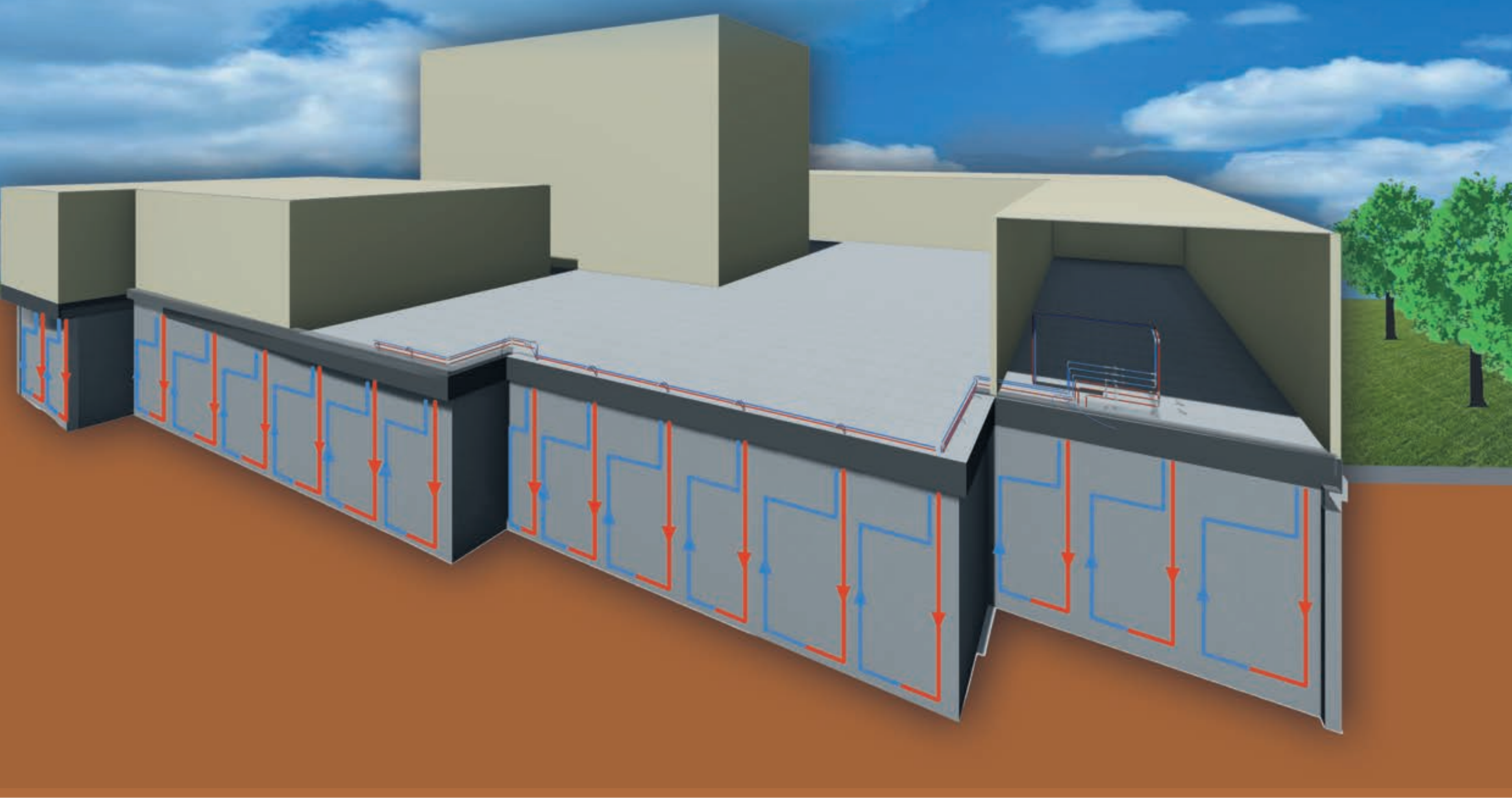
BiGEO GUIDEBOOK

for Renewable and Cost-Effective Building-integrated Geothermal Energy Systems



GEOT€CH project
Geothermal Technology for €conomic Cooling and Heating

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COMSA Corporación and ARCbcn have collaborated in the design and construction of a 100 kW capacity Building-integrated Geothermal Energy (BiGEO) system for heating and cooling an office building in Barcelona (Spain), the demonstration site of GEOTECH project.

COMSA Corporación is the first largest unlisted Spanish group in the infrastructures and engineering sector. With more than a century of experience behind it, COMSA Corporación mainly operates in the fields of Infrastructures and Industrial Engineering; Services and Technology; and Concessions and Renewable Energy.

COMSA Corporación is strongly committed to the construction, operation and maintenance of sustainable nZEB buildings. COMSA Corporación designs and installs BiPV and BiGEO systems, renewable energy generation solutions integrated in buildings and infrastructures.

COMSA implements many different types of projects, from shopping and entertainment facilities to business centres, urban and cultural installations, research and development centres, industrial buildings, and hospitals and health care centres.

ARCbcn is an engineering firm aimed at the design of technical systems developed in various branches of engineering and consulting. We make all projects analysing client's needs to achieve the best solution, offering all its experience to achieve greater guarantee of success. Our engineering stands out for offering the customer a personalized service, quality and commitment.

With a large experience in a wide range of projects using both: new and state of the art technologies, mainly applied in buildings with high technical requirements and needs: scientific facilities, universities, museums and historical buildings.

We are used to act as concept designers, detail engineering designers as well as on site directors during the implementation phase.

This guidebook is a result of the development of several R&D projects including GEOT€CH project, which has received funding from the European Commission Horizon 2020 R&D programme under grant agreement N. 656889. The content of this document reflects only the authors' results and the European Commission is not responsible for any use that may be made of the information it contains.

TABLE OF CONTENTS

1. EXECUTIVE SUMMARY

The construction landscape in Europe has been rapidly changing, with a strong push towards **nearly Zero Energy Buildings (nZEB)** as a way to address the problems faced by climate change, since buildings are responsible for 40% of European Energy consumption[1]. Much of this push comes from new European Directives, such as the Energy Performance in Buildings Directive (2010), which mandates that all new building construction must be nZEB from 2020 onwards[2]. To achieve this, new building developers must not only design, construct and operate efficient buildings that **consume less energy** day-to-day, but also, they must consider the ways their building has the capacity to **produce renewable energy** as well.

One innovative solution is the use of widespread replicable renewable geothermal energy source through **Building-integrated Geothermal Energy systems (BiGEO) based on Foundation Heat Exchangers (FHX).** This guidebook presents reliable BiGEO systems and assesses the performance of the Foundation Heat Exchanger (FHX) as a remarkable solution for new buildings and deep renovation projects with new foundation components. In this way, **BiGEO are marketable, technologically feasible, and cost-effective solutions for sustainable buildings to reach nZEB requirements.**

From a performance perspective, the materials of FHX have the same heat exchange capacity as conventional geothermal Borehole Heat Exchangers (BHX). Moreover, the FHX economic performance is far superior relative to conventional BHX. Demonstration projects have shown **FHX implementation costs to be 82% lower than an equivalent BHX and have achieved a total turn-key installation cost reduction of 40% in the whole ground source BiGEO system for building heating and cooling applications.** On top of this, since the FHX is physically integrated in the foundation, BiGEO systems **don't require additional ground-level footprint** beyond the building itself, while conventional BHX do. This is particularly important in high-density areas such as cities.

To date, BiGEO systems are implemented in 8 sites in 4 countries. These first sites represent a wide range of applications, including tertiary buildings, hotel/residential buildings, transportation projects and industrial applications.

This guidebook documents the **benefits and applicability of BiGEO systems** as well as the design of **replicable solutions to accelerate the adoption of nZEB** involving shallow geothermal systems. It provides Decision Makers with the useful information when choosing the most suitable technical and cost-effective solution for their future projects by including BiGEO systems as a new opportunity for new buildings.

This guidebook has been developed as part of H2020 GEOT€CH[3] project, and includes the results of the developments performed by the authors in several R&D projects related to shallow geothermal solutions. This guidebook is available at the website of the GEOTECH project: ***www.geotech-project.eu/building-integrated-geothermal-guide***

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[1] *European Commission, "Energy Efficiency on Buildings," Directorate-General for Energy, [Online]. Available: https://ec.europa.eu/energy/en/topics/energy-efficiency/buildings*

[2] *European Parliament and the Council of the European Union, "Directive 2010/31/EU of the European Parliament and the council on the Energy Performance of Buildings," 19 May 2010. [Online]. Available: http://eur-lex.europa.eu/legalcontent/EN/TXT/PDF/?uri=CELEX:32010L0031&from=EN.*

[3] *www.geotech-project.eu*

2. INTRODUCTION

As part of the push to achieve Near Zero Energy buildings (nZEB), geothermal energy is a renewable, reliable, widespread energy source that can be used to get there. In the building sector, this can be done through Building-integrated Geothermal Energy systems (BiGEO) based on FHX which perform the thermal exchange with the ground taking advantage of the renewable geothermal energy source to be used for building heating and cooling.

FHX is a new concept for a cost-effective ground heat exchanger embedded in building's foundation that can be connected to a water-to-water or water-to-air heat pump for building's HVAC systems.

2.1. Geothermal heating and cooling

"Geothermal Energy is the energy stored in the form of heat beneath the surface of solid earth."
(see EU Directive 2009/28/EC, article 2)

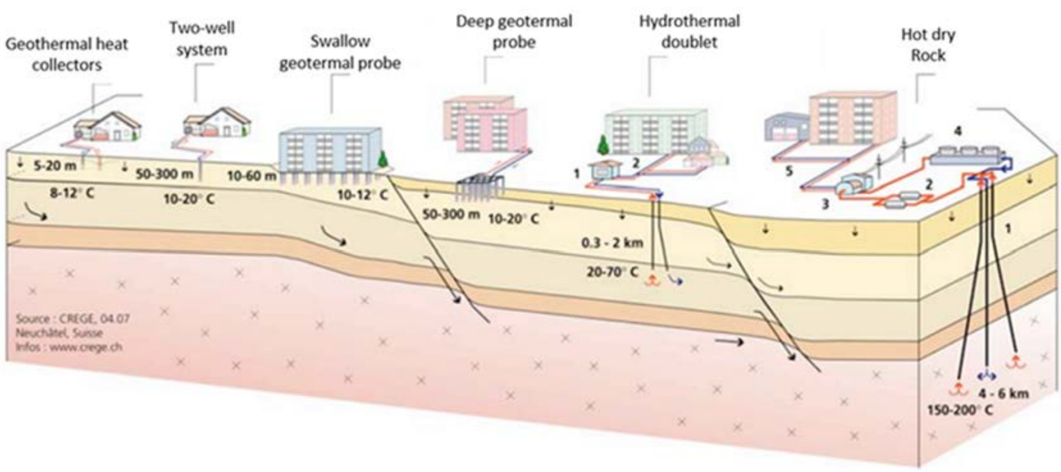

FIGURE 2-1 APPROACHES TO EXPLOITING GEOTHERMAL ENERGY AT VARIOUS DEPTHS[4]

This guidebook is focused on cost-effective shallow geothermal systems to provide renewable energy for building heating and cooling. The ground heat exchange is extracted or injected through geothermal heat pumps or Ground Source Heat Pumps (GSHP) to provide thermal energy to be used for building's HVAC systems. The GSHP uses the earth during the whole year, as a heat source (in winter) or a heat sink (in summer). This system takes advantage of the moderate temperatures in the ground, almost constant during all seasons, increasing the efficiency of the system and reducing the costs of HVAC (Heating, Ventilation and Air Conditioning) and water heating.

Ground temperature is more tempered than ambient temperature, which is more remarkable in summer and winter seasons, so GSHP achieve higher efficiency than air-source heat pumps. The ground's temperature remains almost constant during the year, with moderate variations in the surface.

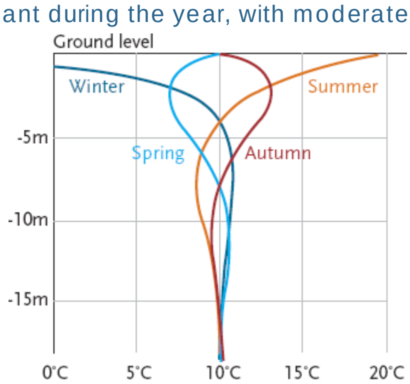

FIGURE 2-2 GROUND TEMPERATURE`S SEASONAL FLUCTUATIONS BY DEPTH[5]

Heat Pumps can provide both heated and cooled water simultaneously for 4-pipe HVAC systems. In these cases the efficiency of the Heat Pump system is increased due to the heating recovery from the building's heating and cooling HVAC circuits.

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[4] CREGE https://crege.ch

[5] Dwyer, Tim & Evans, Yan. CIBSE JOURNAL. Module 15: The increasing potential for ground source heat pumps. Retrieved November 5th, 2018, from https://www.cibsejournal.com/cpd/modules/2010-04/

2.2. Types of geothermal systems

Geothermal heating and cooling systems for buildings can be classified in two main types:

FIGURE 2-3 OPEN LOOP GEOTHERMAL CIRCUIT

- ***OPEN LOOP GEOTHERMAL CIRCUITS***: These systems use water from an aquifer as working fluid and inject or extract heat from it.

FIGURE 2-4 CLOSED LOOP GEOTHERMAL CIRCUITS

- ***CLOSED LOOP GEOTHERMAL CIRCUITS:*** These systems inject or extract heat from the ground through a Heat Exchanger (HX) array in a closed loop.

The three main configurations of closed loop geothermal heat exchanger are: horizontal heat exchangers, Borehole Heat Exchangers (BHX), and Foundation Heat Exchangers (FHX).

FIGURE 2-5 HORIZONTAL GROUND HEAT EXCHANGER SYSTEM[6]

- ***HORIZONTAL GROUND HEAT EXCHANGERS:*** the piping system is installed horizontally at a depth of 1 to 5 meters below ground level, usually in equally spaced trenches. It requires a large area for the installation of the heat exchanger.

FIGURE 2-6 VERTICAL BOREHOLE HEAT EXCHANGER[7] (BHX) SYSTEM

- ***VERTICAL BOREHOLE HEAT EXCHANGERS (BHX):*** In this system, closed circuit in 'U' loops are installed in vertical boreholes typically 100-150m deep, where the ground temperature is more tempered and higher. A small area is required to install boreholes, but this should remain permanently unbuilt.

Comparing horizontal and vertical boreholes, three main differences are easily noticed. The horizontal ground heat exchangers require a larger surface area, but the construction investment required is much less than in the case of vertical boreholes. However, since major depths are reached with vertical systems, these exchange energy with more tempered soils, which increases the efficiency of the system.

FIGURE 2-7 FOUNDATION HEAT EXCHANGER (FHX) SYSTEM USING ENERGY PILES[8]

- ***FOUNDATION HEAT EXCHANGERS (FHX):*** This system consists of closed heat exchangers circuits that are embedded in building's foundation components: screen walls and/or piles. FHX don't require additional drilling (as BHX do) or excavation beyond the needed for the foundation elements. FHX must be installed during the construction of the building. The technology is well suited to larger tertiary buildings.

This guidebook is focused on Foundation Heat Exchangers (FHX) technology as part of Building-integrated Geothermal Energy systems (BiGEO).

[6,7] *Geotermia Información Técnica. Madrid, Spain: Uponor Hispania, S.A.U., 11/2013.*

[8] *Sistema Raugeo Calefacción y Refrescamiento con geotermia. Engineyrs Industrials de Catalunya*

2.3. Benefits of BiGEO based on FHX

BiGEO systems are geothermal installations with ground heat exchangers embedded in foundation elements (FHX). This Building-integrated FHX geothermal implementation has the following benefits:

- ✓ FHX **doesn't require additional geothermal drilling** as BHX do. The ground excavation is already performed for the construction of the building's foundation elements.
- ✓ BiGEO systems have significant reduction of investment costs compared to BHX systems: **82% of cost reduction in the installation of the heat exchanger for FHX technology** (FHX has a marginal cost on the construction of building's foundation), and **40% of cost reduction in the turn-key BiGEO geothermal system compared to BHX systems** (see section 5 of this document).
- ✓ BiGEO systems have significant reduction of the **Return of Investment** compared to BHX systems. The simple payback period for BiGEO system in office buildings is about 4 years.
- ✓ BiGEO **doesn't require additional ground-level footprint** beyond the building itself for geothermal heat exchangers array, while conventional BHX do (see figure 2-8). This is particularly important in high-density areas such as cities.
- ✓ BiGEO systems are reliable solutions for geothermal renewable energy generation integrated in buildings towards NZEB requirements.

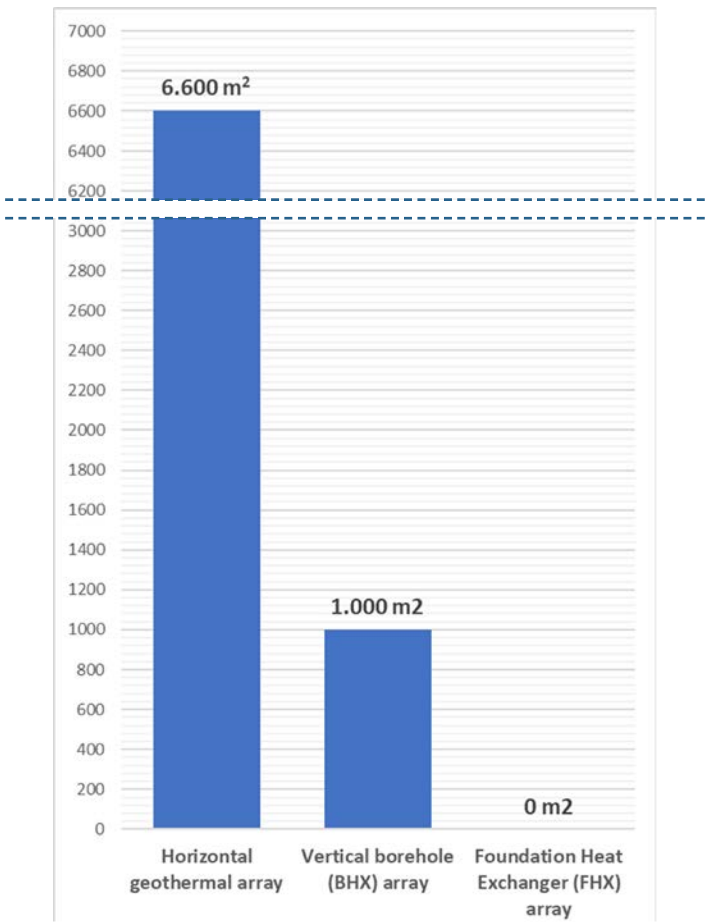

FIGURE 2-8 REQUIRED GROUND AREA FOR HEAT EXCHANGER (HX) ARRAY ACCORDING TO THE HX TECHNOLOGY IN 100KW OF GEOTHERMAL CAPACITY SYSTEMS

BiGEO technology is a cost-effective renewable geothermal solution with an improved FHX design, installation methodology and reliable durability. Dedicated borehole drilling costs are removed, and additional street-level area is not needed for geothermal FHX arrays.

3. APPLICABILITY OF BiGEO SYSTEMS

3.1. Territory suitable for installation of BiGEO systems

As the FHX installation is integrated directly into the foundation of the building, all the critical considerations regarding climate, soil, surface and ground water, building structure (volume and mass) and the presence of foundations of nearby buildings and ground structures should be considered prior to installation. In addition, a prevision of future urban development, excavations and land filling, as well as possible variations in the groundwater level, should be attempted, so that all possible impacts can be considered starting from the design phase. BiGEO systems based on FHX technology are ideal in any soil type that provides a stable, deep foundation with proper drainage- loam soil in particular is ideal for this.

The results of the analysis of suitable zones in Europe for the installation of BiGEO systems based on FHX is represented in Figure 3-1. As reference depth of foundation elements used for the study, 10 m has been selected. The following simplified criteria have also been used for the analysis:

TABLE 3-1 SCREEN WALL TECHNICAL REQUIREMENTS

DEPTH	UCS VALUE	SUITABLE ZONES
>10 meters	NA	Standard installation of energy walls
< 10 meters	< 80 MPa	Standard installation of energy walls
< 10 meters	80 MPa to 150 MPa	Difficult installation of energy walls
< 10 meters	> 150 MPa	Very difficult installation of energy walls

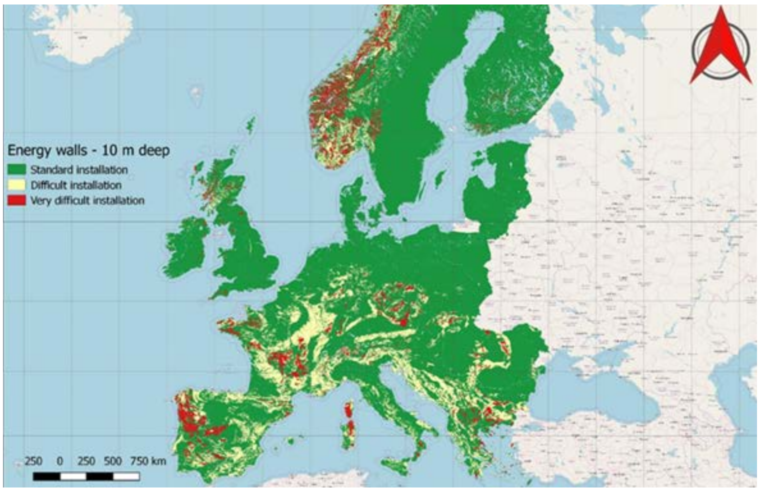

FIGURE 3-1 EASE OF INSTALLATION OF ENERGY WALLS DOWN TO 10 M DEEP IN EUROPE[9]

3.2. Building typologies

New buildings with large foundations and deep retrofitting with new foundation elements (e.g. underground car parks) have the best opportunity of implementing renewable and cost-effective BiGEO systems based on FHX technology.

The implementation of BiGEO systems is recommended for buildings with foundation elements (screen walls and piles) that meet the following characteristics:

TABLE 3-2 SCREEN WALL TECHNICAL REQUIREMENTS

SCREEN WALL (SW) TECHNICAL REQUIREMENTS	EXPECTED RANGE	UNITS
SW depth	min 8	m
SW section width	min 2	m
SW thickness (nominal)	min 45	cm

TABLE 3-3 PILES TECHNICAL REQUIREMENTS

ENERGY PILES TECHNICAL REQUIREMENTS	EXPECTED RANGE	UNITS
Pile depth	min 8	m
Pile diameter	min 20	cm

[9] GEOT€CH project: **www.geotech-project.eu/web-gis**



There are three typologies of buildings according to their thermal load profile, which affects the quantity of heat to be exchanged to the ground. Each typology is defined below, including examples of existing buildings with BiGEO systems (explained in more detail in section 6 of this document) integrated into their HVAC systems.

- ***Type 1: Buildings with a 24-hour a day load profile*** (i.e. hospitals, airports, residences): the load demand profile of this type of buildings doesn't stop according to defined timetables and require constant energy generation for their HVAC systems. Existing buildings with BiGEO systems include: Knightsbridge Palace Hotel (UK), Residential building in Tradate (IT) and Cavas Castillo de Perelada (SP).
- ***Type 2: Buildings without a 24-hour daily demand and a regular profile*** (i.e. offices): office buildings typically have fixed timetables (closed at night, during weekends and holidays) and scheduled ON/OFF HVAC systems (working about 12 hours per day). Existing buildings with BiGEO systems include: GEOTECH FHX large-scale office Building (SP), Vía Célere office building (SP), Parking/Gym "Playa la Concha" (SP) and Mercat de Sant Antoni (SP).
- ***Type 3: Buildings without a 24-hour daily demand and an irregular profile*** (i.e. theatres, museums): this type of building has significantly different thermal load profiles during the day/week/month according to scheduled events. An existing building of this type with installed BiGEO system is the Shanghai Museum of Natural History (CH).

4. BiGEO DESIGN METHODOLOGY, INSTALLATION AND O&M

BiGEO systems are geothermal systems with ground heat exchangers embedded in foundation elements (screen walls and/or piles). BiGEO systems are formed by foundation Heat Exchangers (FHX), hydraulic circuits, geothermal Ground Source Heat Pump (GSHP) and the integration into building's HVAC system.

4.1. Design Methodology

BiGEO heating and cooling systems to be integrated in building's HVAC systems requires a design methodology to consider both building demand profile and ground heat exchange capacity through its foundation elements (screen walls and/or piles).

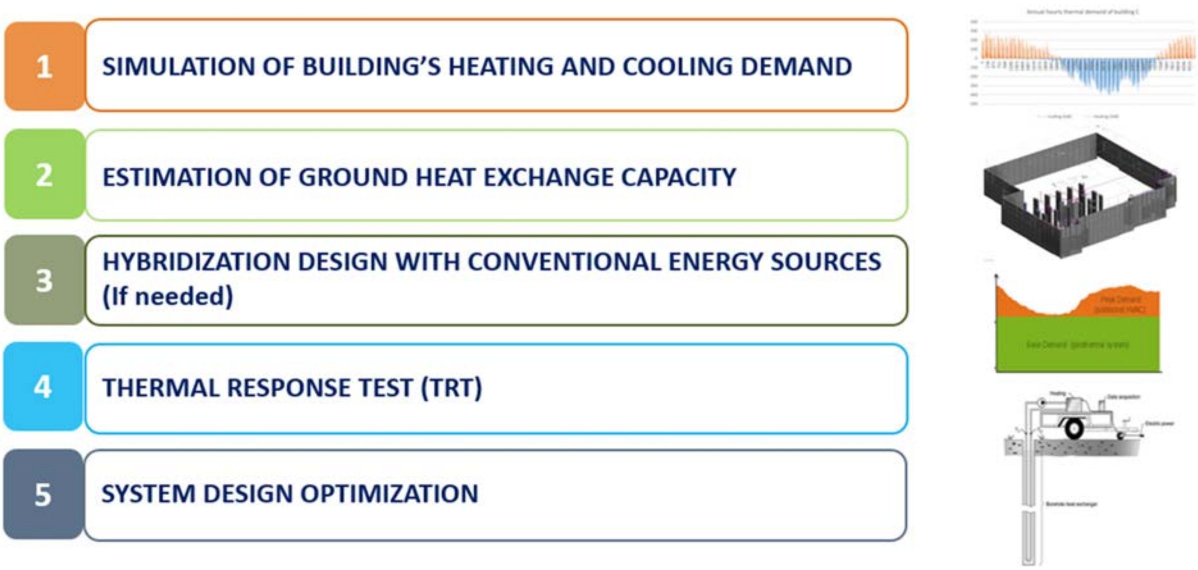

FIGURE 4-1 DESIGN METHODOLOGY FOR BIGEO SYSTEMS

TABLE 4-1 KEY DESIGN DECISIONS AND FACTORS TO CONSIDER IN FOUNDATION HEAT EXCHANGER SYSTEM DESIGN

DESIGN ELEMENT	KEY DESIGN QUESTIONS	KEY DESIGN FACTORS
BIGEO DESIGN	✓ Screen wall depth? ✓ Wall thickness? ✓ Basement wall depth? ✓ Pile size and layout? ✓ Pile diameter and reinforcement position? ✓ Construction method?	✓ Site ground conditions ✓ Architectural form - plan area and number of storeys ✓ Superstructure form of construction and load transfer ✓ Building grid layout ✓ Adjacent buildings and ground
FOUNDATION HEAT EXCHANGER DESIGN	✓ Pipe position and size? ✓ Pipe spacing? ✓ Pipe circuit length? ✓ Peak heating and cooling heat transfer rate achievable? ✓ Annual heating and cooling demand achievable? ✓ Total number of wall/pile elements to be activated? ✓ How much of the heat exchange can be geothermal? ✓ What levels of system efficiency can be expected? ✓ Proportion of FHX acting as retaining wall versus deep foundation	✓ Integration with the reinforcement design ✓ Installation method ✓ Pipe bending radius ✓ Limitations on spacing ✓ Building total heating and cooling load variation during the year ✓ Peak heating and cooling loads ✓ Ground thermal properties ✓ Concrete thermal properties ✓ Number of basement levels ✓ Basement function (carpark?) and ventilation scheme
HYBRID SYSTEM DESIGN	✓ Is hybrid heating necessary? ✓ Is hybrid cooling necessary? ✓ Which conventional energy-sources are available for the hybridization?	✓ Building total heating and cooling load profile during the year ✓ Heating and cooling peak loads ✓ Control strategy ✓ Energy tariffs ✓ Climate conditions
ENERGY MANAGEMENT SYSTEM DESIGN	✓ System operating priority for renewable sources? ✓ Hybrid switching strategy? ✓ Control setpoints? ✓ Pump control strategy? ✓ Temperature sensing and heat metering requirements? ✓ What additional site testing and commissioning is needed?	✓ Integration of EMS and other controls elements ✓ Management of the ground thermal conditions ✓ Operating temperature limits ✓ Monitoring and fault detection needs ✓ Data requirements and communications

4.2. Analysis of the building heating and cooling demands

Building heating and cooling load profiles depend on local climate conditions and building characteristics (isolation, orientation, HVAC sytems, etc). During the design phase of the building, it is recommended the simulation of hourly heating and cooling building demand. Several software tools and calculation methods are available to assist with this task.

Some examples of annual building demand profile are given in Figure 4 2. The figure shows the results of the simulations performed for the same office building in three different European locations with different climate conditions.

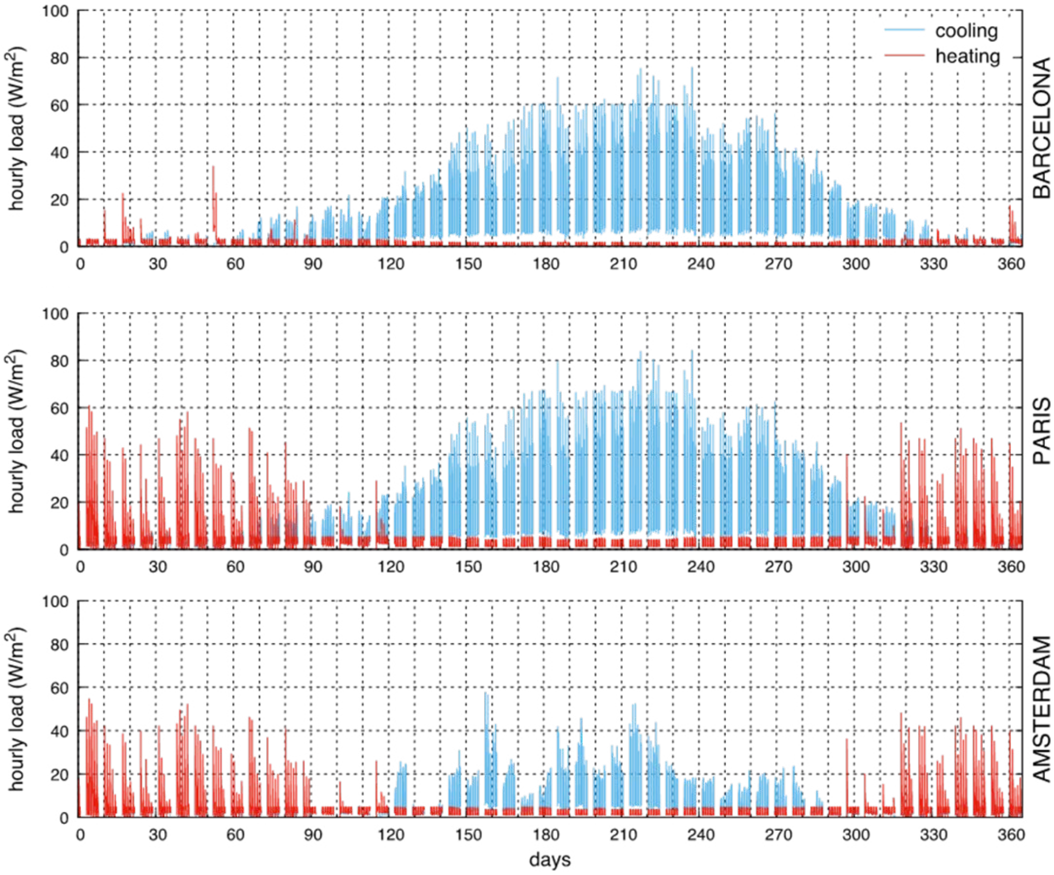

FIGURE 4-2 TYPICAL OFFICE BUILDING LOAD PROFILE IN THREE EUROPEAN LOCATIONS

The evaluation of the ground heat exchange capacity needed to cover the building's heating and cooling demand is studied according to the technical specifications of the commercial geothermal Heat Pump performance to be implemented in the BiGEO system.

4.3. Ground heat exchange potential

The ground heat exchange potential is defined according to the following technical characteristics:

- Geotechnical and ground thermal characteristics: materials, permeability, thermal conductivity, volume heat capacity, etc.
- Groundwater characteristics: water table level, speed and flow direction, annual changes, buildings or infrastructures that could affect the groundwater, etc.
- Ground heat exchanger design (FHX, BHX, etc): depth, pipe size, pipe spacing, active area, etc.
- Heat exchanger fluid: water with/without antifreeze, flow rate, etc.
- Building's thermal demand profile: 24-hour a day demand regular profile, irregular intensive peak demand profile, etc.

The ground heat exchange potential is strongly influenced by the FHX geometric parameters, the fluid flow conditions, the ground thermal conductivity and geotechnical and climate conditions. Hence calculations have been made for a range of thermal conductivities and city locations for both building heating (ground heat extraction) and cooling (ground heat injection) modes. These have been calculated for a typical office building with the load profile shown in Figure 4 2. Values of FHX ground heat exchange potential are given in the following table on the basis of per unit pipe length (m) and per active unit area (m^2) of thermo-activated foundation screen wall (SW).

TABLE 4-2 TYPICAL SCREEN WALL FHX HEAT EXCHANGE POTENTIAL FOR A TYPICAL OFFICE BUILDING IN DIFFERENT LOCATIONS WITH DIFFERENT GROUND THERMAL CONDUCTIVITY

LOCATION	GROUND THERMAL CONDUCTIVITY	GROUND HEAT EXTRACTION PER UNIT PIPE LENGTH		GROUND HEAT INJECTION PER PIPE UNIT LENGTH		GROUND HEAT EXTRACTION PER UNIT ACTIVATED SW AREA		GROUND HEAT INJECTION PER UNIT ACTIVATED SW AREA	
		GROUND HX CAPACITY	ANNUAL GEOTHERMAL ENERGY	GROUND HX CAPACITY	ANNUAL GEOTHERMAL ENERGY	GROUND HX CAPACITY	ANNUAL GEOTHERMAL ENERGY	GROUND HX CAPACITY	ANNUAL GEOTHERMAL ENERGY
	W/m•K	W/m	kWh/m	W/m	kWh/m	W/m²	kWh/m²	W/m²	kWh/m²
ATHENS	0.9	10	0.1	22	19.0	24	0.2	54	47.5
	1.25	13	0.1	25	21.6	32	0.4	62	53.9
	1.6	***16***	***0.2***	***31***	***26.0***	***40***	***0.5***	***77***	***65.0***
	1.9	18	0.3	35	29.0	46	0.6	87	72.5
	2.2	18	0.3	35	29.0	46	0.7	87	72.5
BARCELONA	0.9	8	0.1	21	15.4	21	0.2	52	38.6
	1.25	12	0.1	25	19.2	30	0.3	63	48.1
	1.6	***15***	***0.2***	***30***	***22.8***	***38***	***0.5***	***74***	***56.9***
	1.9	18	0.2	34	25.7	44	0.6	84	64.2
	2.2	18	0.3	34	25.7	44	0.7	84	64.2
MADRID	0.9	8	0.2	20	14.0	21	0.6	50	35.0
	1.25	12	0.4	28	18.0	30	0.9	70	45.0
	1.6	***16***	***0.5***	***34***	***22.3***	***40***	***1.2***	***84***	***55.8***
	1.9	19	0.6	38	25.4	47	1.5	96	63.6
	2.2	19	0.6	39	25.4	47	1.5	97	63.6
ROME	0.9	12	0.2	24	18.1	29	0.5	60	45.3
	1.25	12	0.2	24	18.1	19	0.5	60	45.3
	1.6	***15***	***0.3***	***29***	***21.8***	***37***	***0.7***	***72***	***54.4***
	1.9	17	0.3	33	24.2	42	0.8	82	60.6
	2.2	17	0.3	33	24.2	42	0.8	82	60.6
PARIS	0.9	8	1.8	18	9.9	21	4.6	46	24.7
	1.25	13	2.9	26	15.2	32	7.3	66	38.1
	1.6	***13***	***3.0***	***26***	***15.2***	***33***	***7.4***	***65***	***38.1***
	1.9	14	3.0	27	15.2	34	7.6	67	38.1
	2.2	7	1.6	14	7.9	18	3.9	35	19.7
LONDON	0.9	6	1.7	14	7.0	15	4.2	34	17.5
	1.25	10	2.8	22	11.2	26	7.0	55	28.1
	1.6	***11***	***2.9***	***22***	***11.2***	***27***	***7.2***	***55***	***28.1***
	1.9	12	3.1	24	11.9	30	7.8	60	29.7
	2.2	7	1.8	14	6.9	17	4.5	35	17.2
AMSTERDAM	0.9	7	1.5	16	6.6	17	3.7	41	16.4
	1.25	12	2.5	25	10.3	30	6.2	63	25.8
	1.6	***12***	***2.5***	***25***	***10.3***	***31***	***6.3***	***63***	***25.8***
	1.9	13	2.6	26	10.4	32	6.5	65	26.1
	2.2	8	1.6	16	6.4	20	4.0	41	16.1
NANCY	0.9	7	1.9	15	7.6	18	4.8	37	18.9
	1.25	7	1.9	15	7.6	18	4.8	37	18.9
	1.6	***7***	***1.8***	***14***	***7.2***	***17***	***4.6***	***35***	***18.1***
	1.9	7	1.9	15	7.4	18	4.8	37	18.6
	2.2	7	1.9	15	7.4	18	4.8	37	18.6

4.4. Thermal Response Test (TRT)

A Thermal Response Test (TRT) is recommended to determine accurately the ground heat exchange potential through the obtention of the equivalent thermal conductivity of the ground and the thermal contact resistance between the borehole (BHX or FHX) and the ground.

The TRT equipment is installed with the objective of characterizing the thermal behaviour of the thermo-activated foundation element inducing a controlled thermal disturbance in order to assess the potential of geothermal utilization of the system.

In TRT tests, inlet and outlet temperatures and volumetric flow rate are measured and monitored so heat exchange power can be calculated while the test is running under operational conditions. Furthermore, the external temperature is measured and monitored to analyse its influence. The measuring equipment consists of a water tank with electric heaters, or a heat pump, and a circulation pump. A diagram of the elements of the TRT equipment is shown in Figure 4 3

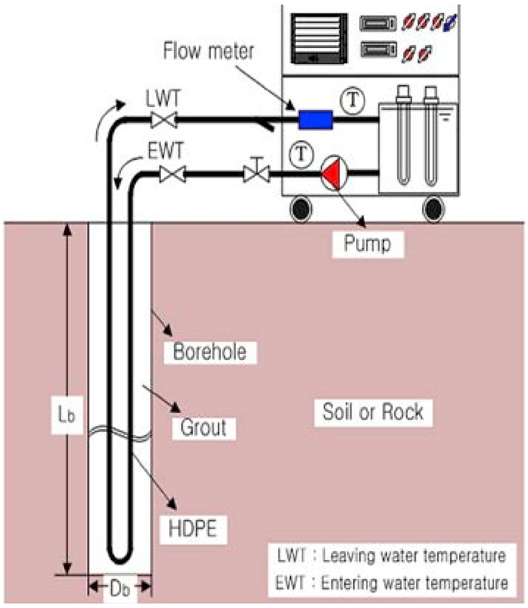

FIGURE 4-3 TRT EQUIPMENT

By measuring the temperature difference between the inlet and the outlet and applying the physical model used in the 'transient line source method' (TLSM), both the thermal conductivity of the ground and the effective thermal resistance of the borehole can be calculated.

4.5. Potential hybrid system configuration

In order to design a BiGEO system based on FHX technology, it is necessary – having estimated the building demand profile and the ground heat exchange potential – to estimate how much of the total building demand can be satisfied by the FHX installation. This has to be considered for both building heating and cooling conditions and also for peak heat transfer and long-term demands.

When the ground heat exchange potential through the foundation elements (FHX) is not enough to cover the building's heating and cooling demand profiles, the BiGEO system has to be hybridized according to the configurations defined below.

Where there is a large difference between the capacity of the ground FHX system and the overall building demand, it may be necessary a hybridization of the BiGEO system with other energy source system, that is called a "load-side hybridization". In this form of hybridization, it is recommended to **prioritize the BiGEO system to provide the baseload demand of the building and to maximize the use of the renewable energy source**. This optimization is shown in the following figure.

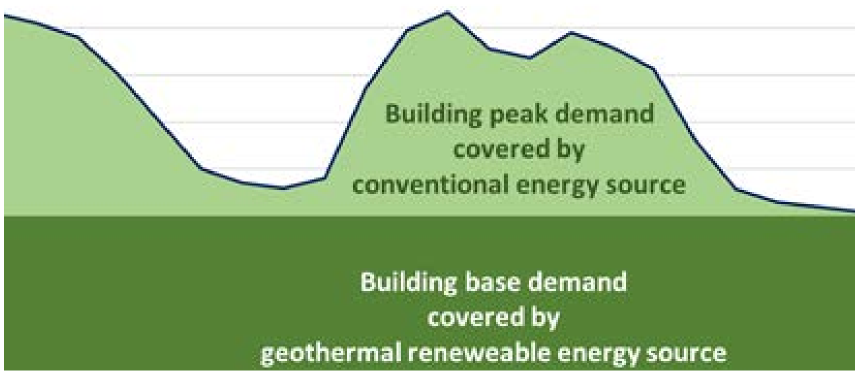

FIGURE 4-4 GEOTHERMAL SYSTEM COVERS THE BASE LOAD, AND FURTHER THERMAL DEMAND IS COVERED BY A COMPLEMENTARY CONVENTIONAL ENERGY SOURCE

Where there is a small difference between the ground heat exchange capacity and the building demand, hybridization may be possible by providing a BiGEO system capable of dealing with all the heating and cooling, with additional heat rejection equipment incorporated in the source-side of the system and/or with additional electrical heating capacity added to the heat pump for peak heating conditions. This "source-side hybridization" is often in the literature on hybrid geothermal heat pump systems. In some cases, a different approach is required for heating than for cooling e.g. source-side heating hybridization and load-side hybridization for cooling.

Hybrid configurations have to be controlled by an Energy Management System (EMS), which should prioritize BiGEO systems in order to maximize the use of geothermal renewable energy source.

4.6. BiGEO design

BiGEO systems are geothermal renewable installations formed by foundation Heat Exchangers (FHX), hydraulic circuits, geothermal Ground Source Heat Pump (GSHP) and the integration into building's HVAC system. All the materials and equipment implemented in BiGEO systems are conventional materials and products used for geothermal installations.

FHX DESIGN

The design and installation procedure of FHX elements (embedded in screen walls or piles) are crucial for the overall heat exchange capability of BiGEO systems.

The implementation of FHX systems is recommended for buildings whose foundation elements have the characteristics detailed in the following tables, and the recommended pipe parameters are the following:

TABLE 4-3 RANGES OF DESIGN PARAMETERS FOR SCREEN WALLS

SCREEN WALL (SW) TECHNICAL REQUIREMENTS	EXPECTED RANGE	UNITS
SW DEPTH	min 8	m
SW SECTION WIDTH	min 2	m
SW THICKNESS	min 45	cm
PIPE LATERAL SPACING	15-30	cm
PIPE DIAMETERS	20 / 25 / 32	mm
PIPE LAYERS	1 to 3	-

TABLE 4-4 RANGES OF DESIGN PARAMETERS FOR ENERGY PILES

ENERGY PILE TECHNICAL REQUIREMENTS	EXPECTED RANGE	UNITS
PILE DEPTH	min 8	m
PILE DIAMETER	min 20	cm
PIPE LATERAL SPACING	15-30	cm
PIPE DIAMETERS	20 / 25 / 32	mm
PIPE POSITION	Centre/rim/helix	

The FHX pipes are tied to the reinforcement cage, and quality-control requirements have to be taken into account in the design and installation process to ensure the avoidance of damaging the pipes during the construction phase, to maintain completely the mechanical resistance of the foundation elements, to optimize the ground heat exchange performance, and to ensure the air-purging of the BiGEO system. The design of the FHX should be performed by an experienced company to optimize the final quality of the BiGEO system (see section 4.7).

FHX ARRAY DESIGN

The hydraulic connection of all the FHX elements to the geothermal heat pump has to be designed to ensure the balance of flow rate through all the HXs. This hydraulic balance optimizes the overall performance of the geothermal system.

The design of the hydraulic system can be performed according to the following configurations (and/or a combination of them):

- Parallel connection of distributed manifolds: the subcircuits run in parallel to a general manifold prior to the geothermal Heat Pump connection.

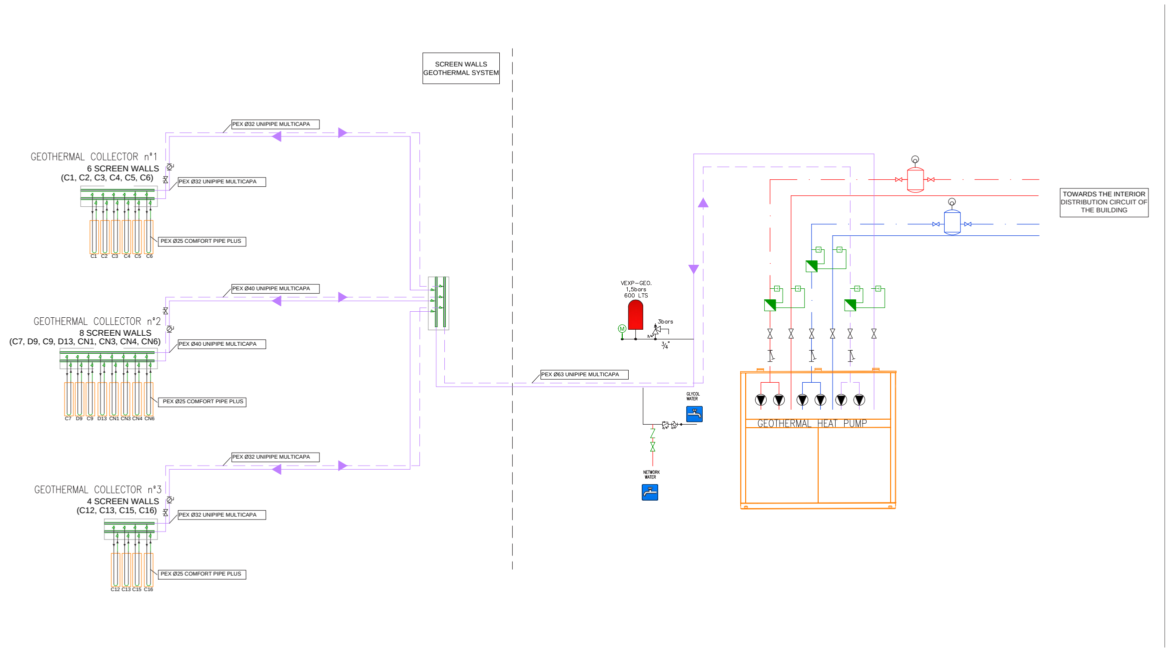

FIGURE 4-5 PARALLEL CONNECTION OF DISTRIBUTED MANIFOLDS

- Serial connection of distributed manifolds: the subcircuits run in series to a general manifold prior to the geothermal Heat Pump connection.

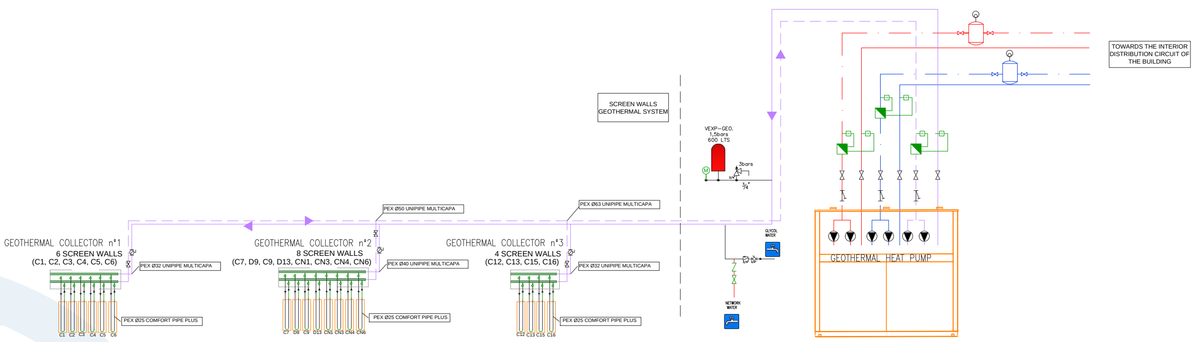

FIGURE 4-6 SERIAL CONNECTION OF DISTRIBUTED MANIFOLDS

- Interconnection of inverted return subcircuits: each subcircuit is connected in inverted return circuit configuration which is hydraulic self-balanced.

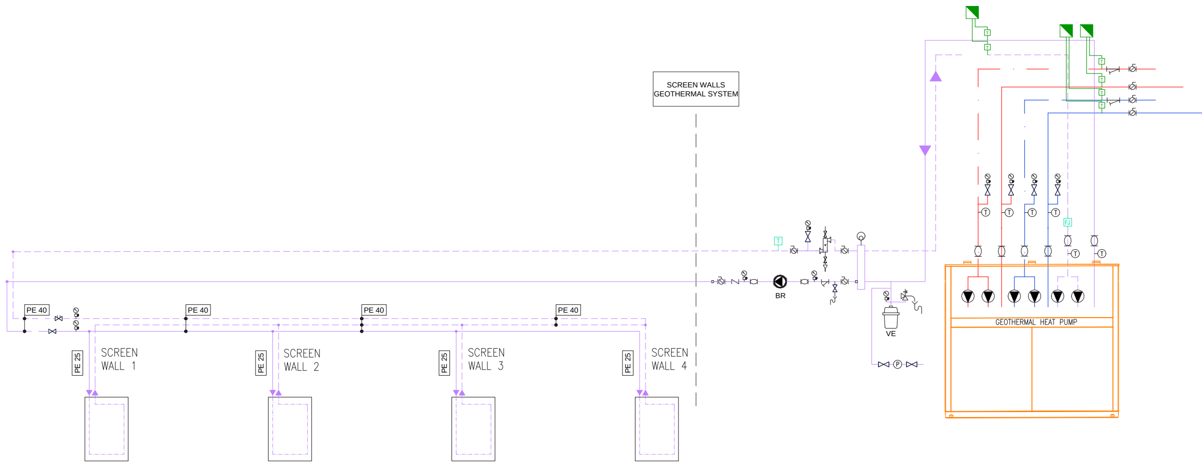

FIGURE 4-7 INVERTED RETURN CIRCUIT

Hydraulic circuits should be insulated to preserve the temperature of the circulating fluid and to prevent condensation on the pipe. Air bleeders should be installed in all the high-points of the circuit to ensure the air purging of the system.

HEAT EXCHANGER FLUID

The thermal conductivity of FHX (or other closed loop ground heat exchangers as BHX are) depends on the heat exchange fluid and the flow conditions among others. In many buildings in warmer climates with higher cooling demand systems, water is used as the principle heat transfer fluid. The designer must assess the risk of freezing at any point in the circuit, including where distribution pipes are exposed to cold environmental conditions, and can mitigate the risk by using antifreeze solutions (e.g. mono-propylene glycol) when it is needed.

4.7. BiGEO system construction

FHX technology reduce geothermal implementation costs by installing the heat exchangers embedded into the foundation elements during the building construction phase, which avoids additional drilling or excavation beyond what is required for the building itself.

The materials and construction procedures of the foundation elements doesn't change because of the implementation of the heat exchanger pipes (FHX). The construction process of the foundation is as usual, and the installation of the FHX pipes has to be coordinated with the excavation, the reinforcement cages construction and the concrete pouring. The heat exchanger pipes and the separators are fastened to the reinforcement cage to prevent friction during the installation process.

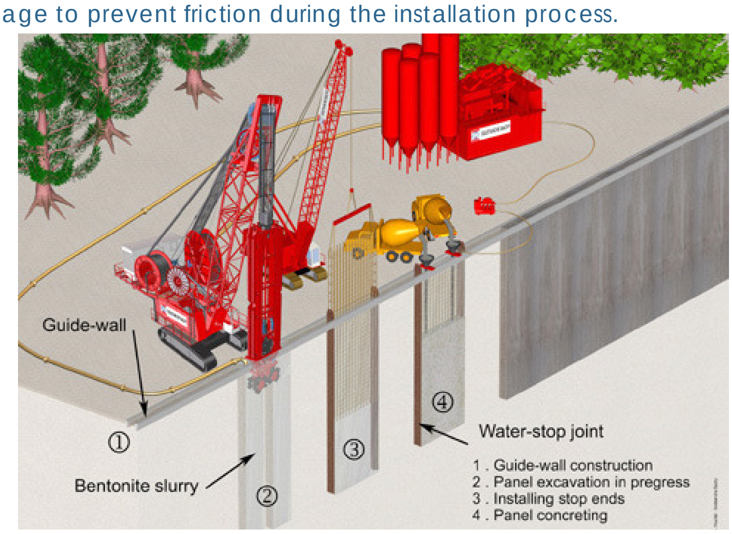

FIGURE 4-8 INSTALLATION PROCESS OF FHX

To ensure the final quality of the FHX installation, it is important that the design and installation process is supported by companies with expertise in BiGEO systems, such as COMSA or ARCbcn (see page 2). These companies can guide the additional steps of the FHX installation process, including the optimal design of the embedded pipes, quality control installation procedures including pressure tests (before and after the construction of the foundation elements) and the integration of the FHX array balanced circuits with the geothermal heat pump, through distributed manifolds or reverse return circuits.

4.8. BiGEO system testing and commissioning

The final commissioning of the geothermal installation should be performed with the technical services of each manufacturer of the installed equipment, mainly with the manufacturers of the Ground Source Heat Pump, the recirculation pumps and the Energy meters.

During the pre-commissioning stage of the ground source system, the initial simulation of the heating and cooling building demand profiles should be revised and confirmed to optimize the final operation of the geothermal system.

Once there is building thermal demand, the geothermal GHSP system will be tested considering two scenarios under building operational conditions:

- Nominal demand placed on the GHSP (including maximum and minimum loads)
- Partial demand placed on the GHSP with support from conventional hybridized systems

4.9. BiGEO Operation & maintenance (O&M)

The Operation and Maintenance of BiGEO systems is the same as O&M of conventional geothermal systems.

It is recommended to control and monitor FHX thermal loop temperatures (FHX inlet temperature, outlet temperature and flow rate) according to the initial design of the geothermal installation. This practice will avoid water freezing or overheating and ground thermal saturation.

The O&M activity is mainly focused on the geothermal Heat pump, the recirculation pumps and the hydraulic system (balance, pressure, etc).

5. BiGEO ECONOMIC ASSESSMENT

BiGEO systems are based on FHX technology, a cost-effective geothermal solution integrated in building's foundation. FHX is formed by a pipe embedded in foundation elements (screen walls, piles, etc) instead of conventional Borehole Heat Exchangers (BHX). BHX technology needs the specific drilling, pipe and grouting material for each borehole, while FHX only needs the required pipe to be fastened to the reinforcement cage of the foundation elements. This reduction of required materials and drilling activity translates to a significant reduction of costs for the implementation of FHX systems.

The implementation of BiGEO has a marginal cost on thermo-activating foundation elements (FHXs) for new buildings or deep retrofitting activities (underground car park floors, etc). A detailed analysis of costs of existing large-scale BHX systems has been performed in order to be compared with the costs of the large-scale FHX system installed in a demonstration site of the H2020 GEOT€CH project in Barcelona. The cooling capacity of the Geothermal Heat Pump (GHSP) associated with this FHX installation is 91,6 kW, while the cooling capacity of existing, comparable BHX installations are:

- ***110 kW.*** Conventional BHX installation in Barcelona city
- ***235 kW.*** Conventional BHX installation in Barcelona city
- ***240 kW.*** Conventional BHX installation in eastern-Pyrenees

Additionally, it has been designed and estimated the overall costs of a conventional BHX system in the demonstration site of GEOTECH project (office building in Barcelona city) with the same cooling capacity of 91,6 kW.

Cost analysis has been performed to compare the costs of heat exchangers (FHX vs. BHX) in existing installations, and to compare the costs of turn-key installation costs for the BiGEO system for each type of heat exchanger. The analysis results are the following:

A. Comparison of costs of the heat exchangers, FHX vs. BHX:

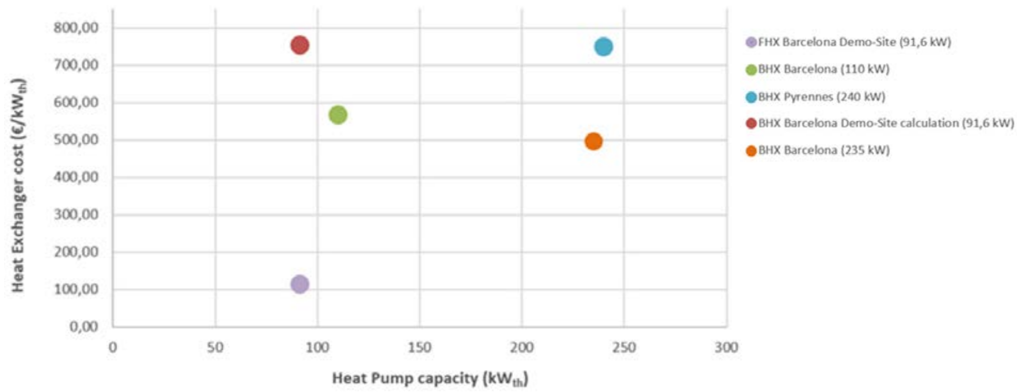

FIGURE 5-1 INSTALLATION COSTS OF GEOTHERMAL HEAT EXCHANGERS, FHX VS. BHX (€/kW$_{TH}$)

B. Comparison of turn-key installation costs of the BiGEO geothermal system for each HX technology (FHX vs. BHX) including the geothermal Heat Pump:

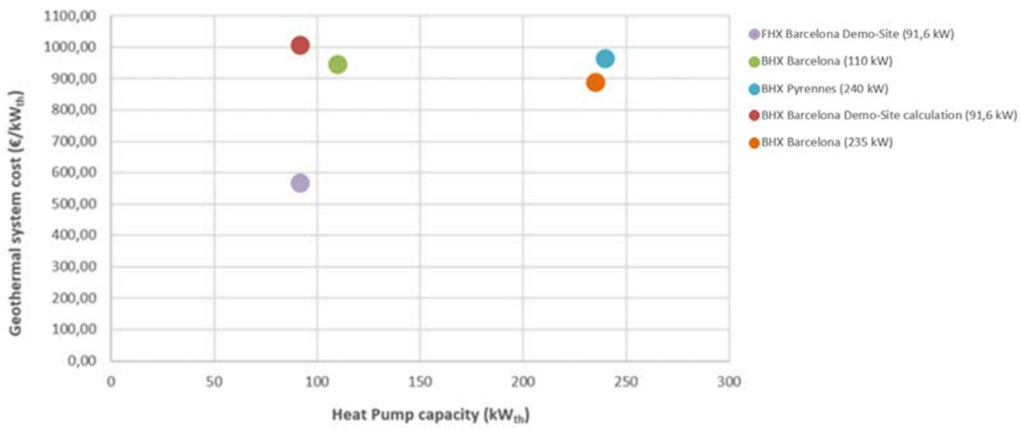

FIGURE 5-2 INSTALLATION COSTS OF BIGEO GEOTHERMAL SYSTEM (€/kW$_{TH}$)

The results show the significant reduction of costs of BiGEO FHX installation in Barcelona demo-site compared to existing BHX installations in Barcelona and Pyrenees. This reduction of costs is quantified in the following tables:

A. Reduction of costs of heat exchangers: FHX vs. BHX

BHX / FHX	BHX IN BARCELONA DEMO-SITE ESTIMATION (91,6 KW)	EXISTING BHX IN BARCELONA (110KW)	EXISTING BHX IN BARCELONA (235KW)	EXISTING BHX IN PYRENEES (240KW)	FHX COST REDUCTION (%)
FHX in Barcelona demo-site (91,6kW)	85%	80%	77%	85%	**82%**

TABLE 5-1 REDUCTION OF COSTS OF HEAT EXCHANGERS (%): FHX VS BHX

B. Reduction of costs of turn-key installation of BiGEO FHX geothermal system compared to BHX geothermal system:

BHX / FHX	BHX IN BARCELONA DEMO-SITE ESTIMATION (91,6 KW)	EXISTING BHX IN BARCELONA (110KW)	EXISTING BHX IN BARCELONA (235KW)	EXISTING BHX IN PYRENEES (240KW)	BIGEO FHX COST REDUCTION (%)
FHX in Barcelona demo-site (91,6kW)	44%	40%	36%	41%	**40%**

TABLE 5-2 REDUCTION OF COSTS OF TURN-KEY BIGEO FHX GEOTHERMAL SYSTEM VS BHX GEOTHERMAL SYSTEM

The total cost reduction for Building-integrated Geothermal Energy systems (BiGEO) based on FHX technology, compared to conventional geothermal systems based on BHX is about 40%.

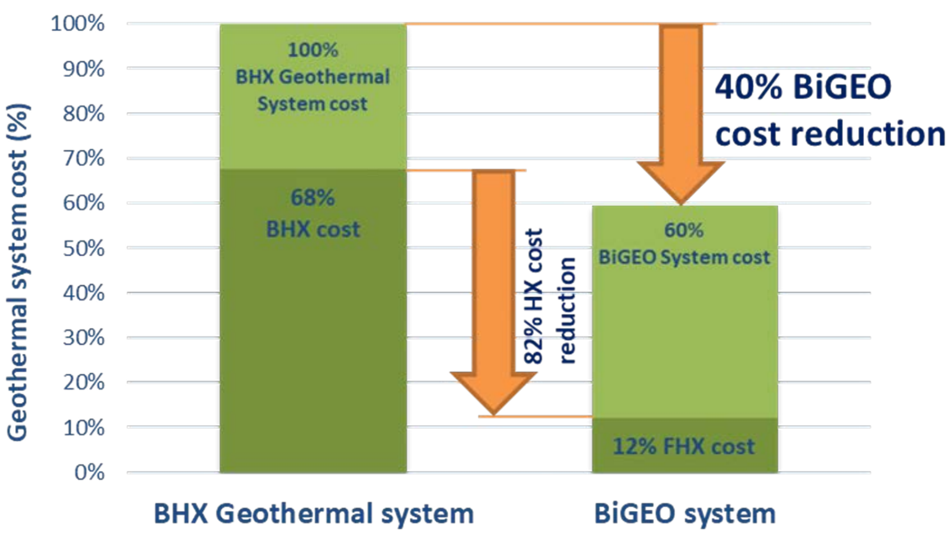

FIGURE 5-3 BIGEO COST REDUCTION COMPARED TO CONVENTIONAL GEOTHERMAL BHX SYSTEM

The initial investment for a BiGEO FHX system in the GEOT€CH demo-site office building in Barcelona is expected to be returned within 4 years.

6. EXISTING BUILDINGS WITH BiGEO SYSTEMS

This section presents existing buildings that have implemented BiGEO systems through the integration of FHX technology. The buildings are summarized in Table 6 1. Building typologies are defined in section 3.2.

TABLE 6-1 KEY PARAMETERS OF EXISTING BUILDINGS WITH BIGEO SYSTEMS

PROJECT TITLE	LOCATION	BUILDING TYPE	YEAR OF CONSTRUCTION	HEAT EXCHANGER TYPE	HEAT PUMP CAPACITY
GEOT€CH BiGEO FHX large-scale office building	Barcelona, Spain	Office building	2019	Screen walls	$100kW_{th}$
Playa de la Concha	San Sebastián, Spain	Car park complex	2009 (refurbishment)	Energy piles	-
Mercat de Sant Antoni	Barcelona, Spain	Market hall	2015 (refurbishment)	Screen wall	$600kW_{th}$
Shanghai Museum of Natural History	Shanghai, China	Museum	2011	Screen walls and energy piles	-
Knightsbridge Palace Hotel	London, United Kingdom	Hotel	2009	Screen walls and energy piles	$150\ kW_{th}$
Tradate residential building	Tradate, Italy	Residential	2015	Screen walls and basement slab	-
Vía Célere	Madrid, Spain	Office building	2014	FHX Screen walls and BHX	$110\ kW_{th}$
Cavas Castillo de Perelada	Girona, Spain	Wine Cellar	2019	Energy piles	$300\ kW_{th}$

6.1. GEOT€CH BiGEO FHX large-scale office building

TABLE 6-1 GEOT€CH BIGEO FHX OFFICE BUILDING

LOCATION	Barcelona, Spain
BUILDING AREA	12.700 m²
YEAR OF CONSTRUCTION	2019
NUMBER OF THERMO-ACTIVATED SCREEN WALLS (SW)	37
SW DEPTH	16 - 18 m
THERMO-ACTIVATED SW SURFACE AREA	770 m²
HEAT PUMP CAPACITY	100 kWth
BUILDING TYPOLOGY	Office building

6.2. Parking “Playa de la Concha”

TABLE 6-2 PLAYA DE LA CONCHA PROJECT DESCRIPTION

LOCATION	San Sebastian, Spain
YEAR OF CONSTRUCTION	2009 (retrofitting)
NUMBER OF ENERGY PILES	153
SW SURFACE AREA	1.500 m²
GEOTHERMAL COLLECTOR	12.800 m²
SW DEPTH	25 - 46 m
BUILDING TYPOLOGY	Parking complex

6.3. Mercat de Sant Antoni

TABLE 6-3 MERCAT SANT ANTONI PROJECT DESCRIPTION

LOCATION	Barcelona, Spain
BUILDING AREA	12.100 m²
YEAR OF CONSTRUCTION	2015 (retrofitting)
SW SURFACE AREA	17.400 m²
GEOTHERMAL COLLECTOR	45.270 m
SW DEPTH	42 m
HEAT EXCHANGE PER UNIT AREA	35 W/m²
HEAT PUMP CAPACITY	600 kW_{th}
BUILDING TYPOLOGY	Markey hall

6.4. Shanghai Museum of Natural History

TABLE 6-4 SHANGAI MUSEM OF NATURAL HISTORY PROJECT DESCRIPTION

LOCATION	Shangai, China
BUILDING AREA	12.029 m²
YEAR OF CONSTRUCTION	2011
SW SURFACE AREA	32.000 m²
SW DEPTH	38 - 40 m
BUILDING TYPOLOGY	Museum

6.5. Knightsbridge Palace Hotel

TABLE 6-5 KNIGHTSBRIDGE PROJECT DESCRIPTION

LOCATION	London, UK
BUILDING AREA	1.100 m^2
YEAR OF CONSTRUCTION	2009
SW DEPTH	36 m
SW SURFACE AREA	3.720 m^2
HEAT PUMP CAPACITY	150 kW_{th}
BUILDING TYPOLOGY	Hotel

6.6. Residential building in Tradate

TABLE 6-6 RESIDENTIAL BUILDING PROJECT DESCRIPTION

LOCATION	Tradate, Italy
BUILDING AREA	1.600 m^2
YEAR OF CONSTRUCTION	2015
SW DEPTH	10,8 m
SW SURFACE AREA	4.100 m^2
HEAT EXCHANGE PER UNIT AREA	12 – 15 W/m^2
BUILDING TYPOLOGY	Residential

6.7. Vía Célere office building

TABLE 6-7 NEW BUILDING OF THE COMPANY VÍA CÉLERE

LOCATION	Madrid, Spain
BUILDING AREA	1.452 m^2
YEAR OF CONSTRUCTION	2014
SW DEPTH	14 m
SW SURFACE AREA	600 m^2
HEAT PUMP CAPACITY	10kWt_{th}
NUMBER OF FHX	12
FHX DEPTH	100 m
BUILDING TYPOLOGY	Office building

* GEOTHERMAL INSTALLATION WITH HYBRIDIZED GEOTHERMAL TECHNOLOGIES: FHX AND BHX.

6.8. Cavas Castillo de Perelada

TABLE 6-8 NEW BUILDING EXTENSION

LOCATION	Girona, Spain
BUILDING AREA	6.700 m^2
YEAR OF CONSTRUCTION	2019
SW DEPTH	15 - 20 m
NUMBER OF ENERGY PILES	356
HEAT PUMP CAPACITY	300 kW_{th}
BUILDING TYPOLOGY	Wine cellar

7. BiGEO SOLUTIONS IN TENDERS

BiGEO systems can be included in both public and private tender processes. The requirements of a tender are stated in the Requests for Tender (RTF) or Requests for Proposal (RFP) documents. It is recommended to consult with companies experienced in the design and construction of BiGEO systems (see page 2) during the tender process.

Two different situations have been considered in which the incorporation of BiGEO solutions in tenders may be of relevance: at the design phase (tenders for developing basic or executive design projects) and at the construction phase (tenders for the construction works of buildings or infrastructures).

7.1. Design phase tenders

Organisations interested in publishing a tender related to the design phase of a new construction with BiGEO systems should consider the following recommendations, so their future construction runs on Foundation Heat Exchanger (FHX) technology.

BUILDING REQUIREMENTS

BiGEO technology is feasible for new constructions or deep renovation projects with new foundation components.

The main requirement to consider in tenders that include BiGEO solutions is that the construction should have a minimum depth and surface area of foundation elements (see section 3.2). Constructions that involve at least one underground floor (for instance for car park purposes or as an area of technical facilities) will have this required foundation structure.

RECOMMENDATIONS FOR TENDERS

Organisations wishing to have their new construction designed with BiGEO solutions should highlight in their tenders that it will be valued design projects that work towards energy efficiency and the implementation of innovative renewable energies following the EU Energy Roadmap 2050. High energy and environmental efficiency objectives are to be declared along with the indication of its aim to tend towards self-sufficiency and reducing installed power, preferably by the implementation of on-site renewable energy sources.

Furthermore, it is encouraged to refer or even include (for instance as an appendix) this BiGEO Guidebook so that companies interested in participating in the tender may have a deeper knowledge of this innovative solution such as the FHX (see section 4).

7.2. Construction phase tenders

Entities seeking to publish a tender for a new construction and that would like to implement BiGEO technology in its future infrastructure, should consider the following issues, depending on if their constructions are already designed with FHX or if their constructions don't consider FHX in their design phase.

CONSTRUCTIONS DESIGNED WITH BiGEO SYSTEMS

Designing the project already considering this technology for HVAC production is the intended way to proceed with implementing FHX technology. In these cases, tenders should only focus on the relevance and crucial aspects of the construction phase.

Section 4 of this Guidebook describes the main working phases involved in the implementation of BiGEO systems and thus, it should be reviewed and, ideally, included in construction tenders so that companies interested in participating in the tender are aware of the requirements of BiGEO implementation.

CONSTRUCTIONS NOT CONSIDERING BiGEO SYSTEMS

In case an organisation wants to publish a tender for the new construction of a building or an infrastructure that, during its design phase, would like to include FHX technology, it is important to consider the following aspects.

It is critical that the tender states that prior to the beginning of the construction works, the construction company (or the responsible entity) must assess the feasibility of implementing FHX in the construction. Tenders should indicate that, prior to start the construction, the design and planning project should be adapted to include FHX in order to have it successfully implemented (see section 4).

8. LEGAL ASSESSMENT

Recent changes in EU legislation on renewable energy and buildings has created more support for geothermal energy and FHX installations. Geothermal energy and certain biomass plants are now considered as forms of renewable energy and has become an area of shared competence between the EU institutions and the different countries of the EU.

Hence, it is worth providing a general overview of the main EU legislation relevant to shallow geothermal energy and FHX installations. A summary of the most recent EU directives has been published by the European Commission, including several to support decarbonisation of the energy sector through energy efficiency and renewable energy sources[10]. As of May 2019, the most recent directives are as follows:

- ***Directive 2018/2001/EU*** on the promotion of the use of energy from renewable sources (RES directive). This directive aims at increasing the share of renewable energies in the overall energy mix within the EU[11].
- ***Directive 2018/844/EU*** on energy performance buildings (EPBD). This directive focuses on the improvement of energy performance of buildings[12].
- ***Directive 2018/2002/EU*** on energy efficiency, aims at increasing the efforts currently made by Member States to use energy more efficiently throughout all stages of the value chain[13].
- ***EU Energy Roadmap 2050.*** The European Commission has issued a roadmap for moving to a competitive low carbon economy in 2050 (COM(2011) 112 final) to ensure that the political measures in place to achieve the 2020 targets are continued to deliver beyond 2020. For instance, it is expected that GHG emissions will be reduced by about 40% in 2050.

Additionally, there are environmental risks associated to drilling, installation and backfilling of borehole heat exchangers. The European Directives that directly affect groundwater contamination are as follows:

- Directive 2000/60/EC establishing a framework for Community action in the field of water policy.
- Directive 2006/118/EC on the protection of groundwater against pollution and deterioration.

These directives address the following points:

- Chemical variation of groundwater in confined aquifers. Of medium probability and high impact, it can be caused by leakage of contaminants from the surface, migration of contaminants from a shallower, bad quality, generally phreatic, aquifer, leakage of additives of circulating fluid due to a break in the pipes;
- Physical variation of ground and surface water. Of high probability but small entity, it concerns temperature variation of water due to geothermal system operation, affecting the ecology of rivers or wetlands;
- Chemical reactions of rocks induced by water. Of low probability and high impact, it follows an uncontrolled groundwater movement caused by vertical drilling and incomplete sealing and can induce subsidence or ground uplift.

Local authorities can suspend authorization procedure for borehole heat exchangers, requiring further investigations, in the following cases:

- In areas of groundwater source protection, close to potable water extraction and springs;
- In contaminated sites, coal mining sites or close to cesspits and septic tanks;
- Beside other vertical geothermal heat exchanger fields, to prevent high temperature variation and long-term resource thermal depletion;
- In areas of archaeological, landscape and environmental value;
- In areas subject to landslide;
- In geological settings characterized by karstic rock or significant thicknesses of evaporite minerals.

8.1. Regulation in Spain

The most important European standard in the framework of geothermal and the other renewable energies is the previously mentioned Directive 2018/2001/EU, which will be adapted by subsequent Spanish transposition regulation. In regulation, global national targets in relation to the share of renewables in the final energy consumption wil be specified. The Spanish target for 2030 is that 32% of

[10] https://ec.europa.eu/energy/en/topics/energy-strategy-and-energy-union/clean-energy-all-europeans;
[11] https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32018L2001&from=EN
[12] https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32018L0844&from=EN
[13] https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32018L2002&from=EN

the final energy consumption comes from renewable sources accordingly with EU regulations.

Additionally, there are several national legislations that affect FHX projects. This includes:

- RITE RD 238/2013, April 5th, which modify some of the technical instructions to adapt it into Directive 2010/31/EU (today 2018/844/EU) on energy performance buildings (EPBD).
- Order FOM/588/2017, June 15th, which modify the "Documento Básico DB-HE -- Ahorro de energía" and the "Documento Básico DB-HS -- Salubridad", of the "Código Técnico de la Edificación", in order to adapt it into Directive 2010/31/EU (today 2018/844/EU) (EPBD).
- Law 54/1980 of 5 November of Mining
- RD 1/2001 July 20th, known as 'Water Law' which adapts the European groundwater framework Directive 2000/60/CE.

8.2. Regulation in the UK

UK regulations relating to building energy efficiency have been guided by the EPBD since 2006. Recently (2010-2016), building regulations required the emission rate that has to be used for heat pump emissions calculations was fixed at 512 gCO_2/kWh. Design standards relating to geothermal heat pump installations for non-domestic buildings are voluntary in the UK. Guidelines have been produced by both the UK GSHPA and CIBSE. The GSHPA has produced voluntary standards for vertical borehole design and installation, and energy pile installations.

Besides the UK building regulations, another driver of the uptake of GSHP and other renewable technologies has been the incentive scheme known as the Renewable Heat Incentive, RHI. This has been designed to incentivize renewable technologies (both domestic and non-domestic) through payments based on kWh of renewable heat used.

8.3. Regulation in Italy

Italy has adapted the precursors of several of the aforementioned European Directives into national legislation. The adaptations are as follows:

- Italy D.Lgs. 28/2011, adaptation of the European ***Directive 2009/28/EU***, precursor to today's Directive 2018/2001/EU
- Italy L. 90/2013, adaptation of the European ***Directive 2010/31/EU***, precursor to today's Directive 2018/844/EU
- Italy D.lgs 102/2015, adaptation of the European ***Directive 2012/27/EU***, precursor to today's Directive 2018/2002/EU.

Additionally, any thermal effect on the mechanical behaviour of the ground structure must be taken into account in all building projects in Italy. The Italian *"Norme Tecniche delle Costruzioni"* (Technical Standards in Construction), recently updated (20 february 2018) report all rules and calculation methods to identify stress of ground structures, subjected to temperature variations and thermal expansion (Chapter 3.5.4). Moreover, guidelines for the correct design of energy piles are present in the Technical Norm UNI:11466-2012: *"Sistemi geotermici a pompa di calore. Requisiti per il dimensionamento e la progettazione"* (Heat pump geothermal systems. Design and sizing requirements).

8.4. Regulation in the Netherlands

In 2013 new legislation (AmvB Bodemenergie) with regard to shallow geothermal energy was implemented, regulating the use of shallow geothermal with regard to environmental regulations, quality certifications, underground thermal interference and permitting.

To assist local authorities with the implementation of shallow geothermal systems, the Dutch Ministery of Infrastructure and Environment (Ministerie van I&M) has developed guidelines (BUM/HUM)[14], in order to harmonize the implementation of geo-energy systems nationwide

[14] *Groenholland, Methode voor het bepalen van interferentie tussen kleine gesloten bodemenergiesystemen, 2011.*

9. ACRONYMS AND TERMS

nZEB: *Near Zero Energy Buildings*

BiPV: *Building-integrated Photovoltaics*

BiGEO: *Building-integrated Geothermal Energy systems*

SW: *Screen-Wall*

FHX: *Foundation Heat Exchanger*

BHX: *Borehole Heat Exchanger*

HX: *Heat Exchanger*

TRT: *Thermal Response TestGSHP: Ground Source Heat Pump*

EMS: *Energy Management System*

HVAC: *Heating Ventilating and Air Conditioning*

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