GEOTHERMAL ENERGY
universal | ecological | economical

SYSTEMS OF CLIMATIZACION AND PRODUCTION OF HOT SANITARY WATER THROUGH LOW AND VERY LOW TEMPERATURE GEOTHERMAL ENERGY IN GALICIA
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1# WHAT IS GEOTHERMAL ENERGY?

The Geological Mining Institute of Spain (IGME) defines Geothermal Energy as “the heat energy that the Earth transmits from its inner layers to the outermost part of the earth’s crust”. It is an inexhaustible, natural energy, and is present at any part of the planet, with greater or lesser intensity.

It is known that, as it is deepened into the Earth, the temperature increases. In other words, there is a continuous heat flow (geothermal gradient in °C/km) from the inside to the outside of the Earth.

At certain points of the planet, this heat flux is very high, multiplying by 10 or 100 normal values. These areas coincide with geologically unstable zones, with significant and habitual seismic activity, or the presence of recent volcanic activity, and, if the geological conditions are adequate, they can harbour high temperature geothermal deposits (T > 150 °C). For example: United States, Central America, Italy, Mexico...

The rest of the earth’s crust are stable zones, with a low heat flow, in which, if there are suitable geological conditions, it is possible to find low temperature geothermal deposits with temperatures below 90 °C. For example, Turkey, France, Switzerland, Spain...
<table>
<thead>
<tr>
<th>Kind</th>
<th>High temperature</th>
<th>Average temperature</th>
<th>Low temperature</th>
<th>Very low temperature</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heat flux</td>
<td>&gt;150°C</td>
<td>90&lt;T&lt;150°C</td>
<td>30&lt;T&lt;90°C</td>
<td>T&lt;30°C</td>
</tr>
<tr>
<td>Temperatures</td>
<td>Earthquakes, volcanoes, hot springs</td>
<td>Hot springs, mineral waters</td>
<td>Hot springs, mineral waters</td>
<td>None</td>
</tr>
<tr>
<td>Evidence on surface</td>
<td>Production electricity</td>
<td>Electrical production with binary cycles, direct heating</td>
<td>Direct heating, balneotherapy with mineral waters</td>
<td>Air conditioning with heat pump</td>
</tr>
<tr>
<td>Applications</td>
<td>United States, Mexico, Italy, New Zealand</td>
<td>United States, Turkey</td>
<td>France, Turkey, Spain</td>
<td>All the world</td>
</tr>
<tr>
<td>Example countries</td>
<td>Geothermal energy: geothermal deposits</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
2# GEOTHERMAL ENERGY IN GALICIA

Galicia is located in a stable area of the earth’s crust, with no recent magmatic and/or plutonic activity, so there is no reference in the bibliography to the presence of high temperature deposits in this territory.

In the past, the possibility of studying the potential presence of deep water reservoirs at a high temperature (> 150 °C) in some areas of Galicia (Ourense, Baños de Molgas) was assessed, however, as until today there are no exploitations or investigation of this type of resources in the Galician community.

Regarding low temperature geothermal resources, and the spa potential of the autonomous community of Galicia is one of the most representative in Spain, with 18 active spas and more than two hundred outcrops of mineral-medicinal and thermal water at all its territory (IGME: Instituto Geológico y Minero de España).

Galician geothermal resources fall within the range “Low temperature” (T < 90 °C), associated to the regional fractures of a crystalline geological substrate (granites and schists) that, in certain zones, make up a loop in the rocks through which water flows from the river courses to depths of 500-2000 meters, surfacing again on the surface with high temperatures (77.4 °C Balneario de Lobios) and a chemical composition different from surface water, with high concentrations in bicarbonates, sodium and silica among others. The studies of the IGME estimate temperatures in depth of between 100-130 °C, although currently there are no deep probes available to verify this data.
Location and temperature of upwelling of different thermal springs of Galicia
Galician geothermal areas of higher temperature, or energy potential, are concentrated mainly in the province of Ourense (Baños de Molgas, Ourense, Prexigueiro, O Carballiño), highlighting the town of Lobios with upwelling temperatures of 77.4 °C.

In the province of Pontevedra, the A Toxa-Caldas de Reis and Caldelas de Tui areas in the south stand out, while in the province of Lugo, the most interesting geothermal area is located in the capital of the province of the same name. The province of A Coruña is the least frequent of hyper thermal upwelling, with mineral-medicinal and thermal springs, of low temperature, in Carballo and Arteixo.

The possible uses of geothermal reservoirs Galicia comprise the direct use of thermal water from the therapeutic point of view (spas), industry (bottling mineral water) or energy (direct use by underground heat exchange). The available thermal energy is insufficient to think, nowadays, of electricity generation, from an economic point of view, although different compression-expansion cycles are being studied, which could be interesting for its application in Galicia in the not very far future.
GEOTHERMAL RESOURCES

The thermal waters, known and used for centuries by humanity, are the most obvious superficial manifestation of what, in its broadest sense, is known as Geothermal Energy. The industrial use of geothermal energy in Europe starts early last century, in Italy, aimed at producing electricity from steam pressure which emerges from geothermal wells (high temperature geothermal).

ICELAND has important upwellings of volcanic origin thermal waters, which are used for the heating of collective housing since 1930 (low temperature geothermal or direct uses, “district heating”).

**GEOTHERMAL RESOURCE** (technical definition) “... that accessible part of the base resource that could be exploited economically and legally in a defined future time” (Mufler & Cataldi, 1978).

The definition of Mufler and Cataldi introduces an economic variable so that thermal energy, present with greater or lesser intensity throughout the planet, is considered a geothermal resource. Geothermal resources are regulated in Spanish legislation through **Law 22/1973 of Mines and its amendment Law 54/1980, Royal Decree 2857/1978 General Regulation for the Mining Regime, and Royal Decree 863/1985 Basic Mining Safety Regulations and Complementary Technical Instructions in the range of Orders (ITCs).**
The current legislation of application is national and autonomous. Competencies in mining are transferred to regional governments, some of which have developed their own legislative framework (Law of 3/2008 Mining Galicia).

In addition to the geothermal resources themselves, mentioned in the previous section, during the last 15-20 years a new modality of geothermal exploitation has been developed throughout the world (also in Galicia) called “of very low temperature” (geothermal heat pumps), which use the subsoil as a means to exchange energy at the natural temperature of the soil at a limited depth. This new set of uses is applied in the market, although the legislation on the subject still hasn’t included them as geothermal uses, and if it mentions them, it is to exclude them from the scope of application of the Mining Law, as in Galicia.

Initially, the “purists” of the sector were reluctant to incorporate this new group of applications to the conventional classification of uses of geothermal energy, although its rapid growth in the world market has meant that, in 2010, the 49% of the “direct uses” of geothermal energy in the world are by means of geothermal heat pump, increasing the installed capacity by 1900% from 1995 to 2010 (IDAE). Systems with a geothermal heat pump will never achieve the efficiency of the “direct uses” of soil heat, in areas with geothermal anomalies, but they are applicable.
in any region of the world, eliminating the need for particular geological conditions, that the direct uses do have.

The systems with heat pump (geothermal of very low temperature, ground source heat pumps, shallow geothermal, geothermal heat pumps... depending on the country) are dedicated exclusively to the generation of heat and cooling energy, and to the production of sanitary hot water, in any sector (residential, industrial and tertiary). These are completely autonomous systems, qualified as Renewable Energy by the European Union and Spanish government, and are the most efficient autonomous air conditioning system currently on the market.

The geothermal potential in Spain is developed and currently taken advantage of, mainly through self-consumption micro-uses, either individual or collective, without commercialization, as an effective tool to reduce the expense in air conditioning and production of hot water from the residential sector, tertiary and industrial, in addition to reducing emissions of greenhouse gases into the atmosphere.
In this guide we will describe the different end uses that geothermal heat could have depending on its intensity, differentiating those areas that have thermal resources from the rest of the Galician territory that has a normal geothermal heat flow.
DIRECT USES OF GEOTHERMIC HEAT

Direct uses of water whose stable temperature exceeds 40° C (minimum utilization threshold, although according to the end use waters with lower temperatures could be used) and which show a sufficient flow rate, have been applied for centuries throughout the world (Iceland, France, United States, New Zealand...) and are known in the world as direct uses of geothermal energy.

Direct uses THERMAL WATER for heating and domestic hot water are possible from soil or temperatures above 40° C water.
Its classic scheme is to transfer this heat to another secondary fluid (water) by means of a plate exchanger (stainless steel), and transfer the thermal energy to the end points of use (underfloor heating, radiators, fan coils ...) which should not be far from the point of extraction to reduce heat losses in the distribution and operating costs of the system. It is not advisable the direct use of thermal water, due to its high mineralization (sulphates, heavy metals ...) that deteriorate the metal parts of the distribution networks (pumps, pipes, valves...).
4.1. Direct uses: open loop

4.1.A. Operating principle

The “open” exploitation of geothermal heat, by means of a plate exchanger, is a function of the hydraulic permeability of the probed point (m² a day) and the minimum outlet temperature of the exchanger, since there must be a thermal jump minimum (pinch) between the primary fluid (thermal water) and the secondary (water from the heating system or hot water) so that the heat transfer in the exchanger is efficient.

The pumping of thermal water from a vertical drilled well will generate a decay of the piezometric level of the thermal aquifer, captive and fissural, until reaching a new equilibrium in which the atmospheric pressure and hydrostatic pressure of the aquifer are equalized.

The temperature of the thermal water pumped, generally, is lower than that of the aquifer, since the contribution of geothermal heat to the flowing water is reduced.
Removable heat power of a thermal water

The extractable heat of a thermal fluid per unit of time is calculated by the following expression:

\[ P = q_w \times c_w \times (T_e - T_s) \times \varepsilon \]  \hspace{1cm} (1)

being:

\( P \) : usable thermal power in W
\( q_w \) : mass flow of thermal water in kg/s
\( c_w \) : specific heat of the thermal water in J/kg\(^\circ\) C
\( T_e \) : thermal water inlet temperature in \(^\circ\)C
\( T_s \) : temperature of thermal water outlet at \(^\circ\)C
\( \varepsilon \) : efficiency of the heat exchanger (0.85 - 0.95)
Simplified cross-sectional profile of a thermal water catchment for energy use in fissural deposits (open system)
### Unit cost of a geothermal heating system (direct open use) depending on the flow rate pumped

<table>
<thead>
<tr>
<th>Flow (L/s)</th>
<th>Flow (m³/h)</th>
<th>Eff</th>
<th>Thermal power (kW)</th>
<th>Daily thermal energy (kWh)</th>
<th>Net thermal energy (kWh)</th>
<th>Net thermal energy (-2%) (kWh)</th>
<th>Electrical power (kWh/day)</th>
<th>COP</th>
<th>Operation cost (€/kWh_e)</th>
<th>Operation cost (€/kWh_t)</th>
<th>Operation cost (€/kWh_t) = 0.85</th>
<th>Expense cost (€/kWh_e)</th>
<th>Expense cost (€/kWh_e) = 0.85</th>
<th>Expense cost (€/kWh_e) = 0.85</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.00</td>
<td>3.60</td>
<td>0.90</td>
<td>0.90</td>
<td>0.90</td>
<td>0.90</td>
<td>0.90</td>
<td>52.80</td>
<td>1.447</td>
<td>0.0051</td>
<td>0.0055</td>
<td>0.0049</td>
<td>0.0493</td>
<td>0.0493</td>
<td>0.0493</td>
</tr>
<tr>
<td>2.00</td>
<td>7.20</td>
<td>0.90</td>
<td>9.00</td>
<td>2.894</td>
<td>28.00</td>
<td>27.00</td>
<td>72.00</td>
<td>2.836</td>
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<td>0.0038</td>
<td>0.0035</td>
<td>0.0036</td>
<td>0.0036</td>
<td>0.0036</td>
</tr>
<tr>
<td>4.00</td>
<td>14.40</td>
<td>0.90</td>
<td>3.61</td>
<td>5.788</td>
<td>52.80</td>
<td>48.00</td>
<td>220.80</td>
<td>5.672</td>
<td>0.0054</td>
<td>0.0055</td>
<td>0.0049</td>
<td>0.0493</td>
<td>0.0493</td>
<td>0.0493</td>
</tr>
<tr>
<td>6.00</td>
<td>21.60</td>
<td>0.90</td>
<td>6.00</td>
<td>8.682</td>
<td>52.80</td>
<td>39.20</td>
<td>312.00</td>
<td>8.509</td>
<td>0.0055</td>
<td>0.0056</td>
<td>0.0054</td>
<td>0.0494</td>
<td>0.0494</td>
<td>0.0494</td>
</tr>
<tr>
<td>8.00</td>
<td>28.80</td>
<td>0.90</td>
<td>9.00</td>
<td>11.578</td>
<td>52.80</td>
<td>42.00</td>
<td>312.00</td>
<td>11.345</td>
<td>0.0053</td>
<td>0.0055</td>
<td>0.0054</td>
<td>0.0493</td>
<td>0.0493</td>
<td>0.0493</td>
</tr>
<tr>
<td>10.00</td>
<td>36.00</td>
<td>0.90</td>
<td>12.00</td>
<td>14.470</td>
<td>52.80</td>
<td>44.80</td>
<td>312.00</td>
<td>14.181</td>
<td>0.0054</td>
<td>0.0056</td>
<td>0.0055</td>
<td>0.0494</td>
<td>0.0494</td>
<td>0.0494</td>
</tr>
</tbody>
</table>

**Notes:**
- **Flow (L/s):** The flow rate of the geothermal fluid that is pumped through the system.
- **Flow (m³/h):** The equivalent flow rate in cubic meters per hour.
- **Eff:** The efficiency of the system.
- **Thermal power (kW):** The thermal power generated by the system.
- **Daily thermal energy (kWh):** The total daily thermal energy produced.
- **Net thermal energy (kWh):** The net thermal energy produced after accounting for losses.
- **Net thermal energy (-2%) (kWh):** Net thermal energy adjusted for a 2% decrease.
- **Electrical power (kWh/day):** The electrical power output on a daily basis.
- **COP:** The coefficient of performance of the system.
- **Operation cost (€/kWh_e):** The cost of operation per kilowatt-hour of electrical energy.
- **Operation cost (€/kWh_t):** The cost of operation per kilowatt-hour of thermal energy.
- **Expense cost (€/kWh_e):** The cost of operation per kilowatt-hour of electrical energy, adjusted for a 2% decrease.

The table provides a comprehensive view of the cost and performance of a geothermal heating system at various flow rates, enabling engineers and planners to make informed decisions about system design and operation.
4.1.B. Materials and methodology

Executing a thermal uptake for energy use in open loop must meet the same construction elements pumping water for therapeutic use, using materials that do not interact with water (stainless steel) and isolating the unconsolidated geological strata by the use of sealing mortars to avoid the mixing of surface and deep water.

These are captures that are made in different phases, respecting the setting periods of the sealing layers between different pipes. The pump, generally water-resistant, will be placed in the cased section of the well, to avoid being trapped by the collapse of the walls of the well in the bare sections.

The execution of the surface seal, prior to deep drilling, will allow the wellhead to be plugged in case the thermal aquifer turns out to be an upwelling area.

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**PRELIMINARY STUDIES**
- Lithology, tectonics
- Water point inventory
- Geoelectrical and magnetic studies

**DRILLING**
- Tubing and ring sealing of the regolith
- Continuous monitoring the deep drilling
- Witressing and final tubing

**ASSESSMENT**
- Pumping test: hydraulic efficiency
- Physicochemical analysis
- Project of use

*Phases of a project of direct geothermal exploitation in open loop*
**Drilling (left), endhole (right). Aquifer thermal spring.**

<table>
<thead>
<tr>
<th>Use</th>
<th>Generation</th>
<th>Issue</th>
<th>Emission temperature °C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Human heating</td>
<td>Pumping or exchange Tmin = 40 °C</td>
<td>Radiating floor</td>
<td>35 – 40</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Radiators</td>
<td>45 – 50</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Forced air</td>
<td>45 – 55</td>
</tr>
<tr>
<td>Sanitary hot water</td>
<td>Pumping or exchange Tmin = 50 °C</td>
<td>Hot drinking water</td>
<td>50 – 60</td>
</tr>
<tr>
<td>Heated swimming pools</td>
<td>Pumping or exchange Tmin = 35 °C</td>
<td>Pool water heat exchanger</td>
<td>35 – 45</td>
</tr>
<tr>
<td>Aquaculture</td>
<td>Pumping or exchange Tmin = 35 °C</td>
<td>Water heat exchanger of the vessels</td>
<td>30 – 35</td>
</tr>
<tr>
<td>Greenhouses</td>
<td>Pumping or exchange Tmin = 35 °C</td>
<td>Floor / radiant tables</td>
<td>30 – 35</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Forced air</td>
<td>40 - 50</td>
</tr>
</tbody>
</table>

*Main DIRECT geothermal uses and interior heat emission systems*
4.1.C. Legislation

*Mining Law* 22/1973, *Law* 54/1980 and its amendment, include geothermal resources in Section D of the classification of geological resources, while mineral and thermal waters are in the B (Art. 3) section.

Article 3.2 of the Law states that... “The occasional and minor extraction of mineral resources, regardless of their classification, is outside the scope of this Law, provided it is carried out by the owner of a land for its exclusive use and does not require the application of any mining technique”. This article is applicable to any geological resource, regardless of its classification. It could be legally studied whether the use of thermal outcrops to warm the dwelling(s) of the owner of the land, respecting the natural flow rate (without pumping), could be considered within this section, which excludes it from the Mining Law.

In the context of the Regulation implementing the Mining Act (*R. D. 2857/1978 General Regulation for the Mining Regime*), the thermal waters may have a therapeutic or industrial purpose within section B. It is important to highlight the difference between “*mining-industrial waters*”, those dedicated to the use of dissolved substances and “*industrial uses*” of the thermal waters that, as indicated in the *Regulation* (Article 5), refers to the thermal use of the same whenever “the heat production is less than 500 therms per hour” (581 kW thermal).

According to the mining legislation, it can be understood that the energy recovery projects of thermal waters that do not exceed 581 kW t of maximum power (thermal energy) can continue the procedure within group B) of the *Mining Law*. As in neither of the two definitions (thermal and geothermal resource) the temperature or condition of the heat-conducting vehicle (water
or water vapour) is mentioned, it is also understood that, if the thermal power of the resource were sufficient, it would be possible to dedicate the thermal springs to the electrical production within group B) of Minas, provided that the heat production of the same was lower than 581 kWt.

The administrative procedure necessary for the realization and legalization of geothermal projects of thermal waters for energy uses is processed in the provincial delegations of Industry, both the execution of the works and the final concession of the geothermal resource, and it must have the basin administrator authorizations, which are described in the applicable regulations for each river basin district.

For the realization of wells in lands belonging to the river basin district of the Miño-Sil will require the authorization of this body, in application of article 28 of Annex III of the Hydrological Plan of the Spanish part of the DH of Miño-Sil 2015-21. Likewise, article 44 of the regulations of the Hydrological Plan of the Galicia-Costa River Basin District (RD 1332/2012) requires obtaining the authorization of the basin manager for direct open geothermal projects.
Energetic use of the thermal waters

Mining Law
Thermal waters = Mineral waters (section B)

Mineral and medicinal
Industrial mining

Mineral and medicinal
Industrial mining
Industrial uses

Regulation for the Mining Regime
Thermal waters = Mineral waters (section B)

Therapeutics
Substances they contain

Therapeutic
Therapeutic
Energy

Administrative procedures of the therapeutic and energetic use of the thermal waters within Mining Law
4.2. Direct uses: closed loop.

4.2.A. Operating principle

If the geothermal potential available in the deposit is sufficient, it is possible to extract heat from the sub-soil in a closed loop, avoiding the pumping of thermal water and reducing the energy and economic cost associated with pumping.

The systems in closed loop carry out the extraction of the thermal energy of the subsoil by means of an intermediate fluid (water) that circulates through a network of pipes in closed loop that are located in the perforation. As the temperature of the circulating fluid is lower than the temperature of the soil, energy is captured and so transferred to the surface in order to be used.

The heat transfer processes that occur in a geothermal exchange well are complex. The heat is transferred to the fluid from the
rock by convection, due to the movement of the deep (thermal) water in the well, by conduction through the walls of the well and the sealing grout (if used) and by the natural convection (vertical movement) that is produced by the different densities of the thermal water of the well.

To calculate the heat extraction capacity \( (q) \) per unit length of pipe, it is possible to simplify all these processes in the following formula:

\[
q = \frac{1}{R} (T_{DHE} - T_b)
\]

being:
- \( q \) : Heat transferred in \( W/m \)
- \( R \) : Overall thermal resistance of the pipe in \( ^\circ C/W/m \)
- \( T_{DHE} \) : Average exchanger temperature in \( ^\circ C \)
- \( T_b \) : Temperature in the walls of the well in \( ^\circ C \)

The term global thermal resistivity combines the effects of internal convection, the conduction of heat in the walls of the pipes and the external convection of the well. Although there are mathematical equations that describe the behaviour of this parameter, they are not excessively precise, that is why, for safety, it is much better to determine it by performing a thermal response test on a specific well.

The transfer of heat from the rock to the pipeline fluid is carried out by conduction of the rock and the movement of the underground hot water (convection). This set of heat transfer processes is called the effective thermal conductivity of the geothermal exchange well. It is possible to model mathematically the thermal behaviour of the exchanger using Lord Kelvin’s linear focus model (1882) adapted by Ingersoll and Plass in 1948. Gehlin and Hellstrom (2003) published a numerical
solution of that equation combining the heat extraction with the thermal resistivity in the following way:

\[
T_{DHE}(t) = T_{est} + \frac{q'}{4\pi k} \left[ \ln \left( \frac{4\pi}{r_p^2} \right) - \gamma \right] + q' R \quad (3)
\]

being:

- \( T_{DHE} \): Average temperature of the fluid as a function of time in °C
- \( R \): Overall thermal resistance of the pipe in °C/W/m
- \( T_{est} \): Stable subsoil temperature in °C
- \( k \): Effective thermal conductivity in W/mK
- \( r_p \): Radio exchange well in m
- \( \gamma \): Euler constant

In areas of geothermal anomalies, the thermal behaviour of the subsurface materials differs greatly from the tabulated values so, a complete exchange well is carried out and it is thermally assessed by a test called thermal response test for a precise calculation of the exchange length required for a given extraction (or injection) heat.

This test, which lasts between 50 and 75 hours without interruption, takes injection/extraction constant of power from and to the well and it measures its thermal response, obtaining the specific thermal parameters of that area: stable temperature (\( T_{est} \) in °C), effective thermal conductivity of the entire well column (\( k \) in W/mK) and the overall thermal resistivity of the exchange well (\( R \) in m/WK). With the data obtained, and using equation (3), it is possible to estimate the maximum thermal energy extraction capacity (\( q' \) in Watios per meter) that could be reached in a sustainable manner over time.
Execution and interpretation of a thermal response test of a closed loop exchange well

4.2.B. Materials and methodology

The realization of a geothermal field for direct closed-loop uses should include in its execution the same security and protection that the open loop thermal aquifer.

The diameters of perforation must allow to introduce the probe (pipes in U simple 4x32 mm or double U 2x40 mm that occupy 100-120 mm in diameter) and the tube of sealed freely, and, in the case of foreseeing aquifer surges, it will be necessary to realize a first section cased in steel and sealed in its backyard to control the illumination of thermal waters and allow the subsequent sealing. If this is not possible, deep air shutters will be used to stop the rise of water and to pump, over, the filling mortar.

Once the hole has been made (broken - percussion with hammer in head and cleaning by air, as the most used drilling method), it will be necessary to test thermally the entire well column and the position of the piezometric level (m) in the well.

The most significant difference of this type of use with respect to very low temperature systems (heat pump) is that the exchange
probe (U-pipe joined at one end by thermo fusion) must be made of a plastic material that supports more temperature. It is usually used cross-linked polyethylene (PE x), which allows to reach maximum working temperatures up to 93 °C at 5.5 bar of pressure.

Plastic materials penalize the transfer of heat by conduction through the walls of the pipe, although its long-term durability is much higher than that of metal pipes. The chemical composition of the thermal waters makes them very aggressive waters with metals, so the buried materials must be able to withstand this interaction, in addition to the temperature.

The geothermal wells in unsealed closed loop can be used as measuring points and periodic sampling of the piezometric level and the quality of the reservoir’s thermal waters, by installing an auxiliary PE x pipe of 25 or 32 mm in diameter, which would allow periodic measurements in depth and even extract water samples from the thermal aquifer for the purposes

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**GEOTHERMAL RESEARCH**
- Execution of exchange well in closed circuit
- Continuous monitoring of the drilling
- Thermal assessment by response test

**GEOTHERMAL FIELD PROJECT**
- Monthly demand of air conditions
- Monthly demand of sanitary hot water (kWh/mes)
- Geothermal field molding

**GEOTHERMAL FIELD EXECUTION**
- Continuous monitoring of the drilling
- Quality control of materials and execution
- Final certificate of geothermal exchange well

*Phases of a project for direct energy use in a closed loop*
of hydrogeological statistics and control of the physical-chemical quality of the waters of the thermal reservoir.

Once the exchange probe has been introduced into the well, the tightness tests are carried out and the hole is completely sealed using an auxiliary pipe of the same material and with a smaller diameter. It is introduced up to 70% of the total depth of the well. The sealing mortar used must withstand the chemical composition of the water, and must be injected by pumping from the bottom to its overflow through the mouth of the well.
In the bibliography geothermal reservoirs of this type are referenced with very shallow piezometric level, where sealing wells are not performed. The convective up/down movement of the hot water inside the drilled hole improves the transfer of energy to the pipeline, although it is convenient for greater physical-chemical protection of the thermal resource to seal completely the well column to maintain the hydraulic pressure of the thermal aquifer in other points of the deposit.

4.2.C. Legislation

It will be necessary to verify if the lands to be explored are included in the perimeter of protection associated with water concessions of group B of the Mining Law or water concessions of the Water Law, since, if this is so, they could condition/prevent the development of the project.

In the case of processing the use of geothermal resources of group D of the Mining Law, the promoter of the project must be the owner of the mining grid (unit used in Spain to spatially identify the location of mining permits and concessions and that is equivalent to about 30 hectares) for the research and use of resources of group D “Geothermal Resources” of the Mining Law.

If the use is considered as an “industrial use” of the thermal waters (in closed loop), the procedure of administrative concession would be similar to the declaration and use of thermal water, which is regulated in Decree 402/1996 Regulations regarding the use of mineral-medicinal, thermal waters and spas in Galicia. In this particular case, no geothermal fluid extraction aquifer occurs, but if it captures/removes a certain amount of thermal energy of the rocks.
In any case, the drilling process is considered by the administration as “mining technique” so according to the Technical Instruction 06.0.06 “Use of geothermal resources” the approvals of the development project by the provincial delegations of the Department of Industry of the Xunta de Galicia will be necessary.

The realization of wells in lands belonging to the demarcation of the Minor-Sil River Basin District will need the authorization of this agency, in application of article 28 of Annex III of the Hydrological Plan of the Spanish part of the Miño-Sil River Basin District 2015-21. Similarly, Article 44 of the regulations of the Plan Hydrological of the Hydrographic Demarcation Galicia-Costa (RD 1332/2012) requires authorization of the basin manager.
5# INDIRECT USES OF GEOTHERMAL HEAT

5.1. Operating principle

For about fifteen years, the so-called “geothermal heat pumps” have been installed in Spain (and in the rest of Europe, Asia and the United States) as a method for air conditioning of premises and the production of sanitary hot water with renewable energies.

In essence it is a water-water heat pump of electrical power, that exchanges energy with the land through U-pipes arranged in a vertical drill hole drilled for this purpose. The well is completely sealed with cement grout to “force” the physical contact of the pipes with the walls of the well. By circulating water through them, thermal energy is captured/released from the nearby subsoil (2-4 m radius) at a relatively stable temperature throughout the year (similar to a cellar located underground). The thermal compression-expansion cycle performed by the heat pump allows to convert the energy “at a very low temperature” (5-15ºC) captured in the soil, in “usable energy” usable to heat (40-55ºC), cool (7-12 ºC) and produce sanitary hot water (55ºC).

In Galicia more than A THOUSAND installations of this kind have been used for years, primarily in single - family homes, but also in industrial establishments, sports centres and public and private buildings...

The subsoil becomes, with this system, a large thermal battery that supplies energy in winter and dissipates energy in summer, using water-water heat pumps and low-temperature emission systems.
Galicia presents some very good geological qualities that advise the use of this type of system for heating, cooling and production of sanitary hot water for the following reasons:

- In areas containing low temperature geothermal anomalies (Ourense, Caldas, Lugo, Carballiño ...), the subsoil remains abnormally hot, which allows to reduce the length required for a given well heating demand. To give an example, a geothermal system in the city of Ourense needs half the length of wells than the same system located in another point of the province.

- In areas with a “normal” subsoil (rest of the territory), the flow of geothermal heat is exceptionally high (100-120 mW/m²). The cost of execution of the systems is reduced by the need for shorter wells.

- Except in very specific geographical areas, the subsoil is very compact and firm (granites and hard metamorphic rocks), with a high thermal conductivity (> 2.5 W/mK), which facilitates and makes it cheaper to drill and introduce the pipes in the well.
• It is a Community with medium/high heating and cooling needs, depending on the altitude and the proximity to the coast, which means that a system of cleaning and/or hot water production must be provided in the buildings.

Very low temperature geothermal utilization systems are the most efficient autonomous heating and cooling method among those currently available in the market.

Although it is not a “geothermal resource” itself, as defined by current legislation, it is a renewable alternative to conventional air conditioning, which generates a reduction in heating costs, the elimination of greenhouse gases and no annual maintenance. The higher the energy consumption for heating and/or cooling, the greater the savings achieved, so it is usual to include them as air conditioning in big administrative, industrial and tertiary buildings with high demands for air conditioning.

Comparison of the efficiency to produce heat from different heating systems.

\[
\text{COP} = \frac{\text{Delivered thermal power}}{\text{Consumed electrical power}}
\]
5.2. Materials and methodology

The design of a geothermal solution of very low temperature for air conditioning, emanates from the calculation of the thermal needs (kW heat-cold) to satisfy and from the knowledge of the thermal properties of the subsoil where it is going to be located.

The first ones are achieved through the use of heat transfer equations, external climate and materials used in the envelope of the building. However, the thermal properties of the subsoil and, in short, the global operation of the system over time of a closed-loop geothermal exchange well, are strongly influenced by the type of lithology, its degree of degradation/fracturing, piezometric level, degree of surface insolation ... etc. An optimal design requires knowledge of the specific parameters of the place where it will be installed, the most important being:

- Thermal subsurface conductivity (W/mK).
- Overall thermal resistance of the exchange well (mK / W)
- Stable Subsoil Temperature (°C)

The efficiency of the system as a whole is a function of these parameters. Without a real knowledge of them, the field of geothermal exchange may be disproportionate by excess (unnecessary costs) or default (lower energy savings than initial estimates or even blocking of the machines).
The numerical modelling of the thermal behaviour of the subsoil starts from the same equations expressed in point 2.2.1, since the operating principle is the same, although the temperature and the geothermal heat flux of the subsoil is notably lower.

There are different commercial programs of design of buried heat exchangers in the market (Earth Energy Design, Ground Loop Design...), and the most used calculation method is developed by the International Association of Geothermal Heat Pumps IGSHPA, which is based on the theory of a heat source in the form of an infinite line of Ingersoll and Plass. The Spanish Technical Association of Air Conditioning and Refrigeration ATECYR drafted in 2012 the “technical guide system design geothermal heat pump” for the Institute for diversification and energy saving IDAE (Ministry of Industry), which should be consulted for a detailed knowledge of the calculation procedure of buried heat exchangers in heating and cooling.
A geothermal solution with heat pump for air conditioning is composed of three fundamental elements:

a) **Geothermal filed**: The most common configuration is vertical closed loop wells which are made outdoors or in the basement of the building. The impulsion and return pipes of all the wells are concentrated in collectors and, from there, they are conducted to the heat pump.

b) **Geothermal heat pump**: Compact and hermetic equipment where the compression-expansion of a refrigerant fluid (R407, R410A) is produced, absorbing energy from a cold source and yielding energy at a higher temperature to a hot source (heating mode). It is possible to reverse the process and produce cooling with the same equipment.

c) **Interior distribution system of** heat-cold-ACS. The heat pump feeds the interior distribution system of the building that is identical to that which would be installed with any other air conditioning system.

*Schematic diagram of a geothermal heat pump system with a very low temperature*
The main difference of geothermal heat pump with respect to aerothermal systems is the focus from / to which energy is extracted / ceded: in aerothermy this focus is the street air, while, in geothermal systems, the focus is on subsoil, either in open or closed loop. The geothermal systems multiply by two the global efficiency of aerothermy, not depending on the temperature and humidity of the outside air, and they allow to work in any range of outside temperature.

Types of geothermal field: a) vertical closed; b) horizontal closed; c) open with reinjection to the aquifer; d) open. (HP: heat pump)

Another fundamental difference between Geothermy and Aerothermy systems is the electrical power necessary for daily operation. Aerothermal systems force to hire twice as electrical power (kW) from the supply company, intended to supply the equipments which generate heat or cold, for the same demand for air conditioning, thus increasing the minimum monthly cost of electricity bill, regardless of the consumption made.
We describe below the different phases of design and execution system geothermal heat pump for air conditioning:

**a. Starting data**

**a.1 Energy demands of the building**

<table>
<thead>
<tr>
<th>System</th>
<th>Peak thermal power (kW)</th>
<th>Annual demand (kWh / year)</th>
<th>Monthly distribution (kWh / month)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heating</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Refrigeration</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hot water</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**a.2 Geological and hydrogeological parameters**

<table>
<thead>
<tr>
<th>Geology</th>
<th>Lithology</th>
<th>Average thermal conductivity (W / mK)</th>
<th>Stable temperature (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hydrogeology</td>
<td>Depth of water table (m)</td>
<td>Presence and depth of aquifers</td>
<td></td>
</tr>
</tbody>
</table>

For installations of less than 30 kW power, this data is obtained from official geological mapping IGME (Magna 1: 50,000), publications or other hydrogeological studies next drilling the puncture. For power exceeding 30 kW, it is advisable to advance an exchange well with a depth, geometry and finishes similar to those of the project and evaluate it in situ by means of a Thermal Response Test (TRT).
b. Data of the heat pump

The heat pumps must have the CE marking, as well as the technical characteristics and performance in accordance with the UNE-EN 14825 or UNE-EN 14511 standards, as applicable. The designer must obtain from the manufacturer the specific data to each model of heat pump:

- Brand, type, year.
- Type and volume of refrigerant.
- Seasonal energy efficiency of refrigeration (SEER) UNE-EN 14825.
- Seasonal heating energy efficiency (SCOP) UNE-EN 14825.
- Rated heating power in kW according to UNE-EN 14511.
- Cooling capacity in kW according to UNE-EN 14511.
- Model circulation pumps for the well loop and air conditioning.
- Operating temperature range in °C.
- Thermal jumps in °C.
- Losses of charge in condenser and evaporator in Pa.
- Capacitor and evaporator flows in m³/h.
- Maximum compressor speed (rpm).
- Minimum compressor speed (rpm).
- Heating / cooling power curves delivered according to the compressor speed.

c. Geothermal air conditioning system design project

- Descriptive report.
- Calculation annexes.
- Blueprints.
- Study of safety and health of the work.
- Study of environmental, energetic and geothermal hazards.
- Specification of technical conditions of the materials and procedures of execution and verification.
- Budget.

**d. Execution of the geothermal field**

**d.1 Drilling**

- For the start of drilling, tubing and sealing of vertical wells, you must have the corresponding administrative authorization of the provincial delegation of industry, the basin manager and the work permit of the town hall where it is carried out.

- The Security Directorate will deliver a copy of the project to the representative of the executing company and verify, with the periodic visits indicated by the mining administration, that during the execution of the work the security requirements set forth therein are met, designating

*Spin drilling with hammer head*
a manager of the drilling company as responsible for its application.

- The Technical Direction of the Work must carry out, among others, the following tasks, verifications during the drilling of the geothermal field, which will be documented and accompanied in the corresponding Work Completion Certificate: redefinition of wells, crossed lithologies, fractured stretches, presence of water, temperature, electrical conductivity and pH wellhead, testing of column temperature and electrical conductivity, total depth, position of the piezometric level, tubing section, detritus management, water and sludge, waste management (plastic, paper, wood ...) and prevention of outcrop of spring aquifers by means of cased and sealed upper sections and / or sealing.

d.2 Placement of the exchanger

The useful life of the geothermal exchanger must be at least 50 years and U-pipes made of high-density polyethylene are usually used, welded at one end by thermofusion or electrofusion, at least PE 100 PN16 sdr 11 (ratio between the diameter and thickness of the tube) . The pipes must have a longitudinal, cumulative meter-to-meter marking and a manufacturer’s certificate with the results of the quality control tests of the geothermal probe before leaving the factory.

The probe must be checked externally before its introduction into the well in case of hard knocks or rubbing of the well, discarding it, if necessary, in the affirmative case. The installer can perform a tightness test of the probe before introducing it into the well, to ensure that the integrity of the materials and probe head are intact.

The head of the probe is protected with a rigid tube (PVC) and
slowly introduced by gravity into the well, aided by carousels or cranes. When reaching the appropriate depth, the injection pipe of smaller diameter than the probe is joined with flanges (60-70% of total depth).

The ballast and the water of the pipes must allow a clean descent by gravity, avoiding any chafing of the pipes at the wellhead. If necessary, introduce water in the probe to force the descent in the first sections. As the probe is inserted, the weight of the same will facilitate its clear descent.

After the placement of the probe in the well, the tests of this need must be carried out, subjecting the probe, previously purged and filled with water, to a pressure of 6 bar for 30 minutes and checking that the pressure does not decrease by more than 1 bar. If the result is satisfactory, the ends of the probe are sealed (with pressure) and the wellhead is protected against external damage.
If the horizontal section is not going to be carried out immediately, it is convenient to leave the pressure wells of 3-4 bar, with a pressure gauge visible in one of the pipes, to be sure that all the probes keep their integrity, and they have not been affected by other excavation sites.

**d.3 Sealing the exchange well**

The exchange well seal must be made by mechanically injecting the filling slurry by the auxiliary tube placed for this purpose. The use of pre-dosed products that comply with at least (UNE 100715-1) is recommended:

- Decantation or free water < 5%.
- Fluency: go through the 4.5 mm Marsh cone.
- Resistant to the ice-thaw cycle.
- Resistant to sulfates and chlorides
- Thermal conductivity ≥ ground conductivity

The dosage and kneading of the injection mixture must be respected, which are expressed in the technical data sheet.

During the injection the probes must be filled with water and pressurized.

Once the mixture overflows through the wellhead, it will stop. After a time (6-8 hours), and once the mortar has hardened, the descents must be completed through the mouth of the sounding until it overflows once more.

It must be checked at all times that the pressure gauge located in the mouth of the geothermal probes does not undergo variations due to the sealing effect, ensuring the complete water tightness of the vertical section of the geothermal exchange well.
d.4 Conduits from wells to heat pump

The pipes from the wellhead to the general impulse and return manifolds are made of plastic materials (high density polyethylene PE100 PN16 sdr11) with a minimum nominal pressure of 10 bar.

It is one of the critical points of the system and, if possible, it would be advisable that there should be no welding between the wellhead and the heat pump return and return manifolds, since, if not done correctly, they can generate water leakage from the well loop in the future.

The horizontal section is arranged in trenches 0.8-1 meters deep, avoiding all contact with sharp rocks or time or anything that may damage the pipes. Avoid making joints in the horizontal section, and if necessary they will be performed by thermal fusion (heat fusion or electrofusion). Do not use metal binding elements since, being buried, they will degrade with time.
In systems that only work in heating mode, isolating this horizontal section conveniently will prevent the winter ambient temperature from influencing the temperature of the fluid that comes and goes from wells.

To ensure a good purge of air from the pipes, pipes with a descending slope of 1 - 2% must be arranged.

Before covering the ditches, it is necessary to raise a plan of location of the conduits, boxes and joining elements that will be attached to the documentation of the installation, in addition to making the corresponding tightness tests, well by well, from the general collectors, to verify and certify that this part of the installation has been correctly executed.

The buried pipes must be marked with plastic, 10 cm above their level of support.

*d.5 Auxiliary elements*

The well loop should have at least the following auxiliary elements:

- Thermometers in pipes / return to wells to ensure that the temperature sensors measure the heat pump correctly.
- Pressure gauge to ensure the tightness of the loop.
- Flow meters per well to ensure that the fluid that drives the heat pump to the exchange wells is distributed evenly between the exchange wells.
- Shut-off ball valves per well to isolate wells if necessary.
- Net filter in the conduction of return to avoid that sands or dirt block the exchanger of heat (evaporator) of the bomb of heat.
Filling and emptying system with auxiliary filling cart. It must be possible to carry out the complete circulation of all the loops, including the exchanger of the machine, with an external equipment and the circulation pump of the equipment.

- Automatic and manual drains.
- Expansion vessel (check that it is not integrated in the heat pump)
- Safety valve set at 3 bar (can be integrated in the heat pump)
- Flexible connections at the point of attachment to the heat pump.

e. Start-up of the installation

Before the start-up of the installation, the documentation accrediting the tests that have been made during the installation must be compiled:

- Certificate of quality of materials
- Certificate of tightness tests in hydraulic loops.

Once the adequacy of the installation has been checked with the provisions of the Regulation on Thermal Installations in Buildings (RITE), the technical instructions for application and that the electrical connection of the heat pump has been carried out in accordance with the provisions of the Electrotechnical Regulation of Low Voltage (REBT), the installation is carried out following the procedure specified by the manufacturer of the heat pump.

After the start-up, the user manual and copy of all the documentation and certificates that describe the executed installation, its operation and its periodic maintenance are delivered to the client.
5.3. Legislation

The installations of air conditioning with geothermal heat pump must fulfill, like any other conventional thermal installation, the stipulated in the Royal Decree 1027/2007, of July 20, by which the Regulation of Thermal Installations in the Buildings is approved. In addition, as it is an electrically powered equipment, the electrical part of it must comply with the provisions of Royal Decree 842/2002, of August 2, which approves the electrotechnical regulation for low voltage.

Regarding the geothermal field, it has to be checked initially that the system is not located in a zone of protection of mineral and / or thermal waters (Law of Mines) or within the Registry of Protected Areas that defines the article 99 bis of the Royal Legislative Decree 1/2001, of July 20, approving the revised text of the Law of Waters.

In the areas of Galicia that are located within the hydrological demarcation of the Miño-Sil, for the execution of the geothermal field, both in open system with double perforation and closed systems, express authorization of the Miño-Sil River Basin Authority is required. “Where the conditions of the installations and their follow-up are accredited to guarantee the protection of the aquifers” (article 28 of Annex III of the Hydrological Plan of the Spanish part of the DH of Miño-Sil 2015-21).

In those areas belonging to the Galicia-Costa demarcation, article 44 of the regulations of the Hydrological Plan of the Galicia-Costa River Basin District (RD 1332/2012), requires the authorization of the watershed administrator.

Regarding the current mining legislation, geothermal deposits of very low temperature, closed loop, are excluded from the scope of Law 3/2008, of 23 May, regulating Galicia mining by the Article
78 of Law 12/2014 of December 22, on fiscal and administrative measures

d) Any use of geothermal resources of little economic importance, particularly those that are useful in heating, domestic or industrial air conditioning and/or domestic hot water, based on geothermal systems with very low enthalpy, with closed loop heat exchangers, up to 200 meters of depth, provided it is carried out by the owner of the land for its exclusive use and that its use does not require the application of any mining technique.

This section is the transposition of what is stated in article 3.2 of Law 22/1973 of Mines:

Two. The occasional and minor extraction of mineral resources, regardless of their classification, is outside the scope of this Law, provided that it is carried out by the owner of a land for its exclusive use and does not require the application of any mining technique.

Indicate that during the operation (use) of the geothermal catchment no “mining technique” is applied.

In 2010, it was published in the Official Journal of Galicia Instruction 5/2010 of 20 July, the Directorate General of Industry, Energy and Mines on the exploitation of geothermal resources in the Autonomous Community of Galicia, which indicated that the use of this type of “geothermal resources” will be governed by what is established for the class of resources in section A) in Act 3/2008, of May 23, on the management of mining in Galicia”. This Instruction is contradictory with art. 78 of Law 12/2014, mentioned above, although we understand that the second prevails over the first as it is a higher-level regulation.
In the autonomous community of Galicia, the provincial delegations of Industry approve the realization of the vertical geothermal field, in closed loop, in strict application of R. D. 863/1985 General Regulation of Basic Mining Safety Standards, on understanding that these works are the exploitation mining of a “geothermal resource”, considering this as defined in article 5 of R. D. 2857/1978 of August 25, General Regulation for the Mining Regime. According to this criterion, it applies art. 107 of the RD 863/1985 and the Complementary Technical Instruction ITC MIE SM 06.0.06 “Exploitation of geothermal resources”.

The application of the mining safety regulations, instead of the current legislation on the prevention of occupational hazards in construction works (Law 31/1995) in the execution of geothermal fields implies, implicitly, a reservation of activity in favour of the Mining Engineers exclusively, which must be present during the realization of the holes, in functions of supervision of safety in the execution of the same. However, the project, by which this work is approved, can be drafted by technicians from other degrees.

For the execution of the work, it will be necessary the liquidation of the following autonomous administrative fees: 32.29.13 Appointment of facultative director of mining exploitation and 32.77.04 Approval of geothermal project of very low temperature.

The installations of air conditioning with geothermal heat pump must fulfil, like any other conventional thermal installation, the stipulated in the Royal Decree 1027/2007, of July 20, by which the Regulation of Thermal Installations in the Buildings is approved. In addition, as it is an electrically powered equipment, the electrical part of it must comply with the provisions of Royal Decree 842/2002, of August 2, which approves the electrotechnical regulation for low voltage.
5.4. Calculation example for a single-family house

a) Starting data

The low temperature geothermal system will meet the heating requirements of a house of 180 m² and the consumption of sanitary hot water calculated for 4 bedrooms according to the CTE-HE4. The heat distribution system will be underfloor heating. The house is located at an altitude of 380 meters above sea level, and a thermal peak heating load of 14.1 kWt at -3 °C outside temperature is calculated.

| THERMAL DEMANDS OF HEATING AND DOMESTIC HOT WATER: CALCULATION CONDITIONS |
|---------------------------------------------------------------|-------|
| Total useful surface heated (m²)                            | 180   |
| Peak demand ratio (W/m²)                                    | 78    |
| Total peak load heating (kW)                                | 14.04 |
| Number of bedrooms                                          | 4     |
| Number of people (HE4)                                      | 6     |
| Energy demand Domestic Hot Water. (kWh t/year person)       | 635   |
| Demand total Domestic Hot Water energy (kWh t/year housing) | 3810  |
| Outside calculation temperature (°C)                        | -3    |
## Monthly Thermal House Demands

<table>
<thead>
<tr>
<th>MONTH</th>
<th>(T_{\text{average}} \degree \text{C})</th>
<th>(T_{\text{minimum}} \degree \text{C})</th>
<th>(P_{\text{base}} \text{ (kW)})</th>
<th>(D_{\text{base}} \text{ (kWh)})</th>
<th>(P_{\text{peak}} \text{ (kW)})</th>
</tr>
</thead>
<tbody>
<tr>
<td>January</td>
<td>6.6</td>
<td>2.4</td>
<td>7.3</td>
<td>5240</td>
<td>10.3</td>
</tr>
<tr>
<td>February</td>
<td>6.4</td>
<td>0.5</td>
<td>7.4</td>
<td>5341</td>
<td>11.6</td>
</tr>
<tr>
<td>March</td>
<td>10.2</td>
<td>2.8</td>
<td>4.7</td>
<td>3437</td>
<td>9.9</td>
</tr>
<tr>
<td>April</td>
<td>13.4</td>
<td>6.4</td>
<td>2.5</td>
<td>1820</td>
<td>7.5</td>
</tr>
<tr>
<td>May</td>
<td>16.5</td>
<td>9.3</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>June</td>
<td>19.0</td>
<td>10.8</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>July</td>
<td>21.1</td>
<td>12.1</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>August</td>
<td>21.6</td>
<td>12.4</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>September</td>
<td>18.9</td>
<td>10.8</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>October</td>
<td>13.8</td>
<td>6.8</td>
<td>2.2</td>
<td>1643</td>
<td>7.2</td>
</tr>
<tr>
<td>November</td>
<td>9.4</td>
<td>5.5</td>
<td>5.3</td>
<td>3841</td>
<td>8.1</td>
</tr>
<tr>
<td>December</td>
<td>6.5</td>
<td>3.1</td>
<td>7.4</td>
<td>5307</td>
<td>9.8</td>
</tr>
<tr>
<td>Year</td>
<td>13.6</td>
<td>6.9</td>
<td>26.628</td>
<td>11.6</td>
<td></td>
</tr>
</tbody>
</table>

\(T\): Temperature  
\(P\): Thermal power  
\(D\): Thermal demand

Heating is established as the dominant mode, with total needs of 26.6 MWh\(_t\)/year (\(\@\) (38/30)), to which 3.8 MWh\(_t\)/year of DHW production will have to be added (\(\@\) 45\(\degree\)C), resulting in total of 30.4 MWh\(_t\) year.

**Base thermal monthly demands in heating**
It is necessary to know what will be the critical moments of maximum demand of the system (maximum extraction in the geothermal field), which will occur in those periods of the day when the outside temperature reaches the minimum value. For the calculation of the peak demand in heating, the following monthly duration of the ambient temperature minima of the place is established:

**PEAK DEMANDS OF THE INSTALLATION**

<table>
<thead>
<tr>
<th>MONTH</th>
<th>$T_{\text{minimum}}$ ºC</th>
<th>$P_{\text{peak}}$ (kW)</th>
<th>Hours at $P_{\text{peak}}$ (h)</th>
<th>Demand (kWh)</th>
</tr>
</thead>
<tbody>
<tr>
<td>January</td>
<td>2,4</td>
<td>10,23</td>
<td>20</td>
<td>204,5</td>
</tr>
<tr>
<td>February</td>
<td>0,5</td>
<td>11,58</td>
<td>20</td>
<td>231,7</td>
</tr>
<tr>
<td>March</td>
<td>2,8</td>
<td>9,97</td>
<td>10</td>
<td>99,7</td>
</tr>
<tr>
<td>October</td>
<td>6,8</td>
<td>7,20</td>
<td>10</td>
<td>72,0</td>
</tr>
<tr>
<td>November</td>
<td>5,5</td>
<td>8,07</td>
<td>15</td>
<td>121,1</td>
</tr>
<tr>
<td>December</td>
<td>3,1</td>
<td>9,79</td>
<td>20</td>
<td>195,9</td>
</tr>
<tr>
<td>Year</td>
<td>3,5</td>
<td>11,6</td>
<td>95,0</td>
<td>924,8</td>
</tr>
</tbody>
</table>

For the calculation of operating hours and power consumption (operating costs) of the geothermal heat pump the following data from the technical specifications of a heat pump with three-phase power of 11 kW t nominal capacity is used in heating (@ 0/35 EN14511), with built-in DHW storage tank.
# Technical Specifications

**Heat Pump Standard Test EN 14511 (face value in bold)**

### Heating. T heating impulsion = 35°C

<table>
<thead>
<tr>
<th>T. Half loop wells (°C)</th>
<th>-6,3</th>
<th>-1,71</th>
<th>2,94</th>
<th>8,46</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heat Capacity (kW t)</td>
<td>9,57</td>
<td><strong>11,1</strong></td>
<td>12,7</td>
<td>14,4</td>
</tr>
<tr>
<td>Electric consumption (kWh e)</td>
<td>2,57</td>
<td><strong>2,6</strong></td>
<td>2,6</td>
<td>2,7</td>
</tr>
<tr>
<td>COP</td>
<td>3,72</td>
<td><strong>4,20</strong></td>
<td>4,81</td>
<td>5,15</td>
</tr>
</tbody>
</table>

### DHW. T impulsion DHW= 4 5°C

<table>
<thead>
<tr>
<th>Average t. loop wells (°C)</th>
<th>-6,17</th>
<th>-1,49</th>
<th>3,2</th>
<th>8,43</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heat Capacity (kW t)</td>
<td>9,25</td>
<td><strong>10,63</strong></td>
<td>12,41</td>
<td>14,65</td>
</tr>
<tr>
<td>Electric consumption (kWh e)</td>
<td>2,96</td>
<td><strong>3,04</strong></td>
<td>3,2</td>
<td>3,22</td>
</tr>
<tr>
<td>COP</td>
<td>3,13</td>
<td><strong>3,50</strong></td>
<td>3,88</td>
<td>4,55</td>
</tr>
</tbody>
</table>

**COP - Heating capacity vs Average temperature loop wells 11 kW**

Output temperature = 45 °C
Input temperature = 35 °C
COP = 35 °C
COP = 45 °C
The standard test according to EN14511 already accounts for the electric consumption of the well circulation pump and heating / DHW. The COP of the machine increases at the rate of 1 decimal of COP for each °C of increase of the average temperature of the loop of wells, for both temperatures of exit of the condenser: 35 and 45 °C.

For the modelling of geothermal field temperatures the SCOP\textsubscript{net} (\textit{net seasonal efficiency coefficient in accordance with EN 14825: 2012}) must be used. It is not usual for manufacturers to provide this information, so the Ministry of Industry, Energy and Tourism (IDAE, 2014) proposes a simplified method of calculating SCOP\textsubscript{net}:

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Condensation temperature (°C)</th>
<th>35</th>
<th>45</th>
</tr>
</thead>
<tbody>
<tr>
<td>COP nominal @ 0/35</td>
<td></td>
<td>4,20</td>
<td>4,20</td>
</tr>
<tr>
<td>Weighting factor</td>
<td></td>
<td>1,18</td>
<td>1,18</td>
</tr>
<tr>
<td>Correction factor</td>
<td></td>
<td>1,00</td>
<td>0,77</td>
</tr>
<tr>
<td>SCOP\textsubscript{net}</td>
<td></td>
<td>4,95</td>
<td>3,81</td>
</tr>
</tbody>
</table>

It is considered that the consolidated stratum is superficial (<3 m), making a perforation by roto percussion with a hammer on the head, from which only 2 meters of plastic were cased annularly. The substrate is considered homogeneous, 75% of the column of the well saturated with water, and with several fractured sections that provide water (usual conditions of crystalline substrates from the interior of Galicia).
If a single perforation is dimensioned, it will be connected directly to the heat pump (filter, filling system, stopcocks, pressure gauge, thermometer and expansion vessel). All buried elements will be high density polyethylene joined by thermofusion or electrofusion. The horizontal system (union of the pipes from the head of the well to the heat pump / distribution manifold) will be carried out at a minimum depth of 80 cm, on bed of sand or non-sharp fines, polystyrene foam insulation 20 mm thick, plastic exterior protection pipe and signaling tape.

The wall passages will be adequately protected to avoid chafing due to the oscillation of the tube with the movement of the brine or the thermal expansion of the pipes. Special care must be taken in the purging of air from the well loop, installing automatic drain traps in those points of greater relative height, either inside the engine room or in an external casing. It is recommended to provide, if possible, a positive slope from the mouth of the geothermal wells to the entry / exit points of the heat pump. The presence of air in the loop reduces the effectiveness of heat transfer from the soil to the brine and from the brine inside the evaporator of the machine. The technician will check the tightness of the connections from the engine room before and after sealing the well and closing the horizontal trench. The direct connection (without connecting pieces, elbows...) of the pipes of the well with the heat pump will avoid possible leakage problems in the future.
b) Dimensioning of the geothermal field according to the method of the International Association of Geothermal Heat Pumps (IGSHPA)

**Step 1:** Defining the configuration of the exchanger and checking the turbulent regime

### CONFIGURATION OF THE GEOTHERMAL FIELD

<table>
<thead>
<tr>
<th>Configuration</th>
<th>Vertical - U simple</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flow</td>
<td>Parallel</td>
</tr>
<tr>
<td>Pipe material</td>
<td>HDPE</td>
</tr>
<tr>
<td>Diameter of exchange pipes</td>
<td>40 x 3.7 mm (1 1/4’)</td>
</tr>
</tbody>
</table>

### CHECKING THE HYDRAULIC SYSTEM IN THE WELL LOOP

<table>
<thead>
<tr>
<th>Number of wells</th>
<th>Nominal flow per well (L / min)</th>
<th>Minimum water flow rate at 4.5 ºC (L / min)</th>
<th>Minimum flow rate propylene glycol 20% at -4ºC</th>
</tr>
</thead>
<tbody>
<tr>
<td>One</td>
<td>26.7</td>
<td>6.4</td>
<td>20.8</td>
</tr>
<tr>
<td>Two</td>
<td>13.35</td>
<td>6.4</td>
<td>20.8</td>
</tr>
</tbody>
</table>

The nominal flow of the well loop is determined in the technical specifications of the heat pump (@ 0/35) for a thermal jump of 3.2-3.8 ºC. It is verified that, if a single exchange well is used, the nominal flow of the well loop generates turbulent flow whether water is used, or water plus propylene glycol at 20% as a heat transfer fluid. However, if it is decided to use two exchange wells, the flow rate of the well pump is not sufficient to generate a turbulent flow rate of the heat transfer fluid in the exchange probe, if water with 20% glycol is selected.
Step 2: Determination of the stable temperature of the subsoil

It is considered the execution of a vertical well of 125 meters depth drilled in consolidated rock with a thermal conductivity of 3 W/mK. The average annual ambient temperature is 13.6 °C and the geothermal heat flow is set at 0.08 W/m² (conservative value for this region of Spain). With these data, the average stable temperature of calculation results:

\[ T_M (^\circ C) = Ta + 1,66 = 13,6 + 1,66 = 15,2 ^\circ C \]

Being a vertical well in consolidated rock, it is considered that there are no temperature oscillations between winter and summer so \( T_M = T_H = T_L \), where \( T_H \) is the maximum temperature that reaches the subsoil along the year and \( T_L \) the minimum.

Step 3: Determination of the minimum temperature of the fluid inlet to the heat pump

The calculation is performed for 3 minimum design temperatures: 0 °C, 5 °C and 8 °C (EWT_{MIN} °C).

Step 4: Cálculo de la diferencia de temperatura entre el subsuelo y el loopo

<table>
<thead>
<tr>
<th>( T_L (^\circ C) )</th>
<th>( T_{MIN} (^\circ C) )</th>
<th>Difference ( T_L - T_{MIN} (^\circ C) )</th>
</tr>
</thead>
<tbody>
<tr>
<td>15,2</td>
<td>0</td>
<td>15,2</td>
</tr>
<tr>
<td>15,2</td>
<td>5</td>
<td>10,2</td>
</tr>
<tr>
<td>15,2</td>
<td>8</td>
<td>7,2</td>
</tr>
</tbody>
</table>
**Step 5: Calculation of the thermal resistance of the pipes to the heat flow (Rp)**

For the calculation of the thermal resistance of the pipes (Rp) the following expression is used:

\[ R_p (\text{mK}/W) = \left( \frac{1}{2 \cdot \pi \cdot k_p} \right) \cdot \ln\left( \frac{D_0}{D_1} \right) \]

For the selected pipe (HDPE 1 1/4 ″ sdr11 40x3.7 mm) the values will be:

\( k_p = \) thermal conductivity of the tube material = 0,42 W/mK  
\( D_0 = \) outside diameter of the pipe = 0,04 m  
\( D_1 = \) inner diameter of the tube = 0,0326 m

\[ R_p = 0,0775 \text{ mK}/W \]

**Step 6: Calculation of the thermal resistance of the subsoil (Rs)**

It is the inverse of the thermal conductivity (W / mK). Considering a conductivity value of 3 W / mK, the thermal resistivity of the subsoil will be:

\[ R_s = 0,375 \text{ mK}/W \text{ (subsuelo rocoso saturado en agua)} \]

**Step 7: Calculation of the utilization factor in heating mode (Fc)**

It has been performed the counting of bin hours in sections of 1°C for the month of January, also calculating the thermal load of the building (kW) for that outdoor temperature according to the thermal demand equation of section 2. The result is a fraction of use in heating mode for the month of the month (the most critical month) of 0,60.
**Step 8: Calculation of buried exchanger length**

\[
L_C \text{ (m)} = \frac{Q_C \times \frac{COP_C - 1}{COP_C} \times (R_p + R_s \times F_c)}{T_L - T_{MIN}}
\]

### CALCULATION OF THE LENGTH OF VERTICAL WELLS ACCORDING TO IGSHPA METHODOLOGY

<table>
<thead>
<tr>
<th>(T_{MIN}(°C))</th>
<th>L wells (m)</th>
<th>Maximum extraction ratio of wells (W/m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>168</td>
<td>50.3</td>
</tr>
<tr>
<td>2</td>
<td>194</td>
<td>43.5</td>
</tr>
<tr>
<td>4</td>
<td>228</td>
<td>37.1</td>
</tr>
<tr>
<td>6</td>
<td>278</td>
<td>30.4</td>
</tr>
<tr>
<td>8</td>
<td>355</td>
<td>23.8</td>
</tr>
</tbody>
</table>

### Variation of the length of wells required as a function of the minimum heat pump inlet temperature (IGSHPA method)

The sizing methodology of the IGSHPA includes in a single calculation formula all the elements to be taken into account
for the calculation of the thermal response of the subsoil to a continuous extraction of energy:

1) The extraction ratio of the heat pump, through the term $Q_c$ (kW) and the performance coefficients in heating mode (COP$_c$).

2) The resistivity of the soil to heat transfer to the exchanger pipes through the term $R_s$ (mK/W). The thermal conductivity of the filling slurry (if used) is not taken into account, or if the well is saturated or not in water, although the designer can manually “improve” the term $R_s$ based on these conditions.

3) The resistance between the walls of the exchange pipe (usually high density polyethylene) and the heat transfer ($R_p$ in mK/W). The use of plastic materials as exchange elements penalizes this parameter, although it increases the useful life of the buried exchanger due to its lower degradation with time. The use of Pex type plastic materials (cross-linked polyethylene) will penalize this term even more, having as its only advantage the support of higher fluid temperatures inside (up to 80°C). The use of Pex tubes in systems operating in cooling mode, in which the machine injects energy into the subsoil, is becoming widespread, although this practice is not technically justifiable, since it is possible to limit the temperature of the brine flow from the machine to the wells and, in addition, if a correct design of the geothermal field is carried out, condensation temperatures above 35-40°C should never be exceeded, since if this were to happen, the efficiency of the machine would be considerably reduced.

4) The use factor $F_c$ (dimensionless) indicates the number of working hours of the heat pump in heating or cooling mode in the most critical month of the year. It is one of the most critical factors since it shows the maximum rate of heat transfer (and recovery times of the subsoil). This parameter is a compromise between the base and peak demands of
the installation (kWh) and the maximum power of the heat pump (kW). A lower power machine will cover the demands of heating and DHW at the expense of a greater number of hours of operation which implies a reduction in the useful life of the heat pump. The geothermal manuals indicate that the designer must select a heat pump that covers 100% of the base needs (kW) and between 75-80% of the peak needs (kW), leaving the remaining 15-20% for the electrical resistances (3.6 kW electrical) that most geothermal heat pumps incorporate from the factory. It is the most efficient long-term design method, since these extreme conditions may not always be reached (climatology). On the other hand, it has to be checked if the selected equipment covers these demands with a number of hours of operation a year “assumable” looking for the heat pump to last as long as possible (15-20 years?), beyond the deadline of system amortization. Of course the key will be in a precise calculation of the thermal demands of the building (base in kWh and annual peak in kW).

5) The temperature difference between the stable subsoil temperature and the minimum heat pump inlet temperature selected by the designer ($T_L - T_{MIN}$) in ºC. The first is easily calculable by means of the testimony of the temperatures of the column of the well once perforated, or from the average annual ambient temperature of the place (ºC) and a value of flow of geothermal heat (W/m²) established by the bibliography. The IGSHPA provides another equation for the calculation of this stable temperature, based on the average temperature (ºC), the thermal amplitude (in vertical systems it is 0) and the thermal diffusivity of the subsoil (m²/s). The estimated temperatures in the project phase have to be validated during the execution phase of the geothermal
wells (thermal testimony by sections and calculation of the geothermal gradient) since this factor has a great influence on the long-term behaviour of the exchange system. The minimum heat pump entry temperature is set by the designer and, again, a compromise must be reached between the cost of drilling the wells and the efficiency of the machine with different inlet temperatures.

In countries with low ambient temperatures (northern centre of Europe 6 - 10 °C), geothermal heat pump systems assume minimum pump inlet temperatures below 0 °C, which requires the use of antifreeze (monoethylene glycol or propylene glycol at 20-30%) in the exchange fluid of the well loop. Designing in these places for minimum temperatures higher than 0 °C involves drilling a number of meters of unassuming wells by the client (drilling costs) and the total cost of the geothermal installation would not be amortized. The thermal jump between the stable temperature and the minimum inlet temperature is very low, which forces to increase the exchange surface. However, in southern Europe, the values of ambient temperature and geothermal heat flow are higher, so it is not justified to design systems for minimum heat pump inlet temperatures around 0 °C. For the equipment described in Figure 2, the penalty is 1 decimal of COPc for each degree of descent of the average temperature of the well loop (inlet temperature to pump + outlet temperature of pump / 2 in °C). In other words, the difference between designing for an average pump inlet temperature of 0 °C or 5 °C is that the heating mode performance of the heat pump will be 5 tenths lower for the lowest temperature.
c) **Use of simplifications for the calculation of the length of the geothermal field**

Considering the basic thermal demands in heating and domestic hot water production, in addition to the peak power supplied by the heat pump, and its performance in both modes of operation, it is possible to calculate the number of hours that the generation equipment will be active during one year of operation.

<table>
<thead>
<tr>
<th>CALCULATION OF NUMBER OF HOURS OF HEATING/DHW ANNUAL USE</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
</tr>
<tr>
<td>Heating @35 °C</td>
</tr>
<tr>
<td>----------------</td>
</tr>
<tr>
<td>Base annual thermal demand (kWh)</td>
</tr>
<tr>
<td>Heat capacity heat pump (kW)</td>
</tr>
<tr>
<td>Hours of annual operation (h)</td>
</tr>
<tr>
<td>Total hours of annual operation (h)</td>
</tr>
</tbody>
</table>

Standard VDI 4640 - Part 2 (Germany) will be used for the values of specific thermal extraction, in W/m, for vertical geothermal uptake:

<table>
<thead>
<tr>
<th>SPECIFIC THERMAL EXTRACTION RATES ACCORDING TO THE NUMBER OF HOURS OF ANNUAL OPERATION</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rocks</td>
</tr>
<tr>
<td>-------</td>
</tr>
<tr>
<td>Granite</td>
</tr>
</tbody>
</table>

The conditions established by the norm will be met:

- **Up to 30 kWt.**
- **Only heat extraction (heating including domestic hot water).**
- The length of the vertical heat exchanger (depth of sounding), individual, should be between 40 and 100 m.

- The minimum distance between two probes must be:
  - At least 5 m for depths of 40 to 50 m.
  - At least 6 m for depths of 50 to 100 m

- Pipes double U shaped with DN 20, 25 or 32, or coaxial tubes with a minimum diameter of 60 mm.

- Not applicable to a large number of small systems in a limited area.

The most conservative value of those offered in the table will be taken for 2400 hours of annual operation: 55 (W/m).

\[
\text{Vaporizer Power} = \frac{\text{Heating Power} \times (\text{COP} - 1)}{\text{COP}} = \frac{11.100 \times (4.20 - 1)}{4.20} = 8.457 \text{ W}
\]

\[
\text{Probe length} = \frac{\text{Vaporizer Power (W)}}{\text{Specific thermal capacity (W/m)}} = \frac{8457}{55} = 153 \text{ m}
\]

A modelling was carried out in Earth Energy Design (EED) for this exchange length, taking as calculation values the same used in the previous evaluations:

<table>
<thead>
<tr>
<th>Year</th>
<th>Month</th>
<th>(T_m) minimum base load (°C)</th>
<th>(T_m) minimum at peak load (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>DEC</td>
<td>1.38</td>
<td>-1.48</td>
</tr>
<tr>
<td>2</td>
<td>FEB</td>
<td>0.61</td>
<td>-4.66</td>
</tr>
<tr>
<td>3</td>
<td>FEB</td>
<td>0.36</td>
<td>-4.91</td>
</tr>
<tr>
<td>4</td>
<td>FEB</td>
<td>0.10</td>
<td>-5.17</td>
</tr>
<tr>
<td>5</td>
<td>FEB</td>
<td>-0.15</td>
<td>-5.42</td>
</tr>
</tbody>
</table>
It is found that modelling for a thermal extraction rate of 55 W/m² is similar to establishing a minimum pump inlet temperature in
the coldest month of the year of 0 °C for the base demands of the building. The average temperatures of the loop of wells of the coldest months of the year (November, December, January and February) are -0.3 °C after the fifth year of operation. By introducing the peak demands, it is possible to reach values of -5 °C of average temperature in the well loop.

The main operating parameters of the system can be compared in a period of 25 years using the same geothermal heat pump described above, linked to a closed loop vertical geothermal field of 153, 175 and 200 meters deep.

| COMPARISON OF OPERATING PARAMETERS WITH DIFFERENT GEOTHERMAL FIELD LENGTHS (VERTICAL WELLS IN CLOSED LOOP) |
|-------------------------------------------------|----------------|----------------|----------------|
| Vertical geothermal field length                | 153            | 175            | 200            |
| Ratio meters well / Power heat pump (m/kW<sub>bc</sub>) | 13,9            | 15,9            | 18,2            |
| Average extraction rate at base load (W/m)      | 37,3            | 32,6            | 27,2            |
| Average extraction rate at peak load (W/m)      | 51,6            | 45,1            | 42,3            |
| Temp. Half loop of wells to base load (ºC)      | 0,90            | 3,15            | 5,35            |
| Temp. half loop of wells at peak load (ºC)      | -2,76           | -0,03           | 2,61            |
| COP<sub>lime</sub> medium to base load (1) (2)   | 4,5 ± 0,25      | 4,8 ± 0,17      | 5,02 ± 0,08     |
| COP<sub>lime</sub> medium to peak load (1) (2)   | 4,1 ± 0,3       | 4,4 ± 0,29      | 4,7 ± 0,22      |
| COP<sub>ACS</sub> medium (1) (2)                | 3,6 ± 0,17      | 3,8 ± 0,18      | 4,1 ± 0,2       |
| Hours ON mid winter to base load (h)            | 1746            | 1620            | 1505            |
| Hours ON mid winter at peak load (h)            | 1895            | 1734            | 1588            |

(1) For the months of November, December, January and February
(2) Period of 25 years of operation.
The increase in geothermal exchange length naturally produces an increase in the average temperature of wells in the long term. The heat pump extracts the same amount of energy, but does so in a larger volume of adjacent rock which reduces the cooling of the same. We have to indicate that the flow of geothermal heat is constant, as well as the thermal conductivity of the rock so the temperature variation will only be a function of the amount of thermal energy that the heat pump extracts from the geothermal field.

As it can be seen, for a length of 153 meters, the average temperature of the well loop during the coldest months of winter (greater thermal extraction needs) is 0.9 °C, that is, 2.9 / -1.1 °C for a thermal jump of 4 °C. Under these conditions the machine will be forced to work between 1,750 and 1,900 hours a year, considering only these four months of winter. The working interval of the well loop will force the use of antifreeze (monopropylene glycol) at 25% by weight as a heat transfer fluid.

For a length of exchange wells of 175 meters, the average temperature of wells amounts to 3.15 °C (0.097 °C for each meter of well added). If the peak demands of the building are considered, it is possible that the temperature drops to -0.03 °C, which will also force the use of 25% antifreeze as a heat transfer fluid (in practice it is possible to check the evolution of the field in the first years of operation and inject glycol later if necessary). The number of working hours of the heat pump is reduced to 1,620-1,730 hours/year (4 winter months), that is, an average of 150 hours less of work per year. Considering an average COP\textsubscript{heating} of 4.3 (base and peak for 153 meters), the reduction in electricity consumption will be 384 kWh\textsubscript{e}/year, that is, about € 69 / year (€ 0.18/kWh\textsubscript{e}) less than the cost of operation. For 25 years the savings would amount to € 1,730, regardless of the increase in the price per kWh\textsubscript{e} over the years. The installation
cost differs, with respect to the previous case, in the drilling, instrumentation and sealing of another 22 meters of exchange well, which would entail an economic cost of € 550-570.

The most conservative geothermal field from the point of view of the extraction of energy, 200 meters of well (18.2 meters of well per kW of heat capacity peak of the heat pump), allows to work in the coldest months of winter with an average temperature of the loop of wells of 5.35 °C, falling to 2.61 °C if the peak heating demands are considered. These temperatures of the geothermal field will make it possible to avoid the use of antifreeze in the well loop. Indicate that antifreeze penalizes the transfer of heat from the walls of the well to the heat-carrying fluid, by reducing the thermal conductivity of the mixture with respect to water under the same temperature conditions. Under these conditions, the average number of working hours per year of the heat pump is between 1,500-1,590 hours, that is, 278 less hours of work with respect to case 1 and 129 hours of work less with respect to case 2. Considering an average COP_{heating} of 4.3 (case 1) and 4.6 (case 2), the reduction in electricity consumption will be 709 and 309 kWh_e/year, that is, € 127 and 56/year (0.18 €/kWh_e) lesser operating cost with respect to case 1 and case 2 respectively. For 25 years, the savings would amount to 3,175 and 1,400 €, regardless of the price increase per kWh and over the years. The installation cost is different, compared to the previous case, in the drilling, instrumentation and sealing of 47 and 25 meters more of exchange well, which would mean € 1,100 and 625 more investment in the geothermal field. However, the use of water as a heat transfer fluid instead of a mixture with antifreeze will mean a saving of € 287 compared to case 1 and € 328 compared to case 2, so the increase in the installation cost of making a well of 200 meters to one of 153 or one of 175 will be about € 813 and 297. The higher installation cost would be amortized by the additional savings generated by 6.4 years for case 1 and by 5.3 years for case 2.
The assessment of the results obtained must be done from different points of view:

1) If the useful life of the heat pump compressor is known exactly for different temperatures of use (in hours of operation), the designer could assess the convenience of increasing the length of wells to safeguard the useful life of the essential element of the heat pump. This data is quantified in many forums as 20 years, but it is not indicated if it is 20 years of total operation of the compressor or 20 periods of operation with a certain number of hours of operation per period. For 20 years of operation of the system, sizing a geothermal field of 200 meters instead of one of 153 will mean a reduction of 5,500 hours of operation of the heat pump, with the consequent economic savings previously calculated and less wear of moving parts and exchangers of the machine. At an average of 1,500 hours of annual operation, the increase in the geothermal field would extend the life of the machine 3.7 years.

2) For the thermal characteristics of the proposed rock as a medium of exchange (granite saturated in water with a thermal conductivity of 3 W/mK) and the stable temperature of the subsoil $T_M$ of the place, the average temperature of the loop of wells in the coldest months of winter (25 years) amounts to 0.1 °C for each meter of increased well. This rise
in temperature generates an increase in the efficiency of the heat pump (the thermal jump between the cold and warm focus is lower) COPc of 1 decimal of COPc for each 10 meters added of the exchange well.

3) Propose a geothermal field with a ratio of 18 m of well per kW of peak power of the heat pump (200 meters) allows the non-use of antifreeze as a heat transfer fluid in the well loop. In some autonomous communities such as the Basque Country, this improvement in the efficiency of the operation of the machine (increase the meters of well and not use glycol) is valued with up to 10% more than the aid that can be requested for the cost of installation of the system. The administrator rewards those systems designed to achieve maximum seasonal efficiency throughout the period of use, in addition to avoiding the use of antifreeze in pipes buried in the subsoil, which could be discharged to the environment in the event of a break or cracking of the pipes by external or internal action.

4) Considering a fixed price of kWh (something unlikely in view of the evolution of electricity prices in recent years) the extra cost, generated by increasing the geothermal field from 153 to 200 meters, is amortized over 6 years of use due to the higher exchange efficiency, higher heat capacity of the heat pump and lower number of hours of operation.
The following describes the public aid that private citizens, companies and public administrations have been able to request during the year 2018, and the call for 2019 (open) for the execution of geothermal climate control systems of very low temperature in the Autonomous Community of Galicia.

YEAR 2018

a) Individuals

Energy Institute of Galicia (INEGA). RESOLUTION of December 26, 2017 renewable energy projects for private individuals (DOGA n°21 of 01/30/2018).
b) Companies, local entities and non-profit entities


<table>
<thead>
<tr>
<th>ITEMS ELIGIBLE FOR SUBSIDIES</th>
<th>FUNDS</th>
<th>PERIOD OF EXECUTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>Geothermal heat pump</td>
<td>€300,000</td>
<td>30.09.2018</td>
</tr>
<tr>
<td>Geothermal resource capturing system</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Assembly and connections</td>
<td></td>
<td></td>
</tr>
<tr>
<td>VAT</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### MAXIMUM SUBSIDY PER PROJECT

<table>
<thead>
<tr>
<th>Local authorities</th>
<th>Non-profit legal entities/woodland communities</th>
<th>Companies, their groups and associations (PYMES + 20%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>80%</td>
<td>50%</td>
<td>50%</td>
</tr>
</tbody>
</table>

**YEAR 2019**

a) Primary agricultural production companies

Energy Institute of Galicia (INEGA). Resolution of January 10, 2019 establishing the regulatory bases and announcing the call for subsidies for equipment projects for the use of renewable energy and energy efficiency in the primary agricultural production companies (DOGA 15/2 / 2019).

- Maximum aid € 100,000 per project and € 300,000 per company.
- Maximum eligible investment: € 1,500 / kW heat capacity of the heat pump
b) Aid to geothermal systems in residential homes (individuals and communities of neighbours)

*Energy Institute of Galicia (INEGA). RESOLUTION of February 21, 2019 approving the regulatory bases of the subsidies for renewable energy projects, of thermal use, targeting private individuals, 2019. (DOGA 05 / 03 /2019).*
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