TRENDS IN THE EUROPEAN RESEARCH IN THE DOMAIN OF HEATING AND COOLING SYSTEMS WITH GEOTHERMAL HEAT PUMPS – RESEARCH PROJECTS FINANCED BY THE EUROPEAN COMMISSION (CHEAP-GSHPs AND GEO4CIVHIC)

TENDINȚE ÎN CERCETAREA EUROPEANĂ ÎN DOMENIUL SISTEMELOR DE ÎNCĂLZIRE – RĂCIRE CU POMPE DE CĂLDURĂ GEOTERMALE – PROIECTE DE CERCETARE FINANȚATE DE COMISIA EUROPEANĂ (CHEAP-GSHPs SI GEO4CIVHIC)

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Abstract: *The EU policy in the domain of energy and the environment has largely promoted the use of renewable energy sources for heating and cooling. One of the most promising technologies able to provide high energy efficiencies and low carbon emissions is the reversible geothermal heat pump. The paper presents the main research directions financed by the EU in this domain, with emphasis on the Cheap-GSHPs and GEO4CIVHIC projects.*

Keywords: geothermal energy, geothermal heat pumps for heating and cooling, energy efficiency, low carbon emissions.

Abstract: *Politica UE in domeniul energiei si al mediului ambiant promoveaza pe scara larga utilizarea surselor regenerabile de energie pentru incalzire si racire. Una dintre tehnologiile cele mai promitatoare, capabila sa furnizeze eficiente energetice ridicate si emisii scazute de carbon este reprezentata de pompa de caldura geotermala. Articolul prezinta principalele directii de cercetare finantate de UE in acest domeniu, cu accent pe proiectele Cheap-GSHPs si GEO4CIVHIC.*

Cuvinte cheie: energie geotermală, pompe de căldura geotermale pentru încălzire și răcire, eficiență energetică, emisii scăzute de carbon

1. Introduction

Shallow geothermal represents a competitive, clean, local and long-term stable technology to provide heating, cooling, hot water and heat storage for buildings (domestic and tertiary) and commercial low temperature heating and cooling utilization (process energy for industry and services).

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Shallow geothermal benefits from the heat stored in the uppermost meters to hundreds of meters on the subsurface – the technology can be applied anywhere in Europe. Regional studies in Germany and Austria indicate that up to 60% of the residential and low temperature heating demand can be covered by geothermal energy [1]. As a surplus, free cooling is provided by the same carbon-free equipment with the capability to cover the increasing cooling demand in urban areas. Supplementary by using shallow geothermal technologies, heat can be stored in the underground making it interesting for sector coupling.

Ground heat exchangers included in the shallow geothermal systems and their installation technologies are mature but more expensive than traditional H&C solutions.

In recent years, the European Commission, through the research and development program Horizon 2020, has mainly funded research projects aimed at more efficient, viable, safer, cost competitive, commercially attractive and more affordable geothermal systems that allow sustainable application both in new and retrofitted buildings, including historical and heritage buildings.

This is also the case of two recent EC-funded research projects in which Romanian Geoexchange Society (RGS) is partner: Cheap-GSHPs – Cheap and Efficient Application of Reliable Ground Source Heat Exchangers and Pumps (2015-2019 / cheap-gshp.eu) [2] and GEO4CIVHIC (Most Easy, Efficient and Low Cost Geothermal Systems for Retrofitting Civil and Historical Buildings (2018 – 2022 / geo4civhic.eu) [3]. These projects assume holistic approaches, aiming at lowering the overall costs and at maximizing the energy efficiency [8].

This paper intends to briefly present some of the priority research directions in the EC's attention as well as the main results – projected or already obtained - of the respective researches.

2. In-depth analysis of the barriers faced by shallow geothermal applications, the applicable legislation and regulations

The research activity in both mentioned projects started with an in-depth analysis of the different kind of barriers and constraints (technical, social, cultural, economic and legislative) faced by the shallow geothermal applications. The resulted conclusions were largely presented to EC and to the public (https://geo4civhic.eu/wp-content/uploads/2019/01/GEO4CIVHIC-D1.1.pdf).

The identified barriers completed and clarified the set of objectives set by the EC and constituted the starting point of the partners' research in the mentioned projects (20 partners from over 10 Member States).

The aim was to explore ways to overcome the technical and nontechnical barriers and to unleash the great potential of the shallow geothermal technology for saving energy and avoiding emissions.

The ingenuity of the engineers and scientists in the wide-ranging disciplines required for the shallow geothermal application can be trusted to deliver the necessary solutions – provided they can be demonstrated to be economically feasible.

At the same time, the projects funded by EU had the objective to realize a comprehensive overview assessment of the legislative and regulatory conditions in all the member states, to identify weaknesses and to suggest regulatory solutions, including in the standardization issue. In Romania one of the biggest shallow geothermal energy system is installed – it is located at ELI-NP Magurele [5] which is a proof for the viability of the geothermal solution.

One of the most common difficulty and barrier in the unstressed development of applications in this field, including and especially manifested in Romania, is the lack of a coherent system of rules for licensing, approving, monitoring and reporting the shallow geothermal applications [6].

3. Extending the scope of HVAC - GSHP systems to existing and renovated buildings, heritage and historical buildings

Buildings are responsible for approximately 40% of energy consumption and 36% of CO_2 emissions in the EU member states [7]. Among them, historical buildings, (i.e. buildings of heritage significance due to their historical, architectural or cultural values) represent a considerable fraction. In the 28 EU countries the building stock before 1919 amounts to 14,3% corresponding to about 65 million of European citizens. If we also include buildings built between 1919 and 1945, the percentage rises to 26,4%, and the occupants reach the number of about 120 million. Roughly one quarter of all buildings in Europe were built before the 1950s. Due to climate change and associated political goals, the need to reduce greenhouse gas emissions (mainly CO_2) associated with energy use in buildings is growing.

The EU is continuously strived to improve energy performance and efficiency in buildings with two major directives: the Energy Performance of Buildings Directive EPBD updated by Directive 2018/844/EU (entered into force on 9 July 2018) and the Energy Efficiency Directive. These have worked as the EU's main legislative instruments promoting the improvement of the energy performance of buildings to ensure the achievement of the initial EU’s 2020 targets and to pave the way for the 2030 energy strategy. The recent EPBD revision also refers to historical buildings encouraging research and testing of “new solutions for improving the energy performance of historical buildings and sites, while also safeguarding and preserving cultural heritage”. In this case, a constant balance must be maintained between the energy management and sustainability solutions and preserving the integrity and significance of the heritage buildings; the coexistence of the two criteria is possible with remarcable achievements.

Historical buildings are considered of heritage significance to present and future generations for their aesthetic, historical, scientific, cultural, social or of a spiritual value. In this perspective, the research results in using GSHP solutions in historical and monumental buildings can pursue / achieve four main goals [8]:

(i) become best practice examples for their sustainable renovation,

(ii) contribute to reduce management / energy operation costs,

(iii) improve building conservation and integrity by maintaining their significance and inherent values unaltered,

(iv) decrease the risk of hazardous events such as fires by eliminating or reducing indoor fossil fuels storage and burning.

4. The unitary regulation of the GSHP systems in Europe

EC, through the projects funded in recent years, is pushing scientific research towards a regulatory framework that includes recommendations for all aspects of GSHP applications: the technical aspects, the environmental aspects, the qualification and certification of the labor force involved (designers, drillers, installers), the authorization / licensing of the applications and equipment, the monitoring parameters, data bases, rules and procedures, the reporting parameters and procedures regarding operation efficiency etc.

Actually, the regulations in force at the national level of the member states regarding all kind of buildings and the historic and heritage buildings provide only the procedure to identify the need for energy improvements and the appropriate solutions that match the requirements (including for the historical building conservation). The contribution that built heritage makes to climate change mitigation policy by improving efficiency and installation of renewable energy sources including geothermal is, however, left to discretion of the heritage conservation authorities, which have to evaluate on a case by case basis the compatibility between heritage conservation and the application of sustainable energy solutions.

In the perspective of the aspects presented below, the EU encourages the research that is focused on compensating the lack of precise regulations, including the ones focused on the application of geothermal technologies to heritage buildings. Finally, the main goal is to achieve a coherent trans-national regulation frame across the countries of consortium and Europe as well, which will lead to a common strategic approach of changing the regulatory framework and removing the technical and non-technical obstacles and constraints.

5. Increase the performances of the ground source heat pumps

The research is focused on developing a new type of ground source heat pump, using a low GWP refrigerant and able to provide high temperature heating water for the traditional heating systems based on high-temperature terminals (radiators).

The objectives regarding the developments of a new type of ground source heat pump are:

- To evaluate the high temperature heat pump performance: energy output, efficiency, reliability, ground temperature levels in several seasons;
- To predict the developed systems performance in the long run by means of computer simulation;
- To compare the new technologies' performances with with standard ones.

A new generation of geothermal heat pump with two cascade cycles, one with natural refrigerant (CO2) and the other with a low environmental impact HFO (R1234ze) fluid has been designed and manufactured. The heat pump has been conceived in order to deliver fluids at high temperatures, up to 80 ° C. This new heat pump prototype is installed at Tesla Technical Museum in Zagreb for the exhibition hall air conditioning.

Figure 1. High temperature cascade cycled heat pump installed at the Tesla Technical Museum in Zagreb (Croatia)

6. Increase the performances of the ground source heat exchangers

The research is focused on developing new types of ground source heat exchangers (GSHE), together with their most adequate drilling machines for easy and low-cost installation [9] [11]. The geometries investigated for the GSHE are: the helicoidal type and the co-axial type.

The objectives regarding the helicoidal GSHE and the corresponding drilling machines developments are:

- To simulate, study and develop new GSHE geometries for boreholes with an enlarged diameter of up to 350 mm.
- Development of a drilling machine capable of drilling boreholes with diameters about 350 mm at depths down to 15 m, by using the so-called ‘enlarged-easy-drill’ technology.
- To simulate, study and develop new GSHE geometries for boreholes with a diameter of 175 mm using a drilling machine which combines ‘Vibrasond’ & ‘easy drill’ drilling technology.
- To identify the best configurations of GSHE and drilling machine.

The objectives regarding the co-axial GSHE and the corresponding drilling machines developments are:

- To develop a new installation technique for the coaxial ground heat exchangers, in order to reduce the installation time – the modified piling technology, involving the use of a rotary-percussion head with pressurized water injection
- To develop a new closure systems for the final part of the installed tube in order to ensure the tightness of the heat exchangers – the so-called „drill-bit-to-lose” which also enables the injection of high-pressure water into the borehole;
- To improve the heat exchanger design (diameter, insulated internal tube,..) and test new materials in order to improve thermal energy exchange with the soil. From the simulations and cost/benefit studies, a stainless steel tube with an enlarged external diameter of 76 mm is the best compromise

between thermal extraction yield and material cost. A co-extruded inner tube with foam insulation has been realized. Together with the reduced borehole resistance of such GSHE's, when compared to conventional double-U's, higher thermal extraction yields in transient operating conditions have been achieved, as demonstrated in the demonstration cases of Athens (Greece) and Putte (Belgium).

The reduction of drilling time and costs by using these new technologies is demonstrated in several geological situations under real conditions at the demonstration sites all over Europe (Germany, Greece and Spain), allowing to reach the objective of installation costs/time reduction proposed in the Cheap-GSHPs project [12] [13] [14] [15].

Figure 2

Large diameter helicoidal GSHE

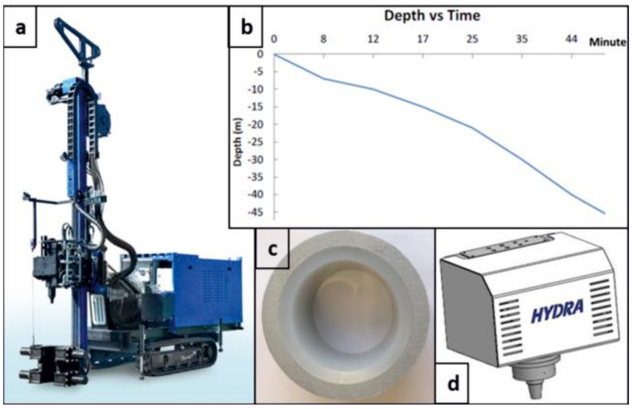

Figure 3

Drilling machine for co-axial BHE: vibrating, rotating machine head (d) mounted on existing penetrometer (a), high pressure pump to inject water through the tip of the GSHE. An insulated inner tube (c) prevents the geothermal fluid going up from being cooled down by the colder fluid coming down. In addition, the fluid velocity inside the GSHE reaches turbulent flow conditions, thereby further increasing the energy exchange with the soil.

7. Software development for multi-criteria analysis and system sizing

A new free software for dynamic simulation of a geothermal system's operational phase was developed with a user friendly interface. The software implements a specific algorithm aimed at evaluating heat pump and the ground source heat exchanger performance. Two different calculation methods have been developed: a simplified model for non-expert users, where only simple inputs are requested and a more complex algorithm, based on a dynamic simulation aimed at more experienced users. The software allows the inclusion of solar thermal collectors to release heat into the ground during summer for heating dominant conditions.

In addition, an inventory of the existing heat pumps has been produced, based on the components technologies (evaporators, condensers, compressors, throttling valves, refrigerants, controllers and other components such as ejectors). This database is used in the Decision Support System (DSS) to guide the user through the heat pump components selection. It includes a cost/benefit guide to help the selection of the best technology for the heat pump in the context of the working conditions included in the selection software. The evaluation of the environmental impact produced by the refrigerant is also performed with respect to the heat pump performance. The tool carries out also the analysis of different typical plant configurations in combination with other renewable energy technologies like solar thermal, wind, photovoltaic and storage systems. The output includes a guideline and cost analysis table, in order to optimize the system configuration. These databases and calculation tools are included in the (DSS), available in the web.

Finally, a new generation of ground source heat pump with two cascade cycles, using low GWP refrigerants - one with natural refrigerant (CO_2) and the other with a low environmental impact HFO fluid (R1234ze) - has been designed and manufactured. The heat pump has been conceived in order to deliver fluids at high temperatures - up to 80°C - to the traditional terminal systems. This new heat pump prototype is installed at Tesla Technical Museum in Zagreb for air conditioning in the exhibition hall. A software and specific guidelines have been realized in order to help all the users in the selection of the best heat pump for the shallow geothermal system under design.

The possible combination with other renewable technologies can been evaluated – in this way, people can become more familiar with these new eco-friendly technologies. The developed DSS includes the databases that are necessary to define all the required input data (subsoil, climate, building, heat pump, other renewable energies). The DSS engine performs the necessary calculations to supply the end user with a series of possible solutions of geothermal plants, by taking into account several variables.
The system includes three different database levels: the data model database that contains auxiliary information necessary for performing the calculations, the database that contains the information about the users and their projects, and, finally, the solution repository that contains the information about the different technologies supported by the DSS. The DSS generates a series of possible solutions adapted to the user's needs. Finally, the possible solutions provided are ranked according to the user preferences in terms of costs, sustainability, return on investment, etc. The software development has resulted in an innovative user-friendly web application that advises end-users with little knowledge of shallow geothermal systems with an initial feasibility analysis for their facilities. With a few simple inputs (type of building, degree of insulation, area in plan, location, climate etc.), the user obtains a preliminary result that allows the estimation of the most appropriate technology for their building according to their own preferences. This tool is therefore very important for bringing geothermal technologies closer to the public, serving as a marketing and dissemination tool.

The use of software tools to design and optimize the GSHP systems have been used in different research studies. For example it was used in modelling a nZEB solar house connected to a GSHP [7] [16].

	Geothermal system	RoI	Space	Cost	LCA
Weight	100.0%	25.0%	25.0%	25.0%	25.0%
Vite R1234ze and Helical	14.8%	7.4%	1.6%	4.8%	1.0%
Alternative R134a and Co-axial	10.8%	3.9%	1.6%	1.2%	4.2%
Alternative R134a and Single U	9.2%	0.6%	1.6%	4.8%	2.3%
Vite R1234ze and Single U	8.3%	1.8%	1.6%	4.8%	0.1%
Alternative R134a and Double U	7.9%	1.8%	1.6%	0.4%	4.2%
Alternative R1234ze and Single U	7.3%	0.4%	1.6%	1.2%	4.2%
Vite R134a and Double U	6.7%	3.9%	1.6%	0.3%	1.0%
Alternative R1234ze and Co-axial	6.4%	0.6%	1.6%	0.1%	4.2%
Vite R1234ze and Co-axial	5.9%	0.2%	1.6%	3.1%	1.0%
Vite R1234ze and Double U	4.9%	1.8%	1.6%	1.2%	0.3%
Alternative R1234ze and Helical	4.0%	0.2%	1.6%	1.2%	1.0%
Alternative R134a and Helical	3.5%	1.0%	1.6%	0.4%	0.5%
Alternative R1234ze and Double U	3.4%	1.0%	1.6%	0.6%	0.2%
Vite R134a and Co-axial	2.5%	0.1%	1.6%	0.6%	0.6%
Vite R134a and single U	2.4%	0.2%	1.6%	0.1%	0.5%
Vite R134a and Helical	2.1%	0.1%	1.6%	0.2%	0.2%
Inconsistency	0.0%	42.7%	0.0%	45.6%	41.3%

Figure 4 – DSS platform – Ranking example of different solutions

8. Environmental impact, risk assesment and market deployment

Standards in Europe related to ground source heat pump systems are categorised and ways to introduce the Cheap-GSHPs technology into these are proposed including the application of geothermal technologies in historical and cultural buildings . The analysis of the applicable standards and the development of the Cheap-GSHPs project technologies highlight shortcomings in the text of the standards that are perceived as potentially inhibiting the route to market of the innovative technologies. A set of recommendations to CEN and IEC committees that are drafting the standards applicable to the Cheap-GSHPs technologies were developed. National standards where modifications may be necessary have been identified and recommendations proposed. Different SWOT analyses developed as a basis of the market support action plan were completed and the supporting measures for the introduction of the „CHEAP" technologies into the market and, particularly, in the historical buildings, were defined. In addition, a Canvas business model for each developed technology was completed and a new business model, called CHEAP GSHPs business platform, was defined. This model, that includes all the partners that want to participate at a European level and that serves to enlarge the market for geothermal energy, will be a key point for the consortium, really creating a new business model to put on the market a new, efficient and cheap shallow geothermal solution.

An action plan has been developed with supporting measures towards the introduction of the Cheap-GSHPs technologies in the market in general and in the historical buildings in particular. This action plan has been communicated to decision makers at national and/or regional level [17].

Several systematic and strategic business models have been defined for making profit and introducing the products developed to the market that will help the developer partners to achieve this goal. The final objective is that the geothermal solution for air conditioning should be included in the market of existing buildings, as well as historical ones, and considered as a competitive proposal compared to traditional systems both in terms of installation and energy costs.

Finally, a new business model has been developed to put on the market new, integrated, efficient and cheap shallow geothermal solutions.

9. Conclusions

In summary, it can be stated that the main objectives pursued by the European Commission in funding the research projects in Horizon 2020 Program were and are the following:

- Increasing the affordability of heating and cooling solutions with geothermal heat pumps in all types of buildings: new or old, public or private, individual or social etc., in all the phases and components of these projects and for all categories of end users by lowering all price categories involved in choosing and implementing these technical solutions [18];
- Increasing the accessibility of the specific information through the widespread dissemination of knowledge regarding the heating and cooling systems with geothermal heat pumps so that all categories of stakeholders receive directly the information that will allow them to make decisions in line with European policies, strategies and Directives.

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