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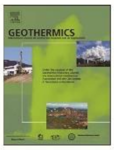

Technical optimization of the energy supply in geothermal heat pumps

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ABSTRACT

Very low enthalpy geothermal systems have been traditionally associated to the use of electricity as primary energy heat pumps supply. Gas engine heat pumps (GEHP) have been recently introduced in the current market. In this research, the electric heat pumps (EHP) as well as the GEHPs (considering natural gas and biogas as combustibles) have been analysed. The calculation of the ground source heat pump (GSHP) system has been made for a building placed in three different areas. Results reveal the influence of the heat pump configuration on the whole geothermal design. This research finally considers the European policies whose aim is a sustainable low-carbon economy by 2020. According to the existing Energy Efficiency Directive, energy requirements are defined for new and existing residential and non-residential buildings in the Member States. Based on these standards, the research compares the geothermal heat pump scenarios and a traditional one to determine if they would meet the regulation. Final results show that the Directive is a highly-demanding regulation that can only be respected by using EHP in one of the areas. The rest of geothermal heat pumps scenarios are much closer to meeting the energy standards than the traditional fossil heating sources.

1. Introduction and background

Ground source heat pump systems use the geothermal energy for heating and cooling purposes (including the production of domestic hot water). The utilization of these systems is increasing in the recent years, especially in China, Europe, USA and Canada (Zhou et al., 2015; Liang et al., 2011; Gao et al., 2012; Verda et al., 2012; Sommer et al., 2015; Sanner et al., 2003; Kranz and Frick, 2013; Freedman et al., 2012, 2013). Heat pumps constitute the key technology of the mentioned installations. In heating mode, heat is extracted from the ground by the set of boreholes. The energy taken from the ground is then lifted by a geothermal heat pump. For cooling applications, this device can be reversed, injecting the excess of heat into the ground. Heat pumps systems commonly use vapor-compression cycle which includes two low (evaporator) and high (condenser) temperature levels. Thus, the indoor heat exchanger is operated as evaporator in cooling mode and condenser in heating mode (Renedo et al., 2007).

One of the main issues concerning the use of heat pumps (HPs) is associated to their primary energy consumption. The performance of a HP is commonly quantified by the COP and SPF_{hp} coefficients, both define the ratio between the heat produced by the HP and the primary energy consumed by it. COP refers to instantaneous values whereas SPF_{hp} considers annual values (Fraga et al., 2018; Hernández-Magallanes et al., 2018; Borge-Diez et al., 2015; Kontu et al., 2019).

The above mentioned primary energy that a heat pump uses depends on the way of powering the compressor shaft. In this regard, heat pumps are usually categorized as electric heat pumps (EHPs) or gas engine heat pumps (GEHPs) (Lian et al., 2005). Most of the current heat pumps models are driven by electric motors that use electricity as motive power. Regarding gas engine heat pumps, these equipment's are recently used as an alternative of the conventional electric heat pumps. They use clean energy such as natural gas, liquefied petrol gas (LPG) or biogas and are able to recover the waste heat released by the engine to enhance the total heating capacity.

Efficiency of electric engines is reasonably high (around 90%), while the energy efficiency of a gas engine is about 30–40%. However, these devices allow recovering the waste heat of the fuel combustion in a range of 60–80% thanks to the engine cylinder jacket. The efficiency difference between both models also affects the performance coefficient (COP) of each one. Thus, given that this coefficient plays a fundamental role in the design of the geothermal loop, the selection of one or the other model (EHP or GEHP) will determine the global drilling dimensioning. Table 1 presents the main characteristics of the mentioned geothermal heat pumps.

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Nomenclature

Acronyms

GSHP	Ground source heat pump
GEHP	Gas engine heat pump
EHP	Electric heat pump
nZEB	Nearly zero energy building
HP	Heat pump
COPCo	efficient of performance
SPF_{hp}	Heat pump seasonal performance factor
LPG	Liquefied petrol gas
EPBD	Energy Performance of Buildings Directive
EED	Earth energy designer
IDEA	Institute for the Diversification and Energy Saving
HCV	Higher calorific value

This research focuses on presenting a technical analysis of the main differences in a very low geothermal system depending on the heat pump contemplated. This analysis is based on the calculation of a ground source heat pump system in three different areas. For each of these study areas, three heat pump alternatives will be considered: (i) electric heat pump, (ii) gas engine heat pump using natural gas and (iii) gas engine heat pump using biogas.

1.1. Nearly zero energy buildings

The European Union is committed to developing a sustainable, competitive, secure and decarbonised energy system. In this regard, the Energy Union and the Energy and Climate Policy Framework for 2030 pretend to reduce greenhouse gas emissions further by at least 40% by 2030 as compared with 1990, increasing the use of renewable energies. The building stock plays an important role in this field since it is responsible for approximately 36% of the total of CO_2 emissions in the Union. In order to achieve an increase of the energy efficiency in this sector, the transformation of existing buildings into nearly zero-energy buildings is of extreme importance. The principal instrument to achieve that aim is the Energy Efficiency Directive that is focused on increasing the energy efficiency at EU level (DIRECTIVE (EU), 2018).

A nearly zero-energy building (nZEB) is defined as a building having a very high energy performance, requiring nearly zero or low amount of energy for covering the energy demand associated with a certain use. That low amount of energy should be covered to a large extent by renewable sources (D'Agostino and Parker, 2018; Deng et al., 2014; Zhang et al., 2016). The ratio of renewable energy production depends on the country and widely varies from one to another Member State. The 2010 Energy Performance of Buildings Directive (EPBD), (DIRECTIVE, 2010) established for all new building in the European Union to accomplish the nearly zero-energy buildings norm from 1 January 2021.

Definitions of nZEB were set in 15 Member States with different terms of what they consider and the values they prescribe. Thus, some countries establish the maximum primary energy consumption, others the maximum carbon emissions and there are others that measure primary energy use of a reference building or the minimum energy efficiency that the building should reach. Regarding the maximum primary energy of a new nZEB, the annual range for the Member States usually reaches values from 20 kW h/m^2 to 220 kW h/m^2 in the case of residential buildings, being the range of 45–50 kW h/m^{2}y the most common one for a large number of areas. These limits are mainly established for new buildings (residential and non-residential) and are rarely introduced for the existing ones.

Table 1
Principal characteristics of the heat pumps considered in this research, EHP and GEHP.

	EHP	GEHP
Engine performance	about 90%	about 30%
COP	4–4.5	1.5–1.6
Fluid temperature	High sensitivity of the evaporator inlet temperature	Low sensitivity of the evaporator inlet temperature
Energy consumption	Reduced electric consumption	High gas consumption
Refrigeration	–	Required
Heat recovery	–	Around 80%
Equipment cost	High	Very high
Operation costs	Dependent on the electric price of the area	Dependent on the gas price of the area
CO_2 emissions	Dependent on the electricity mix	Dependent on the gas fuel

From the technical calculations of all the assumptions considered in this research (electric heat pumps and gas engine heat pumps in three different areas), these scenarios will be evaluated in relationi to the Energy Efficiency Directive previously described. In this way, it will be possible to determine which options respect the energy requirements defined for a nZEB or how close they are of them.

2. Workflow description

As already mentioned in Section 1, the aim of the present research is to compare the conventional electric heat pumps and those pumps which use a gas engine, contemplating natural gas and biogas as fuel compounds. Hence, the dimensioning of a low enthalpy geothermal system has been made in three study areas for each of the heat pumps models considered. For an easier reader comprehension, the following Fig. 1 shows the general workflow followed in this study.

2.1. Selection and characterization of the study areas

As shown in Fig. 2, the European Directive 2009/28/CE (Directiva, 2009) differentiates the areas representatives of the typical European climates (warm, medium and cold climates).

According to the above classification, three study areas belonging to each of the mentioned climates were selected as part of the present research. These areas, graphically situated in the European map of Fig. 3, are described in Table 2.

In the consecutive thermal and geothermal calculations of each scenario, it is indispensable to know a series of characteristics of the areas previously expounded. Such characterization involves the description of the main geology formations that constitute the study areas

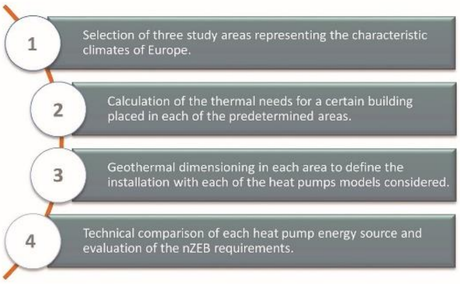


Fig. 1. Description of the workflow followed in the present research.

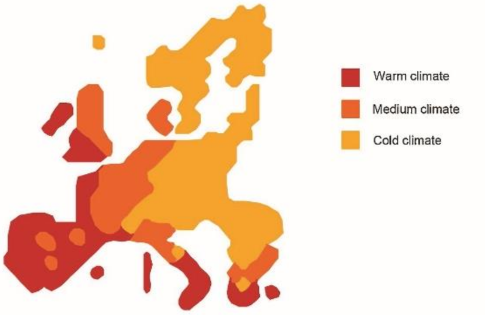


Fig. 2. Representative climates in Europe according to the European Directive 2009/28/CE (Directiva, 2009).

and their meteorological conditions. This information can be found in Appendix A.

2.2. *Definition of the building basis of the study*

With the aim of achieving the purpose of the study, a specific building was defined as the basis of the subsequent calculations in each of the set areas. This building, identical for all the study areas, is a two-storey building whose main dimensions are presented in Table 3.

3. Principal calculations

Although the procedure followed for the calculations in each study area is identical, results widely differ. Thus, the following subsections contemplate the three scenarios in a separated way.

Table 2
Description of the areas selected to address the present research.

Area	Locality	Country	Climate
1	Ancona	Italy	Warm
2	Edimburgh	Scotland	Medium
3	Karlstad	Sweden	Cold

Table 3
Description of the building selected to carry out the present study.

Building main dimensions	
Total Surface (m^2)	173.38
Height (m)	6.25
Windows Surface (m^2)	31.00
Roof Surface (m^2)	86.69
Floor Surface (m^2)	86.69

3.1. *Determination of the energy demand*

Once known the geological and climatological conditions of the study areas, the next step is the estimation of the energy demand for the building previously defined in each area. Whit that aim, a tool based on the Standard Law UNE-EN ISO 13790:2011 was implemented (AENOR, 2011). This tool calculates the annual energy demand of a building in a certain area by the previous introduction of the building dimensions and the monthly mean temperatures of the place. The following Table 4 presents the results obtained for each study area. It must be mentioned that for the places considered in this research, only heating demand was required. It is also believed that calculations would be identical in cooling mode and they would lead to draw the same final conclusions.

Additionally, the tool monthly itemises the thermal gains and losses corresponding to the thermal transfer, ventilation and solar and internal gains. As an example, Fig. 4 shows the simulation for area 1.

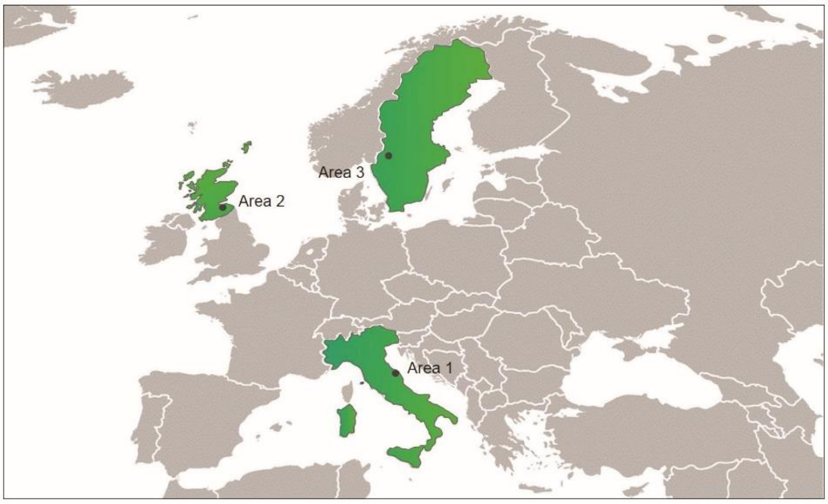


Fig. 3. Location of the study areas considered in this research.

Table 4
Annual energy demand of the building placed in each of the study areas.

	Heating Demand (kWh/year)
Area 1	39,088
Area 2	71,742
Area 3	88,882

3.2. *Geothermal evaluation*

The final purpose of this section is determining the geothermal schema (number of borehole and total drilling length) required in each of the assumptions previously described (electric and gas engine heat pumps in each study area). The specific geothermal software "Earth Energy Designer" (EED), developed by Blocon Software, was implemented for the geothermal dimensioning of each solution. Since the geothermal heat pump design determines the remaining parameters, an individual geothermal calculation was required for each heat pump in each study area.

3.2.1. *Electric heat pump*

In the first place, EED software requires the introduction of a series of parameters concerning each area (thermal demand and climate and geological conditions) and the main installation characteristics (heat exchanger design, working fluid…). One of the requested data is the "Seasonal performance factor" (SPF) which makes reference to the heat pump used in the installation. In the present case, using an electric heat pump, this factor usually takes a value of around 4-4.5. Thus, in this first scenario, a SPF of 4.5 was introduced in EED software for the three areas contemplated in this research. Fig. 5 presents the stage of EED calculation process where the annual demand and SPF are required. Information presented in the mentioned Fig. 5 belongs to area 1.

Applying this software in each area by the introduction of the specific parameters of each case (keeping the SPF of 4.5), the geothermal characterization of each area with the use of electric heat pump is presented in Table 5.

Once known the drilling schema required in each of the study areas, the electric heat pump of each case was defined. First of all, peak power was obtained from the initial demand and the operating hours of each assumption. This power is then oversized since the ground contribution is not exactly known and it could be possible to find additional thermal losses in the building or unexpected energy demands. A habitual practice is to increase the heat pump power on the basis of 35–50 W per m^2 of building area for new constructions (as the building considered in this research). Given that the building is identical for all the cases, a value belonging to the range 35–50 W/m^2 was taken in function of the climatic conditions of each area. In this way, the characteristics of the electric heat pump system related to each area can be found in the following Table 6.

After obtaining the nominal power of each system, a commercial heat pump model was chosen for each area from one of the main producers of electric geothermal heat pumps (Integral systems of heating/cooling with renewable energies, 2018). The electric heat pumps selected in each case are defined by a certain COP for some specific conditions (inlet temperature of 0 °C and outlet temperature of 35 °C). With the aim of estimating the real COP for the conditions given in each area, the temperatures of the working fluid during the installation service life must be known. This information is obtained from the simulations provided by EED software. From these simulations, a medium temperature value (for service life of 30 years) was calculated for each study area. Fig. 6 shows the fluid temperature simulation for area 1. For the rest of areas the simulation methodology was identical.

UE 813/2013 regulation (REGLAMENTO (UE), 2013) establishes a certain relation between the COP and the heat pump fluid inlet temperature. According to this law and the fluid temperatures of each location (deduced from EED simulations), real COPs for each heat pump selected were estimated. Finally, the electricity consumption required to cover the annual thermal needs of each assumption was calculated. All this information is shown in Table 7.

3.2.2. *Gas engine heat pump: natural gas*

The dimensioning process followed in this second assumption is also based on the use of EED software. Operational conditions are the same than in the last case (electric heat pump) and only the SPF must be modified. For gas engine heat pumps, this factor is significantly reduced to values around 1.5 since the amount of fuel consumed relative to the supplied power is higher than in the electric heat pumps. A SPF of 1.5 means a lower ground contribution and a higher heat pump supplying. In the case of electric heat pumps the relation between the ground and the heat pump contribution is 3.5/1. On the contrary, in a gas engine heat pump, the previous ratio is reduced to 1/0.5, meaning that the

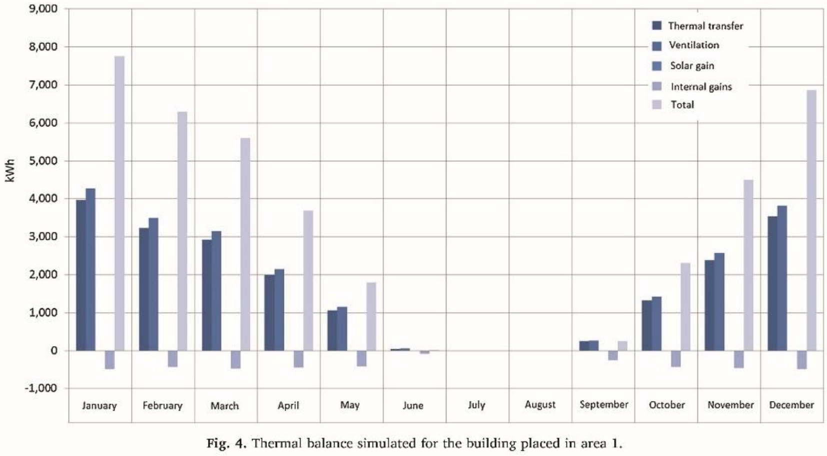
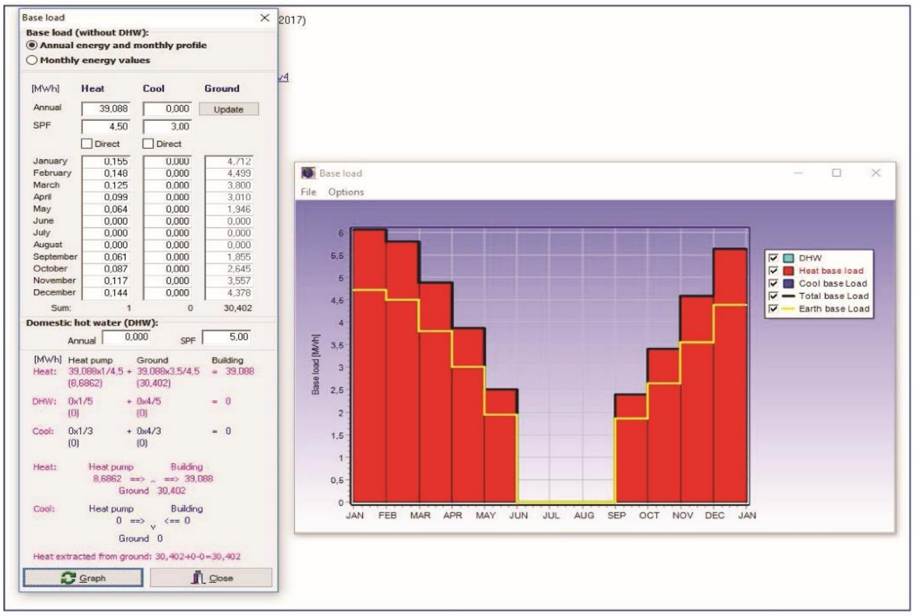


Fig. 4. Thermal balance simulated for the building placed in area 1.



Base load

Base load (without DHW):
● Annual energy and monthly profile
○ Monthly energy values

[MWh]	Heat	Cool	Ground
Annual	39,088	0,000	Update
SPF	4,50	3,00	
	☐ Direct	☐ Direct	
January	0,155	0,000	4,712
February	0,148	0,000	4,499
March	0,125	0,000	3,800
April	0,099	0,000	3,010
May	0,064	0,000	1,946
June	0,000	0,000	0,000
July	0,000	0,000	0,000
August	0,000	0,000	0,000
September	0,061	0,000	1,855
October	0,087	0,000	2,645
November	0,117	0,000	3,557
December	0,144	0,000	4,378
Sum:	1	0	30,402

Domestic hot water (DHW):
Annual 0,000 SPF 5,00

[MWh]	Heat pump		Ground		Building
Heat:	39,088x1/4,5 (8,6862)	+	39,088x3,5/4,5 (30,402)	=	39,088
DHW:	0x1/5 (0)	+	0x4/5 (0)	=	0
Cool:	0x1/3 (0)	+	0x4/3 (0)	=	0

Heat: Heat pump 8,6862 ==> ==> 39,088 Building; Ground 30,402

Cool: Heat pump 0 ==> <== 0 Building; Ground 0

Heat extracted from ground: 30,402+0-0=30,402

Fig. 5. EED calculation process requiring the thermal demand and SPF of area 1.

Table 5
Design of the geothermal system using electric heat pump in each location.

	Area 1	Area 2	Area 3
Number of boreholes	2	3	2
Borehole spacing (m)	30	20	30
Total drilling lenght (m)	227	446	376

Table 6
Characteristics of the electric heat pump system in each location.

	Area 1	Area 2	Area 3
Base load (kWh)	39,088	71,742	88,882
Annual operational period (h)	2,040	2,310	2,700
Power (kW)	19.16	31.06	32.92
Oversizing (kW)	6.07	7.28	8.67
System nominal power (kW)	25.23	38.34	41.59

ground must contribute with 1 part and the heat pump must provide 0.5 parts. Table 8 presents the results derived from the EED calculation using natural gas heat pumps.

The next step is, as in the previous alternative, the dimensioning of the natural gas heat pump from the initial energy needs and the expected operational hours. Since the ground contribution is lower in these systems (33% compared to 77% of contribution in electric heat pumps), the oversizing range of 35–50 W/m^2 previously applied is now reduced to 15–22 W/m^2 given that such additional power is not required in this case. Thus, depending on the climatic conditions of each area, a different value from the range 15–22 W/m^2 was applied. The description of the natural gas heat pump system of each area is presented in the following Table 9.

Once known the nominal power of the system, a gas engine heat pump was selected for each study area. Producers of these devices do not provide the fluid temperature for which the characteristic COP of them is achieved. The residual heat generated in a gas engine could be used to increase the inlet temperature of the working fluid. Additionally, the fluid temperature does not decrease as much as in the electric heat pumps since the ground contribution is not the same, so fluid temperature is commonly higher. For these reasons, the COP of these heat pumps is not so affected by the working fluid temperature. In this way, the COP provided for each heat pump model was directly taken for the corresponding calculations of the natural gas consumption according to the energy needs of each scenario. It is important to highlight that this consumption was increased by 10% with the aim of compensating the additional energy these devices require during the starting mechanism. Table 10 presents the mentioned information for this second assumption.

3.2.3. *Gas engine heat pump: biogas*

The last assumption is based on the use of gas engine heat pumps aided by biogas. The principal difference regarding the above equipment's is that the internal combustion engine is not supplied by natural gas but biogas. As of today, it is not possible to find commercial gas engine heat pumps specifically designed to work with biogas. Therefore, the dimensioning process expected in this section must be addressed from the natural gas heat pumps previously described, considering that the natural gas and biogas consumptions will not be the same. In a natural gas heat pump, the natural gas consumption is lower than the one needed of biogas to achieve the same amount of energy. Since the biogas higher calorific value (HCV) is lower than the natural gas HCV, the volumetric consumption of biogas will be higher than the natural gas use to reach the same effective power.

According to the Institute for the Diversification and Energy Saving

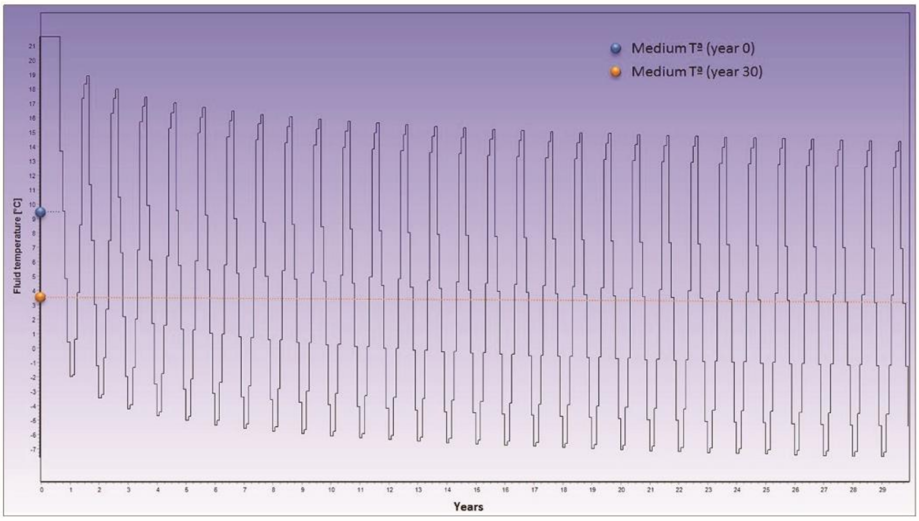


Fig. 6. EED fluid temperature simulations for area 1 using electric heat pump.

Table 7
Working fluid temperature, heat pump COP and annual electricity consumption in each study area.

	Area 1	Area 2	Area 3
Medium fluid temperature (°C)	6.62	6.00	4.25
Heat pump real COP	5.17	5.05	4.98
Annual electricity consumption (kWh)	7,560.54	14,206.34	17,847.79

Table 8
Design of the geothermal system using natural gas heat pump in each location.

	Area 1	Area 2	Area 3
Number of boreholes	1	1	1
Total drilling lenght (m)	114	199	173

Table 9
Characteristics of the natural gas heat pump system in each location.

	Area 1	Area 2	Area 3
Base load (kWh)	39,088	71,742	88,882
Anual operational period (h)	2,040	2,310	2,700
Power (kW)	19.16	31.06	32.92
Oversizing (kW)	2.60	3.12	3.81
System nominal power (kW)	21.76	34.18	36.73

Table 10
Gas engine heat pump COP and annual natural gas consumption in each study area.

	Area 1	Area 2	Area 3
Heat pump real COP	1.57	1.48	1.48
Annual natural gas consumption (kWh)	27,386.50	53,321.75	66,060.95

Table 11
Characteristics of the biogas heat pump system in each location.

	Area 1	Area 2	Area 3
Number of boreholes	1	1	1
Total drilling lenght (m)	114	199	164
Base load (kWh)	39,088	71,742	88,882
Annual operational period (h)	2,040	2,310	2,700
Power (kW)	19.16	31.06	32.92
System nominal power (kW)	21.76	34.18	36.73
Annual biogas consumption (kWh)	27,386.50	53,321.75	66,060.95

"IDAE" (Instituto para la Diversificación y Ahorro de la Energía, 2014), the biogas HCV is of around 46.21% lower than the natural gas HCV. In this way, the volumetric biogas consumption will be 46.21% higher than the natural gas one. In spite of this fact, the heat pump COP will stay constant given that it just depends on the thermodynamic aspect of the cycle. It means that the energy consumption to produce a heat unity is the same, although the volumetric gas consumption is higher. Thus, the dimensioning of these devices and the whole geothermal system will be identical to the process described in the previous section for the natural gas. The design of the geothermal installation for each area is then summarized in Table 11.

4. Discussion

This paper presents an evaluation of several energy sources to supply a geothermal heat pump in a series of places. In the first place, a global discussion of the technical parameters obtained from the set of calculations (Section 3) is required. Regardless of the study area, the technical differences between the electric heat pumps and the gas engine heat pumps are significant.

The use of an electric heat pump in the geothermal system results in a series of important facts:

- The characteristic high COPs of these devices mean a high ground contribution. Therefore, the temperature of the working fluid must be thoroughly controlled during the whole operational period to avoid too low temperatures that could affect the right heat pump operation. Additionally, the notable ground contribution produces high drilling lengths.

- As a result of the mentioned above (high COPs and ground contribution) the electricity contribution is significantly reduced.
- The economy of the process will depend on the electricity price of the area where the system is planned to be placed. In the same way, the environmental field will be also determined by the origin of the electricity used to supply the heat pump and this fact equally depends on the specific area. Both aspects, the economic and the environmental dimensions, will be evaluated in a future research considering the particular characteristics of the three study areas considered here.

Regarding the gas engine heat pumps implemented in a geothermal system, some remarks can be extracted from this work:

- COPs of these heat pumps are lower and thus, the ground contribution is also lower. In this way, the temperature of the working fluid does not require such a comprehensive control because too low temperature levels are not expected in these systems. As a consequence of the above, the drilling lengths are generally lower than the ones required in the traditional electric heat pump systems.
- Since the ground contribution is not high, the gas engine heat pump must cover a large proportion of the total energy demand. Therefore, the gas consumption is considerably high.
- As in the case of the electric heat pumps commented before, the economy of the system will be conditioned by the prices of the gas used as heat pump fuel (natural gas and biogas in this research) that will be specific to each area. In relation to the environmental dimension, it will also depend on the gas selected. Since the natural gas composition is similar in most places, its environmental impact will be equally the same (independent of the place). With respect to the biogas, the emissions associated to this gas are usually considered as zero because of the neutral cycle contemplated during its production.

Focusing on this specific work, Fig. 7 shows the differences among the three heat pumps (electric heat pump, gas engine heat pumps aided by natural and biogas) in each study area from the points of view of the number of boreholes, drilling length, annual energy consumption and real COP.

Analyzing the above Fig. 7 that represents the main results obtained from this work, it is possible to deduce the following statements:

- Gas engine heat pumps present the same technical results for both assumptions, using natural gas or biogas. This is because the devices are the identical, and the only difference makes reference to the fuel used in each case. Thus, as explained in section 3, the energy use will be the same but the volumetric consumption will be much higher for the biogas since it has a lower higher calorific value. The rest of differences between both scenarios will depend on the economic and environmental characteristics of the area where these systems were planned to be installed.
- In regards to the first parameter represented in Fig. 7, the number of boreholes required the geothermal scenario that uses EHP is 50% higher in areas 1 and 3 and 66.7% in area 2 compared to the GEHPs.
- From the drilling length point of view, EHP also requires a higher total drilling length in comparison to the GEHPs. For area 1, this length is 49.78% higher using EHP, 55.38% for area 2 and 53.99% for area 3.
- Comparing now the annual energy consumption, as seen in Fig. 7, this factor is considerably higher when using GEHPs. In area 1, the consumption of gas is 72.40% higher than the electricity use, 73.36% in the case of area 2 and 72.98% in area 3.
- Finally, the real COPs of each system are evaluated. For each scenario (EHP and GEHPs), COPs are quite similar in the three study

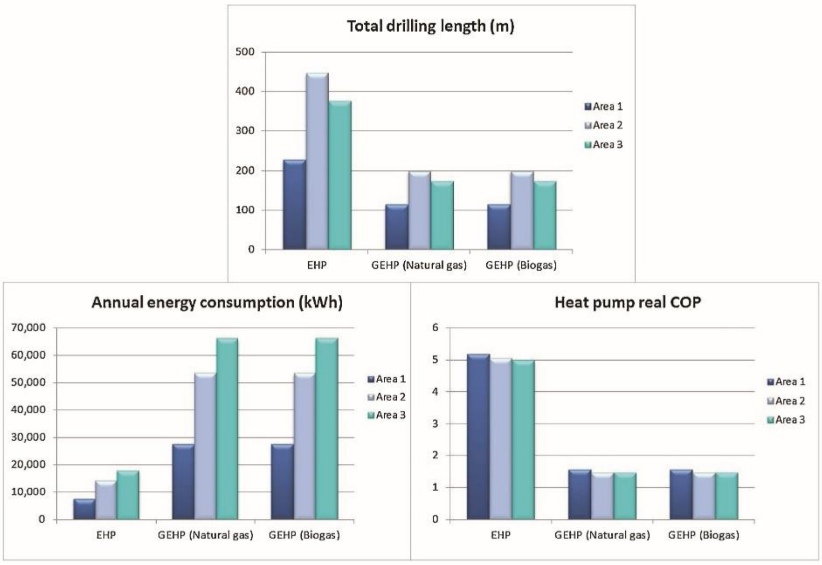


Fig. 7. Comparison of the heat pumps models considered in this research based on the main results obtained before.

Table 12
Maximum primary energy ranges according to the national nZEB definitions. *Still to be approved, **National nZEB Plan (DIRECTIVE, 2010).

	Area 1	Area 2	Area 3
Maximum primary energy [kWh/m^{2}y] recommended range	45-50*	44**	30-75**
Oversized maximum primary energy value [kWh/m^{2}y] considered for the study	65	57.2	97.5

Table 13
Maximum annual primary energy for the building of the present research in each area.

	Area 1	Area 2	Area 3
Maximum annual primary energy [kWhy]	11,269.70	9,917.34	16,904.55

Table 14
Annual primary energy consumption of the geothermal heat pump for each energy source in each study area.

	Area 1	Area 2	Area 3
Annual electricity consumption (kWh)	7,560.54	14,206.34	17,847.79
Annual natural gas consumption (kWh)	27,386.50	53,321.75	66,060.95
Annual biogas consumption (kWh)	27,386.50	53,321.75	66,060.95

Table 15
Differences between the maximum primary energy according to nZEB regulation and the consumption of each energy source in each study area.

	Area 1	Area 2	Area 3
Geothermal electric heat pump	✓ −3,709.16	✗ +4,289.00	✗ +943.24
Geothermal gas engine heat pump	✗ +16,116.80	✗ +43,404.41	✗ +49,156.40
Natural gas boiler	✗ +31,727.10	✗ +68,998.86	✗ +80,865.65

areas. However, differences between the heat pumps models are considerable. COP of the system using EHP in area 1 is 69.63% higher than using GEHPs, 70.69% in area 2 and 70.28% in area 3.

For all the parameters evaluated before, differences between heat pumps are almost stable regardless of which study area is taken into account.

4.1. NZEB regulation

As mentioned in the introductory section, some energy requirements are defined for new and existing residential and non-residential nZEB. Since the basis of the present research is a single family house, the energy indicators that must be taken into account are those referring to new residential nZEB. This numeral indicator is expressed in terms of maximum primary energy in kWh/m^{2}y and as already said, usually reaches a value included in the range of 45–50 kW h/m^{2}y. However, each Member State has own energy requirements. Focusing on the countries selected for the present research, the maximum primary energy for a new residential building in each of the study areas is contemplated in Table 12.

It is convenient to mention that the indicators presented in the above Table 12 make reference to general residential buildings. The building considered in this study is a single family house without surrounding buildings. This fact means a high initial energy demand as presented in Section 3 since the thermal losses are higher in this kind of buildings that have not external protections (surrounding structures). For this reason, the numerical indicators of Table 12 have been oversized to consider the negative aspect of a single house. Thus, numerical indicators (maximum value of the range) of Table 12 were increased in a 30%.

Additionally, in the case of Italy (study area 1), the numerical indicator regarding the maximum annual primary energy is still to be approved. For this reason, the most common indicator (45–50 kW h/m^{2}y) was implanted in this area.

The aim of this section is to compare the maximum primary energy annually required in each of the assumptions contemplated in this study (energy source and area). Based on the calculations of Section 3, the consumption of the primary energy (electricity, natural gas or biogas) for each study area is known. Thus, these data will be compared with the ones defined by the National nZEB Plan (Table 12). According to the oversized parameters of Table 12, for the building included in this study (with an area of 173.38 m^2), the maximum annual primary energy for each area would be limited to the values presented in the following Table 13.

These values would be the limit of primary energy consumption for the building placed in each of the study areas. Remembering the previous section *3.2. Geothermal evaluation*, the consumptions of primary energy in function of the energy source used in the geothermal heat pump were for each area (Table 14):

Observing both Tables 13 and 14, it is easily observable that only using the electric heat pump in area 1, the maximum annual primary energy indicator could be respected.

However, if instead of considering one of the geothermal solutions contemplated before, a traditional energy source was used, the annual consumption would be completely different. If the building of the study was supplied by a common gas natural boiler, the annual energy consumption would correspond with the energy demand already calculated incremented in a 10% because of the efficiency these equipment's have (around 0.9). In this way, the natural gas consumption for a common boiler would be; 42,996.80 kW h for area 1; 78,916.20 kW h for area 2 and 97,770.20 kW h for area 3. Considering the assumption of this research and a traditional natural gas boiler, the following Table 15 shows the differences of consumptions of each scenario in each area regarding the limits of maximum primary energy consumption of Table 13.

In the previous Table 15, there is an unique negative difference meaning that only in the area 1 using a geothermal heat pump system, requirements of a nZEB would be respected. For the rest of scenarios (presenting positive differences) the limits of the mentioned regulation are far from being achieved, especially using a common natural gas boiler.

5. Final conclusions

The present research is mainly constituted by a technical comparison of three different geothermal heat pumps. From a set of calculations in three study areas, some general and more specific differences between the mentioned systems could be deduced. In general terms, the EHP system allows for all the study areas the reduction of the annual heat pump energy consumption thanks to the high COPs these devices have. However, since the ground contribution is higher, using an EHP the temperature of the working fluid must be exhaustively controlled. On the contrary, the use of GEHPs reduce (in all the scenarios) the number of boreholes and hence the global drilling length of the geothermal system. COPs of these last equipment's are considerably lower as well as the ground contribution so that a thorough control of the working fluid temperature is not required. Regarding the fuel considered to supply the GEHPs, the only difference between them makes reference to the gas volumetric consumption which is much higher in the case of the biogas.

Besides the technical evaluation of the three heat pump models, the Energy Efficiency Directive about nZEB is discussed in this research. On this matter, the scenarios considered here (EHP and GEHP systems) and an additional one (traditional natural gas boiler) are analysed to determine if they respect the requirements of the nZEB regulation in each of the study area. Results show that only the electric heat pump system implemented in area 1 would meet the primary energy limits of the mentioned regulation. For the rest areas with EHP (area 2 and 3), the electricity consumption is close to the established limitations. In the case of GEHPs, the differences regarding the energy requirements of the law are notable (specifically for area 2 and 3) but these differences are especially high when the traditional natural gas is implemented.

It follows from all of the preceding that the compliance with the nZEB requirements that the Energy Efficiency Directive establishes could be feasible for some specific renewable systems (as the geothermal EHP). However, as this research proves, the regulatory compliance would be difficult for other systems of the same nature like the geothermal GEHPs, but it would be especially difficult using a non-renewable energy source, as the natural gas boiler.

Finally, it is also worth mentioning that, for the geothermal systems considered here, the energy requirements of a nZEB would be easily achieved by the implementation of different solutions; improved building isolations, heat recovery systems, active construction procedures such as the Trombe mur (BenYedder and Bilgen, 1991) or the increase of the heat pumps COPs, especially for the GEHPs.

It is also necessary to mention that the environmental and economic dimensions considered as fundamental for a complete comparison of the heat pump models will be included in a second part as a new scientific research.

Appendix A

See Tables A1 and A2.

Table A1
Characterization of the main geological formations that constitute the study areas.

Area	Geological Age	Geological formation	Thermal Conductivity (W/mK)
1	Tertiary	Non-consolidated rocks (gravel, mud and sand)	1.0
2	Cambrian Carboniferous	Basalts	1.7
3	Pre-cambrian and Paleozoic	Granites and gneisses	3.1

Table A2
Mean monthly temperatures in each of the study areas.

	Temperatures (°C)		
Month	*Area 1*	*Area 2*	*Area 3*
January	5.4	2.9	−3.8
February	6.9	3.0	−4.1
March	9.5	5.0	−0.4
April	12.9	7.5	4.2
May	16.8	10.2	10.2
June	20.8	13.1	14.7
July	23.3	14.8	16.2
August	23.1	14.4	15.3
September	20.0	12.3	11
October	15.8	9.5	6.7
November	11.3	5.7	1.5
December	7.1	4.0	−2.5

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