UNIVERSITAT POLITÈCNICA DE VALÈNCIA

ESCUELA TÉCNICA SUPERIOR INGENIERÍA INDUSTRIAL VALENCIA

INDUSTRIAL ENGINEERING MASTER THESIS

EVALUACIÓN DE LA REDUCCIÓN DE LAS EMISIONES DE CO2; A PARTIR DEL POTENCIAL DE EXPLOTACIÓN DE LA ENERGÍA GEOTÉRMICA SOMERA. ESTUDIO DE CASO DE LA CIUDAD DE VALÈNCIA

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RESUMEN

Esta tesis describirá los procedimientos y los métodos que permitirán evaluar el potencial geotérmico somero de la ciudad de Valenicia entendida como los beneficios económicos y ambientales que se pueden lograr aumentando la explotación geotérmica somera en tres escenarios diferentes, con un nivel diferente de tecnología. penetración, según la situación del resto de países europeos.

La bomba de calor geotérmica permitirá satisfacer la demanda de H&C y ACS de los edificios de una manera más eficiente en comparación con las tecnologías tradicionales

La parte inicial introducirá la fuente de energía, desde su definición hasta el listado de las ventajas de su explotación. Luego se describirán las diferentes tecnologías utilizadas en este campo, introduciendo la posibilidad de solución híbrida y almacenamiento H&C estacional.

El procedimiento evaluará la reducción de GEI obtenida gracias al aprovechamiento de la energía geotérmica somera pero también se evaluarán otros indicadores:

- sobre terreno: se analizarán las propiedades del terreno necesarias para definir la perforabilidad

- sobre el clima: se definirá la carga de construcción de H&C que debe satisfacerse

- sobre economía: se evaluarán las factibilidades económicas del proyecto mediante el cálculo de algunos indicadores

- sobre el medio ambiente: se definirá el ahorro de energía en comparación con la tecnología actual. Es dado por los diferentes COP. A partir de la energía ahorrada se evaluará la emisión equivalente de GEI ahorrada.

Esos indicadores ayudarán a definir las áreas de la ciudad más adecuadas para aplicar la bomba de calor geotérmica. El procedimiento se explicará paso a paso y luego se implementará para los tres niveles de penetración.

La conclusión resumirá el resultado de los resultados señalando cómo se pueden utilizar los indicadores para ayudar al Ayuntamiento de Valencia a tomar decisiones sobre la extracción geotérmica superficial en la ciudad.

PALABRAS CLAVE

reducción de emisiones; energía geotérmica; estudio de potencial de explotación.

RESUM

L'objectiu d'aquest Treball Fi de Màster (TFM) és realitzar una anàlisi sobre el potencial de l'energia geotèrmica que existeix a la ciutat de València i el seu impacte en la transició energètica de la ciutat i, per tant, en la seua reducció d'emissions de CO_2. Per a això, en primer lloc, es dissenyarà una metodologia per a quantificar el potencial geotèrmic succint en climatització d'edificis, que dependrà de les característiques del terreny (litologia, hidrologia, temperatura, conductivitat tèrmica), tipus de bescanviador geotèrmic, el tipus d'edifici a climatitzar i les seues necessitats tèrmiques. Tot això determinarà els costos estimats d'execució (inversió de capital) i d'operació, obtenint-se el potencial estalvi energètic, econòmic, emissions de CO_2 evitades i la producció d'energia renovable. Una vegada desenvolupada la metodologia, aquesta s'aplicarà a la ciutat de València, obtenint-se el seu potencial geotèrmic i els seus resultats esperats per al cas de la ciutat de València com a estalvis energètics, econòmics, emissions de CO_2 evitades i la producció d'energia renovable. Per tant, el present TFG contempla el disseny d'una metodologia, la seua aplicació en el cas de la ciutat de València, obtenció dels resultats i la seua anàlisi, realitzant una valoració econòmica de l'informe. Aquest treball de fi de grau té una gran relació amb assignatures vistes durant el Màster com són l'eficiència energètica i l'extracció d'energia geotèrmica mitjançant bombes de calor.

PARAULES CLAU: reducció d'emissions; energia geotèrmica; estudi de potencial d'explotació.

ABSTRACT

This thesis will describe the procedures and the methods that will allows to evaluate the shallow geothermal potential of the city of Valencia intended as the economic and environmental benefits that can be achieved increasing the shallow geothermal exploitation in three different scenarios, with a different level of technology penetration, according to the other European countries situation.

Geothermal heat pump will allow to satisfy H&C and DHW buildings demand in a more efficient way compared to the traditional technologies

The initial part will introduce the energy source, from its definition to the listing of the pros of its exploitation. Then will be described the different technologies used on this field, introducing the possibility of hybrid solution and seasonal H&C storage.

The procedure will evaluate GHG reduction obtained thanks to the exploitation of shallow geothermal energy but as well will be evaluated other indicators:

- about ground: will be analyzed the ground properties necessary to define the drillability
- about clime: will be defined the H&C building load that has to be satisfied
- about economics: will be evaluated the economical feasibility of the project by calculating some indicators
- about environment: will be defined the energy saves compared to the actual technology. It is given by the different COP. From the energy saves will be evaluate the equivalent GHG emission saved.

Those indicators will help to define the most suitable city areas in which to apply geothermal heat pump. The procedure will be explained step by step and then implemented for the three level of penetration.

The conclusion will summarize the result of the results pointing on how the indicators can be utilized to help the City de Valencia to make decisions about the shallow geothermal extraction in the city.

KEY WORDS: emissions reduction; geothermal energy; study of exploitation potential.

INDEX

MEMORIA

CHAPER1: INTRODUCTION TO THE ENERGY SOURCE

This section will give an overview about shallow geothermal energy, from its definition to its benefit and also will try to make the point about European and Spanish situation

1.1 DEFINITION AND DESCRIPTION

According to RES Directive (Howes 2009 [1]), shallow geothermal energy is identified as *"the energy stored in the form of heat beneath the surface of the solid Earth".*

This source is a very promising source of renewable thermal energy for buildings and on those years its studying and development is highly increasing in Europe and as well on a worldwide level. It exploits the thermal storage potential of the subsoil. The aim is to obtain a source of heat and cold at a constant temperature that is suitable for a coupling with heat pumps. Geothermal heat pumps are powered by electricity as well as air source heat pumps

Geothermal heat pump is recognized from the International Energy as the most efficient systems to provide air conditioning and DHW to new and existing buildings. That is why it is an important option for the decarbonization of the Greenhouse Gas emission linked to thermal consumption of the public and private housing sectors.

Geothermal energy is also a local resource, accessible in every ground (with a different soil potential). To invest in this sector will create employment and promote the development of new value chains (drillers, installers, engineers, architects).

The strategies around the New Green Deal and its translation into local policies through the Covenants of Mayors, enhance the perception of the need and urgency of the energy transition in our city. This forces us to look at all the energy resources available in the environment, which is why geothermal energy emerges as one of the most sustainable and mature options.

This source of renewable and sustainable energy presents some important advantages in terms of this source for its decarbonized future:

- It is a stable energy source that comes from the ground and can be obtained throughout the day and night, every day of the year
- The net emissions of CO_2 equivalent are low compared to other heating and cooling technologies, which has a positive influence on the reduction of emissions, noise, air quality and the phenomenon of heat islands that occurs in cities. It is a technology that requires electricity to function and that leads us to the electrification of air conditioning systems.
- It is increasingly more profitable as its incentive investment costs are reduced, becoming a very competitive energy source in the market, since the investment cost is higher but the savings in energy consumption are double that, for example, compared to use of aerothermal.

1.2 OVERVIEW OF SPAIN AND EUROPEAN SITUATION

Each different state can define a different depth or output water temperature as limit of shallow geothermal energy. In Spain the limits are 30°C and 250 m (Alejandro García 2019 [2]). Its direct use is carried out with or without a geothermal heat pump for heating or cooling. This type usually found in geothermal installations for buildings or thermal processes. Very low enthalpy geothermal takes advantage of the thermal gradient of the existing subsoil.

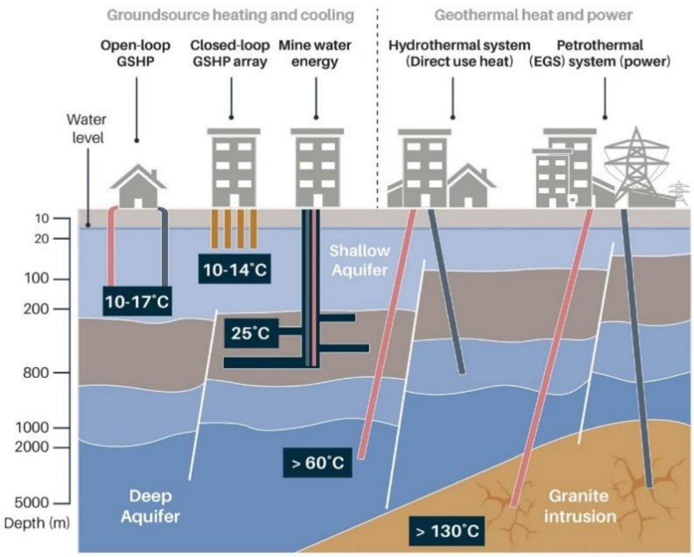

Figure 1. Different types of use of geothermal energy depending on its temperature and depth.

Open-loop: shallow geothermal energy using an open loop. Closed-loop: closed-loop shallow geothermal.

Mine water energy: shallow geothermal energy by exchange with mining wells. Hydrothermal system: direct use geothermal energy (low or medium enthalpy) through exchange with hydrothermal sources at more than 60ºC. Petrothermal system: direct use for the production of electricity and heat through sources at more than 130ºC. Source: British Geological Survey.

The different uses and classifications of geothermal energy can be seen summarized in Figure 1. Although the terms used differ slightly from one country to another, the scheme summarizes the terminology most commonly accepted today in Spain and Europe. Precisely, Spain is one of the countries where the least use of deep geothermal energy is implemented, as can be seen in Figures 2 and 3, which show, in terms of total power, the geothermal energy installed in the different countries of the region. EU for both electricity production (blue) and air conditioning (red). In the case of deep geothermal energy, this may be due to the fact that, as can be seen in Figure 4, Spain is not a country in which high-temperature deposits abound.

However, it is also found in the tail of shallow geothermal energy, and this is mainly due to the general lack of knowledge at the country level about this energy source. Figure 3 shows the number of shallow geothermal installations by EU country in all its applications. The left axis of the graph shows the total number of installations already implemented in each EU country (red) while the secondary right axis shows the new installations carried out in 2018 (grey). It is clearly reflected that the countries in which there are more units are those in which the installation of new equipment grows the most. Compared to the rest of Europe and despite its potential, shallow geothermal energy in Spain has little development.

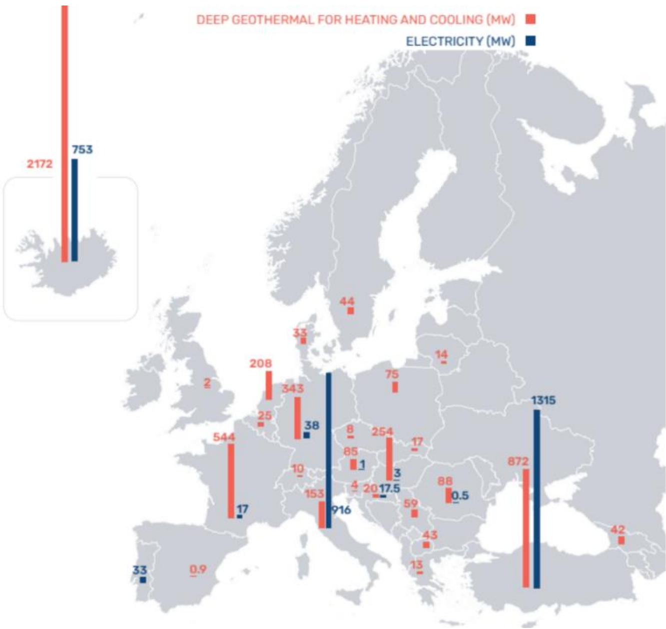

Figure 2. Geothermal energy production capacity of the EU Member States. Source: EGEC Geothermal Market Report

2020.[3]

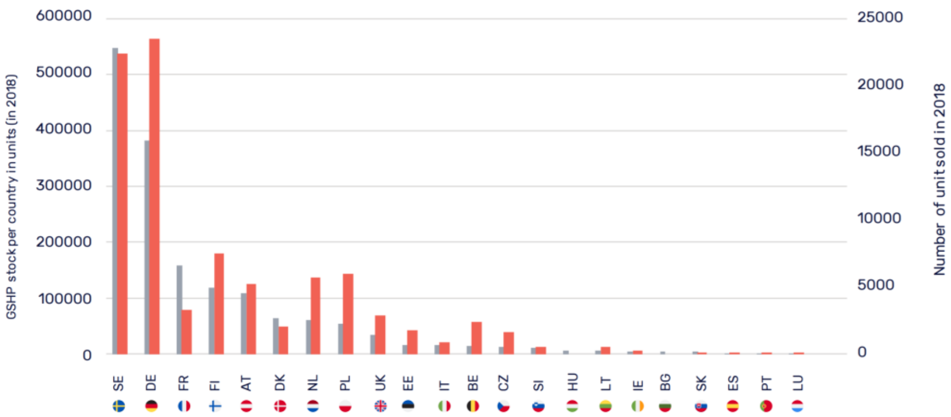

Figure 3. Shallow geothermal use by country in the EU. Source: Geothermal Market Report. On the left axis of the graph total installed installations (red) while the secondary right axis shows new installations in 2018 (grey). Source: EGEC Geothermal Market Report 2020 [3]

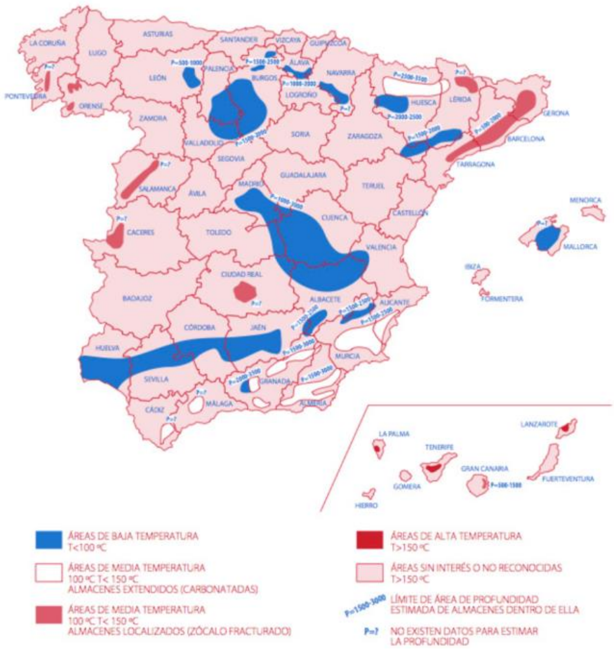

Figure 4. Geothermal areas in Spain. Source: Geo-Mining Institute of Spain (IGME) [4]

1.3 LEGAL FRAMEWORK

At the moment, the city of Valencia doesn't have any specific plan about geothermal energy, in the "Valencian strategy of climate change and energy" signed in 2018 it is mentioned as an energy source to implement and to incentive, but there aren't guidelines

According to MUSE project [5], to accelerate and simplify the use and implementation of geothermal energy is necessary do define a legal framework and technological standards. The document also suggests a series of action to achieve it:

•The meaning of surface geothermal energy should be defined from the local legislation and as well and the competent authority responsible for licensing and its regulation, whit the aim of harmonize the procedures of the legislation.

• Definition of shallow geothermal energy (SGE): it is understood as geothermal energy recovered from the subsoil with the use of geothermal heat pumps, including both OLS (open) and CLS (closed), for, among others, heating, cooling (free cooling as well as chillers based on ground source) and thermal energy storage. The most frequent SGE concepts are linked to the depth of the installations and the water temperature, which must be respectively less than 250m and 30^{o}C in Spain.

• Regulation of the use of the SGE: the national geological institute of Spain has quite extensive powers in terms of legislation on the SGE. It participates in the application of the law and legal regulations, in control, in legal advice, in the evaluation of legal regulations and with all these capacities it can influence the improvement and development of new legislation at the national level.

• Installation application and license: in Spain the application and license procedures differ from case to case and depend on the type of installation and other individual criteria. Despite the general regulations, no specific deadline has been established for the duration of the authorization procedure.

• Measures that facilitate SGE installations: The RED II Directive [7] in its Article 15 refers directly to the application procedures for SGE facilities. It establishes that the member states of the EU will guarantee that any national regulation regarding authorization, certification and licensing procedures that apply to installations and associated transmission and distribution networks for the production of electricity, heating or cooling from renewable sources... is proportionate and necessary and contributes to the application of the principle of energy efficiency in the first place. According to the directive, member states must ensure that:

- administrative procedures are streamlined and expedited at the appropriate administrative level and predictable deadlines are established;

- the rules relating to authorization, certification and licensing are objective, transparent and proportionate, do not discriminate between applicants and take full account of the particularities of each renewable energy technology;

- administrative fees paid by consumers, planners, architects, builders and installers and suppliers of equipment and systems are transparent and related to costs;

- Simplified and less burdensome authorization procedures, including a simple notification procedure, are established for decentralized devices and for the production and storage of energy from renewable sources.

CHAPTER 2: THE TECHNOLOGY

This section will give a technical description of the technologies involved in shallow geothermal exploitation, considering also the possibility of hybrid solution and geothermal storage. The final part of this section explains how those technologies can be coupled with the different areas of the cities, providing a couple of example of existing shallow geothermal systems in the city of Valencia

2.1 DESCRIPTION OF THE TECHNOLOGIES

Shallow geothermal systems are designed to produce heat, cold and domestic hot water using shallow geothermal energy, through a heat pump. Figure 5 shows the basic scheme of operation of a geothermal heat pump.

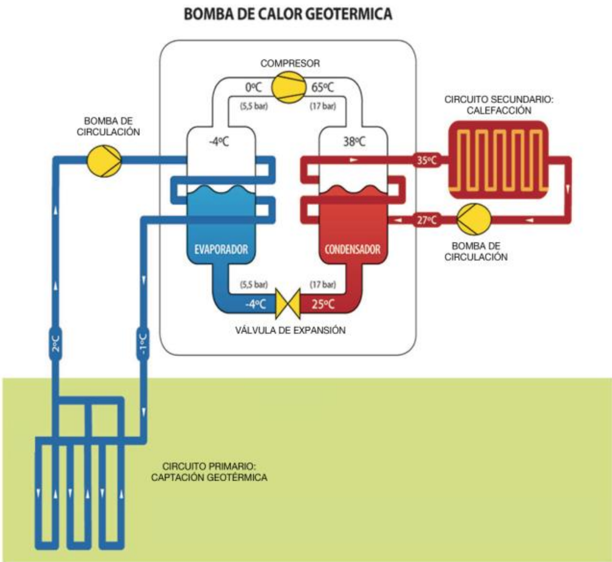

Figure 5. Scheme of basic operation of a geothermal heat pump in heating

Air conditioning systems based on shallow geothermal energy, regardless of whether the specific focus is the ground/subsoil or groundwater, are made up of 3 main elements plus some necessary elements in air conditioning installations (Figure 6). The specific elements of geothermal air conditioning are:

1. Heat pump that transforms the temperature of the geothermal source to the appropriate temperature levels required by the home for the three uses: heating, cooling and domestic hot water;
2. A system of heat exchangers located under the ground that allow energy exchange between the geothermal source and the heat pump;
3. A system that connects the exchangers in the basement with the technical room where the heat pump is located.

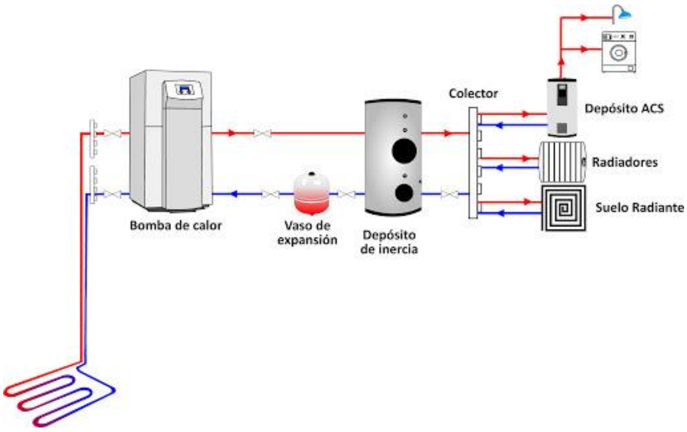

Figure 6. Diagram of DHW installation elements and air conditioning of a geothermal heat pump.

Shallow geothermal systems differ, depending on the type of use, basically by the system by which the geothermal source is connected or coupled to the heat pump. A very important case is the uses that take advantage of the temperature of groundwater contained in aquifers or hydrogeological systems, including lakes (surface uses), rivers or open waters. These systems are classified as “open loop” due to the configuration of the exchanger system which, in this case, constitutes an open circuit that extracts the water with which the pump exchanges energy and then reinjects it into the same or a different aquifer, at the water network, etc. The second large family of uses are the uses that take advantage of the temperature of the subsoil without there being a direct thermal contact between it and the heat pump. In this case, a heat transfer fluid, generally water, that circulates in a closed loop performs the heat exchange. Hence the name "closed-loop" geothermal energy. Within each of these families or types of use, there are in turn different technologies or options that are important to highlight, since they determine in a key-way the applicability of these systems to different uses. In the epigraphs that follow, these types and specific considerations are detailed in greater detail, highlighting the advantages and disadvantages that they possess with a view to their use in the context of the city of Valencia.

2.1.1 OPEN LOOP SYSTEMS

Groundwater is a valuable natural source, especially for drinking water. In addition, the use of groundwater for energy extraction is common in many countries, both for heating and cooling (Figure 7). In general, these open loop systems are more efficient than closed loop systems. This is based on the fact that water is a very good carrier of thermal energy (very high specific heat capacity, 4180 J/kg*K).

Figure 7. Open loop system with groundwater. Source: European project MUSE [5]

Figure 8. Open loop system with surface water. Source: European project MUSE [5]

In open loop systems, the carrier fluid is ground/surface water that is withdrawn and re-injected underground. The open-loop system concept can also be applied to surface water systems including options where water is drawn from a river, reservoir, lake, well, ditch, and other water source (Figure 8). In this system, the extracted liquid circulates through the heat pump exchanger and is returned to its origin or other destination, without suffering any type of contamination during the process, simply a variation in its temperature.

Open loop systems are often preferred over closed loop systems due to higher inlet temperatures and higher efficiency. With open systems, a powerful heat source can be harnessed at comparatively low cost. Especially when a shallow aquifer is used, drilling costs are cheaper than in the case of closed loop exchangers. Groundwater can also be used for direct cooling without heat pump ("free cooling"). The efficiency of free cooling is very high and therefore very interesting.

The great advantage of the open-loop system is that in addition to its lower installation cost (less drilling length required), the geothermal pump has higher performance than closed-loop systems, since groundwater usually has , depending on the area, a constant temperature throughout the year.

Limiting factors are often related to natural conditions, such as insufficient aquifer permeability (to allow production of the desired amount of groundwater with little drawdown) or technologically poor groundwater chemistry (e.g., a high content of iron or manganese, which causes scaling, clogging and corrosion problems). However, proper planning and careful selection of materials can reduce the negative consequences of poor groundwater chemistry.

In addition, groundwater is usually primarily a source of drinking water and its use as a source of energy is secondary. Existing drinking water wells or other water rights must be taken into account in the planning phase. Although open loop systems usually return water to the ground, negative influences could occur due to temperature alteration and increased circulation and movement of water in the reinjection well. In such circumstances, a closed-loop system may or should be considered as an alternative.

Environmental repercussions usually arise only in case of unsustainable use of groundwater, which means very high temperature change. The change in temperature could cause an alteration in the chemistry of groundwater and could disturb its ecological balance. The corresponding permits depend on local conditions and the regulations established by the authorities.

Open-loop geothermal uses are of special interest in the city of Valencia.

Valencia is a city located on the Levantine coast, so it has a very shallow water table, in relation to other locations in the interior of the country and in the Valencian Community itself, where, except for the presence of aquifers or other formations natural groundwater, access to it would require many more meters of drilling. There are also areas, such as the Albufera, with abundant water resources at very low depths. For this reason, open-loop developments have enormous potential in our city, since the techno-economic factor is especially favorable.

In addition, Valencia is located on alluvial land, with an abundant presence of layers of gravel and mud, which make drilling tasks difficult, increasing the cost.

However, this does not imply that closed loop systems are not useful to implement in the city, since the presence of a high water table also benefits heat exchange, and even more so when underground water circulation occurs to balance the temperature

2.1.2 CLOSED LOOP SYSTEMS

HORIZONTAL

Closed circuits or closed loops with horizontal heat exchanger are the easiest closed systems to install, however, in these systems a fairly large surface is required and it is located in the first 5 meters of the surface, with which it is heavily influenced by ambient temperature.

Within horizontal systems there are different possible distributions, some involving a higher density of pipes in the same space, others through ditches, series or parallel connections, etc.

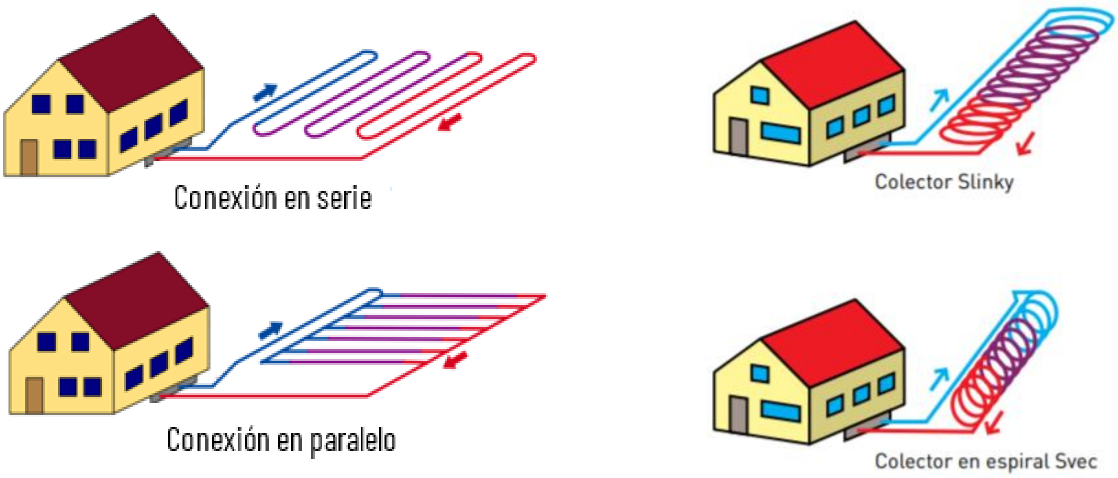

Figure 9. Types of horizontal connections. Source: MANDS, E.; SANNER, B. 2001 [6]

Spiral collectors are very common in the United States, while relatively dense connections, both series and parallel, are more common in Europe. Thermal recharge is mainly provided by solar radiation on the earth's surface. (Figure 9).

The pipes, normally made of polyethylene (PE) through which the exchange liquid circulates: water or glycol water, are installed in trenches at a depth of at least 0.90 meters. The needs are estimated between 10 and 35 m/kW depending on the lithological characteristics, degree of soil moisture and the number of branches in the trench. This system results in a lower thermal performance than drilling boreholes. A variant of this system, which is used in small consumptions, is the direct expansion system, where the exchange is carried out by circulating the coolant fluid from the pump through the ground circuit, increasing efficiency by reducing the number of heat exchangers.

For the design of horizontal heat exchangers, the following variables must be taken into account:

- Trench depth
- Number of trenches
- Space between probes in each trench
- Type of series/parallel pipe connection, see Figure 10.

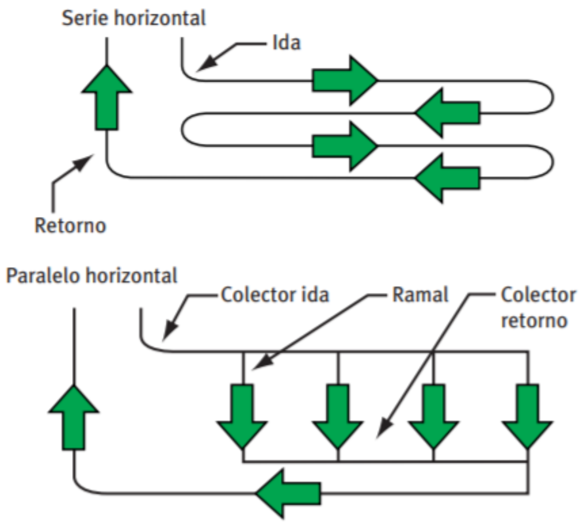

Figure 10. Series/parallel flow of a horizontal configuration. Source: IDAE [8]

The different connections have a number of advantages and disadvantages:

	Connection in series	Connection in parallel
Advantages	Well defined fluid path Trapped air easy to remove by purging. Higher thermal performance per linear meter of tube, since the diameter is higher.	Lower installation cost due to smaller diameters and fluid.
Disadvantages	It requires a larger diameter, which implies a greater amount of fluid and antifreeze (if there is a risk of freezing) Length limited by pressure drop	More complex trapped air removal. Problems to balance flow through loops due to different head losses depending on the length of each branch.

Table 1. Advantages and disadvantages of series/parallel closed loop systems

VERTICAL

This is by far the most common typology in our country (Figure 11) and in Europe due to its multiple advantages. The pipes are installed vertically and exchange heat with the ground along the entire depth that the pipe travels. This type of exchanger can be found, for example, in the Administrative Complex of October 9, where a wing of the old women's prison is heated through closed-loop geothermal energy with Single-U type vertical exchangers. The considerations to take into account in its implementation is that the distance between the geothermal exchangers must be at least 6 meters, so as not to incur thermal conditions and loss of performance between them.

Its implementation in the city of Valencia is also very interesting and can be combined with open loop and DCL systems. They are less efficient systems than the open ones but simple to implement and with a safe operation without the possibility of problems derived from the composition of the water or a bad previous planning study. However, they do require a higher installation cost due to the greater number of meters of drilling required.

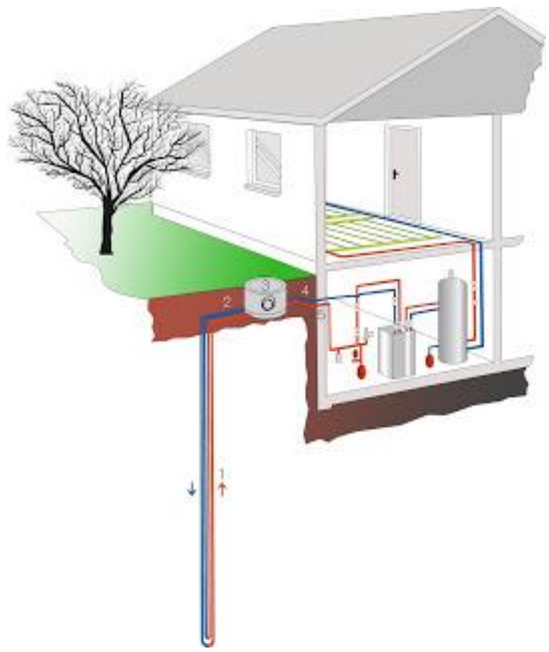

Figure 11. Scheme of a vertical closed loop geothermal exchanger.

Piping configurations of a vertical buried heat exchanger can be classified based on how heat exchange takes place in the ducts and taking into account their geometry. The most common vertical exchangers are those that follow a Single U-shaped distribution (simple U-shaped geometry) and the coaxial one. In Figure 12 you can see a profile of the two exchangers. Coaxial exchangers are very favorable from the point of view of heat transfer, although their installation is more complex and expensive and their hydraulic behavior is also more irregular, on the other hand, the main advantages of the Single-U pipe are its simplicity of installation. design, its ease of transport and its simplicity of installation compared to other alternatives. An installation carried out using the appropriate processes has an almost unlimited life. The main problems have to do with the losses due to the poor fusion of the pipes and the lower parts that make up the U. The main disadvantage of the pipe in a simple U is the relatively low thermal transfer capacity that it possesses, especially in extreme conditions. non-turbulent flow.

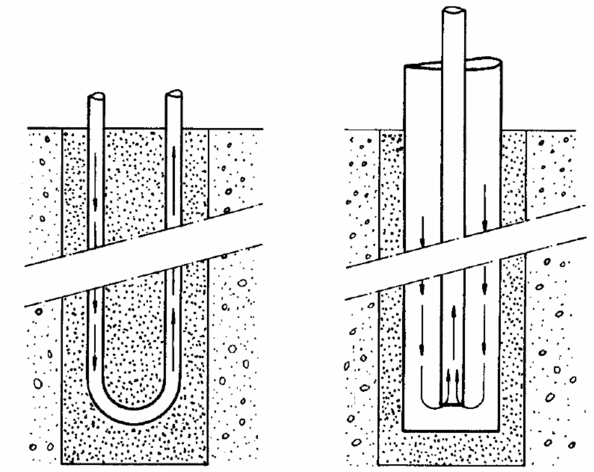

Figure 12. Single-U and Coaxial vertical heat exchanger.

A vertical heat exchanger (BHE) is used to bring a fluid into the ground allowing heat exchange between the subsoil and the fluid (heat extraction, heating mode) or from the fluid to the subsoil (heat injection, heating mode). cooling mode). The vertical exchanger consists of a pipe that contains a fluid; since it needs to be installed to a certain depth, it is usually long and slender. The exchanger must include the design of the fluid return from the deepest point of the collector to the surface. Given the need for the fluid to circulate into and then out of the earth, there are only a few basic options for the geothermal exchanger:

• Coaxial (or concentric) piping, also known as tube-in-tube

• U-pipes (two or more single pipes connected at the bottom)

Over the course of more than 60 years of geothermal exchanger development, various design alternatives have been developed and tested, but due to their cost-effectiveness, only a few simple designs remain (Figure 13).

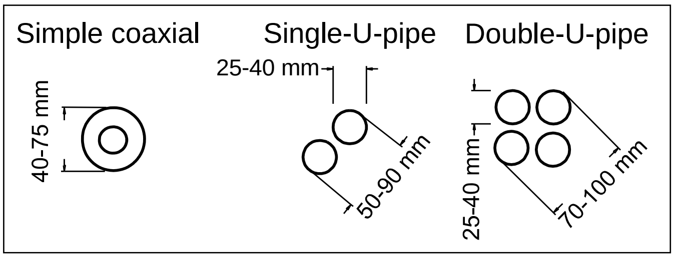

Figure 13. Design types of heat exchangers for shallow geothermal energy.

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2.1.3 ENERGY PILES

The Thermoactive Foundation is a technology applicable to the elements of the reinforced concrete structures of the foundations, "piles" and "screens", to obtain energy for the air conditioning of buildings from the subsoil (Mazariegos A. 2009 [9]). This type of foundation is based on taking advantage of the temperature of the ground to increase the performance of geothermal heat pumps. It involves converting the resistant foundation structure into a geothermal installation by equipping it with exchangers, consisting of networks of plastic pipes, usually made of high-density polyethylene, propylene, polybutylene or PVC through which water or water with antifreeze circulates, producing an exchange of heat between this fluid and the ground passing through the pile. The fluid is conducted to a geothermal heat pump, generating enough energy to air-condition a building.

The use of structural concrete as a heat exchange element with the ground is possible in various types of foundations: Concrete piles, both in situ and prefabricated, hollow concrete, steel or cast iron piles, pile screens, screen walls and slabs. Of all of them, the most frequent are piles of various types, in situ, prefabricated or hollow steel, although the rest of the foundations are also worked on.

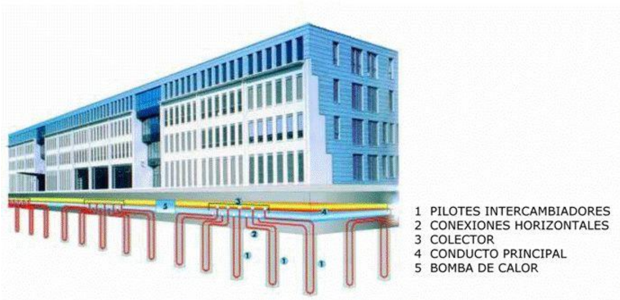

Figure 14. Diagram of building with geothermal piles.

According to Laloui L. (2009 [10]) a geothermal or thermo-active pile is defined as a pile-foundation element equipped with a system of channels inside so that a heat carrier fluid (heat carrier) can circulate exchanging heat with the surrounding terrain. If this equipped pile is connected to a heat pump, it becomes a low- and very low-enthalpy shallow geothermal energy extraction facility, fundamentally of solar origin, at a low cost.

Simplifying, a geothermal pile is a thermally activated pile by installing a heat exchange circuit inside it. To delve into this technology, the concept of the pile will be reviewed first, the types of piles accepted in Spain and later the elements that define a geothermal pile will be analyzed in successive sections, that is, the material itself from which the pile is built, the geothermal circuit installed inside and the heat transfer fluid that circulates transporting energy from the ground to the building and vice versa.

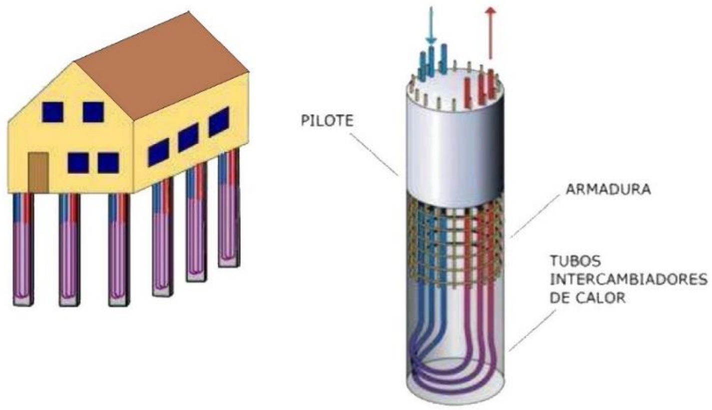

Figure 15. Thermoactive foundations.

The Swiss standard (2005 [11]) defines an energy geostructure as a structure to which is inserted a set of tubes through which a heat transfer fluid circulates that makes possible the exchange of geothermal energy with the ground.

With this definition in mind, the main elements of a thermoactive pile are the type of pile, including the material that makes up the pile (reinforced/prestressed concrete, steel), the circuit of tubes that make up the geothermal exchanger, and the heat transfer fluid.

2.1.4 DYNAMIC CLOSED LOOP SYSTEMS

The DCL system is an innovative method that can be considered a hybrid option between a closed and open loop system. In this case, energy is extracted from the subsoil through the water contained therein by means of a closed ring system.

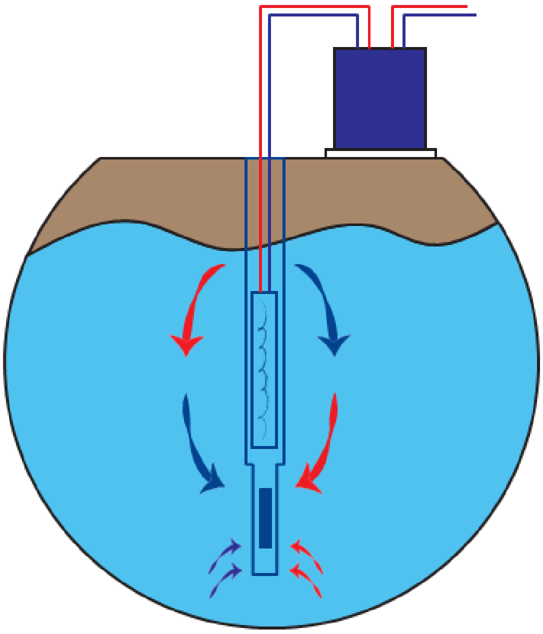

Figure 16. DCL system. Source: ITECON.

Unlike the conventional closed ring system, the DCL system - developed and promoted by the Valencian company ITECON - takes advantage of the effect of convection to multiply the energy transfer ratio, reaching up to 100 kW per well (this implies multiplying by 12 the capacity with respect to the conventional system, see Figure 16).

Contrary to the open system, the DCL system does not extract water from the subsoil since it carries out the heat exchange within the borehole (closed loop). This means that the flows to be transferred are much lower, with lower power pumps and greater system efficiency. In addition, it avoids extracting large amounts of water from the subsoil and returning a large amount of energy in a single drilling, with the thermal effects that this entails.

The DCL system is expressly designed so that it does not generate any effects on the environment by not extracting any water, it only recirculates the water from the aquifer and with no thermal effect on the drilling. Depending on the type of thermal demand required by the building (heating or cooling, DHW, air conditioning...) or the industrial or tertiary process (evaporation or condensation), the primary circuit fluid will flow through the geothermal probe placed inside the perforation to exchange heat with the water from the aquifer (secondary circuit) pumped from the bottom of the borehole and introduced into the DCL probe. The heat exchange occurs without physical contact between the two flows, which allows the use of glycol primary circuits in case the temperatures are close to 0ºC.

2.2 TECHNOLOGIES COMPARISON

To better understand the pros and cons of those different system is better to compare them with a table, also including the traditional Air Source Heat Pumps

	DCL	OLS	CLS	ASHP
ADVANTAGES	High COP-EER	High COP-EER	High COP-EER	-
	High ratio kW/well	High ratio kW/well	-	Well not required
	Free DHW	Free DHW	Free DHW	Free DHW
	Scalable power	Scalable power	-	Scalable power
	Simple procedure	-	Simple procedure	
	No water handling	-	No water exctraction	
	Low cost €/kW	Low cost €/kW		
	Recoverable geothermal probe	No noise		

Table 2. Advantages of the different technologies

	DCL	OLS	CLS	ASHP
DISADVANTAGES	Drilling cost	Drilling cost	Drilling cost	low COP/EER
	Requires underground water	Required at leats 2 wells	Low rateo kW/well	Visual impact
		water handling	non-recoverable geothermal probe	noise
		Complex procedure	Minimum footprint required	Frozing problems
		Hydric stress	High cost €/kW	High energy request
		Requires underground water		

Table 3. Disadvantages of the different technologies

2.3 STORAGE

According to the difference between air temperature and ground temperature, is possible to store heat or cold thanks to a heat pump

2.3.1 AQUIFER THERMAL ENERGY STORAGE (ATES)

In thermal storage concepts, the thermal inertia of the subsoil or certain situations in which there are thermally isolated areas are used to store thermal energy from buildings. A very popular scheme in the Netherlands is known as ATES (Aquifer Thermal Energy Storage) and consists of an open loop system to provide heating and cooling to buildings by extracting hot water for heating and injecting colder water after heat exchange in another underground water well. In this case, and unlike what constitutes a conventional open system, the injection and reinjection zones are used as a thermal store, preventing them from coming into thermal contact and ensuring that they are thermally insulated as much as possible. In winter the system cools the water and re-injects it to the well which is at a low temperature, while in summer the flow of the system is reversed and the heat from the building, transferred to the water, is re-injected into the hot side of the system. These types of systems are ideal when there is water availability, certain geological conditions and, above all, a balance can be sought between the demand for cold and heat from the system.

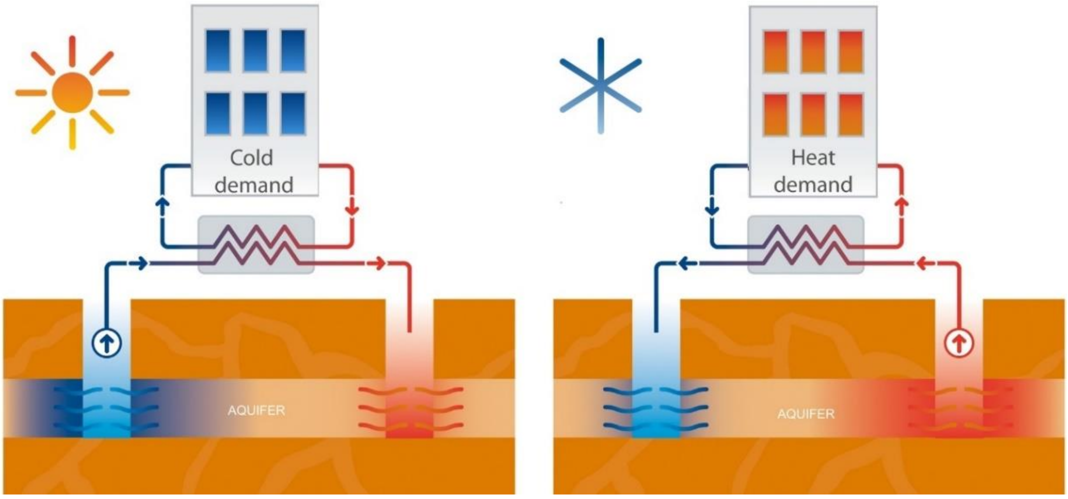

Figure 17. Example of thermal storage in aquifer.

2.3.2 BOREHOLE THERMAL ENERGY STORAGE (BTES)

In the case of closed-loop systems used specifically as thermal storage, the exchange systems are designed with the aim of serving as a storage for the heat produced by sources such as solar energy or residual energy from other types of processes. Typologically, they are systems similar to the closed-loop exchangers mentioned above, however, the configuration and materials surrounding the wells are very different. These systems are currently under development, and there are not many systems in operation. The diagram shows how the configuration of the exchanger is arranged in such a way that the heat is loaded (from a solar energy source or another type) from the center of the exchanger towards the periphery. A hot zone or core is produced in the exchanger that can have quite high temperatures, which requires very different materials from those generally used for shallow closed-loop geothermal energy.

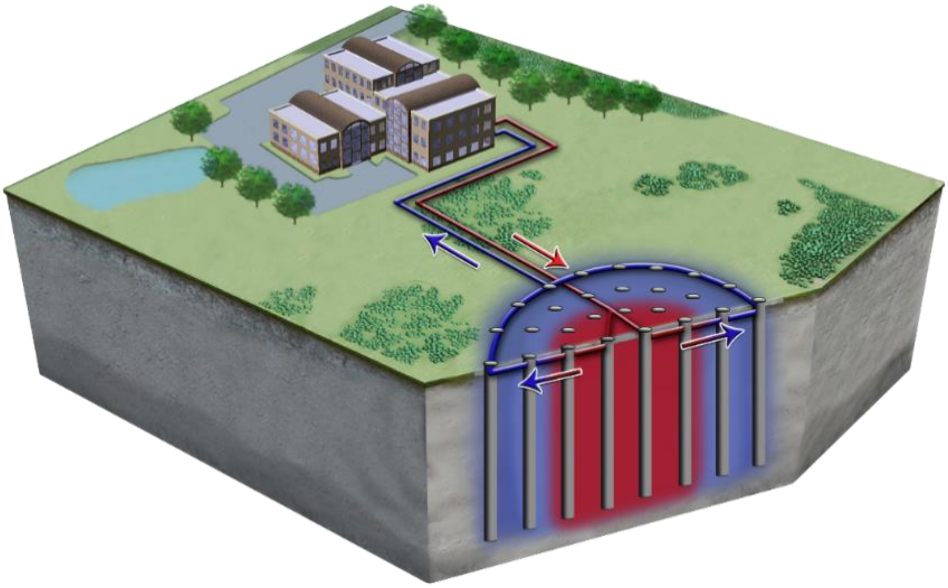

Figure 18. Example of thermal storage in a well.

2.4 HYBRID SOLUTIONS

If the demand for heating and cooling is not balanced, the floor temperature may change after a certain period. This will reduce the efficiency of the heat pump and the energy extracted. Buildings generally have a heating and cooling demand that is not balanced due to climatic conditions in the city. In that case, it is recommended to partially cover the highest load (between heating and cooling) and then supply the remaining demand with other technologies.

2.4.1 SUPPORT ASHP

It is the most natural way to cover the remaining demand. You can opt for the option of an air-water heat pump or also for a double source, that is, one that has an exchanger with the ground and an exchanger with the air. It is also possible to combine the operation of the aerothermal pump with that of the ground in order not to overload the latter, and also optimizing the start-ups according to the environmental and system conditions (Figure 19). In the case of Figure 16, hybridization occurs at the level of the secondary hydraulic circuit. Depending on the temperatures of the circuit, the system's control logic decides which energy source (air or geothermal) is more suitable in each case. These types of systems have been implemented in numerous buildings in Spain and internationally.

An example applicable to the city of Valencia could be the use of aerothermal energy in the winter season for heating during the central hours of the day, on days when temperatures are high, while the first hours of the day and geothermal energy is used in the afternoons, and that central time is used, so that the ground balances its temperatures and in the afternoon the pump is used again with more optimal conditions than if it had not had rest.

With the combination of both sources, it is possible to have higher yields and reduce the installation cost by not having to size the geothermal exchangers with sufficient power to supply the peak demands of the buildings, thus producing very relevant energy savings. (Urchueguía, J. F. 2008 [12])

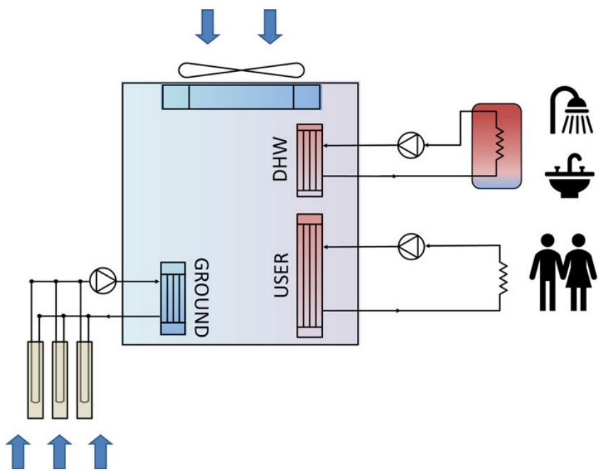

Figure 19. Diagram of the principle of a heat pump with a double source of air and geothermal energy.

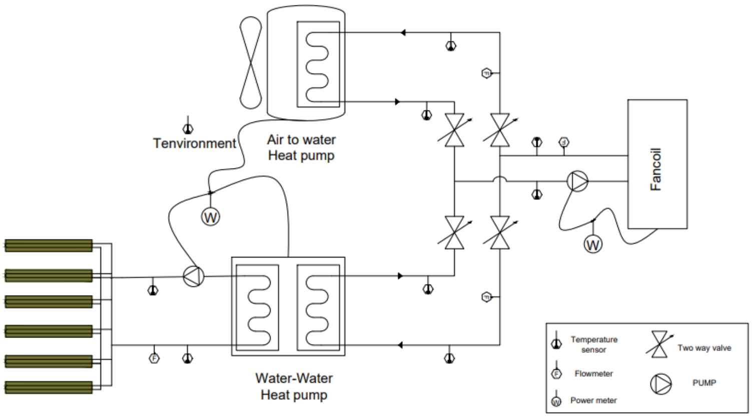

Figure 20. Combination scheme of geothermal heat pump and air-water heat pump.

2.4.2 SOLAR ASSISTED HEAT PUMP (SAHP)

It uses a solar panel and a heat pump to heat the buildings and provide domestic hot water. The connection between the heat pump and the solar thermal panels can be seen in Figure 21. It is a combination of solar thermal energy and geothermal energy that, depending on the interior uses that are made, there are different options, for example, in places where geothermal It is used for DHW and heating, it could be used to heat the water during the hot season and the one that is not consumed by DHW, store it underground for the winter, taking advantage of the vertical exchanger. In the cold season, as an assistant to the geothermal heat pump, direct consumption of DHW and with the surplus energy (if any) heat the vertical exchanger.

In the event that the solar panel is photovoltaic, it can support the heat pump, in the first place, providing all or part of its electrical consumption, and if necessary, you could also have electric water heaters that store hot water with the surplus electrical energy generated in the photovoltaic solar panels.

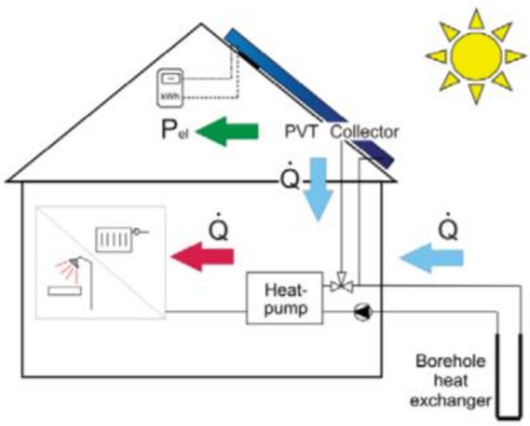

Figure 21. Combination of geothermal energy with solar thermal energy.

2.5 APPLICATION IN THE CITY

Shallow geothermal systems are very versatile, they can work with any type of soil and supply enough energy for different types of buildings located in different areas.

2.5.1 AREAS

A study from REGEOCITIES project [13] defines the most common area pointing out per each of them pros and cons

AREA	PROS	CONS
A **Old areas**	Low visual impact, no operating noise compared to some of the competing technologies. Heating and cooling with a single system. If district heating solutions are already used, the implementation of large-scale SGE applications can use an existing distribution network. In certain cases open loop technologies (ATES) can be implemented by drilling into the basement of the building.	Existing heating and/or cooling of the building. These zones may have infrastructure not represented on plans, making the drilling process risky. These areas may have narrow accesses so there may be access problems for the drilling team. The distribution system exists (or its lack) could limit the incorporation of a geothermal system depending on the level of rehabilitation of the area.
B **Areas with special attention to preservation**	Low visual impact, no sound impact compared to other technologies. There is almost no visual evidence of aboveground installations, except for a few caskets. There are no outside units or fireplaces. Heating and cooling in 1 single system. They do not need fuel supply.	Buildings may be more sensitive to vibrations from drilling. Restoration of patios and other outdoor areas after installation can be expensive. However, restoration may be necessary after any type of renovation. Restrictions due to the archaeological importance of drilling. Installation of supply and return mains through exterior walls or using existing openings, new ones may not be possible. However, this could be done below ground level without visual impact.
C **High density populated urban areas**	They favor the use of large highly efficient geothermal systems (ATES/BTES), a single system for	Risk of thermal interference between geothermal systems due to their proximity. You can limit the SGE implementation options.

	several buildings, rather than individual connected heat pumps. Low visual impact, no sound impact, no outdoor units. Elimination of the health problem related to legionellosis	Existing underground infrastructure, such as subways, water or sanitation pipes, etc. has the danger of restricting implementation options. If heat/cool demand is unbalanced: a source will be needed to rebalance (i.e. solar collector, chiller or lake/stream) There may not be a suitable place for piercings.

AREA	PROS	CONS
D **Low density populated urban areas**	Greater availability of space for wells/perforations. Sufficient space between shallow geothermal systems for recovery. Large buildings such as shopping centers with high thermal loads for heating and cooling.	In some cases, a short distance from the neighbors (detached house)
E **Urban areas in develpment**	Shallow geothermal systems can be designed from scratch. You can invest in geothermal energy, which in this case is easier to install and saves on other infrastructure installations. No visual or sound impact without outdoor units. Possibility of planning large district heating systems with geothermal energy as a heat source in urban plans. Possibility of decontaminating the soil and groundwater in industrial areas through the implementation of geothermal systems. Possibility of planning district heating schemes at very low temperature	Planning possibilities for large district heating systems (with another source of SGE) in the early stages of planning. If large-scale systems (large systems and as many SGE systems) are expected, some organization of the subsurface is needed in order to prevent negative interference between systems and to ensure that each building has the ability to drill. Risk of toxic leakage from contaminated soil (from old industrial estates) to groundwater.
F **Commercial Areas**	In cold weather: there will be a balance between cooling/heating, in favor of large storage (BTES/ATES)	SGE permitting and authorization procedures can be significantly delayed and not coordinated with building permitting procedures.

	Significant reductions in energy costs associated with thermal energy. High performance cooling is possible in this type of building.	
G Industrial areas	Buildings can be designed from scratch. Combination of geothermal energy with heat recovery from industrial processes. Possibility of decontaminating soil and groundwater through the implementation of ATES systems.	Risk to groundwater from contaminated but stable soil layers with toxic waste SGE systems are restricted in the temperature ranges that can supply industrial processes. Many of them have high temperature requirement.

AREAS	PROS	CONS
H Logistic and techinc areas of the city	Heating and recovery of industrial processes that can be used by heat pump coupled to the ground GSHP	Sensitive ecosystems of the protected area.
I Green areas	Large areas of open space suitable for the development of large underground storage systems if there are buildings in the vicinity.	There are no buildings for the supply of thermal energy in the area. Sensitive ecosystems of the protected area.
J Areas with water flow	Water is a very good balance source for heating and cooling with ATES/BTES. The geothermal system can be used directly in water areas or in the underground under water	The heat transfer fluid may not conform to the requirements of safety considerations and protection of water currents. The lack of adequate information on the quantitative and qualitative thermal effects in specific areas, due to the overexploitation of the aquatic environments of ATES systems. Groundwater extraction could make it more difficult to drill geothermal wells in drinking water protection zones.
K Major highways	Geothermal systems could be used to melt ice on roads (or just parts of them, especially on ramp or	The design of the highway infrastructure could constrain implementation options.

and railways.	sloping areas of the road, in winter or when necessary) by placing collectors under the ice. highway. In summer, the asphalt serves as a solar collector.	

Table 4. Pros and cons of shallow geothermal energy in the different city areas

2.5.2 EXAMPLE IN VALENCIA

This section reports some example of building in the city of Valencia that supply H&C demand using geothermal heat pump.

<u>RESIDENTIAL</u>

For a single-family home, the installation of 1-2 vertical wells or a large horizontal exchanger surface is sufficient. Both systems are invisible, the heat pump does not require much space and it would replace the space of a gas boiler.

Es: Family building in Carrer Almirante Cadalso

Location: Carrer Almirante Cadalso, 33, 46005, València

Owner: Private

Building typology: Families

air-conditioned surface: 2.000 m^2

System installed: close loop DLC

Power installed: 170 kW

Year of installation: 2020

Annual heating demand: 110.000 kWh / y

Annual cooling demand: 95.000 kWh / y

Annal DHW demand: 20.750 kWh / y

Cost of installation execution: 119.000 €

Annual cost of installation: 12.250 €

Economic saves: 13.150 €/ y

Energetic saves: 52.450 kWh / y

Emission saved: 18,75 tCO_2 / y

Renewable energy produced: 175.550 kWh / y

OFFICE AND COMMERCIAL BUILDINGS

This application will imply more energy demand in a specific area that will have greater demands than, for example, a home. It is possible to meet this demand by using vertical heat exchangers, which can be installed on any plot of land, but a large number of these will be needed to meet the heating and cooling demand. Groundwater (open loop) heat pumps would be more suitable, but it would require a specific groundwater composition and need more attention on management.

It is possible to have a few heat pumps with high thermal capacity that transfer heating and cooling by hydraulic circuits or several small heat pumps connected to the same network to satisfy the thermal load of shops and houses.

Es 1: CIUDAD ADMINISTRATIVA 9 D'OCTUBRE

Location: Carrer de la Democràcia, 46018, València

Owner: Public, Generalitat Valencia

Building typology: administrative (office)

air-conditioned surface: 1.800 m^2

System installed: open loop system

Power installed: :200kW heating, 180kW cooling

Year of installation: 2011

Annual heating demand: 60.000 kWh / y

Annual cooling demand: 160.000 kWh / y

Annal DHW demand: n/a

Cost of installation execution: 275.000 €

Annual cost of installation: 12.000 €

Economic saves: 15.000 €/ y

Energetic saves: 50.000 kWh / y

Emission saved: 17,85 tCO_2 / y

Renewable energy produced: 165.000 kWh / y

Es. 2: COMPLEJO DEPORTIVO-CULTURAL "LA PETXINA"

Location: Passeig de la Petxina, 42, 46008 València

Owner: Public, City of Valencia

Building typology: sportive

air-conditioned surface: 4.000 m^2

System installed: close loop DLC

Power installed: :450 kw

Year of installation: 2018

Annual heating demand: 258.800 kWh / y

Annual cooling demand: 290.500 kWh / y

Annal DHW demand: n/a

Cost of installation execution: 315.000 €

Annual cost of installation: 30.500 €

Economic saves: 31.900 €/ y

Energetic saves: 127.500 kWh / y

Emission saved: 45,5 tCO_2 / y

Renewable energy produced: 427.400 kWh / y

CHAPTER 3: SHALLOW GEOTHERMAL POTENTIAL

Referring to the situation stressed in the chapter 2.2, it result that in Spain geothermal energy is not as exploited as in several others European countries. Figure 22 shows that the percentage of heat pump per 1000 inhabitations is lower than 1%. Norway and Finland reach up to 12% and the average in the center of Europe is 2%. Following the other countries Spain should be more penetrated by this technology.

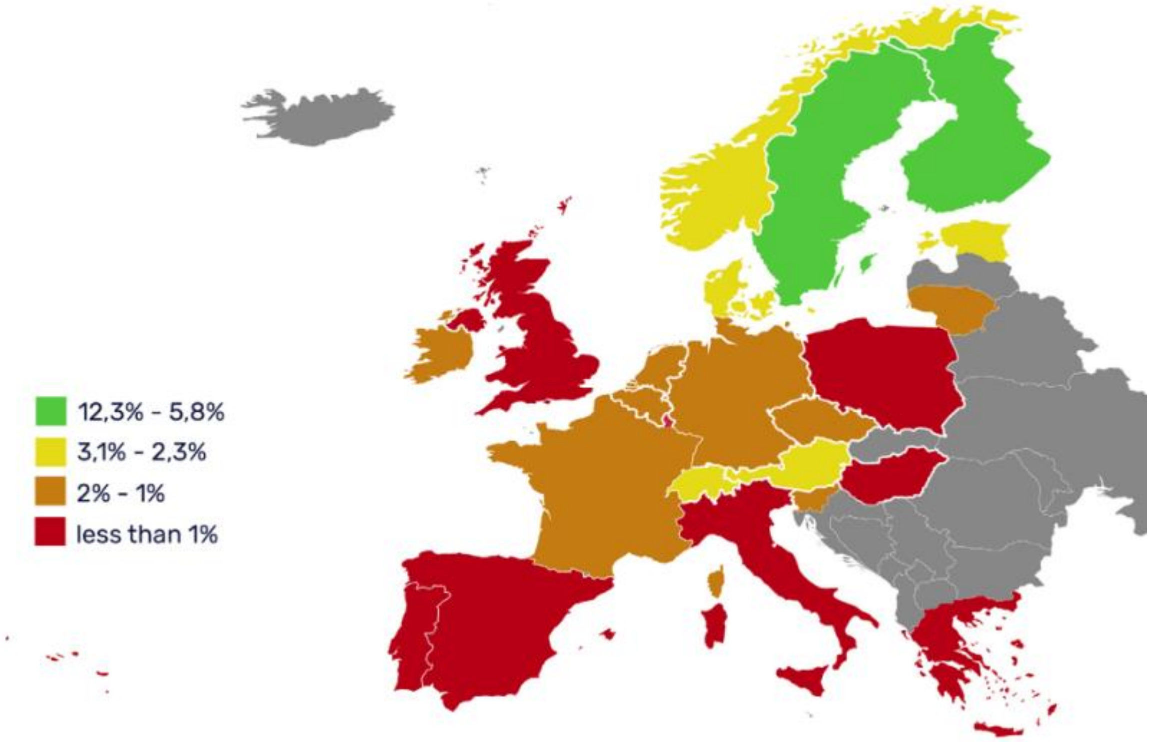

Figure 22. Number of inhabitation with an heat pump each 1000 householders, map of Europe. (EGEC geothermal market report 2020) [3]

The definition of shallow geothermal potential regards the economic and environmental impact that is possible to achieve with a higher diffusion of geothermal heat pump.

This thesis will study three different scenarios, with a different level of penetration of heat pump technology as instrument to satisfy H&C and DHW buildings demand. The impact will be evaluate following a methodology described in the next section.

SCENARIOS

Referring figure (22), scenarios will suppose a percentual increase of heat pump in line with the European percentages. The three scenarios will consider different level of penetration:

- Low: heat pumps increase at 1%

- Medium: heat pumps increase at 3%

- High: heat pumps increase at 6%

CHAPTER 4: METHODOLOGY

Figure 23 shows the relationship between the indicators that will allow the assessment of the technical and economic viability of the implementation of geothermal energy as an energy source for the production of hot water (DHW) and air conditioning of buildings of the city of Valencia.

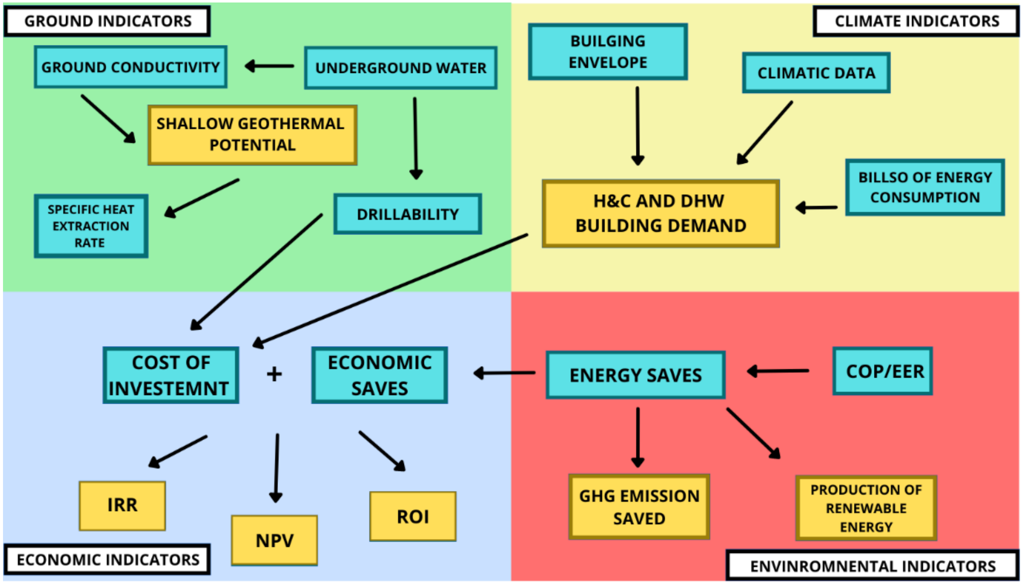

Figure 23. Correlation between indicators and indicators group. Yellow square will regard the main output and the blue one the data necessary to calculate them

These indicators are divided into 4 main groups:

• Land indicators: these will define the geothermal potential of the land where they are located.

• Building indicators: depending on its own characteristics. They will define the thermal energy demand of the building that must be dissipated in the geothermal exchanger.

• Economic indicators: through the estimation of the investment the economic savings of the installation with respect to a reference installation and the return on the investment made.

• Environmental indicators: by calculating the seasonal performance of electrical efficiency of the heat pump (SPF), the energy savings can be obtained with respect to a reference installation, the CO_2 emissions avoided and the production of renewable energy.

The assessment of all these indicators will define the decision-making, identifying the most suitable buildings for the application of a geothermal air conditioning system. The next section will analyze all the indicators and will define the procedure of their evaluation

4.1 GROUND INDICATORS

This chapter describes a series of indicator related to the underground properties that are necessary to go on our analysis

- Subsoil water: Indicates the presence and depth at which water can be found in the subsoil, in order to study the possibility of installing the different surface geothermal systems.

- Conductivity of the ground: depending on the lithology and geology of the area, an indicative data of the thermal conductivity of the ground.

Thermal conductivity is a good indicator to define the ground properties and to define the heat transfer of the soil (Bertermann 2014 [14]) Thermal conductivity was defined by Fourier's Law by means of a logarithm that describes the amount of heat that passes through the soil per unit of time (W/m*K). It is correlated to the soil bulk density and its water content. By increasing the apparent density of the soil, the contact between the solid particles increases the thermal conductivity by conduction. Similarly, thermal conductivity is proportional to the water content, and more in specific is linked with the rock porosity as the porosity, by convection. What happens is that the thermal contact between soil particles is improved by the water and replaces the air. In comparison air has significative low thermal conductivity, about 20 times lower than that of water. This phenomenon occurs mainly in saturated unconsolidated sediments (Fossa 2020 [15]). Therefore, thermal conductivity depends on three factors: the minerals that make up the soil, soil porosity, and the sample water content (Horton, Ankeny, and Allmaras 1994 [16]).

In addition, it has been shown that there are different degrees at which thermal conductivity of the rock is influenced by the effect of water saturation. It depends on the rock formation of origin. With the same water-saturated conditions, thermal conductivity also increases as rock porosity increases (Nagaraju and Roy 2014 [17]). Thermal conductivity values vary from one lithology to another because of this reason.

The data source for the thermal conductivity values is GEO4CIVHIC database [18]. It provides thermal conductivity values classified by major lithological groups. In order to relate the geological information of the study site and the thermal conductivity values, a conversion of the geological classification data into GEO4CIVHIC classification data was carried out. For this, it was necessary to pass through three different level of resolution, from the environment to the main lithology.

The first level is "environment" and the data base propose three different kind

1	**Alluvial plain**
2	**Mountain-hill area**
3	**Coastal area**

Table 6. GEO4CIVHIC envirnoments

The second level regards the "sub-environment" defining several options per each environment

1	Alluvial plain	**1,1**	**high plain**
		1,2	**low plain**
2	Mountain-hill area	**2,1**	**valley plain**
		2,2	**slope**
3	Coastal area	**3,1**	**rocky coast**
		3,2	**shoreline**

Table 7. GEO4CIVHIC sub-environment

This level already provides a general valor of thermal capacity, but each sub-environment has several main lithologies that is the highest level of resolution.

Startin from the 1st environment

	SUB-ENVIRONMENT		**MAIN LITHOLOGY**
1,1	**high plain**	**1.1.a**	**gravel**
	(towards the mountains)	**1.1.b**	**sand**
1,2	**low plain**	**1.2.a**	**sand**
	(towards the sea)	**1.2.b**	**clay**

Table 8. GEO4CIVHIC main lithology for the first environment

Then the second

SUB-ENVIRONMENT		MAIN LITHOLOGY			
2,1	valley plain	2.1.a	gravel		
		2.1.b	sand		
2,2	slope	2.2.a	limestone	2.2.n	diatomaceous rock
		2.2.b	dolomitic limestone	2.2.0	gypsum
		2.2.c	sandstone	2.2.p	marl
		2.2.d	claystone/mudstone	2.2.q	phyllite
		2.2.e	marble	2.2.r	pyroclastic rocks
		2.2.f	conglomerate	2.2.s	quarzite
		2.2.g	gneiss, micaschist	2.2.t	schist
		2.2.h	plutonic rocks	2.2.u	serpentinite
		2.2.i	volcanic rocks	2.2.v	shale
		2.2.l	calcarenite	2.2.z	travertino
		2.2.m	chalckstone		

Table 9. GEO4CIVHIC main lithology for the second environment

And the third

	SUB-ENVIRONMENT		MAIN LITHOLOGY
3,1	rocky coast	3.1.a	limestone
		3.1.b	marl
		3.1.c	sandstone
		3.1.d	calcarenite
		3.1.e	diatomaceous rock
3,2	shoreline	3.2.a	sand
		3.2.b	silt

Table 10. GEO4CIVHIC main lithology for the third environment

For each main lithology is available the thermal conductivity

• Drillability: Shows the simplicity or complexity of the drilling depending on the characteristics of the terrain.

Using the same main lithology reported in thermal capacity, is possible to obtain several characteristics of the ground as the Drillability time and costs provided by GEO4CIVHIC database

• Shallow geothermal potential: It is the annual thermal capacity (in terms of heating or cooling) that the ground can exchange without altering its properties.

The calculations are made with the G.POT method. It offers the possibility of estimating the annual geothermal potential that can be extracted by geothermal technology in 100 m deep drilling for heating and cooling. The method provides the thermal energy per unit of time (hot or cold) that can be exchanged with the subsoil under certain conditions.

• Specific heat extraction ratio: Shows how much heat it is possible to extract for each meter of depth without altering ground properties.

By applying G.POT methods, considering drilling of 1 m length in simulation of 1 h of time as the new variables, the specific extraction rates were estimated. The specific rates also vary depending on the lithology, which is defined and entered into the model using the thermal conductivity.

4.1.1 DRILLABILITY AND SOIL POTENTIAL EVALUATION PROCEDURE

Drillability data (1) comes from a model that considers lithology as input. The same model will provide the thermal conductivity λ.

The **evaluation of soil potential (2)** will regard G.POT method (Gasassi 2016 [19]). Like other methodologies that determine the shallow geothermal potential, this methodology is based on the assumption that the final potential depends mainly on the specific parameters of the subsurface location and its use in the residential sector. The model allows estimating the potential for space heating and cooling separately. Calculate the average thermal load that can be exchanged between a vertical heat exchanger (BHE) and the subsoil per unit time.

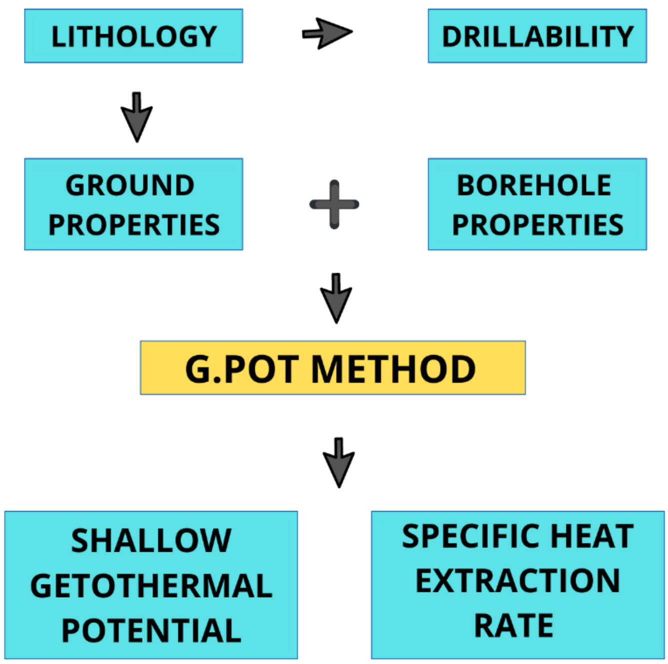

Figure 24. scheme of ground indicator evaluation procedure

1)Once individuated the ground composition is possible to refer to GEO4CIVIC table in order to obtain thermal capacity and some other ground properties related to the Drillability:

- Drilling method: there are several drilling method with different costs that can be used to install the same technology or different ones in different ground conditions (tricone + c; DTH w/o c; ED w/o c). This parameter will define also the drilling time and cost.

- Drilling time: [min/m] data from table
- Drilling cost: [€/m] this cost is really important in order to evaluate the economic feasibility of the installation. Unitary cost is not that high but the geothermal heat pump required several almost 100m length boreholes.

2) G.POT method a set of heat transfer simulations, where some variables will remain fixed, such as BHE properties, and other spatial variations, such as subsurface properties.

- Within the first group, there are the threshold temperature of the fluid, the depth of the perforation, the radius of the perforation, the thermal resistance of the perforation and the simulated time.

- In the second group, there are the thermal conductivity, the thermal capacity and the unperturbed temperature. The duration of the heating or cooling season can be both fixed and varied in the case of the presence of different climatic zones in the area to be studied.

$$Q_{BHE} = \frac{a * (To - T_{\text{lim}}) \, * \, \lambda \, * \, \mathrm{L} \, * \, \mathrm{t'c}}{-0.619t'c \, * \, log(u's) + (0.532 \, * t'c \, - \, 0.962) \, * \, log(c'u) \, - \, 0.455t'c \, - \, 1.619 \, + \, 4\,\pi\lambda * \, \mathrm{Rb}} \quad (1)$$

α: thermal conductivity

λ: thermal capacity

L: borehole length

R_B: borehole thermal resistance

T_0: undisturbed ground temperature

T_{LIM}: minimum or maximum temperature of carrier fluid during heating/ cooling mode

Ts: time over which the sustainability of the heat exchange is evaluated

Other equations parameters are better explained by Gasassi [19]

The order of the procedure is illustrated in the figure (24)

4.2 CLIMATE INDICATORS

• Heating and cooling demand: Energy that the building requires for air conditioning and that must be provided by the geothermal system and seasonality. At this point it is checked whether the energy that must be dissipated by the geothermal exchanger is balanced between the needs for heating and cooling.

To determine the indicator, the following data will be required:

- Climatology of the building area: it’s possible to obtain a model capable of predicting the energy needs of buildings according to different climatic conditions, based on the climatic classification and the number of the seasonal Degree Days, DD.

- Thermal envelope of the building. If it is a building under construction or existing (year of installation).

- Current energy consumption: in the form of bills. This was the methodology used to evaluate the examples.

4.2.1 BUILDING LOADS EVALUATION PROCEDURE

Building H&C consumption is a fundamental parameter evaluate in order to correct dimensioning the geothermal heat pump. It requires the knowledge of the characteristics of the buildings and the specific climate condition and a model that can combine them. It' also possible to obtain it consulting the bills (figure 25)

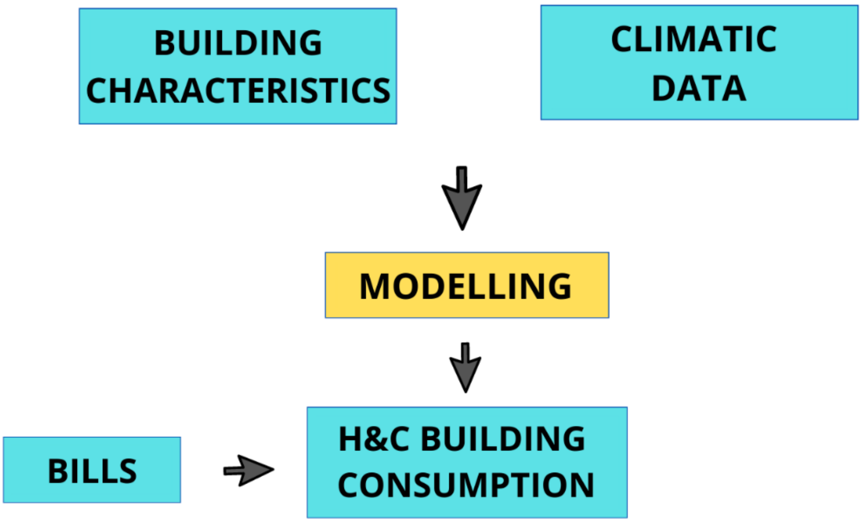

Figure 25. H&C building consumption evaluation procedure

The procedure purposes in the thesis start considering the Starting from the average H&C and DHW consumption [kWh/m^2] of different kind of building. This data is available in Entranze document "Heating and cooling energy demand and loads for building types in different countries of the EU" [21]. It is based on the building typology, their dimension and the climate of the cities.

4.3 INTRO AT ECONOMICS AND ENVIRNONMENTAL INDICATORS

To proceed with the evaluation of economic and environmental indicators, is necessary to calculate the borehole length and the energy saves. The structure of COP and length calculation requires an iteration as reported in figure (26)

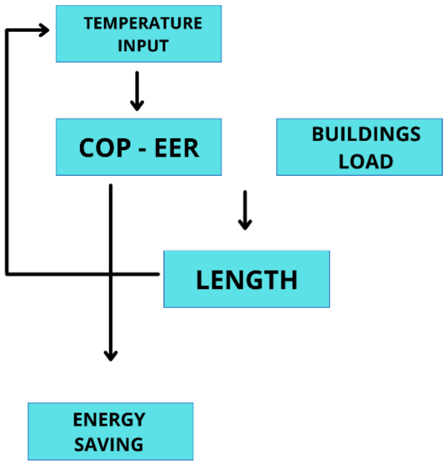

Figure 26. Length and energy saving evaluation procedure

4.3.1 LENGTH CALCULATION

The formula is different for heating (h) and cooling (c) season

$$\text{length\_h} = \frac{\text{Qh} * (1 - 1/\text{COP}) \; * (\text{Rp} + \text{Rs} \; * \; \text{F})}{\text{Tl} - \text{Tmin}} \quad (2)$$

$$\text{length\_c} = \frac{\text{Qc} * (1 + 1/\text{COP}) \; * (\text{Rp} + \text{Rs} \; * \; \text{F})}{\text{Tmax} - \text{Th}} \quad (3)$$

Some inputs are requried:

- Q thermal load of the building.
- F utilization factor (available from tables), It will determine the distribution of the thermal load. It will be multiplied by the ground resistance (available from tables)

- Rp is the thermal resistance between pipe and fluid, it can be evaluated as

$$\text{Rp} = \frac{1}{2 \; * \; \pi \; * \; \text{Kp}} \; * \; ln(D0/D1) \quad (4)$$

Kp is the thermal conductivity of the pipe and D0/D1 is the ratio between outer and inner pipe diameter.

- T_l/T_h are the borehole temperature in heating/cooling mode
- T_{min}/T_{max} are the ground temperature.

Is possible to make a seasonal calculation or as well a month calculation, depends on the resolution of the thermal load data

By having them per months is possible to evaluate 12 different length according to 12 different COP. The most relevant will be the higher length.

Once obtained the length will be necessary to re calculate all the denominator of the (2) or (3) and evaluate the new COP using the recalculated temperature

4.3.2 ENERGY SAVES

According to COP evaluated in the previous calculation, the energy saves can be achieved.

In case of seasoanl COP

$$\text{Energy saves} = \text{Buliding load} * \left(\frac{1}{\text{SCOPt}} - \frac{1}{\text{SCOP}} \right) \quad (5)$$

It represents the different in efficiency between a geothermal heat pump and a traditional heat pump (characterized by a tabled COPt)

In case of the evaluation of buildings load and COP per each month, in necessary to sum all the monthly energy saves of each month (i)

$$\text{Energy saves} = \sum_i \text{Buliding load}_i * \left(\frac{1}{\text{SCOP}t_i} - \frac{1}{\text{SCOP}P_i} \right) \quad (6)$$

4.4 ECONOMIC INDICATORS

•Investment cost: Cost of drilling the ground and to the component installation. Those indicators will show the different prices in terms cost of investment about geothermal heat pump application in different areas. The price will depend on the lithology of that area, the technology used and the borehole length

• Economic savings: intended as the difference between running costs for DHW and air conditioning system operations between traditional systems and geothermal heat pump

Once the thermal consumption in air conditioning has been determined, the electrical consumption that would be obtained with the migration to geothermal energy is calculated.

• Return on investment time (ROI): This is the time in which the investment made by migrating to geothermal energy will be recovered based on the economic savings that it provides compared to the previous installed system.

This indicator will help to consider in how many times the investment will be cover with the actual price. According to the variations of some parameters in the time (energy price, drilling cost, development of new technologies) is important to have a lower ROI in order to don't commit valuation errors

• NPV: Net present value, which consists of the present value of the net cash flows originated by an investment, throughout the useful life of the installation.

It will indicate the net incomes at the end of the system lifetime. Useful indicators for the investors in order to compare the profitability of the investment

• IRR: Internal rate of return, which indicates the economic return offered by an investment, in percentage of the initial investment.

Useful for the investor to see the profit in percentage of the initial investment

4.4.1 ECONOMIC INDICATORS EVALUATION PROCEDURE

Economic indicators will help to understand the economic feasibility of the project. Some indicators are required form the previous sections, as reported in figure (27)

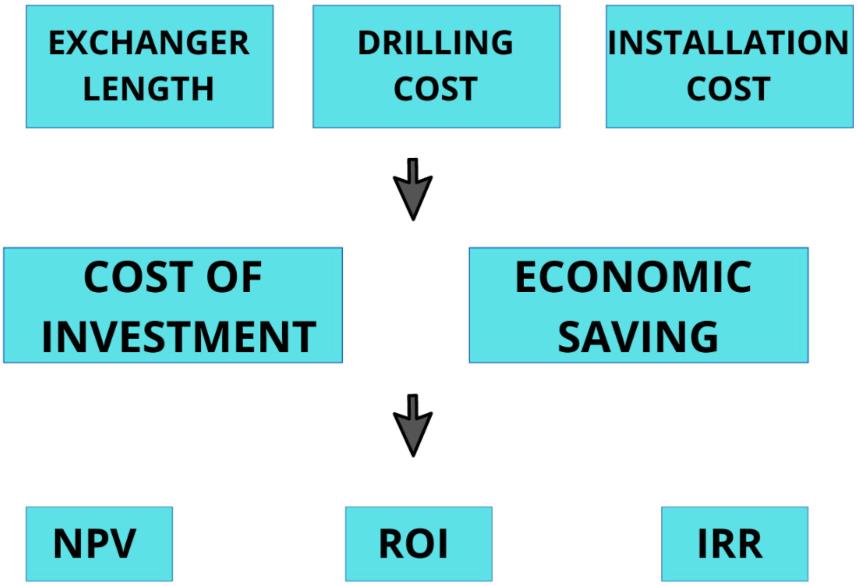

Figure 27. Economic indicators evaluation procedure

Drillability database, will provide the unitary drilling costs per each lithology, so it's possible to evaluate the drilling costs per each area of the city is possible to evaluate the drilling cost per each lithology area

$$\text{Drilling costs} = Length * unitary\ drilling\ costs \quad (7)$$

Investment costs will contain a part that is about the cots of the installed components.

$$\text{Investment costs} = \text{drilling costs} + \text{installation cost} \quad (8)$$

Geothermal heat pump can provide DHW and air conditioning with a lower energy consumption than traditional system. This energy saves calculated previously can be converted in economic saves.

$$\text{economic saves} = \text{cost of energy} * \text{energy saves} \quad (9)$$

Cost of energy is given by the actual cost of electricity [€/kw] in Spain.

Successively the indicators can be calculated

- ROI return of investment [y]: year of return of the investment

$$\mathrm{ROI} = \frac{\text{Investment cost}}{\text{Economic savings}} \quad (10)$$

- NPV net present value: total net incomes of the project

$$\mathrm{NPV} = -\,\text{Investment cost} + \sum_{n} Fn \quad (11)$$

Fn: net cash flow at year n (net considering the economic saving achieved with geothermal heat pumps)

- IRR internal rate of return: the profitability of the project in percentage of the initial investment cost

$$\mathrm{IRR} = \frac{\mathrm{NPV}}{\text{Investment cost}} \quad (12)$$

4.5 ENVIRONMENTAL INDICATORS

• Energy savings: Indicates the reduction in electrical consumption of the air conditioning system due to the better general performance of geothermal heat pumps. This process has been evaluated previously in the economic section, but there the focus was on the cost of energy. This indicator will show how the difference in COP or EER between geothermal heat pump and classic systems will impact positively in the reduction of the energy demand.

• Emissions avoided: Indicates the amount in tCO2 of emissions avoided by saving energy consumption of the air conditioning system.

The processes of electricity production generate emissions. According to the percentage of electricity from the different sources that has a different emission factor is possible to quantify the emission saves from the electricity saved.

• Annual renewable energy production (kWh per year). Amount of renewable energy that is extracted from the medium of exchange (see Figure 34). For this, the SPF or seasonal performance must be calculated. This factor can also be estimated based on European standards, although in installations of a certain size it is highly advisable to monitor this parameter. European legislation, based on the Renewable Energy Directive (RED/2009) specifies a threshold of 2.5 from which a thermal installation is considered for legal purposes as an installation that produces renewable energy. In the image below you can better understand the concept of renewable energy in a heat pump, in this case, the energy extracted or dissipated in the ground would be renewable energy, while the non-renewable part is considered the electricity consumption of the compressor to obtain the necessary conditions for the air conditioning and DHW system to work correctly.

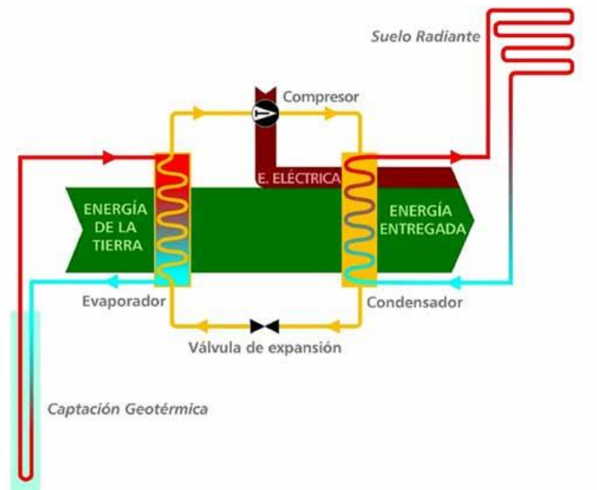

Figure 28. Renewable energy produced by a geothermal heat pump. The renewable part is computed as the difference between the energy delivered and the primary energy needed to produce the electrical energy that is supplied to the compressor. Said primary energy is approximately 2.5 times greater than the electrical energy itself due to the global performance factor of the national electrical system.

4.5.1 GHG EMISSIONS SAVES AND RENEWABLE ENERGIES EVALUATION PROCEDURE

Energy saves has been previously evaluated, starting from that input is possible to proceed with the evaluation of the environmental benefits provided by geothermal heat pumps.

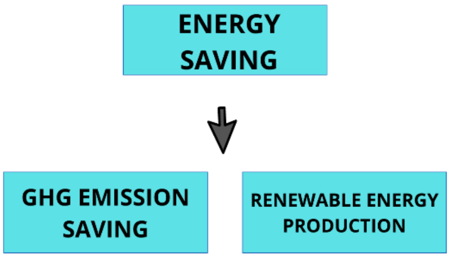

Figure 29 environmental indicators evaluation procedure

Reducing the energy consumption on H&C processes there will be a consequent GHG emission reduction.

$$\text{GHG emission saves} = \text{f} * \text{energy saves} \quad (13)$$

f: emission factor, it considers the emissions associated to the energy production. According to the reference document provided by the Ministry of Industry, Energy and Tourism, the CO2 emission factor of a national conventional electric kWh is 0.357 kg of CO2.

According to the HE-4 (Technical Building Code 2006 [20]), a quote of the energy provided to satisfy building thermal load with geothermal heat pump can be considered as renewable energy.

$$\text{RENEWABLE ENERGY (Eres)} = Q_{\text{usable}} \cdot \left(1 - \frac{1}{\text{SCOP}}\right) \quad (14)$$

This is in order to compare this renewable source with other renewable sources and to get access to incentives related to green energy production

CHAPTER 5: APPLICATION OF THE METHODOLOGY

From the methodology described in section 5 is possible to evaluate all the indicators. This chapter shows the evaluation process and justifies the data during the calculus

5.1 GROUND INDICATORS

According to the methodology, at first will be evaluate the drillability and the soil potential.

5.1.1 DRILLABILITY EVALUATION

According to GEO4CIVC Model [18] the drillability is tabled and linked with the lithology.

The main lithology referred to the city of Valencia is "1.2.b clay". The city is in an alluvial plain, close to the sea and the underground has a first layer of clay. The table 11 shows the results

Main lithology	Thermal conductivity [w/(m*k)]	drillability method	drillability time [min/m]	drillability costs [€/m]
1.2.b clay	2.0	ED w/o c	3-4	20-30

Table 11. drillability data from GEOFORCIVHIC [18]

Valor of thermal conductivity from table can be substituted by the one has been obtained in UPV test site. There are few boreholes used for TRT test and the result is λ= 2,3 w/(m*k) The result is quite similar to the one tabled but by having this data from an higher precision evaluation method is more accurate to use it.

5.1.2 SOIL POTENTIAL

Soil potential can be evaluated with the G.POT method reported in the procedure (formula 1). According to (Cassaso 2020 [18]) the method requires the definition of the site-specific values of thermal parameters of the ground: undisturbed ground temperature T0, thermal conductivity λ and thermal capacity ρc.

The length of the heating/cooling season (expressed in days) can be set with a unique value, or with different values taking into account different
climate conditions.

The geothermal potential is expressed in MWh/year in Watts (considered as a continuous and constant load)

Given the common parameter values and adding the site specifics values, the result will be

Parameter	Symbol	Value	Unit
Threshold fluid temperature	T_{lim}	-2	°C
Borehole depth	**L**	100	m
Borehole radius	r_b	0,075	m
Simulated lifetime	t_s	50	years
Borehole thermal resistance	R_b	0,1	mK/W

T_0 [°C]	λ [W/m*k]	ρc [10^6 J/(m^3 *K)]	t_c [days]	Q_{BHE} [MWh/y]
17,58	2,3	2,5	180	13,27

Table 12. G.POT method data

It expresses the amount of energy that is possible to exchange with the ground without to modify the ground properties.

5.2 BUILDING LOAD EVALUATION

Thermal load is evaluated starting from the data available in the Entranze report [21] mentioned in section 5.2. There is an approximation because there were not data from the city of Valencia. Those data referred to the city of Sevilla that has similar climatic situation.

Figure (30) and (31) report the data of energy needs of buildings and offices in [kwh/m^2]

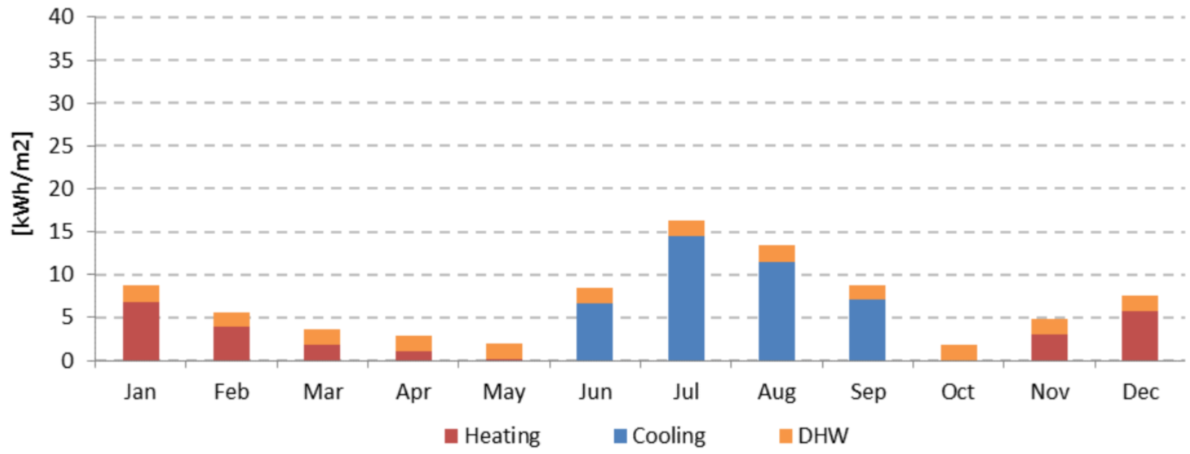

Figure 30 - monthly energy needs [kwh/m^2] for a domestic building in an apartment block in Sevilla [21]

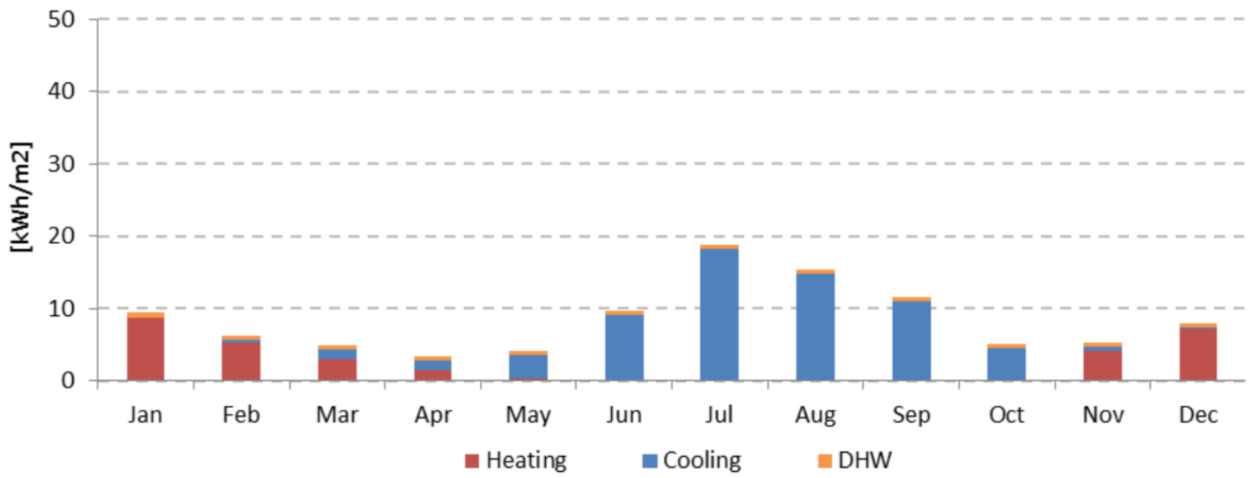

Figure 31. monthly energy needs [kwh/m^2] for an office in Sevilla [21]

According to the report [21] the domestic building is structured in 4 floor and is composed by 12 flats in an area of 1000m^2. The sum of all the monthly consumption is around 80 kwh/m^2.

The offices are considered on a 5 floors building with a surface of 2400 m^2 the sum of the monthly consumption is around 98 kwh/m^2

A resume of this first evaluation is reported in table 13

TIPOLOGY	METRATURE [m^2]	CONUSMPTION PER SQUARED METER [kWh/(y*m^2)]	CONSUMPTION [MWh/y]
Residential building	1000	80	80
Office building	2400	98	235,2

Table 13. Residential and office buildings year consumption

5.3 LENGTH AND ENERGY SAVES EVALUATION

LENGTH CALCULATION

Length calculation per season will follow the formulas (2) and (3)

$$\text{length\_h} = \frac{\text{Qh} * (1 - 1/\text{COP}) \ * (\text{Rp} + \text{Rs} \ * \ \text{F})}{\text{Tl} - \text{Tmin}}$$

$$\text{length\_c} = \frac{\text{Qc} * (1 + 1/\text{COP}) \ * (\text{Rp} + \text{Rs} \ * \ \text{F})}{\text{Tmax} - \text{Th}}$$

It's required the COP. In order to simplify the calculation will be taken from a case study form a heat pump situated in Valencia. The length should be enough to provide air conditioning per each climatic condition, that is why will be considered the COP of the months with the highest H/C demand.

The values of the parameters applied to the case study of the city of Valencia would be:

- **Heating thermal capacity (Qh) and cooling thermal capacity (Qc)**

  Considering the highest energy consuming months from Entranze report is possible to obtain the heat pump installed power to satisfy all the thermal load during the year.

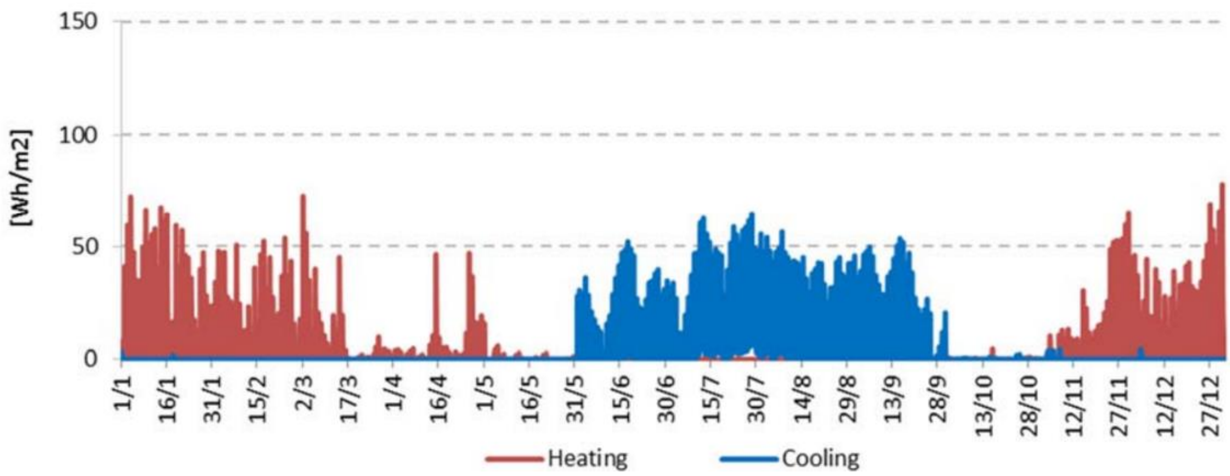

Figure 32. Hourly energy needs for heating and cooling of the residential building located in Seville [21]

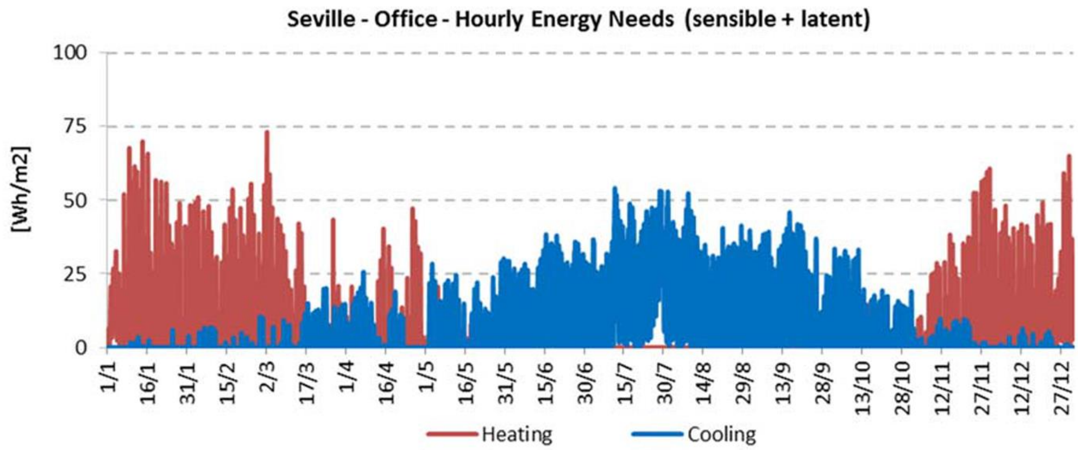

Figure 32. Hourly energy needs for heating and cooling of the office building located in Seville] [21]

Building type	Thermal capacity heating [kW]	Thermal capacity cooling [kW]
Residential building	60	60
Office building	168	120

Table 14. H&C thermal capacity per building type

Coefficient of performance in heating mode (COP_h) and cooling mode (COP_c)

As a COP is required at this stage, we will estimate it by a general value of 4.5 and then check our estimation with the technical data sheet of the heat pump, according to the operating conditions.

Thermal resistance of the pipe (Rs)

The thermal resistance of the pipe, Rp, is calculated by using (4) in chapter 5.3

In this case, a single-U vertical borehole is the type of borehole selected, with a HDPE (high density polyethylene) pipe with a thermal conductivity of 0.42 W/m*K and 1" diameter SDR-11 with a external/internal diameter of 32/26.2 mm. Then the Rp calculated is 0.08 m*K/W.

Rp= 0,0758 W/(m*k)

Thermal resistance of borehole and ground (Rs)

According the data of study case:

- Geothermal heat exchanger: vertical boreholes
- Thermal diffusivity: 0,645*10^-6 m^2/s
- Thermal conductivity: 2.3 W/mK
- Borehoe depth: 100 m
- Pipe spacing: 0.75 m

- Pipe diameter: 32 mm
- Hours of use of the exchanger (heating and cooling): 2,200 hours

From tables a value of Rs is 0.2518mK/W

Thermal load factor:

Part load factor of the heat pump system for heating h or cooling c

Building type	F_heating %	F_cooling %
Residential building	60	40
Office building	70	60

Table 15. Thermal load factor for type of building and season

Temperature in the borehole:

- Since the technology selected is a vertical borehole, T_low and T_high of the ground will be equal and similar to the annual average outdoor temperature in Valencia. Then:
  - T_low = T_high = 19.35 ºC
- The operating temperature in the borehole will be designed as:
  - T_min in the borehole = average temperature in borehole in heating mode: 7.5 ºC (inlet/outlet temperature of borehole: 5/10 ºC)
  - T _max in the borehole = average temperature in borehole in cooling mode: 30 ºC (inlet/outlet temperature of borehole: 32.5/27.5 ºC)

Building type	BHE length heating (m)	BHE length cooling (m)
Residential building	910	792
Office building	2826	2026

Table 15. BHE length for type of building and season

Therefore, for a residential building in the case study of the city of Valencia and the borehole field typology as defined (single-U vertical exchanger of 1" diameter pipe SDR 11), the required borehole heat exchanger length (choosing the most unfavorable option) would be 910 meters, i.e. 9 boreholes 101 meters deep. For the case of an office building, the required borehole field length of 2826, i.e. 28 boreholes of 101 meters, is obtained.

ENERGY SAVES CALCULATION

Applying the formula (5) from section 5.3.2 energy saves can be evaluate

$$\text{Energy saves} = \text{Buliding load} * \left(\frac{1}{\text{SCOPt}} - \frac{1}{\text{SCOP}} \right)$$

Building type	ENERGY DEMAND [MWh/y]	ENERGY SAVES [MWh/y]
Residential	80	18,6
office	235,2	54,6

Table 16. Energy saves per year for type of building

SCOPt: seasonal COP of traditional system ASHP, reference value
SCOPt = 2.2

SCOP: seasonal COP of geothermal heat pump

SCOP= 4.5

According to the number of householders in the city of Valencia and to the number of office buildings is possible to evaluate the energy saves for the three different scenarios.

Valencia has 150 office building and 420'000 householders.

According to the hypothesis, each building is composed by 12 flats. Putting the house holders in 12 flat buildings the results is 35'000 buildings. The percentage will be calculate on this number.

TYPE OF BUILDING	PENETRATION SCENARIOS	PERCENTAGE [%]	BUILDINGS NUMBER	ENERGY SAVES [Gwh]
RESIDENTIAL	1,0	1,0	350	6,51
	2,0	3,0	1.050	19,53
	3,0	6,0	2.100	39,06
OFFICES	1,0	1,0	2	0,109
	2,0	3,0	5	0,273
	3,0	6,0	9	0,491

Table 17. energy saves per scenario

5.4 ECONOMIC EVALUATION

This section will evaluate all the economic indicators described in the methodology, starting from the investment cost evaluation

5.4.1 EVALUATION OF INVESTMENT COSTS

Investment costs are comprehensive of drilling cost plus installation costs.

Drilling cost will depend on the total drilled meters that is equal to the sum of all the boreholes length. Considering the three scenarios is possible to evaluate per each of them the investment costs.

TYPE OF BUILDING	PENETRATION SCENARIOS	TOTAL DRILLED METER [m]	INVESTMENT COST [M€]
RESIDENTIAL	Low (1%)	318’500	19,11
	Medium (3%)	955’500	57,33
	High (6%)	1’911’000	114.66
OFFICES	Low (1%)	5’652	0,339
	Medium (3%)	14’130	0,847
	High (6%)	25’434	1,526

Table 17. investment costs per scenario

Unitary drilling costs were evaluated in the section 6.1.1 and they are 30 €/m

In order to consider the installation costs is necessary to add 30€/m to the unitary drilling costs

According to this evaluation, the total unitary drilling cost is 60 €/m. the results are reported in the table 17

5.4.2 ROI VAN IIR EVALUATION

Starting from the energy saves, by multiplying it times the unitary energy cost is possible to obtain the economic saves per each scenario.

TYPE OF BUILDING	PENETRATION SCENARIOS	Energy saves[Gwh/y]	Economic saves [€/y]
RESIDENTIAL	Low (1%)	6,51	1'953'000
	Medium (3%)	19,53	5'859'00
	High (6%)	39,06	11'718'000
OFFICES	Low (1%)	0,109	32'800
	Medium (3%)	0,273	81'900
	High (6%)	0,491	147'400

Table 18. economic saves per year per scenario

Energy cost per year were obtained considering the energy demand and multiplying it by the average electricity price.

The electricity price considered is 0,3 €/kwh

<u>RETURN OF INVESTMENT</u>

Considering as constant the economic saves and the investment cost per typology of building, the result will be the same per each scenario. Referring to formula (10) in section 5.4:

Residential buildings: ROI = 9,78 years

Offices buildings: ROI =10,35 years

NET PRESENT VALOUR

Net cash flow is as the incomes per year intended as the economic saves compared to traditional systems. Referring to formula (11) in chapter 5.4 the evaluation provides the results in table 19

TYPE OF BUILDING	PENETRATION SCENARIOS	NPV (M€)
RESIDENTIAL	Low (1%)	19,95
	Medium (3%)	59,85
	High (6%)	119,70
OFFICES	Low (1%)	0,316
	Medium (3%)	0,790
	High (6%)	1,422

Table 19. Net present valour per scenario

It considers a geothermal heat pump lifetime of 20 years

INTERNAL RATE OF RETURN

Referring to formula (12), the internal rate of return can be calculated. With the same considerations about ROI, IRR is the same per each scenario.

Residential buildings: IRR= 1,04

Offices buildings: IRR =0,93

5.5 EVALUATION OF ENVIRONMENTAL BENEFITCS

According to the procedure in section 5.5, starting from economic saves is possible to evaluate the GHG emission saves achieved by exploiting geothermal heat pump to satisfy buildings thermal loads.

5.4.1 EVALUATION OF GHG EMISSIONS SAVES

GHG emissions are linked with energy saves by a coefficient, the emission factor. According to formula (13)

TYPE OF BUILDING	PENETRATION SCENARIOS	Energy saves [Gwh]	GHG emission saves [kgCO2/y]
RESIDENTIAL	Low (1%)	6,51	1.087.170,0
	Medium (3%)	19,53	3.261.510,0
	High (6%)	39,06	6.523.020,0
OFFICES	Low (1%)	0,109	18.236,4
	Medium (3%)	0,273	45.591,0
	High (6%)	0,491	82.063,8

Table 20. GHG emisison saves per scenario

According to Ian Tiseo (2021 [22]) the actual emission factor in Spain is 0,167 €/kWh

5.4.2 RENEWABLE ENERGY PRODUCTION

Applying the formula (15) from section 6.5 the renewable energy produced is evaluated

$$\text{RENEWABLE ENERGY (Eres)} = Q_{\text{usable}} \cdot \left(1 - \frac{1}{\text{SCOP}}\right)$$

Q_{usable} refers to the thermal load of the buildings

TYPE OF BUILDING	PENETRATION SCENARIOS	Thermal Load [Gwh/y]	Renewable energy [Gwh/y]
RESIDENTIAL	Low (1%)	6,51	1,512
	Medium (3%)	19,53	4,537
	High (6%)	39,06	9,075
OFFICES	Low (1%)	0,109	0,025
	Medium (3%)	0,273	0,063
	High (6%)	0,491	0,114

Table 21. GHG emisison saves per scenario

CHAPTER 6: CONCLUSIONS

In conclusion in this thesis has been elaborated a methodology that allows to evaluate the shallow geothermal potential of a generic city thanks to the use of some economic and environmental indicators.

The indicators can provide useful information for the policy makers and investors about the economic feasibility of the projects and about their impact on favor of the GHG emission reduction and decarbonizations.

The case study of this thesis is the city of Valencia, and for it have been evaluated three different scenarios of penetration of the technologies. The results underline how shallow geothermal energy can provide interesting economic and environmental benefits.

In the specific has been calculated that on the more moderate scenario

- The residential buildings, with an investment of 19 million for the residential houses, there will be and economic return of 1,95 million per year, that is equivalent of a payback time in 9,78 year. Considering a lifetime of 20 year, the IRR will be 1,04. The environmental benefits will be 1,087 million of kgCO2 avoided and a production of 1,5 GW of renewable energy
- The office buildings, with an investment of 340’000€ will have an economic return of 32'000 €/y that means payback time in 10,35 year. The IRR is 0,98 and the environmental benefit will be 18'200 kgCO2 emission avoided and a quote of 0,025 GWH of green energy produced.

Considering more aggressive scenarios (penetration at 3% or 6%) the benefits will be triplicated or sextuplicate (except for the ROI and IRR)

This report can be useful for the city of Valencia in order to take decision about the development of shallow geothermal energy exploitation. Considering the High initial barrier given by the installation costs, can be introduced some interventions to reduce them. In this way the technology could be more competitive in the market.

One last consideration is that this technology as main advantages has the reduction of energy needed to air conditioning a building and its incomes are calculated considering the price of the energy saves. On this period there are lot of fluctuation on the energy prices due to political reason and this technology can play an important role to be protected from them

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PRESUPUESTO

PART	TIME [h]	COST PER HOURS OF WORK [€/h]	TOTAL COST [€]
DESCRIPTION OF GEOTHERMAL ENERGY CONTEXT	**90**	**10**	**800**
DEFINITION OF A METHODOLOGY TO EVALUATE SHALLOW GEOTHERMAL ECONOMIC AND ENVIRONMENTAL BENEFITS	**60**	**25**	**1500**
ACTUALIZATION OF THE METHODOLOGY AND CALCULUS.	**30**	**40**	**1200**
TOTAL			**3500**

The first part of the job was about reading several scientific papers. Action focused on better understand the context of shallow geothermal potential, like the definitions, pros and cons and technologies involved. Time consuming job but not so complicated.

The second part was a bit more complicated because it requires to study several projects related to geothermal energy and re elaborate them in order to define a correct methodology to evaluate shallow geothermal benefits

The third part was more technical because once evaluated the methodology there was only to do the calculus. This is the most fundamental part because it requires to have a correct knowledge of where to find the numbers to do the calculation