The H2020 project GEO4CIVHIC

– Most Easy, Efficient and Low Cost Geothermal Systems for Retrofitting Civil and Historical Buildings

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Abstract

The market of Ground Source Heat Pumps needs to be increased and one of the barriers is represented by the use of this technology in the retrofit of buildings in urban environments. For this purpose, the H2020 project GEO4CIVHIC has been funded and is currently running. The project develops several solutions for shallow geothermal energy in the retrofit environment, based on the building type, climate and the geological conditions of the underground and considers all aspects of the geothermal system (drilling methodology, ground heat exchangers, grouting, heat pumps). The main objectives are:

- identify and where missing develop modular solutions in drilling (machines and methods) and installing (narrow and reduced spaces), heat exchangers types, heat pumps and other renewable energy/storage technologies, heating and cooling terminals with the focus on each type of built environment (civil and historical);
- generate and demonstrate the easiest to install and cost-effective geothermal energy solutions using and improving existing and new tools.
- Demonstrate the environmental respect and the reduction of CO_2 emissions in the atmosphere

More efficient ground heat exchangers and cheaper drilling methodologies/machines adapted to the built also narrow environment like the historical centers will be realised. This approach will bring to an easy applicability in the building refurbishment presenting different constraints, to reduce the overall drilling cost in the given geological conditions, to fit in different levels of retrofit (partial or deep). For better meeting the different needs of the retrofitted buildings 6 prototypes of heat pumps will be developed and built up, from high temperature heat pumps (when heating terminals are maintained) up to plug & play solutions (for deep retrofit), thus reducing the retrofit costs.

The association of the innovations with different tools like a Decision Support System will enable to find the best solution for each combination of building type/climate/geology to be chosen. Moreover, the design tools will reduce overall engineering costs, avoid design mistakes and form the basis for a major dissemination effort. Application tools will help the users for different practical aspects.

The new solutions in the project will be demonstrated in 3 pilot facilities, in 4 real demonstration sites (warm, mild warm, mild cold and cold climates) and in 12 virtual sites. Demonstrations go from partial to deep renovations and include historical buildings.

The H2020 project started in April 2018, lasts 4 years with an overall budget of 8.36 M€, accounting 19 partners from 10 countries.

1 Introduction

The building retrofit market today barely reaches 1 % of the actual building stock [1]. In addition, the interventions are of shallow nature in the majority of the buildings. The Energy Transition initiative of the European Commission is focusing on increasing the retrofitting of the building stock from the current 1 % level to 3 % and to shift the nature of the interventions towards deep retrofits. The Energy Efficiency call topics EE-10-2016 (accelerated and cost-effective deep renovation) and EE-11-2016 (overcome deep-renovation barriers) are the steps in this direction. The present call topic is one further step of many in research and innovation to increase shallow geothermal applications in buildings in any kind of constrains, internal (high temperature terminals) and external (narrow or difficult to attain free spaces). The revision and implementation into legislation of the EPBD, the Energy Efficiency Directive and the Renewable Energy Directive by the EC, coupled with financial support mechanisms (e.g. tax reductions for deep retrofits, premiums for renewable energy systems) will contribute as well.

The application of shallow geothermal installations in the built environment is not well developed [2] at today. The main barriers are:

1. higher upfront investments compared to other conventional solutions like condensation gas boilers for heating and direct expansion systems for cooling;

2. difficulties of cost effective and environmentally friendly drilling in the built environment;

3. need to change Heating and Cooling (H&C) terminals in order to adequate performance from heat pumps, particularly in historical buildings;

4. low levels of awareness on the techniques and its advantages, reluctance to risks and/or lack of experience amongst the designer and operators (architects, installers, building owners) in the ultra-conservative building industry.

To overcome the above barriers, the total investment cost of geothermal systems has to decrease compared to alternative solutions. The high drilling cost needs to be tackled. Drilling with highly efficient but heavy and large drilling machines is difficult and often impossible in the built environment, in particular in the historical centers. The use of smaller, less powerful machines leads to even higher drilling costs.

Increasing the thermal efficiency of the Ground Source Heat Exchangers (GSHEs) is another way to reduce the total length of GSHEs to install. Ample research in this field has been done [3], [4] and is ongoing as part of the H2020 projects Cheap-GSHPs [5], GEOTeCH [6] and GEOCOND [7]. These developments have to be integrated and/or taken one step further. Development of the Heat Pumps (HPs) towards a higher efficiency with any kind of terminals and lower costs should also contribute to the decrease of the total investment or the increase of the overall efficiency. HPs with good performance at higher temperatures avoid the need to replace all or part of the heating terminals [8], [9]. Hybrid heat pumps, i.e. dual source (air to water and water-to-water) HPs can reduce further the total length of GSHE needed [10]. The combination with other Renewable Energy Sources (RES) as solar could improve the return on investment [11] [12]. Shallow geothermal systems are more complex to realize than conventional solutions, in particular when barriers and constraints are present. Critical aspects include correct design, adequate performance in operation and costs for the installation. Providing tools, training material/support to designers, instruct installers and operators facilitate the realization of geothermal installations, reduces costs, improve the awareness and overcome reluctance towards this technology.

The project aims at reducing these gaps and increase the operating efficiency making shallow geothermal one of the standard applications in retrofitting. The stable nature of geothermal as a renewable energy source, the ability of heating/cooling with only one system and the higher residual value of buildings retrofitted with this technology are additional key factors for investors who are focusing on the long-term value of retrofits.

The main goal of GEO4CIVHIC proposal is to tackle all of the above-mentioned areas by developing and demonstrating more easy to install in any reality and more efficient GSHEs, using drilling machine innovations tailored for the built environment and developing or adapting HPs and other hybrid solutions for retrofits through a holistic engineering, construction and controls approach.

The present paper presents the general aspects of the GEO4CIVHIC project showing the initiatives and the proposed results in the project.

2 Methods

The overall methodology of GEO4CIVHIC follows a holistic approach with the activities grouped by type and organized in a logical sequence from research over innovation to demonstration and evaluation. The communication, dissemination and exploitation runs in parallel over the four other phases. The all-important development of the innovations and tools is tackled in the second phase. First, the basis for driving these innovations and for monitoring the project progress and results is researched.

Once the developments have been realized the project moves into an extensive demonstration phase. Field tests of the key innovations are followed in a third phase by pilots, full case demonstrations and virtual case studies. Upon results evaluation, a solid basis is built for market exploitation supported by training events, workshops and dissemination activities.

The consortium partners cover all the important aspects and areas in the value chain of shallow geothermal plants. The overall work and single tasks have been organized such that partners work along the main innovation themes in multi-disciplinary groups.

This approach maximizes their knowledge, expertise and synergies for the benefit of the project innovations. phases are shown in more detail below.

2.1 Phase 1: Preliminary cost analysis and barriers identification

Barriers for geothermal plants in retrofit projects of existing buildings need to be known to drive the innovation and the subsequent exploitation. They are usually not only of economic or technical but also social, cultural and legislative nature. The entire partnership is involved in this task. The partners closest to the stakeholders (architects, SME's, industry) use their contacts and networks.

Geothermal maps have and are being developed at different scales in European, National and Regional projects. The "drillability", understood as the eligibility of the soil for the best drilling method and the best heat exchanger to use, is not included. In GEO4CIVHIC this key factor will be added to the maps and guides for later use in the decision making and the performance evaluation process (including the traditional drilling methods and the improved technology developed in the project).

Information about the cost and performance of heating/cooling plants, including shallow geothermal ones, is needed to set quantified key performance indicators for the innovations' evaluation and to support business models. These plants depend on the energy demand profile of the building, the heating/cooling terminals and for geothermal also on the soil. These demand profiles will be generated via modelling of different building types, building structures, climates and undergrounds to cover the European market. This is then followed by a cost and efficiency study.

2.2 Phase 2: Technological Innovations and Tools

The innovation activities in this phase follow respectively a hardware (drilling, borehole heat exchangers, heat pumps) a middleware (BEMS) and a software track (decision support, engineering tools, app's, controls).

The drilling method, already developed in Cheap-GSHPs for unconsolidated soils, will be improved using a more powerful and efficient rotation-vibration drilling head mounted on a compact drilling machine. This to enable to use this technology in all types of unconsolidated soil and even soft rock. A new head and the corresponding drilling rig are developed jointly. The drilling rig design will also address the barriers (compactness, weight, flexibility) and the reduction of non-productive times. The latter will be done by

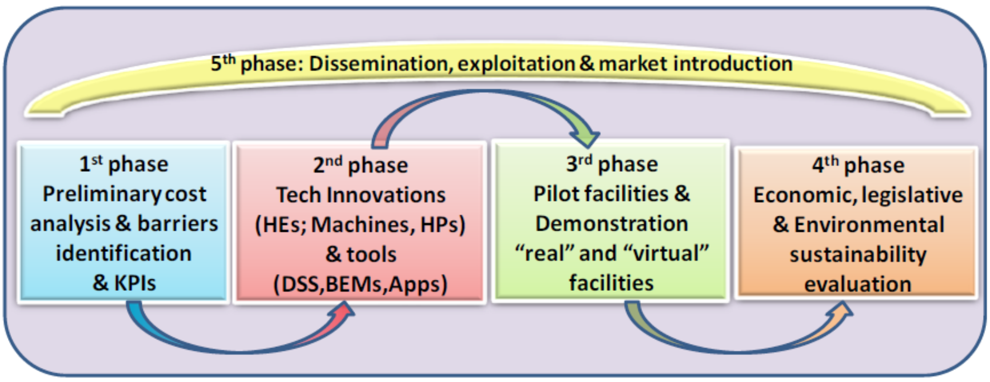

Figure 1. The five phases of the project GEO4CIVHIC.

semi-automated operator support equipment for fast mounting/dismounting of shafts/casings and heat exchanger's installation.

The efficiency and cost of co-axial heat exchangers can be improved, building on the developments already realized in Cheap-GSHPs. The powerful drilling head allows to increase the external diameter but the potentially negative implications on drilling speed and depth need to be verified as well as the impact in thermal performance (laminar vs. turbulent geothermal fluid flow) and pump size/consumptions. An optimization exercise, also with performance data from Cheap-GSHPs, is foreseen. Other improvements to study are new tube materials (plastics) and grouts (conductivity), which will come from the project GEOCOND; in fact, different new grouting and pipe plastic materials are being developed aimed at further increasing efficiency and decreasing operating costs of GSHP solutions.

Four new HPs will be developed based on the analysis of possible HVAC solutions in new and retrofitted buildings for meeting high and low temperature with one or two sources. Another HP faces the trend in the market to move to smaller-size heat pumps suitable for the retrofitted buildings with low energy demand (nZEB, ZEB or PEH). A compact geothermal heat pump, easy to install and to integrate in existing buildings, will be developed. Finally, a low temperature HP with mid-term low GWP fluid will be also developed.

The development of a middleware solution regards the connection between the HPs and the other RES like solar thermal, PV or wind and allows the interaction and coordinated control of these technologies. For this purpose, a development of intelligent control algorithms, in connection with BEMS, will be made, in order to increase the overall efficiency of the installations. The last track is about ICT tools. The Web based Decision Support tool and the engineering tools to size the GSHEs will be based on the tools developed in Cheap-GsHPs and will be improved during GEO4CIVHIC. The repository with solutions for drilling, heat exchangers, HPs is built in first period of the project using the knowledge and experience from the partners in each of their areas of expertise. The tool will then be adapted for any kind (civil and historical) retrofitted building applications.

Moreover the "drillability" guide and geothermal maps will be carried out for helping users in the selection of the most appropriate drilling method and heat exchanger choice.

2.3 Phase 3: Demonstration in "real" and "virtual" demonstration facilities

The demonstration phase is the moment of truth, where the innovations have to be checked and tested. A cascade of test and demonstration sites is set up, having specific innovations to validate. The pilot facilities are sites where specific innovations are tested and improved, while demonstration facilities are sites where buildings are retrofitted and the GSHP solutions of GEO4CIVHIC are installed. In the Figures below the 3 pilot facilities and the 4 demonstration facilities are shown with the related innovations descriptions. The pilot facilities are intended to check and test some specific technologies which are developed during the project (3 prototypes of HPs, 3 co-axial solutions, innovative materials and better coupling with RES). The demonstration facilities are supposed to be used to check the retrofit (shallow or deep) of the buildings with installation of 4 different prototypes of HPs (different also from pilot facilities) and two different solutions of co-axial pipes. Overall 7 prototypes of HPs will be developed, 3 types of co-axial and one type of very shallow GSHEs will be developed and tested.

In both pilot and demonstration facilities monitoring campaigns will take place and models will be run in order to have a better understanding of the problem

Pilot facility n. 1 (CNR), Italy
3 innovative small size HPs, together with novel co-axial pipes solutions

Pilot facility n. 2 (TECNALIA), Spain
Innovative small size HP + RES and testing/optimization of BEMS

Pilot facility n. 3 (UPV), Spain
Very shallow heat exchangers, special grouting and new materials for pipes

Figure 2. The three pilot facilities which are used in the project.

by tuning them and finding general results (e.g. not influenced by the actual climatic conditions but referenced to average climatic conditions). Results of real demonstration facilities will give not only the performance of the proposed solutions, but also the installation costs and the possible problems in using the drilling machine and the installation of the GSHEs. Costs and problems also of the building retrofit will be useful information to look at.

Demonstration facility 1
Malta (warm)
Co-ax GSHE + HP
prototype n. 1

Demonstration facility 2
Italy (mild warm)
Co-ax GSHE + HP
prototype n. 2

Demonstration facility 3
Belgium (mild cold)
Co-ax GSHE + HP
prototype n. 3

Demonstration facility 4
Ireland (cold)
Co-ax GSHE + HP
prototype n. 4

Figure 3. The four real demonstration facilities which are used in the project

During the development and demonstration of the new technologies, risk assessments will be made in parallel and coupled back to the development teams.

Beside the real demonstration facilities there are 12 virtual demonstration facilities. In these sites retrofit of buildings have been planned or realized or will be in progress. The innovations of GEO4CIVHIC will not be installed, but will be sized and a feasibility study will be carried out. The owner could at a later stage implement the developed solutions since substantial parts of the engineering work will have been done. At the same time, the costs and renovation problems in the building will be used for enlarging the data base of solutions and cost-benefit analyses.

2.4 Phase 4: Economic, legislative and environmental sustainability evaluation

After the demonstration phase sufficient information is available to evaluate the cost and efficiency impact of the different developed solutions. Material costs, production, assembly and installation costs are known by now and can be extrapolated towards larger scale application. The benefits and also the environmental impact can be defined using LCA and LCCA methodologies demonstrating how these technologies are environmentally friendly and strongly help in the reduction of the CO_2 in the atmosphere.

Several consortium partners have been participating in previous projects on shallow geothermal systems covering standards, regulative and legislative aspects. They will make conformity verifications and possible recommendations on the integration in standards and regulations for these new technologies.

2.5 Phase 5: Dissemination, exploitation and market introduction

The fifth pillar phase, comprises all the horizontal, supporting activities of the project. It regards the broad and attractive sensitization, communication and deployment activities aimed at reaching different kinds of stakeholders and SME's along the supply chain. Awareness is one of the main barriers for shallow geothermal systems next to the high upfront capital cost.

Dissemination and Exploitation take place during the whole project where the GEO4CIVHIC solutions will be used for specifically targeted exploitation activities by the consortium with different actions and events during and after the end of the project.

Moreover, the training material available during the project will provide precious available material, not only related to the results of the GEO4CIVHIC project, but also to the most recent important innovations realised during the last European projects where some partners were involved. This material will fundamental to increase familiarity with heat exchangers types and installation, heat pumps, controls and, as a consequence, can remove fear. The big industrial representative in the consortium makes possible to develop a realistic and complete exploitation plan for each step in the chain. An exercise on the financial incentives, most probably not well known by many stakeholders, will provide an additional support to the business plans.

Also, the options to link up with regional structural fund initiatives on RES need to be included in this modelling exercise. Finally, the cluster with the other successful projects presents an opportunity to include in the hybrid plant configurations the latest developments in the other renewable heating and cooling technologies.

3 Building types examined in the project

In this paragraph particular reference to the building types which are going to be analysed in real and virtual cases will be shown in order to make stakeholders better understand the problem of retrofitting buildings and to provide suitable heating and cooling by means of GSHPs.

It has to be underlined that the key problem to be solved in the project is to provide more suitable solutions for retrofit of buildings in urban areas. The key point of GEO4CIVHIC is to look at both existing and historical buildings with different types of renovation, i.e. shallow retrofit or deep retrofit.

For this purpose, on one hand the problem will be examined by using archetypes in order to generalize results (see another paper proposed at CLIMA 2019), on the other hand the real and virtual cases will provide feed-back on the applications of the proposed solutions and on the real costs, i.e. costs for retrofitting the envelope, the HVAC costs and GSHP costs.

As already mentioned, 4 real cases and 12 virtual cases are being analysed in the project. So far the data collection of the buildings are ongoing and for some of them some preliminary energy modelling has been carried out.

As could be seen in the next table, the 16 cases are subdivided in: existing buildings and historic buildings. Defining historic buildings is not always clear and simple. I a very simplified way a building can be considered historical when it has been constructed 50 years back in the past. So we have defined existing buildings built after 1960 and historic buildings the ones built before, even if exceptions may occur. As can be seen there is a good variety of buildings as for the age, being 7 existing buildings and 9 historic buildings.

A further analysis has been carried out considering also the climatic conditions based on the classification carried out in Cheap-GSHPs project [13]. The subdivision has been carried out into: Warm (W),

Table 1. Description of the real and virtual demonstration sites and subdivision among age and climate: Warm (W), Mild Warm (MW), Mild Cold (MC), Cold (C).

		Age			Climate		
	Location	**Existing**	**Historic**	**W**	**MW**	**MC**	**C**
Real	Malta		X	X			
	Italy		X		X		
	Belgium	X				X	
	Ireland		X				X
Virtual	Greece	X		X			
	Spain		X	X			
	Romania	X			X		
	Romania	X			X		
	Italy		X		X		
	Croatia		X		X		
	Germany		X			X	
	Belgium		X			X	
	Ireland		X				X
	Switzerland	X					X
	Spain	X		X			
	Holland	X				X	
		7	**9**	**4**	**5**	**4**	**3**

Mild Warm (MW), Mild Cold (MC), Cold (C) climates. As might be observed in Table 1, the subdivision among climates is also consistent, dealing with all possible solutions from dominant heating cases to dominant cooling cases, passing through balanced cases. As a matter of fact, there are 3 cold climates, 4 mild cold climates, 5 mild warm climates and 4 warm climates.

The work which is being carried out is providing and will provide a huge amount of information which needs to be set up in a well-organized data base which needs to be robust and consistent with the other data sets coming from the other tasks. All information will be used for the costs and environmental analysis which will be ready almost at the end of the project.

4 Conclusions and discussion

The present paper shows the general methodology which lays below the project GEO4CIVHIC which is one of the biggest research activities in the next three years in the frame of shallow geothermal energy. The project deals with the retrofit of buildings in urban areas and aim at providing technologies suitable for very narrow places with important barriers of different kind. All the developments will go in four main directions:

- novel types of GSHEs and drilling technologies;
- novel types of heat pumps dealing with low and high temperature solutions and with one or two sources;
- middleware solutions for enhancing the coupling between GSHP solutions and RES;
- software solutions for helping designers in sizing and designing GSHP technologies and to provide more awareness to stakeholders through software and apps;
- reduction of the CO_2 emission in the atmosphere in a future sustainable production of energy.

The project lasts until March 2022, hence results will be ready in the next future. The main purpose of the present paper is to show also the real and virtual building cases which are going to be analysed in the project to have a wider overview of the project and its potentialities.

Most of the technologies which are going to be developed in GEO4CIVHIC have to be protected for patent potential applications and hence no further details can be provided so far for prototypes and machines which are going to be developed and produced. ■

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