STATE OF THE ART OF TECHNOLOGIES, SOLUTIONS, PERSPECTIVES AND OBSTACLES OF HEAT GEOSCHANGERS AS PART OF AIR CONDITIONING SYSTEMS BASED ON GEOTHERMAL HEAT PUMPS

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Abstract. In Romania, as well as in the European Union, the largest amount of energy is used in constructions; 40% of the total consumption is used for heating buildings. Given the considerable age of most real estate, the renovation of this sector using solutions with systems based on geothermal heat pumps is one of the most cost-effective variants, intelligently combining efficiency with environmental protection. Despite their very high efficiency and the fact that we are talking about green, renewable energies, they are scarcely used in Romania. It is proven that heat pumps with a heat exchanger, in a parallel vertical system, are the most efficient solution even if slightly more expensive than horizontal or slinky systems. The study of the technology of heat exchangers is based on the analysis of some parameters that characterize both the materials for pipes and the characteristics of the layers crossed by the pipes that make up the thermal energy transfer system from the geological layers to the geothermal heat pump. This paper aims to illustrate an overview of possible solutions regarding the type of heat exchangers and their efficiency.

Keywords: geothermal energy, geo heat exchangers, heat pumps, rock heat transfer.

Rezumat. Stadiul artei de tehnologii, soluții, perspective și obstacole ale geoschimbătoarelor de căldură ca parte a sistemelor de aer condiționat bazate pe pompe de căldură geotermală. În România, ca de altfel și în Uniunea Europeană, cea mai mare cantitate de energie se utilizează în construcții; 40% din consumul total se utilizează pentru încălzirea clădirilor. Având în vedere vechimea considerabilă a majorității fondului imobiliar renovarea acestui sector folosindu-se soluțiile cu sisteme bazate pe pompe de căldură geotermice, este una dintre cele mai rentabile variante, combinând inteligent eficiența cu protecția mediului. În ciuda eficienței lor foarte ridicate, a faptului că vorbim despre energii verzi, regenerabile, în România, ele sunt folosite într-o măsură foarte redusă. Este dovedit că pompele de căldură cu schimbător de căldură în sistem vertical paralel sunt soluția cea mai eficientă chiar dacă ceva mai scumpă decât sistemele orizontale sau de tip slinky. Studiul tehnicii geoschimbătoarelor de căldură se bazează pe analiza unor parametrii care caracterizează atât materialele pentru țevi cât și caracteristicile straturilor prin care trec țevile ce alcătuiesc sistemul de transfer termic al energiei din formațiuni către pompa de căldură geotermică. Lucrarea de față se vrea a ilustra o imagine de ansamblu a soluțiilor posibile privind tipul geoschimbătoarelor de căldură și eficiența acestora.

Cuvinte cheie: energie geotermală, geoschimbătoare de căldură, pompe de căldură, transfer termic prin roci.

INTRODUCTION

As it is well known, the real estate sector is energy intensive and a significant part of it concerns air conditioning, i.e. heating, cooling, ventilation, domestic hot water, i.e. 60-80% of the energy needed in buildings is consumed here. The building stock in Romania, like the European stock, is mainly made up of buildings that are over 40-50 years old, which means that their energy efficiency is very poor. The European Commission has published a series of directives such as EPBD (DIGLIO et al., 2018) and EED (Directive 2018/2002/EU) which aim to identify solutions with significant energy saving potential for buildings (PRICĂ, 2015). In these directives we find the main solutions for increasing the energy efficiency of buildings, and a very important place is occupied by the widespread use of renewable energies such as geothermal energy used both in the retrofitting of existing buildings and in the construction of new ones, whether residential, industrial or commercial.

In this context, the use of heat pumps is also gaining momentum in EU countries, with 1.6 million heat pumps installed in 2020 alone, a 5% increase compared to 2019. Perhaps surprisingly, Italy, France and Spain are leaders in this sector (Ren21.Net) although the first users of these systems were the Nordic countries. Figure 1 shows the ratio of the number of heat pumps using air as a source (ASHP) to those using geological formations as a source (GSHP). The big variation in the type of pumps comes from the type of climate; for Mediterranean countries, where the need for air conditioning is higher, ASHP pumps are more popular while, as the latitude increases, GSHP pumps are more popular where either the cold and heat needs are about equal (as is the case in Romania) or, for northern areas, the heat needs are higher.

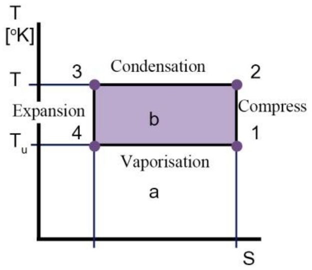
STATE OF THE ART AND DEVELOPMENT TRENDS

Theoretical background

The operating technology of heat pumps is based on an ideal thermodynamic cycle, the reversed Carnot cycle.

It transfers a quantity of heat energy from a low temperature source to a higher temperature sink. Systems of this type are based on the thermodynamic properties of refrigerants, on the transfer of energy from one state to another. The electrically driven steam compression heat pump operates on the principle of the inverted Carnot cycle, the ideal T-S diagram of which is shown in figure 1. The main processes taking place are (BADENES et al., 2015; BULLARD & NIBLETT, 1951): 4 -1 – steaming, 1 - 2 – compression, 2 - 3 – condensation, 3 - 4 – expansion.

The expansion process is very important for the performance of the heat pump, here the pressure levels in the two heat exchangers are established.



Legend

T - temperature of the body receiving the heat - thermal agent
T_u - body temperature gives up heat - cold source
a - energy taken from the outside environment , from geological formations
b - energy consumed by the compressor
a + b - total energy released to the thermal agent
s - entropy - energy content at a given state

Figure 1. Diagram of the ideal inverted Carnot cycle.

Heat source of the pump

Heat pumps can have various heat sources such as:
a.- air,
b.- water:
b1- surface - rivers, lakes
b2 - underground - groundwater, geothermal
c. - geological formations
d. - solar radiation.

Of all these sources, geothermal water and geological formations at depths greater than 10 m are the ones that do not show large temperature variations, i.e. they provide good operating conditions for heat pumps.

Geological formations provide high and virtually inexhaustible energy potential. It can be found anywhere on the planet and is free of charge.

Origin and characteristics of geothermal energy

Throughout the year, although the outdoor temperature varies considerably from a season to another, it remains relatively constant at depths greater than 10m. Because heat transfer through rocks is not high, geological formations have the capacity to absorb and store thermal energy. The thermal energy for a given depth comes from internal thermal energy - geothermal energy - mostly from the Earth's energy as a planet, to which the solar energy is added and stored at the top, but in extremely small quantities.

It is the internal structure of the Earth as a planet that basically dictates how much geothermal energy exists at a given depth and in a given area, and how this energy is transferred through rocks.

The circulation of geothermal energy is from the inside to the outside of the planet. Of the phenomena within the Earth's interior, geothermal flow is the most important manifestation of energy.

The geothermal energy coming from the Earth as a planet is given by:
- the slow decay of radioactive substances found naturally in most rock types,
- proximity to magma zones - magma chambers,
- proximity to the Earth's fluid core in areas where the Earth's crust is thinning,
- natural demagnetization of paramagnetic rocks.

The density of the heat flux received by the Earth from the Sun on average is: $q=0.13W/m^2$.

The slow decay of radioactive substances is a characteristic of matter and was revealed with the discovery of the radioactive elements – uranium, thorium, actinide and potassium. Initially thought to be the exclusive property of these elements, Le Bon and E. Rutherford discovered that these elements are the primary stage in the evolution of matter, a stage that the other elements have already covered. However, the true cause of the atom's disintegration is not known.

The natural disintegration of U, Th and K, which manifests itself in α and β corpuscular radiation and γ electromagnetic radiation, can provide an important source of energy. The concentration of these three elements in the earth's crust is important.

Types of geothermal energy extraction systems

Initially we started from simpler typologies like those in figure 2. Subsequently, in order to obtain a higher amount of energy but at a lower cost, more and more types were found.

The type of geoheat exchanger will be chosen according to several factors: the heating and cooling requirements of the building, the type of rock from which energy is extracted or its hardness, its heat transfer coefficient, its humidity, etc. Each of these factors has its own importance in the correct calculation of the geoheat exchanger size and the parameters that will allow a higher or lower efficiency.

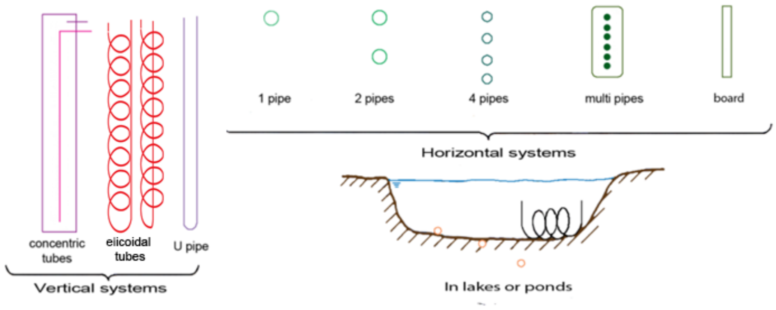


Figure 2. Main GSHP typologies.

Table 1. Types of heat exchangers.

Closed systems				**Open systems**
Horizontal		Vertical		Vertical
Serials	Parallels	Serials	Parallels	
	Slinky		Energy pylons	

Depending on the type of pipe placement in the ground, the systems can be vertical and horizontal.

They have the advantage of having a single diameter over the entire length and the same flow rate. Series systems are unbalanced systems because the energy is not evenly distributed and the gaps between the first and last loops are large, need a large volume of circulating fluid (antifreeze) lower efficiency than other systems due on the one hand to the thermal characteristics of the antifreeze, but on the other hand to the larger diameters (JAVED CLAESSON, 2011). Parallel systems are by far the best because no matter how many loops are connected, each loop extracts about the same amount of energy from the ground. Differences can occur depending on the moisture content of the rocks being crossed and/or their mineralogical composition.

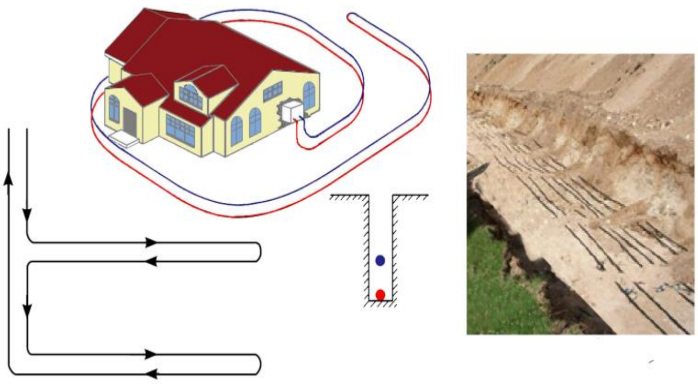


Figure 3. Horizontal systems mounted in series.

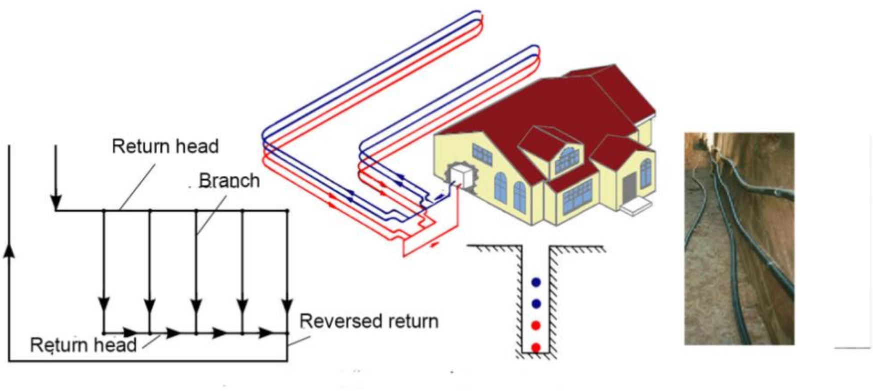


Figure 4. Horizontal systems mounted in parallel.

The mathematical equation for the calculation of the available energy (heat) of the warm medium is:

$$Q_c = \frac{L(t_g - t_w)}{R}$$

Where $\mathbf{Q_c}$ - available energy [W];

L - length of pipes [m];

t_g - temperature of geological formations [°C];

t_w - the temperature of the fluid [°C];

R - thermal transfer resistance [m°C/W].

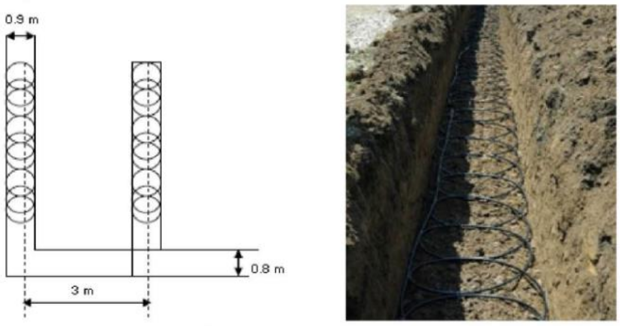


Figure 5. Horizontal slinky systems (unwound coil).

Slinky systems are space-saving; less land area is required by having shorter trench dimensions for the same length of heat exchanger. A slinky system will reduce the length of the GSC by about two thirds compared to the two horizontal pipe version.

There are several construction variants; the coil in the trench and the return pipe is installed above the coils for better thermal discharge, i.e. the lap and return are no longer thermally influenced, or another variant involves 30 to 32 cm diameter coils, which make installation easier and space distribution more versatile.

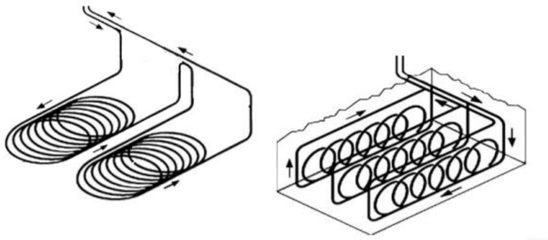


Figure 6. Different types of slinky

The basis of Geo Heat Exchangers systems are vertical wells. Figure 7 shows such a well.

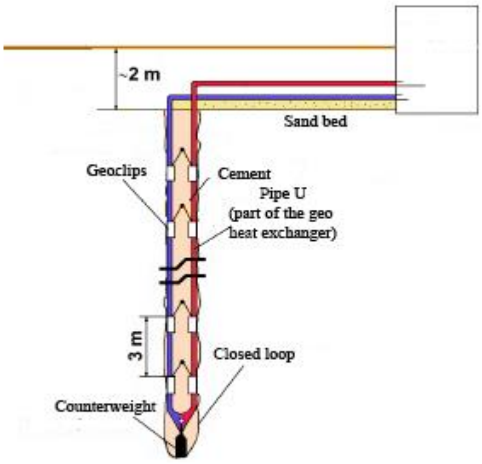
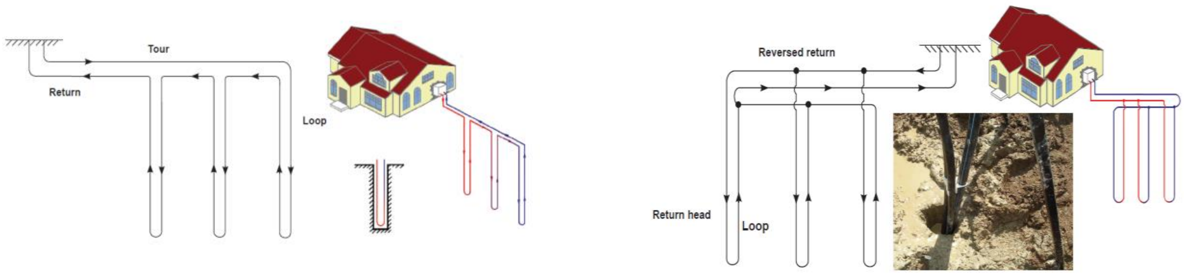


Figure 7. Vertical well (loop).



a b

Figure 8. Geoheat exchangers vertical system a with serial loops, b. with parallel loops (PRICĂ, 2015).

To calculate the length of the GHE (LUND et al., 2009) it is necessary to know the temperature required to be collected from the geological formations and the temperature of the fluid at the outlet of the collector circuit. The length of the header is:

$$L=\frac{G_0 \Upsilon_0 C_p}{k d_1 \pi x} \cdot ln\left(\frac{T_0-T_{sol}}{T_x-T_{sol}}\right) \quad (1)$$

L - length of pipe section needed [m]

T_x - temperature of the fluid in the pipe at a distance “x“ [K]

T_{sol} - soil temperature at the depth of burial of the pipeline (assuming that is approximately constant at distance “x”) [K]

T_0 - initial temperature of the fluid at the entrance to the long stretch “x„ [K]

K - heat transmission coefficient between the pipe and soil, is determined by measurements for various materials

For greater efficiency, double loops are used, i.e. 2 pipes on the return and 2 on the return. These can be seen in Fig. 12.

Today there is a whole range of innovative pipe material solutions that can ensure high heat transfer:

- Graphite (flake or expanded): 1.1 W/(m·K)
- Graphene
- Aluminum wires: 0.625 – 1.25 W/(m·K)
- Nanomaterials: 0.7 W/(m·K)

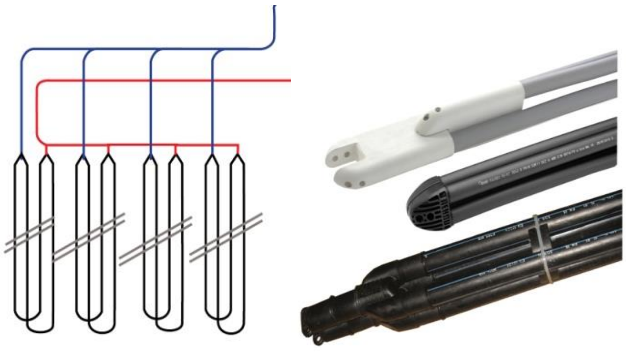


Figure 9. Double U-loops.

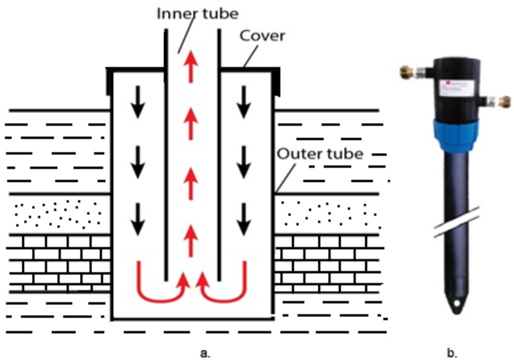
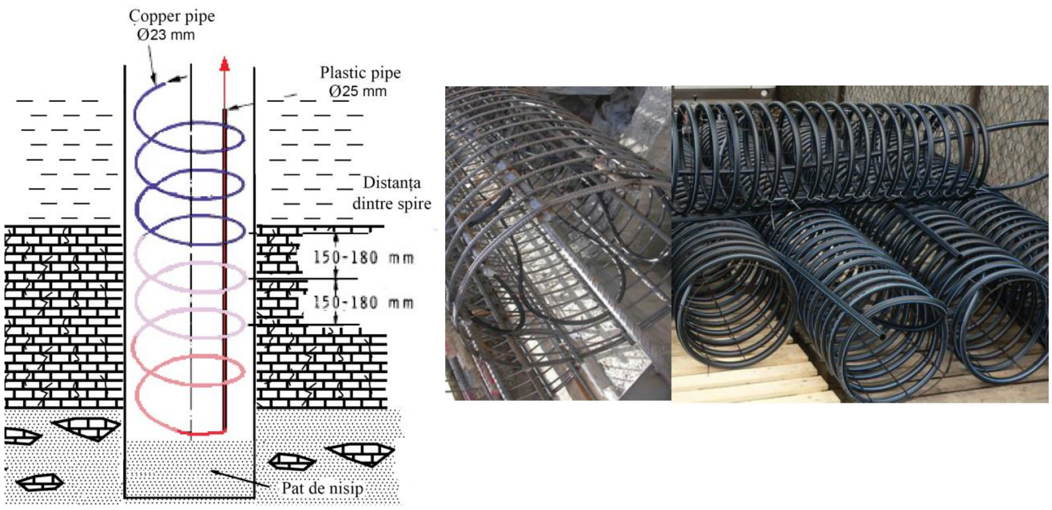


Figure 10. Coaxial tubes.

At the moment, 3D helical systems are successfully used to reduce the installation costs of the geo heat exchanger (YANG et al., 2010).

Helical tubes can be installed both vertically and horizontally. If they are placed in a vertical position and a greater depth is chosen, drilling costs will be higher, but thermal efficiency will also be higher.

There are several types of helical systems. Some are made of PeHD pipe; others can be made of Copper pipe coated with various types of insulation.



a. b.

Figure 11. Helical Geo Heat Exchangers a. scheme, b. metal skeleton molds.

MATERIALS AND COMPONENTS OF GEO HEAT EXCHANGERS

The main material used for U conducts is PeHD, Pn 6 or Pn 10 depending on the depth to which the loops will reach.

Considering ASHRAE guidelines regarding geothermal energy (BUNTEBARTH, 1991), geothermal heat exchanger heat resistance (GHE) and the thermal conductivity of the crossed geological formations must be taken into account as key variables when designing GSHP. Reducing the thermal resistance of the GHE is important as it has a significant impact on the overall performance of the geo exchanger. Another key parameter is the thermal conductivity of the U-loop and the system configuration. The layout of the pipes is limited by economic constraints but also by the formations in which they are placed. The borehole thermal resistance Rb, i.e. the thermal resistance between the working fluid inside the pipe and the borehole wall, is an important parameter and obviously depends on the nature of the material the borehole is made of. For a classical single-tube U-shaped arrangement and under the assumption of symmetry between tubes (Figure 12), a basic definition of Rb is given, as shown in the following equations:

$$\mathbf{R_b} = \frac{R_f + R_p}{2} + \mathbf{R_p} \quad (2)$$

Where: $\boldsymbol{R_f}$- the conductive resistance of the grout: $\boldsymbol{R_f} = \frac{1}{2\pi h r_1}$ (3)

$\boldsymbol{R_p}$- he conductive resistance of one pipe: $\mathbf{Rp} = \frac{1\ln(\left(\frac{r_2}{r_1}\right)}{2\pi k_p}$ (4)

where Rg - the conductive resistance of the grout,
h - the convection coefficient of the fluid,
kp - the thermal conductivity of the tube,
r_1- inner radius of the tube, r_2 - the and outer radius of the tube.

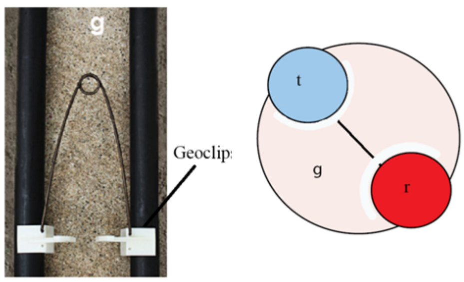


Figure 12. Correct position of pipes inside the borehole with geoclips.

In order to get the maximum amount of energy from the geological formations, GHE pipes must have as large a contact surface as possible. Geoclips or spacers are the devices without which the amount of energy obtained is minimal. As such, the purpose of geoclips is to ensure the best heat transfer between the GHE and the ground. Absence of spacers (geoclips) can decrease effectiveness by up to 30**%.** (*Closed-Loop/Ground Source Heat Pumps Systems*. Installation Guide).

According to studies the thermal conductivity of the pipe and the backfill cement and the configuration of the system play an important role in the efficiency of geothermal ground heat exchanger systems.

The thermal conductivity of the filler material has a maximum influence on system performance. The choice of filler cement thermal conductivity and heat capacity is very important for GSHP efficiency (DAVIS, 1988; DIGLIO et al., 2018). It has been shown that the GHE efficiency is proportional to the cement thermal conductivity for all possible configurations (FRIDLEIFSSON et al., 2008; ***. Geo-Education, 2010) and is inversely related to the GHE length and its cost.

A significant decrease in Rb was found to be detected for grouts with a thermal conductivity up to 2 W/(m-K), while a less intense decrease can be obtained with values up to 4 W/(m·K). As far as the grout material is concerned, an optimum value between 2.5 W/(m·K) and 3.3 W/(m·K) was determined (BADENES et al., 2020). Of course there are other technical characteristics that this material must meet to achieve its purpose.

Today, even in the field of grouting, innovative solutions are also used, such as:

- Sand: 1–2.91 W/(m·K)
- Graphite: 2.73–2.91 W/(m·K) (flake or expanded)
- Aluminum shaving: 3.27–3.75 W/(m·K)

Graphite is, next to sand, the most widely used additive for increasing the thermal conductivity of the injection material, either in flake or expanded form. The carbon content of graphite is the reason why it is the most common choice. Its insolubility in water is also an advantage as it prevents any risk of contamination. The study by Lee et al. on the thermal performance of seven bentonite-based grouts to which either silica sand or graphite was added showed that graphite was more efficient than sand, with a conductivity of about 3 W/(mK) at a concentration of 30% by weight, while the same amount of sand achieved a thermal conductivity of only 1 W/(mK). At the same time, it turned out that a higher amount of additive in the mixture leads to an increase in the viscosity of the mortar which increases the consumption of the mortar feed pump, increases the risk of grout bead discontinuity as such decreases the performance. A team led by Delaleux has shown in their research that keeping the graphite content below 10% improves thermal conductivity by up to 5 W/(mK). By inserting expanded natural graphite (CENG) particles with a maximum graphite content of 5%, this leads to a 33% reduction in the required BHE and a 30% reduction in the total cost of GHE.

Of these, the thermal properties of the soil, moisture, porosity, permeability, mechanical strength are important and are chosen according to these. For a correct choice, the characteristics of geological formations are determined with the help of thermal response tests (TRT).

The main filler materials are bentonite base and super silica sand or cement, due to their low permeability, high swelling potential and high strength. In general, each designer has a preferred base grout, the recipe of which he adapts to the specific conditions of each site.

Also, mechanical properties such as viscosity and injection speed should not be ignored and must be taken into account when using these materials. It is very important that they are injected from the bottom up, with the injection pipe being pulled out at such a speed that it does not come out of the material and create air voids.

DESIGN OPTIMIZATION AND EXECUTION CONTROL

The advantages of using these technologies can be considerably reduced or even cancelled out in the absence of well-developed design and implementation control procedures. They prevent over- or underestimating the size of the system, both of which lead to poor system performance. Proper design and control optimization are absolutely necessary to achieve maximum system resilience, both in terms of installation and operating cost.

The main aspects of the optimization procedure to be considered are:

- definition of the objective(s);
- identification of the variables to be optimized and the technological constraints of the procedure;
- determination of the optimization problem (what is to be optimized);
- the choice of the optimization method (DAVIS, 1988).

There are several procedures to reduce the energy consumption of GSHP systems by optimizing design and control solutions, which are validated based on simulations (less often with simplified applications).

A design specifically adapted to the geo heat exchanger site and the presence of air conditioning in the building is the first means of reduce energy consumption in HVAC systems. The best design is to determine the optimal plant configuration and heat transfer mechanisms, involving boreholes (no., diameter, depth, etc.) and transient response of the system. In terms of design optimization, a clear distinction must be made between thermodynamic objectives aimed at GSHP performance (COP and total energy consumption), and economic objectives (installation costs, operating costs, total costs), which are aimed at reducing the various types of system costs.

As such, the main objective will be set and then the problem variables to be optimized will be determined. The relative constraints must also be taken into account (maximum drilling depth, maximum available land area, relief or tectonic features, etc.). To this end, a careful analysis must be made of the variables that have the greatest influence on the chosen objective.

Configuration design and optimization are long-standing, long-debated desiderata, and hawse have come to distinguish first between single-objective optimization (SOO), in which a single function is evaluated, and multi-objective optimization (MOO), in which multiple functions are targeted and subject to various optimization constraints. The optimization method is then chosen, depending strictly on the modelling approach used for the design of the GSHP. One can choose a simplified model (ASHRAE approach) (***. ASHRAE Geothermal Energy, 2015) , based on a method governed by empirical rules that does not require computer codes, and detailed calculations on precise mathematical models (TSEMEKIDI-TZEIRANAKI et al., 2016; ZHANG et al., 2018), this being the most commonly chosen model precisely because of its ease of use.

In general, the methods are based on thermal response factors (either numerical, analytical or hybrid models), thus there are numerical thermal models, artificial neural network (ANN) models and state space models. Based on the chosen model, different design optimization methods can be used.

However, simplified models are recognized as being unable to cover the complexity of interactions between the GHE and other system components, such as the evaluation of the penalty temperature Tp, a key parameter of the ASHRAE procedure, which represents the interaction between the borehole field and the soil after a certain running time. Thus, it was found that using the simplified model (ASHRAE,) underestimates the BHE length by more than 10%.

As such it is clear that methods based on mathematical models have a higher accuracy in terms of optimal design (***. Geo-Education, 2010): however usually only one borehole was taken into account which does not always lead to similar results when dealing with a multi-borehole field, so further study remains to be done in this respect as well. Of course there still remain challenges and strategies for control optimization and using the potential of artificial intelligence for optimization of certain parameters, system modeling and control optimization.

Another often neglected aspect is control execution. Since thermal welds are used to connect vertical systems to horizontal paths, their non-conformity can totally compromise system performance. The radius at which the vertical loop is connected to the horizontal pipe is also extremely important in achieving an efficient system.

Monitoring compliance with the sequence of layers under and over the horizontal GHE or the horizontal components of the vertical GHE ensures system integrity and efficiency.

The execution of the well, the insertion of the pipes and the grout are operations that require certain procedures that must be strictly observed in order for the pipe system to work at optimal parameters.

PROSPECTS AND BARRIERS FOR GEOTHERMAL HEAT PUMP SYSTEMS

Opportunities and trends

The European Commission has set itself a certain strategy and well-defined targets so that practically, by 2050, a 36-39% contribution to decarbonisation of heat can be achieved in terms of environmentally friendly solutions [18]. In this respect, it is clear that heat pump technology in general and geothermal technology in particular is the most attractive due to its high efficiency and cost-effectiveness (ABBASI et al., 2021; HONORÉ ANOUK, 2018).

Some of the presented technical solutions can provide high energy requirements, such as closed vertical well systems.

A current trend, clearly generated by global warming, is a decrease in demand for heating and an increase in demand for cooling (FRIDLEIFSSON et al., 2018) even Nordic countries have started to feel the need for air conditioning in the warm season. One of the main strengths of heat pumps in these conditions is that they can provide both heating and cooling with the same device, and can even produce domestic hot water.

For both the retrofitting of an old building and the construction of a new building, the choice of heating/cooling system and domestic hot water system is based on the investment and operating costs (JAVED & CLAESSON, 2011) in relation to the efficiency of the system. For the buildings sector, a reduction of 20-40% for heating and 30-50% for cooling could be achieved which would lead to considerable savings on monthly bills.

Martinopoulos et al (MARTINOPOULOS et al., 2018) have shown that heat pumps in general, but especially geothermal heat pumps, have the lowest operating costs, but have higher investment costs than conventional gas boiler systems, or power plants. Another important aspect in the choice of the system is the building envelope or building insulation, the glazed area and the use of the building. Since the efficiency and capacity of the heat pump depends on the temperature difference between the heat source and the heat distributor, air-to-water or air-to-air systems, where the cold source is ambient air, are clearly disadvantageous in cold climates or when coupled with high temperature terminals such as radiators (radiators), which is common in existing buildings.

Up to a depth of about 10 m, the temperature of geological formations is influenced by weather conditions, after which the temperature drops on average by 3.3 m every 10 m, so that, at depths of 75-120 m, the formations can have temperatures of at least 12-14^{o}C, which is sufficient for the efficient operation of a geothermal heat pump.

Not to be overlooked, geothermal energy is practically everywhere, and the energy supplied by a well is on average 5.5 kW thermal, which is optimal for the efficiency of a heat pump. As a result, we can consider that in any area there are optimal conditions for installing a geothermal heat exchanger.

It is worth highlighting the possibility of coupling the GSHP with high temperature heating terminals (classic radiators) without a drastic reduction in efficiency. This makes GSHP technology a feasible solution for retrofitting existing buildings. Because adopting such a system for old buildings only involves setting up a heat generator (geo heat exchanger) the costs make retrofitting easier and cheaper. The main barriers actually slowing down the spread of GSHP technology are investment and installation costs which are still the most important and expensive part.

In the context of the rapid and steep rise in the price of fossil fuels, the use of geothermal heat exchanger-based systems is the best option.

Another major advantage, not to be neglected, is that most of them are pollution-free and use water as an energy carrier. Geothermal heat pumps do not have a firebox, they run on electricity which can be produced by photovoltaic panels, thus ensuring the independence of the system, and electricity consumption is very low for these systems because only the compressor and the circulation pump need electricity.

Obstacles

In Romania, although there are concerns about geothermal systems, there are not as many projects as there is potential for. One of the main problems is the initial cost of installation which is higher than for conventional, so the potential of these solutions is still largely untapped due to economic issues related to drilling and installation costs. **(**KARYTSAS & CHOROPANITIS, 2017).

Another problem is the lack of adequate legislation for this system; based on the lack of information from authorities as such, the environmental agencies that award drilling approvals either do not give their consent or give it treating geothermal drilling as water drilling (between 20% and 60%.) (EC, Horizon 2020, Work Programme for 2016-2017).

Moreover, the lack of information also manifests itself at the level of the population, which does not have much data on the real cost of such a system, how long it takes to recover the investment, what the monthly costs are after installation, etc.

There is no coherent programme to subsidize and encourage the use of this resource. There is a program called Green House, but for individuals, for example, it is sporadic and inconsistent. Moreover, the only given subsidy is for the heat pump, around 8500 , which can sometimes be insufficient (when the heat pumps are of EU origin) and the whole system is not taken into account, as the most expensive part is the drilling.

In our country, geothermal air conditioning is not addressed as a possible integrated component in a hybrid system, combined with a solar and/or wind component for example.

The importance of geological issues in the design of geothermal air conditioning systems is often underestimated. A careful geological analysis will result in the correct pricing of the project which depends on the correct assessment of the heat transfer between the geological formations and the plant which will lead to the estimation of the correct number of wells required and their depth. The incorrect estimation of the number of wells will lead to a malfunction of the system.

There are modeling programs such as EED or GLD, which are very efficient and complex and give solutions that have proven to be correct, but for their application it is necessary to introduce accurate geological parameters, correctly estimated or calculated in situ. The correct determination of these parameters is essential and involves either performing a TRT or taking samples from a test borehole and correctly analysing them.

CONCLUSIONS

Analyzing all types of geo heat exchangers can help us reach the conclusion that are many good solutions, but some of them are more expensive than others. From my calculations, made with the help of a modeling software that also calculates comparative prices – Earth Energy Designer – it emerged that, for example, for a system of 120 wells with a useful depth of 75 m, the dual circuit system is the best option (***. ASHRAE Geothermal Energy. 2015):

- Dual circuit system cost: 257810 EUR,
- Costs for coaxial circuit system: 989554 EUR.

Also, using the same cooling and heating loads for the same target in the EED simulation, the required number of wells was reduced from 112 to 84, so also a better price.

The big difference in cost comes from the greater cost of geo drills, but also the laborious workmanship translates in bigger prices.

Although the amount of energy extracted from the ground would be higher, since the possibility of contact between supply and return isolation is extremely limited, basically consisting in choosing a thicker pipe inner wall, this solution is not more effective than the double circuit.

It is very important to note that solutions are not invariable and perfectly valid, but there is a perfect solution for a certain area and a certain type of building. As such, each case is dealt with separately and the best solution is chosen in terms of price-efficiency ratio.

For borehole heat exchangers, research is focusing on designing more compact and easier to install heat exchangers and using more efficient materials. Studies are also being carried out on the design of smaller, more efficient and less costly machines (drilling machines that can be used even inside a basement for example). In this paper, the current situation and future trends in GSHP technology have been analysed, giving an overview of several aspects such as: pipe materials, grout materials, optimal design and control strategies.

A new benchmark of 2.5-3.3 W/(mK) was defined for the thermal conductivity of grout materials, which was found to be proportional to GHE efficiency and inversely related to GHE length and cost. To achieve this optimal value, graphite thermally enhanced grouts have proven to be the best option, both in terms of know-how and thermal conductivity results; thermal conductivities up to 5 W/(mK) with a 33% reduction for the required BHE and 30% for the total cost of the GHE.

The EU's interest in developing the exploitation of the potential of GSHP is reflected in several research projects aimed at increasing the cost effectiveness of such a system, the construction of more efficient heat pumps and the design of more efficient heat exchangers when using shorter boreholes.

Another shortcoming is the lack of a coherent and up-to-date database on the sequence of rock types in areas where residential buildings are constructed. The price of a TRT is still prohibitive, and the geotechnical study being done for the building permit covers an insufficient depth.

It is very important to harmonize the legislation in Romania with the European legislation in order to stimulate the use of this renewable resource to consume less resource without sacrificing comfort.

It is also important to disseminate information on both the efficiency and the real costs of installing heating, cooling and domestic hot water systems in order to encourage their greater use.

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