

Innovative drilling methods, heat pumps and tools to address shallow geothermal in the built environment: H2020 project - GEO4CIVHIC

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ABSTRACT

The H2020-project GEO4CIVHIC, started in April 2018 and tackles the main barriers for ground source heat pumps in existing buildings: construction of ground heat exchangers under constrained site conditions (like drilling in courtyards, gardens, basements etc.) using a novel drilling methodology and compact drilling rig; adapting the heat pumps to supply the temperatures needed for older heating and cooling systems that cannot be easily replaced; overcoming various non-technical barriers. Starting partly from results of previous projects like Cheap-GSHPs (see more on <http://cheap-gshp.eu/>), and developing new ideas, the project will also provide the tools for a larger implementation of shallow geothermal in the built environment, in particular in historical buildings. After practical demonstrations in 3 pilot sites, the solutions will be applied in four real buildings. In addition, 12 virtual demonstrations (simulation) using real buildings as a

basis will show if the solutions found can fulfil the desired objectives, and will help in further optimising the technologies. Guidelines, education and dissemination will make the new technologies known and facilitate their dissemination and application in the market.

1. INTRODUCTION

A major obstacle to the decarbonisation in the building sector is the low share of new construction and of deep renovation in existing buildings. In addition, integration of Renewable Energy Sources like shallow geothermal for heating and cooling in existing and in particular older and historical buildings faces even more specific problems than in newly constructed buildings. Shallow geothermal technologies have contributed substantially to decarbonisation in new construction and good examples of refurbished buildings using geothermal energy also exist. However, as market statistics demonstrate, shallow geothermal continues to face barriers in new constructions and even more in deep renovations of existing buildings, mostly due to the built environment. Therefore, to realize a wider deployment in existing buildings, in particular in historical ones, the

technologies need to be developed further and innovative ideas must be tested and brought to market. This is the main purpose of H2020-project GEO4CIVHIC. The acronym of the project stands for “Most Easy, Efficient and Low Cost Geothermal Systems for Retrofitting Civil and Historical Buildings”. The project consortium consists of 19 partners from 10 countries (BE, CH, DE, ES, FR, GR, IE, IT, MT, RO), coordinated by the National Research Council (CNR-ISAC) from Italy; more details under <http://geo4civhic.eu>. The project started on April 1st, 2018, and will be completed by March 30th 2022.

Project GEO4CIVHIC, tackles the main barriers for ground source heat pumps and heat exchangers in existing buildings: installation of ground heat exchangers under constrained site conditions (like drilling in courtyards, gardens, basements etc.); adapting the heat pumps to supply the temperatures needed for older heating and cooling systems that cannot be easily replaced, realizing small size heat pumps for deep renovations, optimizing dual source heat pumps to reduce overall borehole length; providing engineering and decision support tools and overcoming various non-technical barriers. The project builds partly on results of the H2020 project Cheap-GSHPs (see more on <http://cheap-gshp.eu>), develops new ideas and provides the tools for a larger implementation of shallow geothermal in the built environment, in particular in historical buildings, e.g. Emmi et al. (2017). After practical demonstrations in three pilot sites, the solutions will be applied in four real buildings. In addition, twelve virtual demonstrations (simulation) using real buildings as a basis will show if the solutions found can fulfil the desired objectives, and will help in further optimising the technologies. Eventually, guidelines, education and dissemination will be needed to make the new technologies known and to facilitate their dissemination and exploitation in the market.

2. SHALLOW GEOTHERMAL IN THE BUILDING MARKET

The market for shallow geothermal installations and the corresponding ground source heat pumps (GSHP) in Europe (Sanner, 2017), had a very dynamic development until about 2008, followed by some years of stagnation and even decrease, and a first sign of recovery in 2016 as shown in Figure 1. However, the situation was quite different in individual countries. While air-source heat pumps had a steady increase in sales in most countries, the sales of GSHP went down in some of the larger countries, as the examples in Figure 2 show. Some countries, located mainly in Northern Europe, had a dynamic growth, when new GSHP installations are compared to the already existing stock. Here the leaders are Poland with 15 %, Estonia with 16 %, the Netherlands with 9%, Belgium and Lithuania both with 21 % of sales in 2016 compared to the existing stock end of 2015, as to information in the 2017 EGE Market Report.

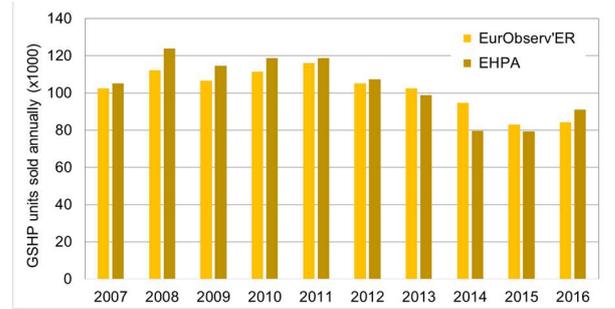


Figure 1: Market for ground source heat pumps (GSHP) in Europe 2007-2016, after data from EurObserv'ER and EHPA.

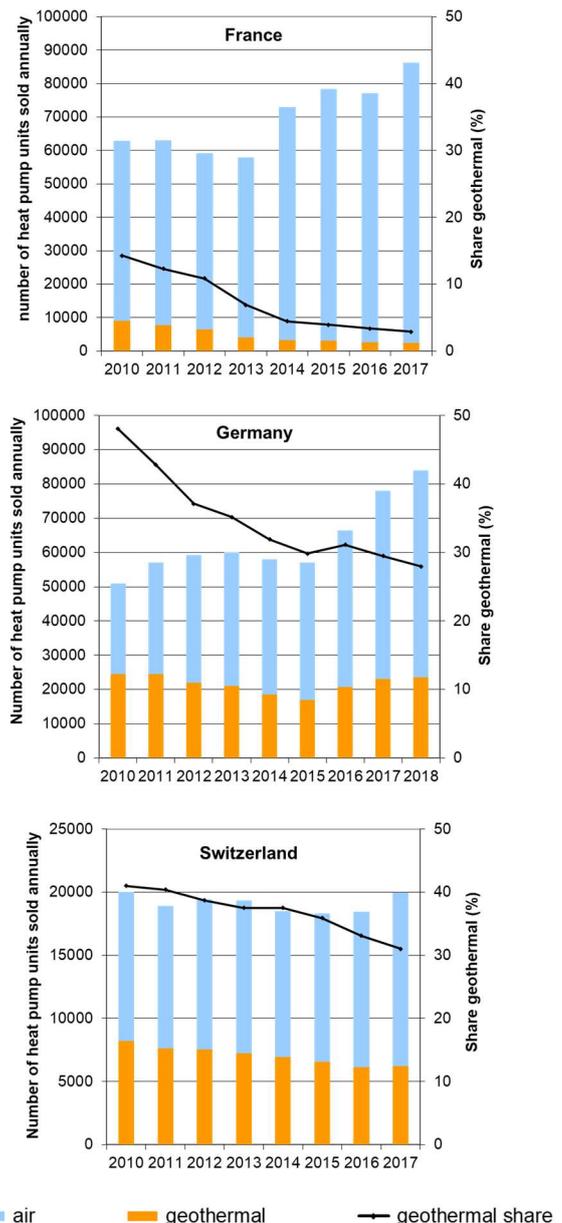


Figure 2: Sales of air-source heat pumps and GSHP in France, Germany and Switzerland, and share of geothermal heat pumps in the total heat pump sales (after data from AFPAC, BWP and FWS)

The penetration of GSHP into the overall market of heating appliances can only be assessed for some countries. Recent data from BWP in Germany, based on numbers from the Association of the German heating industry BDH and from the Germany statistical office DESTATIS, allow for assessment of the distribution of the main heat sources in new buildings and in the total market for heating appliances (Figure 3). In new buildings, heat pumps of all types meanwhile account for about 40 % of all heating systems, new or replaced, in Germany.



Figure 3: Shares of total sales of heating appliances in Germany and shares of heat sources stated in applications for new building permits in Germany, after data from BWP

Most statistics, however, do not give numbers on the distribution of sales between applications in new and in existing buildings. Based on the values used in Figure 3, and some additional information for 2017, it is possible to determine the share of heat pumps (of all types) that goes into existing buildings. The value is about 35%. Figure 4 shows the distribution of application in new and existing buildings for heat pumps, in comparison to the conventional heating appliances. The fact that a large proportion of conventional heating appliances sold annually goes into the replacement market, while most of the heat pumps go into new

buildings, underlines the large potential heat pumps might address if they could be made more suitable for the use in existing buildings.

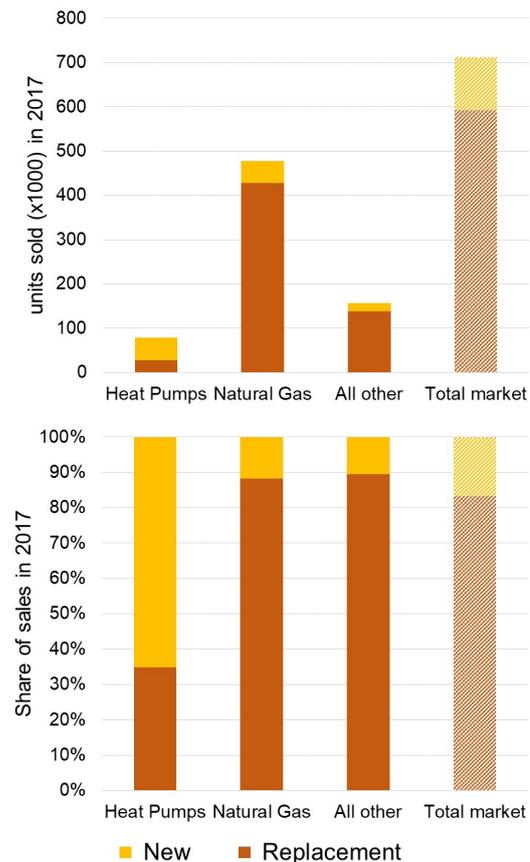


Figure 4: Number of units sold in 2017 and shares of sales of different heating appliances in Germany going into new installations or into replacement in existing buildings, calculated after data from BWP

The reasons for such a gap between installation of heat pumps and of conventional heating appliances in existing buildings are dealt with in the following chapter. This gap, on the other hand, can be seen as a huge opportunity if suitable technologies can be rolled out. Considering that the large potential in existing buildings as seen in Figure 4 for Germany is found in countries with well-developed GSHP markets dating back into the 1970s, it can be expected that the potential is even much higher in emerging markets like in Eastern and Southern Europe.

3. BARRIERS TO THE INTEGRATION IN EXISTING BUILDINGS AND THE BUILT ENVIRONMENT

3.1 Integration challenges for geothermal into existing buildings

Replacing heating (and cooling) systems in existing buildings is more complicated than designing a system for a new building. Typical constraints are: space limitations in technical rooms, existing distribution systems and emission units. While the energy needs of the building might be well known from past consumption, improvement measures like insulation, new doors and

windows can alter the energy demand drastically. Better insulation usually means substantial reduction in heating demand, but this can also mean the need for additional ventilation or an increase in the cooling demand. In any case. A very thorough energy analysis is required when refurbishing existing buildings.

The simplest way for refurbishing a heating/cooling system is just to replace it with basically the same technology, but using the latest and most modern components available, and adapting it to lower heat loads if the building envelope is also improved. This will however perpetuate the use of fossil fuel based heating and cooling conflicting with the EU directives out of the Energy Transition Initiatives.

When changing fully or partly to shallow geothermal energy while refurbishing a heating/cooling system, several other factors have to be considered; some concerning heat pumps:

- terminals and distribution often are designed for high temperatures, requiring heating supply temperatures in excess of 60-70°C (this is almost always the case in the historical buildings), more than most heat pumps are not able to achieve these temperatures at acceptable Coefficient of Performance (COP).
- thermal peak load often is high compared to the average load (for most large buildings).
- the thermal energy demand for Domestic Hot Water (DHW) can be high for residential buildings.
- the existing electric power supply network may pose constraints to electrically driven heat pumps.

The issues listed above are valid for all types of heat pumps, no matter what heat source/sink they use. They might be responsible for most of the gap for heat pump sales for existing buildings as observed e.g. in Figure 4. Some of the items, however, already constitute the basis for possible solutions; e.g. in cold climates with no or moderate cooling needs, interventions on the envelope will reduce heating demand, leaving the existing radiators oversized and allowing reduction of supply temperatures to 50–60°C. Another opportunity could be to exchange part of the high-temperature terminals with low-temperature radiant panels and keep part of the existing terminals; high supply and low return temperatures can be achieved, by reducing water flow rate in the radiators, which is optimum for combination with heat pumps using CO₂ as working fluid.

3.2 Challenges for drilling in the built environment

Drilling for BHE installation for existing buildings has to be done in an environment with numerous constraints, ranging from limited access to annoyance of neighbors:

- accessibility of the drilling site
- available space on the drilling site (for drilling rig, storage of drill pipes and equipment)
- local regulations: e.g. noise and fuel emissions, working hours

- hidden risks (e.g. underground infrastructure like power lines, gas pipelines, sewers, etc.)
- disposal of mud and debris

The space requirements for classical rotary drilling and ancillaries for depths up to ca. 200m are substantial, an area of at least 100m² is typical (Figure 5). Also there are considerable space requirements for moving and working and in particular behind the mast. While drillers often are ingenious in overcoming space constraints, working safety regulations set limits to compromise. Around existing buildings, the space required is often not available, and hence new solutions with much smaller footprint and less ancillary hardware are desired. On the other hand, achievable drilling depth, borehole diameter and rate of penetration should be in the same range as those of conventional rigs..

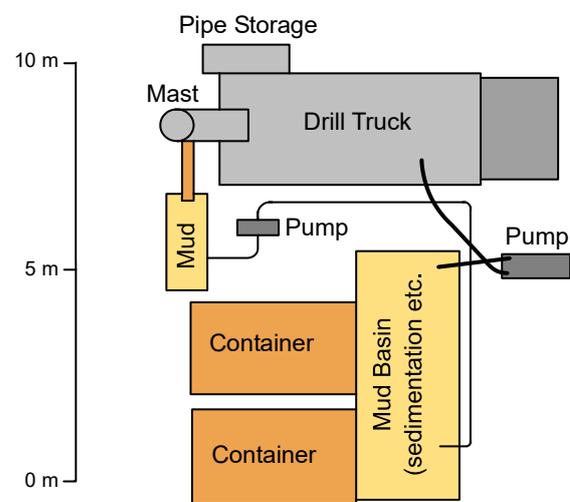


Figure 5: Schematic layout of a conventional rotary drilling site (re-drawn after a graph from J. Uhde)

Drilling for shallow geothermal in the built environment might encounter further challenges than just having the available area. The access to the drill site might be impossible for the chosen drilling rig, leading to cases where a crane was used to move the rig into drilling position (Figure 6). In cities, the buildings often constitute an uninterrupted street façade, with small passageways leading into courtyards.

The extra costs associated with these specific constraints are a heavy burden on the economic feasibility. Smaller, versatile drilling rigs and technologies allowing for fast drilling under space restrictions definitely are needed for a wider application of shallow geothermal energy in the built environment.

3.3 The economic challenge of shallow geothermal

Beside these technical, factual and legal barriers, the economy of GSHP is another problem that needs to be addressed. The installation costs for GSHP are usually higher than for more conventional heating solutions; for the case of BHE in a new building costs range from about 15.000 € to 25.000 € for a typical single family house with 12,5kW heating demand, e.g. Bertermann et

al. (2015). For comparison, the price for a condensing gas boiler in the 15kW range would be about 3.000-5.000 € (without installation, gas supply and chimney, which would bring the total to some 7.000-10.000€). Hence much lower energy and operating cost for GSHP solutions are required for making them competitive with the conventional alternatives. In installations planned solely for heating and DHW, this is hard to achieve, while it is easier in installations with a share of cooling in summer.



Figure 6: Drilling rig hoisted into place using a mobile crane (photo Geo-Green sprl)

The constraints in existing and in particular historical buildings, which are often located in the centre of the towns, aggravate the situation, e.g. by increased installation costs due to the above mentioned constraints and by increased operation costs e.g. due to reduced heat pump efficiency at higher supply temperatures. Whilst GEO4CIVHIC and other European research projects are working on cost reductions and efficiency increases (see for example EU-H2020 project Cheap-GSHPs), other initiatives will be needed to overcome this economic gap. Imposing by law a minimum and sufficiently large share of renewable energy in building renovations, financial support schemes when switching from fossil fuel to renewable energy sources for heating and cooling are necessary complementary steps. Some are already underway.

3.4 Overcoming the barriers to shallow geothermal in existing building

To overcome the barriers against wider use of shallow geothermal energy for existing buildings, project GEO4CIVHIC sets out on investigating more closely the barriers, identifying and developing suitable solutions. Beside work in the large area of non-technical barriers, the main objectives in the area of technical development are:

- to improve and develop innovative drilling methodologies and machine components as well as Ground Source Heat Exchangers targeted at the difficult and confined urban settings.
- to develop and demonstrate innovative and compact heat pumps for both low and high temperature terminals suitable for all buildings, climates and ground conditions.
- develop and make available different tools for preliminary feasibility assessment and analysis of different solution sets that will achieve user-optimized energy management solutions.

Regarding the above developments, the project will build up on previous work done in the H2020-project Cheap-GSHPs, e.g. Badenes et al. (2016), Bernardi et al. (2016), Bertermann et al. (2018), Müller et al. (2018), De Carli et al (2018), Dalla Santa et al. (2017), Galgaro et al (2017) and Zarrella et al. (2017). In addition, heat pump developments from the H2020-project GEOTeCH might be further optimised (see more on <http://geotech-project.eu>). Finally, heat exchanger material developments from the H2020-project GEOCOND might be tested in one of the pilot sites (see more on <http://geocond-project.eu>). The detailed approaches to the objectives listed above will be shortly discussed in the following chapter to the extent allowed by the confidentiality and the intellectual property rights. The development work will include all the necessary non-technical issues like acceptance, regulation, standards etc., and will be accompanied by demonstration and testing, in order to prove the suitability of the solutions found. Upon the evaluation of the results, training events, workshops and dissemination activities will support the market exploitation plans of the respective project partners.

4. DEVELOPMENT WORK IN PROJECT GEO4CIVHIC

4.1 Drilling machine, drilling methodologies and heat exchanger developments

One of the drilling methodologies developed within Cheap-GSHPs is the piling of stainless steel co-axial heat exchangers using a rotary and vibrating drilling head. Promising results were achieved in several unconsolidated soils. A patent request has been filed recently in Italy protecting one of the two variants of this piling methodology which will be used in GEO4CIVHIC.

Apart from the high rate of penetration and the low water consumption as drilling fluid, this method does not require a lot of power making it very suitable for a compact drill rig. The method and the rig will be adapted for drilling in the built environment taking also into account the lessons learned from the Cheap-GSHPs project. To extend the application to almost all types of soil, including soft consolidated ones, a compact but powerful roto-vibrating drill head will be built. This head will be mounted on a compact and versatile drilling machine with a suitable footprint for the built environment and with the possibility to take off the

power pack. To reduce the labour and to speed up the shaft and casing manipulations, a semi-automatic feeder will be developed as well. Grouting materials and/or recipes may need to be adapted to allow proper grouting whilst being compatible with the drilling methodology.



Figure 7: Drilling machine with roto-vibrating drill head (photo Hydra srl)

As an alternative to the external heat exchanger tube out of stainless steel, a novel plastic material of higher conductivity is considered to be tested in one of the pilot sites. This material is currently under development in the H2020-project GEOCOND. Finally, some very shallow heat exchangers will be researched and evaluated as complementary solutions to the mainstream development of the co-axial heat exchanger.

4.2 Heat pump developments

Several heat pump innovations will be pursued in the GEO4CIVHIC project. A small plug and play heat pump is being developed for deep renovations and NZEB (Near Zero Energy Building). This heat pump fits in individual apartments of deeply renovated multi-family buildings connecting directly to the existing distribution system and terminals. The high temperature heat pump developed in Cheap-GSHPs for use in historic buildings will be optimized. An approach linking the issues of heat pump development and cost reduction for the ground heat exchanger is the dual-mode heat pump, combining the geothermal source/sink with an air source/sink and running from air source in heating mode (or to air sink in cooling mode) as long as air temperatures allow for acceptable efficiency. Thus the geothermal source/sink is saved for situations with very cold or very warm air, and the ground heat exchanger can be reduced in size accordingly. A high temperature and a low temperature application as well as optimized control strategies will be tested within the project using

the learnings from a similar heat pump used in the GEOTeCH project. In certain deep renovation projects radiant panels or other low temperature terminals may be installed in part of the building whilst high temperature terminals need to be kept in other parts of the building, for instance, to avoid excessive renovation costs. A heat pump, capable to operate at these two levels of temperature will be developed and demonstrated.

Suitable alternatives to present high GWP refrigerants for heat pumps (R134a and R410A) will be researched and used in several of the above mentioned prototypes.

4.3 Design and decision support tool

Several developments and tools will support the feasibility assessment and facilitate the engineering of shallow geothermal plants in the built environment in combination with a deep renovation.

Thematic geothermal maps will be built at municipal level for the main demonstration sites containing the geological and hydrogeological information to define the thermal properties and the local heat exchange capacity. One innovation will be the superposition on these maps of the appropriate drilling techniques to be used and the estimated drilling time. In addition, an application for the user (drillers, owners, designers) will allow to complete on site a preliminary evaluation of the feasibility of the drilling solutions in that specific underground. The smart phone/tablet based application will be based on the drillability maps.

The Decision Support System (DSS) developed in Cheap-GSHPs will be extended and include repositories with the results of the developments within the GEO4CIVHIC project (drilling methodologies, heat exchanger types, retrofitted building energy loads and costs, heat pumps). This will allow users to select the appropriate technologies and identify the technical and economic feasibility.

Develop and make available different tools for preliminary feasibility assessment and analysis of different solution sets that will achieve user optimized energy management solutions.

5. PLANNED DEMONSTRATIONS

To test prototypes and to validate the results, several pilot and demonstration sites are foreseen, as listed in Table 1. These locations cover real test and demonstration sites and a number of virtual demonstrations, based on detailed feasibility studies and simulations for existing buildings. These virtual demo sites will allow to test the suitability of the developments in a much wider range of buildings, climates and geologies whilst the real demo sites are validating the results used in these simulations.

Some of these demo sites are historic buildings, where particular constraints for the use of shallow geothermal energy can be encountered. Such barriers comprise:

- shapes, volumes and construction characteristics not suitable for the necessary technical interventions.

- underground conditions usually unknown, presence of historic or archaeological remains might have to be investigated before drilling.
- in listed buildings, barriers are linked to the total respect of the aesthetical aspects (outside, and often also inside), with special permissions from the authorities required before any intervention.

Table 1: Planned Pilot and Demonstration sites

Type of site	Location	Purpose
3 Pilot sites	Padova (IT), Bilbao (SP), Valencia (SP)	Test of components (BHE, grout, heat pump etc.)
4 Real Demo sites	LaValletta (MT), Ferrara (IT), Battel (BE), Wicklow (IR),	Validation of the methods and components developed in GEO4CIVHIC and their impact in real-world installations
12 Virtual Demo Sites	Alexandroupolis(GR) Valencia (SP), Voluntari (RO), Bucharest (RO), Padova (IT), Split (HR), Erlangen (DE), Attre (BE), Dublin (IR), Muzzano (CH), Soest (NL), Lleida (SP)	Validation of the methods and components developed in GEO4CIVHIC and their impact by doing feasibility studies and simulations on really existing buildings

The project aims at proposing solutions to such peculiar sites also in cooperation with UNESCO and their conservational authorities abiding by the letter and spirit to the regulations for the protection and integrity of built heritage.

6. CONCLUSIONS

Project GEO4CIVHIC targets a field of applications for shallow geothermal energy drastically under-developed, as shown in section 2 of this paper. The improvements in energy efficiency and use of shallow geothermal systems as renewable energy sources shall be made available for the large market of replacement of heating/cooling installations and refurbishment of existing buildings in the built environment.

The project aims at achieving this goal by developing work providing technical solutions for overcoming the existing barriers, mainly with novel drilling tools and enhanced heat pumps. Based on a survey identifying all possible barriers to shallow geothermal application in existing buildings, either technical or socio-economic, the project partners work on suggestions for and development of suitable solutions.

A specific emphasis is given to historic buildings, i.e. those dating from before the mid of the 20th century, including listed buildings. The constraints here are even

more severe, and in particular the heat pump technology must answer to the characteristics of heating (and cooling) systems that cannot be changed.

If successfully completed, the impact of fully opening the large market for heating and cooling in existing buildings to shallow geothermal installations could hardly be overestimated.

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H2020-projects:

- Cheap-GSHPs: Cheap and Efficient Application of reliable Ground Source Heat Exchangers and Pumps. <http://cheap-gshp.eu>
- GEOTECH: Geothermal Technology for Economic Cooling and Heating. <http://geotech-project.eu>
- GEOCOND: Advanced materials and processes to improve performance and cost-efficiency of Shallow Geothermal systems and Underground Thermal Storage <http://geocond-project.eu>