2018 - 2022

MOST EASY, EFFICIENT AND LOW COST GEOTHERMAL SYSTEMS FOR RETROFITTING CIVIL AND HISTORICAL BUILDINGS

Acronym	GEO4CIVHIC	Start date	01/04/2018
Website	www.geo4civhic.eu	Duration	4 years
Topic	LCE-17-2017	Coordinator	CNR – ISAC
Type of action	IA	Contact	Adriana Bernardi
Call	H2020-LCE-2017-RES-IA		(a.bernardi@isac.it)

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www.geo4civhic.eu

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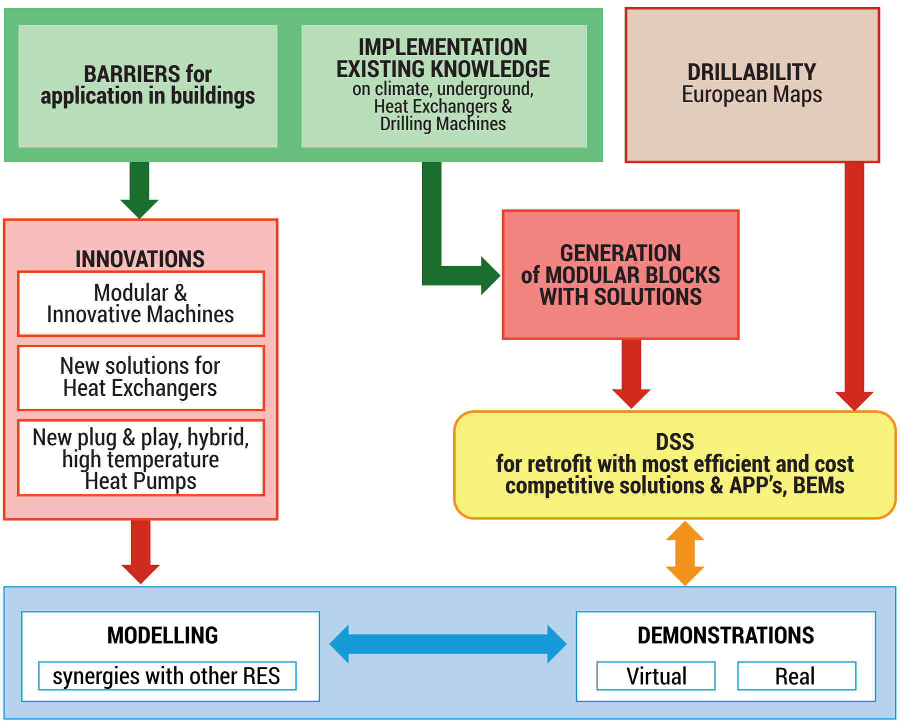
✔ **The main goal of GEO4CIVHIC is to develop and demonstrate easier to install and more efficient ground source heat exchangers, using innovative compact drilling machines tailored for the built environment. The project also aims to develop or adapt heat pumps and other hybrid solutions in combination with renewable energy sources for retrofits through a holistic engineering and controls approach, for improving the return of investments.**

✔ **GEO4CIVHIC's target is to accelerate the deployment of shallow geothermal systems for heating and cooling in retrofitting existing and historical buildings. It is based on innovative solutions investigated by an international expert group of companies and research centres.**

DUAL APPROACH WILL BE APPLIED TO ACCELERATE THE PENETRATION OF SHALLOW GEOTHERMAL ENERGY PLANTS IN RETROFITTED BUILDINGS:

OVERALL TECHNOLOGICAL APPROACH OF THE PROJECT



Reduce cost, increase efficiency and ease of installation of each of the main components of the value chain of the geothermal plant by developing:

- technical innovations in drilling
- borehole heat exchangers
- heat pumps
- controls
- integration of other hybrids

Develop engineering and decision support tools in a holistic approach to

- identify the most appropriate solutions
- raising awareness
- increasing credibility and supporting implementation

PROJECT'S OBJECTIVES

The GEO4CIVHIC activities are organised in three groups named Blocks.

✔ **1. Technical Block** - will address the technical innovations and solutions to be realised and demonstrated starting from the state of art and the specific needs of building retrofits. Innovations are introduced in each component: Drilling Machines and Methodology, ground heat exchangers design and materials, compact and hybrid HPs for high and low temperature terminals. A Decision Support System (DSS) will deliver the most suitable technical solution allowing for the use of other renewable energy sources and optimization of the controls.

✔ **2. Economic & Market Block** - addresses the introduction of these technologies to the market. The broad consortium stakeholders including architects, drilling machine builders, drillers, heat pumps suppliers, engineers and academics specialised in shallow geothermal applications and HVAC systems, heat pumps will provide their expertise.

✔ **3. Environmental & Standardization Block** - deals with the legislative, environmental and European standard conditions, with the project innovations for which recommendations and modifications will be developed through experienced consortium partners members of standards organisations and geothermal associations.

ACTIVITIES BLOCKS OF THE GEO4CIVHIC PROJECT

TECHNICAL BLOCK

identification of the barriers for application in refurbishing civil & historical buildings

development ofdrilling/head machine& efficiency improvement of heat exchangers

development of innovative heat pumps for low ad high temperature terminals

integrated decision support system, engineering tools and control algoritms

demonstration in retrofitted or being retrofitted buildings where drilling is difficult

OUTPUTS
innovations targeted for application in refurbished of civil and historical buildings with installation barriers;
more efficient and cheaper technological solutions overcoming the barriers
combinations of different technologies
dss, bems & app's

ECONOMIC & MARKET BLOCK

opportunitiy identification in the market
geothermal systems as a standard renewable

teaching, training, dissemination
architects and engineers association involvement

OUTPUTS
Higher market penetration
New start-up and job specialisation
New centers of specialisation
Innovative application in historical buildings

ENVIRONMENTAL & STANDARDISATION BLOCK

shallow geothermy for a sustainable environment
enhancing the knowledge on recommendations

integration of development in eu standardisation
for application in civil and historical buildings

OUTPUTS
Evaluation of environmental impact
Training packs for the sensibilisation towards choices
more nature based solution
Contribution to new EU standards in the civil and historical building environment & RES

OBJECTIVES OF THE TECHNICAL BLOCK

- **Objective 1** – To identify the main gaps and barriers to deploying shallow geothermal systems in the built environment.
- **Objective 2** – To improve and develop innovative solutions regarding drilling methodologies and machine components as well as ground heat exchangers targeted at the difficult and confined urban settings
- **Objective 3** - To develop and demonstrate innovative heat pumps for both low and high temperature terminals suitable for all buildings, climates and ground conditions.
- **Objective 4** – Develop and make available different tools for preliminary feasibility assessment and analysis of different solution sets that will achieve user optimized energy management solutions.
- **Objective 5** – To demonstrate the project developments and innovation in different buildings including historical buildings: 3 pilot sites, 4 real buildings and 12 virtual sites.

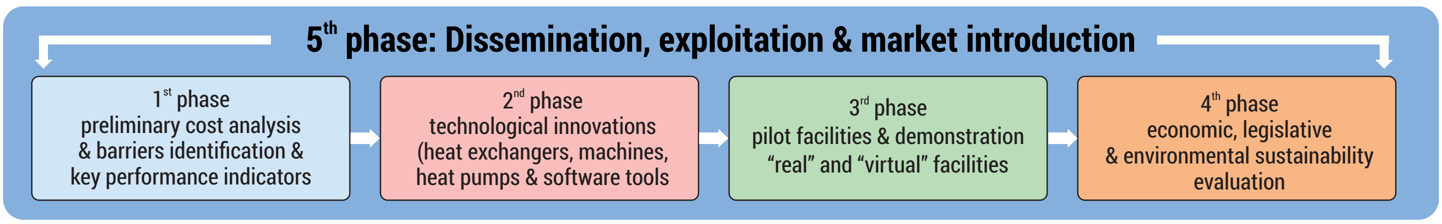
OBJECTIVES OF THE ECONOMIC AND MARKET BLOCK – FOCUSED ON INCREASING THE SHARE OF SHALLOW GEOTHERMAL SYSTEMS IN THE BUILDINGS RETROFIT MARKET.

- **Objective 6** - To provide the building retrofit market with a solid economic value basis leading towards a general acceptance of the ground source heat pumps as a standard renewable energy source in Europe.
- **Objective 7** -To organize intensive teaching, training and dissemination activities to convince stakeholders/users of the value and the performance achieved with the shallow geothermal systems using the GEO4CIVHIC innovations.

OBJECTIVES OF ENVIRONMENT & STANDARDS BLOCK

- **Objective 8** - To enhance the knowledge on recommendations towards common standards, regulations permits and the awareness of the contribution of the shallow geothermal systems to a more sustainable environment.
- **Objective 9** - To enhance the activity inside the committees working and collaborating in European standards (CEN) for the use of shallow geothermal systems.

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 activities can be subdivided in four phases. The communication, dissemination and exploitation runs in parallel over the four other phases. First, the basis for driving these innovations and for monitoring the project progress and results is researched. The innovations are developed in the second phase. Once the developments have been realized the project moves into an extensive demonstration phase. In fact, field tests of the key innovations are followed in a third phase by pilot, 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.



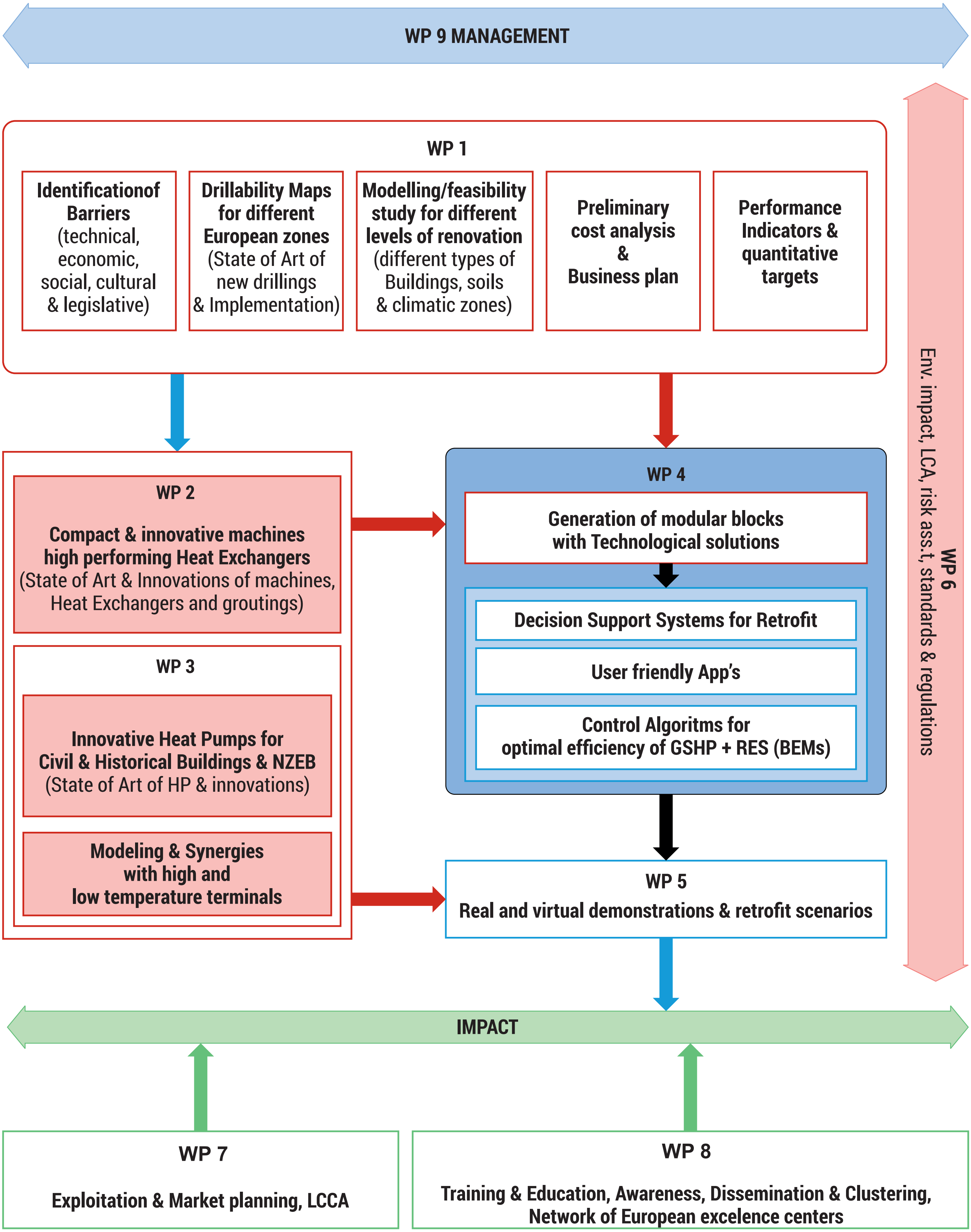
INNOVATIONS TO BE ACHIEVED BY THE GEO4CIVHIC PROJECT

- Vibration-rotation drill head
- Compact, versatile drilling machine
- Semi-automatic feeder for drilling machine
- Co-axial heat exchangers (steel and plastic)
- Adaptation of well point
- Dual source heat pumps
- Two stage heat pump for high temperature terminals
- Low mid-term GWP refrigerant heat pump working at low temperature
- European drilling maps
- Application for on-site drillability assessment
- Decision support system
- Building Energy Management (BEM) control optimization for RES synergies
- Application to guide user towards energy savings actions

WORK PACKAGES

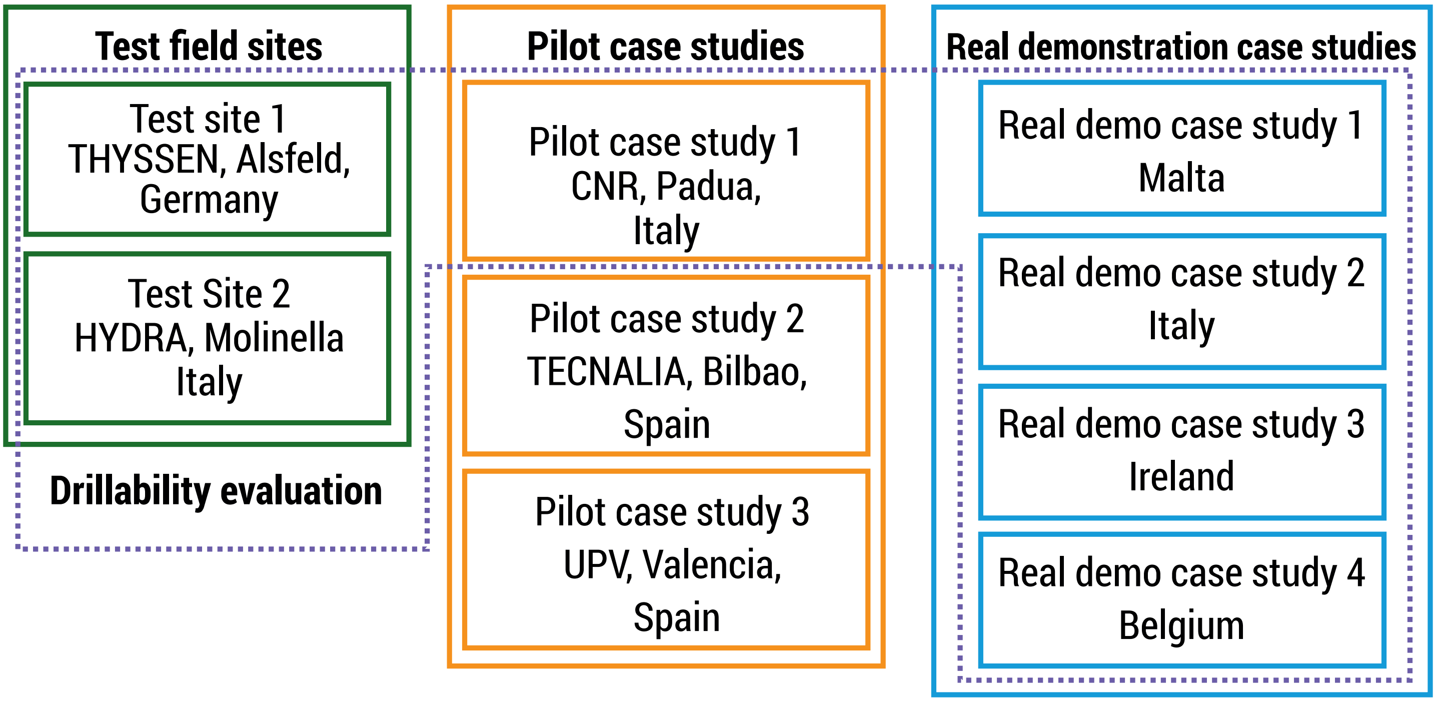
WP NO.	WORK PACKAGE TITLE	LEADER
1	Barriers identification, case study modelling and preliminary feasibility studies to define key performance indicators and the basis for the innovations	UNIPD
2	Powerful vibration-rotation drilling head mounted on compact drilling machine to install the improved co-axial heat exchangers	FAU
3	Innovative Heat Pumps for Civil and Historical Buildings & NZEB	GALLETTI
4	Decision Support System with design tools, Building Energy Management System and Apps	TECNALIA
5	Demonstration of efficiency of installation of shallow geothermal and heating and cooling in individual retrofitted installations	RED
6	Environmental impact, Risk assessment and Standard Regulations	GEOSERV
7	Demonstration of cost-effectiveness and efficiency for the systems, exploitation and market	SOLINTEL
8	Training, education, dissemination and knowledge sharing (clustering)	RGS
9	Project and consortium management	CNR-ISAC

PERT DIAGRAM



DEMONSTRATION SITES

- **2 field test sites** to validate and improve the drilling methodology and machine components.
- **3 pilot case studies** in existing infrastructure, to check and validate the adapted well point technology, a novel high conductive plastic co-axial GSHE, two very shallow heat exchanger solution, the plug and play heat pump and the optimized controls.
- **4 real demonstration case studies** (1 civil and 3 historical) in different built environments, undergrounds and climatic conditions will be used to test the shallow geothermal system with the innovative drilling machine, the improved ground heat exchangers and the novel heat pumps
- **12 virtual" demonstration case studies"** where the DSS and design tools will be applied.



TEST FIELD SITES

The test field sites are used for improving the technologies and to develop the innovations within the project. There are 2 companies as partners producing technologies for the drilling: THYSSEN and HYDRA; HYDRA is also a drilling company.

1. Alsfeld, Germany: the new concepts are related to novel technology for the head of the machine: the head is a core technology for the overall drilling machine. As already explained, THYSSEN will develop a more compact head to be set up in the drilling machine as well as the technique to join the shafts in order to transfer in a more efficient way the energy into the tip of the drill bit. In the test field site 1 the innovative head together with the improved solution in joining the shafts will be compared with the traditional technologies in order to check the performance.

2. Molinella, Italy: all the other components of the innovative drilling machine (more compact and modular) will be carried out by HYDRA (Task 2.3). In this field test site the overall innovative machine will be compared with the traditional machine to check the overall performance in terms of time and costs for the drilling.

PILOT SITES

Pilot demo site No. 1
CNR Research Area of Padua (Italy)

This one floor house of 65 m^2 has 4 main rooms and sanitary facilities. It is available to test building materials and HVAC systems in a controlled situation. A devoted and complete monitoring system will permit to evaluate the accurate efficiency of the innovations for every innovation and synergically.

Pilot demo site No. 2
TECNALIA (Bilbao, Spain)

KUBIK is a singular building for R&D&I focused on the development of new concepts, products and services for the improvement of energy efficiency in buildings. In other words, for Configuration of Zero Energy Buildings. Its uniqueness lies in its ability for generating realistic scenarios on which to research energy efficiency resulting from the integration of constructive solutions, air conditioning and lighting systems and energy supply from conventional and renewable energies.

Pilot demo site No. 3
UPV (Valencia, Spain)

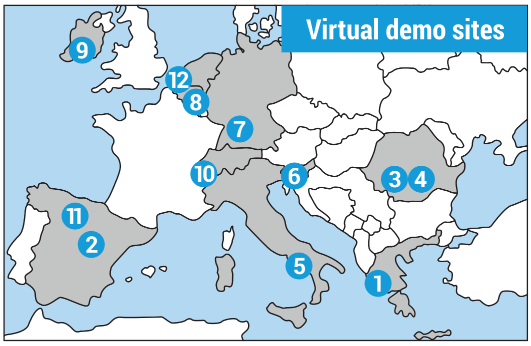
Geothermal Heat Exchangers Test Site is a facility to perform monitored thermal response tests within the UPV Campus. This installation allows to generate a planned thermal load (heating or cooling) by means of a heat pump with a 3-way valve that modulates and controls the injected heat rate. Subsequently, the logged thermal behavior is compared with mathematical models to obtain the main thermal parameters of the experimental borehole heat exchangers.

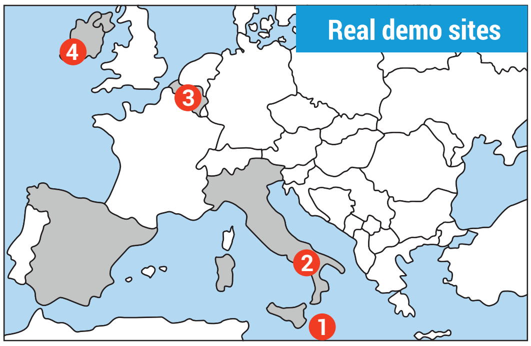
DEMONSTRATION SITES

Demonstration sites (WP5) host the overall GSHP systems, including the building to be renovated, the heat pump and the ground heat exchangers.

The GEO4CIVHIC Project will use both real and virtual demonstration sites, in order to validate the new technologies and software tools at real scale.

		Real demo sites				Virtual demo sites											
Location		Malta 1	Italy 2	Belgium 3	Ireland 4	Greece 1	Spain 2	Romania 3	Romania 4	Italy 5	Croatia 6	Germany 7	Belgium 8	Ireland 9	Switzerland 10	Spain 11	Holland 12
Age	Existing			X		X		X	X						X	X	X
	Historic	X	X		X		X			X	X	X	X	X			
Climate	Warm	X				X	X									X	
	Mild Warm		X					X	X	X	X						
	Mild Cold			X								X	X				X
	Cold				X									X	X		
Type	Residential			X	X			X	X							X	X
	Non-resid	X	X			X	X			X	X	X	X	X	X		





1.Msida Bastion Garden (La Valletta Malta)

Msida bastion garden served as a protestant cemetery from 1806-1856. It was restored in 2002. The majority of the property is a garden/cemetery. At the top of the property, which sits on the Floriana bastions, is a large room which is currently used as a display area but will be converted in the future to a tea room/museum. The accessibility is very narrow being in the garden numerous remains.

Based on the resulting energy demands and probable mismatch between heating and cooling demands (warm climate) a hybrid two-source low temperature heat pump (Task 3.5) will be installed here.

2.UNESCO Historical building (Ferrara, City of the Renaissance, and its Po Delta)

The 'Angel's Gate' building is a historical building in which the medium sized hybrid dual source high temperature heat pump developed will be installed. The building is located within the core area of the World Heritage property "Ferrara, City of the Renaissance, and its Po Delta", in a mild warm climate. The building is also protected under the national cultural heritage legislation, under the supervision of the Ministry of Cultural Heritage and Activities and Tourism, and especially of the Ministry's local offices (Soprintendenza) in charge with monitoring compliance with the national legislation.

The Angel's Gate is a remarkable example of fortified heritage, associated with Ferrara's defensive walls built in 1525 and designed by the renowned renaissance architect Biagio Rossetti. Conceived as a watchtower, it commands a special view to the walls of the town and to the surrounding landscape, which remained exceptionally well preserved for hundreds years. The building frequently hosts expositions and meetings organized by local authorities, and it is equipped with an old, inadequate heating system without cooling. Working in close cooperation with the City's department for Urbanism and Urban Regeneration, GEO4CIVHIC will turn this iconic element of the city's urban landscape into a more accessible, sustainable and comfortable site for visitors, while preserving its historical features and characteristics.

3.Residential House Battelse Bergengn 32 2800 Battel

This real case is a residential building in a mild cold climate. In this case the building is a two-story detached existing building which will be retrofitted by means of insulating the walls and roof and replacement of the windows. The first estimations lead to circa 8 kW as power to be installed after the refurbishment. In the ground floor radiators are present (which will be left) while on the first floor a radiant system will be installed. Hence the two temperature levels (single source) heat pump studied in will be installed and tested.

4.Residential HouseGreystones, Co.(Wicklow, Ireland)

The building dates back to the 1890's. The building was extended about 15 years ago to a total floor area of 165m^2 with the inclusion of a new kitchen. The windows are largely single glaze and there is floor insulation in the kitchen and living room. There is no insulation in the walls apart from the kitchen. The attic insulation was upgraded last year. The bungalow is currently heated using gas fired central heating and freestanding radiators. Further renovations are planned including the improvement of insulation in the floors and the introduction of a 12kW heat pump. The emitters will be kept running at medium/high temperature after the retrofit, therefore a one source high temperature heat pump will be installed and tested.

1.Museum of Natural History of Alexandroupolis - Greece, Leader: CRES

The Museum of Natural History of Alexandroupolis has been constructed in the beautiful and green spot of Platanotopos of Maistro at the eastern settlement of Alexandroupolis town. It is a modern building fully harmonized with the local natural environment. It appears as an integral part of local environment, highlighting all the merits of local gifted nature. Its architectural design makes it a piece of earth's crust of triangular shape lifted from one side, with a hinge point on the ground and the top-point at the meeting of its two equal sides.

This ensures an easy access to the highest point of the roof, which is an interesting observatory of the living beings and the landscape morphology. Under this envelop spaces are revealed where the goods and advantages of the rich land are displayed and the necessary information is provided, with the objective to provide vital environmental education to visitors.

The Museum includes the following four halls, each one with its own thematic area:

- Hall I - introduction
- Hall II - biodiversity of the Prefecture of Evros - multimedia
- Hall III - ecosystems
- Hall IV - Man and the Environment

2.Administrative building "Palacete de la Cruz Roja" – Spain, Leader: UPV

This building is a special education center for children with brain paralysis. It has: dining room, computer classroom, sports facilities, psychological and health care, motor department (hydrotherapy), communication department and learning department.

All these facilities are distributed in 3 floors:

- Floor 0 - 522 m^2
- Floor 1 - 391 m^2
- Floor 2 - 327 m^2

3.Residential building Avangarde Forest 2 – Romania, Leader: PIETRE

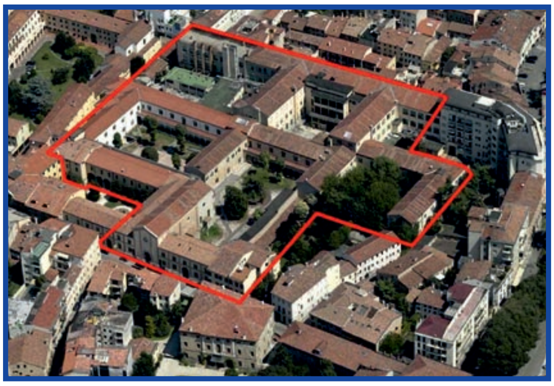
The residential district avangarde forest 2 from Voluntari was built in 2013 and it is composed of 28 modern houses divided in 3 modules of 8 houses and one with 4 houses. Every house has a surface of 180 m^2(p+1+m) and a related land of 110 m^2.

The proposed house (virtual case) is in the southern extreme, composed from ground floor, first floor and attic, with 3 bedrooms and 1 large living room, 4 bathrooms, located on each floor, spacious kitchen and at the attic there is a generous terrace. The owner is a Romanian family. During the year 2017 the family has decided to expand the house by creating a wooden and glass veranda and refurbish reshaping the outer heat coattermo system on polystyrene with a thickness of 8 cm, that in a few years has presented many defects (detachment, insect pockets, etc). The entire building is heated with a floor heating system using an independent gas boiler on gas; for cooling split system units are installed.

4. Residential building in Bucharest - Romania, Leader: RGS

Romania's representative in the Solar Decathlon Europe 2014 contest, now research center for indoor quality and energy efficiency, EFdeN House is a single-family house prototype. It is energy-positive over a yearly energy balance, built with sustainable materials, uses water efficiently and has a BMS integrated. The main architectural feature, the integrated greenhouse works in the way of energy efficiency by preheating air for ventilation.

Other passive strategies include ceramic ventilated façade, thermal mass and phase-changing materials. The structure is metallic, walls and floors are sandwich panels made of wood and thermal insulation. No GSHP system is installed, the house being conditioned using an air sourced heat pump. Virtual analysis of a geothermal system would offer insights regarding its contribution towards even higher energy efficiency, its feasibility in Romanian climate and the contribution towards reaching nZEB/ZEB standards in a sustainable building of the particular given characteristics.



5. University building "Ex Ospedale Geriatrico" (Padua – Italy), Leader: UNIPD

The building named "Ex OspedaleGeriatrico", an important historical complex, located in the centre of Padua, which is currently being renovated (30 M€ project), to become the main Campus of the School of Humanities of the University of Padua.
The building's space is divided in:

- 4000 m^2 for the library (216 seats)
- 2300 m^2 for classrooms (1500 seats)
- 3800 m^2 for offices (350 seats)
- 600 m^2 for an auditorium

The building is of great importance for which will be of outmost importance for stakeholders and owners/managers of large building stocks to be renovated, as the University of Padua (600.000 sqm of buildings). There is a deep renovation in action with low temperature terminal units, high efficiency heat recovery units for the ventilation. The building will be heated and cooled by a reversible GSHP and an air to water reversible heat pump. The overall plant is 900 kW in both heating and cooling. The GSHP is 300 kW and will operate in heating and cooling with 60 traditional GSHE's of 120 m depth. The reversible air to water heat pump is 620 kW.

6. Historical Complex of Split with the Palace of Diocletian (Croatia), Leader: UNESCO

A renovation of a historic building of the World d Heritage Site of the Historical Complex of Split is located in a coastal mild warm climate is planned. Based on the considered interventions the preliminary design will be carried out and different HP solutions with co-axial pipes will be evaluated. The building will be selected after an accurate screening of UNESCO with the Croatian National Commission for UNESCO (Ministry of Culture) along with the management authority of the site.

7. University Building Erlangen Loewenichstraße 28 (Erlangen, Germany), Leader: FAU

Building belongs to the paleontology department of the University of Erlangen. It was built in 1893 and is located in the historical city center of Erlangen. Based on the different solutions in the preliminary design, alternative GSHP systems will be considered coupled with co-axial heat GSHE's.

8. Historical building "Castle of Attre" (Attre – Belgium, Leader: GEOGREEN)

The Attre Castle is a listed building in the national list of exceptional building in Belgium. It was built in 1752 and offers about 1.200 m^2 of living space. The renovation of the castle is in progress.

In this case the high temperature hybrid two source heat pump system with the co-axial probes will be considered for heating the building.

9. Carnegie Clondalkin Library - Ireland, Leader: GEOSERV

The Carnegie Clondalkin library is a detached six-bay two-storey public library dates back to 1912. Facade comprises horizontal bands of random limestone blocks, red brick and roughcast rendering with red brick buttresses and granite string course. Roughcast rendered east and west elevations. Metal casement windows to ground floor, set in groups of three with central semi-circular fixed light above. Timber casement windows to first floor. Timber door with carved stone hood and fanlight.

Pitched slate roof with sprocketed eaves and roughcast rendered chimney stacks. The Clondalkin library will be used as virtual case study site to test the viability of deployment of the GEO4CHIVIC technologies to listed and historical buildings in Ireland.

10. Administrative building AIL - Aziende Industriali di Lugano (Muzzano – Switzerland), Leader: SUPSI

The administrative building of AIL (Aziende Industriali di Lugano) is located in Muzzano, Switzerland. The building was built in 60's ages, and it is actually heated through a gas co-generator, thermal solar panels and a gas burner. In 2017 the construction site began, with the goal of a complete energetic refurbishment of the building and the creation of new offices.

The Energetic Reference Area of the completed building is about 6'000 m^2 (3'500m^2 for the refurbishment and 2'500m^2 for the new building part). The gas co-generator and the gas burner are going to be decommissioned, and the future heat will be produced through heat pumps coupled with boreholes heat exchangers. Solar panels will be kept on the roof.

The building will also be cooled (only sensitive cooling) in order to regenerate the ground. The GSHE will comprise more than 4 boreholes and in accordance with Suisse normative (SIA 384/6) a dynamic simulation of the operating GHSP system was performed. The end of the retrofit is expected during 2018, and thanks to several smart meters, it will be possible to compare the heat consumption before and after the refurbishment. The project is following the Suisse energy label for sustainable buildings called Minergie. A ground response test was performed, in order to know the thermal ground parameters and the length of the GSHE required. All the costs of the refurbishment will be available.

11. Residential Building Mariënheuvel Soest (Soest – Netherlands) Leader: CNR-ISAC

This building is one of the three real demo cases present in 4RinEU (H2020 winner project in the frame of the call EE-10-2016) and was taken over in the GEO4CIVHIC Project as virtual demo site due to Woonzorg Nederland and EURAC courtesy.

This residential social building belongs to and is managed by Woonzorg Nederland. It is a residential building with three floors and around 72 dwellings (2-room, average surface around 58,5 m^2). It presents high primary energy consumption, around 180 kWh/m^2y for heating and domestic hot water production.

In fact, it was built with quite poor constructive standards and low quality, and requires a deep renovation.

The building was built in 1980 and it has a concrete structure and double layer brick walls with internal air gap and double-glazing windows with wooden frame. The building presents a non-insulated pitched and flat roof (around 1.300 m^2).

The climate in which the building is located presents following monthly average temperatures: January: 2.8°C; August: 17.2 °C

The HVAC system consists of: central collective condensing gas boilers recently renovated for the heating supply and central separate boilers with storage for DHW production. The building presents natural ventilation supply and mechanical exhaust ventilation with vertical duct distribution.

The cost analysis and the energy simulations are carried out in the frame of 4RinEU project. A preliminary design of a GSHP system with the technologies proposed in GEO4CIVHIC will be carried out by UNIPD-DII.

12. Residential Building La Vall 09, Bellpuig (Lleida – Spain)Leader: CNR-ISAC

This building is one of the three real demo cases present in 4RinEU (H2020 winner project in the frame of the call EE-10-2016) and was taken over in the GEO4CIVHIC Project as virtual demo site due to AHC and EURAC courtesy.

This residential social building belongs to the Catalan Government and it is managed by the Housing Agency of Catalonia (AHC, Agència de l'Habitatge de Catalunya). It is a multi-family building from 2006 and it presents a rectangular geometry with a west-east orientation and a horizontal roof.

The block has three floors for 15 dwellings (average surface around 50m^2) and a half-underground floor use as a garage. The block represents a strategic case study for the renovation with a replication potential for the social housing building stock in Spain.

The building has a concrete structure and its envelope presents quite a low-quality insulation and several thermal bridges. The façades are composed by a single brick wall (15cm), insulated in the inside with mineral wool (4cm), then an internal gap and a plasterboard wall. The openings represent around 40% of the main façade and have double-glass windows with aluminum frames. Although the building is quite new, it presents high primary energy consumption. In fact, it was built during the housing bubble with poor standards and low quality.

The climate in which the building is located presents following monthly average temperatures (2006): January: 7.4°C, August: 25.1 °C

The HVAC system consists of electric radiators (for heating the apartments) and separate boilers inside the apartments for producing DHW with the support of collective solar thermal panels (placed on the roof).The building has a natural ventilation for the main rooms, and there is an extractor fan in the kitchen (but not in the bathrooms).

The cost analysis and the energy simulations are carried out in the frame of 4RinEU project. A preliminary design of a GSHP system with the technologies proposed in GEO4CIVHIC will be carried out by UNIPD-DII.

1. COORDINATOR:

INSTITUTE OF ATMOSPHERIC SCIENCES AND CLIMATE - NATIONAL RESEARCH COUNCIL (CNR - ISAC)
CONSIGLIO NAZIONALE DELLE RICERCHE NATIONAL RESEARCH COUNCIL (CNR)
Corso Stati Uniti 4, 35127 Padova, Italy www.isac.cnr.it
Contact person: Adriana Bernardi, a.bernardi@isac.cnr.it

2. UNIVERSITA' DEGLI STUDI DI PADOVA (UNIPD)

Via 8 Febbraio 2, Padova 35122, Italy
www.unipd.it
Contact person: Antonio Galgaro, antonio.galgaro@unipd.it

3. UNIVERSITAT POLITECNICA DE VALENCIA (UPV)

Camino de Vera SN Edificio 3a, Valencia 46022, Spain,
www.upv.es
Contact person: Javier Urchueguia jfurchueguia@fis.upv.es

4. RESEARCH AND ENVIRONMENTAL DEVICES SRL (RED)

Viale dell'Industria 58 B, 35129 Padova, Italy,
www.red-srl.com
Contact person: Luc Pockelé, luc.pockele@red-srl.com

5. TERRA GEOSERV LIMITED (GEOSERV)

Unit 1 Ballyogan Business Park, Ballyogan Road Sandyford,
Dublin D18P2E0, Ireland, www.geoservsolutions.com
Contact person: Riccardo Pasquali, rpasquali@geoservsolutions.com

6. GALLETTI BELGIUM (GALLETTI)

Essenestraat 16, Ternat 1740, Belgium
www.galletti.be
Contact person: Fabio Poletto, fabio.poletto@hiref.it

7.FUNDACIONTECNALIARESEARCH&INNOVATION

Parque Cientifico y Tecnologico de Gipuzkoa Paseo Mikeletegi 2,
Donostia San Sebastian 20009, Spain, www.tecnalia.com
Contact person: Amaia Castelruiz Aguirre, amaia.castelruiz@tecnalia.com

8. THYSSENKRUPP INFRASTRUCTURE GMBH (TKI)

Hollerstrasee 7A, Essen 45127, Germany
https://www.thyssenkrupp-infrastructure.com/en/
Contact person: Alexander Hose, alexander.hose@thyssenkrupp.com

9. UNESCO REGIONAL BUREAU FOR SCIENCE AND CULTURE IN EUROPE

Place de Fontenoy 7, Paris 75352, France, www.unesco.org/venice
Contact person: Davide Poletto, d.poletto@unesco.org

10. FRIEDRICH-ALEXANDER-UNIVERSITAT ERLANGEN NURNBERG (FAU)

Schlossplatz 4, Erlangen 91054, Germany www.uni-erlangen.de
Contact person: David Bertermann, david.bertermann@fau.de

11. SOCIETATEA ROMANA GEOEXCHANGE (SRG - RGS)

Bdul Pache Protopopescu 66 Sector 2, Bucharest 021414, Romania
www.geoexchange.ro
Contact person: Robert Gavriliuc, robertgavriliuc@yahoo.com

12.CENTRE FOR RENEWABLE ENERGY SOURCES AND SAVING (CRES)

Marathonos 19th Km, Pikermi 19009, Greece www.cres.gr
Contact person: Dimitrios Mendrinos, dmendrin@cres.gr

13. HYDRA SRL (HYDRA)

Via Guiccioli 6 Fraccione San Pietro, Ghiaroni 40062, Italy
www.hydrahammer.it
Contact person: Davide Righini, davide@hydrahammer.it

14. UBEG DR ERICH MANDS U MARC SAUER GBR (UBEG)

Reinbergstrasse 2, Wetzlar 35580, Germany www.ubeg.de
Contact person: Burkhard Sanner b.sanner@ubeg.de

15. GEO GREEN SPRL (GEO-GREEN)

Rue De Priesmont Marbais 63, Villers La Ville 1495, Belgium
www.geo-green.be
Contact person: Jacques Vercruysse, info@geo-green.be

16. PIETRE EDIL SRL (PIETRE EDIL)

Str Slanic 2 Et 3 Ap 3 Sector 3, Bucharest 030242, Romania
www.pietre-edil.ro
Contact person: Leonardo Rossi, archleonardorossi@yahoo.it

17. SOLINTEL M&P SL (SOLINTEL)

Avenida de Jerez 33, Nuevo Baztan 28514, Spain,
www.solintel.eu
Contact person: Michele Vavallo Michele.vavallo@solintel.eu

18. DIN L-ART HELWA (DLH)

133 Melita Triq, Valletta VLT 1123, Malta,
https://dinlarthelwa.org/
Contact person: Luciano Mule Stagno lmulestagno@gmail.com

19. SCUOLA UNIVERSITARIA PROFESSIONALE DELLA SVIZZERA ITALIANA (SUPSI)

Stabile Le Gerre, Manno 6928, Switzerland www.supsi.ch
Contact person: Sebastian Pera, sebastian.pera@supsi.ch

GEO 4 CIVHIC

2018 - 2022

MOST EASY, EFFICIENT AND LOW COST GEOTHERMAL SYSTEMS FOR RETROFITTING CIVIL AND HISTORICAL BUILDINGS

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