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## Deliverable D6.3

# Recommendations for the planning and implementation of new GSHP systems in dense urban environments and related tool

## WP6

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## Publishable summary

Deliverable D6.3 is a public document delivered in the context of WP6, Task 6.2 – “Proximity of Ground Source Heat Exchangers in Urban Environments”.

The objective of this task was to identify possible recommendations and try to resolve or prevent possible thermal interferences between nearby geothermal plants, in order to guarantee maximum efficiency for all geothermal systems, even over the long term. Studies and physics confirm that if geothermal plants are near to each other, there are thermal interferences that can have important effects for the good functioning of the system over time.

In **chapter 1**, different reports have been collected, summarized and evaluated, in order to provide an overview of the state of the art related to interferences between GHEs. We came up with a set of basic chronological steps in order to define and allocate responsibility to all the actors involved in the licencing, planning, design, construction and operation of geothermal plants. These steps are represented in a 6-steps circular diagram. The licencing system (P.1), the presence of an official database where data are collected (P.2) and the optimization phase (P.3) are the first three steps of the procedure. After the realization of the geothermal system, there follows: verification that the project has been carried out as described (P.4), the updating of the database after the implementation phase which is essential to ensure that the correct data is present for future nearby installations (P.5). The monitoring and supervision is the last step of the procedure, in which it is possible to verify the effective energy system functioning, to update the licensing system and the database, and finally to evaluate any possible adjustments if necessary (P.6).

In **chapter 2**, the procedure represented and described in chapter 1 has been applied to all case studies of the GEO4CIVHIC project, both real and pilot cases. Actual use of the application can shed light on how best to exploit it, maximising its potential, as well as give an idea of the shortcomings currently present, and offer possibilities to improve some specific areas. What is above all lacking is the presence of an official database and thus its updating, this should be strongly matched with the licensing system.

Finally, **chapter 3** tries to show, thanks to some specific simulation programs (TRNSBM and FEFLOW) the main parameters that can limit or increase the thermal interference between geothermal plants. Some specific geothermal configurations have been analysed concentrating on the thermal effects of one system on another; the configurations are a geothermal system with 1 BHE near to another similar one, and a geothermal system with 26 BHEs near to a small one with 1 BHE. These results confirm the problem, especially in the long term, and try to give suggestions to and promote awareness among designers and planners.

Moreover, an easy to use simulation tool has been developed with UNIPD, which is called ETHICAL (acronym for Easy THERmal InterferenCe evaluation). ETHICAL tool can be of great help in facing, planning and solving a complex and difficult problem such as thermal interference between nearby geothermal systems.

	<b>Abbreviations</b>
ANRE	Agentia Nationala pentru Reglementare in domeniul Energiei
BHE	Borehole Heat Exchanger
Cheap-GSHPs	Cheap and Efficient Application of reliable Ground Source Heat Exchangers and Pumps
CHF	Swiss Franc
DHW	Domestic Hot Water
EED	Earth Energy Designer
EIA	Environmental Impact Assessment
EIS	Environmental impact Statement
EPBD	Energy Performance in Buildings Directive 2002/91/EC (EPBD, 2003) & subsequent amendments
EPC	Energy Performance Certificate
FEFLOW	Finite Element subsurface FLOW system
GEO4CIVHIC	Most Easy, Efficient and Low Cost Geothermal Systems for Retrofitting Civil and Historical Buildings
GESPOS	Gestione Sondaggi, Pozzi e Sorgenti
GHE	Ground Heat Exchanger
GSHP	Ground Source Heat Pump
GWh	Gigawatt-hour
HFC	Hydrofluorocarbon
HTHP	High Temperatures-High Pressures
HVAC	Heating, Ventilation and Air Conditioning
IDEA	Instituto para la Diversificación y Ahorro de la Energía
Ktoe	Kilo tonne of oil equivalent
kW	kilowatt
kWh	Kilowatt-hour
MRA	Malta Resource Authority
nZEB	Nearly Zero Energy Building
NREAP	National Renewable Energy Action Plan
SBM	Superposition Borehole Model
SCOP	Seasonal Coefficient of Performance
RES	Renewable Energy Sources
vGHE	vertical Ground Heat Exchanger
VRV	Variable Refrigerant Volume
TRT	Thermal Response Test
TWh	Terawatt-hour

## Introduction

Within the framework of GEO4CIVHIC project, environmental impact, risk assessment and standard regulations are analysed in WP6. Within 6.2 the proximity of Ground Source Heat Exchangers in urban environments will be addressed.

In urbanized areas, a combination of district heating and stand-alone GSHP systems can result in minimum primary energy requests to supply heat to all the users, nevertheless different constraints on GSHP such as thermal interferences between neighbours have to be considered [1].

Deployment and high density of vertical GSHEs in urban and built environments are considered in this task concerning the potential reductions in environmental impacts and its consequences on the working systems.

An analytic tool has also been developed, capable of easy evaluating the temperature variation of the ground and of the fluid into the pipes for closed and open loop systems.

The structure of the deliverable is here briefly presented.

**Chapter 1:** Recommendations based on international experience: contain studies, articles, and documents; this information is summarized and the main findings are shown at the end of the paragraph. A table summarizes the main arguments arising from the different documents and a diagram shows a hypothetical flow of work necessary for the licencing system, to understand where interference problems could be present.

**Chapter 2:** Case studies analyses (Table 1): some selected information important for assessing thermal interferences is analysed: these data are selected from a bigger data collection made for GEO4CIVHIC project. Information is connected to building, subsoil, installation, operation, regulation and costs. For every real and virtual case, general description, data selected and final comments about interference are reported.

**Chapter 3:** Methods, criteria and tool able to foresee and prevent interference: different configurations and distances between BHEs fields have been analysed through simulations. A sensitivity analysis on different geometric and thermal parameters has been done. The effects of the thermal interference have been made explicit, in order to prove the effect that near geothermal systems can have each other. An easy tool for a preliminary sizing and evaluations of geothermal systems called ETHICAL (Easy THERmal InterferenCe evALuation) has been developed and proposed.

**Chapter 4:** Conclusions, best practices and recommendations. This section summarizes all processes previously described.

Table 1: Real and virtual case studies.

<b>Case Study Type</b>	<b>Description</b>	<b>Responsible Partner</b>
Real	Historical Building La Valletta Malta	DLH
Real	Historical Building Ferrara	UNESCO
Real	Residential Building Mechelen	GEOGREEN
Real	Historical Residential Building Wicklow Ireland	GEOSERV
Virtual	Museum of Natural History of Alexandroupolis	CRES
Virtual	Administrative building "Palacete de la Cruz Roja"	UPV
Virtual	Residential building Avangarde Forest	PIETRE
Virtual	Residential building in Bucharest	RGS
Virtual	University building "Ex Ospedale Geriatrico"	UNIPD
Virtual	Historical building in Split CROATIA	UNESCO
Virtual	University Building in Erlangen	FAU
Virtual	Historical building "Castle of Attre"	GEOGREEN
Virtual	Carnegie Clondalkin Library	GEOSERV
Virtual	Administrative building "AIL (Aziende Industriali di Lugano)"	SUPSI
Virtual	Residential Building Marienburg Soest - Netherlands	CNR-ISAC
Virtual	Residential Building Alsamora 6	CNR-ISAC

# 1 Recommendations based on international experience

In this chapter a list of projects, documents and articles describing the state of the art of interference problems is presented; they are presented chronologically, in order to show how concepts and ideas emerged in different sectors of activity or nations. Moreover, all the information and considerations here described have been analysed in order to select and propose workflow planning capable of recognising, correcting and reducing problems of ground source interferences.

## 1.1 State of the art

The sources are mainly scientific reports, that consider problems connected with interference or some geothermal problem that could have a relevant impact on the choice of guidelines, because they underline some specific aspects.

*Table 2 - A list of previous works from European Countries, with a particular focus on Swiss geothermal experience, where the topic of shallow geothermal systems and prevention from future interference problems is well-known and addressed.*

Year	Title	Country	Chapter
1999	Prospects for ground-source heat pumps in Europe	Germany	1.1.1.
2000	Neubaugebiete mit Erdwärmesonden in Werne und Dortmund-Mengede	Germany	1.1.2.
2007	Geothermische Energie im Kanton Zürich - Grundlagen und Potenzial	Switzerland	1.1.3.
2012	Wärmeversorgung: potenziale der Quartiere	Switzerland	1.1.4.
2012-2015	ReGEOcities	Germany, France, Denmark, Netherlands, Sweden, Ireland, Belgium, Italy, Spain, Romania, Greece	1.1.5.
2014	Erdsondenpotenzial in der Stadt Zürich	Switzerland	1.1.6.
2015	Erdwärmesonden im Dichtestress	Switzerland	1.1.7.
2015	Optionen zur Vermeidung nachbarschaftlicher Beeinflussung von Erdwärmesonden: energetische und ökonomische Analysen	Switzerland	1.1.8.
2017	Scientific achievements and regulation of shallow geothermal systems in six European countries – A review	Italy, Germany, Spain, United Kingdom, France, Sweden	1.1.9.
2017	Das Recht und die Regulierung der Erdwärme	Switzerland	1.1.10.
2017	Procedura di autorizzazione nei diversi Cantoni per l'installazione di sonde geotermiche verticali	Switzerland	1.1.11.
2017	Haute densité de sondes géothermiques calcul des effets à long terme d'installations géothermiques dans un quartier	Switzerland	1.1.12.
2018	Report on different kind of barriers for shallow geothermal in deep renovation (D1.1)		1.1.13.
2018	Strategische Planung von Erdwärmesonde	Switzerland	1.1.14.
2018	Integrating a thermal model of ground source heat pumps and solar regeneration within building energy system optimization	Switzerland	1.1.15.

Year	Title	Country	Chapter
2018	A Novel Tool for Assessing Negative Temperature Interactions between Neighbouring Borehole Heat Exchanger Systems	Netherlands	1.1.16.
2018	Thermal influence of neighbouring GSHP installations: relevance of heat load temporal resolution	Sweden	1.1.17
2019	Bericht «Überprüfung der Auslegungskennwerte zur strategischen Planung von Erdwärmesonden»	Switzerland	1.1.18.

### 1.1.1 Prospects for ground-source heat pumps in Europe

This article [2] discussed the situation of GSHPs in Europe: at that time Sweden and Switzerland had already had a tradition in this technology, but also in Austria, Germany and Netherlands GSHPs were increasing. To guarantee the environmental quality due to the growing numbers of GSHPs, standards and guidelines were issued (e.g. German VDI-guideline 4640 "Thermal Use of the Underground" (draft published 2/1998). The German states of Baden-Wuerttemberg and Brandenburg, and the Swiss canton of Berne, had collected information, including maps, to help citizens and authorities in the licensing procedure.

The question set was "how sustainable is shallow geothermal energy"? The exploitation through GSHPs drop temperature of the ground, or could be planned to operate without artificial thermal recharging of the ground? The answer, thanks to monitored data, was that correct sizing allow to operate in a sustainable way for long periods.

The issues due to the presence of several actors involved in GSHP installation, such as designers, drillers, heat pumps manufacturers, installers etc, had been already appeared at that time.

Moreover, it was suggested the presence of straight politics at European level would have improved the optimization and diffusion of this technology.

### 1.1.2 Development areas with geothermal probes in Werne and Dortmund-Mengede<sup>1</sup>

This article [3] explained two projects in German (Werne and Dortmund-Mengede), that at that time were probably the largest residential areas in Europe supplied by GSHPs. The accommodations were equipped individually with geothermal probes and their length was calculated using EED software. It was necessary to counteract the mutual influence in heat extraction and to provide longer probes lengths in the case of particularly dense buildings. The EED program was applied to a district to ensure a secure long-term heat supply, compared to the application to the VDI 4640 guideline, which cannot be use for larger geothermal probe fields.

### 1.1.3 Geothermal Energy in the Canton of Zurich - Fundamentals and potential<sup>2</sup>

This work comprises the current state of knowledge on geothermal energy for the Canton of Zurich (year 2007). Data about geothermal potential (deep and surface geothermal resources) are presented. Knowledge of geothermal potential is here considered as the first step in understanding

<sup>1</sup> Neubaugebiete mit Erdwärmesonden in Werne und Dortmund-Mengede

<sup>2</sup> Geothermische Energie im Kanton Zürich - Grundlagen und Potenzial

how better to exploit it. This is one of the first works about geothermal potential, and it has allowed us in the following projects here described to exploit geothermal systems and to better understand and solve possible future problems. Even if this report is not specifically focused on interferences, it is the key work that allows the exploitation of geothermal energy and the bases for future Swiss projects that tackle the problem of interference.

#### **1.1.4 Heat supply: potentials of the neighbourhoods**<sup>3</sup>

The city of Zurich has developed an energy supply concept for the year 2050 (EC 2050). It shows that the 2000-Watt targets in the construction sector can be achieved through accelerated building renovation and as wide as possible use of renewable energies.

The specific building heating demand (kWh/m<sup>2</sup>/y) was calculated with the standard SIA 380/1 for a number of different types of buildings and then applied to all buildings of the city. Subsequently it was applied to the regional development of the city of Zurich, which defines the urban densification for every urban area. The main factors that influences the heating energy demand in future are: the growing number of energy reference area and the increases in efficiency.

- In areas of the city where there is a high building construction potential, the energy reference area increases, but the energy efficiency standard will be significantly better compared to existing buildings. On the other hand, in areas such as the city centre, the area remains more or less the same, but improvements in building efficiency are limited, so possible savings of energy are lower in future.
- About heating use, a spatial proximity between supply and demand is considered to be necessary in the framework of the EC 2050 (balance energetic and environmental benefits between district heating networks and BHE systems).

#### **1.1.5 ReGeoCities**

"The ReGeoCities project worked on the integration of shallow Geothermal Energy at a local and regional level. It examined and promoted best practices and an intelligent regulatory framework, supporting cities to reach their SEAPs (Sustainable Energy Action Plans) and the 2020 climate and energy goals". The project shows that in most of the analysed countries regulation exists for BHE but with different procedures and conditions. Some nations do not have any regulations; others have regulation based on long and complicated license procedures. The legislative and regulatory frameworks of 10 EU countries were considered, highlighting best practices that have supported huge development in countries such as Sweden, Germany, France and Denmark [4].

The recommendations propose a centralized and simplified administrative process which differentiates the requirements for the authorization of small domestic or residential systems through a simplified online registration or communication process. For large systems, a more complex authorization is envisaged, including risk assessment, environmental impact assessment, authorization and subsequent monitoring. Even if such topic is not focused on interference problems, it gives a normative base and it allows to clear the differences between countries where regulation for geothermal systems is more or less developed.

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<sup>3</sup> Wärmeversorgung: potenziale der Quartiere

### 1.1.6 Geothermal potential in the city of Zürich <sup>4</sup>

In 2007, the state of knowledge on geothermal energy for the Canton of Zurich was presented [5]. In 2008, the voters of the City of Zurich committed themselves by a large majority to reducing energy consumption to 2'000 Watts per person. The Energy Supply 2050 concept (ES 2050, [6]), developed by the City of Zurich in the context of this energy policy specification in the municipal ordinance, assumes, in the efficiency scenario, that from 2050 onwards oil and natural gas will only cover to 5% to 10% of heating demand, while heat pumps (electricity and environmental heat) and district heating will provide the highest proportion of heat demand. Geothermal heat, surface water, fresh air and unused waste heat serve as heat sources for heat pumps. The present study [7] is a follow-up to ES 2050. With a special focus on the high heating demand density in the urban context, as required from the present European project, the potential of BHEs for heating and cooling supply was examined in more detail. The current status regarding the dimensioning of BHE systems was researched (standard SIA 384/6) and the essential theoretical principles summarized. These basics were compared with the current situation of geothermal energy use in the city of Zurich and with the expectations formulated within the framework of urban energy policy for the future use of energy systems with BHEs.

A conservative calculation shows that a sustainable extraction of heat from the subsurface is only possible in each singular specific context. A significant and sustainable use of shallow geothermal energy is therefore not possible without further adoptions. The reasons are the increasing use of geothermal energy in the city of Zurich, which leads to ever closer BHE distances and thus to mutual influence and the approach limited to 50 years for the design of BHEs in accordance with the SIA standard. The effective natural potential is therefore not sufficient to sustainably provide the amount of energy intended for geothermal energy use in the EC 2050.

In the Swiss climate, with predominance of building heating instead of cooling, the increasing mutual influence of BHEs causes a growing cooling of the subsurface. This can be reduced or even compensated by means of a forced regeneration of the subsurface (e.g. from solar collectors, cooling buildings or heat from the ambient air). The active regeneration of the subsoil has already been tested for individual objects and is absolutely necessary for larger BHE fields with small BHE spacing and is therefore state of the art. In the city of Zurich, however, only 15% of the installed systems are exposed to heat injection into the ground (active regeneration). The remaining plants usually have only a few BHEs, which are designed only for heat extraction. However, active regeneration is also possible for small systems or single BHE.

Since the distance between different geothermal systems (both large and small) is usually greater than the typical distance between the probe and the probe of the individual system, the effect of thermal interference or the benefits of regeneration can only be felt in the long term.

Low-temperature district heating networks are a suitable technology for a quantitatively significant heat supply via actively regenerated BHE fields, since they use different heat sources (heat wastes, cooling needs, solar collectors' surplus, etc.). Heat consumers can be connected with each other. BHEs assume the role of a seasonal storage facility in such networks.

In the urban area of Zurich, on the basis of three pilot sites, the question whether sufficiently large BHE fields could be realized as seasonal heat accumulators under the local conditions (heat demand at individual object level and space available for BHE drilling) has been examined. It has been shown that the heat demand expected in the year 2050 can be provided by actively regenerated BHEs fields

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<sup>4</sup> Erdsondenpotenzial in der Stadt Zürich

in the three investigated areas. These pilot areas are representative of many urban areas. This is an important aspect for the present European project, which wants to address interferences problems in areas of density. In the urban context, however, small and independent BHE systems also play a role, as they can also be regenerated from a technical point of view.

### 1.1.7 Stress between near geothermal BHE<sup>5</sup>

This article [8] summarized the case of the city of Zurich, where both a technical report and a research project underline the necessity of having clear regulations in shallow geothermal exploitation and an energy management of the subsoil, by recharging it. Moreover, it tackles the problem caused by public and private law, which could be in conflict, if the law is not clear enough in some specific areas. Finally, possible physical interference has been taken into account (for example, the railway FFS of Zurich has replaced private facilities as a precaution). Another suggestion proposed here is the adding simulation of technical standards and experience methods.

### 1.1.8 Options to prevent neighbourly influence of BHEs: energetic and economic analyses<sup>6</sup>

This study [9] was conducted to compare methods to compensate mutual influence of adjacent BHEs plants by active regeneration or additional BHEs. The report investigated how different heat sources are suitable for the regeneration of BHE fields, which degrees of regeneration can be achieved with the different methods, and what effect the regeneration has on the heat production costs. On the basis of the simulation results and the assumptions made, the following statements can be made:

- If neighbouring objects are taken into account in the design, this results in a massively stronger BHE cooling over a long period of time. With the assumptions made in this study, which reflects a geothermal density of circa  $35 \text{ kWh m}^{-2} \text{ y}^{-1}$ , the BHEs cool down by an additional 7 K after 50 years compared to a situation without neighbouring BHE plants. Even partial regeneration can counteract the long-term cooling of dense geothermal energy. This allows a higher geothermal heat utilization density and/or a longer operating time of the BHE fields.
- If a complete regeneration (100%) is to be aimed for, this is only possible with large covered or selectively uncovered solar collector arrays under the options considered. Under the assumptions made, however, complete regeneration is not necessary.
- The variant of the over-dimension of the BHE length in order to guarantee frost-free operation of the field during the first 50 years operation is not recommended either economically (heat production costs) or from the point of view of sustainability (progressive cooling after 50 years). Active regeneration is usually cheaper and definitely more sustainable.
- The differences between the heat production costs with different regeneration methods are small. Therefore, none of the regeneration methods can be favoured. The regeneration method can thus be selected depending on the specific application situation (energy supplies, temperature levels, technology available and installable, etc.).

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<sup>5</sup> Erdwärmesonden im Dichtstress

<sup>6</sup> Optionen zur Vermeidung nachbarschaftlicher Beeinflussung von Erdwärmesonden: energetische und ökonomische Analysen

From a technical point of view, it is possible to retrofit active regeneration only when a critical usage density has been reached. This means that the BHEs can be designed in the usual manner. However, if there is a critical usage density in the neighbourhood, regeneration should be planned over a large area (for all objects in the neighbourhood). For existing plants, this means that a regeneration must be retrofitted when a critical utilization density is reached. When a critical temperature has already been reached, a temperature drop can only be prevented with a complete regeneration. The partial regenerations should be installed in the neighbourhood when a high BHEs density is being reached (and not only when the critical temperature is reached).

The use of the respective regeneration technology ultimately depends on various factors: the BHEs density on site and the strength of the cooling; the degree of regeneration to be achieved; the possibilities of the respective regeneration technology for the specific building project and the preferences of the client.

### **1.1.9 Scientific achievements and regulation of shallow geothermal systems in six European countries**

This paper reviews scientific literature on geothermal heat pumps; regulation and technical guidelines for some European countries, focusing on environmental effects caused by open and closed loop systems [1]. The article underlines that in urbanized areas, a combination of district heating and stand-alone GHP systems can result in minimum primary energy demands to supply heat to all the users [10], considering constraints such as thermal interferences [11]. This paper presents important factors to consider during the design phase with respect to variation (on a short and long time scale), the use of GIS-based maps of shallow geothermal potential as a tool and also considers solar assisted systems as a solution to regenerate heat.

The proposal for the European legislative framework are that:

- licensing should be delegated to local/regional level administration
- licensing should be as simple (clear) as possible
- low risk systems should be defined for open and closed loops. E.g. Germany applying a capacity limit (>30 kW), needs to support the plants by calculation and modelling. For smaller plants, notification is enough but the designer should guarantee that neighbouring registered boreholes/wells are not affected (i.e. temperature decrease is less than 0.5°C)
- monitoring should be implemented in the licensing criteria.

### **1.1.10 The law and the regulation of geothermal energy <sup>7</sup>**

Although thermal aspects of interference are taken more into account, there are important areas to consider: this article focuses on geothermal regulations in Switzerland, trying to collect the main references and the problems present nowadays [12]. Even if this article concerns a specific country, these aspects are also key points for all European Countries.

The most relevant issues are two:

- the first one concerns the disputes between land-owners, due to the fact that plants in proximity can influence each other, from both the thermal (lower efficiency in existing systems, freezing the ground or blocking the HP) and physical (inclined drill, which could go in the terrain of the neighbours) point of view;

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<sup>7</sup> Das Recht und die Regulierung der Erdwärme

- the second one concerns the fact that the State wants to protect the underground and also wants to create infrastructures, so legislators and lawyers have to reconcile several aspects. Legal right in geothermal issues are twofold: civil and the public rights. Usually these categories are separate and lawyers are skilled in one of the two areas of interest (civil court for the civil right and administrative courts for the public right). This is a huge problem, because it is not clear how both rights can solve about geothermal issues, when there are disputes concerning both<sup>8</sup>.

The city of Zurich has a great experience for anticipating problems caused by proximity. Unclear regulations about geothermal energy is a barrier to the spread of this technology.

In this matter there is also a dissertation [13] that sheds light on the interface between federal civil law and cantonal public law underground. It shows under which conditions the landowner is entitled to use geothermal energy on the basis of the Civil Code and what applies in the relationship between several neighbouring landowners. It also examines what influence cantonal legislation has on this right of use and what the legal situation is if cantonal law does not regulate the use of geothermal energy.

A representative example reported in this dissertation happened in Canton Argau, in Switzerland, where a drilling of 240 m had a lateral deviation of 57 meters, going in depth in others cadastral.

### **1.1.11 Authorization procedures in the various cantons for the installation of vertical BHEs<sup>9</sup>**

SFOE (Swiss Federal Office of Energy) analysed Swiss regulations in Cantons (for the 2015-2016 period) and it allowed interchanging in information and different experiences [14]. The cases show that there are some points shared and others that could be different.

The "Ordinanza sulla protezione delle acque/Ordonnance sur la protection des eaux/Gewässerschutzverordnung"<sup>10</sup> (814.201 OPAC), which is a national ordinance, requires an authorization linked to water protection issues, not specific for the BHEs; the Cantonal office for water protection releases the permit. In most Cantons, a building permit is necessary for the installation of BHEs. In most cases, cantonal authority release permits, in others it is the remit of municipality authorities. In almost all case (with the exception of 2 Cantons) there is a minimum distance from the border of the neighbour. There are cantonal websites with localization of BHEs. There is a depth limit, with the exception of 3 Cantons.

This document shows that even in a small country with a long experience in BHE installations, procedures and regulations can be different Canton by Canton, and a common set of new procedures and requirements could be implemented with a certain amount of difficulty.

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<sup>8</sup> Due to the high costs of a court case, there have not been, to our knowledge, cases where a private citizen has faced litigation caused by interference between BHEs (until 2017). The Civil Code it is not clear on the property rights regarding the subsoil: to which depth does property in Switzerland belong to the owner or belong to State. In the Civil Code the property is of the owner as long as he has an interest in the subsoil. For this reason, there is an open question considering geothermal issues. Precisely to avoid conflicts between different use of soils, Cantons have introduced several regulations in the last 7 years: it is necessary to respect SIA 384/6, since this standard governs technical issues, but it does not ensure avoidance of interference between probes, problems between neighbors, or a correct use of the resources. However, in Switzerland it is currently not clear where the physical limits of the private property of the subsoil lies. (Does it correspond to the surface border? Do they concern infrastructures or even take into account thermal effects?).

<sup>9</sup> Procedure di autorizzazione nei diversi Cantoni per le installazioni di sonde geotermiche verticali

<sup>10</sup> Waters Protection Ordinance, article 32, paragraph 2, letter f.

### **1.1.12 High Geothermal Probe Density - Calculation of Long-Term Effects of Geothermal Facilities in a Neighborhood<sup>11</sup>**

This work [15] evaluates thermal interactions between geothermal probe fields and the effect of thermal recharge.

A thermal recharge of the ground, in the context of the long-term influence of BHEs, profits above all the installation where it is carried out. The solution of increasing the length of the probes in the case of a district with a high density of BHEs for the extraction of heat is clearly not durable over time. Thermal recharge is therefore a collective effort in which everyone should participate. However, it can be said that two probes will never influence each other if the distance between them is greater than their depth. This makes it possible to delimit the area to be considered for the analysis of the long-term influences of neighbouring installations. On the other hand, the effect becomes increasingly important with a lower and lower distance. We cannot accept that BHEs from an installation are laid a few meters away from another.

It has been seen that the long-term influence of neighbouring installations on a given installation results in a further lowering of the minimum temperature of the fluid. The "first come first served" rule does not work because if new facilities can take into account existing facilities, the opposite is not usually possible. However, it is important to be able to size an installation taking into account future installations or by making arrangements to adapt the installation if necessary. The long-term influence of one facility over another depends directly on the exploitation of the geothermal resource. The study showed that the higher the density of BHE systems and the number of installations, the less the geothermal resource can be exploited by each facility. One way to limit this and control its use is to provide a thermal refill. It's important to determine how much geothermal resource it going to be used, and consequently to know the mandatory thermal recharge in order to prevent thermal problems.

The three criteria involved are:

- minimum distance between two-field probes (unless specifically considered in the design);
- elevation of the minimum fluid temperature for the design of the installation, in order to anticipate the long-term effects of neighbouring installations;
- a limit to the total extraction of the geothermal resource by installation, in order to limit and contain the long-term effects on neighbouring installations.

In this study, an evaluation of the oversizing of the system in terms of BHE length, necessary to compensate the lack of heat exchange, has been represented through a formulation.

### **1.1.13 Report on different kind of barriers for shallow geothermal in deep renovation (D1.1)**

The report, presented for the GEO4CIVHIC project, summarized the main barriers present against shallow geothermal energy in building refurbishment. Among the limitations for design of underground systems the interference between GSHPs and the fact that the thermal footprint has to be determined where there are other GSHPs in the surroundings are mentioned. The study of the

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<sup>11</sup> Haute densité de sondes géothermiques - Calcul des effets à long terme d'installations géothermiques dans un quartier

thermal behaviour over time is necessary and recommended in order to limit the thermal drift in the underground.

It is proposed to consider as KPI to check the sustainability of proposed solutions and it should be dealt in T1.3 and T1.4 [16].

#### **1.1.14 Strategic planning of geothermal BHE<sup>12</sup>**

For a sustainable and equal use of the underground during 50 years of the working system, the following actions are necessary: planning aids for design taking into account (possibly future) uses and spatial planning aids for local authorities for optimal use of their resources. This resource takes up both aspects.

For public authorities, criteria are fixed to help and define the unregulated areas. These are based on specific heat demand densities of the building zones (in MWh/ha/y). For planners, the "land area-related heat demand" (in kWh/m<sup>2</sup>/y) provides an additional design ratio, which allows the consideration of potential neighbourhood uses, and it is included in the calculation. If this is greater than a fixed value (8 kWh/m<sup>2</sup>/y), measures must be taken to avoid neighbouring conflicts during future operational years due to heat over-extracted heat (oversizing or higher regeneration are required).

#### **1.1.15 Integrating a thermal model of ground source heat pumps and solar regeneration with building energy system optimization**

This paper describes a methodology for the optimization of a building energy system including a detailed thermal model of a borehole heat exchanger based GSHP. The novelty of this model is that it enables the study of dynamic temperature changes within the ground during operation. Furthermore, a model of solar thermal collectors is also included, which enables the study of solar regeneration of the ground in the short and long-term. The results indicate that, increasing the solar thermal collector area can lead to significant emissions savings, but has high investment costs. A larger solar thermal collector area also helps in reducing the total length of the borehole heat exchanger, resulting in savings in investment costs (The methodology has been applied to a single-family residential building in Zurich, Switzerland). Additionally, in another report the analysis of the recharge effect showed that the improvement of the mean performance coefficient of the heat pump is small and it does not compensate the additional electric energy consumption induced by the circulation pump when solar gains are injected into the ground. However, the overall system efficiency is only slightly decreased (1 to 2 %). The solar thermal recharge of the ground proves to be an interesting solution to avoid overheating problems in the solar collectors [17].

#### **1.1.16 A Novel Tool for Assessing Negative Temperature Interactions between Neighbouring Borehole Heat Exchanger Systems**

This research assesses the negative interaction between nearby BHE systems. There are comments and discussion on the problem, simulations with creations of nomograms and table helping comprehension. The normative and protocols currently do not take into account operations of different and nearby systems (superposition). Available information is usually limited and a line

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<sup>12</sup> Strategische Planung von Erdwärmensonde

source method<sup>13</sup> can help the evaluation. Some evaluation on the presence of flowing ground water has been made. Some important recommendations are:

- Needs of registration, at least the system into the lot, if the coordinates are not possible (this give an error of 10% on the evaluation);
- Definition of zones of interference, where public authority must pay attention (decrease of efficiency, and increase of technical problems);
- Definition of the limit of temperature tolerance between different systems in mutual interference (e.g. up to 0.1K could be defined as acceptable, since a "small effect" is tolerable);
- Definition of maximal energy extraction of the lot (e.g. In kWh/m/y). Maps can really help municipalities;
- A tool for collecting and evaluating effects should be provided.

### **1.1.17 Thermal influence of neighbouring GSHP installations: relevance of heat load temporal resolution**

The paper describes the potential problem of the thermal interference of GSHP in urban environment, almost always using BHE. The lack of dedicated tools, drove the authors to develop their own. They investigated the importance of the time step definition of the load profiles, and the uncertainty of the neighbors' energy needs (important especially during the design phase). For long term evaluations, yearly average loads are acceptable. Tools are necessary for long term evaluations. In Sweden, 20% of the single-family buildings use a GSHP (the most common system is BHE). Analysis and thermal response tests (in term of continuous line heat sources with uniform and constant heat flux in a semi-infinite, uniform, isotropic media with constant properties) are showed in graphs with distance and thermal interference. Some recommendations are:

- measures need to be taken to prevent strong thermal interference between different borehole systems in densely populated areas;
- a tool that allows an accurate estimate of boreholes thermal interaction is necessary to be able to design the system;
- guidelines for how systems in densely populated areas should be designed or allowed is fundamental;
- the general rule for single-family buildings recommends 20 m as a minimum distance between 2 boreholes on neighboring properties. The need for guidelines induced the Swedish authorities to set up rules to avoid thermal interaction among neighboring systems;
- increase the time analysis (and so the area of influence).
- the lifetime of a heat pump is around 20 years, while the lifetime of a borehole can be longer. Increase the time analysis (so the influenced radius).

### **1.1.18 Review of the Design parameters for the strategic planning of BHEs<sup>14</sup>**

In densely built-up residential areas the technology has already reached the limits of available resources. For optimal and equal use of the ground, new design criteria are required - especially for dense use in residential areas with a high density demand - which take sufficiently into account the requirements for existing and future neighbourly use. The Commission for the revision of SIA 384/6

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<sup>13</sup> It is usually used to assess long-term effects. A power of extraction constant over time, all year and for all years

<sup>14</sup> Überprüfung der Auslegungskennwerte zur strategischen Planung von Erdwärmesonden

has addressed this issue. Huber (Huber Energietechnik Zürich) and Poppei (CSD Ingenieure AG) have chosen the so-called "heat extraction" for each plot of land. To calculate the index, the following parameters shall be known: heating demands, ground surface properties, the COP of the heat pump and an assumed probability of having other BHEs in nearby plots of land; this will be implemented in the revision of SIA 384/6 (required in Switzerland in the next few years). Depending on the level of this index, planning or approval authorities can set higher requirements for the design. For the moment, this method has been applied in some areas of the Cantons of Zurich and Bern [18].

## 1.2 Results and suggestions

The problems related to interference between neighbouring BHEs are increasingly debated in countries where the installation density of low enthalpy geothermal systems has increased (Switzerland, Germany, Sweden and Netherland).

Among the main aspects that can occur in the case of medium-large thermal interference between nearby BHEs, not considered in the design and construction phase, there is the decrease of the soil temperature which, from project to project, can be lowered with greater velocity over time (the velocity in lowering the temperature increases compared to a BHE that does not have thermal influences from a nearby system).

At the end of this review, we summarize major points coming out from articles, reports and other resources available on this topic (shown and described in Table 3).

The first and main result is the need to have clear and simple regulation about geothermal energy exploitation. A common platform where different information is available (like a data base or a GIS map) can greatly help the management of increasing installation of BHEs and consequently allow easier prevention or solution to interferences problems. Moreover, a difference in the dimension of plants in terms of evaluated drilling length emerges: more detailed information is necessary for larger BHE systems (simulation and monitoring of plants are useful to project and control the trend over time). Regeneration is quite often mentioned as a good opportunity to prevent thermal interference. Another strategy to prevent interference is regional planning for district, which can define authorised areas, and a methodology that can monitor installations as much as possible.

Table 3 summarizes the main points evaluated on in the various studies, for which further study was considered important in order to reduce or prevent thermal interference between systems.

For each study, the topics covered were ticked; this, in addition to helping the reader of this report read the reports that deal with a specific point, also gives weight to the topic dealt with, especially if considered in different reports.

The knowing of the geothermal potential of an area is the basis for geothermal energy exploitation in the best way possible, however clear regulations are necessary to monitor the BHEs. The licencing system should be as simple and centralized as possible in such a way to help people who wants to install BHEs. Where more complex authorization is required (e.g. in case of large geothermal installations), the presence of a public platform or GIS based map can be very useful. Some cities use the definition of distinct area of the city based on the energy demands of the buildings to manage the future installations. In some cases, simulation of BHEs and regeneration could be a way to prevent interference.

Table 3 - Resources and major points emerges from the review.

Year	Title	Knowing geothermal potential, lack of knowledge and experience contractor	Clear regulation	Centralized and simplified administrative processes	Local/regional simple licensing	For large systems more complex authorization	Defining distinct areas	Platform /GIS map	Simulation	Regeneration	Monitoring	Chapter
1999	Prospects for ground-source heat pumps in Europe	✓	✓									1.1.1.
2000	Neubaugebiete mit Erdwärmesonden in Werne und Dortmund-Mengede								✓			1.1.2.
2007	Geothermische Energie im Kanton Zürich - Grundlagen und Potenzial	✓										1.1.3.
2012	Wärmeversorgung: potenziale der Quartiere						✓	✓				1.1.4.
2012-2015	ReGEOCities			✓		✓						1.1.5.
2014	Erdsondenpotenzial in der Stadt Zürich									✓		1.1.6.
2015	Erdwärmesonden im Dichtestress		✓						✓			1.1.7.
2015	Optionen zur Vermeidung nachbarschaftlicher Beeinflussung von Erdwärmesonden: energetische und ökonomische Analysen									✓		1.1.8.
2017	Scientific achievements and regulation of shallow geothermal systems in six European countries – A review				✓			✓			✓	1.1.9.

Year	Title	Knowing geothermal potential, lack of knowledge and experience contractor	Clear regulation	Centralized and simplified administrative processes	Local/regional simple licensing	For large systems more complex authorization	Defining distinct areas	Platform /GIS map	Simulation	Regeneration	Monitoring	Chapter
2017	Das Recht und die Regulierung der Erdwärme		✓									1.1.10.
2017	Procedura di autorizzazione nei diversi Cantoni per l'installazione di sonde geotermiche verticali		✓					✓				1.1.11.
2017	Haute densité de sondes géothermiques calcul des effets à long terme d'installations géothermiques dans un quartier									✓		1.1.12.
2018	Report on different kind of barriers for shallow geothermal in deep renovation (D1.1)								✓			1.1.13.
2018	Strategische Planung von Erdwärmensonde									✓		1.1.14.
2018	Integrating a thermal model of ground source heat pumps and solar regeneration within building energy system optimization									✓		1.1.15.
2018	A Novel Tool for Assessing Negative Temperature Interactions between Neighbouring Borehole Heat Exchanger Systems						✓					1.1.16.

Year	Title	Knowing geothermal potential, lack of knowledge and experience contractor	Clear regulation	Centralized and simplified administrative processes	Local/regional simple licensing	For large systems more complex authorization	Defining distinct areas	Platform /GIS map	Simulation	Regeneration	Monitoring	Chapter
2018	Thermal influence of neighbouring GSHP installations: relevance of heat load temporal resolution										✓	1.1.17.
2019	Bericht «Überprüfung der Auslegungskennwerte zur strategischen Planung von Erdwärmesonden»							✓				1.1.18.

As a result of this review analysis, and thanks to the main key points that have been found, a complete licensing system is going to be proposed. This procedure aims at describing, systematically, to the regulations that shall be developed and followed, at a regional or national level, for a good management of GSHP systems. Here is a summary of the information in the chart shown in Figure 1.

LICENCING SYSTEM: it is necessary to have a system of procedures that is clear and rigorous, which can take into consideration all aspects and information useful for the project to be accepted. The procedure must be simple and not too onerous, and shall consider relevant aspects in the field of interference. A differentiation is recommended based on the size of the system, (for example simple and complex systems) and for which a more in-depth study may be requested. In order not to create confusion between private individuals, professionals and public administrations, the system must be coherent and approved at least at national level, while its management can be delegated at regional level. A system that includes sanctioning methods or financial incentives can help to improve the quality of work of the professionals involved.

1. OFFICIAL DATABASE: the data collected in the first phase of the procedure (licensing system) can be easily updated and used both in the context of better territorial management of the BHEs, and to prevent interference between nearby plants, a geo-localized database is necessary, even better with public access, or through log-in. This tool allows a valorisation of the information, an increase in knowledge, a better monitoring of dissemination trends of BHEs, prevention from interference and an easy access to areas where there are legislative restrictions, making the diffusion of the plants more efficient and rapid, through a more aware management of past and future installations.

2. **OPTIMIZATION AND FINAL DESIGN:** an optimal system allows you to simultaneously satisfy the temperature of the heat transfer fluid with the minimum number of BHE installed. The optimization of the system must therefore make it as efficient as possible from an economic, energetic and environmental point of view.

For the final design, the following must be evaluated:

- thermal requirements: the geothermal system must be able to meet the thermal needs which, through equipment (such as heat pumps, circulation pumps, heat exchangers), are transferred from the ground to the building. In order to ensure a long-term proper working of the system, it is therefore necessary to estimate as accurately as possible the thermal requirements necessary for the building which can be satisfied by geothermal energy, bearing in mind that they must remain the same over the years, or in any case their modification does not penalize the overall functioning of the system;
  - number and arrangement of BHEs: exchange heat with the ground; their arrangement geometry in term of distance between them, depth and configuration is a fundamental parameter for the correct evaluation of the functioning of the geothermal system;
  - distance from the boundary and from other nearby plants: the presence of BHEs close to the boundary can increase at the present time or in the future, the probability of thermal interference with systems installed in the neighbourhood. Although phenomena of thermal interference can also reach a considerable distance, it is advisable to keep a distance from the border of about 5-10% of the depth of the BHE. A BHE too close to the border could also incur in a very rare but dangerous cross-border damage between neighbours due to the typical deviation that the geothermal probes have during the drilling phase;
  - evaluation of corrective or compensation solutions: in cases where you are in the neighbourhood of another geothermal plant, it is necessary to evaluate solutions in order to cancel or limit the negative effects of thermal interference between plants.
    - A) It is advisable to review the arrangement of the probe field, so as to stay sufficiently far from the nearby geothermal plant.
    - B) Although not economically optimal, it is possible to increase the perforation length of the probe field, this has the consequence of increasing the average temperature of the fluid and reducing the effect of long-term overcooling.
    - C) Regarding soil regeneration, this is the solution that is most convenient also in the paper reviewed. In this regard there are multiple ways to recharge the soil (reference paper 1.1.6 SPF 2015 Optionen zur Vermeidung nachbarschaftlicher Beeinflussung von Erdwärmesonden / Options for avoiding neighbourly interference with geothermal probes).
    - D) Lowering the thermal requirement of a building satisfied using a geothermal system. This solution can be reached with a greater degree of insulation of a building or with the aid of an auxiliary energy source in parallel.
3. **REALIZATION GUARANTEE:** once the technical aspects are defined, one of the steps that is often missing is a verification that the project is carried out as described, and therefore all the specifications considered during phase 3 are actually put into practice. It is possible to work on two aspects: the first is to ensure that the companies that deal with the construction of the plants are certified or that they are able to carry out the work using state of the art methods. This aspect can be improved through training of professionals with regular courses and updates, both as regards techniques and materials for the construction, and the other

hand the regulations or good practices existing in the geothermal field. The other aspect where action should be taken to carry out checks by the competent authorities during the construction phase and before putting the system into operation.

4. **UPDATING OF DATABASE:** it may often happen that during the works especially the drilling, it is not always possible to carry out the project exactly as it was planned: impediments related to some geological issues, as well as setbacks of another nature, may make it necessary to change the length of the construction site and number or location of the perforations. Precisely for these reasons, the updating of information subsequent to the implementation phase is essential to ensure that the correct data is present in the databases. The lack of this point means that the information in the database is incorrect and that therefore future considerations are based on data which is not up to date.
5. **MONITORING SUPERVISION:** the last step is the system monitoring phase, where different data are collected allowing direct feedback and understanding of the functioning of the system, as well as investigation as to whether or not it respects what is explained in the previous points. If, during the operational phase, the stated conditions are not respected, it is therefore possible to change the system settings or, alternatively, repeat the licensing procedure (point 1) to evaluate compliance with the regulations and then update the database (point 2). In the case of important changes necessary for the system for its correct operation, these changes must therefore be updated and if they are substantial, the request should be restarted in the licensing procedure. Monitoring can be particularly costly economically, also for this reason it should be mainly foreseen in large plants. Obligations such as annual taxation or renewable concessions in the short term (a few years), would help to monitor the functioning and correct installation of the systems over time according to when designed and declared.

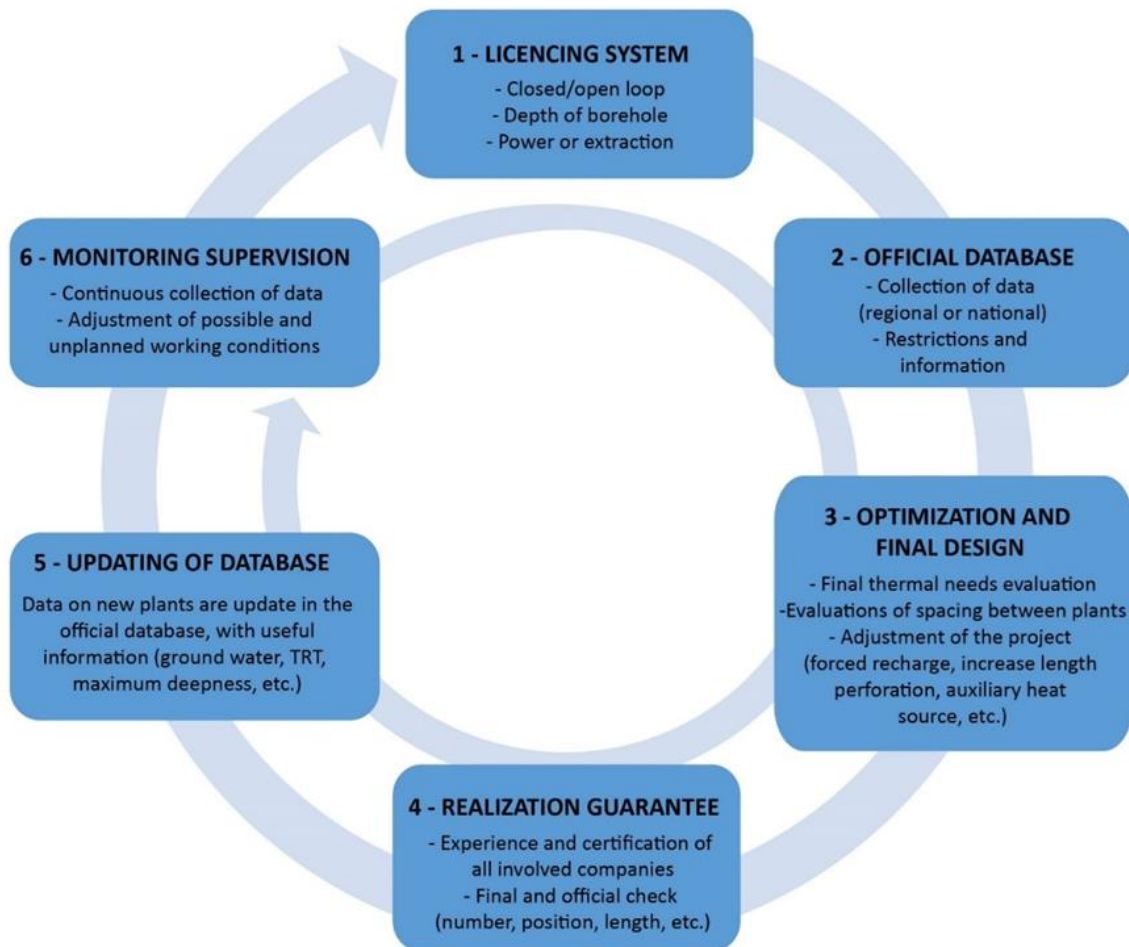


Figure 1 - Summary of the theoretical phases considered during the installation of a shallow geothermal system, from the presence of a licencing system to the final monitoring phase.

## 2 Proximity interference procedure analysis applied to Real and Virtual Case Study Sites

In this chapter the real and virtual cases were analysed. The possible theoretical interference with the neighbourhood was examined using recommendations from chapter 1 and previous experience in this sector.

For every case study the analysis was conducted with the following approach:

- data analysis: from the data collection of the GEO4CIVHIC project some specific information were selected;
- regulation context: local legislation and regulation, coming from the partner description and previous project (ReGeoCities and Cheap-GSHPs);
- application of the theoretical diagram: the system structured for this project, showed in Figure 1 was applied;
- summary of the case study: information, suggestions and best practice were commented always with the aim to prevent and reduce the possible thermal interference of near plants.

For every case studies, data were analysed. Not all the case studies have all information. Especially for the virtual case it is quite difficult to have the necessary data or information.

The data collected were grouped by different arguments (Building, Underground, Installation, Regulation, Costs). These topics are the same of the excel datasheet used during the collecting phase and were collected basic answers such as YES, NO, - (not available, not answered) and in some cases with TBca (to be calculated) or TBco (to be confirmed).

For every case studies, we try to indicate which steps of procedures are complete (↑), incomplete (↓), not complete with a different degree of completeness (↗, ↘) or data are missing (?).

This synthesis is here presented in Table 4.

Table 4 - Summary of the status refer to steps present in the Flow Diagram before.

Case study	Historical Building Valletta Malta	Historical Building Ferrara	Residential Building Mechelen	Residential Building Wicklow Ireland	Museum of Natural History of Alexandroupolis	Palacete de la Cruz Roja	Residential building Avangarde Forest	Residential building in Bucharest	University "Ex Ospedale Geriatrico"	Historical building - Split Croatia	University Building in Erlangen	Historical building "Castle of Attre"	Carnegie Clondalkin Library	Administrative building ALL (Switzerland)	Mariëburg Soest - Netherlands	Alsamora 6, Catalonia
Refer number	R1	R2	R3	R4	V1	V2	V3	V4	V5	V6	V7	V8	V9	V10	V11	V12
Nation <sup>15</sup>	M	I	B	IRL	GR	S	RO	RO	I	HR	G	B	IRL	CH	NL	SP
1 - Licencing permit system	↑	↗	↑	↓	↑	↓	↘	↗	↗	↓	↑	↑	↓	↑	↑	↓
2 - Official database	↘	↓	↑	↓	↗	↓	↓	↓	?	?	↑	↑	↓	↑	↑	?
3 - Optimizati n of the final design	↑	↑	↘	↑	↑	↘	↑	↑	?	?	↗	↘	↑	↗	↑	?
4 - Realization guarantee	↗	↗	↘	↓	↑	↓	↘	↘	?	?	↑	↗	↓	↘	↑	?
5 - Updating of database	↘	↓	↗	↓	↗	↓	↓	↓	?	?	↑	↘	↓	↘	↑	?
6 - Monitoring supervision	↓	↑	↓	↓	↗	↗	↓	↓	↑	?	↑	↓	↓	↘	↑	?

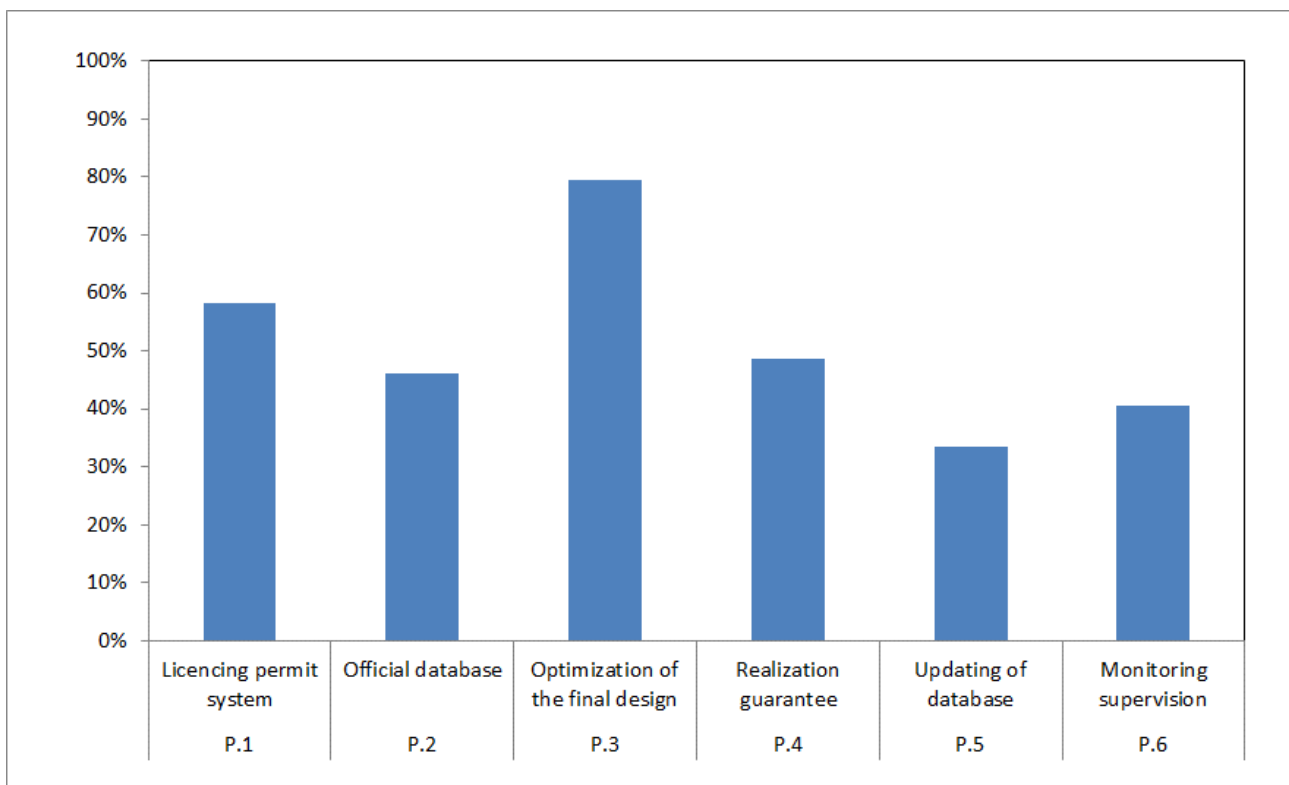
The application of flow diagram (presented in Figure 1) to the single cases of GEO4CIVHIC project, gives the results showed, to the different phases (1 to 6). To present the results as percentage, results were transform from a qualitative score (e.g. ↑) to a quantitative score, as shown in the following table.

<sup>15</sup> International abbreviation for the name of the Nation where case study is located.

Table 5b – Quantitative score assessment.

Qualitative score	Quantitative score assigned
↑	3
↗	2
↘	1
↓	0
?	NULL

Figure 2 - Results of the topics connected to interference. (Higher the percentage is, higher the completeness of the topics is).



Analysing the selected topics (Phase 1 to 6), the graph shows that the worst phases are the updating of databases (P.5) and the presence of an official databases (P.2).

Then we have the monitoring phases (P.6) with 40% and the realization guarantee (P.4), with a percentage higher than 49%. After there is the presence of a licencing permit system (P.1), with 58% and the optimization of final design (P.3), higher than 79%.

## 2.1 Real Case Study Site

### 2.1.1 Msida Bastion Historic Garden Building, La Valletta (MALTA)

This is a single storey public building with a floor area of 97 m<sup>2</sup> where retrofit and the installation of a dual ground and air source heat pump will be included. There is no existing cooling technology, the whole cooling as well as heating demand is expected to be covered by means of a new geothermal system (two BHEs).

The authority responsible for permit (P.1) is Malta Resources Authority and, if drilling is to be performed on the road, Transport Malta. The Malta Resources Authority keeps a register of applications for borehole drillings.

The application process necessitates the specification of the coordinates of the boreholes and it is possible to know the location and the distance between others BHEs and in case review the design (P.2, P.3).

The authority may also carry out an installation inspection (P.4). There is not any definition of interference, which is not a topic for the moment.

*There should not be an overcooling problem because the cooling demand is higher than the heating demand. Some overheating of the ground could affect neighbour systems; some particular attention could be placed on the maximum allowed temperatures. However, in view of the location of the plant and the very small number of GSHP installations in Malta there is no envisaged issues in this regard.*

### 2.1.2 Angel's Gate, Historical Building in Ferrara (ITALY)

The Angel's Gate (Porta degli Angeli) is within the borders of the World Heritage property on the city of renaissance of Ferrara and its Po delta. In the 16th century, it was considered one of the most prestigious entrances of the entire city walls. It originally only consisted of the lookout tower, to which later was added the lower building, formerly used as a military building or base. In 1984 external walls were renewed with construction of a new internal steel staircase, the heating system and the electrical system were realized. Angel's Gate and specifically the watch tower were restored by the Municipality of Ferrara and officially inaugurated in May 1999

In October 2018 the Councillor for Urbanism and Urban Regeneration of Ferrara committed to delivering a set of data that would be needed to perform the first energy assessment of Angel's Gate's indoor spaces. A resolution was submitted to the city council in order to provide internal binding provisions for the implementation of the project. In December 2018 UNESCO representatives obtained more data from by the "Servizio Beni Monumentali" office of Ferrara.

The building was originally a watchtower and now it is used as exhibition hall for public activities, it is now equipped with an old, inadequate and obsolete heating system. No cooling system is active. This will be removed and replaced using one of the innovate heat pumps developed by the project.

GEO4CIVHIC System: dual source Heat pump, Co-axial heat exchangers, N° Borehole: 4, Deep: 100 m. Vibro-drill head will be used. In the case of the Hydra-RED method, another Hydra machine with the Hydra drilling head will be used.

The preliminary project of the geothermal power system installation is currently being implemented.

1. Thermo-technical design of heating and cooling system inside the building (heating and cooling loads of the building and in its heating/cooling terminals; detailed piping and electrical drawings)
2. Control room design (Containing the heat pump, the buffer tanks and the circulation pumps)
3. Early Provisions for the security and fire suppression plan.

Mid 2019 we successfully implemented the Preliminary thermo-technical design of heating and cooling system inside the building

In the past months, in compliance with the European and local technical/normative standards, interfacing with the local conservational and other relevant offices and technical services (Archaeological authorities, Fire Brigade dept., etc.), and on the basis of the preliminary study we undertook a definitive design for the project. On the basis of the definitive design as approved by the city of Ferrara and UNESCO, the executive design (a final design of the project) was undertaken. There is not specific information on the licencing system for geothermal topic. (P.1)

At the moment there is not a database publicly available. (P.2)

There is a design phase of summer and winter air conditioning system inside the building, at the service of the heat pump envisaged by the client, final electrical system design for the mechanic, final design of civil works for the plants and a work maintenance plan. (P.3)

There are inside checks (from the start of the construction until the start-up of the system), but local authorities will be also present during delicate phases. (P.4)

Due to the fact that a publicly available database is not present, also the updating is not possible, for the moment. (P.5)

There will be a monitoring system to measure thermal energy supplied from the geothermal field, from the air source and the thermal energy used inside the building (heating in winter, cooling in summer). Also the electrical energy consumption will be measured. (P.6)

*Due to the available data and to the lack of information, it is difficult to know, evaluate and in case correct some possible problem related to the presence of other geothermal installations. Despite the uncertainty and difficulty to find information, it is suggested to inquire from neighbours if other geothermal systems have been installed previously. It is important that any possible future installation near to this one will be able to know in such a way as to prevent and limit any sort of thermal interference with this one (otherwise this one might be penalized).*

### **2.1.3 Residential Building in Mechelen (BELGIUM)**

This building is retrofitted with insulation of walls, roofs and substitution of window, moreover an 8 kW dual heat pump and radiant floor system will be installed. A cooling system is not currently present; the whole cooling demand will be covered by new geothermal system.

For this part of Belgium (Flanders) and specially this case study of Mechelen where the planned drillings will reach a depth of 90 m, no permit is necessary, but the company who is drilling has to declare the project on a web system of the regional authorities. A regional map on a public website indicates for each cadastral area the maximal depth authorized without permit. For the cadastral area of our case study of Mechelen, the maximal depth is 150 m. Deeper than 150 m, a permit class 2 (to the regional authorities) is required. (P.1)

The authorities manage the register of the installed system but is not public available. (P.2)

There are no restrictions in urban area or specific permit for drilling. Information about heating and cooling have to be calculated during the project for this reason, for the moment it is not possible have details about the percentage of recharge. (P.3)

Inspection might be performed by authorities, but rarely occur. (P.4)

*Due to the available information and to the lack of some others choice, it is difficult to know, evaluate and in case correct, some possible problem related to thermal interference between different and near systems. Despite the uncertain and difficult to find information, it is always suggested to inquire from neighbours if other geothermal systems have been installed previously.*

#### **2.1.4 Historical Residential Building in Greystones, Co. Wicklow (IRELAND)**

This is a single storey historical residential building; 14kW medium/high temperature heat pump using closed loop heat exchangers will displace a gas fired central heating system, with the existing radiator and heating terminals retained. There will not be a cooling system.

There are no specific permits for closed loop GHSP systems (P.1). For Open Loop systems and Aquifer Thermal Energy Storage a permitting process is applicable for the abstraction and discharge (or re-injection).

Neither notification nor registration process is in place. (P.2)

The presence of a GSHP is generally outlined as part of any planning application for construction works (new or retrofit) when these are required. However, it does not provide any technical details with respect to the system and its components. There is no register of the installed/operating system and there are no urban area restrictions. Generally, the distance between neighbouring BHEs is not known due to the lack of any database; this would only be known to the designer, however the designer has no obligation to submit this data to any authority. Commonly a 'rule of thumb' is used to set a minimum of 6m spacing between any GHEs and/or boundary. In the case of this case study site, the configuration has been chosen based on the space available to complete the collector which requires a total of 3 No. Coaxial stainless steel heat exchangers to meet the demand modelled for the house and the 14kW. Where professionals and trained designers are involved, a model considering the appropriate spacing through the use existing geological survey databases to determine any nearby users would be completed. (P.3)

Once completed the contractor/driller currently has no obligation to submit borehole information from ground source heat exchangers to any authority (P.4, P.5). This obligation is applicable for open loop systems similar to that applicable for the drilling and completions of water supply wells.

*There are no other systems near this collector – the neighbouring buildings are all historical buildings with gas boilers and poor insulation. The 'rule of thumb' where a minimum of 6m spacing between any GHEs and/or boundary is generally used; this can help to limit possible interference effects even in the future. Due to the available information, it is difficult for everyone to know, evaluate and in case correct, some possible problem related to the presence of future geothermal installations. For this reason, it is important that any possible future installation near to this one will be able to know so prevent and limit any sort of thermal interference with this one (otherwise this one might be penalized).*

## 2.2 Virtual Case Study Sites

### 2.2.1 Museum of Natural History, Alexandroupolis (Greece)

This Museum plans a retrofit of the building consisting of upgrading the interior design and bringing the energy performance to an nZEB standard. For this purpose, as part of WP5 of this project, the following cumulative retrofit options have been examined and evaluated:

- Upgrading the thermal insulation of the building envelope (partial retrofit)
- Replacing existing low efficient lights with higher efficiency devices such as LED (moderate retrofit)
- Replacing existing air source HVAC system with a dual GSHP system (deep retrofit)

Each retrofit option has been studied in terms of technology requirements, technical specifications, investments costs, energy savings and economic performance. For this purpose, the building energy behaviour has been simulated on an hourly basis under present, partial and moderate/deep retrofit options. The BHE and the performance of the GSHP system has also been simulated.

The results of the above studies indicated that after moderate or deep retrofit, the cooling peak load in the summer (21.27 kW<sub>th</sub>) becomes only ~50% of the heating peak load in winter (41.23 kW<sub>th</sub>). This led us to design the heating and cooling system using two heat pumps of the same capacity (21 kW<sub>th</sub>) each. One will cover all cooling needs during summer and the base heating load during winter and the second will cover only the peak heating load during winter. The first heat pump will be a ground source one, while the second one can be either air or ground source. The second heat pump despite having 50% of the capacity will cover only 2% of the heat load (according to the simulation results), therefore a GSHP using the same BHE will be adopted for the second heat pump, which is a more efficient and more economical solution than an air source heat pump.

The necessary permit (P1) will be issued by the installer through application to local regional authority, which also holds a database for internal use (P2).

According to the simulation results, the ground heat exchanger will consist of 7 BHEs, each one 100 m deep. The heat carrier fluid will be water with 25% ethanol. The distance between two successive BHEs will be 10 m. System optimization and final design is complete. (P3)

The installation inspections, checks and realization will be performed by the technical service of the building owner, which is the Municipality of Alexandroupolis. (P4)

The same applies to the inputs in the testing and operation database (P5) and to the system energy monitoring. (P6)

*The museum is located in a greenfield 150 m away from nearby Maistros village, while the closest neighbouring building structure is located 50 m away, therefore there will be no thermal interference with any neighbouring BHEs that may be constructed in the future.*

### 2.2.2 Palacete de la Cruz Roja, Valencia (Spain)

This historical building should consider a renovation proposal including structural and architectural aspects as well as energy efficiency. The current system is an air-to-air heat pump for air conditioning of the building and an additional air-water heat pump for pool heating and dehumidification. The case study site considers an optimized HVAC system based on shallow

geothermal energy using the heat pump and heat exchanger technology developed by the project. It is not decided with which percentage of cooling demand will be covered by the new geothermal system.

There is not a specific licensing procedure for geothermal systems. Upon completion of the work, the installation must be registered in the Regional Ministry of Industry as well as any thermal installation, no specific permission is required for drilling. Restrictions are applicable for GHES installations in areas where main utility infrastructure is present (water, electricity, gas etc...); for closed loop, where borehole exceed 100 m depth and total capacity is lower than 70 kW, no EIA/EIS is not required. (P.1)

There is not any database. (P.2)

There may be internal checks from installer company. (P.3, P.4)

There is also a general validation of the whole thermal installation (like any other installation, boiler...) once the installation is finished and with official registration (P.4). Normally, on the part of the installer/designer is to keep a distance between BHEs of at least 6-10 meters to avoid thermal interference between them. (P.3)

No suitable indicators are used to quantify interference between different BHEs, as monitoring for this power is not required (P.6). In any case, monitoring the installation to check the thermal heat injected and extracted in the ground, the thermal needs provided by the heat pump, electrical consumption and the efficiency of the system is recommended.

*The lack of several steps in the processes do not allow to prevent interference problem a percentage of recharge of terrain should be foreseen. Despite the collection of information is uncertain and difficult, it is suggested to inquire from local authorities if other geothermal systems have been installed previously and to design as far as possible a thermally balanced borehole heat exchanger system (same heat extraction as heat injection into the ground) to avoid thermal interference with neighbouring areas.*

### **2.2.3 Residential building Avangarde Forest (Romania)**

This residential building completed in 2013 is part of a complex of 28 similar houses. The building has a floor area of 180m<sup>2</sup> and is equipped with radiant floor and a gas fired boiler. The house is going to be enlarged and the envelope is going to be insulated. In this case the solution will be a small size reversible low temperature HP with co-axial GSHEs. It is expected a multi split air conditioning system and cooling demand will not be covered by new geothermal system.

Energy resources are publicly available on the ANRE website: <https://www.anre.ro/> (ANRE has no data base on geothermal systems is only interested in electricity production from renewable energy sources). There is a licensing system: ANRE Order 22/2006. The authority responsible for the permit is the National Authority for energy regulation. (P.1)

There is no database or register of installed system. (P.2)

There are no standards at Romanian level - Only the Thermal Response Test was adopted, but is currently suspended (TC341 / N525). There is EN ISO standard 17628. (P.3, P.4)

If the system is used in order to sell energy, annually monitor system is imposed by ANRE. If it's for local/single use, no (P.6). No information about interference are presented.

*There is not actually any information about heat exchangers installed, pipes, depth of hole and heat carrier fluid and the energy demand for heating, hot water and cooling is referred to the present building. Due to the available data and to the lack of some other information, it is difficult to know, evaluate and in case correct, some possible problem related to thermal interference between different and near systems. Despite the uncertain and difficulty to find information, it is suggested to inquire from neighbours if other geothermal systems have been installed previously.*

#### **2.2.4 Residential building Bucharest (Romania)**

This is a single-family prototype house, now used as research centre for indoor quality and energy efficiency. The virtual case considers the use of a GSHP proposed in the project against air source technology currently in use.

The EFdeN house is an active house that produces more energy than it consumes (positive annual report) and reaches the indoor comfort parameters corresponding to a green, comfortable building. The house has been designed to meet European standards regarding the energy efficiency. The house, designed in Bucharest as a very efficient solar house, participated at the contest Solar Decathlon Europe.

The licensing system for GSHP systems is regulated by Provision No. 799 of the Ministry of Forests and Environment with respect to the water management permit available on the website. A simple open installation does not need a special approval procedure; the wells being considered as any other water supply solutions. The same situation is for closed systems where drilling to depth lower than 100 meters' must not be specially approved as a solution accessing earth energy, but as a solution accessing underground waters. The approval is in this case included in the "Environment Authorization" and is issued by the National Waters Authority according to Provision No. 799 presented above. There is also a series of laws and provisions at national level which are relevant to energy efficient buildings or geothermal energy implementation: Law 159/2013, law 121/2014, Law 372/2005 republished, ministry order 691/2007, 799/2012,87/2008 and the nZEB National Plan. (P.1)

On the GEOEXCHANGE website the known geothermal systems in Romania along with their financing sources are outlined. (P.2)

The optimization of the prototype was realized using detailed numerical simulations with DesignBuilder software. The house was 3D modelled and energy consumption was rigorously analysed. The implementation of ground-source heat pump solution was equally modelled in the software. The use of EED software was necessary for better understanding of the earth exchanger design. The numerical simulations were enhanced with precise experimental measurements of thermal response test (TRT) thus the thermal properties of the ground were determined. (P.3)

The existing database will be updated with the data from this study while the monitoring supervision of different aspects (energy efficiency, system parameters, reduction of CO<sub>2</sub> emissions compared to classical systems, etc.) will be in charge of the Romanian research team. (P.5)

*A licencing system and a public database is likely missing. Anyhow, planners and people involved in the process have possibility to prevent or correct thermal interference effects. It is important that any possible future installation near to this one will be able to know and consequently prevent and limit any sort of thermal interference with this one (otherwise this one might be penalized).*

## 2.2.5 University building "Ex Ospedale Geriatrico" (Italy)

This is an on-going deep renovation of a historic building pertaining to the University of Padua.

Regulations specify that if groundwater is exploited, a request must be submitted to the local department (Genio Civile). A notification to ISPRA is required for every borehole deeper than 30 m (P.1). No information concerning closed loop exploitation is available.

It is present a geological report for the site. The overall plant capacity is about 900 kW for both heating and cooling. A GSHP of 300 kW<sub>el</sub> will operate in heating and cooling with 60 GHEs of 120 m depth. The system is coupled with 620 kW reversible air to water heat pump. The deep retrofit and the performance of the hybrid solution using co-axial BHE against the conventional ones installed is being carried out as part of this study site. For heating technology: 2 reversible geothermal heat pumps and 2 reversible air-water heat pumps. 25% of cooling demand is expected to be covered by geothermal system (P.3).

UNI provides non mandatory rules for GSHP installation. (P.3, P.4)

A monitoring requirement for closed ground source heat exchangers is mandatory for plants size above 100 kW (collection of daily data, temperature, flow rate, power consumption). (P.6)

*Information are missing for some aspects. However thermal needs calculation demonstrates the possibility of optimizing the system: the monitoring and the presence of 25% of cooling from geothermal system should prevent/correct any interference problems. It is suggested to inquire from neighbours if other geothermal systems have been installed previously (or the aim to install them in future).*

## 2.2.6 Historical Building, the Museum of Croatian Archaeological Monuments, Split (Croatia)

The Historical Complex of Split with the Palace of Diocletian was inscribed in the World Heritage List in 1979. The Museum of Croatian Archaeological Monuments (MHAS) is a monumental building located just outside the historic city centre of Split. Even though it is not part of the local World Heritage site, the MHAS is one of the oldest Croatian museums and the only museum in Croatia that was founded with the unique task to explore, collect, present and study the remains of tangible and intangible culture of the early medieval period. The Museum has been listed on the Register of Protected Cultural Heritage of the Republic of Croatia since 2011. The building of the MHAS was constructed from 1972 until 1976. The architectural complex is characterised by the grouping of functional elements of pure volumes within the complex and their integration with nature. The Museum consists of the following basic spaces: an office building and building with the exhibition, the Museum workshops and event space.

The palace is a historic building and a UNESCO World Heritage Site where renovations are planned. The case study site is considering HP solutions developed by the project with co-axial heat exchangers.

There is no dedicated licensing system in place for GSHPs. No differentiation for different type of source: it is necessary a planning permission and a building permit for capacity > 30 kW. There is no specific drilling permission. (P.1)

*Due to the lack of information, it is difficult to know, evaluate and in case correct, some possible problem related to thermal interference between different and near systems. Despite the uncertainty*

*and difficulty to find information, it is suggested to inquire from neighbours if other geothermal systems have been installed previously.*

## **2.2.7 University building Erlangen (Germany)**

The University of Erlangen-Nürnberg (FAU) is renovating the historic Palaeontology Department building built in 1893. For this building different possible solutions for making the building more efficient are being considered and the use of GSHP systems with co-axial heat GSHE's is considered as part of the virtual case study site.

A licensing system in Bavaria is applicable. Above groundwater table a simple notification process is applicable. When the water table is intersected, a permit is required. More complex licensing system are applicable to open loop system. (P.1)

A database and a tool application of the Bavarian Ministry are present. (P.2)

For any BHE less than 100 m deep a permission is required, for more than 100 m a license is also required. If system extract > 50 kW, local authority gives permission to install GSHP, if is less than 50 kW an external expert's opinion is necessary to be added to application. For vGHE (max 30 kW and annual heating extraction limited between 100-150 kWh) there is a planning guidelines for construction. Spacing: 5m for BHEs between 40-50m depth and 6m for BHEs up to 100m depth. Minimum distance of 2m from building wall is required. For larger system (>30 kW), in an unclear geological situation a pilot drilling should carried out and TRT have to be done. Possible solutions for making the building more efficient are being considered and the use of GSHP systems with coaxial heat GSHE's is considered as part of the virtual case study site. (P.3)

Information about percentage of heating, DHW and cooling covered by geothermal are not available for the moment. There is not a specific definition of interference or indicators about it, but for different kinds of GHE installations the authorities send out authorized experts to check the installation process and also the in-house installation of the plant. (P.4)

Thanks to a database the distance to the closest GHE can be defined by a measurement tool at a web application of the Bavarian Ministry of environment. (P.3)

A monitoring system is necessary for large system (>50 kW) and for smaller ones if they receive incentives. (P.6)

*Thanks to the presence of licencing system, update database, check of plants, presence of spacing and monitoring the case should not have problem about interferences. In general, planners and people involved in the process have possibility to prevent or correct effects.*

## **2.2.8 Attre Castle (Belgium)**

The Attre Castle is in the national list of exceptional buildings in Belgium. The virtual case will consider the deployment of two hybrid source heat pump with stainless steel co-axial heat exchanger probes.

There is a licensing system. For this part of Belgium (Walloon), a permit class 3 (only a declaration to the municipality) is necessary. The permit class 2 (permit to the regional authorities) is only request for sites located in a protected zone of public water wells.

There is a register of installed system, but not with the operational system data. The register is not publicly available; it is possible to require a permission to the authorities. There are no urban area restrictions. (P.2)

An inspection of the authorities is always possible but happens rarely. (P.4)

Monitoring requirements are applicable for open loop system. (P.6)

*Due to the lack of information, it is difficult to know, evaluate and in case correct, some possible problems related to thermal interference between different and near systems. However, thanks to the presence of licencing system, basic database, planners and people involved in the process have possibility to prevent effects.*

### **2.2.9 Clondalkin Library (South Dublin, Ireland)**

The building is a historic building comprising a detached six-bay two-storey public library. This virtual case study site is used to test the viability of deployment of the GEO4CHIVIC technologies including a high temperature HP.

There is no register of GSHP system or restrictions applicable to urban areas where the site is located. The distance between the GHEs is not known: generally, this would only be known to the designer, however the designer has no obligation to submit this data to any authority. The only 'rule of thumb' used is a minimum of 6m spacing between any GHEs and/or boundary. (P.1, P.2)

Professional and trained designers would model the spacing and use existing geological survey databases to determine any nearby users. The number of heat exchangers is being determined by the model; other information is not available or has to be confirmed. No percentage of cooling demand is covered by new geothermal system. (P.3)

Once completed the contractor/driller currently has no obligation to submit borehole information from ground source heat exchangers to any authority (P.4, P.5). This obligation is applicable for open loop systems similar to that applicable for the drilling and completions of water supply wells.

For installation inspections: none at all for closed loop systems - large scale open loop and Aquifer Thermal Energy Storage, no checks per say are performed (P.4) however monitoring data (subject to license conditions) may have to be submitted. (P.6)

*Some important steps of the process do not exist, due to this fact should be consider particular attention to the present case from the interference point of view. The 6 meters' distance, presented as 'rule of thumb', should help preventing interferences problem, in any case that "rule" is not formally required from public administration. Due to the available data and to the lack of information, it is difficult to know, evaluate and in case correct some possible problems related to the presence of other geothermal installations. Despite the uncertainty and difficulty to find information, it is suggested to inquire from neighbours if other geothermal systems have been installed previously. It is important that any possible future installation near to this one will be able to know in order to prevent and limit any sort of thermal interference with this one (otherwise this one might be penalized).*

## 2.2.10 Administrative building "AIL (Aziende Industriali di Lugano)" (Switzerland)

The AIL (Aziende Industriali di Lugano) case study is an administrative building from the 1960s located in Muzzano, Switzerland. The building with a total useful floor area of 6'000 m<sup>2</sup> has been completely refurbished during 2018-2019 in order to achieve the Minergie®<sup>16</sup> standard. In detailed this building required renovation and enlargement, considering three different thermal zones with different legal requirements (renovation of a part built before 2000, renovation of a part built after 2000 and a new construction).



Figure 3: Disposition of drilling on the project plan (left), and of the cantonal database (right). The scheme with the BHE disposition on the field, at a minimum distance of 4.5m from the border (5% of 90m depth). A screenshot of the BHE recorded on the cantonal database is also shown (this information is available for the public, and during years).

In Cantone Ticino, there is a licencing permit system, that in Switzerland partially differs Canton by Canton. A distance from the adjacent lot of 5% of the length of the closer BHE required by the public administration (90m of depth so 4.5 m) is a specific requirement that goes in the direction to limit possible interferences. This is more than one accepted and required rule of thumb, though. (P.1)

Even the database can change from one region to another (there are several databases), anyhow in almost every canton there are basic information on the geothermal systems. In Cantone Ticino BHEs information are collected in a database called GESPOS: an historical database that includes geological surveys, wells, springs, piezometric level, water protection areas and GHEs (number, position, depth and heat extraction of both open and closed-loop systems). GESPOS data are not publicly available, but it is possible to ask access to it ones, or paying an annual subscription for the access to the database. (P.2)

In Switzerland the standard SIA 384/6:2010 is the dedicated norm for the sizing and good realization of BHEs systems. It requires that dynamic simulation programs must be used starting from 5 probes systems and the presence of other near systems must be take into account<sup>17</sup>. In the AIL case study

<sup>16</sup> Minergie is a Swiss construction standard for new and modernized buildings.

<sup>17</sup> At the moment the Swiss standard ties to consider installations proximity, but without giving a harmonized method. There are no specific ore mandatory requirements, even if in case of proved thermal interference the

engineers and architects worked together to define thermal requirements. A recharge ratio of the ground of about 43% has been foreseen in this system thanks to the presence of geocooling. The geothermal sizing has finally been done by the driller using EED software. (P.3)

After the realization, there is not a final control of the realized geothermal systems, but in Cantone Ticino there would be the possibility to do it (only very rarely this is implemented). Nevertheless, many drillers have a quality label which guarantees that all the works have been done following the state of the art and SIA standard (this label is required in case that refurbishments ask for public incentives). (P.4)

The database is not always updated, the disposition and number of installation can be different from the reality (something can change during the planning and realization, and possible update are not verified). Anyhow, if a system is even not realized and since a fee is requested every 10 years, it is supposed that owners will inform the public administration (probably a more frequent fee can ensure more verified data). (P.5)

An energy monitoring system of the plant has been required by the owner (AIL) and implemented by the planner (IFEC). The monitoring system has been mainly installed because of the complexity of the thermal system and with the aim to optimize it (presence of GSHP, geocooling, gas burner, air-cooling machines, solar thermal panels). Unbalanced energy demands could in fact compromise the thermal restoration of the ground, also penalizing the efficiency of the whole geothermal system. This monitoring system is not required by public offices and data are not publicly available. (P.6)

*The existence of a database very easily allows placing and considering any installed or future systems. Thanks to this it is possible to consider any possible interferences between geothermal systems (current or future). The AIL case study site does not present evidence of possible actual problems due to the thermal interference with the neighbourhood. Geocooling can reduce significantly possible future negative thermal effects that this system could potentially give to futures ones. Anyhow, if in the future a new geothermal system will be installed in proximity, any thermal interference will have to be verify and, possibly, prevented (in order not to penalize one or both systems).*

### **2.2.11 Residential Building Marienburg Soest (Netherlands)**

This building is one of the two real demo cases present in 4RinEU project (H2020 call EE-10-2016). The case study comprises a three storey building with 65 dwellings with an average surface area of 50 m<sup>2</sup> used as service and support structures for elderly people. A preliminary design of a GSHP system with the technologies proposed in GEO4CIVHIC is considered as part of this virtual case.

A permit is necessary. A declaration is required where installed capacity is below 70 kW and it must include: owner, drilling company, plan and location of boreholes, thermal effect, data of installation, system, depth of boreholes. Above 70 kW a permit is needed, municipality decides on the basis of nearby existing users and the long thermal impact. A description of the expected effect has to be included. (P.1)

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planner/designer should have considered the specific condition (some lawsuit has been already discussed in Switzerland, so there are precedents). A revision of the dedicated standard (SIA 384/6) is therefore going to be published in 2020, in order to define a methodology to quantify and force a recharge ratio of new systems, with different requirements and a special focus to dense areas.

There is a national database, data do not seem to be publicly available. For BTES: the system has to be registered, design and construction has to be done by a licensed person or company. (P.2)

There is a minimum return temperature return (-3°C) and a maximum (30°C). Negative interference with existing system is not permitted. (P.3)

Monitoring, registration of certain parameters can be required. Municipality designs "area of interference" to prevent interference: these are zone where the amount of SGE system is expected to be high.

*Specific information of this case study is missing, but the detailed licensing process and also the attention to the thermal interference and high dense area, should allow preventing interferences problem in Netherlands. Planners and people involved in the process have possibility to prevent effects, despite any suggestion and rules seems to be required (thermal recharge of the ground, distance from the neighbour, maximal quantity of energy exploited, etc.).*

### **2.2.12 Residential Building Alsamora 6 (Spain)**

This is the second demo case of the 4RinEU (H2020 call EE-10-2016) project. The study site is located in Lleida in Catalunya and comprises a four storey, multi-family building of 24 dwellings with an average surface area of 45 m<sup>2</sup>. A preliminary design of a GSHP system with the technologies proposed in GEO4CIVHIC is considered as part of this case study site.

*Specific data of this case study are missing. The absence of a strong licencing system should be considered in order to prevent interference problems. Due to the lack of information, it is difficult to know, evaluate and in case correct, some possible problem related to thermal interference between different and near systems. Despite this lack, it is highly suggested to inquire from neighbours if other geothermal systems have been installed previously (or aim to be installed in the future).*

### 3 Methods, criteria and easy tool able to foresee and prevent interference

In the case of sufficiently close geothermal systems, thermal interference is created between them. The direct consequence is a ground temperature decrease in the zones surrounding the vertical ground heat exchangers.

The heat transfer between BHE and the surrounding soil is therefore penalized compared to situation without thermal interferences. In the absence of relevant precautions, the fluid temperature inside the BHE undergoes sub-cooling, because the heat pump will still need to exchange heat with the ground in order to supply thermal needs of the buildings. The temperature difference between fluid and soil must therefore remain the same with respect to the cases without interference so as to allow the heat exchange necessary for the heat pump. Consequently, the fluid temperature inside the BHE will become lower.

Furthermore, the "geothermal resource" component, predominant with isolated installations (without nearby installations), gradually gives way to the "thermal accumulation" component as the number of nearby installations increases, thus reducing its geothermal extraction potential.

#### 3.1 Problems and correlations - Simulation and standardisation

At the design phase, it is normally very difficult to calculate neighbourhood effects with standard design software and regulations, partly because the available information regarding neighbouring systems is very limited, but also because standard tools are not designed to deal with different types of systems (and non-standard tool are used and applied with difficulty).

Systems can have different energy profiles, different borehole depths, or different spatial configurations and distances; these specific particularities can generate many difficulties in standardised sizing.

Normally, the main and dedicated national and international standards that deal with BHE sizing (e.g. VDI, SIA, ASHRAE, etc.) consider isolated systems without the installation of other nearby systems. Even simulation tools currently available either rarely consider the possibility of simulating the thermal influence of nearby systems: they are often difficult to use and require good programming skills.

However, standards agree that system sizing must absolutely avoid the freezing of the surrounding soil, imposing temperature values that must remain within certain limits (typically minimum  $-1.5^{\circ}\text{C}$  for the average forward-return fluid temperature in the BHEs).

This limit must be considered during the sizing phase in order to fix it during the following operational years of the system (e.g. the Suisse SIA 384/6 requires that this limit must not be exceeded during the first 50 years of operation).

Specific dynamic simulation software have been used in this study; results have been compared with a simple and easy tool, developed within the context of this project, capable of facilitating and speeding up geothermal analysis and dimensioning.

A common and simple method consists in comparing cases with and without interference, in order to assess the decreasing temperature of the BHE fluid, following the interference of a nearby higher temperature limit in order to avoid the freezing of the surrounding soil ( $-1.5^{\circ}\text{C} + |\Delta T_{\text{penalization}}|$ ).

The assessment is based on the method of a "line source heat extraction", in order to compute the temperature of the closed-loop fluid (average in-out) over a period of several years [19].

The constant line source heat extraction method is imposed in order to extract/inject from/into the ground a constant heat linear quantity over time. The physical size of the heat extraction is expressed in W/m, and it can always be calculated for each type of system by knowing the energy exchanged with the ground and its BHE length.

This is the formula for calculating line source heat extraction:

$$\phi[W/m] = \frac{E_{gr}[Wh]}{8760[h/y] * L[m]}$$

Where:

- E<sub>gr</sub>: thermal energy exchanged with the ground
- L : drilling length (depth per number of BHEs)

To clarify and fix the concept, here are presented two cases:

- example 1 (of 2):  
For a single-family house with 1 BHE of 100m depth, a heating requirement of 9.8 MWh/y and an SCOP (Seasonal Energy Efficiency Ratio) fixed to 3.5 [-], the annual energy exchanged (extracted) with the ground obtained is 7 MWh/y.  
→The constant line source extraction for this example is therefore 8 W/m.
- example 2 (of 2):  
For a single-family house with 1 BHE of 100m depth, a geo-cooling energy requirement of 2.6 MWh/y, a heating requirement of 9.8 MWh/y and an EER of 3.5 [-], the annual energy exchanged (exacted) with the ground obtained is 4.4 MWh/y. This case foresees and it is equivalent to a thermal regeneration of the ground of about 37%.  
→The constant line source extraction for this example is therefore 5 W/m.

In the following paragraphs, simulations have been carried out in order to investigate the issue, proposing some evaluations and criteria able to reduce thermal interference. In particular, interference effects between two simple and nearby systems (one BHE each) and a complex system (26 BHEs) adjacent to a simple one (1 BHE) are shown.

Different parameters have been modified in order to raise awareness of the main aspects that should be taken into account (heat extraction from the ground, thermal conductivity of the ground and distance between systems).

Parameters set for all the simulations are summarized in the following table:

Table 6 - Thermal parameters and system properties assigned and fixed to the numerical model.

Depth of every borehole (L)	100 m
Volumetric heat capacity (c)	2.0 MJ/m <sup>3</sup> K
Undisturbed ground temperature (T <sub>in</sub> )	12°C
Geothermal heat flux	0 W/m <sup>2</sup>
Heat carrier fluid (Monopropylenglycole)	25 %
BHE diameter	135 m
Type of BHE	Double U (DN 32)
Borehole thermal resistance (R <sub>b</sub> )	0.1 (mK)/W
Borehole thermal resistance (R <sub>a</sub> )	0.4 (mK)/W
Spacing between BHEs (into the same system/field)	8m

The following table shows all the variable parameters used in simulations:

Table 7 - Thermal parameters and system properties that have been varied in the analysis.

Distance between different geothermal system	8m – 20m – 50m – 100m
Constant line source extraction ( $\phi$ )	2 W/m – 5 W/m – 8 W/m
Thermal conductivity of the ground ( $\lambda$ )	2 W/(mK) – 3 W/(mK)

NB: The present work has considered the prevalence of heat extraction compared to heat injection. This is very often a correct hypothesis considering residential buildings in cold and temperate climatic zones. The opposite could nevertheless occur in warm climates.

Considering this last case, with a typical overheating of the ground due to an excess of cooling, national and international standards are less rigid compared with the undercooling case; this last one could be more dangerous due to the ground frost. However, national and international standards place the attention on the maximum admissible temperature of the fluid into the probe, which should be in compliance with the tightness of the materials and with the cooling machine evaporator (temperatures above 40°C are usually not recommended). In this work no overheating of the ground has been investigated.

### 3.1.1 No groundwater flow – any convection effect

Conditions without a moving aquifer in the ground (any convection effect) have been simulated and analysed in two main configurations.

The first is a single BHE system influenced by another identical one (following called “*Small field near to another small field*”) and the second is a large BHEs system close to a single BHE system (following called “*Large field near to a small field*”).

For the second case study, the field configuration of the Swiss pilot case (AIL case study with 26 BHEs) has been taken into account.

The following simulations have been done using the TRNSBM<sup>18</sup> module for TRNSYS<sup>19</sup> [20], which is the TRNSYS version [21] of the SBM program (Superposition Borehole Model, [22]). The latter was used to determine the g-functions based in the EED program (Earth Energy Designer).

<sup>18</sup> The Superposition Borehole Model for TRNSYS

<sup>19</sup> Transient System Simulation Tool

Small field near another small field

The following figure shows the different layouts disposition analysed for this case study.

The blue BHE represents the reference system (such as the system we are studying).

The red, orange and green BHEs represent the near and identical systems shifted respectively to a distance of 8m, 20m, and 50m from the reference system.

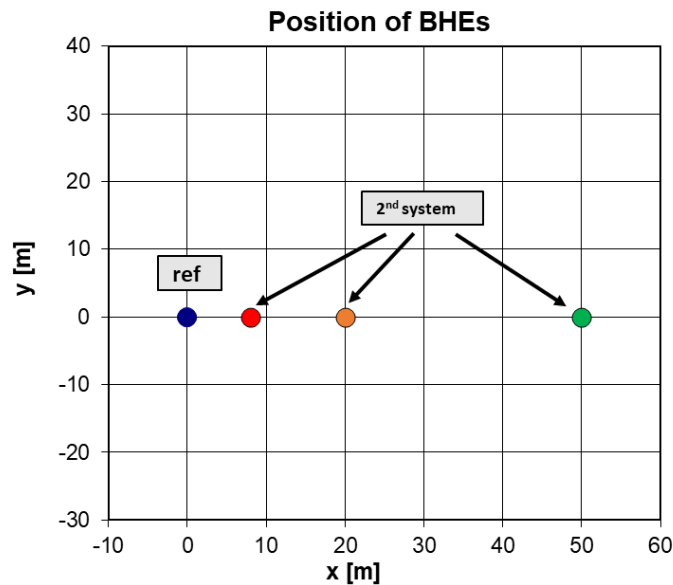


Figure 4 - Different configurations analysed for the case the "Small field another small field" case.

The average fluid temperature (inlet-outlet) of the reference system is the fixed point setting for the interference analysis (equivalent to "it would be a stand-alone system").

The following graphs (Figure 5) describe the decreasing temperature with respect to the reference system; the increasing temperature difference due to the thermal interference with other nearby system.

Since systems are identical and symmetrical, thermal effects on the reference system are the same that can be seen on the nearby one.

Average difference of temperature of the BHE field fluid  
Single field affected by a nearby one

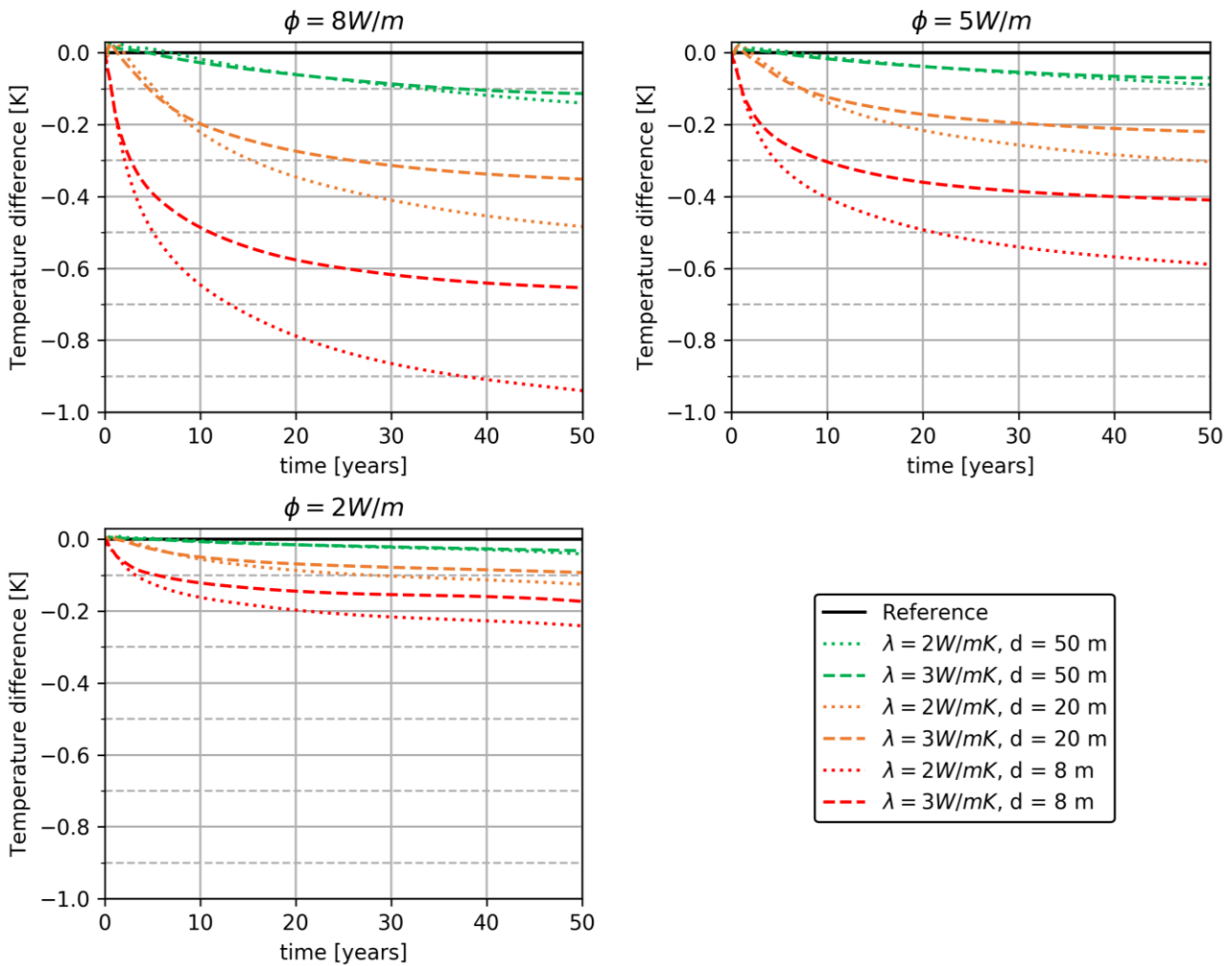


Figure 5 - Size of the average temperature difference of the fluid (inlet-outlet) due to the presence of a nearby system (single field affected by a nearby one). All differences are related to the reference case without a nearby system. (Simulations performed with TRNSBM).

Results state that the thermal impact on a single BHE are highly dependent on the distance between the two systems. Although it is not delimited to the few meters near to the system, it reduces significantly by increasing the distance. Thermal conductivity of the ground also has a great influence especially when systems are more in proximity. Moreover, thermal interference effects become lower reducing the linear heat extraction parameter.

The quantification of the temperature decrease depends on the heat extraction, working time, and ground properties; this temperature information can be used to quantify and if necessary correct and reduce the thermal interference between systems.

Large field near to a small field

The following image shows the AIL case study (Swiss pilot case in GEO4CIVHIC project), with the current and final arrangement of the BHE field (red symbols for System "B" are installed probes).

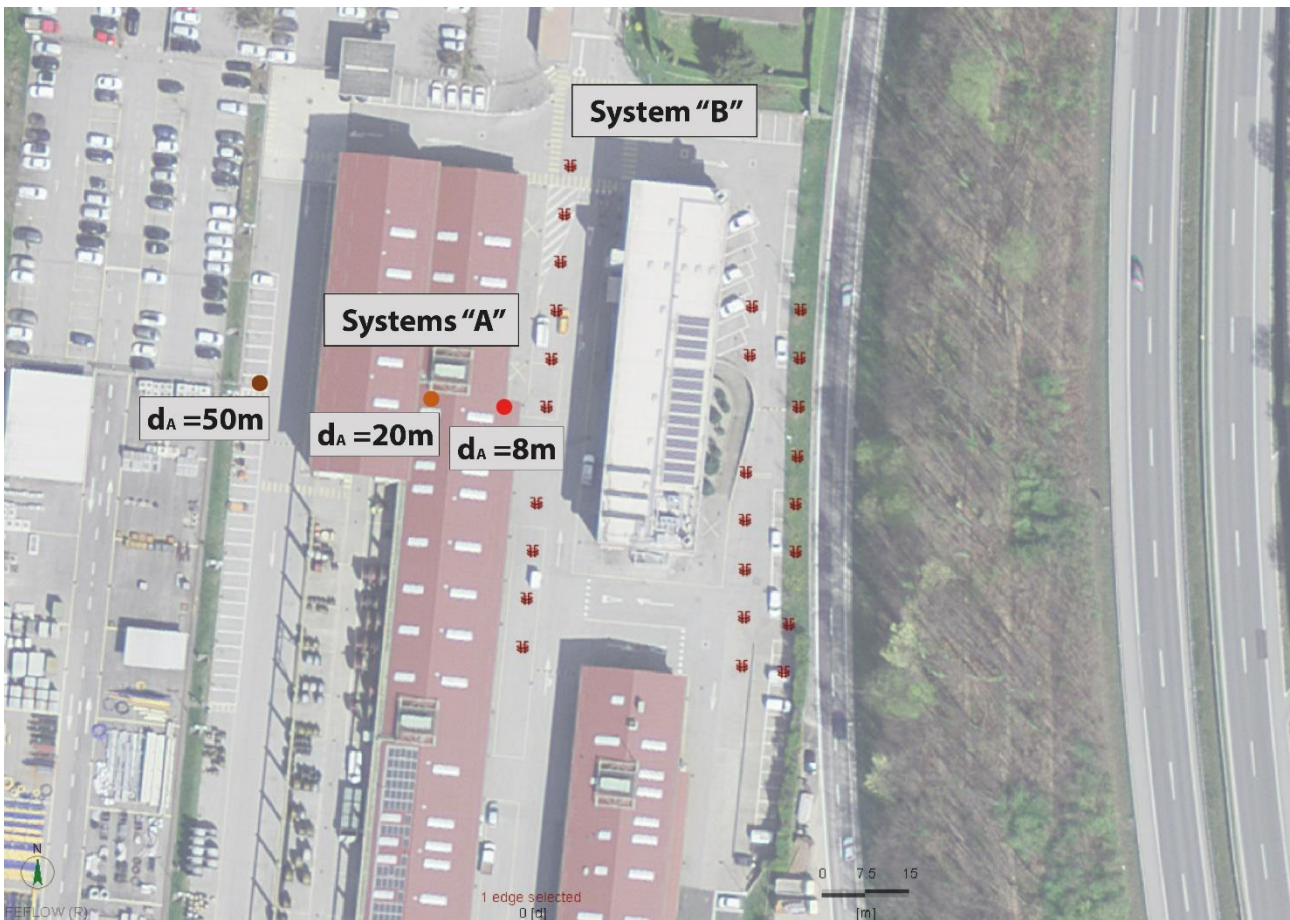


Figure 6 - Probes final position for the AIL case study site (System "B") and the position of Systems "A" at several distances (8, 20 and 50 meters – probe  $d_A=100m$  is out of the figure).

In Figure 7, there is the presentation with the arrangement of the single BHE systems (A), placed at various distances on the west side of the AIL geothermal system (B).

These are currently not realistic scenarios, since a depot and some car parking are currently present. It is nevertheless interesting since in the future (next 20-30 years) no one can predict urban development planning of this type, and in any case, this example can be used to understand and show the real interference that a large BHE field can have on a nearby small one.

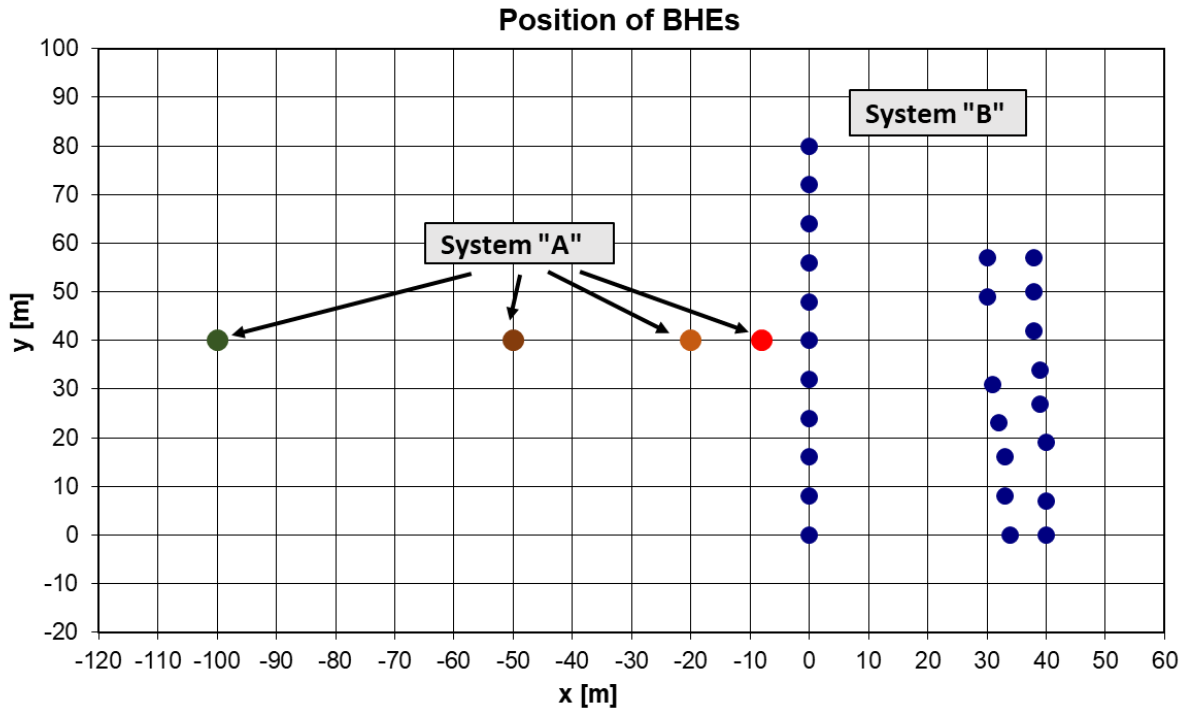


Figure 7 - Different configurations analysed for the “Large field near to a small field” case.

The average fluid temperature (inlet-outlet) of the two different systems has been set as a fixed point for the interference analysis of both cases (the reference temperature of the systems is the same for “A would be a stand-alone system” and “B would be a stand-alone system”).

Contrary to the previous case (Small field near to another small field), the systems are not identical and symmetrical. Consequently, the thermal effects of system A on system B are different and unbalanced compared to the thermal effects of the system B on the system A.

The following graphs in Figure 8 describe the temperature decreasing of the BHE fluid “A” (small system), related to the thermal interference of “B” (large system).

Average difference of temperature of the BHE field fluid  
Single field (A) affected by the multiple field (B)

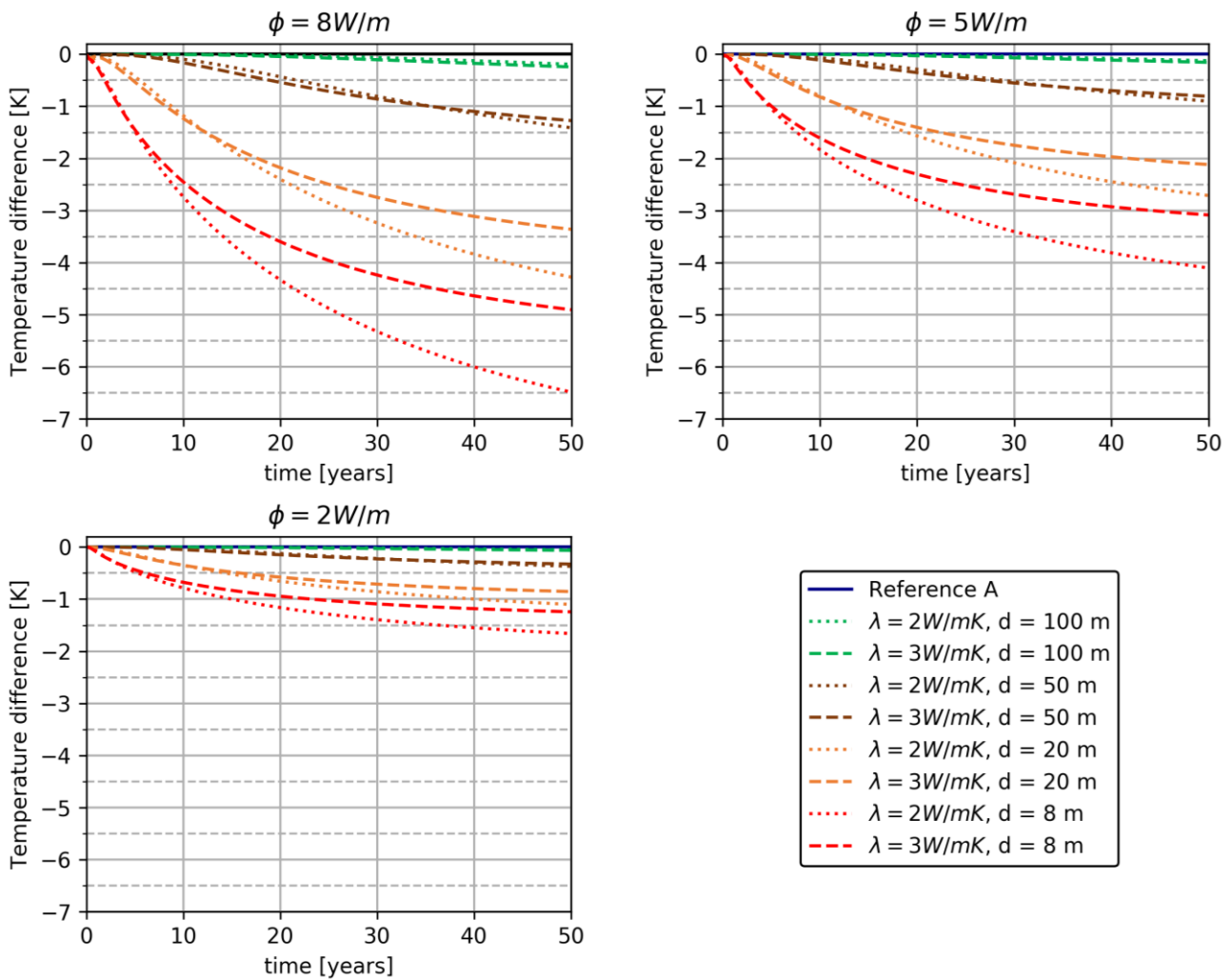


Figure 8 - Size of the average temperature difference of the fluid (inlet-outlet) due to the presence of a nearby system (single field A affected by a near large field B). Differences are related to case A without the nearby system. (Simulations performed with TRNSBM).

Results state that fluid temperatures of system A are greatly affected by system B. The effects of system B on system A are significant even at a distance of 50m (50% of the probe depth), and effects can be reduced also with a lower linear heat extraction. Only by combining low linear heat extractions with a sufficient distance between systems, does system B not affect small field "A" too much.

As stated in the previous case study *Small field near to another small field*, the thermal conductivity of the ground has a great influence especially when systems are more in proximity.

The following Figure 9 graphs describe the decreasing temperature of the BHE fluid reference "B" (large system), affected by the thermal interference of "A" (small system).

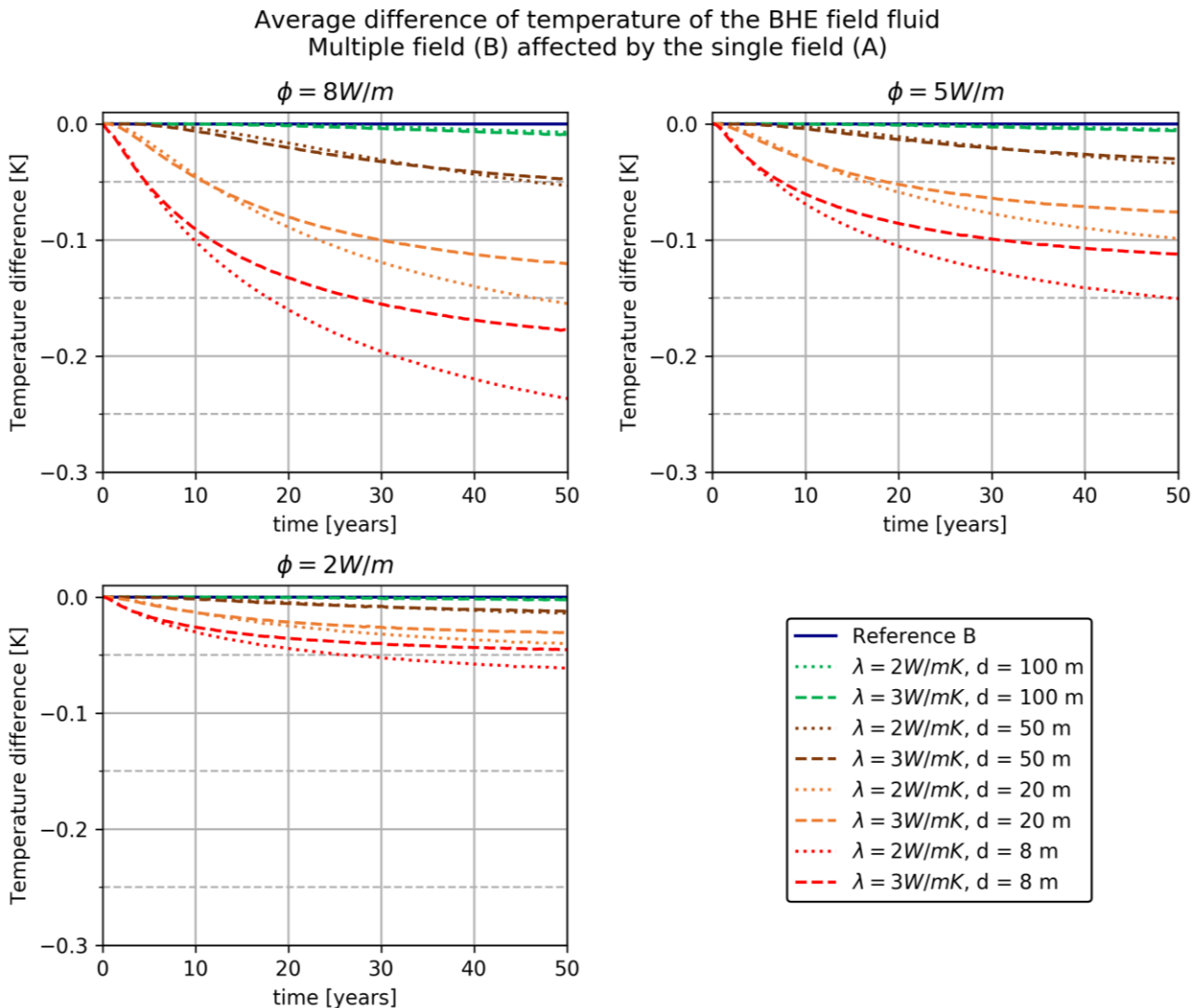


Figure 9 - Size of the average temperature difference of the fluid (inlet-outlet) due to the presence of a near system (large field B affected by a single field A). Differences are related to case B without the nearby system. (Simulations performed with TRNSBM).

Results state that fluid temperatures of the system B (multiple field) are less affected by system A (single field), and the temperature penalization of the system A on the system B is almost negligible.

### 3.1.2 Moving aquifer in the ground – convection effects

Groundwater is present almost everywhere, but it is only available and flowing in useful quantities in aquifers. An aquifer is defined as a geological layer or formation that allows water circulation within it, through pores or cracks.

In order to understand the effect of the groundwater flow on the thermal interference of nearby BHE systems, the AIL case study has been used in this paragraph.

Concerning the geothermal system, the same parameters of the previous paragraphs have been used (see Table 6 and Table 7).

Concerning the aquifer, simulations use Ticino regional mean values. The following two tables summarise the parameters.

Table 8 - Average hydraulic gradients and horizontal hydraulic conductivities for the main aquifers within Cantone Ticino (Switzerland). Vedeggio aquifer is the one where the AIL probe field is installed.

Aquifer	Average hydraulic gradient	Average horiz hydr. Conductivity (m/s) → m/day
Piano di Magadino	0.002	0.00165 → 143
Vallemaggia	0.008	0.00084 → 73
Vedeggio	0.006	0.00126 → 110
Laveggio	0.009	0.000674 → 60
Chiasso	0.006	0.00025 → 22
<b>Average</b>	<b>0.006</b>	<b>Logarithmic average 0.00078 m/s → 70 m/d</b>

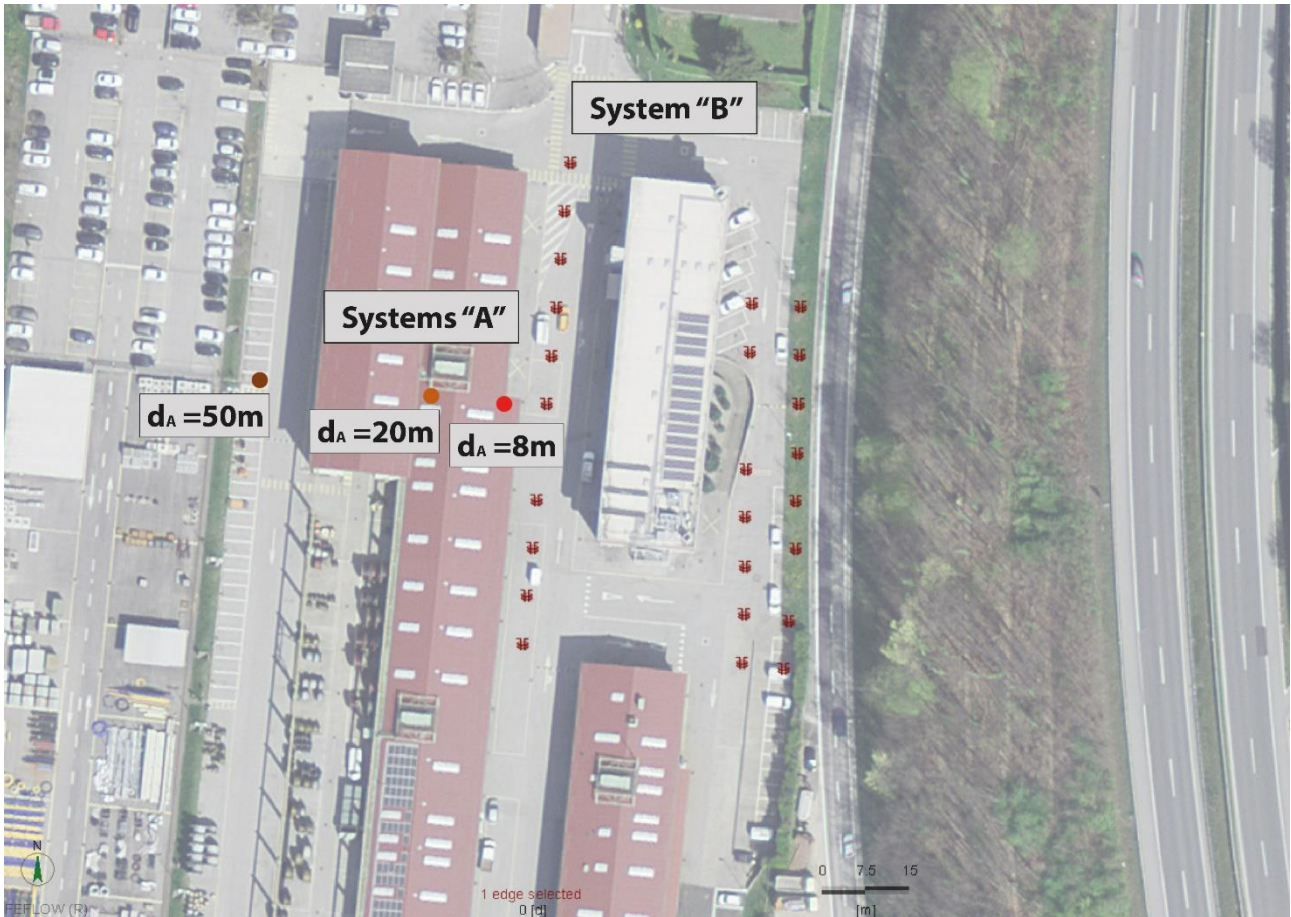
Table 9: Hydrogeological and thermal properties assigned to the numerical model.

	Property	Value
FLOW	Specific storage (1/m)	0.0001
	Hydraulic conductivity xx/yy/zz (m/day)	70/70/7
	Hydraulic gradient	0.006
	Darcy velocity [ $k^* \nabla h$ ] (m/day)	0.42
	Fluid density [groundwater] (kg/m <sup>3</sup> )	1000
	Fluid viscosity [groundwater] (kg/md)	97.1136
	Porosity	0.3
HEAT	Volumetric heat capacity of water (MJ/m <sup>3</sup> k)	4.2
	Volumetric heat capacity of solid (MJ/m <sup>3</sup> k)	2.2
	Thermal conductivity of fluid (W/(mK))	0.65
	Thermal conductivity of solid (W/(mK))	2
	Thermal dispersivity: horizontal/vertical (m)	5/0.5

The hydraulic gradient of 0.006 was set by imposing a hydraulic head of 4.8 m a.s.l. East and a hydraulic head of 0 m a.s.l. West. The distance from the West and East constant heads is the distance between model borders, therefore the hydraulic gradient is:

$$\text{Hydraulic gradient} = \frac{4.8m}{800m} = 0.006$$

The analysis was executed by considering different groundwater flow directions. As in the previous paragraph, the single probes have been placed at 8, 20 and 50m away from the AIL geothermal system (see Figure 7).



Single field affected by the multiple field with moving aquifer

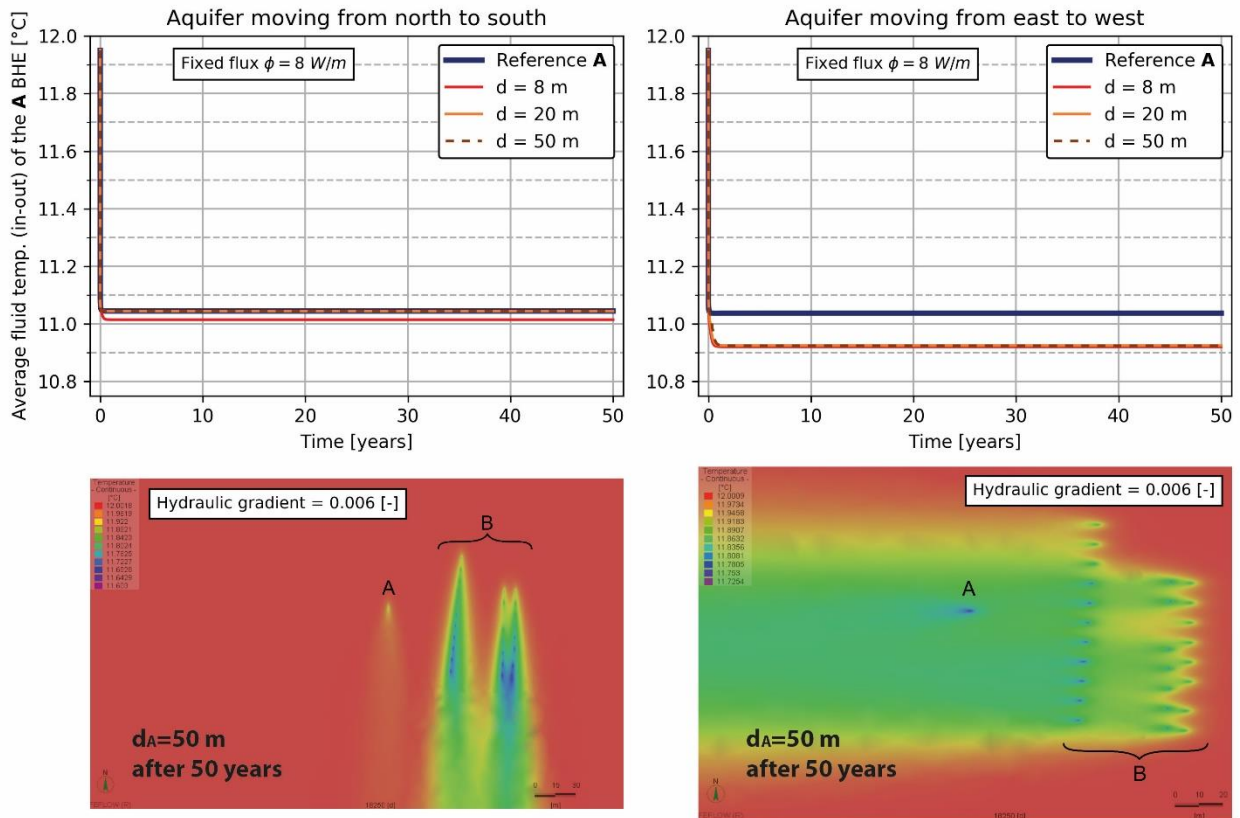


Figure 10 - Size of the average temperature difference of the fluid (inlet-outlet) due to the presence of a nearby system and groundwater flow. (Simulations performed with FEFLOW).

**Aquifer moving from North to South:** in these simulation scenarios, groundwater flow direction was set from North to South, and the single probe was simulated at a distance of 8 m, 20m and 50m West from the AIL BHEs field. Results show that at a distance of 8m from the AIL field, the single probe slightly interacts with the system to a large degree, with its average inlet/outlet temperature decreasing by 0.03K after a few years and then it remains constant. Placing the single probe at larger distances does not cause any type of thermal interaction. This means that in this case the single probe would not be affected by the field operation probe.

**Aquifer moving from East to West:** in these simulation scenarios, groundwater flow direction was set from East to West and the single BHE was simulated at distances of 8m, 20m and 50m from the AIL BHEs field. Results state that the thermal impact on the single probe is limited to 0.12K, independent of the distance from the field probe. This means that the presence of a strong groundwater flow that restores the extracted heat contributes to levelling the thermal impact produced by both the single probe and the probe field. Another observation can be made regarding the thermal impact: this BHE field layout tends to be favourable for the dissipation of the cold thermal plume, since its distributed layout and the optimal distance between adjacent probes (8m) contributes to mitigating the total thermal impact on the subsurface.

NB: The cases here described and investigated in subparagraph 3.1.2 are generalized with some fixed hydrogeological parameters. For a correct assessment of thermal interference with the presence of flowing underground water, it is always necessary to take into account the whole hydrogeological context in which the geothermal systems are inserted, their usage profiles and their energy balance.

### **3.1.3 ETHICAL: Easy Thermal Interference evaluation**

As demonstrated in the previous paragraphs, the presence of nearby plants can be highly penalizing for all geothermal systems. Few tools are currently able to evaluate these effects in order to correct or limit them; furthermore, they are often expensive and not simple to use. Within GEO4CIVHIC project, a useful and easy tool for a preliminary sizing of geothermal has been developed and proposed [23].

Technical and administrative organizations systematically manifest the need for easy tools and methods in order to provide assessments able to face the problem and applying precautions.

The tool developed in this context is called ETHICAL (acronym for Easy Thermal Interference evaluation). Such tool is expected to be easy to use, with a clear procedure, and without a computer code or complex setting calculations. It is useful and important to face the problem and it can limit possible thermal and technical problems at urban scale between nearby geothermal systems. For its ease and speed of calculation, this tool is recommended for both authorities and consultants. It allows calculation of the thermal effect for several systems that differ in: number and depth of boreholes, type of heat exchanger used, energy demand profile and design efficiency of the system. The distances between different BHEs and systems can be manually defined case by case.

In detail, two tools have been developed, one without the presence of a flowing aquifer (no convection effects), and the other with the possibility of setting some simple parameters that foresee the presence of moving underground water.

It's possible to open and download these tools from the following link (click on it or copy-paste it on your browser):

[geo4civhic.eu/files/ETHICAL\\_WithoutMovingAquifer.xlsm](http://geo4civhic.eu/files/ETHICAL_WithoutMovingAquifer.xlsm)

[geo4civhic.eu/files/ETHICAL\\_ActiveMovingAquifer.xlsm](http://geo4civhic.eu/files/ETHICAL_ActiveMovingAquifer.xlsm)

**Results comparison and validation**

The AIL case study site (previously analyzed in 3.1.1) was used to validate ETHICAL comparing its results with the TRNSBM tool. For simplicity, some parameters have been fixed; in particular, results refer to:

- A line source heat extraction of 8W/m,
- An average temperature difference of the fluid of a single plant affected by a large one after 20 years of operation,
- A thermal conductivity of the ground of 2 W/(mK),
- A situation without the presence of an underground moving aquifer.

*Table 10: Comparison between ETHICAL and TRNSBM, using the AIL case study (26 BHEs) site and a hypothetical nearby small single system (1 BHE).*

	Distance between different geothermal systems							
	8 m		20 m		50 m		100 m	
	Fluid temperature drop - comparison between TRNSBM and ETHICAL [K]							
	TRNSBM	ETHICAL	TRNSBM	ETHICAL	TRNSBM	ETHICAL	TRNSBM	ETHICAL
8 W/m	-4.4	-6.2	-2.5	-3.5	-0.5	-0.6	0.0	0.0
5 W/m	-2.8	-3.8	-1.6	-2.2	-0.3	-0.4	0.0	0.0
2 W/m	-1.2	-1.5	-0.7	-0.9	-0.1	-0.2	0.0	0.0

Results show a good correspondence between these two programs, in particular, the ETHICAL tool tends to be more conservative in results than the TRNSBM, which overestimates the effects.

The ETHICAL tool, which is simple and ready to use, allows users even with less experience in programming and in dynamic simulations to assess thermal interference between systems. With its ease of use and speed of calculation, compared with other tools like TRNSBM or FEFLOW, the ETHICAL tool represents an excellent tool to help in facing, planning and solving a complex and difficult problem such as thermal interference between nearby geothermal systems.

### 3.2 Considerations able to foresee and prevent interferences

The long-term thermal influence of nearby geothermal installations leads to prompt decrease of the BHE fluid temperature, in addition to the typical and well-known drop due to the seasonal effects of systems.

The often-used rule "first come, first served" does not work, because if new installations can take into account existing ones, the reverse is generally not possible or difficult to apply. For this reason, it is always important to size and plan installations taking into account possible future systems or mind eventual measures to adapt the plant.

The sizing generally considers the installation as if it was unique, without the presence of adjacent systems, as stated in the most European standards and norms (typically minimum  $-1.5^{\circ}\text{C}$  for the average forward-return fluid temperature in the BHEs during a few working decades). If it is possible to predict the over decreasing temperature ( $\Delta T_{\text{penalization}}$ ), the minimum temperature limit must be corrected by the effect of long term neighboring systems ( $-1.5^{\circ}\text{C} + |\Delta T_{\text{penalization}}|$ ). This method can avoid the freezing of the surrounding ground, or the stop of the GSHP system.

The long-term thermal effects of one installation on another one depends directly on the exploitation of the geothermal resource. As proved in this chapter, it is possible to reduce them by using smaller constant linear heat sources (combining the extraction with the reinjection into the W/m, see page 42 of this report). Furthermore, the study shows that the higher the density of the probes and the number of installations, the lower the geothermal resource that can be exploited by each installation.

One way to limit this effect, without penalizing user-heating demands, is to provide a thermal recharge of the ground. This may indeed contribute to decreasing the constant line source extraction from the ground. When it is possible to establish the geothermal resource needed, consequently the necessary thermal recharge for the desired geothermal system can therefore be defined.

These considerations can be extended also in warm climates, which have prevalence of heat injection compared to heat extraction. Nevertheless, soil subcooling as the most critical problem because of the risk of the freezing of the soil. New heat pumps have usually blocking systems that does not allow the ground freezing (consequently reducing or stopping the building heating). Considering the overheating of the ground, it is important to pay attention on the maximum admissible temperature, which is in compliance with the tightness of the materials and with the cooling machine evaporator (temperatures above  $40^{\circ}\text{C}$  are usually not recommended). The same concept of the  $\Delta T_{\text{penalization}}$  can be defined and applied for the overheating condition.

Following the formula on page 42, there are consequently two main options to reduce the constant line heat extraction:

- by fixing the drilling length, the heat extraction has to be reduced (for example recharging the ground balancing as much as possible the energy demand);
- by fixing the heat extraction, the drilling length has to be increased (for example by drilling deeper, or by increasing the number of BHEs).

Of course, both possibilities can be implemented simultaneously, paying attention to keep the same desired and optimal result.

Following these considerations, and results of this chapter, the three criteria capable of reducing thermal interference between nearby systems are the following:

1. there must be a minimum distance between the geothermal fields. If systems are closer less than 50% of the drilling length (distance calculated as the closest point between probes, see as example fig. 6 and 7), it is still possible to obtain some negative effect on geothermal systems;
2. during the sizing step, increase correctly the minimum fluid temperature in order to anticipate the long-term effects of nearby systems. This can be done augmenting the total drilling length, if any change on the annual heat extraction can be implemented;
3. limit the annual extraction of the geothermal resource per installation. This can be done annually recharging the ground, so recharging the ground and reducing the annual heat extraction.

All criteria here described in some aspects go beyond the specific skills of engineer or technicians involved, since a basic knowledge of nearby pre-existing installations is required, as well as a future estimation of geothermal systems that will be installed nearby.

Technical skills therefore also require good and far-sighted territorial knowledge and planning.

However, the existence of flowing groundwater can alter what was previously stated, since a thermal convective component modifies heat transfers between BHEs and the ground.

The simulated scenarios in this chapter (paragraph 3.1.2) has highlighted the importance of simulating groundwater flow when considering thermal interactions between closed-loop shallow geothermal systems. The groundwater flow contributes to mitigating the thermal impact on the subsurface by continuously reinstating the extracted heat, since usually groundwater temperature is usually observed at values of 12-14°C. The presence of a consistent groundwater flow contributes therefore to reinstating the extracted heat. In the simulated cases, the layout of the probe field and the extraction rates (8 W/m) were favorable conditions for the creation of a reduced thermal plume.

Simulations proved that taking the correct direction and magnitude of the groundwater flow and taking into consideration the real probe layout is fundamental for a realistic estimation of the thermal interferences that can be observed where a great density of shallow geothermal systems is observed.

The tool developed in this aspect of the GEO4CIVHIC project is ETHICAL (acronym for Easy THERmal InterferenCe evALuation). It is easy to use, with a clear procedure, and without a computer code or complex setting calculations. It is a useful and important tool for tackling the problem and can limit and prevent eventual thermal and technical problems at urban scale between nearby geothermal systems. For its ease and speed of calculation, this tool is recommended and ideal for both technical and consulting companies and public administrations.

## 4 Conclusions, best practices and recommendations

Environmental policies at European level foresee the achievement of strategic objectives in 2030 and 2050 in favour of a sustainable future with low CO<sub>2</sub> emissions. The increase in renewable energies, combined with energy efficiency, are priority themes in current energy strategies. In this context, the spread of geothermal energy represents an important element, particularly in the low enthalpy, where GSHPs are an increasingly widespread reality. The increase of these geothermal installations, if on one hand it must certainly be supported and incentivized, on the other it must be regulated and carried out properly, so as to be efficient and effective.

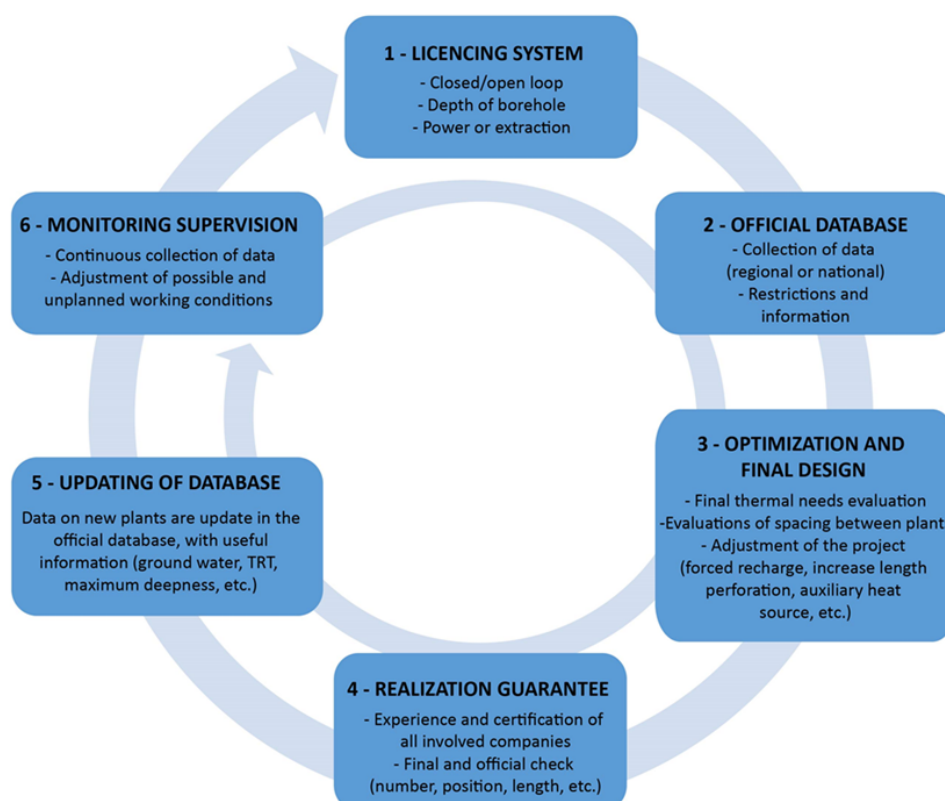
The objective of this task was to identify possible recommendations aim at preventing and resolving interferences between adjacent geothermal plants, in order to guarantee maximum efficiency of all systems, even over the long term.

In order to be able to offer such these recommendations, first a literature review was performed, analysing case studies from various location in Europe where the issue of thermal interference between neighbouring geothermal plants was somehow addressed or considered.

Studies and physics confirm that if geothermal plants are near each other, they might cause interferences that can have significant effects on the operation of the system. This is due to a sub-cooling of the ground, which can become excessive if the systems are not coordinated properly. In this case, the heat transfer between the BHE and the surrounding soil, is degraded, as compared to an ideal situation without thermal interferences.

Starting from these considerations, in **chapter 1** are described a set of steps to be followed by all the actors involved in the planning, design, construction and operation of a geothermal plant, thereby implicating public administration, professionals and private citizens. These steps are represented in the following circular diagram:

*Figure 11 - Summary of the theoretical phases considered during the installation of a shallow geothermal system, from the presence of a licencing system to the final monitoring phase.*



In order to reduce, and avoid as much as possible the interference between geothermal plants, it is important that in the context of national procedures, which are then applied at regional and local level, all these steps be explicitly defined. In a perspective of densification and increase of geothermal systems, it is important they be considered in a forward-looking approach, thereby thinking not only about what exists at a given moment, but also of future evolutions. For example, if you consider an isolated system that does not initially have any interference problems, in the case of installations in proximity in the following years, the interferences will have effects both on the existing system and on the new ones. Nevertheless, the new system during the planning phase has the possibility to limit its own interference problems, the opposite is more difficult since it means to inspect, and in case of need, modify somehow the existing one. Malfunctions of a system that could not foresee the future presence of other nearby systems cannot be attributed to designers. On the other hand, the designer may have a part of responsibility over the operation and the interferences ensued by the installation of a new system, near a previous one.

For this reason, territorial energy planning has considerable importance and the public administration should facilitate it by setting a standard procedure that follows the logic of the previous diagram.

1 – Licensing system: it is necessary to have a system of procedures that is clear, which can take into consideration all aspects such as the type of system (open or closed system), the extraction power, the depth of the BHEs and the spatial location. The procedure must be simple and standardizing the collection and evaluation of all the information necessary to limit thermal interferences from neighbouring geothermal systems (and if necessary halt or adjust projects).

2 - Official database: the data collected in the first phase of the procedure can be easily updated, and used both in the context of improving management of the BHEs, and preventing interferences between nearby BHEs. A geo-localized database is necessary, and would ideally be available publicly, or via log-in credentials. This tool would allow a valorisation of information, an increase in knowledge, a better monitoring of dissemination trends of BHEs, prevention of interferences and easy access to areas with legislative restrictions; finally making the diffusion of the plants more efficient and rapid through a more conscious management of past and future installations.

3 - Optimization and final design: the optimal system is always the one that allows you to satisfy the temperature limits of the heat transfer fluid with at minimum number of BHE installed. The optimization of the system must therefore make it as efficient as possible from an economic, energetic and environmental point of view. For the final design the thermal requirements of the building, the number and arrangement of BHEs, the distance both between the border of other plants and finally preconceive corrective measures and compensation solutions must be evaluated and studied.

4 - Realization guarantee: once the technical aspects are defined, one of the steps that is often missing is a verification that the project is carried out as originally ensuring that the specifications define in phase 3 are put in practice. In order for this to happen, there can be an intervention on two aspects: the first is to ensure that the companies that deal with the construction of the plants are certified and that they are able to carry out the work using state of the art methods. This aspect can be improved through training of professionals with regular courses and updates, both in regards to techniques and materials for the construction, and in regards to the regulations or good practices existing in the geothermal field. The second aspect is the regular inspection by the competent authorities, both during the construction phase and before putting the system into operation.

5 - Updating of database: it often happens that during the installation, especially in the drilling phase, it is not always possible to carry out the project exactly as planned. There might occur impediments related to some geological issues, as well as setbacks of another nature, may make it necessary to change the duration of the construction site and the number or location of the perforations. Precisely for these reasons, updating the information subsequent to the implementation phase is essential to ensure that the correct data is present in the databases. Failure to do so results in incorrect information in the database and thwart the adequate design of future installations.

6 - Monitoring supervision: this is the last step, which may not always be present, but is especially important in large BHEs. Collected monitoring data allows to understanding the operation of the BHEs and to evaluate eventual adjustments to be made. In case important changes are necessary for the correct operation of the system, these changes must be updated in the database and if they are substantial, a request should be delivered to the licensing procedure.

In **chapter 2** the previous procedure has been applied to all the case studies of the GEO4CIVHIC project, both real and pilot cases, in order to clarify its application and potential, as well as to present shortcomings currently present and a wide range of possibilities to improve some specific area.

**Chapter 3** made use of specific simulation programs (TRNSBM and FEFLOW) to present the main parameters that can limit or increase the thermal interference between geothermal plants. The studied configurations analysed (*Figure 4: Small field near another small field*, *Figure 6* and *Figure 7: Large field near to a small field*,) demonstrate how interference problems can also be present between neighbouring systems with a single probe each. Moreover, a large system adjacent to a small one strongly penalizes this last one. The graphs presented in *Figure 5*, *Figure 8* and *Figure 9* provide a visual method to display the temperature difference with which a system should be oversized, according to the main national and international European standards. The simulation programs used that allow these analyses are often difficult to use. For this reason, in the context of this project, a tool named ETHICAL (Easy THERmal InterferenCe evALuation) was developed, that aims to be user-friendly, with a clear procedure, and without a computer code or complex setting calculations. The ETHICAL tool allows users, even with low experience in programming and in dynamic simulations, to assess thermal interference between adjacent BHE systems.

This work therefore aims to give all the players operating in the geothermal sector the recommendations, guidelines and methods suitable for reasoning and evaluating the effects of thermal interference between adjacent plants. Following these recommendations, it is possible to prevent long-term BHE thermal interference problems on an urban scale, sufficiently accounting for existing and future neighbouring systems.

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