Techno-economic Assessment of a Geothermal Energy System for a Single Family House

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Abstract

This thesis examines installation of a geothermal energy system as an alternative sustainable solution. The thesis is divided in two parts: the first part studies the feasibility of the installation of a geothermal energy system regarding the technical specifications. The second part determines the profitability of the system. The system is meant to cover the hot tap water demand of a single family house. Geothermal properties of the area, power consumption of the house, technical specifications of the components forming the system are the parameters that make up the basis for the final solution. Furthermore, an economic assessment is performed in the second part, taking into account the costs, loans, increment of prices and payback times. The results indicated that, if only hot tap water is provided with geothermal energy, the system will not be economically profitable due to a payback time of about 22 years. If also space heating was provided with geothermal energy, the payback time decreases to 2 years. Therefore, retrofitting the existing diesel based system with a geothermal energy one might be a very attractive solution if the heat demand is sufficiently large and carefully assessed.

Language: English Key words: Techno-economic assessment, geothermal energy system, heat pump, Single family house, technical specifications, economics, payback time.

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Terminology and abbreviations

°C	Degree Celsius
mW/m^2	Milliwatt per square meter
HVAC	Heat, Ventilation and Air Conditioning
GHP	Ground Heat Pumps
DOE	Department of Energy
COP	Coefficient of Performance
UTM	Universal Transversal Mercator
SHW	Sanitary Hot Water
kW	Kilowatt (10^3 W)
L/day	Liters per day
Kg/L	Kilograms per liter
kJ/kg°C	Kilojoules per kilogram Celsius
kWh	Kilowatt hour
kJ	Kilojoule
Trnsys	Transient System Simulation Tool
L/person	Liters per person
kcal/kg°C	Kilocalorie per kilogram Celsius
ICG	Cartographical and Geographical Institute of Catalonia
VDI	Verein Deutscher Ingenieure (German association of engineers)
DN	Nominal Diameter
PE	Polyethylene
CPI	Consumer Price Index
CO_2	Carbon Dioxide
kJ/hour	Kilojoule hour
W/ m K	Watts per meter Kelvin
m	Meter
c€/kWh	Cents per kilowatt hour

1. Introduction

The sustainable development is increasing nowadays with the increasing global warming, the extinction of species, pollution and other environmental threats. In the present situation it is clear that the supply of energy is based on fossil fuels (coal, oil and natural gas). Alternative solutions have to be found to cover of this demand of energy.

In 2008, the global organization Greenpeace handed a report /1/ to the *Generalitat of Catalonia*, the government of Catalonia, in which it was stated that by the year 2050 Catalonia could cover the 100% of its own demand of energy with renewable energies. According to the study, Catalonia would be able to cover 17 times its own energy demand only with the use of renewable sources. The cost of production would have a much lower cost than its production. Also the first investment would be amortized in a period between 3 and 10 years time.

In the report it was said that the area of Lleida would have the biggest potential in the production of energy through geothermal energy, with other green alternatives like wind power, solar photovoltaic and thermo solar. Among these technologies the one with the more potential would be the geothermal energy, its potential can be seen in the Figure 1, map extracted from the *Cartographic and Geologic Institute of Catalonia (ICG)* /2/, where the temperature at a depth of 100 m is shown, this temperature is constant all over the year and its linked to the geothermal potential of the area.

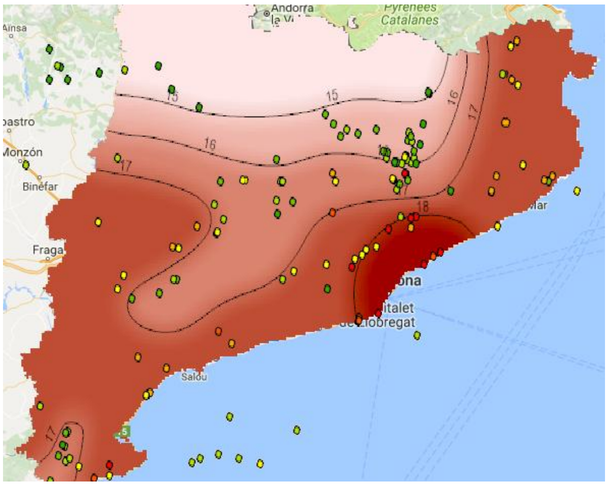

Figure 1: Map of the geothermal potential for extraction at 100 m depth (Source:ICG /2/)

The study of the geothermal energy in Catalonia and Spain was important in the 80's with the petrol crisis. The *National Geology and Miner Institute of Spain* made an document in which where compiled all the thermal points were compiled /3/. However at the beginning of the 90's the price of the petrol went down and all the investigation on this field was left aside. Nevertheless, the investment and installation of new geothermal heat pumps was not stopped at all and by the year 2010 in Catalonia there was the following amount of heat pumps installed shown in the Figure 2.

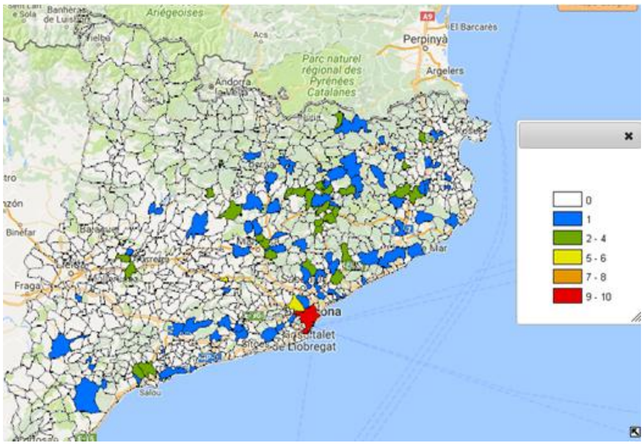

Figure 2: Number of geothermal heat pumps installed in Catalonia (Source:ICG /2/)

This project emerges out of the awareness of the current cost of the hot water consumption in the location that is going to be studied, Lleida (Catalonia, Spain). As an habitual consumer of SHW it has been raised some awareness about how much money is spend in this basic service. So that a sustainable alternative that generates economical benefits, or at least some savings, to the production of hot tap water is proposed. The plan is so to substitute the current diesel based system for the demand of sanitary hot water (SHW). Seeing the potential of the area regarding the geothermal energy production, this might be the most suitable energy source to implement.

Therefore, the purpose of this work is to study the feasibility of the installation of a geothermal energy system, so that a techno economic assessment for hot tap water in a single family house can be performed.

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2. Geothermal Energy in Households

2.1. Introduction to Geothermal Energy

Thanks to the heat energy stored in the Earth the geothermal energy is generated. The geothermal gradient, what stands for the difference of temperature between the core of the planet and the surface, elements visible in Figure 3, gives a continuous conduction of thermal energy in the form of heat. The adjective geothermal originates from the Greek roots, ‘’ge’’ meaning earth and ‘’thermos’’ meaning hot /4/.

The energy produced depends on the area and it can be exploited by the human beings to produce, like in this example, hot tap water.

In order to extract this energy there has to be a liquid that is heated inside a closed system. The geothermal source heat pump is the one who is doing this work, extracting heat from a source and transferring it into a building. Ground source heat pumps (GSHP) employ a heat exchanger in contact with the ground or groundwater to extract or dissipate heat.

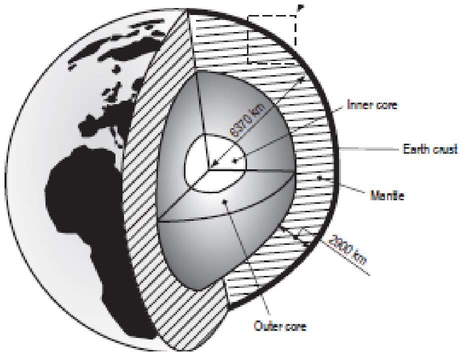


Figure 3: The Earth crust, mantle and core (Source: Geothermal Energy Utilization /5/

The resources can be divided into low, medium and high enthalpy (or temperature) resources /5/. The classification into the different systems varies depending on what source is chosen, as an example *Hochstein (1990) /6/* classifies Low enthalpy resources as the ones with a temperature below 125 °C, Intermediate as the ones between 125 and 225 °C, and high enthalpy resources the ones with a temperature above 225 °C.

2.2. Geothermal Gradient

Geothermal gradient is the increment of temperature registered as we go deeper in the inside of the Earth to the inner parts of it. The geothermal gradient observed in mainly all the surface of the Earth, know as *normal geothermal gradient,* is about 2.5-3 °C for every each 100m. However in some parts of the earth this increment is even bigger /6/.

It enables to determine the heat flux that can be transmitted from the inner parts of the cortex to the outer parts and represents the quantity of geothermal heat that can be extracted per surface area and is expressed in mW/m^2.

2.3. Geothermal Fluid

The heat stored in the rocks and ground is so diffuse that it can be extracted directly in an economic way, so that a fluid is needed to transport this energy to the surface through geothermal probes, horizontal collectors or water-air heat exchangers buried on the floor. The characteristics of the geothermal fluids, including the chemical, the temperature and the quantity of non-condensable gases can affect the design of the energy system /6/.

2.4. Geothermal Heat Pump

This is the device that extracts the heat from the ground at a relatively low temperature, it increases its temperature through a consumption of electricity to enable its use in HVAC systems. This technology is used in low temperature sources (< 30 °C), present in any surface all around the world. According to the Department of Energy of the United States (DOE) the geothermal heat pumps use between 25 % and 50% less electrical energy than the conventional HVAC systems /7/.

2.5. Types of geothermal Heat Pump Systems

There are four basic types of ground loop systems. Three of these -- horizontal, vertical, and pond/lake -- are closed-loop systems. The other type of systems are the open-loop ones. Each one has its own advantages and depending on the place that it is planned to install a geothermal system, the most suitable solution would depend on the characteristics of each type of the system.

2.5.1. Closed – Loop Systems

Most closed-loop geothermal heat pumps circulate an antifreeze solution through a closed loop -- usually made of plastic tubing -- that is buried in the ground or submerged in water. A heat exchanger transfers heat between the refrigerant in the heat pump and the antifreeze solution in the closed loop. The loop can be in a horizontal, vertical, or pond/lake configuration /8//9/.

2.5.2. Horizontal (Closed – Loop Systems)

This type of installation is generally most cost-effective for residential installations, particularly for new construction where sufficient land is available. It requires trenches at least four feet deep /8//9/.

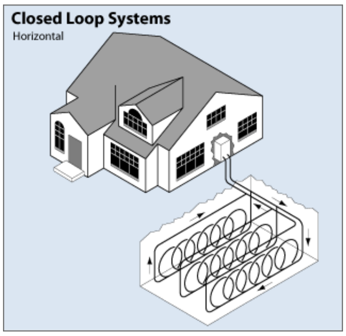


Figure 4: Closed loop system (Horizontal)(Source:U.S Department of Energy/7/)

2.5.3. Vertical (Closed – Loop Systems)

Large commercial buildings and schools often use vertical systems because the land area required for horizontal loops would be prohibitive. Vertical loops are also used where the soil is too shallow for trenching, and they minimize the disturbance to existing landscaping /8//9/.

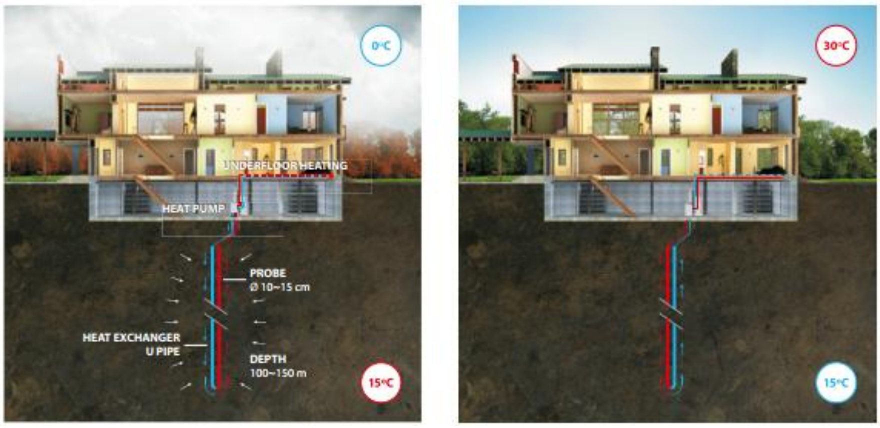


Figure 5: Closed loop system (Vertical)(Source:FERROPLAST/18/)

Their depth varies between 60 and 200 meters and 10 to 15 cm in diameter. In this holes heat collectors are introduced and those collectors are more commonly named geothermal probes.

Normally these systems are used in low temperature systems, otherwise there are savings on space as there is little space occupied /8//9//10/.

2.5.4. Pond/Lake (Closed – Loop Systems)

If the site has an adequate water body, this may be the lowest cost option. A supply line pipe is run underground from the building to the water and coiled into circles at least eight feet under the surface to prevent freezing /8//9//10/.

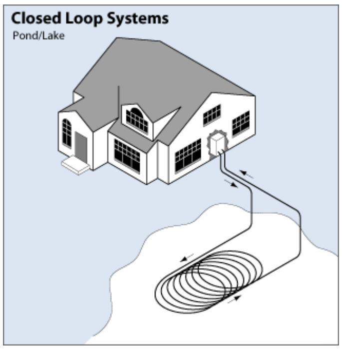


Figure 6: Closed loop system (Pond /Lake)(Source: U.S Department of Energy/7/)

2.5.5. Open – Loop Systems

This type of system uses well or surface body water as the heat exchange fluid that circulates directly through the GHP system. Once it has circulated through the system, the water returns to the ground through the well, a recharge well, or surface discharge. This option is obviously practical only where there is an adequate supply of relatively clean water, and all local codes and regulations regarding groundwater discharge are met /8//9//10/.

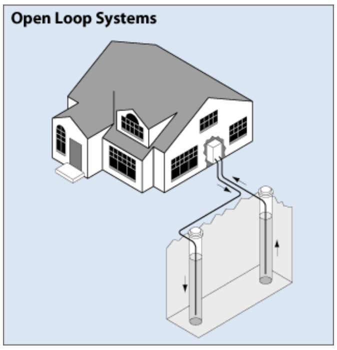


Figure 7: Open-Loop system(Source: U.S Department of Energy/7/)

2.6. Characteristics of a Geothermal Installation for Production of Hot Tap Water

Geothermal fluid: when the antifreezing liquid has to be chosen some characteristics have to be checked, such as the boiling point, which has to be below the target temperature , a high heat of vaporization, a moderate density in liquid from, a relatively high density in gaseous form, and a high critical temperature /11/.

COP: it stands for Coefficient of Performance. It is a ratio of useful heating or cooling provided to work required. In a GHP the different energies are the work (W) that is provided by the compressor, the heating power provided by the condenser (Q_h) and the heating power that absorbs the evaporator (Q_c) /12/.

According to the first law of thermodynamics:

$$Q_{h=}Q_c + W \quad (1)$$

In a ground heat pump the useful energy is the output flow from the heat pump (Q_h) which is obtained by increasing the pressure of the inlet geothermal fluid until the vapor temperature is reached. In order to increase the pressure there is a compressor in the heat pump, which uses electricity to provide the system the energy needed to increase the pressure, this input of energy to the system is work (W).

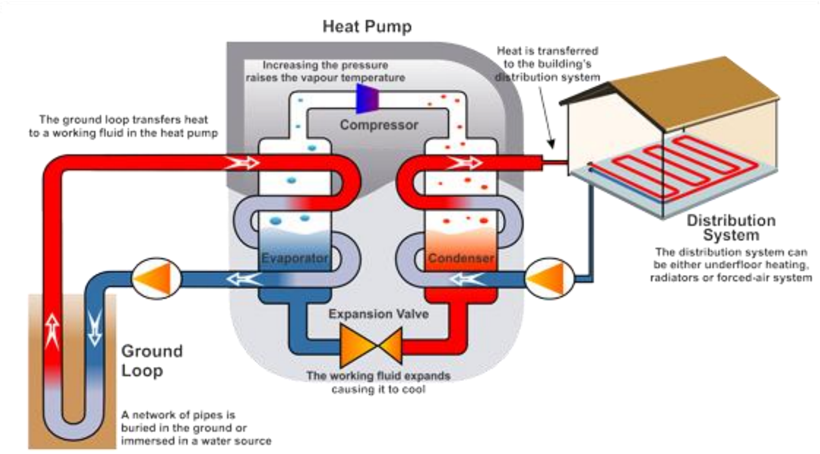


Figure 8: Heat pump cycle

$$COP = \frac{Q_h}{W} = \frac{Q_c + W}{W} \quad (2)$$

So the Coefficient is the ratio between the output (Q_h) and the input (W). As an example, if the COP of a heat pump is 3.5 it means that it provides 3.5 units of heat for each unit of energy consumed.

3. Methodology

3.1. Place of Study

The house and place of study is in Lleida (Spain), the UTM coordinates of the house are: 41.624704, 0.591167. It is a house of two adults and four children. The actual supply of hot tap water is through a diesel boiler. The application of the geothermal installation would not be such a big problem as there is enough space in the area to place it. In this house there are, as said before, two adults and four children, so the children would be considered as 2 persons, as they do not consume that much water. Below, photos of the house and the place of study are represented.

Figure 9: Place of study in the map

Figure 10: Photo of the house

Figure 11: City of Lleida in the Catalonia map

3.2. Technical Configuration of the System

In this first main part of this project, the technical configuration of the system will be determined, what means that the elements of the geothermal such as the heat pump, the heat absorption system and the geothermal fluid are going to be determined in order to do an economic assessment taking into account the market price of these elements and the costs of installation of them. Besides these elements have to meet certain specifications that would lead to the covering of the demand of hot tap water of the building.

3.2.1. Heat Pump

In order to choose the heat pump is necessary to know which is the consumption of SHW so the amount of power consumed to heat up the water can be known.

The energetic demands of the house depend on many factors. In order to determine the consumption of SHW in the building it is going to be used different calculations methods. By applying different methods are taken into consideration different factors to calculate the energy demand. Once the calculations are made, the data is going to be compared and the most restrictive consumption it is going to be chosen, what means that the highest consumption in kW is going to be considered as the current consumption.

First Method (Technical Building Code & Ecoefficiency Decree)

In the first calculation method the *Technical Building Code* /13/and the *Ecoefficiency Decree of the Generalitat de Catalunya* /14/ are going to be used, using from it the calculus methodology and the data for these calculations. The data extracted from both documents is the same, and the data of interest is the water consumption per person:

The names resources /13/ /14/ show the consumption per person of sanitary hot water at a reference temperature of 60 °C. It results to be 28 L/day per person for a single family house. Applying then the first law of thermodynamics (equation 3) /12/ it is obtained the heat load (rate of heat transfer) for heating up the water.

$$\dot{Q} = V \cdot \rho \cdot c_e \cdot \Delta T \quad (3)$$

In the previous equation we have the total volume of water consumed per day (V) expressed in (L/day), the density of the water (ρ) expressed in (kg/L), the heat capacity of the water (c_e) being (4.18 kJ/kg·°C) and the difference of temperature (ΔT) expressed in (°C).

Having this equation, the values of some of the previous parameters have to be calculated.

First of all the volume of water consumed per day can be calculated like:

$$V = nº\ people\ x\ daily\ consumption\ of\ water\ per\ person \quad (4)$$

Afterwards it is determined the temperature difference, that is the difference between the temperature of the water in the city water supplying system and the temperature that is wanted to be reached, which is going to be 60 °C. Looking at the *Technical Building Code /13/* we find the monthly average temperature of the cold water in Lleida, that is 7°C in the coldest months and 20°C in the hottest.

The calculus of the named difference of temperatures is:

$$\Delta T = (T_{hot\ water} - T_{cold\ water}) \quad (5)$$

Knowing all this data can be determined the heat load applying the equation (3).

Then is needed to know the power consumption, which can be obtained by applying the conversion 1 kWh=3600 kJ to the found heat transfer, and then multiplying the daily heat transfer by the number of days of the month. Following all this procedure it will be obtained the power consumption per month for the SHW system in kWh/month. Applying finally the equation 6 it is going to be known the power needed, so the output power of the heat pump (it is considered 8 hours of consumption of hot tap water).

$$\textbf{Total SHW power (First method)} = \frac{\dot{\mathbf{Q}}\ (\mathbf{kWh/month})}{\mathbf{SHW\ usage}\ (\frac{\mathbf{hours}}{\mathbf{month}})} \quad (6)$$

Second Method (Trnsys)

Another method to calculate the energy demand in order to provide SHW to the building is using the software called Trnsys (Transient System Simulation Tool). With this too the water consumption per day will be simulated, and it will be done according to an estimated amount of hot water consumption per day, taking into consideration that this amount of water is consumed during the time of 8 hours of usage of hot tap water. It is considered that the temperature of the cold water is 7 °C, the temperature during the month of January, when it would be harder to heat up the water. So having this in mind it is simulated the system in the software and it is extracted the information needed.

Third Method (Catalan Institute of Energy)

The last calculation method is done according the procedure of the *Catalan Institute of Energy* /15/. This method is similar to the one described in the first calculation method, with some differences in the assumptions taken, and the data source.

First of all is calculated the volume of hot tap water consumed per building with the equation 7:

$$V = f * N * n * v \ (7)$$

Where:

f = simultaneity factor (given to be 1)

v = SHW consumption per person (given to be 55 L/person)

n= number of people in each building

N = number of households in each building

Besides is calculated the difference of temperature between the inlet and the outlet, using the same equation than in the first method (equation 5). Taking into consideration that the temperature of the hot water is 45°C this time. The temperature of the cold water is given here by table 1:

Table 1: *Temperature of the cold water in Lleida*

	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sept.	Oct.	Nov.	Des.	Avg.
Barcelona	8	9	11	13	14	15	16	15	14	13	11	8	12
Girona	6	7	9	11	12	13	14	13	12	11	9	6	10
Lleida	5	6	8	10	11	12	13	12	11	10	8	5	8
Tarragona	6	7	9	11	12	13	14	13	12	11	9	6	10

Applying the equation 8 is found the energy demand per day:

$$Q = V * \delta * c_e * \Delta T \quad (8)$$

Where:

V = volume of hot tap water consumed per building

δ = density of the water (1 kg/L)

c_e= specific heat of the water (4.18 kJ/kg°C)

ΔT = temperature difference (°C)

Then dividing this result (kWh/day) into 8 hours of usage of SHW per day it is obtained the power that the heat pump would need to supply.

Selection of the Heat Pump

Once the output of the heat pump is determined then it has to be chosen a model that meets the requirements. The company that is going to be chosen is Vaillant /16/, which provides a range of different heat pumps according to the needs. In order to choose the correct one is going to be checked the technical specifications they provide, especially the heating output of the heat pump, which is the value calculated in the last part.

3.2.2. Geothermal Fluid

In order to determine the geothermal fluid that has to be used in the circuit it is necessary to check the specifications given by the company. There is given the type of geothermal fluid that is going to be used. Furthermore, in order to see what properties will have the fluid in the operation conditions some features of the geology are going to be checked.

The fluid to be chosen has to have antifreezing properties so when the temperature of the soil is the most cold, it does not freeze so that the system can continue operative. The antifreeze fluid is mixed with water when is used in the circuit.

To check the properties of the fluid as mentioned previously, it is going to be checked the *ICG* (*Cartographical and Geographical Institute of Catalonia*) map of surface temperatures/2/ (Figure 12), so it would be seen at what temperature the fluid would be working on its operation environment.

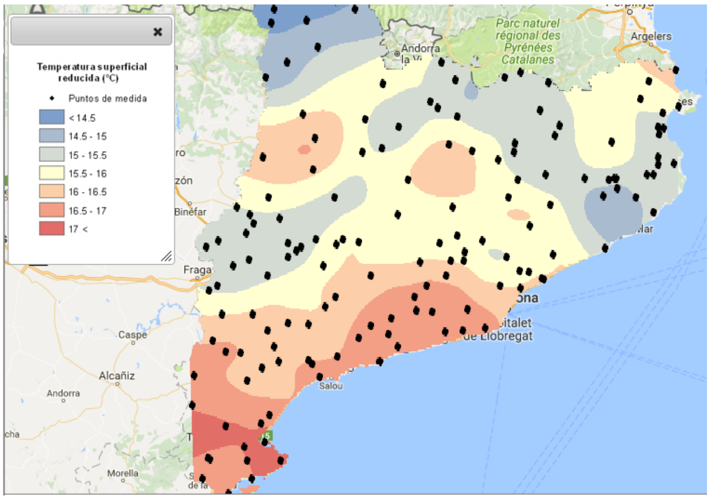
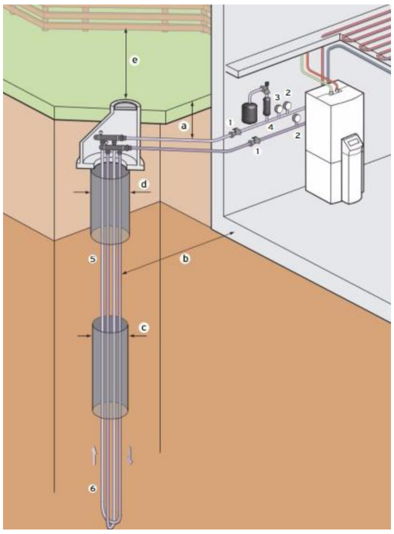


Figure 12: Surface temperature in Catalonia (Source: ICG/2/)

Then properties such as the thermal conductivity, specific heat and boiling point can be checked knowing that temperature and with the data given by the manufacturers of antifreeze fluids.

3.2.3. Heat Absorption system

The heat absorption system is chosen according the instructions given by the manufacturer, then according to the conductivity of the soil it has to be chosen one type of system. This system is the one that is going to hold the flow of the geothermal fluid, which would bring the heat from the soil to the heat pump.



1. Closing valve
2. Temperature indicator
3. Pressure indicator
4. Compensation deposit for the saline solution
5. Double U probe
6. Invertion head

Figure 13: Elements of the piping system (Source: GeoTherm Vaillant manual/19/)

The element to be dimensioned is the length of the double U probe, which would depend on the conductivity of the soil (λ). Therefore it is going to be checked again the ICG website where now the map of geothermal conductivity of the soil (Figure 14) is the one of our interest.

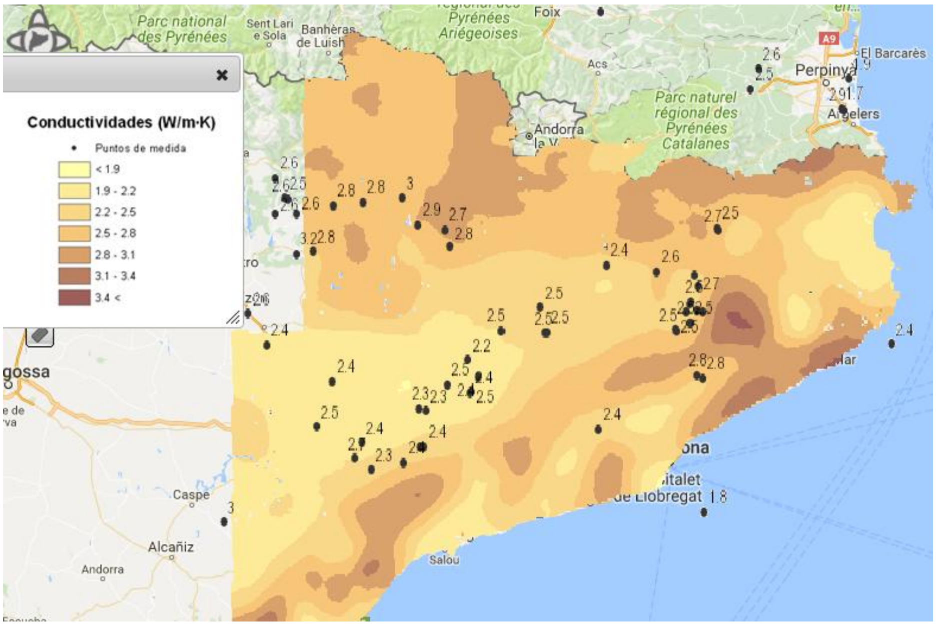


Figure 14: Conductivity of the soil in Catalonia (W/m·K)(Source: ICG /2/)

With this data and the VDI 4640 /17/, which is a document where guidelines to the dimensioning and use of thermal energy used in the European countries, can be know the extraction rate for unit of depth. The geothermal probes manufacturer chosen gives some guidelines based on the VDI 4640, so this is going to be the criteria to follow in order to dimension the probes. The table 2, only valid for vertical heat extraction, gives the named rate according to the conductivity of the ground:

Table 2: Specific extraction rate of boreholes for heating power <30 kW(Source: Norm VDI 4640, FERROPLAST /18/)

THERMAL EXTRACTION VERTICAL CATCHMENT SYSTEM	OPERATING HOURS PER YEAR	
TYPES OF SOIL – GENERAL VALUES	1800 h	2400 h
Inappropriate, Dry sendiment. Conductivity λ<1.5 W/mK	25 W/m	20 W/m
Normal, Consolidated rock. Conductivity λ<3 W/mK	60 W/m	50 W/m
Consolidated rock. High thermal conductivity. Conductivity λ>3 W/mK	84 W/m	70 W/m

Then ones we have the ratio of extraction can be calculated the length of the probe needed using the equations 9 and 10, extracted from the manufacturer's guidelines.

$$P_{cold(evaporator)} = \frac{P_{h(demand)}(COP-1)}{COP} \quad (9)$$

$$Vertical\ probe\ lenght(m) = \frac{P_{cold(evaporator)}(W)}{Extraction\ rate(\frac{W}{m})} \quad (10)$$

Then once we know the length of the vertical probe it must be determined the diameter of the double-U collectors. This can be done by looking which has to be the diameter of the piping system according to the heat pump instructions manual /19/ (table 3).

Table 3: *Dimensioning of a vertical geothermal probe (Modified from: Planning information geoTHERM /19/)*

Heat Pump Model	Heating capacity (kW)	Capacity of the evaporator (kW)	Drilling depth required (m)	Number of drillings	Depth of the well (m)	Piping system
VWS 61/2	6.7	5.6	190	2	95	DN32
VWS 81/2	9.0	7.5	255	3	85	DN32
VWS 101/2	12.1	10.1	344	4	86	DN32
VWS 141/2	16.1	13.4	455	5	91	DN32

Then as the diameter is known, can be chosen which specific model is desired from the catalogue of the geothermal probes manufacturer (Figure 15).

DOUBLE VERTICAL PE-100 GEOTHERMAL PROBE

Code	No. Pipes	Pipe Ø (mm)	Thickn. (mm)	Probe length (m)	Weight (Kg)
246005	4	32	2,9	80	87
246006	4	32	2,9	100	109
246007	4	32	2,9	125	136
246008	4	32	2,9	150	163
246009	4	40	3,7	80	136
246010	4	40	3,7	100	168
246011	4	40	3,7	125	210
246012	4	40	3,7	150	252

Figure 15: List of double vertical PE-100 geothermal probes (Source: FERROPLAST/18/)

Finally to know the total length of the system, following the advice of the manufacturer about the distance between the borehole and the building, can be calculated the total length of the piping system (heat absorption system) with the equation 11.

$$Length\ piping\ system = vertical\ probe\ length + borehole\ distance\ from\ building \quad (11)$$

According to the geothermal probes manufacturer the borehole has to have an specific diameter in a range. So a diameter of the driller has to be chosen according to this criteria. Furthermore, ensure that the probe is not going to move inside the borehole it has to be chosen an infilling material. This material has to have a good conductivity; otherwise not enough heat would be transferred to the geothermal fluid leading to a malfunctioning system.

3.3. Economics

In this chapter it is going to be determined the cost of the installation of the geothermal system in this building, besides it is going to be compared the annual cost of the operation of the new system in comparison with the old one running on diesel.

In order to calculate the cost of running the diesel based boiler it is going to be necessary to be known the annual consumption for the SHW (calculated for the selection of the heat pump), the Coefficient of Performance and the price of the energy produced with diesel, the CPI and other additional costs. With all this data it is going to be known the total cost per year.

To see if the new geothermal system is economically viable, it is going to be calculated first the total cost of the installation, including the cost of the materials and components, adding to it the installation costs. Once the total cost of the installation is known, afterwards is calculated the annual cost of running the geothermal system. With this data, it will be calculated the payback time by taking off from the total cost of the installation the savings expected by using the geothermal system instead of the diesel based system.

At this stage is going to be considered the consumer price index (CPI), extracted from the *National Institute of Economy* /20/, what stands for the change of the price level of market basket of consumer goods and services. It will be useful in order to calculate the payback time taking into account that the price of the diesel as well the electricity to run the compressor in the geothermal heat pump will increase over the years.

In order to promote the realization of activities that favor the energetic saving, the improvement of the energy efficiency, the use of renewable energies and the reduction of the CO_2 emissions in the existent buildings, the Ministry of Energy and Tourism through the Institute of Diversification and Energy Saving, launched a program called PAREER-CRECE /21/ with a budget of 200 millions of Euros.

This program is meant to cover the actuations that are of the following typology: improvement of the energy efficiency of the thermal and illumination installations, substitution of the conventional energy by biomass in the thermal installations and the substitution of the conventional energy by geothermal energy in the thermal installations.

Among the beneficiaries of this programs are included the owners of existential buildings destinated to any activity either they are of a public or private kind of personality. This means that this building could ask for this monetary help to construct this energy system.

The received loan consists of two parts, one part is without counter-payment, so the money that is given does not have to be returned, this amount is up to a maximum of a 30% of the total cost of the total cost of the installation. The second part of the payment must be returned to the institution that is giving this loan in a maximum period of 12 years, the maximum amount of money given is 60% of the total cost of the installation. The type of interest of the loan given by the organization is only linked to the value of the Euribor. To calculate the payback time of the installation is going to be considered the best case, so the maximum amount of money is given. With the Excel function NPER that determines the number of periods needed to payback the money given in a loan knowing the amount returned in each period, the rate of interest, it is calculated the amount of money that should be paid each month to return all the money received in between the period of 12 years.

4. Results

4.1. Heat Pump

Tables 4 and 5 present the results from the heat pump determination based on the methods in 3.2.1.1.

Table 4: *Rate of heat transfer to heat up the water in a single building with 4 people at a consumption rate of 112 L/day and a reference temperature of 60 °C*

Month	T cold water(°C)	ΔT (°C)	$\dot{Q}$ (kW)
January	7	53	0.86
February	9	51	0.83
March	10	50	0.81
April	12	48	0.78
May	15	45	0.73
June	17	43	0.70
July	20	40	0.65
August	19	41	0.67
September	17	43	0.70
October	14	46	0.75
November	10	50	0.81
December	7	53	0.86

Table 5: *Monthly power and energy load for the heating up of the water*

Month	$\dot{Q}$ (kW)	Days	$\dot{Q}$ (kWh/month)
January	0.86	31	213.6
February	0.83	28	185.7
March	0.81	31	201.5
April	0.78	30	187.2
May	0.73	31	181.4
June	0.70	30	167.7
July	0.65	31	161.2
August	0.67	31	165.2
September	0.70	30	167.7
October	0.75	31	185.4
November	0.81	30	195.0
December	0.86	31	213.6

As can be seen in Tables 4-5, the maximum energy demand in one month is about 213.6 kWh/month. Then taking into account this monthly power consumption, and the consideration that the SHW system is going to be used 8 hours/day during the 31 days of January, the following results are obtained:

$$\textbf{Total SHW power (First method)} = \frac{213.6\text{kWh/month}}{31\text{ days/month x }8\text{ h/day}} = \mathbf{0.86\ kW}$$

Applying the **second method**, from the software Trnsys is extracted that the amount of power consumption is 3109 kJ/h (Figure 16), what means: **0.86 kW**

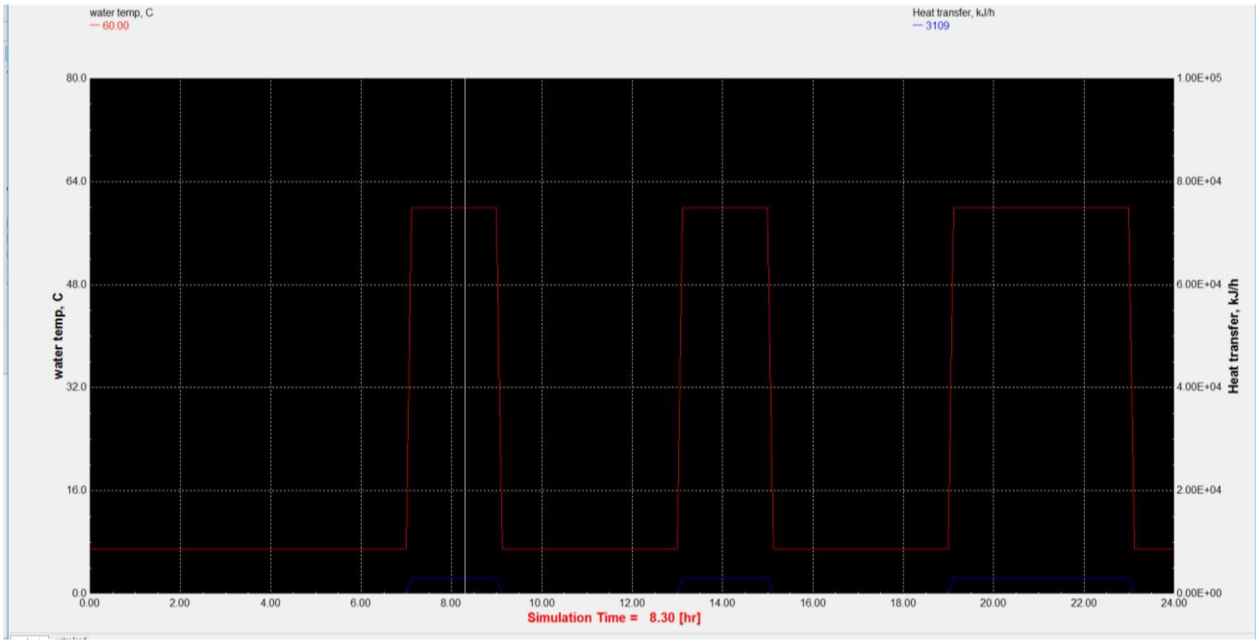


Figure 16:Power consumption for SHW (Source:Trnsys Software)

With the procedure in the **third calculation method** is found that the SHW consumption is 220 L/day, linked to it a power consumption of 10.22 kWh. Then if this power consumption is divided into the estimated 8 hours of consumption of SHW is found that the heat pump should have an output power of **1.27 kW.**

The most restrictive value is so **1.27 kW**, so it is needed to find a heat pump that covers this demand. The company Vaillant is providing a series of heat pumps with different specs (Figure 17) /22/ , and from there can be selected the most suitable geothermal heat pump (GHP) for the system, one that is capable to provide 6 kW as heating output.

Figure 17: Technical Specifications of the heat pump models (Source: Vaillant /22/)

Ground source heat pumps						
		geoTHERM 6kW	geoTHERM 8kW	geoTHERM 10kW	geoTHERM 14kW	geoTHERM 17kW
	Unit	VWS 61/2 230V	VWS 81/2 230V	VWS 101/2 230V	VWS 141/2	VWS 171/2
Dimensions						
Height without connections	mm	1200	1200	1200	1200	1200
Width	mm	600	600	600	600	600
Depth without/with column	mm	650/840	650/840	650/840	650/840	650/840
Weight with/without packaging	kg	154/139	161/146	164/149	182/174	189/174
Electric connection						
Compressor and auxiliary back-up heater		1/N/PE 230V 50Hz	1/N/PE 230V 50Hz	1/N/PE 230V 50Hz	3/N/PE 400V 50Hz	3/N/PE 400V 50Hz
Control		1/N/PE 230V 50Hz	1/N/PE 230V 50Hz	1/N/PE 230V 50Hz	1/N/PE 230V 50Hz	1/N/PE 230V 50Hz
Slow-blow fuse	A	16/20	25/25	25/25	3x25	3x25
Inrush current without limiter	A	-	-	-	64	74
Inrush current with limiter	A	<45	<45	<45	<25	<25
Electric power consumption						
- max. at B20W60	kW	2.8	4.0	4.9	6.8	7.7
Auxiliary back-up heater	kW	2/4	2/4	2/4	2/4/6	2/4/6
System of protection EN 60529		IP 20	IP 20	IP 20	IP 20	IP 20
Ground loop collector						
Brine type		ethylene glycol 30%	ethylene glycol 30%	ethylene glycol 30%	ethylene glycol 30%	ethylene glycol 30%
Max. operating pressure	bar	3	3	3	3	3
Min. inlet temperature	°C	-10	-10	-10	-10	-10
Max. inlet temperature	°C	20	20	20	20	20
Rated volume flow ΔT 3K	l/h	1453	1936	2530	3334	3939
Residual pump head ΔT 3K	mbar	381	332	263	252	277
Electric power consumption of the pump	W	132	132	132	205	210
Heating circuit						
Max. operating pressure bar	bar	3	3	3	3	3
Min. flow temperature	°C	25	25	25	25	25
Max. flow temperature	°C	62	62	62	62	62
Rated volume flow ΔT 10K	l/h	517	697	848	1187	1538
Residual pump head ΔT 10K	mbar	486	468	450	551	603
Electric power consumption of the pump	W	93	93	93	132	205
Refrigerant circuit						
Refrigerant type		R407C	R407C	R407C	R407C	R407C
Quantity	kg	1.9	2.2	2.05	2.9	3.05
Admissible operating over pressure	bar	29	29	29	29	29
Compressor type/oil		Scroll/Ester	Scroll/Ester	Scroll/Ester	Scroll/Ester	Scroll/Ester
Inside acoustic power	dBA	49	51	53	52	53
Performance data						
Heating output (B0W35 ΔT 5K acc. to EN 14511)	kW	6.0	8.1	10.5	13.8	17.3
Electrical power consumption	kW	1.4	1.9	2.5	3.2	4.1
CoP (Coefficient of Performance)		4.2	4.2	4.2	4.3	4.3
Heating output (B0W55 ΔT 5K acc. to EN14511)	kW	5.5	7.5	9.4	13.6	16.1
Electrical power consumption	kW	2.1	2.8	3.4	4.6	5.6
CoP (Coefficient of Performance)		2.6	2.7	2.8	2.9	2.9

4.2. Geothermal Fluid

The geothermal fluid chosen is one of the products given by the manufacturer MEGlobal /23/, being ethylene glycol 30% the geothermal fluid the most suitable and recommended by the geothermal heat pump manufacturer. It is sold for the production of polyester resins, alkyd-type resins, deicing fluids, heat transfer fluids, electrolytic capacitors, textile fibers, paper, leather, adhesives, glue and solvents. But the property that is of the most interest in our system is the antifreezing one.

As said before, it would have different properties depending in what percentage of weight is present in a water solution and in which temperature is working. The technical specifications of the heat pump determine that the % in weight must be 30 % (Figure 18). Otherwise from Figure 12 can be seen that the surface temperature of the area of study is about 15.5 °C. Then with this data, the graphics given by the company would give the fluid properties.

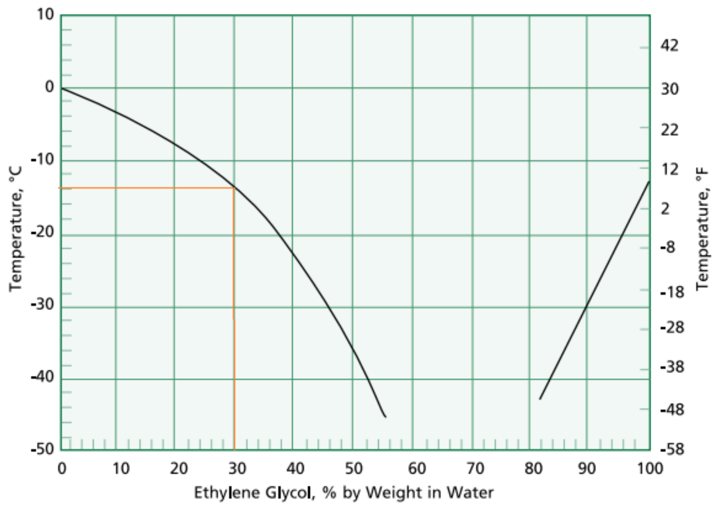


Figure 18: Freezing point with 30% by weight in water (Source: MEGlobal/23/)

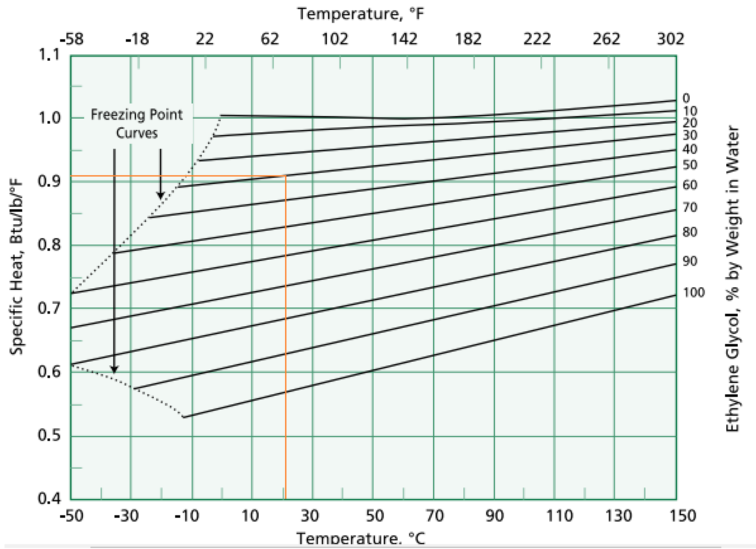


Figure 19: Specific heats of aqueous ethylene glycol solutions (Source: MEGlobal/23/)

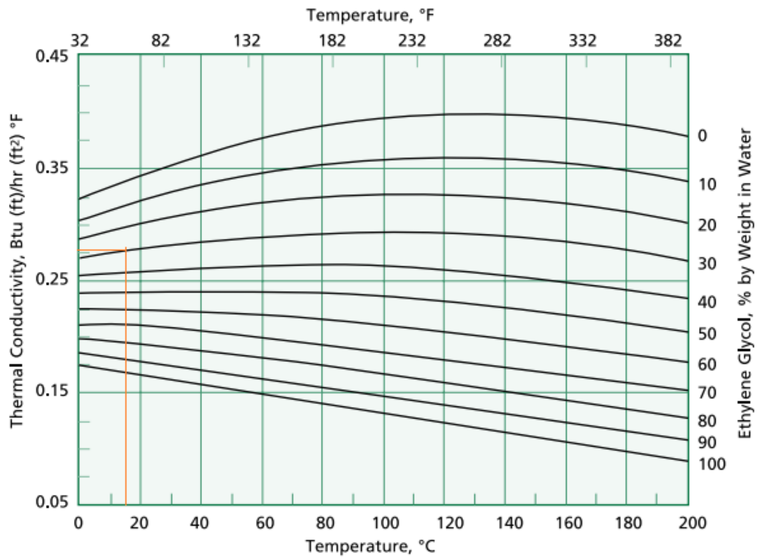


Figure 20: Thermal conductivities of aqueous ethylene glycol solutions (Source: MEGlobal/23/)

Summing up the most relevant properties the geothermal fluid:

Freezing point: -14°C

Specific heat: 3.809 kJ/(kg·C)

Thermal conductivity: 0.485 W / m K

4.3. Heat Absorption System

The results are based on the conductivity of the soil map from the ICG (Figure 14) and the table of the specific extraction rates (table 2). From the map of conductivity of the soil is extracted that the conductivity in the area of Lleida is about 2.5 W/m.K. Then with this data looking at the table 2, with an operation time around 2400 h and a conductivity (λ) between 1.5 and 3 W/m·K, it is obtained an extraction rate of 50 W/m.

Therefore, applying the equations 9 and 10, and taking the Coefficient of Performance (COP) from the technical data from the manufacturer (Vaillant) we obtain:

$$P_{cold(evaporator)} = \frac{1.27(4.2-1)}{4.2} = 0.967 \text{ kW}$$

$$Probe\ lenght(m) = \frac{967\ W}{50 \frac{W}{m}} = 19.4\ m$$

From the table 3 can be seen that all the models use the same diameter for their piping systems, so by looking at the double vertical geothermal probes catalogue (Figure 15) can be seen that the model most suitable is the one with code 246005, with 4 pipes and a diameter of 32 mm, as found before. And then applying the equation 11 is found that the length of the piping system is:

$$Length\ piping\ system = 19.4 + 3 = 22.4\ m$$

The installation must be done following the instructions of the manufacturer /18/.So there are some considerations to take into account here. The borehole for the geothermal probes should be carried out by a specialized company, using the most appropriate technology.

The minimum distance from the building to install where to install the vertical probe is about 3m. The depth of the borehole is increased until 21 to ensure the covering of the demand.

The holes are filled with a geothermal mortar based on cement /24/.This mortar has a high thermal conductivity (≥ 2 W/mK), great fluidity, no segregation, long setting time, excellent mechanical strength and sulphur resistant. When filling the borehole with the probe already placed in it, this mortar is added in a mixture of approximately 30%, achieving a homogeneous mass.

Figure 21: Geothermal mortar (Source: Morteros Tudela Veguin/24/)

The probes are made of high density polyethylene (PE-100) which are the best current alternative for the production of geothermal probes. It has a nominal resistance of 16 bar. Their scratch resistance has been improved and they have high thermal conductivity.

4.4. Economics

First of all must be known the cost of running the current diesel based installation. The demand to be covered by this system is found in ‘’4.1.Heat Pump’’. There could be seen the monthly consumption, then if they are all summed up it is obtained an annual consumption of 2225,841 kWh/a. The price per kWh produced by diesel fuel is established by the government of Spain /25/, and it is 13 c€/kWh. The efficiency of the boiler can be between 80-75% /26/, we choose it to be 80%. Then the result of the cost per year is 361.7 €.

The same method is applied for the geothermal installation. Otherwise it is going to be considered the first investment that has to be done in order to install the geothermal system and also its annual cost. For the annual cost of the geothermal system has to be considered the coefficient of performance from the technical manual of the heat pump, and the current price of the electricity, given by the electrical supply company. The COP of the heat pump is 4.2, the price of the electricity for running the GHP is 0.14 €/kWh and the resulting cost of running the installation 74.79 €/year.

Then it is going to be determined the cost of the installation, it is going to do through one company ''*Quali Geotermia*'' that makes estimations of the installation of a geothermal system. The estimation of the cost is given according to the parameters given to the company, and these ones are the number of drillings needed, the depth of them and the type of geothermal probe. The prices of all the material, components and services are shown in the table 6.

Table 6: *Cost of installation of the geothermal system*

Estimation of the cost of installation

Nº	Quantity	Description	Cost(€)
1	1	Geothermal Heat Pump Vaillant GeoTHERM VWS 61/2	6781.32
2	1	Geothermal probe FERROPLAST 32x2,9 mm (80 mts.)	497.8
3	1	Transportation of the Geothermal equipment, mounting, mounting of the of the geothermal probes, materials transportation, and transport of the specialized personal.	800.00
4	21	Perforation for the installation of the geothermal probe, with a depth of 21 m (32 €/U.)and diameter between 115 and 150 mm, introduction of the probe, injection of the geothermal mortar, tube for the injection of the geothermal mortar. Included the pressure, sealing and circulation tests.	857.00
5	1	Ethylene Glycol 30%	17.00
6	21	Geothermal Mortar, high conductivity 2,0 W/mK	84.00
7	1	Hours of work for the installation of the geothermal probe 40.00 €/h	40.00
8	1	Hours of work for the sealing of the perforation with the geothermal mortar 100.00 €/h	100
Total cost of the installation			9177.12
Total cost of the installation plus taxes (21%)			11104.32

The final cost of the installation results to be 11104.32 € including taxes. Then with it is calculated the payback, that would be the time necessary for the savings on diesel will equal the cost of the installation, adding to it the costs of running the geothermal system and the interests of the loan given by the Ministry of Energy. So in other words, the payback time would be the time necessary to get back the money paid for the first investment through the savings of the geothermal system in comparison with the diesel one.

The CPI by the year 2017 is 2.3 %, that value is going to be taken for the calculations of the payback time. Then considering that the program PAREER-CRECE will cover 30% of the total cost of the installation it would mean 3331.29 €, and for the money that needs to be returned to the institution by the period of 12 years, it would be 6662.59 € (60% of the total cost of the installation.

So with an interest of -0.11% (Euribor by the year 2017 /27/) and the amount of 6662.59 € of the loan is found that every month should be paid 551.25 €. This amount it is going to be added on the annual cost of the geothermal installation (Cumulative consumption + 10% of the total cost of installation) during the first 12 years. In the table 7 is shown the calculation table for the payback time.

Table 7: *Calculation of the payback of the system with a loan*

Years	Diesel + CPI 2,3 %		Consumption geothermal System + CPI 2,3%		Payback geothermal system	
	Annual cost	Cumulative cost	Annual cost	Cumulative cost	Cum. cost geo. + 0,1% total cost	Payback
1	361.70	361.70	74.80	74.80	1736.48	1374.78
2	370.02	731.72	76.52	151.31	2364.24	1632.52
3	378.53	1110.25	78.28	229.59	2993.77	1883.52
4	387.23	1497.48	80.08	309.66	3625.09	2127.61
5	396.14	1893.62	81.92	391.58	4258.26	2364.64
6	405.25	2298.87	83.80	475.38	4893.31	2594.44
7	414.57	2713.45	85.73	561.11	5530.29	2816.84
8	424.11	3137.56	87.70	648.81	6169.24	3031.69
9	433.86	3571.42	89.72	738.53	6810.21	3238.79
10	443.84	4015.26	91.78	830.31	7453.24	3437.98
11	454.05	4469.31	93.89	924.20	8098.38	3629.07
12	464.49	4933.80	96.05	1020.25	8745.68	3811.88
21	569.98	9625.70	117.87	1990.48	9715.91	90.21
22	583.09	10208.79	120.58	2111.06	9836.49	-372.30
23	596.50	10805.29	123.35	2234.41	9959.84	-845.45
24	610.22	11415.51	126.19	2360.59	10086.03	-1329.49
25	624.26	12039.77	129.09	2489.68	10215.11	-1824.65

*Annual payment of 551,25 €

CPI: Consumer Price Index

In the case the installation it was not finally financed by the institution stated the result would vary a lot, and it is shown in the table 8.

Table 8: *Calculation of the payback of the system without a loan*

Years	Diesel + CPI 2,3 %		Consumption geothermal System + CPI 2,3%		Payback geothermal system	
	Annual cost	Cumulative cost	Annual cost	Cumulative cost	Cum. cost geo. + 0,1% total cost	Payback
1	361.70	361.70	74.80	74.80	11179.11	10817.41
2	370.02	731.72	76.52	151.31	11255.63	10523.91
3	378.53	1110.25	78.28	229.59	11333.90	10223.66
4	387.23	1497.48	80.08	309.66	11413.98	9916.50
5	396.14	1893.62	81.92	391.58	11495.89	9602.27
6	405.25	2298.87	83.80	475.38	11579.70	9280.82
7	414.57	2713.45	85.73	561.11	11665.42	8951.98
8	424.11	3137.56	87.70	648.81	11753.12	8615.57
9	433.86	3571.42	89.72	738.53	11842.84	8271.42
27	653.30	13331.68	135.10	2756.84	13861.15	529.47
28	668.33	14000.01	138.20	2895.04	13999.35	-0.66
29	683.70	14683.71	141.38	3036.42	14140.73	-542.98
30	699.42	15383.14	144.63	3181.05	14285.37	-1097.77
31	715.51	16098.65	147.96	3329.01	14433.33	-1665.32
32	731.97	16830.61	151.36	3480.37	14584.69	-2245.93
33	748.80	17579.42	154.84	3635.22	14739.53	-2839.89
34	766.03	18345.44	158.41	3793.62	14897.94	-3447.51

Then at this stage is considered to cover all the demand that the diesel boiler is covering nowadays. The family claims to spend around 1200 L/ year of diesel for the SHW and space heating. Then knowing the energy density of diesel, 34.92 MJ/L, the annual consumption is so 11640 kWh/a, matching the usual single family consumption in Catalonia /29/. Knowing this data, it is going to make an estimation of the payback time of the installation following the methodology done before. The costs of the installation will differ on the depth of the drilling for the geothermal probe, the quantity of geothermal fluid and the quantity of mortar. The geothermal pump is still working on its range of capacity, 3.98 kW for 8 hours of operation each day of the year. With this heating output, applying the equation 10, it is obtained a power into the evaporator of 3.037 kW, linked to a probe length of 62 m. The total cost is given by the company, and it is about 12890.28 €.

Applying the same methodology in the economics it is obtained that the installation with the best case regarding the amount of money given by the loan, the geothermal system installation will payback by the 2nd year, paying 639.9 €/year during 12 years, and in the case it won't have any loan for it, the payback time would be of 9 years.

5. Discussion

After the whole techno economic study of the installation of a geothermal installation in a single family house in Lleida some observations can be added to this project.

The current geothermal potential of the area has been proven with the data given by several studies and official institutions treated. So the installation of this system in this area would make sense regarding this topic. Otherwise the market nowadays is capable to supply to the owners the necessary components and services to install such a kind of system in their homes. In the case of study, known the needs of the house regarding the SHW consumption, a feasible technical solution was found for it. Must be said that the technical solution for this system was a little oversized, as the found maximum need of power for the SHW was only about 1.27 kW and the GHP was able to give 6 kW of heating output. Linked to this small value there is a short length of the geothermal probe needed, they are usually buried around 60-100 m into the ground, but in this case was only about 21 m.

Regarding the economics of the system, it can be seen that the payback time of the installation taking into account the replacement of the actual diesel system is too large (34 years) even if a loan was given to the installation (25 years). This problem is related to the small needs for the SHW consumption. As seen in ''4.4.Economics'', in the case that the geothermal system was meant to cover also the space heating demand (currently covered by the diesel based system), the system would be more profitable as the payback time would me smaller. This is caused by the difference of efficiency of each technology although the cost of production per kWh is similar between the two technologies.

6. Conclusion

This geothermal energy system would be technically feasible but not economically beneficial in a short term period. However, if both demand of SHW and space heating of the house was considered, which currently is covered by the diesel system, it would be economically interesting to install the system thanks to a payback time of 2-9 years.

So as a conclusion can be stated that the family could cover the whole energy consumption for SHW and space heating with the geothermal system. This would require a large investment cost, but it would be paid back in a time period of 2 to 9 years depending on the level of governmental subsidies for renewable energy installations.

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