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GES-CAL: A new computer program for the design of closed-loop geothermal energy systems

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ABSTRACT

The purpose of this paper is to present a new tool developed for the calculation and design of shallow closed-loop geothermal systems. Most of the available geothermal computer programs only allow to consider vertical heat exchangers configurations (i.e. single or double-U tubes), being the horizontal and helical designs excluded. As an attempt to fill this gap, GES–CAL tool, presented here, is capable of providing the complete design of all the most common configurations used in low enthalpy geothermal systems. This software was initially developed for its implementation in the region of Ávila (Spain), including the most relevant results of previous author's researches in this area. Throughout this work, the new software is deeply described and implemented in the calculation of three different study cases. Results of GES–CAL are complementary compared with the ones obtained from the most used geothermal software, EED (Earth Energy Designer). From the analysis of these results, it was possible to conclude that GES–CAL tool constitutes an optimal solution for planning a shallow geothermal system, but especially for those installations placed in the region of Ávila. In this area, the well field can be designed in more precise way which results in lower drilling lengths and, hence, lower initial investments. The conclusions of this work indicate that GES–CAL offers remarkable advantages such as the automatic calculation of the space energy demand, the inclusion of all the heat exchanger configurations and an economic and environmental evaluation of the final geothermal solution.

1. Introduction

Ground source heat pump (GSHP) systems are generally constituted by a series of boreholes and heat pumps with the final purpose of providing heating and/or cooling to buildings. The well field consists of a variable number of boreholes with a certain length and spaced by a previously set distance. When defining the configuration of a closed-loop geothermal system, the most common practice is to use specific sizing tools. However, several input parameters need to be determined prior to the implementation of the mentioned computer tools. The principal input parameters refer to the building and ground loads, flow rate, heat pump temperature limits, ground thermal properties, borehole and heat pump characteristics and the design operation period (Monzo et al., 2016). Building and ground loads are typically determined using separate tools, whereas the remaining parameters need to be defined according to the geological formations where the building is placed, the user preferences and the ground availability. Although all the input parameters are crucial in the final geothermal schema, the thermal conductivity of the ground is considered as one of the most influential values to properly design a wellfield (Blázquez et al., 2017a, b; Blázquez et al., 2018a, 2018b; Nieto et al., 2019). In this context, previous studies showed that a ± 10% uncertainty on the ground thermal conductivity lead to an uncertainty of ± 7% on the global drilling length of a particular case (Bernier, 2002).

Once the required initial data are known, computer tools are required for obtaining the total drilling length, with different levels of complexity and accuracy (depending on the software). According to Spitler and Bernier Spitler and Bernier (2016), there are five levels (*L0* to *L4*) of GSHP sizing tools. *Level L0* corresponds to simple solutions that are mostly used for small systems for only heating applications. In large systems, they are bound to give erroneous results caused by ground thermal imbalance. These procedures should only be considered as a reality check for more advanced sizing tools. *Level L1* uses two heat pulses (building peak heating and cooling loads) and are interesting just from an historical perspective. They evaluate the ground thermal resistance using the infinite line source that turns to be an unprecise approach for long-term estimations (Cane and Forgas, 1991; Caneta Research Inc, 1992). *Level L2* methods are characterized by using

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Nomenclature

GSHP	Ground source heat pump
EED	Earth energy designer
LPG	Liquefied petroleum gas
HP_{pw}	Initial heat pump power (kW)
E_d	Space energy demand (kWh)
W_p	Working period (1800h or 2400h)
COP	Heat pump coefficient of performance
L_h	Total pipe length in heating mode (m)
E_{dh}	Energy demand in heating mode (kWh)
COP_h	Heat pump coefficient of performance in heating mode
R_p	Pipes resistance factor
R_s	Ground resistance factor
F_s	Utilization factor
T_L	Ground minimum temperature (°C)
T_{MIN}	Inlet minimum temperature (°C)
L_c	Total pipe length in cooling mode (m)
E_{dc}	Energy demand in cooling mode (kWh)
COP_c	Heat pump coefficient of performance in cooling mode
T_{MAX}	Outlet maximum temperature (°C)
T_H	Ground maximum temperature (°C)
k_p	Thermal conductivity of the pipe material (W/mK)
D_O	External diameter of the pipe (m)
D_I	Internal diameter of the pipe (m)
λ	Ground thermal conductivity (W/mK)
E_i	Exponential integral function
α	Ground thermal diffusivity (m^2/s)
r	Pipe radius (m)
t	Operational period of the pipe (s)
T_m	Ground medium temperature (°C)
A_s	Annual amplitude of the average daily temperature
X_s	Depth (m)
T_{IH}	Fluid inlet temperature in the heat pump in heating mode (°C)
T_{OH}	Fluid outlet temperature in the heat pump in heating mode (°C)
T_{IC}	Fluid inlet temperature in the heat pump in cooling mode (°C)
T_{OC}	Fluid outlet temperature in the heat pump in cooling mode (°C)

temporal superposition of three successive load pulses (peak ground load, average monthly ground load and the yearly average ground load) to size the drilling field. Going further, *level L3* compiles the most popular software tools which rely on monthly averaged loads and monthly peak loads. These methods are supposed to be more accurate than the ones of *L2* given that they follow more closely the time evolution of the loads. Finally, *level L4* methods consider hourly building or ground loads as the starting point of the borehole size. Aside from the load's time scale, the calculation process of *L4* is identical to *L3* methods (Ahmadfard and Bernier, 2019).

Within the *L3* methods, EED (Earth Energy Designer) software stands out for being one of the most used tools during the geothermal calculation sequence (Hellström et al., 1997; Eugster and Sanner, 2007). Since the presentation of the preliminary version in the second Rauischholzhausen Symposium in 1994 (Hellström and Sanner, 2020), EED has experienced a large number of improvements, making this software a potential solution for the design of ground source heat pump systems. In this context, EED allows to accurately define the final schema of a vertical closed-loop system, being also capable of evaluating the average and the peak monthly mean fluid temperatures over the design period of the installation. It is also worth mentioning that the most recent version of EED can also operate as *L4* software.

Although there are many other specific tools focused on the design of GSHP systems (GLHEPRO, 2007; Chiasson, 2016), most of them only consider vertical closed-loop heat exchangers, that is to say, horizontal and helical configurations are usually excluded in the calculation of these PC programs. With this need in mind (among others), a new software capable of addressing the design of multiple heat exchangers schemas was developed. GES–CAL tool was, thus, created with the intention of incorporating the latest results in the low enthalpy

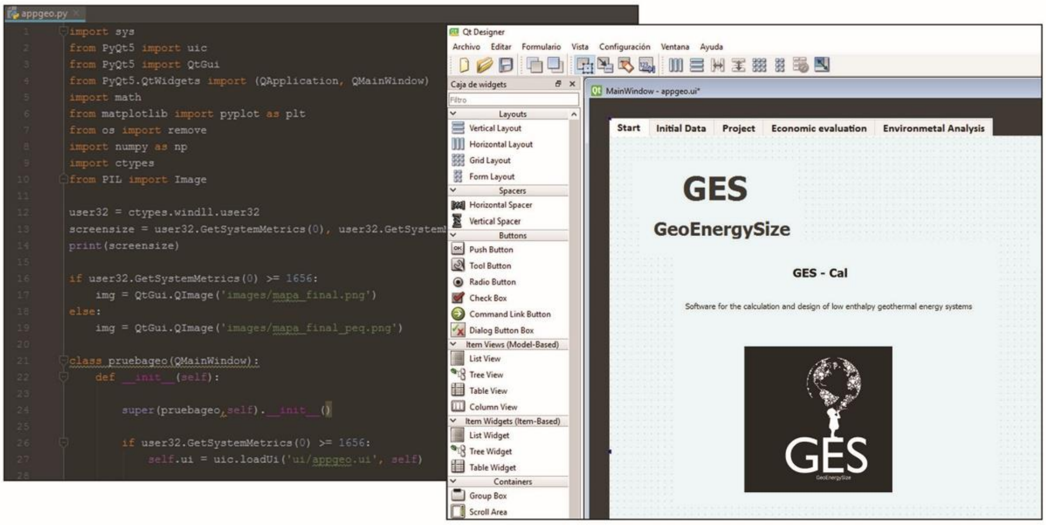

Fig. 1. Working environment of GES–CAL, Pycharm (on the left) and QT Designer (on the right).

geothermal field from an interactive and user-friendly point of view. The objective of this paper is to present and introduce GES–CAL software as an updated solution for the dimensioning of vertical, horizontal and helical closed-loop heat exchangers. The following sections contain a general description of the tool as well as its validation through its implementation on several specific study cases and its comparison with EED software. Since the use of real results for the validation of the tool is inviable (periods of around 25–30 years would be required to ensure a proper design of the system), the comparison with the EED results is the option selected for GES–CAL validation.

1.1. GES–CAL: a new geothermal computer program

GES–CAL is an innovative geothermal modelling software developed by a team of researchers from the TIDOP Research Group (University of Salamanca) with wide experience in the analysis and optimization of low enthalpy geothermal resources (Blázquez et al., 2016,2017c,2017b,2017d,2019a). GES–CAL has been designed to be a flexible and user-friendly computer tool for assessing the technical calculation of closed-loop geothermal systems. The preliminary version of this software was specially conceived for its implementation in the region of Ávila (Spain). The large amount of reliable information coming from previous researches in the area makes it appropriate for the development of this first GES–CAL version. Other facts that contributed to include Ávila in the tool were, among others: the great variation of the ground thermal conductivity in the region, the existence of a large area of granitic formations with high thermal conductivities and the urgent need of promoting shallow geothermal systems in this region (the number of these systems is tremendously low).

1.2. Fundamentals of GES–CAL software

The software tool GES–CAL has evolved out of previous studies and scientific researches developed through laboratory tests and experimental field works. According to the results and conclusions of these studies, GES–CAL was written in the Python IDE PyCharm, using the QT Designer framework.

As can be observed in the QT framework of Fig. 1, the tool is constituted by five principal modules. The first of them, the starting window, presents a brief description of the software, whereas the remaining modules (initial data, project, economic evaluation and environmental analysis) are directly focused on the technical development of the shallow closed-loop system. The following subsections contain a detailed description of each of these modules. Additionally, the main functions of the program are summarized in the flowchart of Fig. 2. As can be seen in this Fig. 2, after the introduction of the information concerning the project (space demand, heat pump, ground, heat exchangers and grout), the software suggests several possible system designs. Then, selecting one of the proposed options, the user finally obtains the final well field schema besides an economic and environmental system evaluation.

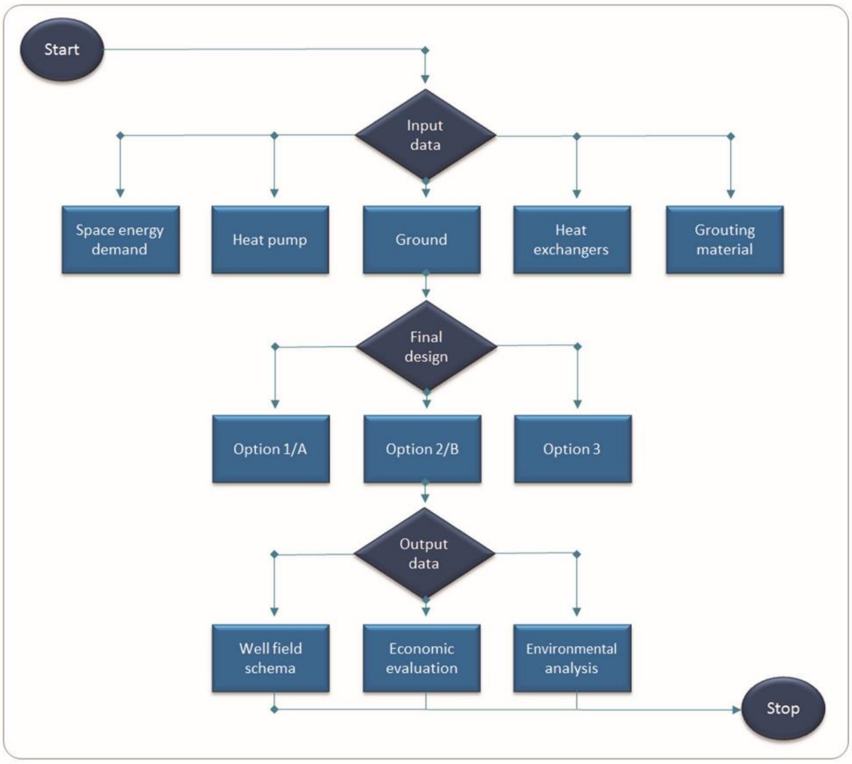

Fig. 2. Flowchart for program GES–CAL.

1.2.1. Initial Data

GES–CAL tool requires, from the user, the introduction of some specific initial conditions of the general shallow geothermal system. This required information refers to the space energy demand, the heat pump working properties, the ground characteristics and the heat exchangers configuration.

- The energy demand can be introduced by the user (if known) or can be automatically calculated by GES–CAL from some space information. The calculation process of this module is based on the application of the procedures specified at the regulation ISO 52016-1:2017 (ISO 52016-1, 2017ISO 52016-1, 2017), applicable to buildings at the design stage, to new buildings after construction and to existing buildings in the use phase. According to the methods of the mentioned law, heating and/or cooling demands are automatically obtained from the previously inserted information about the space (type of demand, area, height, year of construction and orientation). The incorporation of this module avoids the use of additional energy demand tools facilitating, to a great extent, the global geothermal design.
- Once detailed the space energy demand, the user must define the heat pump model (electric or gas engine), the annual operative period (1800–2400 h) and the heat pump preliminary COP. GES–CAL allows the user to adjust the final heat pump power depending on the working period selected. With all this information, GES–CAL calculates the minimum heat pump power required in the system (Eq. (1)).

$$HP_{pw} = \frac{E_d}{W_P \cdot COP} \quad (1)$$

This initial value calculated from Eq. (1) is then oversized with the aim of obtaining the final heat pump power. GES–CAL applies a specific factor depending on the initial power previously obtained. The principal purpose of this over dimensioning is to deal with possible unexpected system variations. At the end of this step, the user knows the final power of the heat pump that will constitute the geothermal generation plant.

- Following up in the initial data module, the next stage is the definition of the ground area available (width and length) and the introduction of the ground thermal conductivity. As mentioned above, the initial version of GES–CAL was specially designed for the region of Ávila. The development (in previous author's researches) of the thermal conductivity map of this region allowed adding it to GES–CAL tool. In this way, if the user wants to design a geothermal system in Ávila, the ground thermal conductivity can be directly obtained in GES–CAL by clicking on the particular area of the thermal conductivity map. On top of the above, when selecting the area in the map, the tool automatically describes the drilling method that should be applied in the case of using vertical heat exchangers. On the contrary, if the area of implementation is not the Ávila region, GES–CAL offers the possibility of manually introducing the thermal conductivity value of the surrounding ground.
- The initial module is finally completed with the selection of the heat exchanger configuration. One of the most notable strengths of GES–CAL tool is that allows the geothermal dimensioning for the most frequent heat exchangers; horizontal, vertical and helical designs. When selecting one or another heat exchanger, the user must also define the pipe material and diameter and the simple-U or double-U configuration in the case of vertical systems. For these vertical designs, GES–CAL also requires the selection of the material that will be used as geothermal grout. In this context, the tool proposes several options including the materials with the highest thermal conductivities (based on previous author's studies (Blázquez et al., 2017d)). It is worth mentioning that the tool only recommends the use of helical configurations for sedimentary ground with the aim of avoiding difficulties when drilling the high diameter holes.

Each of the steps of the initial module of GES–CAL tool described above can be observed in Fig. 3.

1.2.2. Project

Once introduced the particular conditions and characteristics of the closed-loop system, the project tab of GES–CAL calculates the design

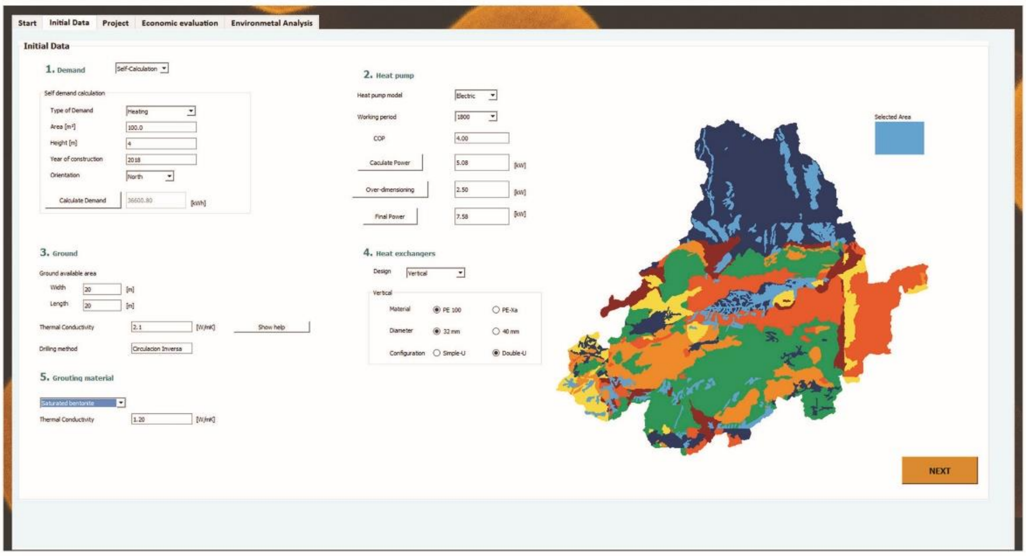

Fig. 3. Initial data module in GES–CAL software.

parameters with the aim of defining the total pipe length and the final schema of the system.

The calculation of the total pipe length derives from the implementation of the expressions described in Eqs. (2) and (3), for heating and cooling mode respectively (Instituto para la diversificación y ahorro energético, 2020).

$$L_h = \frac{E_{dh}\cdot\frac{COP_h-1}{COP_h}(R_p + R_s\cdot F_s)}{T_L - T_{MIN}} \quad (2)$$

$$L_c = \frac{E_{dc}\cdot\frac{COP_c-1}{COP_c}(R_p + R_s\cdot F_s)}{T_{MAX} - T_H} \quad (3)$$

According to the above expressions, a series of parameters must be previously defined. These parameters are obtained as the following Eqs. (4)–(10) describe (Carslaw and Jaeger, 1959).

$$R_p = \frac{1}{2\cdot\pi\cdot k_p}\cdot\left(\frac{D_0}{D_1}\right) \quad (4)$$

$$R_s = 1/4\pi\lambda E_i(-r^2/(4\alpha t)) \quad (5)$$

$$F_s = \frac{E_{dh} \text{ or } E_{dc}}{HP_{pw}} \quad (6)$$

$$T_L(X_s) = T_m - A_s\cdot e^{\left(-X_s\sqrt{\frac{\pi}{365\cdot\alpha}}\right)} \quad (7)$$

$$T_H(X_s) = T_m + A_s\cdot e^{\left(-X_s\sqrt{\frac{\pi}{365\cdot\alpha}}\right)} \quad (8)$$

Finally, inlet and outlet temperatures (T_{MIN} and T_{MAX}) are estimated by taking into account the inlet and outlet interval of temperatures of the fluid for both heating and cooling modes. Thus, T_{MIN} and T_{MAX} are obtained as follows:

$$T_{MIN} = \frac{1}{2}(T_{IH} + T_{OH}) \quad (9)$$

$$T_{MAX} = \frac{1}{2}(T_{IC} + T_{OC}) \quad (10)$$

The general expressions of Eqs. (2) and (3) are valid for both heat interchangers, vertical and horizontal. The characteristics of the configuration in the particular case are reflected in the ground resistance factor (R_s), defined in Eq. (5).

Once obtained the total pipe length of the system, GES–CAL determines the most optimal distribution for the geothermal field depending on the heat exchanger previously selected (horizontal, helical, simple-U or double-U).

In the case of horizontal heat exchangers, the tool offers two possible designs considering the available ground area:

- Option A, straight pipes are placed in series in the trench made on the ground. This alternative is characterized by requiring large land areas, being only viable for specific conditions.
- Option B, pipes follow a spiral pattern which allow lower land use. This option is specially recommended when the ground area is limited but horizontal configurations deserve to be used.

On the contrary, when vertical heat exchangers were selected in the initial module (either for simple or double-U tubes), GES–CAL proposes three possible schemas for the well field design.

- Option 1 is always the alternative with the lowest global drilling length and number of boreholes. The borehole length is, however, higher in this first option due to the reduction of the borehole number.
- Option 2 offers an alternative solution that increases the number of boreholes, reducing the individual borehole length but requiring an increase of the total drilling length.
- Option 3 is the solution characterized with the highest number of boreholes and total drilling length but lower borehole length.

Finally, when the geothermal project is planned to be constituted by helical heat exchangers, GES–CAL tool follows a similar pattern than in the previous case, offering three different drilling schemas depending on the number of boreholes and total drilling length. Fig. 4 presents an example of the final schema proposed by the tool for a particular helical geothermal project.

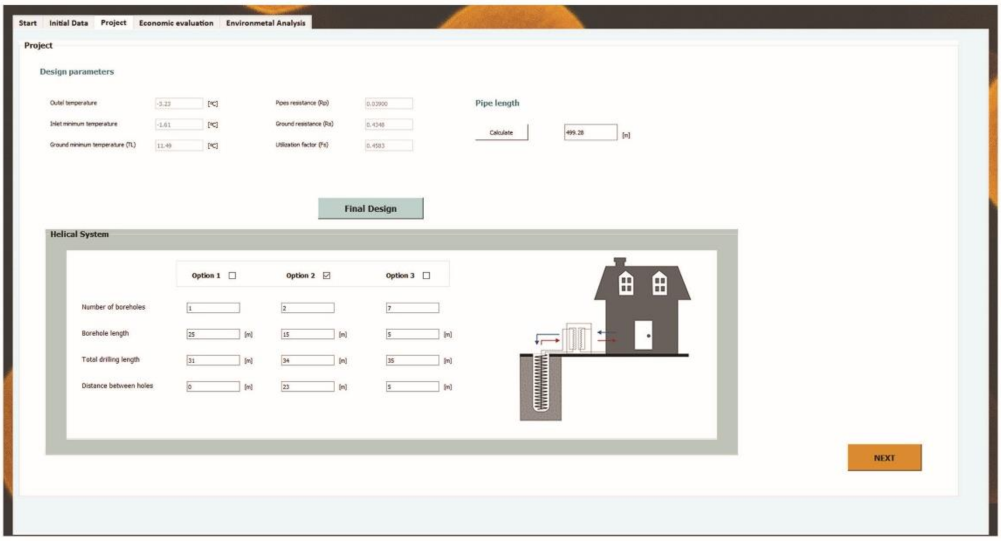

Fig. 4. Final design of a helical closed-loop system at the project tab in GES–CAL software.

1.2.3. *Economic and environmental evaluation*

Once defined the well field schema and the principal design parameters, GES–CAL also includes two additional modules to evaluate the geothermal project from an economic and environmental point of view.

- Starting with the economic section, the tool is capable of calculating the initial investment and operational costs associated with the geothermal solution selected in the previous tab. The global initial investment is, in turn, broken down into the following main categories: drilling, ditches and manifold installation, heat pump/accessories, grouting material, heat carrier fluid and heat exchangers/accessories. For its part, the annual operational costs only require to consider the heat pump operation (including also the costs associated to the electricity consumption of the circulation pumps) and the system maintenance. Taking into account all this information, GES–CAL also offers the possibility of comparing the geothermal system with other energy sources; natural gas, electricity, diesel oil and LPG (Liquefied Petroleum Gas). This comparison is based on the initial investment and operational costs involved in the implementation of each alternative system to supply the same space energy demand. Finally, the tool graphically displays the evolution in costs of each energy source and the geothermal one for a period of 25 years. The above described economic module can be observed in Fig. 5.
- As mentioned before, the environmental aspect is also addressed by GES–CAL software. In this way, the last module is exclusively focused on the determination of the greenhouse gases emission associated to the operation of the geothermal system and the remaining energy sources contemplated in the tool (natural gas, electricity, diesel oil and LPG). As shown in Fig. 6, CO_2 emissions accumulated for each energy solution in the year 25 are also displayed in this last tab of GES–CAL.

2. Practical application

This section is mainly focused on the application of GES–CAL tool in several particular cases. Results will be then compared to the ones obtained by the use of EED software using the same initial conditions. Table 1 presents the preliminary information concerning each of the study cases that will be geothermally sized by GES–CAL and EED software.

The cases included in the above Table 1 have been selected according to the representative climates in Europe, European Directive 2009/28/CE (Directiva, 2009; Blázquez et al., 2019b). The region of Ávila (representative of the warm climate) has also been chosen since, as previously commented, GES–CAL tool was mainly designed for this area. The results of applying GES–CAL are included in the following Table 2.

In addition to the technical calculation presented for each of the study cases (Table 2), GES–CAL also provides the initial investment and operational costs of the geothermal solution and the environmental evaluation through the estimation of the CO_2 emissions.

It can be noted from Table 3 that operational costs and CO_2 emissions are the same for all the schemas of each study case. The reason derives from the fact that the global heat pump electricity use is the same; that is to say, although some configurations require more power for the recirculation pumps, it is compensated by shorter operating times. Thus, since the electricity use is identical, the operational costs and CO_2 emissions (that derives from the heat pump working) are also the same for all the configurations of the same study case.

Along the same lines, EED software was tested under the same initial conditions. Results of this tool can be observed at Table 4. As previously commented, this tool only allows the geothermal design for vertical heat exchangers, single-U or double-U tubes, so that; horizontal and helical calculations are not included in this Table 4.

3. Discussion of results

The three test cases considered in this work are used in an inter-model comparison of the new tool GES–CAL and EED software. It is worth mentioning that EED software has been chosen for the validation of GES–CAL since it is considered as one of the most consolidated and reliable geothermal tools. In the first study case, it is assumed that the space is located in the region of Ávila, with the purpose of implementing the tools in the area for which GES–CAL was specifically developed. This first case together with the other two scenarios cover

Fig. 5. Economic evaluation of the geothermal project made by GES–CAL software.

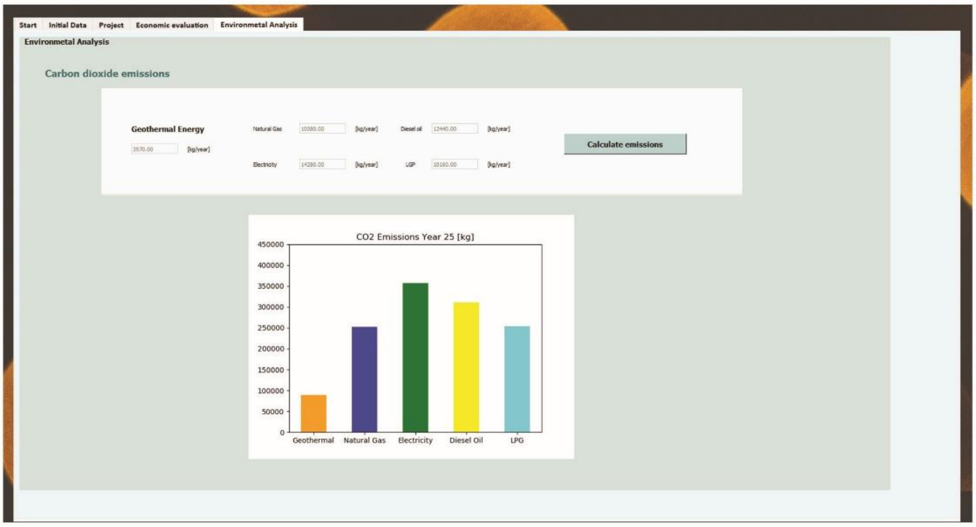

Fig. 6. Environmental analysis of the geothermal system provided in GES–CAL tool.

the spectrum of the representative European climates, as mentioned in the previous section.

Based on the results of the practical application presented in the above section, the following statements can be deduced:

3.1. *Heat exchanger design*

The global design of the geothermal system is mainly determined by the configuration of the heat exchanger selected during the calculation process. Using GES–CAL tool the user has the possibility of evaluating the implementation of horizontal, helical or vertical heat exchangers. As shown in Table 2, the same system is configured with all the mentioned heat exchangers to finally choose the most optimal schema taking into account the economic and environmental evaluation of the software (Table 3).

When using EED tool, only vertical heat exchangers are considered. For this reason, for the three study cases of the previous practical application, only this vertical design (single-U and double-U) can be selected when applying this software.

3.2. *Analysis of the working fluid*

One of most remarkable strengths of EED software is the evaluation of the working fluid evolution during all the lifetime of the system. This fact allows accurately adjusting the drilling length required in function of the fluid temperature. It is especially important for high power installations in which the working fluid is likely to reach extremely low temperatures that will inevitable affect the right heat pump operation.

In the case of GES–CAL, all its internal calculations are conceived to ensure that the temperature of the working fluid will never reach a certain value. This tool does not provide the graphical evolution of the fluid temperature, but it establishes a temperature limit always respected when defining the final design. In general, calculations cannot be as adjusted as using EED, but results ensure that the temperature of the fluid will not interfere in the heat pump operation. This fact means that for the same case, EED could reduce the total drilling length (that could be significant in high power projects) in relation to GES–CAL results.

3.3. *Drilling length*

The most relevant factor that allows the comparison of both GES–CAL and EED tools, is the total drilling length required in the geothermal solution. Considering Tables 2 and 4, there seems to be great agreement between both the programs, this comparison can be observed in a graphical way in the following Fig. 7.

Observing the previous graphs of Fig. 7, differences between GES–CAL and EED are of below 4% for both single and double-U tubes of scenario 2 and 3. In these cases, the drilling length proposed for the geothermal system by GES–CAL is slightly higher than the one of EED. However, this high agreement is not found in scenario 1, in which EED suggests the highest drilling length for both configurations (single and double-U). Differences in this first case are notable (around 20%) and a deeper explanation of this fact is presented below:

- GES–CAL was mainly developed for the region of Ávila, the location for the space of case 1. The high knowledge acquired about the thermal properties of the geological formations of this place, implemented in the tool, makes GES–CAL a more efficient solution for the design of GSHP systems in this region.

Table 1
Study cases considered in the implementation of GES–CAL and EED.

Study case	Energy demand (kWh)	Space location	Geological formations
SC 1	23,889	Ávila (Spain)	Adamellite
SC 2	71,742	Edinburgh (Scotland)	Basalts
SC 3	88,882	Karlstad (Sweden)	Granite and gneisses

Table 2
Results obtained from GES–CAL tool for each of the selected study cases.

	SC 1	SC 2	SC 3
Horizontal*	Pipe length = 716.93 m	Pipe length = 1758.89 m	Pipe length = 1411.80 m
	Ground area = 89.61 m^2	Ground area = 219.86 m^2	Ground area = 176.47 m^2
Helical	Number of boreholes = 3	Number of boreholes = 6	Number of boreholes = 5
	Total drilling length = 39 m	Total drilling length = 83 m	Total drilling length = 73 m
Single-U	Number of boreholes = 1	Number of boreholes = 3	Number of boreholes = 3
	Total drilling length = 112 m	Total drilling length = 315 m	Total drilling length = 305 m
Double-U	Number of boreholes = 1	Number of boreholes = 3	Number of boreholes = 3
	Total drilling length = 96 m	Total drilling length =299 m	Total drilling length = 253 m

* Spiral pattern has been selected.

Table 3
Economic and environmental information for each scenario obtained in GES – CAL software.

		Initial investment (€)	Operational costs (€/year)*	CO_2 emissions (kg/year)*
SC 1	*Horizontal*	37453.09	1122.50	3146.06
	Helical	36533.97		
	Single-U	20870.78		
	Double-U	21168.79		
SC 2	*Horizontal*	71676.54	1643.00	4694.55
	Helical	61954.61		
	Single-U	33309.55		
	Double-U	30680.19		
SC 3	*Horizontal*	54934.76	2144.00	6185.02
	Helical	56552.90		
	Single-U	29937.74		
	Double-U	29151.72		

- The thermal conductivity of the surrounding ground can be highly adjusted in GES–CAL (for the region of Ávila) which also allows adjusting the final drilling schema. This thermal parameter has huge influence on the global drilling length. As shown in previous researches, a slight reduction of the ground thermal conductivity means a significant increase of the drilling length proposed by EED, and vice versa (Blázquez et al., 2017b).
- The calculation process of both programs allows getting similar results when the ground thermal conductivity is the same (or very similar). However, when this parameter is different (as in scenario 1), results need to be also different.
- For different scenarios (cases 2 and 3), GES–CAL provides an optimal solution but requiring a higher drilling depth (slightly higher) than EED, due to the limitation of the working fluid temperature.

Regarding the number of boreholes proposed by each software, results directly depend on the restriction of the maximum drilling length that the user can establish in the tool. For this reason, the comparison of this factor does not have a significant role in this work.

3.4. Environmental and economic aspects

The economic and the environmental issues are often the main reasons for choosing or discarding a specific system. Through the additional environmental and economic modules of GES–CAL, the user can easily compare each solution proposed by the tool and select the most appropriate one from the previous evaluation of GES–CAL. For the cases considered here, as shown in Table 3, attending to the initial investment, the single-U configuration would be the most recommendable option for case 1 and double-U tubes for cases 2 and 3. In relation to the operational costs, these are the same for all the options of the study case, as well as the CO_2 emissions, given that the heat pump (source of the emissions and annual costs) is identical for the solutions of a case. In addition to these data, as already explained in Section 2, GES–CAL software also allows the comparison of the geothermal system with other traditional energy sources. One of the main purposes of this tool is to contribute to the diffusion of shallow geothermal systems. Through GES–CAL, the user can easily check the influence of the GSHP system on the global environmental side and climate change mitigation and also on her/his own economy.

4. Conclusions

The geothermal industry needs effective multidisciplinary solutions to deal with an effective design of the most widespread installations; low and very low enthalpy geothermal systems. In this context, one of the principal goals of this work is to propose an alternative tool that could be used to define the most optimal design of a GSHP system. Thus, the paper presents the new geothermal techno-economic and environmental simulation tool GES–CAL. Through the implementation of this software in the design of three different specific cases, results of GES–CAL are evaluated and compared with the ones obtained from EED, one of the most used geothermal software.

Both sizing tools are mainly compared on their ability to predict the total drilling length required in the system using single-U and double-U tubes (the only configurations included in EED). From the analysis of the whole ensemble of results, this work concludes that GES–CAL software provides high accurate geothermal designs, especially for those systems placed in the region of Ávila (GES–CAL was initially developed taking into account the thermal and geological properties of the ground in this region). For the rest of locations, the tool has proven to be an acceptable solution, providing both GES–CAL and EED similar results. However, in these locations, EED usually gets more adjusted configurations due to the evaluation of the heat carrier fluid temperature. It must be clarified that there is not limitation for the general use

Table 4
Results obtained from EED tool for each of the selected study cases.

	SC 1	SC 2	SC 3
Horizontal	–	–	–
Helical	–	–	–
Single-U	Number of boreholes = 1	Number of boreholes = 3	Number of boreholes = 3
	Total drilling length = 134 m	Total drilling length = 313 m	Total drilling length = 290 m
Double-U	Number of boreholes = 1	Number of boreholes = 3	Number of boreholes = 2
	Total drilling length = 115 m	Total drilling length = 288 m	Total drilling length = 251 m

Fig. 7. Drilling length proposed for each tool in the three cases under study.

of GES–CAL in other locations; but, additional information is available for the region of Ávila.

The comparison of both computer tools and the low deviations among the results of both programs (< 4% for the general use) have denoted that GES–CAL software constitutes a reliable and recommendable option for the design of all types of GSHP systems. Additionally, GES–CAL tool offers a series of relevant modules that must be highlighted:

- Automatic calculation of the space energy demand from the introduction of the most influential building information.
- Implementation of experimental parameters based on previous studies that allows obtaining more precise results.
- Possibility of designing the geothermal system considering the group of the most common configurations: horizontal, helical and vertical (single or double-U tubes) heat exchangers.
- Economic and environmental evaluation of the final geothermal solution through the determination of the initial investment, operational costs and emission of greenhouse gases. Both evaluations are complemented by the comparison of the system with other traditional and non-renewable energy sources. These modules constitute one of the most remarkable strengths of GES–CAL tool, adding a valuable contribution regarding the common geothermal software.

Interested scientists can download the software package from a public archive that can be found in the following link: https://github.com/TIDOP-USAL/GES-CAL. More information about the software operation can be obtained by contacting the corresponding author of this research.

To conclude this work, it is considered appropriate to mention that GES–CAL software is and will be subjected to a constant process of improvement derived from the incorporation of the newest contributions in the field.

CRediT authorship contribution statement

Cristina Sáez Bláquez: Investigation, Methodology, Writing - original draft, Writing - review & editing. **Ignacio Martín Nieto:** Data curation, Methodology. **Rocío Mora:** Methodology. **Arturo Farfán Martín:** Supervision. **Diego González-Aguilera:** Supervision.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

Supplementary material related to this article can be found, in the online version, at doi:https://doi.org/10.1016/j.geothermics.2020.101852.

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