Use of Ground Source Heat Pumps (GSHP) in Heating and Climatization of the Military Academy: Amadora Quartering (a case study)

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July 2017

Abstract

This dissertation studied the feasibility of a Geothermal Heat Pump (GHP) system used for the climatization of the dormitory building at the Amadora's Campus of the Military Academy, as well as for the Domestic Hot Waters (DHW). The building has a capacity of 78 students and a floor area of 839 m2. Initially, the thermal loads of the building to be replaced by geothermal energy were evaluated, following the methodology presented in the Regulation of Energy Performance of Housing Buildings (REH) and using RETScreen software. The amount of energy required estimated for the DHW was 46.36 MWh/year, for space heating 27.83 MWh/year and space cooling 25.76 MWh/year.

The installation of a vertical closed circuit Geothermal Heat Pump system (Vertical GSHP) and an open circuit Groundwater Heat Pump system (GWHP) was evaluated through the RETScreen software. A comparison of the technologies used in the Amadora's Campus, a natural gas boiler with COP=0.68 and an air conditioning system with EER=3.5, was made with the GHP system to be installed with a COP=4. After analyzing the two systems, the financial results obtained for a project life of 15 years were respectively for the Vertical GSHP and GWHP systems a net present value (NPV) of € 24,117 and € 32,450, an internal rate of return (IRR) of 18% and 34%, and a return period (RP) of approximately 5 and 3 years.

Keywords: *RETScreen*, Ground Source Heat Pump, climatization, Balance sheet

1. Introduction

This project comes up to meet two attractive energy needs. The first being the substitution of the existing inefficient system for climatize the living space of the dormitory building in Military Academy - Amadora Quartering, and the second the use of a renewable source of energy to contribute to the implementation of the proposed European Community plans / targets to increase efficiency 20% by 2020 as well as the reduction of CO_2 emissions by 20% (Schibuola & Scarpa, 2016).

This dissertation was focused on the investigation of existing surface facilities and their ability to withstand a geothermal intervention, evaluating the thermal loads that can be replaced by geothermal energy. Of greater importance is the feasibility study of the most appropriate scenarios considered for a conceptual phase of a pilot geothermal installation. The feasibility study, in addition to evaluating the most favorable methodologies, also evaluates the investment needs, the easiness of exploration and construction, as well as the most important economic indicators in the typical evaluation of a project, such as the Net present Value (NPV), Internal Rate of Return (IRR), and Payback Period (PR).

2. Fundamental theory

The building sector accounts for about 40% of final energy consumption and 36% of total greenhouse gas emissions in the European Union (EU), and because of the high potential for energy savings, is a key sector for the targets set by the EU. Most of the final energy consumption in the buildings, about 67% in the EU residential, is used for heating. Two-thirds of the heat supplied is generated by fossil fuels, mostly by natural gas boilers. In Portugal, due to the moderate climate, the space heating is not significant, but together with the cooling of spaces already represents great energy consumption in the buildings (Carvalho et al., 2015).

The subsoil, even at low depths, proves to be a very stable source of thermal energy, which can be harnessed for the benefit of the thermal comfort of the human being. It is in this domain that geothermal energy of very low enthalpy fits.

The most part of Europe presents soils with approximately constant temperatures at depths between 10 m and 15 m. At a little over 50 m the values are around 10ºC and 15ºC. These are temperatures that, from the point of view of energy efficiency, can be used for the air conditioning of buildings, by means of the use of a Ground Source Heat Pumps for example. The greatest benefit of GSHP is that they are much more efficient than traditional climate control systems.

2.1. Heat Pump (GHP)

Heat Pumps represent the only technology whose purpose is heating, and where the coefficient of performance (COP) is greater than unity. The increase in energy consumption worldwide makes it possible today to use Heat Pumps in space heating and cooling, as well as to produce Domestic Hot Waters (DHW). Generally, Heat Pumps can be divided into two categories: Air Source Heat Pumps and Ground Source Heat Pumps. The Air Source Heat Pump uses ambient air as an evaporator / condenser to provide heating or cooling in the building. Since the ambient temperature can vary greatly the efficiency in this type of Heat Pump also varies. This is a problem when one wants to apply this system in cold climates for example. Alternatively, Ground Source Heat Pumps use the soil as a source of heat to overcome the efficiencies obtained with the Air Heat Pumps (Hakkaki-Fard et al., 2014).

2.1.1. Overview and the different types of Ground Source Heat Pumps (GSHP)

Ground Source Heat Pumps (GSHP) is a term used for a wide variety of systems that uses soil, groundwater, or surface water as a heat source or heat sink. GSHP's are subdivided by the type of external heat exchanger system, that they have. This includes Ground-Coupled Heat Pumps (GCHP) where the heat exchangers are a closed-loop underground piping system, and Groundwater Heat Pumps (GWHP) which are open circuit piping systems with water wells.

The application of GSHP are mainly used in residential buildings, can be very attractive to buildings with few resources for maintenance such as school buildings, academies etc.

2.1.2. Ground-coupled heat Pumps (GCHP)

The GCHP are a subset of GSHP, also known as Closed Circuit GSHP. The Vertical GCHP is the most used. The geothermal heat exchanger is typically constructed of U-shaped high density polyethylene (HDPE) pipes for fluid return, buried in vertical holes as shown in

Figure 1. Vertical tubing can be prefabricated over a range of 25 to 40 mm of nominal diameter. Usually the holes have a depth between 60 to 90 m, depending on the drilling conditions of the site in question. Deeper holes are not very common, as the pressure drop in the piping are higher (Kavanaugh & Rafferty, 2014).

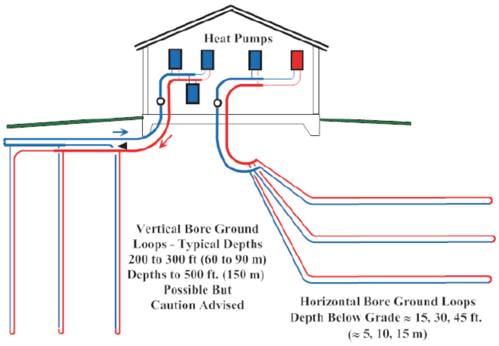

Figure 1 - Closed Circuit Ground Source Heat Pump with Vertical circuit options on the left (Kavanaugh & Rafferty, 2014)

The advantages of vertical GCHP are: i) they require a relatively small area of land, ii) they do not need a large amount of piping and consequently iii) it is not necessary to spend as much energy with water pumping, they are also the most efficient in terms of performance compared to other systems GCHP (Soni et al., 2015).

The major disadvantage is associated with its typically high cost due to the difficulty of installing the geothermal circuit, requiring specialized equipment and personnel (Kavanaugh & Rafferty, 2014).

2.1.3. Groundwater Heat Pumps (GWHP)

As previously mentioned another type of GSHP is the GWHP or open circuit. Typically, according to Kavanaugh & Rafferty (2014) a single large volume well is sufficient to serve a building.

The most common GWHP system utilizes a central heat exchanger to transfer heat from the growndwater circuit to the closed water circuit which is connected to the Heat Pump unit. The GWHP have a lower investment cost than GCHP systems, the size of the system is quite flexible, the technology has been used for decades, because until the GCHP recent development GWHP were the most common (Park et al., 2015).

The disadvantages are due to the fact that this system can only be used if groundwater is relatively suitable in terms of quality and local environmental regulations permit its use. There are several studies focused on key environmental changes caused by surface geothermal systems. In the GWHP some heterogeneous chemical reactions have been described as the main factor for potential environmental problems.

3. Case Study Background

3.1. GSHP Systems in Portugal

The use of geothermal systems in space heating and cooling in Portugal is not as usual in comparison with other European countries (Carvalho et al., 2005). The main energy used for this purpose is natural gas, coal, solar, wind and biomass (Costa & Amaral, 2011).

According to Costa & Amaral (2011) in Portugal the open circuits GSHP were initially used in residential installations. However, the lack of information on the environmental impacts of the open circuit was the reason for the replacement of this by closed circuit, such as GCHP.

In 2013 a case study was carried out at the University of Aveiro to promote the use of GCHP technology. The study presents a simple numerical method to facilitate the assistance for studies of heat transfer between soil and building foundations (Cruz, 2013).

Colaço (2015) elaborated a case study where the climatic and geological parameters of 12 Portuguese cities were evaluated, to understand the appropriate conditions in the GCHP installation. A correlation was obtained between the efficiency of the systems and the size of the geothermal system. In general, the calculations of the efficiency of the geothermal probes show that the Portuguese territory has an enormous potential for the use of this type of systems.

3.2. Regional Climate

The Municipality of Amadora fits in the temperate Mediterranean climate, the same characteristic of the Iberian Peninsula.

Weather data for the Amadora region is provided through the *RETScreen* software, which collects and examines weather station data located in the nearby land as well as the NASA satellite data, in recent years. The data obtained for the region are represented in the following table (*RETscreen,* 2015).

Table 1 - Location of climate data (*RETscreen*, 2015).

Amadora	**Units**	**Climate data location**
Latitude	˚N	38,8
Longitude	˚E	-9,1
Elevation	m	114,0
Heating design temperature	°C	5,8
Cooling design temperature	°C	32,1
Soil temperature	°C	18,5
Earth temperature amplitude	°C	10,0

The warm period lasts approximately 4 months, from June to September, characterized by average monthly temperatures in the order of 20 ºC to 22 ºC. In contrast to the previous situation, there is a period from November to March where periods with monthly averages below 15 °C are recorded, January being the coldest month of the year. Between the two previous periods the transition months appear, in which the mild temperatures are registered.

3.3. Location, geomorphological and geological setting of Amadora region

The Military Academy - Amadora Quartering, it’s located in sheets No 430 and 431, military cartography of Portugal, on a scale of 1/25000, of the Cartographic Services of the Army, in the Freguesia of Venteira and Municipality of Amadora.

Table 2 - Thermal properties of rocks characteristic of the Amadora region at 25 ºC (Colaço, 2015).

Rock type	**Thermal, Conductivity (k) [W.m^{-1} K^{-1}]**			**Specific heat (Cp) [J.kg^{-1}.K^{-1}]**	**Rock Density (ρ) [kg.m^{-3}]**
	Min.	Mean	Max.		
Basalt	2.0	2.2	2.4	712 – 879	2880
Limestone	1.4	2.4	3.4	920	2400
Sandstone	2.0	2.5	3.0	1005	2560

3.4. Military Academy dormitory building

The chosen building for the case study is one of the dormitory buildings for the internal students of the Military Academy. This building was considered to carry out the feasibility study of this case study case because it is closer to the "boiler house", making it possible to take advantage of part of the thermal energy distribution system, namely some pipes and heat exchangers. The chosen building can be seen in Figure 2.

Figure 2 - Three-dimensional view of the dormitory building.

The building consists of three floors, ground floor (floor 0), first floor (floor 1) and second floor

(floor 2), as can be seen in Figure 2. The building has an area of Implementation of 535 m^2, and each floor has a right foot of 2.70 meters. The building under study serves as a dormitory and has a maximum capacity for 78 internal students. The structure of the building is made of reinforced concrete, consisting of pillars, slabs and beams. The three floors are of the same plant, which is represented in Figure 3. The space conditioned area of each floor, considered for the determination of the required thermal load in the different seasons, is the sum of the red spaces in Figure 3.

The sum of the spaces to be conditioned has the value of 279.8 m^2, in each floor. Since the building has three floors of equal plant, the total area to be conditioned is equivalent to 839.0 m^2.

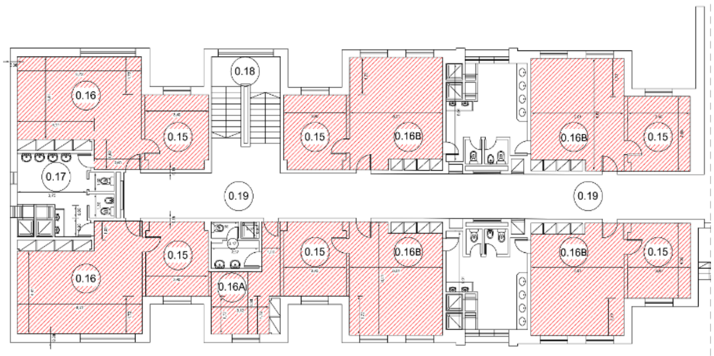

Figure 3 - Floor 0, equivalent in Floor 1 and 2. Conditioned areas in red. Figure adapted from the project plan of execution of the building housing the students of Military Academy - Amadora Quartering

3.4.1. Building envelope

The outer envelope refers to the set of elements that separate the conditioned interior space and the exterior environment of the building. The double outer walls of the building, the flat roof of floor 2 and floor 0 pavement, are the elements considered as external envelope in the case study.

The wall area of the exterior envelope in each floor is measured by the interior side of the building according to the Despacho no. 15793-E / 2013. Knowing that the three floors are the same size, the total area of the exterior envelope wall is 542.0 m^2. The roof of floor 2 and pavement of floor 0, the area of each of these elements equals the area obtained before, the sum of the spaces to be conditioned 279.8 m^2 per floor.

The heat transfer between the conditioned air space and the surrounding environment is characterized by the coefficient of thermal transmission (U) of the elements that make up the boundary between the two regions.

The coefficient U of the various opaque elements that make up both the outer envelope, not including glazing elements and the interior, are determined, according to the European standard EN ISO 6946, by equation (1) in W / m^2 ° C,

$$U = \frac{1}{R_{si} + \sum_j R_j + R_{se}} \qquad (1)$$

Table 3 summarizes the values of the coefficients of thermal transmission in W / m^2 ° C, obtained for the different elements of the building envelope.

Table 3 - Calculated thermal transmission coefficients for different elements of the envelope

Envelope	Element	U [W/m^2.°C]
Outer	Double outer walls	0.460
	Roof floor 2	0.651
	Pavement floor 0	0.600
Inner	Interior wall	1.587

4. Demonstration and application of the methodology

For sizing the Ground Source Heat Pump system in a conceptual phase it is first necessary to determine which thermal loads of the building will be replaced by the system. In order to carry out an adequate quantification of the thermal loads of the building under study, the current Portuguese Regulation of Energy Performance of Housing Buildings (REH) was applied. This Regulation establishes the requirements for new or subject to interventions residential buildings as well as the parameters and methodologies of characterization of the energetic performance, in nominal conditions, of all the residential buildings and their technical systems, in order to promote the improvement of their thermal behavior and the efficiency of their technical systems. Thus, it is possible to quantify the useful energy needs for heating, cooling and domestic hot water needs of the building under study, through the local climatic and physical characteristics of the building, described before.

4.1. Nominal annual useful energy needs for heating (N_{ic}), cooling (N_{vc}) and domestic hot water preparation (Q_{AQS})

The methodology used to determine the annual nominal thermal energy needs follows the Despacho no. 15793-I / 2013 pursuant to Decree-Law no. 118/2013 of August 20 and its regulations, which was transposed in accordance with European Standard, EN ISO 13790: 2008.

Equations (2), (3) and (4) allows the calculations of the annual nominal useful energy needs for heating (N_{ic}), cooling (N_{vc}) and domestic hot water preparation (Q_{AQS}), respectively.

$$N_{ic} = \frac{(Q_{tr,i} + Q_{ve,i} - Q_{gu,i})}{A_p} \qquad (2)$$

$$N_{vc} = \frac{(1-\eta_v)Q_{g,v}}{A_p} \qquad (3)$$

$$Q_{AQS} = \frac{M_{AQS}.4187.\Delta T.n_d}{3600.10^6} \qquad (4)$$

Where:

- $Q_{tr,i}$ represents the heat transfer by transmission in the heating season through the building envelope in kWh.
- $Q_{ve,i}$ represents the heat transfer by ventilation in the heating season in kWh,
- $Q_{gu,i}$ represents the useful thermal gains in the season, resulting from solar gains through windows, lighting, equipments and occupants in kWh.
- The term A_p is the conditioned interior area of the building floor measured in m^2.
- $Q_{g,v}$ represents the gross thermal gains in the cooling season in kWh, and η_v the utilization factor of the thermal gains in the cooling station.
- The term ΔT represents the temperature increase required for the preparation of DHW, which for the purposes of this calculation takes the reference value 35 ° C, according to the current Decree-Law, the network water which has an average temperature throughout the year of 16.8 ° C, according to the software used, *RETscreen,* after being transformed into DHW its temperature is 52 ° C.
- The term n_d represents the number of days of consumption of DHW during the year, that is, 365 days.
- The term M_{AQS} represents the DHW average volume used in the building, considering a consumption of 40 liter/student the total volume is 3120 liters.

The calculations obtained in the previews equations gives the values of 33.17 kWh/m^2 for N_{ic},18.44 kWh/m^2.year for N_{vc} and 46,36 MWh/ano for DHW preparation. Considering the 839 m^2 previously defined as total building area to be conditioned, N_{ic} and N_{vc} take the values of 27.84 MWh/year and 15.48 MWh/year, respectively. For more details in the previews obtained results the full dissertation document must be consulted.

4.2. Sizing of the Ground Source Heat Pump (GSHP), energy balance

In order to obtain the capacity or power of the heat pump to be installed, as well as the size of the associated geothermal heat exchanger allowing the efficient use of the heat pump, the *RETscreen* software was the tool used to design the main components of the GSHP system. The capacity, or power, of the heat pump to be installed covers the peak heating and cooling loads. The peak load represents the maximum power that the system needs to provide in the cooling and heating of the hottest and coolest day of the year, respectively. Typically, the hottest and coldest day of the year occurs in the cooling and heating season, respectively. The *RETscreen* software makes it possible to calculate the peak loads for the cooling and heating seasons. It is necessary to set some parameters for the software to perform the desired calculations, the energy needs, building area, as well as the climate data.

Table 4 shows the load balance result obtained through the *RETscreen*, with the average heating and cooling load requirements per season, and the peak loads. It is also possible to observe that the energy value required for heating throughout the year is higher than the energy for cooling, which indicates that the system is sized from the heating peak load.

Table 4 - Balance of the useful energy building load obtained

	Heating [kW]	**Cooling [KW]**
Peak load	21.01	6.37
Average season load	12.74	4.35
Useful Energy	74.19 MWh	25.76 MWh

To choose a unit with the maximum power Appropriate to peak load requirements. The search for the Heat Pump equipment unit most appropriate to the case study was carried out in the Iberian market through CYPE Ingenieros, S.A. (2016). The performance characteristics of the chosen water-to-water geothermal reversible heat pump unit to produce DHW, heating and cooling, can be observed in the following table.

Table 5 - Ecoforest's Heat Pump water-water equipment commercialized in the Iberian peninsula (CYPE Ingenieros, S.A., 2016)

Brand	**Ecoforest**
Model	ecoGEO B4 5-22
Power supply	Trifásica
Cooling Nominal Power [kW]	29
Heating Nominal Power [kW]	25
EER	5
COP	4.9

4.2.1. Geothermal Heat Exchanger System

The *RETScreen* software allowed the evaluation of the geothermal heat exchanger system to be chose. For the case study two geothermal heat exchanger systems are evaluated, the vertical closed circuit geothermal heat exchanger system described in Figure 1 and the open circuit groundwater geothermal heat exchanger system.

After inserting all the necessary variables in the *RETScreen* software, the calculation results of the two types of geothermal heat exchanger system can be observed in Table 6.

Table 6 - Main scaling parameters obtained in the *RETScreen* software for the two systems considered

Vertical closed circuit system	
Necessary terrain area	146 m^2
Borehole Lenghth	579 m
Geothermal system Loop	1157 m
Open circuit groundwater system	
Number of supply wells	1
Required groundwater flow	1 l/s
Well pump power	0.5 kW
Central heat exchanger	23.7 kW

For the vertical closed circuit, geothermal heat exchanger system, the parameters obtained were calculated considering that the *RETscreen* model considers a high density "U" polyethylene tubing with a nominal diameter of 32 mm with a concrete mortar. Obtaining the required land area is done considering that the typical depth of drilling is 91 m, according to the *RETscreen* model, with the value of the borehole length being a cumulative value calculated by the model. The loop length of the geothermal system needed to cover the peak heating load represents the approximate length of all the piping that will be installed under the ground, where the loop solution is 100% water.

5. Economic viability, results

To carry out the economic analysis, it is first necessary to make a comparison between the system to be installed, with the existing system of air conditioning for the building under study. The calculation of the annual costs of the energy used in € for each system can be done through equation (5),

$$Energy\ anual\ cost_i = \frac{\text{Total energy}_i}{COP_j} \times energy\ price \qquad (5)$$

Where the index “i” represents either heating or cooling, and the index “j” represents the different technologies

The existing system for space heating and DHW in the building is a natural gas boiler with considered yield of 68%. The natural gas price for the region of Amadora (Lisboagás) is 0.0588 €/kWh plus 56.88 €/year for the fixed tariff term (ERSE, 2016).

For space cooling, it is compared with an air conditioning system, with a conventional EER of 3.5. The prices of electricity in medium voltage are 0.13 € / kWh in Portugal, according to (ERSE, 2016).

To calculate the annual energy cost of the GSHP system, the COP considered is 4. This value represents an annual efficiency that takes in to account the effect of intermittent operation of the Heat Pump unit (*RETScreen*, 2015).

Table 7 - Cost of energy, in €, for the different technologies considered in the case study

Technology	**COP/EER**		**Heating**	**Colling**	**Anual Total**
	Heating	Cooling	Energy cost [€]	Energy cost [€]	Energy cost [€]
GSHP	4	4	2192.08	760.99	2953.07
Boiler	0.68	-	6472.42	-	6472.42
Air-conditioned	-	3.5	-	956.67	956.67

The annual savings are 4476 €, which is equivalent to the sum of the energy costs of the boiler and air conditioning, minus the GSHP energy costs in table 7.

In order to finalize the financial analysis, it is necessary to calculate some essential parameters in the evaluation of a project, these are:

The Net present value (NPV), is the amount that compares the amount of capital invested in the project with the future values of cash flows, after being discounted by the interest rate. The internal rate of return (IRR) is another important parameter in evaluating a project. This rate is what makes the NPV equal to zero. Generally, the higher the IRR, the more desirable the project. The return period (PR) represents the number of periods, or years, that is required for the accumulated cash flow to equal the initial investment (Oliveira, 2014). Table 8 shows all the parameters considered for the financial analysis.

Once all the necessary parameters are obtained, the NPV obtained for the case study has the value of € 24,117 and € 32,450 for the vertical geothermal and groundwater system, respectively. The NPV value is positive, the IRR value is relatively high compared to the interest rates of recent years (Trading Economics, 2016).

Table 8 - Common economic parameters considered for the case study

Parameters		
Project life	15 years	
Interest rate [a]	3.6 %	
Energy anual savings	4.476 €	
Price of the Heat Pump equipment [b]	12.942 €	
Maintenance cost, after 10years[b]	8.918 €	
GSHP	**GCHP**	**GWHP**
Geothermal system cost [b]	12.233 €	3.658 €
Annual maintenance cost [b]	157 €	64 €
NPV	24.117 €	32.450 €
IRR	18%	34%
Return period	≈ 5 years	≈ 3 years

[a] (Trading Economics, 2016)
[b] (CYPE Ingenieros,S.A., 2016)

The analysis carried out in previous studies shows that heat pumps with high efficiency in most cases demonstrate a very positive savings in energy consumption and in greenhouse gas emissions. The results can vary substantially depending on the key factors considered, namely the heat pump efficiency, the CO_2 emission factors, the thermal and electric energy production mix of the region and the thermal load that will be replaced by the heat pump system. The results of this case study demonstrate a reduction in carbon emissions and final energy consumption. To encourage investment in high-efficiency Ground Source heat Pumps technologies, financial support and tax incentives are used in some countries and should be expanded as they enable rapid growth in the implementation of this technology, particularly in the modernization of thermal systems in old buildings.

6. Conclusion

The GSHP systems contributes to an improvement in energy efficiency, and this study aimed to demonstrate the feasibility of its application in Portugal. To carry out the study of economic viability, it was necessary to understand:

- The thermal energy used in the building, to reach the required peak loads for the design of the system 21.01 kW and 6.37 kW for the heating season (winter) and cooling (summer), respectively. The load peaks depended not only on the characteristics of the building but on the climate of the area. These were essential to get the Power of the BCG unit needed to install.
- The geographical conditions of the site, to understand the type of technology system to be applied. For the case study two types of GSHP were evaluated, the vertical GCHP, since it is the most studied in Portugal, and GWHP or open circuit since the terrain presents two water wells near the building. The type of material from which the soil is composed was of extreme importance because the higher the thermal conductivity of the material the more easily the heat is transferred to / from the fluid circulating in the geothermal circuit, the higher the conductivity the greater the efficiency of the system.
- The design of the system was important to know the area required to install the vertical GCHP system (142 m^2), to obtain the power of the central heat exchanger in the GWHP system (23.7 kW) and to obtain the costs related to the replacement of the System in the building by the geothermal system.

In making the Financial Statement for the two geothermal systems considered for the case study, it is concluded that the two systems are economically feasible, since the investment costs are reimbursed in 3 years for the groundwater system and 5 years for the Vertical system. The gains after the 15 years of operation are € 32,450 and € 24,117, respectively for the underground water system and vertical system. This result confirms the energy efficiency of the heat pump and allows a considerable margin of error to be obtained in case of uncertainty.

Although the system of BCASub considered to be the most interesting from the financial point of view, it is necessary to consider the fact that this system can only be used if groundwater is relatively adequate in terms of quality and local environmental regulations permit its use. (Garrido Schneideret al., 2016).

Therefore, it is concluded that the vertical BCAS system is more appropriate because they are the most studied in Portugal, they require a relatively small area of land, they are also very efficient in terms of performance (Soni et al., 2015).

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