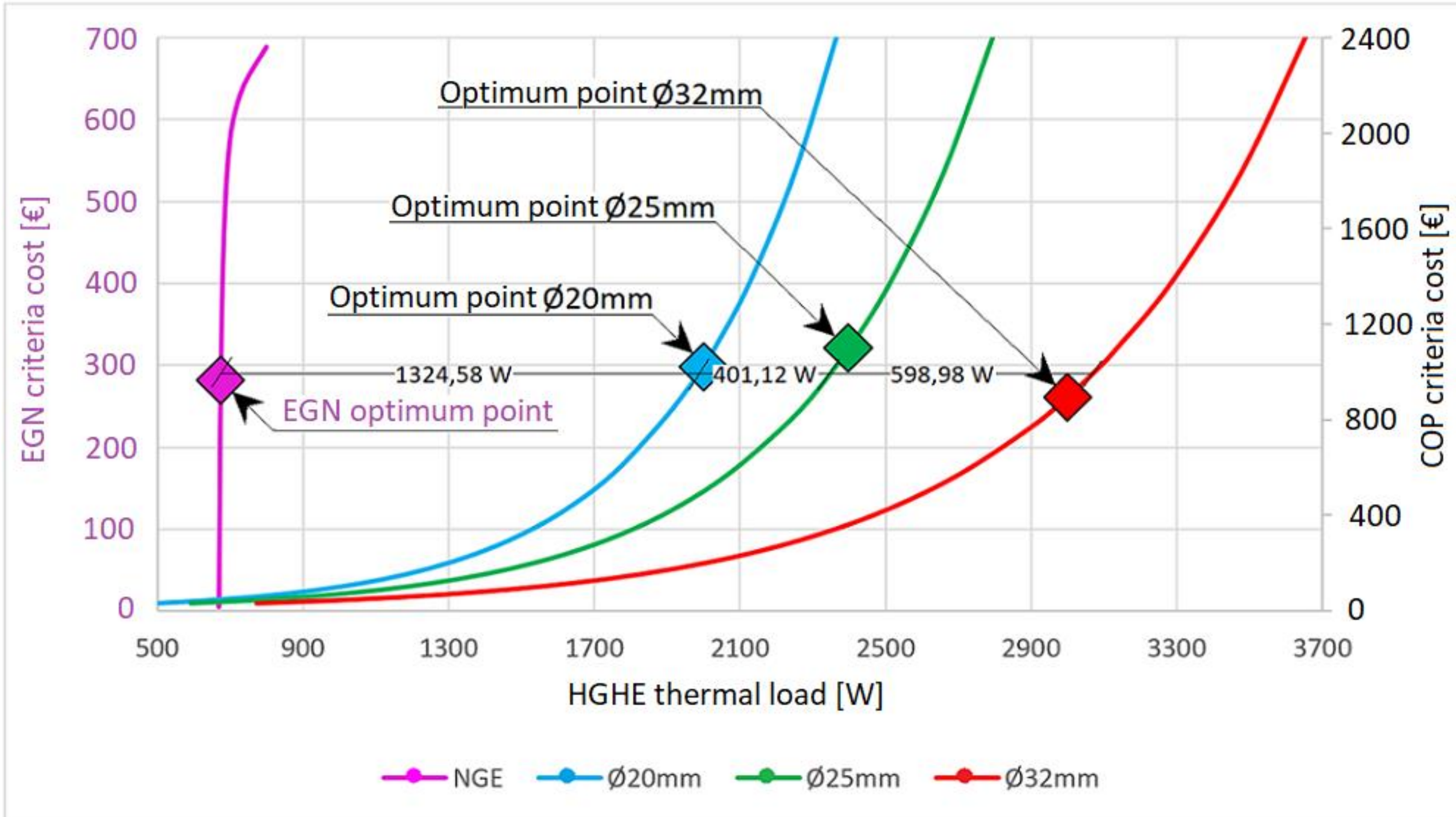

Figure 3 – Optimal points from the EGN and COP criteria

6. CONCLUSIONS

Analyzing the results obtained with the two optimization criteria, it was observed that the optimal points, although they are the best solutions, have several disadvantages. The lack of space is one of the biggest disadvantages for physical parameters. Also, limiting the thermal load of the system in terms of thermal irreversibility is a disadvantage, especially when the install space is sparce. The pipe diameter and the pipe step have an important impact, representing the largest share of the thermal load of the HGHE, followed by the material-based parameters. It was also found that the installment depth is not an important parameter, the difference in thermal load of HGHE being insignificant. This aspect being due to the large temperature variation at the soil surface, up to a depth of 7-10m. The main conclusion of the study is that to optimize the thermal performances of HGHEs, external energy is needed to be supplied to the system from auxiliary sources. The impact of an auxiliary source consists in providing help during peak loads and maintaining thermal equilibrium inside the HGHE.

References:

[1] Dragomir G., Șerban A., Năstase G., Brezeanu A.I., Wind energy in Romania: A review from 2009 to 2016, Renewable and Sustainable Energy Reviews, Romania, 2016;

[2] Năstase G., Șerban A., Năstase A.F., Dragomir G., Brezeanu A.I., Iordan N.F., Hydropower development in Romania. A review from its beginnings to the present, Renewable and Sustainable Energy Reviews, Romania, 2017;

[3] I. Sarbu and C. Sebarchievici, "General review of ground-source heat pump systems for heating and cooling of buildings," Energy Build.;

[4] P. M. Congedo, G. Colangelo, and G. Starace, "CFD simulations of horizontal ground heat exchangers: A comparison among different configurations," Appl. Therm;

[5] M. Ehrgott, Multicriteria Optimization. Berlin, Heidelberg: Springer-Verlag, 2005.