Catalogue of techniques and best practices

for the utilization of Near-Surface Geothermal Energy

Deliverable D.3.1.1 – Catalogue of techniques and best practices for the utilization of Near-Surface Geothermal Energy

16/12/2015 – 14/12/2016: The catalogue is an internal document summarizing the different methods for the use of NSGE in the Alpine environment. It also includes technical schemes and facts of best practice case studies assessed in the participating countries.

This document was written in the course of the ERDF funded project GRETA (2016 - 2018). It is the first deliverable of the Work Package 3 (WP3 or WPT2) "*Operational criteria for the utilization of Near-Surface Geothermal Energy in the Alpine environment*". The Geological Survey of Austria (GBA), as responsible partner in the WP3, elaborated this catalogue with contribution from the involved project partners[1].

The preliminary studies for this deliverable (Del.3.1.1) were carried out within activity 3.1 – the assessment of existing techniques and best practices for the utilization of Near-Surface Geothermal Energy (see http://www.alpine-space.eu/projects/greta/en/project-results/work-in-progress/wp3-technical-criteria).

This catalogue summarises the results from an assessment of existing techniques and best practices for the utilization of Near-Surface Geothermal Energy (NSGE). For this assessment, the involved partners surveyed their national territories within the Alpine environment to include the different methods for the use of NSGE and to reveal the huge variety of opportunities in best practice examples. Those examples also include technical schemes and facts of best practice case studies assessed in the Alpine environment of the participating countries.

[1] TUM; ARPA VdA; GeoZS; BRGM; POLITO; EURAC; TripleS; INDURA; CA; Uni Basel; Regione Loimbardia

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1 Introduction

This catalogue deals with existing techniques and best practices for the utilization of Near-Surface Geothermal Energy (NSGE) in the Alpine region. It was conceived to show the broad applicability of NSGE systems and to explain their differences.

It is not easy to decide which type of NSGE-use is suitable to meet the individual demand in consideration of the environmental conditions. This catalogue shall help the reader to better understand the range of NSGE techniques including their applicability and their limitations.

1.1 The importance of heat pumps

Almost all NSGE systems are exchanging energy with the ground via heat pumps – only few systems (e.g. free cooling, see Chapter 0) exchange heat with the ground directly. The heat pump provides space heating and cooling for buildings as well as domestic hot water production using shallow geothermal energy. Geothermal heat pump systems feature three main components:

- The **ground side**, to extract/inject heat out of or into the ground (ground water / solid underground / artificial ground like the fundament of buildings);
- The **heat pump itself**, to transfer heat from a cold source to a hot sink;
- The **building side**, i.e. the equipment inside the building that transfers the heat or cold into the rooms (radiant heating / floor heating / etc.).

A heat pump (HP) transfers heat from a “heat source” to a “heat sink”. The heat source is cooled down, and the heat sink heated up. When the building requires heating, the heat source is the ground side, and the heat sink the building side. Reversely when the building requires cooling, the heat source is the building side, and the heat sink the ground side. A HP uses a relatively small amount of electrical power to transfer energy from the heat source to the heat sink. With 1 MWh of electricity, the HP typically produces 3 to 6 MWh of heat [1].

The HP operates through the compression and the phase changes of a refrigerant fluid through four phases (cf. Figure 1):

- evaporation: heat is abstracted from the source and the “cold” liquid evaporates;
- compression: the “cold” vapour is compressed (and also heated) by means of the mechanical work of the compressor;
- condensation: the “hot” vapour is chilled and then liquefied in the condenser. The heat gained in the previous phases is therefore conveyed to the “hot sink”;
- expansion: the “hot” liquid passes through a valve, losing pressure and chilling.

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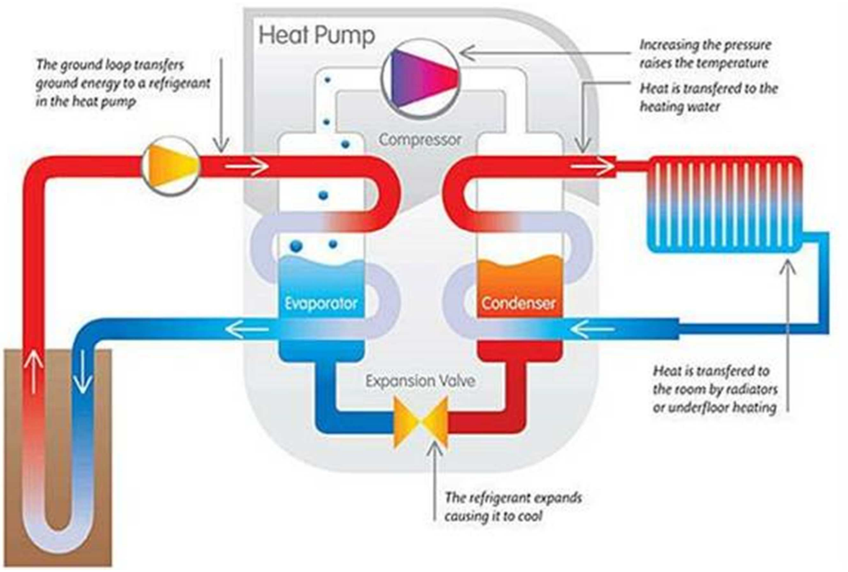

Figure 1: A simplified diagram of a heat pump in heating mode (source: http://groundenergysupport.com/)

1.2 The range of NSGE installations

There are two main types of NSGE systems, depending on the operating principle:

- **Open-loop systems:** the heat carrier fluid is water, which can be extracted from the ground with well(s). Water is usually reinjected into the same aquifer (cf. Figure 2). NSGE systems exploiting water from springs also fall into this category;

- **Closed-loop systems:** the heat exchange medium is the underground, considering both the solid and the fluid phase. The heat exchange is performed through the circulation of a heat carrier fluid through ground heat exchangers placed in the underground. There are several types, the most common ones are: horizontal loops, borehole heat exchangers, compact forms of ground heat exchangers, thermo-active structures (pipes in any kind of building underground element in contact with the ground), etc. (cf. Figure 3, Figure 7, Figure 9).

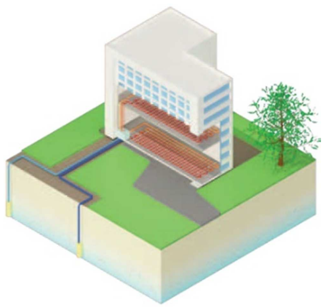

Figure 2: Open-loop system, with one pumping and one injection well (doublet) (© geothermie-perspectives.fr, ADEME-BRGM).

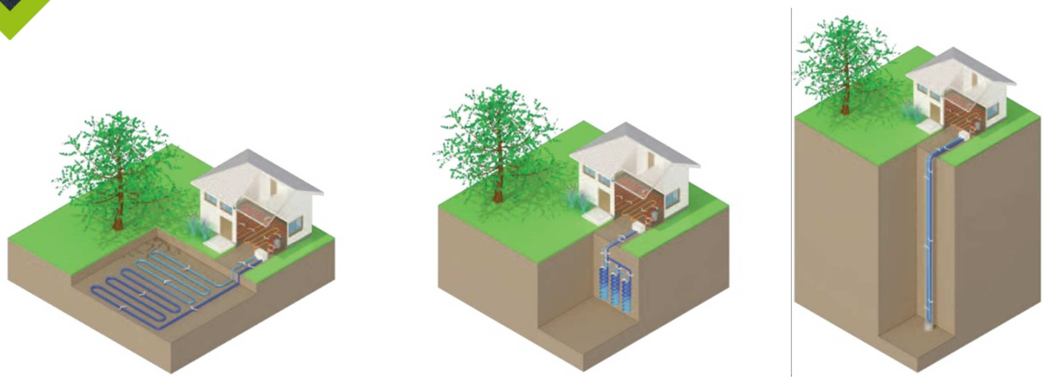

Figure 3: Three technologies of closed-loop systems for individual houses: horizontal GHE (left), compact GHE (middle), borehole heat exchangers (right) (© geothermie-perspectives.fr, ADEME-BRGM).

1.2.1 Open-loop systems

Open-loop systems require an aquifer to be present on site. An aquifer is an underground layer from which groundwater can be extracted in a technically and economically feasible way [2] – usually though a pumping well, less often with a freely flowing well (i.e. artesian wells, in which that rises to the ground surface due to overpressure of the aquifer). Open-loop systems are often preferred to closed-loop systems because of the higher efficiency of heat transfer between the carrier fluid and the heat exchanger, and to the economies of scale that can be achieved in large plants [1, 3, 4].

- ***Standing column well***

The German VDI 4640 describes standing column wells or coaxial wells as intermediate design between borehole heat exchangers and groundwater wells, because the working principle could be pictured like a closed loop GWHP-system [5]. In the centre of the borehole a riser pipe with a pump and a filter at the bottom end is installed. The annular space is filled with permeable gravel. When the well is in production water from the heat pump percolates downwards in the annular space, which can optionally be sealed against the surrounding ground, and extracts heat. At the bottom the pump in the riser pipe transports the water to the heat pump and the loop is closed. Further information is available at [6-9].

- ***Doublets and multi-well GWHP***

Typically, an installation has at least two wells (see Figure 4): one for pumping, one for injecting the water back in the aquifer once the HP has transferred the energy.

Depending on the aquifer productivity on the one hand and the user demand on the other hand, the number of wells and the size of the HP are determined. Depending on groundwater levels and temperatures, HPs are installed in depths of only a few meters up to 100 meters.

The pumping and injection wells must be located at an appropriate distance in order to secure the long-term performance of installation. In case of heating-dominated demand the system needs to be prevented from a thermal short circuit as a result of cooled down water flowing from the injection well back to the pumping well [10, 11].

Reinjection is sometimes performed into surface water bodies such as channels, lakes, rivers. Although this results in a local depletion of the aquifer, due to the missing reintegration of the

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abstracted groundwater, this solution prevents reinjection issues such as well clogging, thermal plume, and thermal recycling. Also, this solution is adopted when groundwater is abstracted from artesian aquifers, in which groundwater comes to the ground surface due to its overpressure.

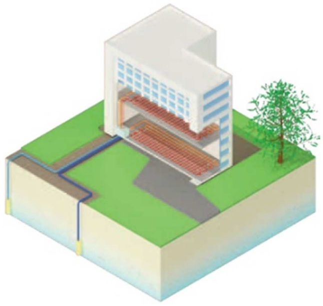

Figure 4: Open-loop system, with one pumping and one injection well (doublet) (© geothermie-perspectives.fr, ADEME-BRGM).

1.2.2 Closed-loop systems

Closed-loop systems can be installed in almost every ground condition because no aquifer is needed. Indeed, thermal exchange in these systems is performed through the circulation of a brine (water or a mixture of water and anti-freezing fluid) in a closed pipe loop buried in the ground. These systems are a modular solution – they can be used from individual houses to large collective housing buildings or tertiary building depending on the length of the installed pipes. Three types of these systems can be distinguished, characterized by the design of the heat exchanger: horizontal heat exchangers, compact heat exchangers and borehole heat exchangers.

- ***Horizontal heat exchangers***

    - *Installed in the natural underground:* the heat exchangers are typically installed at 1 to 3 meters below surface (illustration see Figure 5). They require large space, thus they are more often installed in rural than in densely populated areas. Within this document, the system is categorized as **“Shallow Heat Collector”**, abbreviated with **“SHC”**.

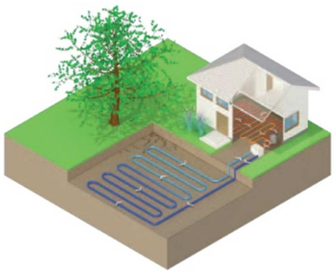

Figure 5: Closed-loop systems for individual houses: horizontal GHE (© geothermie-perspectives.fr, ADEME-BRGM).

    - *Installed in underground building elements:* the heat exchangers are typically installed within foundation plates. They can be installed in almost every building but need to be considered in an early planning stage. These systems are often described as “thermo-active structures”, “thermal component activation”, “thermal activation of building units”, etc. Within this document, the system is categorized as **“Geostructure”**.

- ***Compact heat exchangers***

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- *Installed in the underground: the heat exchangers are typically sized between 2.5 - 4* m length and are installed vertically in the first meters of the underground (see Figure 6). They can be seen has a compromise between horizontal and vertical heat exchangers in terms of required space. Within this document, the system is categorized as **"Shallow Heat Collector"**, abbreviated with **"SHC"**.

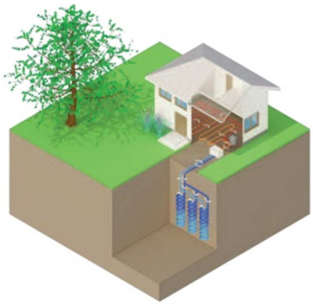

Figure 6: Closed-loop systems for individual houses: compact GHE (© geothermie-perspectives.fr, ADEME-BRGM).

- *Installed in underground building elements*: the heat exchangers are typically installed within vertical piles ("energy piles") (see Figure 7). They can be installed in almost every building but need to be considered in an early planning stage. These systems are often described as "thermo-active structures", "thermal component activation" "thermal activation of building units", etc. Within this document, the system is categorized as **"Geostructure"**.

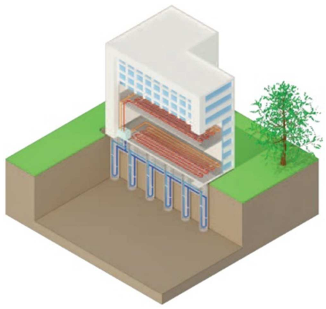

Figure 7: Closed-loop system for collective housing, tertiary and industrial buildings: fields of pile heat exchangers, a thermo-active structure (© geothermie-perspectives.fr, ADEME-BRGM).

- ***Borehole heat exchangers (BHE)***
  A BHE is made of a vertical borehole where a loop of pipes is installed. Typically, BHEs are up to 150 m long but may also reach depths of 300 – 400 m depending on underground properties and demand [12]. The system may consist of a single borehole (see Figure 8) or a BHE field (see Figure 9). The sizing (number and length of wells) of BHE fields should be performed after a thermal response test of the first BHE drilled on site, in order to estimate the site-specific ground thermal conductivity [13-19]. The borehole is sealed with grouting material to ensure a high-quality thermal transfer between the ambient soil/rock and the BHE but also to prevent aquifer communication.

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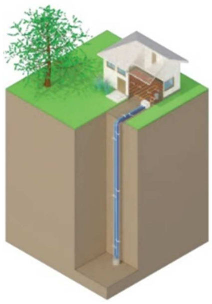

Figure 8: Closed-loop system for individual houses: borehole heat exchanger (© geothermie-perspectives.fr, ADEME-BRGM).

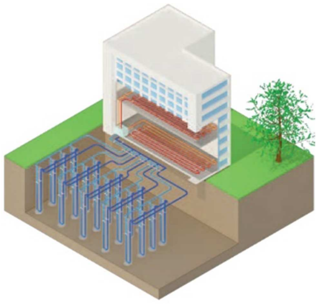

Figure 9: Closed-loop system for collective housing, tertiary and industrial buildings: fields of borehole heat exchangers (© geothermie-perspectives.fr, ADEME-BRGM).

1.3 Underground Thermal Energy Storage

Underground Thermal Energy Storage (UTES) aims at storing excess heat in the ground in summer and retrieve it in winter. The excess heat can be provided by solar panels or a waste incineration plant for instance. It is stored in an aquifer (ATES) or in the ground through a field of borehole heat exchangers (BTES) (cf. Figure 10 and Figure 11). Criteria of UTES suitability are provided in section 0 p 43.

Figure 10: Aquifer Thermal Energy Storage (ATES): excess heat is stored in an aquifer (left) in summer and retrieved in winter (right) (© underground-energy.com)

Figure 11: Borehole Thermal Energy Storage (BTES): excess heat is stored in the ground through a field of borehole heat exchangers in summer (left) and retrieved in winter (right) (© underground-energy.com)

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1.4 Commonly used techniques of utilization of NSGE installations

In order to get an overview of commonly used techniques of utilization of NSGE, a survey among the partner countries was carried out by completing the "questionnaire 1" (see http://www.alpine-space.eu/projects/greta/en/project-results/work-in-progress/wp3-technical-criteria).

The result of this questionnaire is summarized in Table 1, where the different technologies were grouped depending on the heat source as **a)** groundwater (open-loop systems) **b)** natural ground (closed-loop systems: heat collectors and borehole heat exchanger) **c)** geostructures, i.e. closed-loop systems installed in underground structures such as tunnel, foundations or mines. Different usages were considered **I)** heating-only systems, which is a common usage in the cold Alpine climate **II)** cooling-only systems, e.g. within data centers or industrial processes **III)** heating and cooling, and **IV)** storage, in which heat from other sources (i.e. solar or waste heat) is stored for its use in winter times.

Table 1 : Compiled table – overview of commonly used techniques of NSGE-utilization in all partner countries.

		Sources		
Techniques	LEGEND o not commonly used ● commonly used • commonly used only in 1 country	**a) Groundwater**	**b) Natural ground**	**c) Geostructures**
	I) Withdrawal (heating only)	● single well ● doublets ● multi well	● single BHE ● BHE field ● heat collector	● energy piles o tunnel walls
	II) Withdrawal (cooling only) o direct o indirect • both	• single well (Standing Column Well, SCW) ● doublets ● multi well	• single BHE ● BHE field o heat collector	• energy piles o tunnel walls
	III) Seasonal (heating & cooling)	● single aquifer usage	● single BHE ● BHE field ● heat collector	● energy piles o tunnel walls
	IV) Storage	o single aquifer usage o multi aquifer usage	● BHE field	o abandoned mines • thermally activated building elements

1.4.1 Common principles of NSGE use in the Alpine Space

This section gives a summarised overview of statements concerning the way NSGE is utilised in the Alpine Space and which techniques are applied for the different uses or demands.

Borehole Heat Exchangers (BHE) are the most common installations throughout the whole Alpine Space and, due to their broad applicability, diffused both as single BHE for small plants and BHE fields for larger plants.

The use of **Groundwater Heat Pumps** (GWHP) is overall dependent on the availability of a productive aquifer in an economic feasible depth. This characteristic, of course, requires a specific hydrogeological knowledge at a local scale, but apart from this some principles can be stated. GWHP

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systems are often more efficient and economically convenient than closed-loop systems, especially for large applications [1, 3]. Furthermore, large cooling demands can be covered very efficient with free groundwater cooling. Industrial production sites, where big demands come from machinery or process cooling, often use this efficient technique.

Statistics on **Shallow heat collectors** (SHC) are very difficult to be collected, because they are not reported to authorities in most countries (only in Italy and in parts of Germany). For statements on SHCs we can only use small scale surveys, which are not representative for the whole Alpine Space.

1.4.2 National characteristics of NSGE use

Surveys on shallow heat collectors showed that they are adopted mainly in small residential applications in France, Austria and Slovenia), while they are scarcely diffused in Italy.

BHEs are the most common technology for NSGE systems in all countries, especially for small size plants.

The usage of NSGE-systems for cooling purposes is more usually covered by groundwater uses than by BHE applications. Most frequent uses are cooling production processes at industrial sites and air-conditioning at office buildings. Those applications are common in Germany, Italy, Austria and parts of France (Lyon), while they are rare in other countries, such as Slovenia.

Ground Water Heat Pumps (GWHP) represent the most widespread NSGE system for large power in France. Furthermore, they are common in Austria, Slovenia, Germany and in large cities of northern Italy. The use of single-well applications (Standing Column Wells), where both abstraction and reinjection are performed into the same borehole, is not very diffused.

Aquifer Thermal Energy Storage (ATES) is diffused in Germany, but not in the Alpine Space part. A well-known example is the German Reichstag in Berlin [20, 21]. ATES is not diffused in the other Alpine Space countries. This can be attributed to the high hydraulic gradient of aquifers, which induces the migration of thermal plumes downstream the injection well(s).

Closed-loop systems in geostructures [22] usually do not have to be reported to authorities, and hence it is hard to assess their diffusion. Surveys showed that among these systems, thermally activated building elements like energy piles are the most common uses and are diffused in some parts of the Alpine Space (Switzerland, Austria Germany and in small parts of Slovenia). They are installed mainly in large buildings like supermarkets or office buildings. One of the most prominent examples for thermally activated building elements is the Zurich airport which is air-conditioned by this technology [23]. More unusual uses like installations in tunnel walls or in abandoned mines are rare and represented only by few examples.

This information represents the base for Table 5, which shows the applicability of commonly used shallow geothermal systems at different climatic conditions and for different usage profiles.

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3 Suitability of NSGE systems for different building types and different climate zones

Besides the local ground and aquifer properties, the suitability of Ground Source Heat Pumps (GSHPs) for heating and cooling of a building strongly depends on the usage profile and on local climate conditions, which influence the proportion of heating and cooling needs. In this chapter, some useful hints are provided to assess the suitability of GSHPs. Two different assessments are performed, for closed-loop (Borehole Heat Exchangers) and open-loop (Ground Water Heat Pumps), considering their different technical and economic peculiarities.

3.1 Usage profile and climate conditions

Ground Source Heat Pumps are characterized by the following advantages:

- Possibility to integrate heating and cooling in the same plant: this characteristic is shared with Air Source Heat Pumps and allows for a reduction of the extra-cost for installation, when both heating and cooling are needed;
- Building appearance and space demand: compared to split air conditioners, GSHPs do not require the installation of external units which are detrimental for the appearance of the facade. In comparison with boilers and additional tank installations, heat pump systems consume considerably less space for the whole installation;
- Longer service life of the equipment: compared to Air Source Heat Pumps (ASHPs) the GSHPs do not require an external unit, which is subject to atmospheric conditions;
- Noise: Air Source Heat Pumps have noisy fans, while GSHPs operate silently. This is a great advantage in urban contexts;
- Low running costs: GSHPs can reduce the running cost for heating and cooling:
    - Heating: the saving depends on the ratio between the cost of electricity and of the alternative combustibles. Usually, LPG and oil are the most expensive ones, thus making GSHPs competitive in areas not connected to a natural gas grid. Compared to Air Source Heat Pumps (ASHPs), GSHPs allow for a higher efficiency, especially in cold climates where the de-icing of heat exchange elements increases the running costs for ASHPs. Biomass is very cost-effective, but as fossil fuel boilers the effect on the air quality should be carefully assessed.
    - Electricity price vs. other heat carrier medium prices: I.e. the price of natural gas strongly varies from one country to another: for example, Germany adopted a strong taxation of electricity and a low taxation of gas, which impairs the economic convenience of heat pumps for heating;
    - Cooling: as electricity is the most common energy driver for cooling, electricity price and full-load operating hours are the key factors which influence the convenience of GSHPs compared to ASHPs. High electricity prices and an intensive utilization of the plant foster the economic convenience of GSHPs.

Ground Source Heat Pumps are characterized by the following disadvantages:

- Relatively high installation cost: GSHPs are the Heating, Ventilation and Air-Conditioning (HVAC) solution with the highest installation cost, both for heating (when compared to oil or gas boilers, biomass boilers or air-source heat pumps) and cooling (compared to chillers

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cooled with air or evaporative condensers). On the other hand, the difference of installation costs varies depending on the alternative:

- Fossil fuel boilers (oil, LPG, natural gas) are very cheap, especially for large plant sizes;
- Biomass boilers have an intermediate cost between fossil fuel boilers and heat pumps;
- Heat pumps are the heating solution that requires the highest initial investment. GSHPs require a further investment for wells or ground heat exchangers;

3.2 Climate zones

According to Tsikaloudaki et al. (2012, [24]), 6 climatic zones can be identified, based on Heating Degree-Days (HDD) and Cooling Degree-Days (CDD):

A) High cooling needs (CDD ≥500) and low heating needs (HDD <1500), which is typical of the Mediterranean area;
B) High cooling needs (CDD ≥500) and medium heating needs (1500≤ HDD <3000), which is typical of the plain areas close to the sea (Po plain, Rhone plain) and of the Adriatic coast;
C) Low cooling (CDD <500) and heating (HDD <1500) needs, which is typical of some maritime areas such as Marseille, with mild winter and summer;
D) Low cooling needs (CDD <500), medium heating needs (1500≤ HDD <3000), which is typical of most cities in the Alpine Space (central Po plain, Alsace, most of Slovenia);
E) Low cooling needs (CDD <500) and high heating needs (HDD ≥3000), typical of piedmont and mountainous areas.
F) Considering the climate severity of the Alpine area, a further class (F) is added to describe mountainous towns with very high heating needs (HDD ≥3750) and no cooling needs (CDD = 0).

Heating and cooling degree-days can be defined in different ways. The authors calculated HDDs using monthly average temperatures and a base value of 18 °C [2] for both heating and cooling:

$$HDD = \sum_{i=1}^{12} (T_b - T_i) \quad if\ T_i < T_b$$

$$CDD = \sum_{i=1}^{12} (T_b - T_i) \quad if\ T_i < T_b$$

The climate of a number of cities and towns in the Alpine Space area was studied. Monthly temperature values were taken from the European project PVGIS [25] and HDD/CDD were calculated for the following locations:

[2] This approach is a variant of the well-known ASHRAE method, which calculates the 65°F (18.3°C) HDD and CDD.

Table 2: Locations selected for the climate zone assessment according to Ref. [24].

Italy	Genova, Padova, Torino, Trento, Venezia, Aosta, Belluno, Bolzano, Cuneo, Milano, Sestriere
Germany	Freiburg, Ingolstadt, Sonthofen, München
France	Nice, Avignon, Marseille, Annecy, Lyon, Strasbourg, Briançon,
Austria	Innsbruck, Wien, Villach, Graz, Linz, Saalbach, Salzburg, Lienz, Eisenstadt, St. Michael im Lungau
Slovenia	Koper, Ljubljana, Maribor, Cerkno
Switzerland	Basel, Davos, Bern
Liechtenstein	Vaduz

According to this approach, the locations reported in Figure 12 belong to the following zones:

A) Nice, Genova
B) Venezia, Padova, Trento, Torino, Koper, Avignon
C) Marseille
D) Milano, Bolzano, Aosta, Belluno, Cuneo, Lyon, Annecy, Strasbourg, Basel, Vaduz, Innsbruck, Wien, Cerkno, Ljubljana, Maribor, Eisenstadt
E) München, Ingolstadt, Linz, Graz, Villach, Salzburg, Lienz
F) Briançon, Davos, Saalbach, Sestriere, Sonthofen, Sankt Michael im Lungau

Zone C is more typical of the Portugal coast [24], and only Marseille falls into it. Also, it has quite a high cooling demand (CDD = 451), and hence it has been aggregated to zone A for the evaluation of the suitability of different GSHP typologies (Table 5) and for the evaluation of pros and cons of GSHPs in different climate conditions and different usage profiles (Table 4).

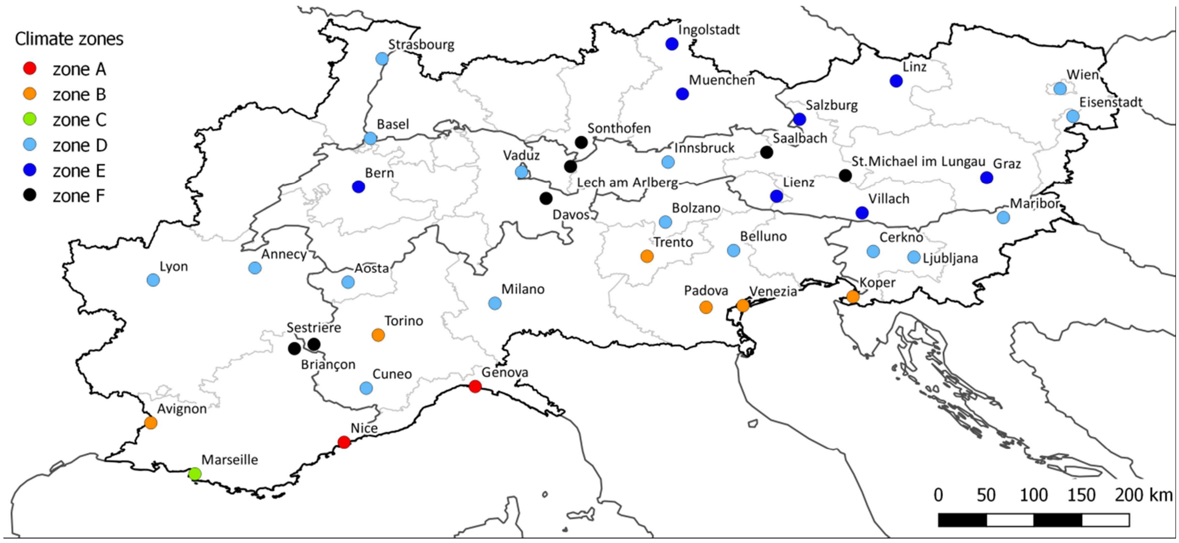


Figure 12: Climate classification of different cities and towns across the Alpine Space area, according to Ref. [24].

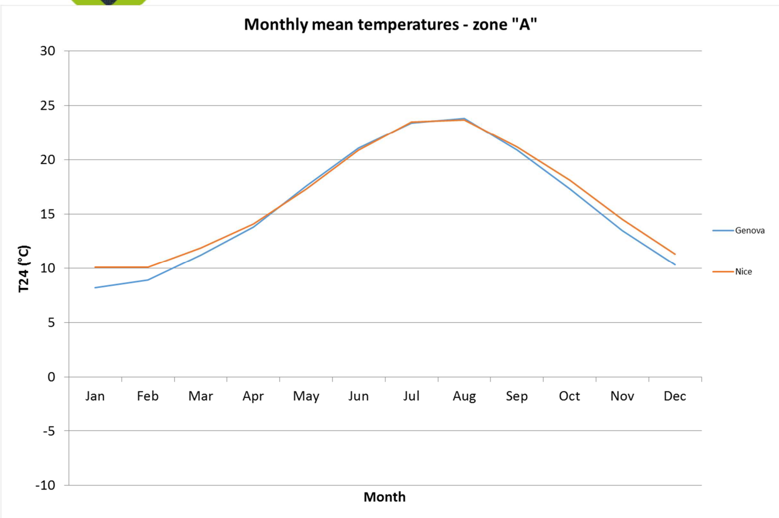


Figure 13: Annual evolution of monthly mean temp. in the climate zone “A”.

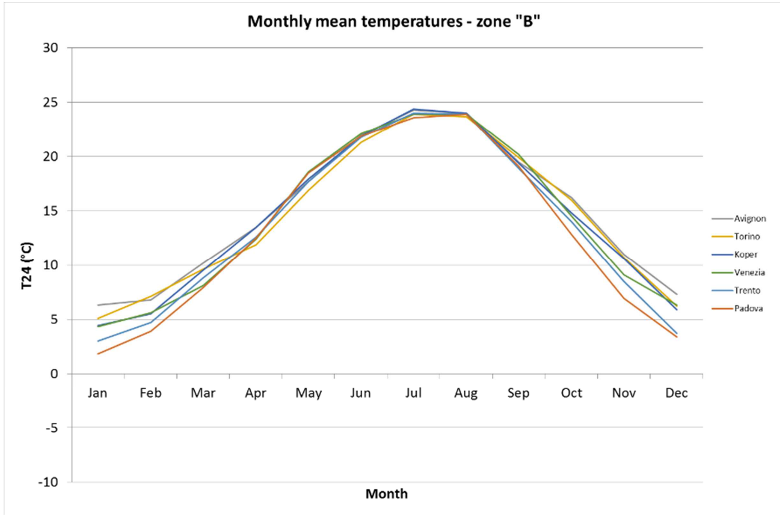
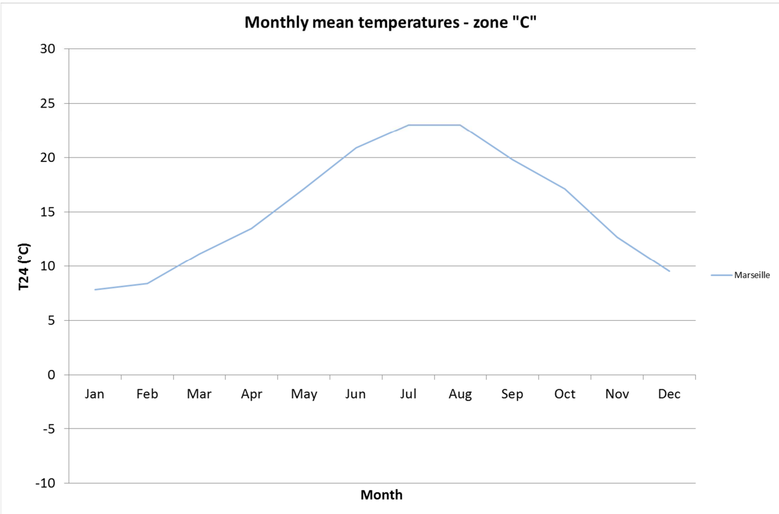


Figure 14: Annual evolution of monthly mean temp. in the climate zone “B”.



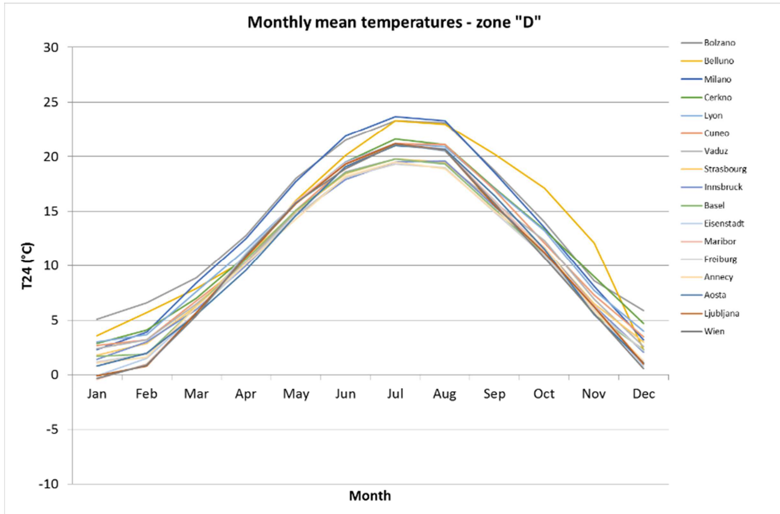


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Figure 15: Annual evolution of monthly mean temp. in the climate zone "C".

Figure 16: Annual evolution of monthly mean temp. in the climate zone "D".

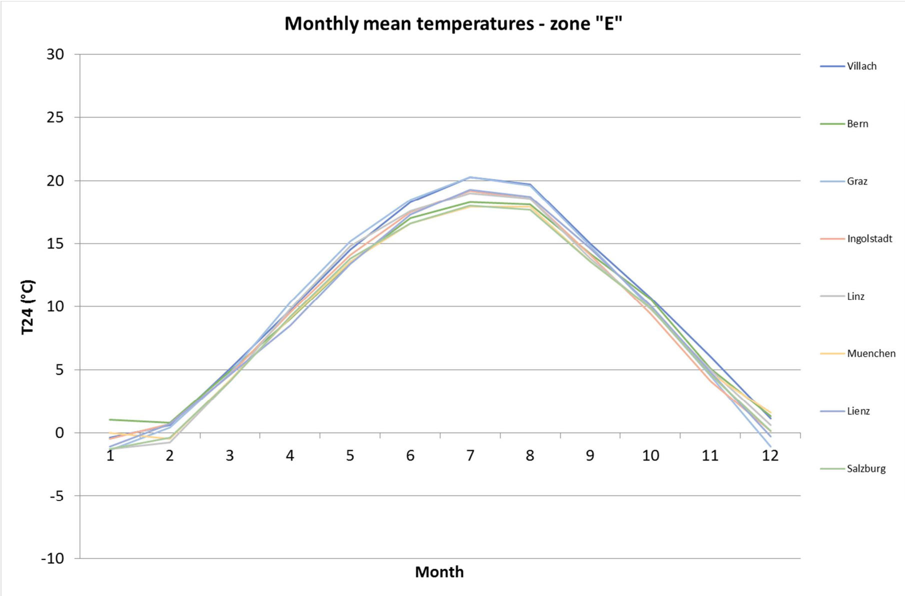

Figure 17: Annual evolution of monthly mean temperatures in the climate zone “E”.

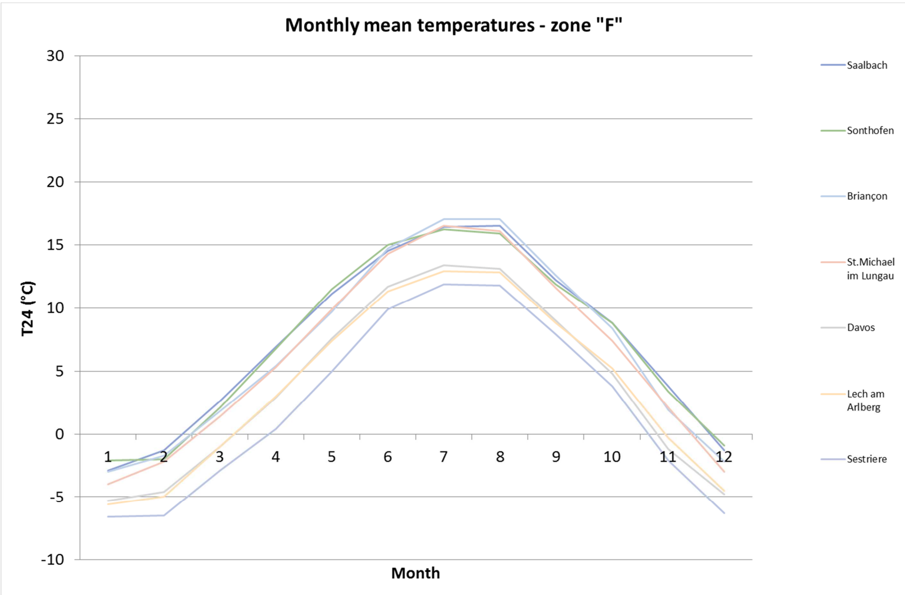

Figure 18: Annual evolution of monthly mean temperatures in the climate zone “F”.

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Table 3: Monthly mean temperatures, Heating Degree-Days (HDD), Cooling Degree-Days (CDD), and climate classification of some cities and towns in the Alpine Space.

City	Long	Lat	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	HDD	CDD	Classification
Genova	8.9328	44.4111	8.2	8.9	11.2	13.8	17.6	21.1	23.4	23.8	20.9	17.3	13.5	10.3	1303.2	527.2	A
Nice	7.2663	43.7034	10.1	10.1	11.9	14.1	17.3	20.9	23.5	23.7	21.2	18.1	14.5	11.3	1106.6	533.3	A
Avignon	4.8100	43.9500	6.3	6.8	10.2	13.5	17.7	22	24.3	24	19.5	16.2	11	7.3	1659.9	546.3	B
Koper	13.7333	45.5500	4.4	5.5	9.5	13.5	17.9	21.9	24.4	24	19.4	14.8	10.6	5.9	1869.5	543.4	B
Padova	11.8667	45.4167	1.8	3.9	7.9	12.5	18.5	21.9	23.6	23.9	19.1	12.8	6.9	3.4	2321.9	522	B
Torino	7.7000	45.0667	5.1	7.1	9.6	11.9	16.9	21.3	23.9	23.7	19.9	16	10.7	6.2	1829.4	515.6	B
Trento	11.1167	46.0667	3	4.7	8.8	12.6	17.7	21.8	24	23.9	18.9	14	8.5	3.7	2146.2	509.9	B
Venezia	12.3358	45.4375	4.3	5.6	8.1	12.4	18.6	22.1	23.9	23.9	20.2	14.5	9.1	6.3	1985	573.4	B
Marseille	5.3700	43.2964	7.8	8.4	11.1	13.5	17.1	20.9	23	23	19.8	17.1	12.7	9.5	1412.2	451	C
Annecy	6.1333	45.9160	1.1	1.6	6.2	10.2	14.3	18.2	19.5	18.9	15	11.7	5.9	1.3	2863.6	80.4	D
Aosta	7.3167	45.7333	0.8	2	5.5	9.6	14.6	19.1	21	20.7	16.4	11.5	5.5	1.1	2874.5	209.7	D
Basel	7.6000	47.5667	1.7	1.9	6.2	10.6	15.1	18.5	19.8	19.3	15.2	11	5.5	2.3	2796.5	111.1	D
Belluno	12.2167	46.1403	3.6	5.7	7.9	10.6	16	20.1	23.3	23	20.2	17.1	12.1	2.3	2079.5	448.3	D
Bolzano	11.3500	46.5000	5.1	6.6	8.9	12.8	18	21.5	23.3	23.1	18.7	14	8.6	5.9	1938.3	448.4	D
Cerkno	13.9915	46.1283	2.9	4.1	7	10.9	15.8	19.5	21.6	21.1	17.1	13.3	9	4.7	2543.2	228.3	D
Cuneo	7.5478	44.3894	2.7	3.2	6.8	10.3	15.1	19.1	21.2	21.1	16.9	12.1	7.3	3.5	2334.5	252.7	D
Eisenstadt	16.5280	47.8460	-0.1	1.5	5.6	11.2	15.9	19.3	21.2	20.5	16	11.1	6	0.8	3219.7	55.8	E
Freiburg	7.8500	79.8933	1.2	1.9	5.7	10.2	14.6	18.1	19.3	19	14.9	10.9	5.9	2.2	2843.7	215.7	D
Innsbruck	11.3833	47.2667	1.4	3	6	10	14.6	17.9	19.5	19.6	15.4	11.6	6.3	2.1	2858.2	74.3	D
Ljubljana	14.5083	46.0556	-0.1	0.8	5.7	10.8	15.7	19.3	21.2	20.6	15.5	11.2	6.2	1	2775.3	96.1	D
Lyon	4.8400	45.7600	3	3.7	7.6	11.5	15.8	19.5	21.2	20.9	17	13.2	7.7	4	2878.1	218.8	D
Maribor	15.6455	46.5576	-0.4	1	5.6	11	15.9	19.4	21.2	20.7	15.9	11.4	6.3	1.1	2372.8	234.1	D
Milano	9.1833	45.4667	2.3	3.9	8.4	12.5	17.7	21.9	23.7	23.3	18.5	13.5	8.1	3.2	2848.4	224.9	D
Strasbourg	7.7500	48.5800	1.8	2.9	6.3	10.8	15	18.4	19.8	19.5	15.5	11.6	6.5	3	2248.7	473	D
Vaduz	9.5210	47.1410	2.4	3.2	6.5	10.3	14.9	18.6	19.8	19.4	15.8	12.3	6.9	2.6	2634.7	117.2	D
Wien	16.3667	48.2000	-0.3	0.9	5.4	11	15.8	18.9	21.1	20.6	15.7	10.7	5.6	0.6	2680.1	114.3	D

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City	Long	Lat	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	HDD	CDD	Classification
Briançon	6.6356	44.8964	-3	-1.7	1.8	5.4	9.7	14.7	17	17	12.6	8.4	1.9	-2.2	5165	0	F
Davos	9.8333	46.8000	-5.3	-4.6	-1	2.9	7.6	11.7	13.4	13.1	9	4.8	-1.2	-4.8	5182.8	0	F
Lech am Arlberg	10.1440	47.2110	-5.6	-5	-1	3	7.4	11.3	12.9	12.8	8.8	5.2	-0.3	-4.5	3250.7	62	E
Muenchen	11.5667	48.1333	0	-0.5	4.2	9.1	13.6	16.6	17.9	17.9	13.6	9.9	4.7	1.6	3916.5	0	F
Salzburg	13.0550	47.8090	-1.3	-0.4	4.1	9.2	13.8	16.6	18	17.7	13.6	9.9	4.6	0.1	3897.2	0	F
Sestriere	6.8833	44.9500	-6.6	-6.5	-2.9	0.4	5	9.9	11.9	11.8	7.9	3.8	-2.1	-6.3	3102.3	12.4	E
Sonthofen	10.2811	47.5158	-2.1	-2	2.1	6.8	11.5	15	16.2	15.9	11.9	8.8	3.4	-0.9	3168.5	135.9	E
Villach	13.8500	46.6167	-0.4	0.6	5.1	9.7	14.5	18.3	20.3	19.7	15	10.7	6	1.1	2921.6	203.7	D
Bern	7.4500	46.9500	1	0.8	4.9	9	13.5	17	18.3	18.1	14.2	10.6	5.1	1.3	4069.9	0	F
Graz	15.4333	47.0667	-1.4	0.4	4.7	10.3	15.2	18.5	20.3	19.6	14.8	9.9	4.5	-1.1	3245.9	0	E
Ingolstadt	11.4333	48.7667	-0.5	0.7	4.6	9.5	14.1	17.5	19.2	18.6	14.1	9.4	4.1	0.1	3329.9	0	E
Lienz	12.7630	46.8280	-1.1	0.7	4.6	8.5	13.4	17.3	19.3	18.7	14.6	10.1	4.8	-0.3	3222.4	49.6	E
Linz	14.2833	48.3000	-1.3	-0.8	4.1	9.8	14.8	17.6	19	18.6	13.8	9.8	5	0.6	5751.3	0	F
Saalbach	12.6370	47.3904	-2.9	-1.3	2.6	6.9	11.1	14.5	16.4	16.5	12.2	8.8	3.8	-1.3	3015.2	133	E
St.Michael im Lungau	13.6370	47.0960	-4	-2.2	1.4	5.3	9.9	14.3	16.5	16.1	11.6	7.4	2.1	-3	4259.3	0	F

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3.3 Thermal loads

A key issue to design geothermal heat pump systems are thermal load and annual energy balance of the building. Particular attention should be paid to the correct sizing of the system, in order to maximize the efficiency and keep it economically competitive compared to alternative combustibles. For this reason, it is necessary to perform a detailed and precise evaluation of the thermal loads of the building. The energy demand of the construction, to be met by the geothermal heat pump, depends on a large number of variables, the most relevant of which are:

- Climate condition (external air temperature and solar irradiance)
- Building type (related to the final use, occupancy and internal heat gains)
- Envelope thermal insulation (thermal resistance of windows, walls, ceilings and floors)

In order to assess the typical thermal load profiles of the buildings in the Alpine Space, an analysis through simulation software was performed. Dynamic calculations of the energy demands and thermal load profiles were implemented with TRNSYS commercial software, using the building models prepared by Matteo Rivoire for his Master thesis work at Polytechnic of Turin [26]. Buildings have been modelled with Type56 module of TRNSYS. Different cases have been considered in the analysis:

- Climate condition: following the climatic zone classification reported in Chapter 3.2, five locations have been identified for the studied buildings, one for each climate area:
    - Zone A: Genova (Italy)
    - Zone B: Torino (Italy)
    - Zone D: Innsbruck (Austria)
    - Zone E: Munich (Germany)
    - Zone F: Davos (Switzerland)
- Building type: three different types of building are considered in the analysis, according to the possible applications for geothermal heat pumps:
    - Residential building (unoccupied during the day, low internal gains)
    - Office (occupied 10 hours/day during the working week, high internal gains)
    - Hotel (occupancy distributed throughout the year, seasonal schedules)
- Envelope thermal insulation: in order to cover both the old and the new constructions in the Alpine Space, the analysis focused on two typologies of thermal insulation of the building:
    - Bad insulation: typical of old buildings (period: 1930-1975), low quality or no insulation of walls, ceilings and floors, single-glazed windows and highly conductive frames
    - Good insulation: new building envelope (period: 2000-today), low-conductivity walls, ceilings and floors, double-glazed windows and low-conductivity frames

The building models have been modified according to the cases explained above. The stratigraphy of walls, ceilings and floors has been modelled using the reference values from Tabula project [5] (building class 3-4-5) for the bad insulation case and from current Italian UNI/TS 11300 standard for the good insulation case. The set-point temperatures, internal heat gains, air ventilation and infiltration profiles have been also taken from UNI standard.

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Results – Monthly energy demand

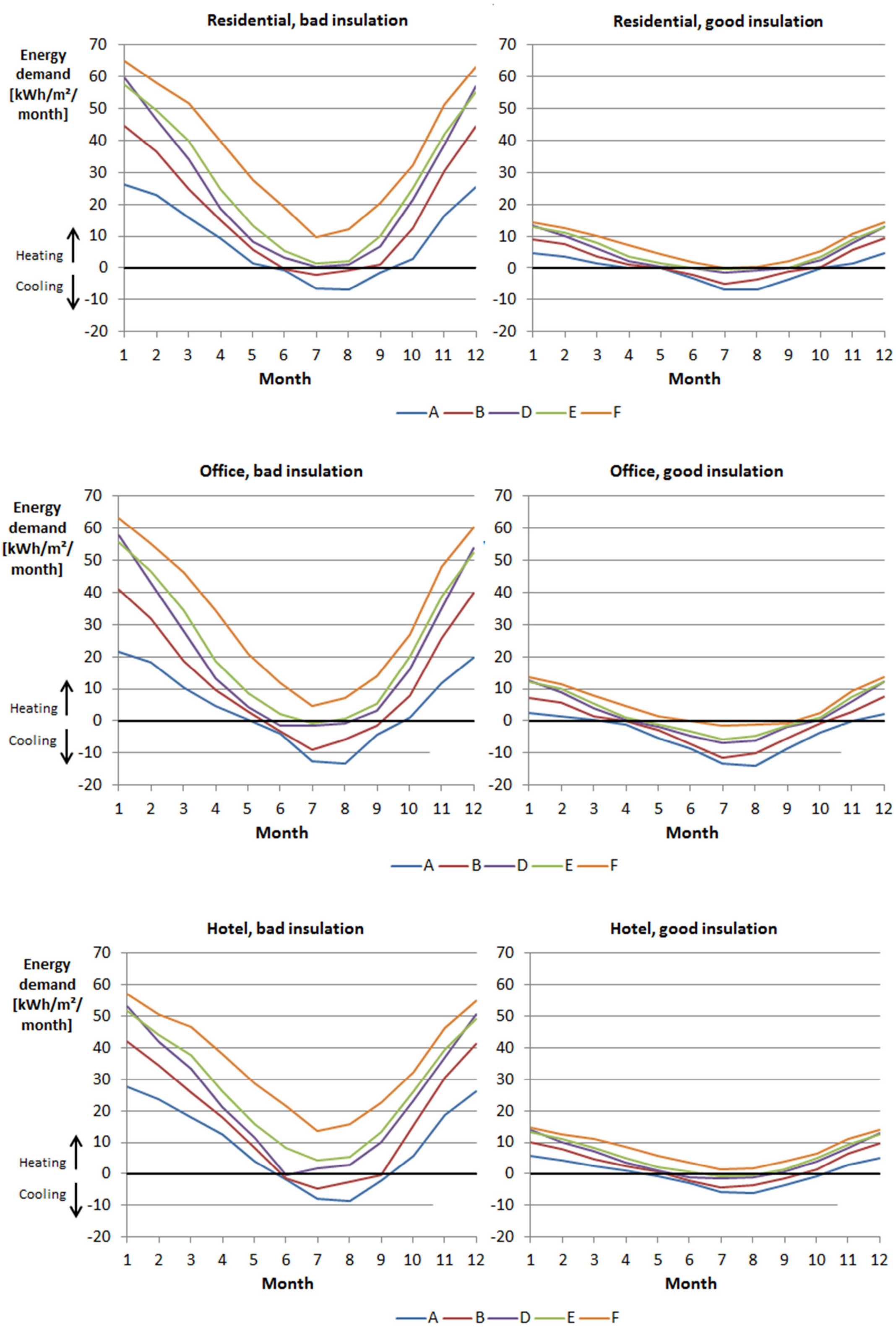

Figure 19 : Monthly specific energy demand for heating and cooling of the buildings, in different climate zones.

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Results – Annual energy demand

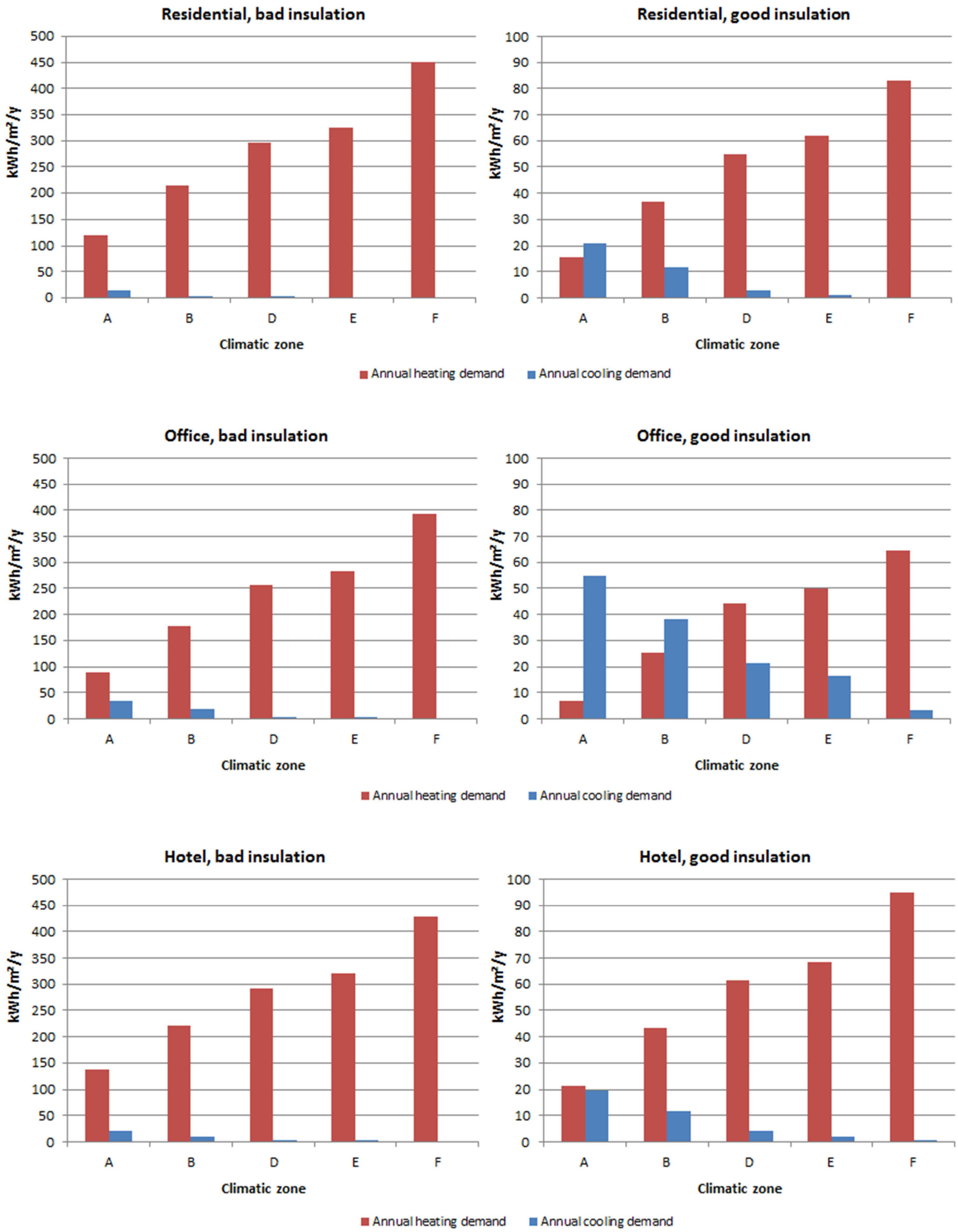

Figure 20: Annual specific energy demand balance of the buildings, in different climate zones.

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Results – Cumulate heating loads

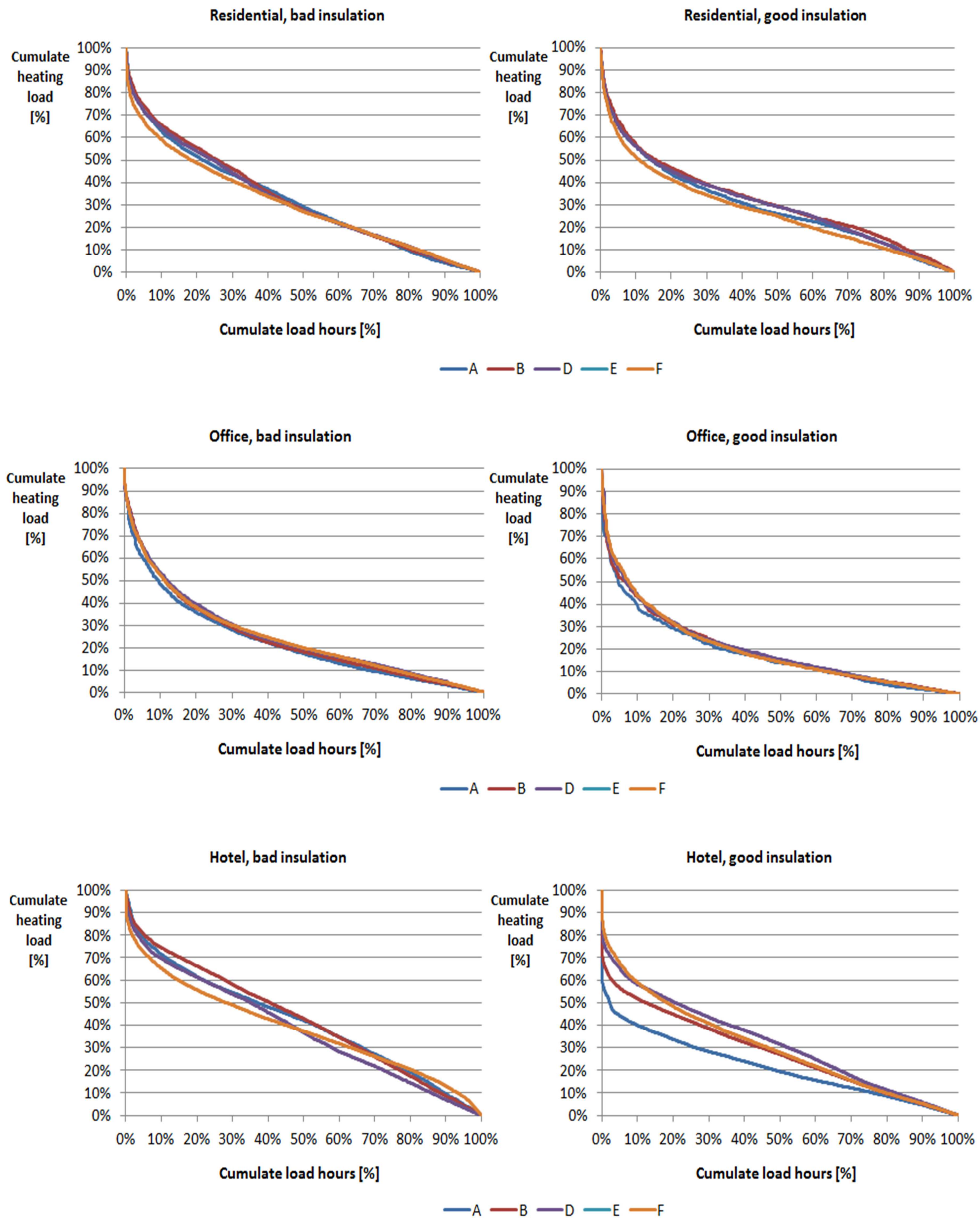

Figure 21: Heating load cumulate distributions for the buildings, in different climate zones.

Results – Cumulate cooling loads

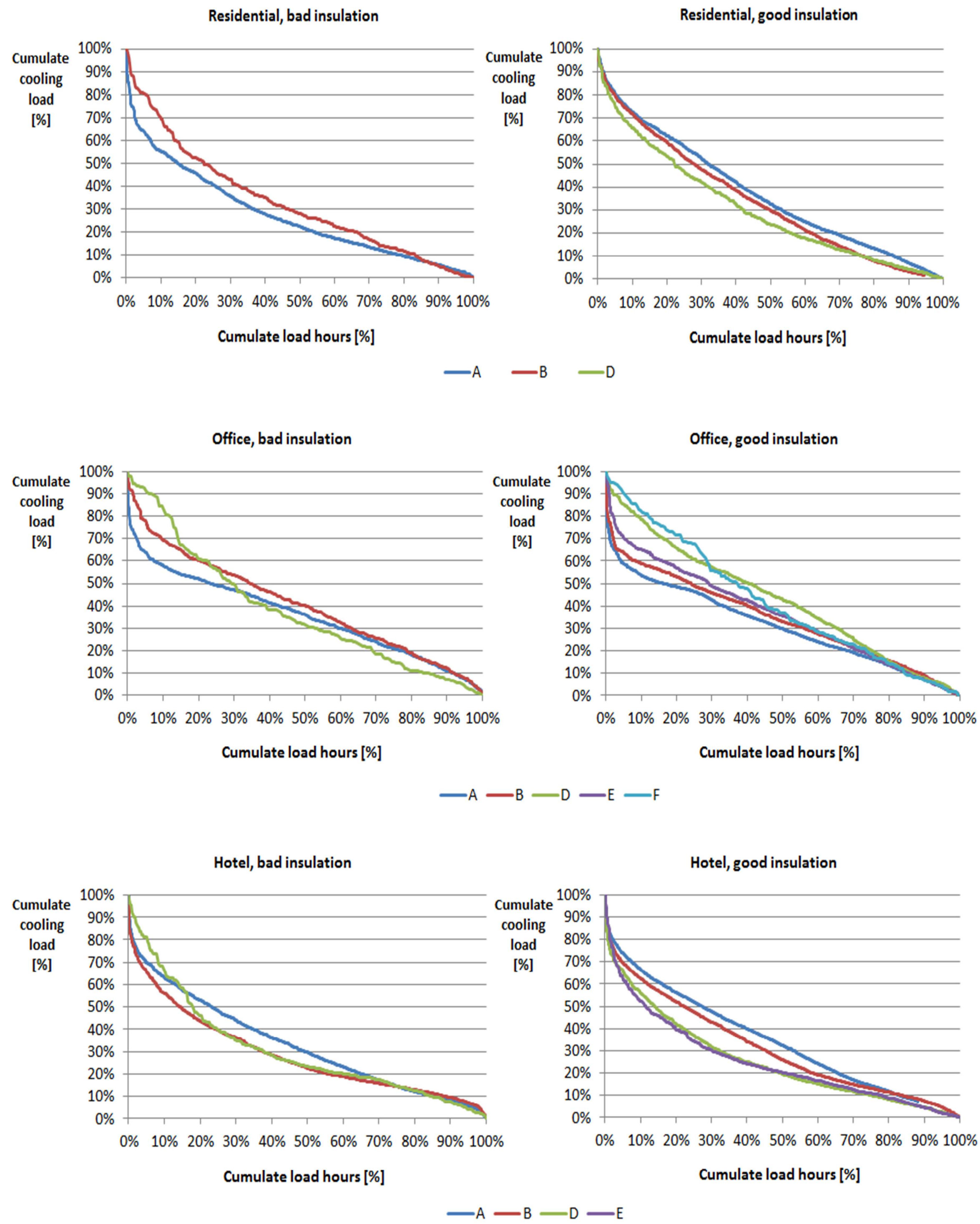

Figure 22: Cooling load cumulate distributions for the buildings, in different climate zones.

Considering the specific monthly and annual energy demand shown in Fig. 1-2, residential and hotel buildings have quite similar characteristics, due to the same amount of specific internal gains, mainly related to people occupancy. The specific energy consumption for hotels is slightly higher because of the peculiar occupancy schedule, with seasonal peaks during holidays and higher comfort standards

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required. The office building is characterized by a higher demand for cooling during summer, due to the massive internal gains produced by occupancy and appliances. Buildings with good insulation envelope need significantly lower energy for heating than bad insulated buildings (>80 % consumption reduction), resulting in a more balanced demand between heating and cooling which is a particularly favourable condition for the installation of a geothermal heat pump system. The amount of energy exchanged with the ground during the year affects the soil temperature and therefore the future performance of the system. For this reason, an overall annual balance between heat extracted from and injected into the ground is the most desirable condition in order to maintain a high efficiency of the GSHP/GWHP system during the years. This balance is more likely to be achieved for the buildings in the hot climate areas (A and B, Fig. 2) while in the coldest climate zones the heating demand overcomes the cooling demand. The office with good insulation envelope resulted to be the building with the most balanced energy demand for heating and cooling for most of the climate zones taken in consideration in the analysis. The cooling season is usually longer for well insulated buildings, because of the higher relative influence of the internal gains during the warmer months of the year.

The analysis of the cumulate heating and cooling loads of the buildings (Fig. 3-4) showed that there are no significant differences in the shape of the load curve among the different climate zones. This means that the distribution of thermal loads during the year mostly depends on the characteristics of the building and the occupancy and use. Heating load curves for the buildings with low quality insulation are quite regular, whereas a better insulation envelope leads to a lower number of high-load hours during the year. A heat pump with a nominal power equal to the 60 % of the higher peak is able to satisfy the energy needs of a well-insulated building for over 90 % of the heating operating hours. Therefore, it is possible to integrate a heat pump designed to cover the heating load for most of the year with a backup heating source (e.g. electric resistance or boiler), achieving a high overall efficiency of the system while keeping a low investment cost. Cumulate cooling load curves have a more linear shape compared to the heating load curves, and the climate zone has a stronger influence on the shape of the peak loads. The reason for this behaviour can be found considering that in cooling mode (summer) the solar heat gains play an important role in determining the energy demand of the building, especially in case of a well-insulated envelope. A heat pump with a nominal power equal to 60 % of the higher cooling peak is able to cover on average the cooling demand of a well-insulated building for around 80% of the total cooling hours during the year.

Conclusions

- Climate zone: for residential buildings and hotels, the most suitable demand profile for ground/groundwater source heat pumps can be found in hot climates of zones A and B. Offices are characterized by a cooling-dominated or well-balanced demand in most of the climatic areas, especially in the plains and cities (zones B, D, E)
- Building type: office buildings are characterized by large cooling demands because of the high internal gains coming from people and appliances. Therefore, the energy demand is usually more balanced than for residential and hotel buildings. The highest heating peak loads are concentrated in few hours per year, thus allowing to design the heat pump system at only 40 % of the maximum load in order to cover more than 90 % of the demand. Hotels and residential buildings are characterized by a heating-dominated energy demand,

therefore the economic convenience of the heat pump compared to conventional technologies is reduced and should be carefully assessed. More than 90 % of the total annual demand for heating can be covered by installing a heat pump capacity equal to 60 % of the maximum peak load throughout the year.

	Heat pump design power/max peak load (to cover 90% of load operating hours)			
Building type	**Bad insulation**		**Good insulation**	
	Heating	***Cooling***	***Heating***	***Cooling***
Residential	64%	62%	55%	72%
Office	52%	63%	43%	65%
Hotel	70%	61%	53%	61%

- Envelope thermal insulation: buildings with good insulation have shown similar monthly energy demand profile for heating and cooling (Fig. 1). A low-conductive envelope cuts down the heating demand and increases the cooling demand of the building, compare to the bad insulation case (Fig. 2). In addition, the better insulation allows to install smaller heat pumps with the same percentage of covered heating demand (see table above). Therefore, the newest buildings are more easily suitable for geothermal heat pump system while for the oldest buildings an accurate analysis of the payback time for the initial investment has to be carried out.

3.4 Conclusions

The analyses conducted in the previous paragraphs allow some conclusions to be drawn on the suitability of GSHPs for different climate conditions and usage profiles, which are reported in the previous paragraphs.

The following aspects have been addressed:

- Cooling demand: the higher the cooling demand, the higher the economic convenience of GSHPs, for the following reasons:
    - for cooling, electricity is the dominant energy vector (absorption heat pumps are rarely used for cooling), and GSHPs allow for a significant reduction of the energy expense. It is straightforward that, the larger the cooling demand, the larger the margin for savings;
    - if cooling is needed for a building, the additional cost for a GSHP compared to conventional cooling techniques is lower than the additional cost compared to conventional heating techniques. Of course, this holds true if the cooling peak load is not much lower than the heating peak load;
    - the temperature of the shallow geothermal reservoir is naturally below the room and the outer air temperature in the cooling season. This reduces the temperature

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spread the GSHP has to accommodate and makes it economically superior to conventional chillers and even to GSHP heating, where the needed spread is higher;
    - if the ground is sufficiently cold (e.g., at the beginning of the cooling season), the heat exchange can be performed between the building and the ground directly, without the heat pump. This cooling mode is called “free cooling” and it allows for significant energy and economic savings.
- Length of the heating and of the cooling season: the higher the number of full-load operating hours per year, the larger the saving margin for GSHPs with the same installation cost;
- Terminal operating temperatures: well-insulated buildings can work with a lower temperature of heating terminals, or a higher temperature of cooling terminals, thus achieving a higher COP of the heat pump;
- Balance between heating and cooling demand: the ideal thermal load is perfectly balanced between heating and cooling, thus avoiding long-term temperature drift of the ground;
- Ground temperature: it is close to the annual mean air temperature, and hence it strongly depends on climate. Higher ground temperatures are more favourable to heating operating mode, and vice versa. Therefore, the suitability of ground temperature for the application of GSHPs also depends on the usage profile, e.g., a cool ground is generally more favourable for an office building, which is deemed to have higher cooling loads compared to a residential one. Ground temperature can be a serious issue at elevations over 1500 m or at locations near surface water infiltration where cold water run;
- Domestic Hot Water: DHW requires a higher temperature compared to heating terminals (e.g., 55 – 60 °C against 30 – 35 °C of radiant panels). For this reason, a lower heat pump COP is achieved. If high load peaks are foreseen for DHW, an alternative or complementary source can be considered to avoid oversizing of the heat pump and low COP. On the other hand, when the demands for cooling and DHW are combined, the use of heat pump results in a noticeable energy saving, as part of the excess heat of building cooling is used for water heating. Heat storage may be needed to match the daily mismatch between DHW and cooling.

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Table 4: Positive and negative aspects on the suitability of shallow geothermal systems for different building types and different climate zones.

Building type	**Climate zone A** (Genova, Nice) + C (Marseille) *HDD<1500,CDD≥500*	**Climate zone B** (Avignon, Torino, Koper, etc.) *1500≤HDD<3000, CDD ≥500*	**Climate zone D** (Milano, Lyon, Ljubljana, etc.) *1500≤HDD<3000, CDD <500*	**Climate zone E** (München, Bern, Vaduz, etc.) *3000≤HDD<3750, CDD<500*	**Climate Zone F** (Davos, Saalbach, Sonthofen, etc.) *HDD≥3750, CDD=0*
Residential with bad-normal insulation	**Influence:** ++ Heating and cooling with the same system ++ Competitive in absence of natural gas pipeline and district heating --- Unbalance on heating side, ground cooling trend (-- in case of open-loop systems) ---- High temperature for heating terminals -- Low temperature for cooling terminals (but low cooling load)	**Influence:** +++ Quite long heating season (quite high no. of operating hours/year) ++ Competitive in absence of natural gas pipeline and district heating ---- High temperature for heating terminals --- Almost only heating use, ground cooling trend (-- for GWHPs)	**Influence:** ++++ Long heating season (high no. of operating hours/year) +++ Competitive in absence of natural gas pipeline and district heating ---- Only heating use, ground cooling trend (-- for GWHPs) ---- High temperature for heating terminals	**Influence:** +++++ Very long heating season (very high no. of operating hours/year) ++++ Highly competitive in absence of natural gas pipeline and district heating ------ Only heating use, strong ground cooling trend (--- for GWHPs) --- Suitability of ground/water temperature (<10°C) should be carefully assessed ---- High temperature for heating terminals	**Influence:** +++++ Very long heating season (very high no. of operating hours/year) ++++ Highly competitive in absence of natural gas pipeline and district heating ------ Only heating use, strong ground cooling trend ---- GWHPs are hardly feasible ---- High temperature for heating terminals
Residential with good insulation	**Influence:** ++++ High temperature for cooling terminals +++ Low temperature for	**Influence:** ++++ Low temperature for heating terminals +++ High temperature for	**Influence:** +++++ Low temperature for heating terminals +++ Competitive in absence	**Influence:** +++++ Low temperature for heating terminals ++++ Highly competitive in absence of natural gas	**Influence:** +++++ Low temperature for heating terminals ++++ Highly competitive in absence of natural gas

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Building type	**Climate zone A** (Genova, Nice) + C (Marseille) *HDD<1500,CDD≥500*	**Climate zone B** (Avignon, Torino, Koper, etc.) *1500≤HDD<3000, CDD ≥500*	**Climate zone D** (Milano, Lyon, Ljubljana, etc.) *1500≤HDD<3000, CDD <500*	**Climate zone E** (München, Bern, Vaduz, etc.) *3000≤HDD<3750, CDD<500*	**Climate Zone F** (Davos, Saalbach, Sonthofen, etc.) *HDD≥3750, CDD=0*
	heating terminals **++++** Balanced yearly thermal load **+++** Possible free cooling (only with GWHPs) **++** Competitive in absence of natural gas pipeline **--** A large share of heat demand is for DHW, with low COP **--** Warm ground/water which reduces the efficiency for cooling (- for GWHPs)	cooling terminals **++** Very good ground/water temperature for heating and cooling (i.e. 13÷15°C) **+++** Possible free cooling with groundwater heat pumps **++** Competitive in absence of natural gas pipeline **--** An important share of heat demand is for DHW, with low COP	of natural gas pipeline **+** Good ground/water temperature for heating and cooling (i.e. 11÷13°C) **---** Largely prevailing heating use, ground cooling trend (-- for GWHPs)	pipeline **----** Only heating use, ground cooling trend (-- for GWHPs) **----** Suitability of ground/water temperature (<10°C) should be carefully assessed	pipeline **----** Only heating use, ground cooling trend (-- for GWHPs) **----** GWHPs are hardly feasible
Office with bad insulation	**Influence:** **+++** Relatively high demand for cooling **++** Acceptable ground/water temperature for heating and cooling (i.e. 15÷17°C) **---** High temperature for	**Influence:** **++** Very good ground/water temperature for heating and cooling (i.e. 13÷15°C) **++** Competitive in absence of natural gas pipeline **---** High temperature for	**Influence:** **+++** Competitive in absence of natural gas pipeline **+** Good ground/water temperature for heating and cooling (i.e. 11÷13°C) **----** High temperature for	**Influence:** **+++++** Very long heating season (very high no. of operating hours/year) **++++** Highly competitive in absence of natural gas pipeline **------** Only heating use,	**Influence:** **+++++** Very long heating season (very high no. of operating hours/year) **++++** Highly competitive in absence of natural gas pipeline **------** Only heating use,

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Building type	**Climate zone A** (Genova, Nice) + C (Marseille) *HDD<1500,CDD≥500*	**Climate zone B** (Avignon, Torino, Koper, etc.) *1500≤HDD<3000, CDD ≥500*	**Climate zone D** (Milano, Lyon, Ljubljana, etc.) *1500≤HDD<3000, CDD <500*	**Climate zone E** (München, Bern, Vaduz, etc.) *3000≤HDD<3750, CDD<500*	**Climate Zone F** (Davos, Saalbach, Sonthofen, etc.) *HDD≥3750, CDD=0*
	heating terminals -- Unbalance of thermal load on heating side -- Low temperature for cooling terminals	heating terminals --- Almost only heating use, ground cooling trend (-- for GWHPs) - Low temperature for cooling terminals	heating terminals	strong ground cooling trend (--- for GWHPs) --- Suitability of ground/water temperature (<10°C) should be carefully assessed ---- High temperature for heating terminals	strong ground cooling trend (--- for GWHPs) ---- GWHPs are hardly feasible ---- High temperature for heating terminals
Office with good insulation	**Influence:** +++++ Very high demand for cooling +++++ High temperature for cooling terminals ++ Low temperature for heating terminals --- Warm ground/water which reduces the efficiency for cooling (- for GWHPs) --- Very strong unbalance of thermal load on the cooling side, ground heating trend (-	**Influence:** +++++ Balanced yearly thermal load ++++ Low temperature for heating terminals ++++ High temperature for cooling terminals ++ Competitive in absence of natural gas pipeline -- High heating load peaks -- High cooling load peaks	**Influence:** +++ Acceptable balance of the yearly thermal load +++++ Low temperature for heating terminals +++ High temperature for cooling terminals +++ Competitive in absence of natural gas pipeline -- High heating load peaks -- High cooling load peaks	**Influence:** ++++ Highly competitive in absence of natural gas pipeline +++++ Low temperature for heating terminals ++ High temperature for cooling terminals ++ Appraisable cooling load -- High heating load peaks	**Influence:** ++++ Highly competitive in absence of natural gas pipeline +++++ Low temperature for heating terminals ++ High temperature for cooling terminals ++ Appraisable cooling load ---- GWHPs are hardly feasible -- High heating load peaks

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Building type	**Climate zone A** (Genova, Nice) + C (Marseille) *HDD<1500,CDD≥500*	**Climate zone B** (Avignon, Torino, Koper, etc.) *1500≤HDD<3000, CDD ≥500*	**Climate zone D** (Milano, Lyon, Ljubljana, etc.) *1500≤HDD<3000, CDD <500*	**Climate zone E** (München, Bern, Vaduz, etc.) *3000≤HDD<3750, CDD<500*	**Climate Zone F** (Davos, Saalbach, Sonthofen, etc.) *HDD≥3750, CDD=0*
	- for GWHPs) --- High cooling load peaks -- High heating load peaks				
Hotel with bad insulation	**Influence:** ++ Part of the cooling and DHW may be produced simultaneously, resulting in higher system performance. Requires buffer though. --- unbalance of thermal load on the heating side, ground cooling trend (-- for GWHPs)	**Influence:** ++++ Relatively high demand for cooling ++ Part of the cooling and DHW may be produced simultaneously, resulting in higher system performance. Requires buffer though. --- Almost only heating use, ground cooling trend (-- for GWHPs)	**Influence:** +++ Competitive in absence of natural gas pipeline	**Influence:** ++++ Highly competitive in absence of natural gas pipeline ++ Part of the cooling and DHW may be produced simultaneously, resulting in higher system performance. Requires buffer though.	**Influence:** ++++ Highly competitive in absence of natural gas pipeline ++ Part of the cooling and DHW may be produced simultaneously, resulting in higher system performance. Requires buffer though. ---- GWHPs are hardly feasible
Hotel with good insulation	**Influence:** +++++ Balanced yearly thermal load ---- High heating load peaks	**Influence:** +++ Relatively high cooling load ++ Competitive in absence of natural gas pipeline --- High heating load peaks	**Influence:** +++ Competitive in absence of natural gas pipeline --- High heating load peaks -- Relatively high cooling load peaks	**Influence:** ++++ Highly competitive in absence of natural gas pipeline --- High heating load peaks --- Strong unbalance of	**Influence:** ++++ Highly competitive in absence of natural gas pipeline ---- GWHPs are hardly feasible

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Building type	**Climate zone A** (Genova, Nice) + C (Marseille) *HDD<1500,CDD≥500*	**Climate zone B** (Avignon, Torino, Koper, etc.) *1500≤HDD<3000, CDD ≥500*	**Climate zone D** (Milano, Lyon, Ljubljana, etc.) *1500≤HDD<3000, CDD <500*	**Climate zone E** (München, Bern, Vaduz, etc.) *3000≤HDD<3750, CDD<500*	**Climate Zone F** (Davos, Saalbach, Sonthofen, etc.) *HDD≥3750, CDD=0*
	--- High cooling load peaks	--- High cooling load peaks		thermal load on the heating side, ground cooling trend (-- for GWHPs)	--- High heating load peaks --- Strong unbalance of thermal load on the heating side, ground cooling trend

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4 Application of NSGE methods in the Alpine region

Near-surface geothermal energy can be used to cover heating and cooling demands of a broad range of consumers. The decision about the most suitable technique of utilization is not an easy task as the market offers a wide range of systems all of which are especially designed for a specific demand and specific climatic-, geological- and hydrological settings. The intention to give an idea about which of these systems to choose for which case, but also to show the variability of shallow geothermal systems is illustrated in Table 5.

The climate classification reported in the previous chapter was used to assess the suitability of different near-surface geothermal techniques with different building types.

The classification of near-surface geothermal techniques was performed through a simplified version of the one reported in Chapter 0:

- BHEs (Borehole Heat Exchanger): it includes both single BHE plants and BHE fields;
- GWHP (Ground Water Heat Pump) doublet/field: open-loop systems composed of one (doublet) or more (field) abstraction and reinjection well (s);
- Shallow heat collector: Include heat collector systems that can be installed after excavation of the ground – no drillings are needed (horizontal heat collectors, thermal baskets, etc.);
- Surface Water Use: surface water is used to exchange heat– no drillings are needed (water from lakes, streams, springs, waste water, drainage water from tunnels, mines, etc.);
- Geostructures: all kinds of closed-loop installed into ground structures such as energy piles and tunnel walls;
- Free cooling: direct heat exchange with the ground, without the use of a heat pump.

Different utilization profiles have been considered:

- Detached house;
- Housing estate, i.e. larger residential buildings;
- Office buildings;
- Hotels;
- Swimming pools;
- Supermarkets;
- Snow/ice production;
- De-icing in transport infrastructures;
- Cooling industrial applications (e.g. data centers, refrigeration)
- Heating and cooling industrial applications.

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Table 5: Feasibility of different GSHP typologies, depending on the climate zone and on the application.

Climate zones / Applications		**Climate zone A** (Genova, Nice) + C (Marseille)	**Climate zone B** (Avignon, Torino, Koper, etc.)	**Climate zone D** (Milano, Lyon, Ljubljana, etc.)	**Climate zone E** (München, Bern, Vaduz, etc.)	**Climate Zone F** (Davos, Saalbach, Sonthofen, etc.)
		HDD <1500, CDD ≥500	*1500≤ HDD <3000, CDD ≥500*	*1500≤ HDD <3000, CDD <500*	*3000 ≤HDD< 3750, CDD <500*	*HDD ≥3750 CDD = 0*
Detached house (mainly heating and DHW, usually low/no cooling demand)	**BHEs**	✓	✓	✓	✓	✓
	GWHP doublet/field	✓	✓	✓	✓	✋ (check GW temp.)
	Shallow HC	✓	✓	✓	✋ (large HC area needed due to rigid climate)	
	SWHP	✓	✓	✓	✋ (water temp. may be low due to rigid climate)	
	Geostructures	Mainly due to the small plant size and delimited fabric this technology is hardly ever used for detached houses				
	Free cooling	✋ (complicates plant layout)		✋ (due to negligible cooling loads this technology does not apply here)		
Housing estate (mainly heating and DHW, usually low/no cooling demand)	**BHEs**	✓	✓	✓	✓ (recharge essential!)	
	GWHP doublet/field	✓	✓	✓	✓	✋ (check GW temp.)
	Shallow HC	✓	✋ (large HC area needed to meet heat demand)		✋ (large HC area needed due to rigid climate)	
	SWHP	✓	✓	✓	✋ (water temp. may be low due to rigid climate)	
	Geostructures	✓ (advisable to implement this technology in combination with other techniques as it may not meet heating demand)				
	Free cooling	✓	✓	✋ (due to negligible cooling loads this technology does not apply here)		
Office building (large cooling demand due to internal heat gains)	**BHEs**	✓	✓	✓	✓	✓
	GWHP doublet/field	✓	✓	✓	✓	✋ (check GW temp.)
	Shallow HC	✓	✓	✓	✋ (yes for cooling, usually negligible)	
	SWHP	✓	✓	✓	✋ (yes for cooling; check GW temp. for heating)	
	Geostructures	✓	✓	✓	✓	✓
	Free cooling	✓	✓	✓	✋ (yes for cooling, usually negligible)	
Hotel (large demand of	**BHEs**	✓	✓	✓	✓ (recharge essential!)	
	GWHP doublet/field	✓	✓	✓	✓	✋ (check GW temp.)

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<table>
<tr><th rowspan="2">CLIMATE ZONES
APPLICATIONS</th><th></th><th>Climate zone A
(Genova, Nice) + C
(Marseille)</th><th>Climate zone B
(Avignon, Torino, Koper, etc.)</th><th>Climate zone D
(Milano, Lyon, Ljubljana, etc.)</th><th>Climate zone E
(München, Bern, Vaduz, etc.)</th><th>Climate Zone F
(Davos, Saalbach, Sonthofen, etc.)</th></tr>
<tr><th></th><th>HDD <1500, CDD ≥500</th><th>1500≤ HDD <3000, CDD ≥500</th><th>1500≤ HDD <3000, CDD <500</th><th>3000 ≤HDD< 3750, CDD <500</th><th>HDD ≥3750 CDD = 0</th></tr>
<tr><td rowspan="4">heating and DHW)</td><td>Shallow HC</td><td colspan="3">✋ (large collector area needed to meet heating demand)</td><td colspan="2">✋ (large HC area needed due to rigid climate)</td></tr>
<tr><td>SWHP</td><td>✔</td><td>✔</td><td>✔</td><td colspan="2">✋ (water temp. may be low due to rigid climate)</td></tr>
<tr><td>Geostructures</td><td>✔</td><td>✔</td><td>✔</td><td>✔</td><td>✔</td></tr>
<tr><td>Free cooling</td><td>✔</td><td>✔</td><td colspan="3">due to negligible cooling loads this technology does not apply here</td></tr>
<tr><td rowspan="6">Swimming pool (usually heating only application)</td><td>BHEs</td><td>✔</td><td>✔</td><td>✔</td><td>✔</td><td>✔ (recharge essential!)</td></tr>
<tr><td>GWHP doublet/field</td><td>✔</td><td>✔</td><td>✔</td><td>✔</td><td>✋ (check GW temp.)</td></tr>
<tr><td>Shallow HC</td><td>✔</td><td>✔</td><td>✔</td><td colspan="2">✋ (large HC area needed due to rigid climate)</td></tr>
<tr><td>SWHP</td><td>✔</td><td>✔</td><td>✔</td><td colspan="2">✋ (water temp. may be low due to rigid climate)</td></tr>
<tr><td>Geostructures</td><td colspan="5">Mainly due to the small plant size and delimited fabric this technology does not apply here</td></tr>
<tr><td>Free cooling</td><td colspan="5">No cooling loads needed - this technology does not apply here</td></tr>
<tr><td rowspan="6">Supermarket (relatively constant heating and cooling demand)</td><td>BHEs</td><td>✔</td><td>✔</td><td>✔</td><td>✔</td><td>✔</td></tr>
<tr><td>GWHP doublet/field</td><td>✔</td><td>✔</td><td>✔</td><td>✔</td><td>✋ (check GW temp.)</td></tr>
<tr><td>Shallow HC</td><td>✔</td><td>✔</td><td>✔</td><td colspan="2">✋ (large HC area needed due to rigid climate)</td></tr>
<tr><td>SWHP</td><td>✔</td><td>✔</td><td>✔</td><td colspan="2">✋ (water temp. may be low due to rigid climate)</td></tr>
<tr><td>Geostructures</td><td>✔</td><td>✔</td><td>✔</td><td>✔</td><td>✔</td></tr>
<tr><td>Free cooling</td><td>✔</td><td>✔</td><td>✔</td><td>✔</td><td>negligible cooling loads</td></tr>
<tr><td rowspan="5">Snow/ice production (ski tracks, skating tracks)</td><td>BHEs</td><td colspan="4">Underground (inlet) temp. usually too high</td><td>✔</td></tr>
<tr><td>GWHP doublet/field</td><td colspan="3">Water temp. usually too high</td><td>✔</td><td>✔</td></tr>
<tr><td>Shallow HC</td><td colspan="4">Underground (inlet) temp. usually too high</td><td>✔</td></tr>
<tr><td>SWHP</td><td colspan="3">Water temp. usually too high</td><td>✔</td><td>✔</td></tr>
<tr><td>Geostructures</td><td colspan="5">Mainly due to delimited fabric this technology does not apply here</td></tr>
</table>

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Applications \ **Climate zones**		**Climate zone A** (Genova, Nice) + C (Marseille)	**Climate zone B** (Avignon, Torino, Koper, etc.)	**Climate zone D** (Milano, Lyon, Ljubljana, etc.)	**Climate zone E** (München, Bern, Vaduz, etc.)	**Climate Zone F** (Davos, Saalbach, Sonthofen, etc.)
		HDD <1500, CDD ≥500	*1500≤ HDD <3000, CDD ≥500*	*1500≤ HDD <3000, CDD <500*	*3000 ≤HDD< 3750, CDD <500*	*HDD ≥3750 CDD = 0*
	Free cooling	Low terminal temperature				
Road / railway / platform de-icing	**BHEs**	Temperatures rarely drop below 0 °C → no need for de-icing!		✓	✓	✓
	GWHP doublet/field			✓	✓	✋ (check GW temp.)
	Shallow HC			✋ (low efficiency)		
	SWHP			✓	✓	✋ (low water temp.)
	Geostructures			✓	✓	✓
	Free cooling			No cooling loads needed - this technology does not apply here		
Cooling of industrial applications (e.g. data centres, machinery cooling, refrigeration)	**BHEs**	✋ (low efficiency)	✓ (recharge essential)		✓ (recharge advisable)	
	GWHP doublet/field	✋ (low efficiency)	✓ (recharge essential)		✓ (recharge advisable)	
	Shallow HC	✋ (low efficiency)	✋ (large HC area needed)			
	SWHP	Advisable to use of free cooling instead, efficiency is higher!				
	Geostructures	✓ (advisable to implement this technology in combination with other techniques as it may not meet heating demand)				
	Free cooling	✓	✓	✓	✓	✓
Heating and cooling of industrial buildings (usually large demand due to bad insulation)	**BHEs**	✓ (recharge advisable)				
	GWHP doublet/field	✓	✓	✓	✓	✋ (check GW temp.)
	Shallow HC	✋ (only for heating)		✋ (large HC area needed)		✋ (only for cooling)
	SWHP	✓	✓	✓	✋ (only for cooling)	
	Geostructures	✓	✓	✓	✓	✓
	Free cooling	✓	✓	✓	✓	✓

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5 Description of techniques of utilization

Within this chapter, the most commonly used techniques of NSGE utilization are described according to their suitability for heating and cooling in the alpine region. The focus was set on the most common techniques – borehole heat exchangers and groundwater heat pumps. However, the attempt was to present a more or less complete catalogue and to also integrate systems which are rarely used – including a description why this is the case.

5.1 Suitability for Borehole Heat Exchangers

BHEs are closed-loop systems and are made up of (one or multiple) vertical boreholes where a loop of pipes is installed. They reach in depths of up to 400 m but the more common depth is between 50 and 150 m. They are suitable for the detached house as well as for large applications as upscaling is fairly easy. BHE are not dependent on the presence of groundwater, thus they can be installed in almost every environment. If BHEs are used for heating only purposes, in the long term the underground will suffer from the down-cooling and amount of heat extraction will drop. That is why it is advisable to recharge (reheat) the underground by injecting excess heat in summer and look at the underground more like a storage than a source of heat only.

Within this chapter, only very general statements are made on the dimensioning of BHEs, based on the German VDI 4640 guidelines. The spacing of wells if only heat extraction is performed shall be at least 5 m if the well length is <50 m and at least 6 m if the well length is 50 – 100 m in order to avoid mutual influence. Typically spacing is in the range of up to 10 m, dependent on available space. If BHEs are used for heating and cooling i.e. for storage, the spacing is recommended to be as low as 2 - 5 m. As general guideline, values for poor underground – that would be e.g. dry sediments – 20 – 25 W/m of specific heat extraction can be achieved. For normal underground (solid rock or water-saturated sediments), values between 50 – 60 W/m can be stated, for consolidated rock with very high thermal conductivity values up to 85 W/m. Especially for larger installations it is common to perform a thermal response test at a test probe on site for ideal dimensioning of the required well meters and the number of wells.

It is always advisable to not oversize the system which results in short and intensive load but rather to operate the probe more constantly and with lower performance. The grouting or backfilling material plays an important role as it controls the heat transfer between the BHE and the surrounding underground. The higher the quality of the grouting material and the way the grouting is carried out, the more efficient is the system.

Using BHE for heating/cooling has the following main advantages:

- BHEs can be drilled in almost every environment as they do not need the presence of an aquifer
- They can be implemented for single households as well as for large applications
- They yield constant performances as the influence from annual outside air temperature variation is negligible

The main disadvantages are:

- Drilling costs are high, that is why this system bears high Installation costs

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Awareness of possible challenges:

- If there are Anhydrites in the underground, BHEs are usually not permitted. This is due to the risk of connecting aquifers and further to hydrate the Anhydrites which results in the swelling to Gypsum. Gypsum has a larger volume than Anhydrite, thus the rising of the surface land is the result.

5.2 Suitability for Groundwater Heat Pumps

Groundwater heat pumps are open loop systems. The basic design consists of two separate wells, one for production equipped with a submersible pump and one for injection of groundwater after thermal use in the heat pump or through free cooling. This spatial separation prevents a short circuit and should guarantee a thermally unaltered heat carrier throughout operation of the heat pump. This is the main advantage that makes open loop systems more efficient in comparison with closed loop systems.

The drawback of GWHPs is that they need groundwater in a sufficient depth, quantity and quality at the installation site. The groundwater has to be tapped with a well, which has to be a locally designed. In hydrogeological heterogeneous areas this raises the planning effort for GWHP systems, because some aquifer characteristics are crucial for a reliable operation.

First of all, the well yield has to be high enough to supply the nominal flow rate of the heat pump. The well yield is dependent from the well design itself and from aquifer properties, like the hydraulic conductivity and must be confirmed by a pumping test. Heat pumps need around 0,25 m^3/h for each kW of evaporator capacity, so an exemplary detached house with a 10 kW heat pump would need a flow rate of around 0,7 L/s.

Furthermore, the well's flow rate can change over time. Reasons can be seasonal or permanent water table variations, aging of the well by precipitation of minerals or the movement of solid particles over time and the drilling of other wells, of course. Knowledge about those influences will reduce the risk of a system failure, but also increases the maintenance effort. Thus, before the installation of a GWHP several hydro-chemical parameters are measured to assess the risk of iron or manganese encrustations or the occurrence of corrosive waters. If parameters are critical, the appropriate technical installations can be adapted in advance. To eliminate the risk of calcareous precipitations, the temperature spread by the heat pump should not exceed ± 6 K, according to the VDI 4640. Apart from geogenic chemicals, the presence of contaminated sites could also interfere with the thermal use of groundwater. If a contaminated site is suspected, the relevant substances have to be analysed.

Using GWHPs for heating/cooling has the following main advantages:

(i) GWHP can reach the highest efficiency numbers, because of very constant groundwater temperatures
(ii) As a result, GWHP systems have very low operating costs
(iii) Very little space is needed also for large installations
(iv) Easy application of very efficient free cooling with groundwater is possible
(v) When the depth to groundwater is low, installation costs decrease significantly

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5.3 Suitability for Shallow Heat Collectors

Shallow heat collectors or ground heat collectors are closed loop systems. They consist of tubes which are buried in the soil underneath the depth of frost penetration, typically at 1 to 3 m below surface. The tubes can either be placed horizontally, like in an underfloor heating system, or in other specially designed shapes. Some examples are called slinky heat collectors, coil or spiral heat collectors, but also more vertical shapes have been invented, like thermal baskets and trench heat collectors.

Apart from their design, all shallow heat collectors have in common that they are buried after excavation of the ground. This significantly reduces installation costs in comparison with GSHPs and GWHPs where drilling is needed, but it also excludes areas were hard rocks are at the surface or in shallow depths. Here excavation would not be economically feasible. Another common feature arises from their shallow burial. The temperature in 2 m depth is highly influenced by seasonal meteorological variations. Even the diurnal variation for instance, can be seen in depths of up to 60 cm. Therefore, depending on the meteorological conditions and thermal properties of the soil, the undisturbed ground temperature in winter at the depth of the heat collector will not be far above 0°C. This, of course, negatively influences the effectivity of the heat pump compared to GSHPs and GWHPs, because a higher temperature spread has to be accommodated.

Shallow heat collectors use latent heat by freezing the ambient soil water (334 kJ/kg) in order to supply the demanded geothermal heat. In addition, after freezing the system takes the benefit from the increased thermal conductivity of ice (2.25 W/mK at -5 °C) which is 3.8 times higher than the thermal conductivity of water. The addition of cooling agent (water/glycol mixture) in the collector tube allows the circulation of the heat carrier fluid with temperatures below 0°C and following for example the design regulations in Germany a cooling of the ambient ground to up to -4 °C is normal (Ramming 2007). The Germany VDI 4640 just gives relative deviations from the undisturbed ground temperature of ± 12 K for the weekly average and ± 18 K for peak loads. Through the heating period in the winter this leads to a steadily growing ice shield around the heat collector. For an efficient use in the next season a thermal regeneration of the ground, respectively a melting of the ice shield in summer time, is of paramount importance. Therefore, the ground surface of the collector area must not be sealed to ensure a sufficient replenishment from solar heat which is transported by conduction through the ground and advection from infiltrating rainfall into deeper layers. Here the shallow burial which provides a fast thermal regeneration of the collector is an advantage in comparison with GSHPs, but it also shows that the installation depth is crucial. It should be optimised in a way that the collector is properly isolated from low winter temperatures to provide enough heat for heating season, but also sufficiently regenerates in summer time. Especially in Alpine environments this requirement may lead to not suitable areas or to a not appropriately designed shallow heat collector.

As with GSHPs, a combined heating and cooling with preferably balanced demand is most desirable. When cooling in summer is applied the process of thermal regeneration speeds up and leads to better start conditions for the next heating season.

Depending on the horizontal character of specific shallow heat collector, the areal demand of this system can be very high and in densely populated areas the area consumption might obstruct

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installations at all. Florides and Kalogirou (2007, [27]) suggest a typical horizontal loop length of 35 to 60 m for 1 kW of heating or cooling capacity. The Germany VDI 4640 gives a maximum total annual extraction value of geothermal heat of 50 to 70 kWh/m^2 each year [5]. In Sweden Rosén et al. (2006,) suggests a range of 60 to 85 kWh/m^2 each year.

The section above showed some major characteristics have to be observed for the suitable use of shallow heat collectors. In summary they are:

- Shallow heat collectors have to regenerate in summer, so the installation site must not be built over and has to be large enough for sufficient natural regeneration
- A balanced heating and cooling demand would be the ideal solution to speed up thermal regeneration and support the opposing seasonal load cycle.
- The installation depth is important, because the collector has to be isolated from low winter temperatures to provide enough heat for heating season, but also needs to regenerate with the heat flow from the surface in summer time.
- Installations depth is 1 to 2 m where seasonal temperature influences are still strong and therefore, the temperature spread the heat pump has to accommodate is normally higher compared to GSHPs and GWHPs
- Economic feasible installation is only possible in soils, not in rocky or blocky areas
- Especially in the Alpine Space at higher altitudes the occurrence of rocks and deep reaching frost lines have to be considered in the planning phase.

5.4 Suitability for Surface Water Use

Surface water use remain a very niche application. This is mainly because the heat consumer needs to be connected directly to the surface water body for efficiency reasons. The other option is to install heating grids, which are fed by these low-temperature systems.

The heat content of the surface water body is extracted via a heat pump or directly via free cooling. Useable water bodies can be of natural origin – e.g. streams, lakes or wells, or anthropogenic influenced – e.g. sewage water or drained water from tunnels.

Waste (sewage) Water use

Waste water is any water that has been adversely affected in quality by anthropogenic influence and is seen as a renewable heat source for HPs. Besides this, sewage is the subpart of waste water and is a term used for waste water that often contains faeces or urine.

The heat loss from the urban runoff indicates a large potential. Water has a high heat capacity and density, and, therefore, provides a concentrated heat source. In all kinds of low-grade heat sources, urban runoff is widely used due to its advantages such as:

- the huge amount that is produced in cities every year
- temperature is constant all over the year and its temperature is almost 20 °C higher than the ambient air temperature
- it contains a large amount of heat energy

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The waste water source heat pump has become increasingly popular due to its advantages of relatively higher energy utilization efficiency and environmental protection. This is related to the huge potential:

- in any city, almost 40 % of the produced heat is sent to the sewerage system as waste heat
- the amount of waste water is significantly high and its flow rate is almost constant year-round

Since the 1980s, centralized systems in Germany, Switzerland and in the Scandinavian countries have utilized the heat from waste water either in the sewage system or in the effluent of sewage treatment plants. It is estimated that over 500 WWSHPs are in operation world-wide (Hepbasli et al., 2014) [8].Thermal ratings are in the range of 10 – 20.000 kW. Studies in Switzerland and Germany indicated that 3 % of all buildings could be supplied with heat on the basis of waste water. More than 100 waste water heat recovery plants with between 100 and 70.000 kW heat are already operating in Switzerland and Scandinavia.

HPs using heat of wastewater are widely applied in Europe, USA, Japan, South Korea and China. These HP units are reliable and economical sources of heat. The efficiency of HP using waste heat as a heat source is always higher than that of an ambient air HP. A modern HP can process 160 t/day of urban runoff. Such HPs consume about 8 MWh of electricity per day and are able to generate more than 32 MWh of heat per day (Alekseiko et al., 2014) [9].

Lake, stream and well use

Natural surface water can be used to extract heat by the means of geothermal heat pumps or directly via free cooling. Naturally, the temperature varies strongly during the year as the surface water temperature normally relates closely to outside air temperatures.

Lakes can reach temperatures of up to 30 °C in summer [11] but may freeze largely in winter times. However, buildings that do have a heating demand also on warmer days such as badly insulated old buildings or spa areas as well as installations like swimming pools can profit from this direct water use.

Streams do not reach as high temperatures compared to lakes, though the temperature variation during the year is less strong. Comparing mean daily temperatures of random selected rivers in Switzerland, temperatures of > 10 °C are reached from around April to October/November [10] – this is a common working temperature for GWHPs.

Wells usually drain with very constant water temperatures – they may be very low if they are draining melt water but also high if they drain from deep groundwater bodies. Groundwater wells usually drain with constant discharge in contrast to those wells drained by rain or melt water.

The big advantages of these systems are:

- The system is easy to install as no drillings have to be carried out
- In case of continuous temperatures and discharge rates efficiency can be very high

5.5 Suitability for Geostructures

Within this document, we use the term "Geostructures" for different types of thermally activated parts of buildings. Common terms are also "thermo-active structures", "thermal component activation" or "thermal activation of building elements".

Geostructures are categorized as a closed-loop system, meaning that brine (water or a mixture of water and anti-freezing fluid) circulates in embedded pipes. If these pipes are installed in fundament plates, pile walls or piles of buildings or e.g. within walls of tunnel tubes where they extract energy from the underground, they are referred to shallow geothermal systems.

This technology is favourably used for cooling rather than heating purposes, though both is applicable. Applying this system to a building helps to increase its energy efficiency because the existing substance (fundaments, piles, walls etc.) is used both as heat exchanger and as thermal storage.

As the tubes are embedded into the building substance, the use of this technique has to be incorporated in an early planning stage of the building. Installation costs are relatively low as no extra drillings or excavation of the ground are needed.

Especially in urban areas, where space is limited, geostructures represent a good option of NSGE use. This technology is promoted for all kinds of new buildings, not only for large e.g. office buildings but also for single houses (recently published text on thermal component activation by the Austrian Cement Association [38]). From the heat providing side, the usage of underground installations like tunnels or mines are ideally suitable for the extraction of heat because they usually hold relatively high and constant temperatures. From the consumer's side, the usage is less appealing as those installations are usually not connected to or not in the vicinity of heat consumers.

Using geostructures for heating/cooling has the following main advantages:

- The system can be integrated in almost every new building
- It does not require extra space as it is integrated into the building substance
- The investment costs are relatively low compared to other NSGE systems as no drillings or excavations of the ground are needed

The main disadvantages are:

- The efficiency is relatively low compared to other NSGE systems

Awareness of possible challenges are:

- The design has to be calculated carefully, once the building is constructed, hardly any changes to the system are possible
- If piles stand in groundwater, a permit may be required (VDI 4640)
- Geostructures must never reach the frost limit as this can have massive effect on the concrete surface and the building– this has to be taken into account in design calculations (VDI 4640)

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Suitability for Free Cooling

Building cooling is usually performed through a heat pump, exploiting the air or the ground as a heat sink. However, the ground can be cooler than the operating temperature of the cooling terminals, thus allowing to operate the heat exchange without the heat pump and hence to achieve a noticeable energy saving [28]. This operating mode is called “free cooling” and it is an interesting option, as the heat pump usually accounts for 80÷90% of the total energy consumption of a NSGE system, while the rest is due to the circulation of the heat carrier fluid inside the ground heat exchangers (closed-loop systems) or the extraction and reinjection of groundwater (open-loop systems).

To perform ground free cooling, the pipe layout of the NSGE system should be arranged properly. For smaller heat pumps, where the BHE circulation pump is usually included, a number of models is available on the market with a free cooling option. For larger systems, a heat pump bypass should be foreseen. An evaluation should be therefore performed to assess whether ground free cooling is possible for a sufficient number of hours per year. General rule are not available, but the following conditions should be assessed:

- Free cooling introduces a higher complexity of the NSGE system, which should be compensated by energy and economic savings. For this reason, free cooling in buildings with (relatively) low cooling requirements is generally not worth the additional expense;
- At the end of the heating season, the ground(water) should be cool enough for a direct heat exchange with the cooling system of the buildings. This depends on the operating temperatures foreseen in heating mode;
- Heating and cooling season can be separated by a recovery period, in which no heat is extracted and hence the ground(water) gets warmer due to the propagation of the thermal plume. This period depends on the characteristics of the building, on its usage profile and on the climate. For example, well-insulated buildings are more sensible to solar heat gains in late Spring; the cooling season in office buildings starts earlier due to the high internal heat gains. The shorter the recovery period between the heating and cooling season, the more free cooling is likely to be feasible;
- Some applications are characterized by a largely prevailing or exclusive cooling mode, e.g. data centres [29];
- The operating temperature of the cooling terminals: in cooling mode, ceiling/wall radiant panels operate at higher temperatures compared to fan coils, and hence they are deemed to be more suitable to operate in free cooling [30-32].

Considering these conditions, ground source free cooling can make an appraisable contribution for the reduction of building energy demand in the Alpine Space.

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Suitability for Underground Thermal Energy Storage

Some seasonal solar energy storage Borehole Thermal Energy Storage (BTES) have been operational for several years, line Drake Landing Solar Community in Canada [33], Neckarsulm in Germany [34] (for older experimental work see synthesis [35]). These two installations store solar energy to match heating requirement of buildings. In both cases, seasonal storage is complementary to a gas boiler. At Drake Landing, 90% of the energy consumed by the 52 individual homes connected to the grid is supplied by solar energy (either live or via storage) [36]. In Neckarsulm, more than half of the annual energy is supplied by the gas boiler room. In both cases, the amount of stored energy is about 700 MWh at Solar Drake [36] as at Neckarsulm [34]. In both cases, the boreholes are short (30 to 35 m) in order to minimize the storage volume / area ratio (and correlated losses); the number of boreholes is much higher at Neckarsulm (528) than at Drake Landing (144), while the quantities of stored and depleted energy are similar. Quality data is collected on Drake Landing sites. Models for thermal dynamic simulations have been validated.

The thermal behavior of a BTES is now well understood. Lessons have been learned:

- Seasonal storage yield increases over cycles and tends to an asymptotic value as the ground heats up year after year (eg. 6 % in the 1st year to 54 % in the 5th year for Drake Landing Solar (and still increasing), Neckarsulm). For Neckarsulm, an efficiency of 70% under steady state is expected [34].
- Storage costs are between 50 and 100 € / m^3 water equivalent [37] (estimate based on 4 BTES). The costs depend strongly on the use, in particular the temperature of return to the BTES.
- An insulating material shall be placed on the surface. Materials (pipes, borehole grouting materials) must be adapted (fluid temperatures up to 70 to 80 ° C)
- Underground flow, even at low velocities (i.e. vDarcy <10 $m.a^{-1}$) greatly reduces storage efficiency. At present, the BTES seem limited to areas with low permeability.

5.6 Conclusions

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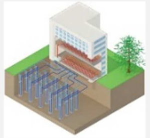
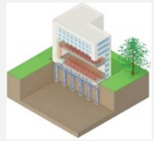
Table 6: Comparison of the suitability the different techniques of utilization of NSGE

	Borehole Heat Exchanger 	**Groundwater Heat Pump** 	**Shallow Heat Collector** 	**Surface Water use**	**Geostructures** 
System type	Closed-loop	Open-loop	Closed-loop	Open-loop	Closed-loop
Free cooling potential	MEDIUM	HIGH	MEDIUM	HIGH	MEDIUM
Need of drillings?	YES	YES (exception: spring)	NO (ground excavation)	NO	NO
Need of an aquifer?	NO	YES	NO	Surface water	NO
Depth of installation	Normal: 50-150 m Maximum: up to 400 m	Normal: 10-20 m Maximum: up to 100 m	Normal: 1,2-1,5 m Maximum: up to 3 m	Deep point in the surface water reservoir	Depending on building construction
Installation costs	High	Medium	Low	Low	Medium
Influenced by seasonal temp. variation?	LOW	LOW - MEDIUM depending on aquifer	HIGH	HIGH	MEDIUM
Efficiency	Medium	High	Low	Medium – high	Medium
Space demand	Low	Low	High	Low	No extra space demand
Specific heat extraction (VDI 4640)	20-100 W/m	0,25 m^3/h per kW evaporator capacity	8-40 W/m^2	0,25 m^3/h per kW evaporator capacity	Constraint: System shut down at 0°C
Size of thermal plume	LOW	HIGH	LOW – MEDIUM	HIGH	LOW - MEDIUM

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Main advantages	+ Can be installed almost everywhere + Constant performance + Easy upscaling for applications sizes	+ High efficiency, especially in free cooling + Medium installation costs	+ Low installation costs	+ High efficiency, especially in free cooling + Low installation costs	+ Can be integrated in many new buildings + No extra space demand
Main disadvantages	- Relatively expensive	- Availability of a productive aquifer	- Influenced by outside air temp. - Lower efficiency	- Influenced by outside air temp. - Constant performance cannot be guaranteed	- Relatively low efficiency
Awareness of possible challenges	! Anhydrite layers in the underground ! Karstic rocks in the underground	! Groundwater chemistry	! Rocky ground ! Low ground temperatures at high altitudes		

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6 Best practice examples

Every partner country was asked to perform a survey and provide a list of examples of existing near-surface geothermal energy plants which proved to be effective and sustainable. Non-conventional applications were highlighted, to give insight on the variable fields of application of NSGE. The most interesting examples were chosen to serve as "best practice examples" (see chapter 6 Best practice example).

To be able to present a concise compilation of current best practice examples with many different techniques and/or topic-related examples, 2-3 sites from this list per country were selected for data-gaining.

For the Del. 3.2.1, which is the second deliverable in this WP, an analysis of the site-specific parameters of these examples will be carried out. From this analysis, relevant operational criteria as well as technical/environmental constraints for shallow geothermal plants shall be derived and in addition, a system comparison will be carried out. The main goal of this follow up deliverable will be the quantification of operational and environmental thresholds. Those thresholds will build the basis of an adjusted quantification of the resource which contributes to the special surroundings of the Alps. As a result local municipalities in the project's case study areas will benefit from the derived thresholds, because they lead to a more accurate mapping and in addition to an improved implementation of NSGE in their local energy planning.

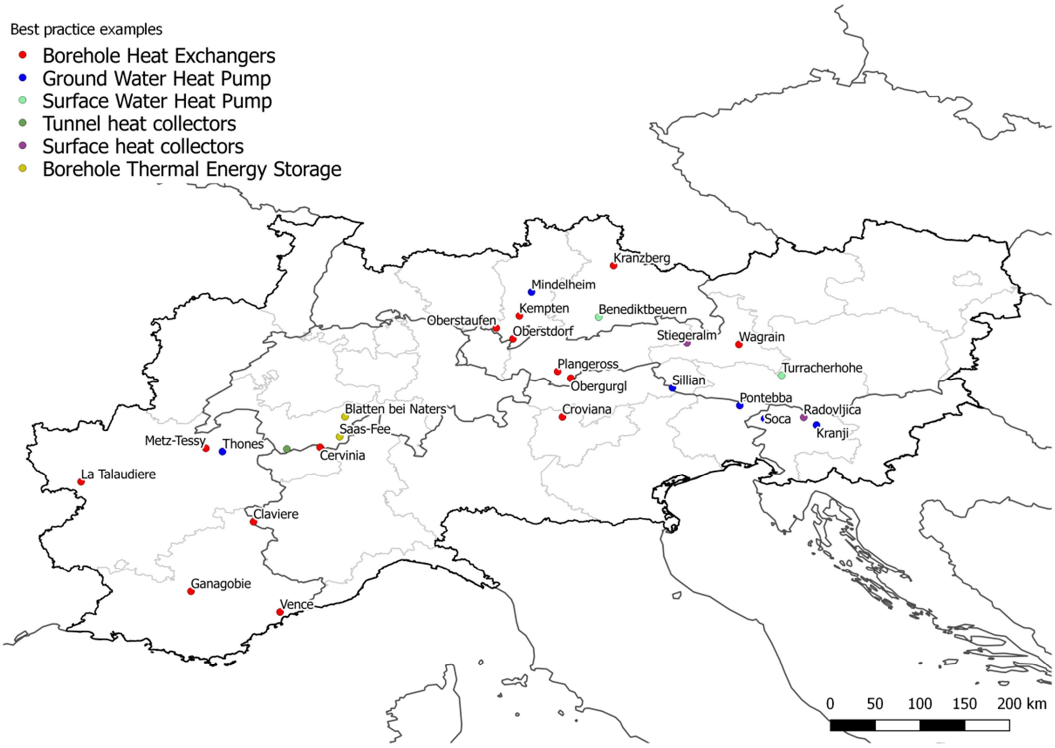

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Figure 23 –Best practice examples collected in the Alpine Space area. Red dots are Borehole Heat Exchangers, blue dots are Ground Water Heat Pumps, and green dots are Ground Heat Collectors.

After scanning the national situation of well performing / innovative / interesting / exotic / etc. uses of NSGE, all partner countries provided a list of those "best practice examples". In order to present an interesting list of examples, showing many different systems and uses under different climatic conditions, a selection of about 5 examples per country were chosen to be described in more detail.

Table 7: List of best practice examples from all partner countries

Technique/ system	Nr.	Heating/ Cooling/ DHW	Short description of the use	Country	Altitude
GWHP	1	H/DHW	Campsite (KLIN)	SLO	439 m
	2	H/C	Office buildings (heating), machine cooling (company Grob)	GER	606 m
	3	H/C	National interprofessional nordic center - heating, water cooling to produce snow (Kranj)	SLO	378 m
	4	H/C	Locker rooms heating, ice rink cooling (Pontebba)	IT	570 m
	5	H	Production hall and offices (company Euroclima)	AUT	1083 m
	6	H/C	Industrial building (Thônes)	FRA	461 m
	7	H	Industrial building (Rhone-Alpes)	FRA	574 m
	8	H	Open-air pool (Lido Benediktbeuern)	GER	617 m
	9	H/C	Palazzo Lombardia (Milano)	IT	120 m
BHE	10	H	Bar ("Pit-stop")	IT	2400 m
	11	H	Collective housing (Metz-Tessy, France)	FRA	461 m
	12	H	Railway switch (Oberstaufen)	GER	790 m
	13	H	Railway switch (Oberstdorf)	GER	813 m
	14	H/C	Parador Resort (Vence)	FRA	280 m
	15	H/C	Detatched house (Kranzberg, system GeoCOAX)	GER	490 m
	16	H	Settlement Ludwigshöhe (Kempten)	GER	607 m
	17	H/DHW	Hotel & pools, DHW-supply (Hotel Crystal)	AUT	1905 m

	18	H	Mountain restaurant (Sunna Alm)	AUT	2291 m
	19	H	Restaurant (Gipflstadl Wagrain)	AUT	1854 m
	20	H	Industrial building (La Talaudière)	FRA	507 m
	21	H	Monastery of Ganagobie	FRA	650 m
	22	H/C/DHW	Bus and train garage at Croviana (Val die Sole)	IT	1400 m
	23	H/DHW	Olympic swimming pool (Radovljica)	SLO	439 m
SHC	24	H	Chalet in winter sports region (Stiegeralm)	AUT	1487 m
	25	H/DHW	Chaberton residence (Claviere)	IT	1760 m
	26	H/DHW	Holiday resort Reka Blatten - Belalp	SWI	1327 m
BTES	27	H	Saas-Fee district heating supply for the community	SWI	1792 m
Direct water use	28	C	Machinery (company EGO)	AUT	1088 m
Surface water use	29	H	Lake-water-pool (Hotel Hochschober)	AUT	1763 m
Geostructures	30	H	Tunnel Great St. Bernard - heat extraction from tunnel air for administrative building on the north portal	SWI	1850 m

6.1 Combination of SGS with other techniques

In

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Table 2, the application of different shallow geothermal systems for different climate zones and uses are displayed. Additionally, the possible combination of different SGS among each other is indicated. Certainly, in many cases, the coupling of SGS with other techniques like solar panels, oil/gas-boilers, etc. is common and reasonable. Combining SGS with other techniques may result in a better performance of the system and in decreasing the system costs by avoiding oversizing of NSGE installations. Numerous combinations of SGS with non-SGS techniques are practical but the evaluation of this topic is not subject of this study. To give a rough idea about established examples, see the following list which is derived solely from the best practice examples collected within this study:

Coupled BHE – solar panels
Example Nr. 17 "Hotel Crystal", Obergurgl, Austria (heating and DHW) – coupled BHE field (76 wells) with 200 m² solar panels: heating up the reservoir in summer via solar panels to achieve better performance of the system.

Example Nr. 18 "Sunna Alm", Restaurant, Austria (heating) – coupled BHE field (7 wells) with solar panels: heating up the reservoir in summer via solar panels to achieve better performance of the system.

Coupled shallow heat collector – oil heater
Example Nr. 23 "Olympic swimming pool", Radovljica, Slovenia (heating) – use the oil boiler and solar panels to cover peak load demand.

6.2 Awareness of possible challenges of SGS

During the best practice example collection, the need to state possible challenges one can face in building and operating shallow geothermal systems was revealed. By surveying for interesting examples, time and again examples of not well-working or problematic installations appeared. In order to raise awareness and spread the learning effect for planners, the project partners decided to show these instances as well. The following list of possible challenges was derived simultaneously to the collection of best practice examples and does not claim to be complete.

6.2.1 Underground is colder than expected

Cold river water infiltration – *Example: GWHP was installed too close (within about 50 m) to the nearby river/stream*

Especially in mountainous areas where rivers/streams are recharged with melting water or cold rain water, water temperatures of these rivers are very low – even over long distances of several 10s of kilometers. They infiltrate adjacent ground water bodies and may significantly cool these aquifers. Installations suffer from a lower efficiency and heat pumps need to be dimensioned correspondingly.

! When planning a GW-based SGS close to a river/stream, pay special attention on the local hydrogeological conditions; check the temperature profile of the aquifer; check if there is a deeper aquifer you can use.

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Cold underground in high altitude locations – *Example: BHE installation in high altitude location (> 2000 m) suffer from very low (even negative) underground temperatures*

In high altitude areas with very low outside air temperatures and a long period of snow cover (thus not enough solar radiation to heat up the ground), underground temperatures may drop into the negative range. Installations dealing with negative temperatures do work, though efficiency is certainly low.

! When planning a SGS in high altitude locations, pay special attention on the thermal regime of the underground (also the thermal rock properties) - carry out a thermal response test for dimensioning the installation. Recharge the system by heating up the ground in summer time – either via the seasonal use of the system or by combination with non-SGS systems like solar panels.

6.2.2 Unexpected mineralization of groundwater

Well/GWHP corrosion – *Example: GWHP installed close to an abandoned mine suffers from sulfur corrosion*

Main influential factors for well corrosion [3] are: groundwater with low/high pH-value, mineralized water; water enriched in: Oxygen, Chloride, Sulfur, CO_2, NH_3.

In geological units with high content of soluble Sulfur/Chloride/etc. minerals and their drainage array, as well as close to existing or abandoned mining areas, groundwater may be saturated with these corroding elements. In agricultural areas (especially conventional agriculture), groundwater may be corrosive due to the consumption of fertilizers which diffuse into the aquifer.

! When planning a SGS use in areas bearing the potential of corrosive water, check the water geochemistry. There are technical solutions for all of these problems but it is necessary to know before realizing the installation.

Well clogging – *Example: GWHP (doublet) installed for a small paper factory, but after 7 years of operation problems with well clogging appeared due to (probably) unsuitable well completion and not so good hydro geological conditions (water became dirty).*

! When planning a SGS use in areas with the potential of problems with water quality, check the water geochemistry. There are technical solutions for all of these problems but it is necessary to know before realizing the installation. More experienced drillers are needed.

6.2.3 Reduction of aquifer productivity

Ebbing of a karstic aquifer – *Example: GWHP installed in a productive karstic spring suffers from ebbing of the water*

Aquifers in karstic rocks can be problematic in terms of NSGE-use due to e.g. the heavy fluctuation of water tables, discharge rates and temperatures. Karstic springs may significantly decrease discharge rates or run dry in dry seasons or in winter when all precipitation is stored as snow cover. On the other hand, karstic rocks can be a great water source for SGS systems as flow rates tend to be very high.

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! Before installing a GWHP in a karstic spring, detailed hydrological studies should be carried out taking into account the drainage area and its seasonal fluctuations. This implies an observation period of at least one year, if no studies are available from literature.

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