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Deliverable D1.1

Report on different kind of barriers for shallow geothermal in deep renovation

WP1

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Lead beneficiary	14 – UBeG (Burkhard Sanner)
Other authors	01 – CNR (Adriana Bernardi, Gianluca Cadelano) 02 – UNIPD (Michele de Carli, Guiseppe Emmi, Laura Carnieletto, Angelo Zarrella) 03 – UPV (Borja Badenes, José M. Cuevas, Javier F. Urchueguía) 04 – RED (Luc Pockele, Paolo Sivieri, Francesco Gramegna) 05 – GEOSERV (Ric Pasquali, Nicolas Wall) 06 – GALLETTI (Fabio Poletto) 07 – TECNALIA (Amaia Castelruiz) 08 – TKI (Arno Romanowski) 09 – UNESCO (Davide Poletto) 10 – FAU (David Bertermann) 11 – RGS (Doina Cucueteanu) 12 – CRES (Dimitrios Mendrinos) 13 – HYDRA (Davide Righini) 15 - GEOGREEN (Jacques Vercruysse) 16 – PIETRE (Leonardo Rossi, Loredana Fodor) 17 – SOLINTEL (Dery Torres, Michele Vavallo) 18 – DLH (Luciano Mule' Stagno) 19 – SUPSI (Marco Belliardi)

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Contents

Summary

The document D1.1 “Report on different kind of barriers for shallow geothermal in deep renovation” is a public document delivered in the context of WP1, Task 1.1: “*Review and identification of the different barriers (technical, social, cultural, economic and legislative) for shallow geothermal applications in building renovation*”. In order to explore ways to overcome the barriers and to unleash the great potential SGE has for saving energy and avoiding emissions, this report presents the collection and analysis of obstacles against SGE use in building refurbishment. The barriers are grouped into two main types, technical and non-technical barriers, with an extra section considering the specific problems posed by historic buildings.

Technical barriers are deemed to be overcome more easily, with development work ongoing since many years and new solutions found constantly. The ingenuity of the engineers and scientists in the wide-ranging disciplines required for SGE application can be trusted to deliver the necessary solutions – provided they can be demonstrated to be economically feasible. Section 1 of this report lists the many barriers and classifies them according to their place in the design and installation process, and to the technical nature of the constraints, be it limited available space or existing heat distribution systems not suited well for lower supply temperatures. Possible pathways how to overcome stated barriers are already hinted at in most cases, directing development work in GEO4CIVHIC towards relevant issues and possible solutions.

Dealing with the non-technical barriers is less straightforward and needs to address a large number of different aspects, ranging from the perception individual persons might have of SGE to questions of economic viability and environmental impacts. Changing negative perception of a SGE-based energy refurbishment in terms of feasibility, reliability and affordability can be a difficult task. Section 2.1 investigates all relevant stakeholders and looks at their possible objections; shortcomings in regulation and economic barriers are dealt with in Sections 2.2 and 2.3, respectively. Somewhat in a hybrid category is section 2.4, where environmental issues are addressed; these have both a technical and non-technical side, as technology can be employed to mitigate environmental influence.

Section 3 elucidates the specific barriers encountered with historic buildings. Many issues are similar to those in newer buildings, however, often exacerbated by the nature of the buildings considered, by the surroundings they usually are found in, and often also by specific regulations securing their historic integrity.

Appendices provide information on protection of historic buildings and on the ReGeoCities classification of typical building zones in cities.

Abbreviations

GEO4CIVHIC	Most Easy, Efficient and Low Cost Geothermal Systems for Retrofitting Civil and Historical Buildings
BHE	Borehole Heat Exchanger
BTES	Borehole Thermal Energy Storage
CAPEX	Capital Expenditure
DHW	Domestic Hot Water
DTH	Down-The-Hole drill / Down-hole hammer
EWT	Entering Water Temperature
GHE	Ground Heat Exchanger (general term, includes BHE)
GSHP	Ground Source Heat Pump
HP	Heat Pump
IP	Intellectual Property
NPV	Net Present Value
NZEB	Near-Zero-Emission Building
OPEX	Operational Expenditure / Operating Expenses
PBT	Pay-back Time
RES	Renewable Energy Sources
ROI	Return on Investment
SFH	Single Family House
SGE	Shallow Geothermal Energy
ZEB	Zero-Emission Building

Introduction

Task 1.1 reviews different kinds of barriers for renovation of buildings and, more importantly, why geothermal heating and cooling solutions (SGE) are rarely applied in such renovations. In cases of renovation and refurbishment, the technical barriers against SGE are usually much higher than for green-field developments, as constraints in site availability and the need to adapt to given building equipment call for bespoke solutions in each case.

Beside technical and regulatory barriers, lack of knowledge (and even misinformation) about new technologies like SGE can be identified as a main barrier to their spreading. Targeted information and communication strategies highlighting the possible advantages and debunking the perceived obstacles need to be created.

A classification of typical building zones in cities was used in a previous EU-funded project ReGeoCities, and is proposed for use also in GEO4CIVHIC. It is shown in Appendix C.

The report D1.1 evaluates the specific issues and classifies the different constraints, to focus the development within the project on the most widespread problems and the most promising solutions. Special attention is be given to barriers related to the application of the technologies in historical buildings, which have particular constraints.

1 Technical Barriers

1.1 Design of SGE for existing buildings

When designing shallow geothermal energy systems (SGE) for existing buildings, the choices the designer has on methods, parameters, sizes etc. are limited by meeting requirements of existing equipment, by space constraints, etc. The possible degrees of freedom for design are much reduced in comparison to most new buildings, and in particular to new buildings on the greenfield. This chapter summarises and evaluates these barriers to SGE design.

1.1.1 Building energy needs, insulation, windows, etc.

A main question is whether it is possible to do a deep energy renovation of the building envelope (cf. 1.1.2). The main objective here would be a reduction of both the peak thermal load and overall energy consumption of the building. The other important question is whether to replace existing heat/cold distribution and emission installations by low temperature systems like fan-coil units and/or radiant floor/wall/ceiling systems, in order to improve the energy efficiency. In any case, a more detailed energy analysis of the thermal behaviour of the building for the correct sizing of the heat pump is subject to other tasks in this project.

Old buildings are usually not well insulated, with single-glazed windows, resulting in high energy needs. Therefore, in those cases where a global retrofitting action is not considered and only the addition of a SGE system is contemplated, this could result in prohibitive capital costs. The key item is how much you can insulate a building and work on retrofit of envelope and installations before adding renewable energy options, which could include a SGE system. Building typologies are different due to the age of construction as well as the possible use in urban context. As a matter of fact, most of the buildings have been built before any regulation or restriction on the energy consumption in buildings was in force.

It is important to have reference buildings in order to understand the most widespread type of building, allowing for information on the possible solutions which can be proposed in combination with GSHP. Some European projects have to be mentioned here, since they represent a good basis for the analysis of the state-of-the-art and the actual status of buildings in Europe.

The first project that collects existing building types across Europe is the EU project TABULA - EPISCOPE [1], where a database of typical energy consumptions of buildings has been set up. TABULA (www.building-typology.eu) was the first part of the project (2009-2012), which developed a Web-Tool describing the residential building stock of the project partners' countries. EPISCOPE (www.episcope.eu) was a further extension of the project (2013-2016), which elaborated the building stock models to assess the energy refurbishment, providing a huge amount of combinations of residential buildings and HVAC systems including NZE-buildings. The database provides the energy performance assessment before and after renovation, accounting actions both on the envelope and on the plant. The project TABULA - EPISCOPE is based on national criteria according to the building and plant features and to the weather conditions. The results are the overall consumptions of the buildings.

Another project is iNSPiRe (http://inspirefp7.eu/, 2012-2016), whose goal was to develop a support tool that enables to predict the energy impact of different building retrofit solutions.

iNSPiRe uses the TABULA building database to carry out an energy performance assessment accounting several system typologies in seven locations in Europe. The iNSPiRe report [2] focused mainly on the generation of systematic and modular renovation packages that can be applied directly on the building, reaching different target heating demand levels.

As an example of reference values for existing buildings and historical buildings, based on a preliminary statistical analysis on buildings carried out in Task 1.3, the average values of transmittance of the archetypes defined in Task 1.3 are shown in Table 1. It is obvious that the current average values of the transmittance are quite high and hence also the heat losses.

Building type	Age	Climate	Roof	Walls	Floor	Windows
Terraced house	existing	warm	1.65	0.89	1.36	3.55
		average	0.70	1.05	1.01	2.85
		cold	0.29	0.35	0.41	2.35
	historical	warm	2.30	1.75	1.29	4.97
		average	1.19	1.75	1.38	3.69
		cold	0.54	1.11	0.79	2.72
Apartment block	existing	warm	0.79	0.79	1.15	3.90
		average	0.82	1.01	0.68	2.93
		cold	0.13	0.22	0.16	1.43
	historical	warm	1.76	1.35	1.07	5.19
		average	1.80	1.81	0.95	3.41
		cold	0.32	0.59	0.66	2.50

Table 1 – Average U-values [W/m^{2}K] which came out from the statistical analysis based on TABULA database carried out in Task 1.3

Another important aspect is the use of the building. In urban context the buildings are mostly used for civil purposes. In GEO4CIVHIC both residential buildings and office buildings are addressed, with energy demands differing due to occupancy time, internal loads, etc. As a matter of fact, in residential buildings the internal loads are low, while in office buildings the internal gains can be quite high. Also ventilation rates differ a lot, whether a mechanical equipment is installed or not. The use of the system is almost continuous in residential buildings (day, night, weekend), while office buildings are mainly used during daytime, and usually not used at weekends. Another important issue is the requirement for Domestic Hot Water (DHW): in residential buildings DHW is a constant energy demand, required throughout the year in winter and summer, which on average can be accounted at 15 kWh/(m^2 y); in office buildings this is a minor energy demand, and many times it may be easier and cheaper to install distributed electrical boilers.

As for the energy demand, it is important to underline that the energy demand in buildings is not only related to heating, but cooling is increasingly used in buildings, not only in warm climates but also in mild climates. This is due to the change in habit of occupants (people live more and more in conditioned spaces), and aggravated by climate change (last summers were exceptionally hot even in central and north Europe). Finally, when living in moderate environment (heated spaces in winter and cooled spaces in summer), health and productivity may increase and hence cooling systems are installed more and more in residential buildings.

An important item related to the cooling energy demand are the latent loads (e.g. from moisture, humidity etc.). Usually they are not very well defined or are not even considered in the calculations. This means that the cooling energy demand is underestimated. This has two main inconveniences. In mild climates the latent energy could lead to a balance of the energy required by the ground and hence the released heat during summer could match and counterbalance the heat extracted by the ground in heating conditions. In warm climates this energy could lead to overheating the ground if it is not taken into account during the sizing.

1.1.2 Improved insulation in existing buildings

For existing buildings with medium insulation level (e.g. buildings form the 1990s), a key question is whether the integration of a GSHP system itself could be efficient enough to cover the energy needs, or if a complete, deep refurbishment including an improvement of insulation together with an installation of GSHP could attain more appropriate results [1]. Two main topics should be firstly considered before a refurbishment action:

- Can the GSHP efficiency outweigh insulation deficiencies of the building?

  Here the answer is probably yes, but it will mean a significant over-dimensioning of the system, which will drastically increase capital costs.
- Is there a match between interventions on the envelope and GSHP?

  This is probably the most productive action in terms of energy savings and capital costs because the level of actuation for reducing the U-values will directly have repercussion on the sizing of the GSHP.

These two questions are mutually related, since they are linked to the costs of the required interventions. These may typically include substituting the windows, using double or triple glazing windows, the increase in insulation on the roof, on vertical walls or the ground; and, at the same time, designing a GSHP installation adapted to the new energy demands. When looking at increasing the insulation, it has to be checked how this can be done, depending on the type of building structure.

Moreover, in urban environments it has to be checked if the external insulation is feasible or not, since the building is usually in line with other buildings and local regulations may not allow to reduce the front space especially when it is directly on the street. Limitations on external insulation can be particularly severe for historic and/or listed buildings (cf. chapter 3).

Constrains and costs of interventions and potential benefits have to be considered against (first question) or in conjunction with (second question) the costs and benefits of the GSHP system. For a more general assessment, cost-benefit analyses and case studies within project GEO4CIVHIC could be helpful.

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[1] The comment of an architect on this issue is: "*In serious energy upgrading projects one shouldn't even think of inserting an SGE plant or low temperature systems with GSHP without heavy renovation and insulation. Although some companies propose it, it is a mistake and anyway it would have a high and unjustified cost for a mild intervention.*"

1.1.3 Existing distribution systems and emission units

In most refurbishment projects the question has to be asked if existing distribution systems, emission units etc. should be kept or replaced.

Five types of plants are the most common in civil buildings: radiators, fan-coil units, chilled beams, radiant systems and full-air systems.

Radiators usually work between 50 °C and 80 °C with a temperature difference between supply and return of about 15-20 °C. They had been sized for a greater temperature drop but usually, especially in large and old plants, due to the hydraulic unbalances in order to provide sufficient heat in the underprivileged flats (usually the most distant from the technical room).

Fan-coil units usually provide heating and cooling with 5 °C temperature drop. In cooling conditions, they typically work with a supply temperature between 7 °C and 10 °C if they have also to dehumidify the air. Temperature in cooling conditions could be higher, but in this case dehumidification has to be provided by another system (usually the fresh air). In heating conditions, the supply temperature depends on the size of the coil; temperatures may range from 45 °C to 55 °C, with the latter value suitable for older plants. The temperature drop over the fan coil is usually 5 °C in both heating and cooling.

Chilled beams are practically fan-coil units with large coils so as to allow low temperature differences between indoor air temperature and water temperature. In this kind of systems the fresh air is usually integrated. The supply temperature is usually 40 °C in heating conditions (with a temperature drop of 3-5 °C) and 16 °C in cooling conditions (with a temperature drop of 3 °C).

Radiant systems are a more recent distribution system made of pipes embedded in the floor (mostly used for residential buildings), ceiling (mostly used for office buildings) or walls (less common than the other types of radiant systems). The supply temperature in heating conditions ranges from 25 °C for very well insulated buildings up to 35 °C. Sometimes supply temperature could be even higher depending on the covering of floor and on the design heat load of the building. The temperature drop is usually 5 °C for radiant floor and wall, 3 °C for the radiant ceiling. In cooling conditions, the supply temperature may range between 16 °C and 19 °C. The temperature drop is usually about 3 °C for each type of system. In case of radiant cooling, attention has to be paid to humidity content in order to avoid surface condensation.

Full air systems were mainly used in the past in office buildings and in larger spaces (e.g. commercial centres). They are also used frequently in buildings with a huge people density, e.g. libraries, cinemas, classrooms, etc. Full air systems are also proposed today in passive residential buildings, due to the low amount of peak power needed for heating and the need to ventilate the houses anyway. Although some of these systems are proposed also for cooling, they present some problems to fulfil comfort requirements in design conditions and hence are not able to provide comfort all over the summer season.

	Radiators		Fan coils		Chilled beams		Radiant systems		Full air	
	T_{supply}	Δt	T_{supply}	Δt	T_{supply}	Δt	T_{supply}	Δt	T_{supply}	Δt
Poor insulation	70-80	15-20	55	5	40	3-5	40	5-7	60	5
Good insulation	50	10	45	5	35	3	25-30	3-5	45	5
Cooling	-	-	7-10	5	16	3	16-19	3	7	5

Table 2 – Average supply temperatures [°C] and temperature drops [°C] in the most common types of heating/cooling systems used in existing and retrofitted buildings

As can be seen in this analysis, summarised in Table 2, the cooling temperature supply can be either low (7 °C) or high (16-19 °C), with a temperature drop of usually 3-5 °C. The heating temperature supply can be high (60-80 °C), medium (40-55 °C) or low (25-35 °C). The temperature drop can go from 10-20 °C with radiators down to 5 °C with coils systems and 3 °C with radiant systems.

When retrofitting buildings where a low/medium temperature supply system is already present, a conventional heat pump can be installed. If the supply temperature is high, the choice of heat pump is difficult, as heat pumps providing heat at high temperature level are not yet well established on the market. Usually heat pumps may reach 60 °C for producing DHW, but it is not recommended to exceed this value. Hence in old buildings with radiators and poor insulation it is very difficult to install a heat pump without changing the emitters. However, development on high-temperature heat pumps is ongoing, and some examples exist with temperatures reaching up to 70-90 °C (cf. 1.3.2). The drawback of any high temperature supply with heat pumps is the low efficiency, due to the high temperature lift from ground-side temperatures to the ones required for heating supply.

In case radiators are replaced with radiant systems all the plant has to be renewed, i.e. the radiant system plus the distribution system. In case radiators are replaced with fan-coil units, the problem is that the temperature difference of the water is 2-4 times the one with radiators. This means that the distribution system may not be able to guarantee the required flow rate of the new system. Moreover, the existing pipes usually are not or poorly insulated, and if due to the climate the building needs cooling, condensation on the pipes may occur when water is flowing inside at an average temperature of 10 °C. For these reasons, when radiators have to be replaced, all the heating/cooling system has to be changed, i.e. emitters and distribution system.

In moderate climates, the technology of direct cooling from the ground (a.k.a. “passive” cooling, “geocooling”), which bypasses the heat pump when cooling, is applied widely since the first small demonstration plants over 30 years ago [3]. In countries like Austria, Germany, and in particular Switzerland (where the first patent on this technology was filed in 1986 [4]), it is used frequently in plants of various size, including some rather large installations. While there are limits (no latent load, low cooling potential), there are some clear advantages (very low operation cost, very high efficiency, ground thermal recharge). The limitations are sometimes overcome by combining direct cooling in the shoulder seasons with conventional cooling using chillers for peak cooling load days; in regions with warmer climate and certain humidity the technology should not be used, as it does not provide for dehumidification. Direct cooling requires specific cold emission systems (cooling ceilings, thermally activated building parts –

TABS, large-size fan coils) due to the relatively high supply temperatures in the order of 16-20 °C, which often comes as a barrier to its application in refurbishment projects.

1.1.4 Space constraints for technical rooms and distribution

In a refurbishment the space constraints for technical room is a valid question, since the spaces are quite reduced, especially in an urban context. For this reason it is useful to see the main characteristics of the different technologies. In general, mechanical rooms usually are located in the basement, and/or in very confined surroundings.

Oil boilers need a tank for storing the fuel oil, hence usually two rooms are needed in this case. Often the room where the oil tank is located cannot even be considered as a proper room, but space is very narrow and with limited height. The location of natural gas boilers is similar to the one of the oil boilers, but in this case the additional room is not needed.

Air to water heat pumps and/or chillers need to be installed in the outdoor environment. They might also be installed inside the building, but in these cases air conduits are required, and centrifugal fans have to be installed, which usually require higher electrical power due to the higher pressure drop compared to axial fans usually mounted directly on the machine. There is also the possibility to install split units, with external condenser/evaporator and with compressor and all other components located inside. In these cases the distance between the internal main body of the heat pump/chiller and the external condenser/evaporator cannot be too long. The main restriction to air heat pumps and/or chillers is the noise which might be generated in the outdoor environment. In any case a buffer tank for the heating/cooling water and a tank for DHW have to be installed, and this means an additional volume to take into account.

GSHP are comparable in size to an internal unit of a split air-to-water heat pump. This means that also in this case, a buffer tank for the heating/cooling water and a tank for DHW have to be installed, with the additional volume taken into account. Moreover, the ground-side pipe conduits and manifolds have to be included in the analysis, in order to check if they can installed inside the building or have to be located outside along the connection with the BHEs.

As for hybrid or bivalent solutions, i.e. dual-source heat pumps, the combination of problems and benefits of the above mentioned air-to-water heat pump and GSHP solution have to be considered together.

An analysis taking into account the volume of the different solutions as a function of the type of building (archetype from Task 1.3) and the peak power needed for heating and cooling (related to building envelope and climate) has to be carried out to take into account the feasibility and/or the limits of the proposed solution.

1.1.5 Limitations for design of underground system

Space availability for installing the borehole field for a GSHP installation is always considered a crucial issue due to the standard dimensions of a common BHE field. In many cases the space availability will depend not only on already existing free space as gardens, parking lots, etc., but also on the level or intensity of the refurbishment action (higher levels will probably mean more possibilities for drilling). An analysis of the usual layout of urban environments has been made, in order to answer to the question of limitations for installing GSHP systems in the urban area. It has been found that the most common type of urban buildings is an aligned configuration (Figure 1.1). Depending on the layout of the city, there might be buildings with small internal courtyards or even with gardens. As an example, two city-centres in the same climatic area in Northern Italy are shown in Figure 1.2: Ferrara (a) and Padua (b). It can be seen that Ferrara has few and narrow patios, while Padua has internal wide courtyards with even large gardens.

Figure 1.1 Example of typical aligned buildings in different climates

a

b

Figure 1.2 Example of typical aligned buildings in different climates; aerial view of two different urban contexts: Ferrara (a) and Padua (b) (source: Google Earth)

Two archetypes have been decided in Task 1.3: a terraced house for single users (Figure 1.3) and an apartment block for multi-users (Figure 1.4).

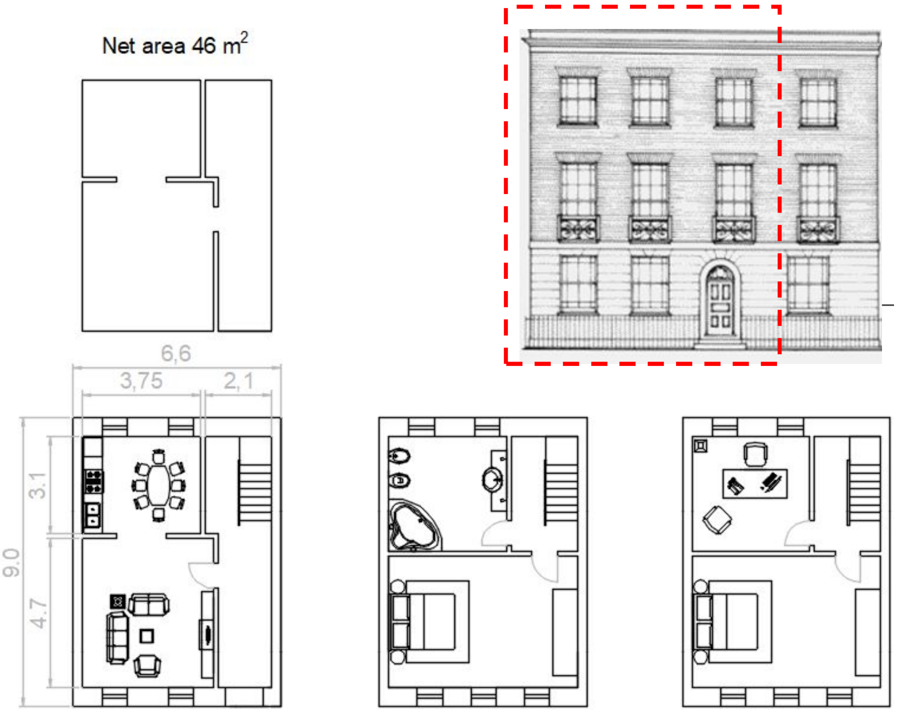

Figure 1.3 Example of terraced house representing a single user (3 storeys)

Based on these preliminary analyses it has been found that the main problem which may be encountered is generally the restricted area available for GHE installation (cf. 1.2.1). Among these problems there are the already mentioned limited dimensions of gardens to install the BHE at the required distances. In order to identify the problems which may arise from the building type, dynamic simulations in three climates have been performed in Task 1.3 for three types of building envelopes in each archetype. The single user building has been supposed to be residential, while the multi-user building can be either residential or an office building.

Figure 1.4 Example of apartments block representing a multi-user (5 storeys, 4 flats on each)

Based on these simulations a set of possible peak power values for the required heating/cooling systems have to be matched with the possibly available space for the building, checking if the BHE can be installed in the courtyards (if any), in the footprint of the building, or both.

For the single user building, if more than one BHE is required, they need to be positioned in a line, due to the narrow lot; some possible layouts are shown in Figure 1.5. Possible locations are in the courtyard (a), in the courtyard and in the footprint of the building (b), or only in the footprint of the building (c). Drilling in the footprint of the building would of course only be possible in those cases where a very intense refurbishment is planned, but will usually not be possible where just the enhancement of the thermal envelope of the buildings is foreseen. In some countries (e.g. Switzerland) temperature restrictions to avoid freezing apply when putting BHE underneath a building, sometimes this type of placing is banned outright.

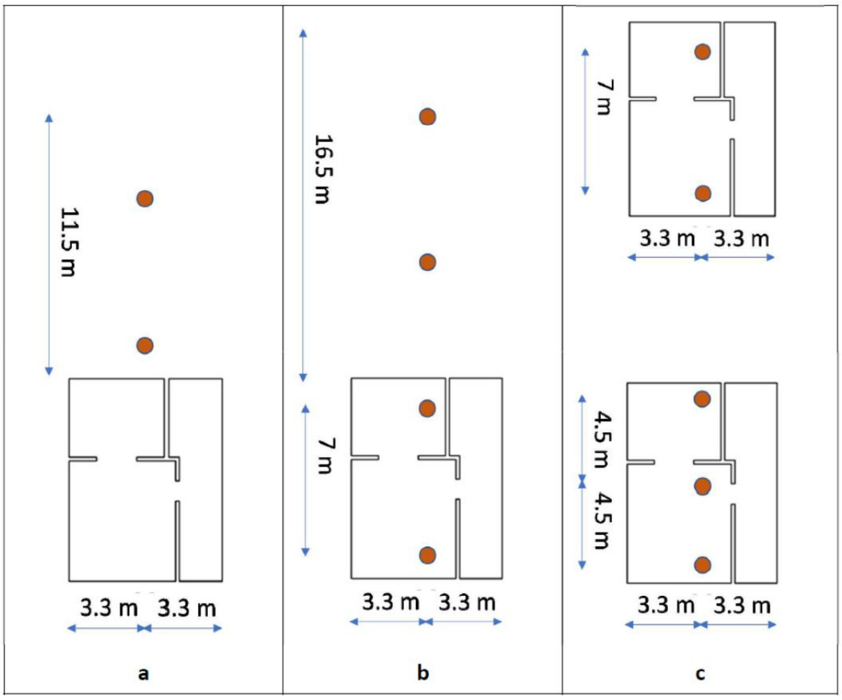

Figure 1.5 Example of possible layouts of the BHE field in a single user building when using the courtyard (a), both footprint and courtyard (b) and footprint of the building (c)

For a preliminary analysis it has been decided that 3.3 m as distance from the neighbouring lots is possible (corresponding to the centre of the building), and that 7 m spacing would be an optimum distance between boreholes. As can be seen, depending on the available space of the courtyard up to 4 BHE can be installed in this case, with optimal spacing at least in the direction of the BHE-field. When dealing only with the footprint of the building (c), 2 BHE may be installed (upper picture), and it has to be checked if 3 BHE with much smaller distance may be still considered sustainable or not (lower picture).

The multi-user building necessarily will host a matrix of GHEs; some possible layouts are shown in Figure 1.6. Possible locations are in the courtyard (a), in the courtyard and in the footprint of the building (b), or in the footprint of the building only (c), with the same restrictions as described above. For this preliminary analysis it has been decided that 3.0 m as distance from the neighbouring lots is possible and that a spacing distance between boreholes between 6.0 m and 6.5 m is a good compromise. As can be seen, depending on the available space of the courtyard, up to 15 BHEs can be installed in the courtyard alone (a). When dealing only with the footprint of the building (c), again 15 BHEs may be installed. If GHEs can be installed both in the building footprint and the courtyard (b), 25 BHEs might be installed.

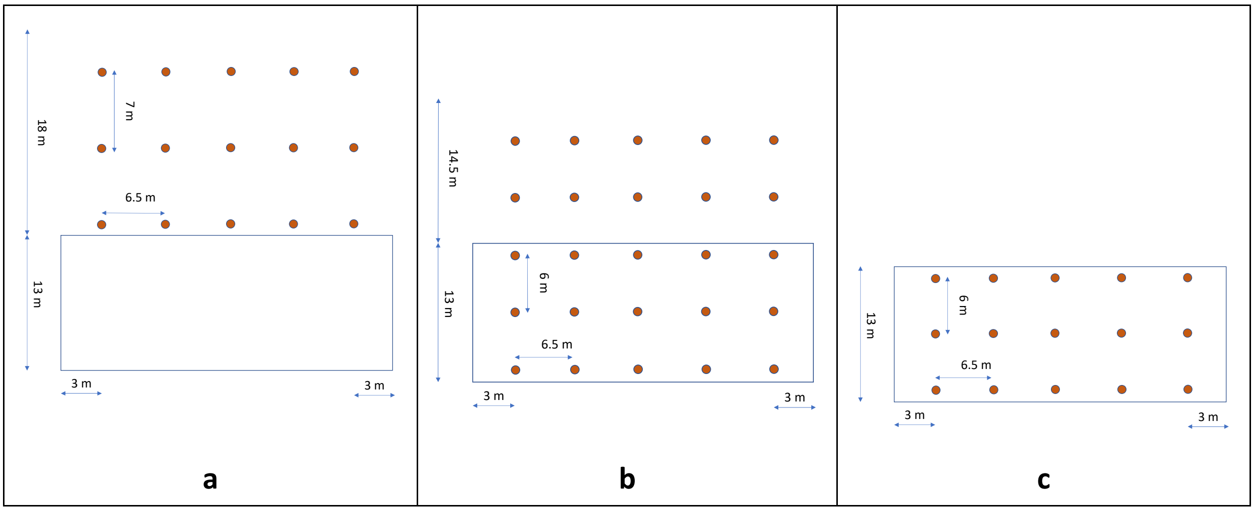

Figure 1.6 Example of possible lay-outs of the GHEs field in a multi-users building when using the courtyard (a), both footprint and courtyard (b) and footprint of the building (c)

The problem with horizontal piping must also be considered, especially if the BHEs are installed in or under the foundations, in the footprint of the building (cases (b) and (c) in Figure 1.5 and Figure 1.6). In these cases, also the temperature limits for static loads have to be taken into account, as the GHEs are installed underneath the foundations; this is similar to the usual problems occurring with energy piles.

Of course, the main limitation which has to be observed is the interference with other buildings and possible GSHP systems installed there, and hence the thermal footprint has to be determined in areas with other GSHPs in the surroundings. This aspect will be investigated in Task 6.2.

All design of SGE installations in existing buildings will have to study thoroughly the thermal behaviour of the BHE field over time, in order to avoid or to limit a gradual thermal drift in the underground. This should be considered as possible KPI in order to check the sustainability of the proposed solutions, and will be further dealt with in T1.3 and T1.4.

1.1.6 Other considerations

Theoretically, the integration of geothermal systems should not interfere negatively with other energy systems. Research in this aspect currently focuses on the interaction between geothermal systems and other additional renewable energy systems to obtain a higher energy efficiency. As a result, excess thermal energy is often used to preheat (or cool) other applications such as swimming pools, garages, dwellings, etc., or to store thermal energy in the ground for future seasonal demands.

The time of pre-construction activities and of execution of works for BHE creates difficulties in the management of the building site schedule. Works must be carried out before excavations and foundations structural works, and therefore can generate delays not appreciated by constructing companies. An organization of BHE and SGE system is necessary that allows to start in short time (immediately after the request) and perform as fast as possible.

1.2 Difficulties for drilling and GHE installation in built environment

"*Most of the building sites do not correspond to the desires of the drilling companies. Flexibility and exact knowledge of the possibilities are therefore very important*." (J. Uhde) [2]. This quote is true for any construction site, but even more for sites within the built environment. Drilling in the built environment has to adapt to numerous constraints caused by the site conditions and surroundings. These constraints can be basically divided into primary technical issues (accessibility, available working area, existing obstacles, etc.) and other issues, caused indirectly by technology or plainly non-technical (noise, smell, vibrations, visual obstruction, regulations, etc.). Several areas of direct and indirect technical difficulties for drilling and GHE installation in built environment have been identified, as detailed below. Deliverable D2.1 covers the current drilling techniques and gives examples of how to overcome some of the site constraints.

1.2.1 Space constraints, accessibility

SGE underground systems can have considerable (vertical BHEs) or even large (horizontal GHE) requirements in area, which may not be available in urban locations. A minimum distance between individual BHE on the surface has to be observed because drilling usually is not totally vertical and slight deviations can add up to some metres for deeper boreholes; also thermal interactions have to be considered (cf. 1.1.5). The German standard VDI 4640 [5] recommends a distance of 5 m for BHE less than 50 m deep and 6 m for deeper BHE.

Two main constraints are predetermined by the site geometry: The size of the available area for drilling, and the access to this area (small entrances, limited space to move the drilling machine to the correct location, etc.). Drilling rigs need a certain room to manoeuver, and room around for the workers, material and accessory equipment. Room is required in particular behind the mast, for adding and removing tubes. Novel systems with vertical tube handling and storage can somewhat reduce the required area. On very small sites sometimes equipment like compressor (for DTH) or mud containers need to be located outside, with longer air hoses and pipes required to connect them to the rig and the respective cost and hassle. This is also valid for grouting, if material handling, mixing and pumping has to be done at a distance from the borehole to be grouted.

Obstacles like balconies, trees, walls, gates etc. can further limit the working room, not to speak of existing, nice gardens. While most problems with accessibility to the drilling site can be overcome somehow, by narrow rigs or even by lifting[3], the drilling location as such needs a certain area and any obstacles can cause delays and increase cost. Often the available area only allows for a small rig, capable of installing boreholes of considerably less than 100 m depth, while on the other hand the heating/cooling load would require for deeper BHE to make the best use of the available area. Only a combination of more powerful, albeit small rigs, improved BHE and technologies to reduce the heat requirement from the ground (e.g. by dual-source heat pumps) has the potential to provide economically acceptable solutions for such sites.

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[2] quoted from Geotrainet drillers course material, Peine, DE, March 2010

[3] In the case of lifting a compact drilling machine over houses or other obstacles into gardens, street area in front of the house may be required for placing the crane. Specific preparations are required in this case: about 15 days before a permit needs to be obtained from the local authorities to block the street (police, municipality) and a fee is generally requested.

The most difficult situation is if no or not sufficient area is available outside of buildings. Drilling inside a building basement, underground parking or similar is basically possible, but associated with various problems and increased cost. The basic geometrical problem is the ceiling height, restricting the mast height of the drilling rig and the possible length of individual drill pipes. For deeper boreholes, a short mast and short drill pipes (e.g. 2 m instead of 5 m) will mean an increase in gross drilling time. In addition, when drilling inside existing buildings with the drilling rig positioned on floors other than the basement (for instance when the machine reaches the basement through a hole in that floor), the structural strength of the floor needs to be verified. Engine fumes and heat need to be controlled. A drilling rig optimised for indoor drilling would best have the power generation outside, with hydraulic, pneumatic or electric transmission to the mast and drill head. For DTH, compressors also should be outside the building. Development in this field could open a potential for GSHP in existing buildings that hitherto is virtually untouched.

Accessibility of the area in certain historic city centres - e.g. Venice, Brugge, medieval cities - is even more difficult and sometimes not possible at all, although project partners have drilled in a commercial building at the San Marco square in Venice.

1.2.2 Existing underground infrastructure

A specific problem with drilling sites in built environment is the high probability of existing underground infrastructure (gas and water supply piping, sewers, electrical power cables, etc.). Good maps and diligent survey are crucial, with improved methods for detection of underground items desirable. Drawings and maps of the utilities in the streets are often available at municipal level but private properties do not have such drawings. However, the gardens behind the houses are normally free since the utilities are coming from the street. Use of Geo-radar may be useful to avoid incidents and in the case of drilling in Historical Building areas (cf. chapter 3.3). A specialised company is then required. While drilling into an artificial cavern like a metro line or railway tunnel is rather rare, it has nevertheless happened (cf. D2.1, chapter 3).

In Italy public infrastructures are seldom in the underground of private buildings and private areas. There may be in the common areas of complexes with more buildings, but in that case utilities are defined by specific conventions and there are precise maps of their path. Therefore, in the case of total renovation of buildings (with replacement of all sub-services), it’s not a big issue.

1.2.3 Energy, material supply and waste removal

Drilling requires energy, either produced on site (e.g. diesel engine), or brought in by cable (electric power). Supply of fuel for diesel engines and lubricants needs to be secured and might be subject to accessibility problems as stated in 1.2.1. Similar problems exist for supply of other materials like tools, replacement parts, mud additives (e.g. bentonite), grouting material, etc. Another problem can arise from waste removal, mainly of drill cuttings or mud from rotary drilling. And finally, the supply of water and the possibility to get rid of possible higher amounts of water from the borehole is crucial.

1.2.4 Noise, dirt, vibration

Drilling in the built environment always means drilling in the vicinity of others, be they residents, office occupants, passers-by or others. Noise, dust, dirt, smell, vibrations etc. are caused by the drilling process and must be controlled for minimum impact on the surroundings. Also noise and disturbances caused by material supply and waste removal (cuttings) interfere with the neighbours. Communication plans need to be devised and appropriate shielding installed. Usually neighbours are willing to accept some temporary nuisance if they know it is for a good case, like clean energy.

1.2.5 Dangerous remains of previous conflicts

Caution is required with dangerous remains of past conflicts, a particular problem until today with WWII-bombs in areas having suffered air raids on cities, in Germany, UK, and elsewhere. Also more recent conflicts e.g. during the break-up of Yugoslavia have left remains, and furthermore the conversion of land from military domain to other uses bears some potential for related risks. Investigations by dedicated authorities or specialised companies will need to precede drilling activities in affected areas.

1.2.6 Other barriers for drilling and GHE installation in built environment

Often there may be time constraints in the daily working window, i.e. not before 8.00 am and after 8.00 pm, or during weekends or public holidays. This limits the range of time to work. In most countries (e.g. Italy) there are a regulations establishing times and maximum noise intensity during works, either on municipal or higher level. It is usually possible to request a specific exemption for short periods.

As always, the geology needs to be checked carefully. Anhydrite may expand with the water from the drilling and lead to stability problems, gypsum residues or layers of gypsum may be dissolved and lead to subsidence. Even old mine shafts or caves, if present, could collapse.

1.3 Difficulties with heat pump integration in existing buildings

For using new heat pump installation, two main issues are obvious: The space constraints given by the pre-existing building infrastructure, and the thermal constraints (supply temperatures, fluid flow velocities). This chapter lists and evaluates below the barriers to heat pump use in existing buildings.

1.3.1 Limited space for the installation

As already mentioned in paragraph 1.1.4, the heat pump requires a tank for the heating/cooling system in order to increase the inertia of the hydronic circuit and thus to reduce the frequency of switching the compressor on and off.

In case of DHW provided by the heat pump, an additional tank for DHW beside the buffer tank is required, in order to supply sufficient heat for DHW while keeping installed thermal output of the heat pump low, as well as limiting electric power input to the heat pump. Several options are available in this case. The simplest solution is to feed heat to the DHW tank directly from the heat pump, and to use the warm water in the tank directly in the building (Figure 1.7, A). In this case weekly anti-legionella cycles are needed to reduce the risk of growth of this bacterium. In order to avoid these cycles, production of hot water at the moment it is actually used is necessary (instantaneous production). This means that an intermediate heat exchanger has to be installed, including an additional pump. The disadvantage of this option is that higher temperatures of the water in the tank are required compared to solution A, but no anti-legionella cycles are needed. There are two options for instantaneous production: the first option is to install an external hydronic kit with heat exchanger (Figure 1.7, B) and the second option is to include the heat exchanger internally inside the tank (Figure 1.7, C). Option B requires additional space, while the option C is less intrusive, even though the tank needs more volume to host the internal heat exchanger.

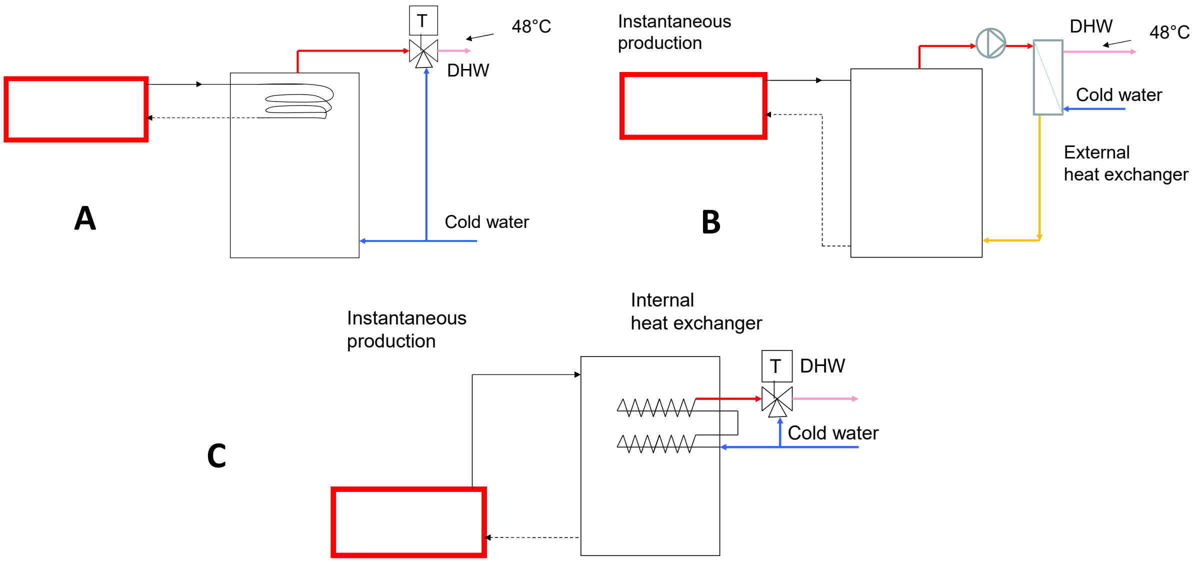

Figure 1.7 Example of possible layouts for producing DHW: directly from the storage tank (A), with an external heat exchanger (B), and with an internal heat exchanger (C)

An additional item to be considered is the electric panel which has to be installed/enlarged compared to the existing one.

As for the pumps, the circulation pump for the heating/cooling circuits usually is already installed in the case of the heat pump. On the other hand, the pump for the GHE-field often is not included in the heat pump. As for the manifold, this may be installed either in the technical room or outside within the connection to the ground circuit.

In case it is not possible to install the heat pump inside the building, it might be installed outside, but needs to be protected against inclement weather like rain or snow. Moreover, the acoustics may become a problem when installing a heat pump in the outdoor space. The resulting need to build an insulated place would increase the costs.

The possible solutions for a multi-user water-to-water heat pump are shown in Figure 1.8. In Figure 1.8 (A) the typical solution of a centralised system is shown. This is the typical solution, and the main problems are related to the energy metering systems and respective costs, and to the heat losses from the DHW distribution[4]. In some cases it might be more efficient to install a central heat pump for the heating and/or cooling, and add for DHW decentralised heat pumps (air-based or from a water loop) to produce the warm water directly in each flat. In order to reduce the distribution losses an alternative solution is represented by the system shown in Figure 1.8 (B), where decentralised water-to-water heat pumps are installed in each flat

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[4] In a case with centralised DHW supply to ca. 40 apartments in north-western Germany, monitoring showed that the heat losses from distribution and transmission in a poorly insulated system were almost as high as the actual heat within the warm water delivered at the taps (info from a confidential study performed by UBeG in 2017).

("water-loop" heat pumps, a layout originating from North America). The main problem of this solution is the control strategy of the ground circuit / water loop, since this should work with variable flow velocity in order to reduce pumping energy in times of low demand.

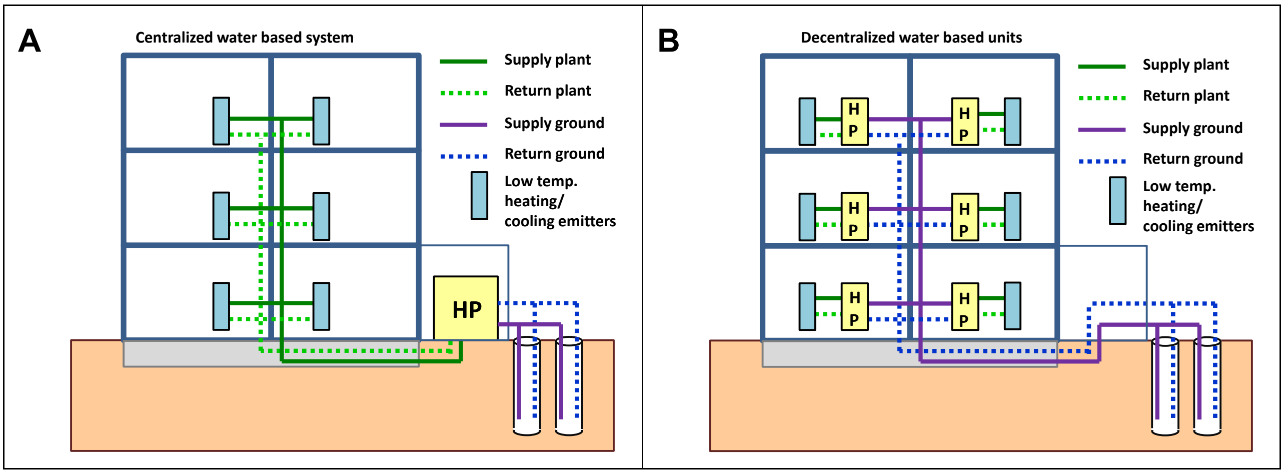

Figure 1.8 Example of possible types of GSHP systems: centralised solution (A) and decentralized solution (B)

1.3.2 High temperature terminals

Most heat pumps have maximum heat supply temperatures of 55-60 °C, some can achieve 70 °C. Older heat distribution systems often require 70-90 °C to provide for comfortable warmth in the rooms. The solutions is to either change the building heating system (cf. 1.1.3), or to use heat pumps that can meet the required temperature levels. This problem is valid in particular for historic buildings and buildings classified as of cultural interest by authorities, in which case it may not be possible to replace the existing systems. In these cases is the inclusion of high temperature heat pumps with lower efficiency can be justified from an energy point of view.

The availability of heat pumps with heating supply temperature above 65 °C still is limited. While a number of heat pumps achieving the value of 65 °C appeared on the market over the last decade, first for capacities below 20 kW, and meanwhile for capacities exceeding 100 kW, heat pumps with supply temperatures of 70 °C and more are still scarce (Figure 1.9). Development on high-temperature heat pumps is ongoing, and some examples exist with temperatures reaching up to 70-90 °C (cf. 1.3.2). However, the heat pumps designed for 90 °C or more are destined for district heating or industrial applications, and thus available only in the higher capacity range. Furthermore, the minimum temperature for water entering the evaporator (EWT) is almost 10 °C, and thus unsuitable for the combination with closed-loop GHE like BHE.

A general drawback of any high temperature supply with heat pumps is the low efficiency (low COP), due to the high temperature lift from ground-side temperatures to the ones required for heating supply. The use of new refrigerants for heat pumps is expected to open possibilities for higher supply temperatures with acceptable COP. A promising fluid for heat pumps with high temperature water distribution systems is CO_2. This fluid in the supercritical cycle may lead to high COP, but a wide range of temperatures for the different uses are needed to cool down the condenser, i.e. from 20°C-30°C up to 80°C-90°C. This is quite difficult in buildings with high temperature terminals because they usually work in a range 60°C-90°C as shown in paragraph

1.1.3. Another possible solution is to use ammonia as refrigerant fluid, but it is usually not recommended to use it inside the buildings due to toxicity and odour. On the other hand, new fluids are appearing in the market, but they are slightly flammable and hence they are not fully accepted by users and/or technicians.

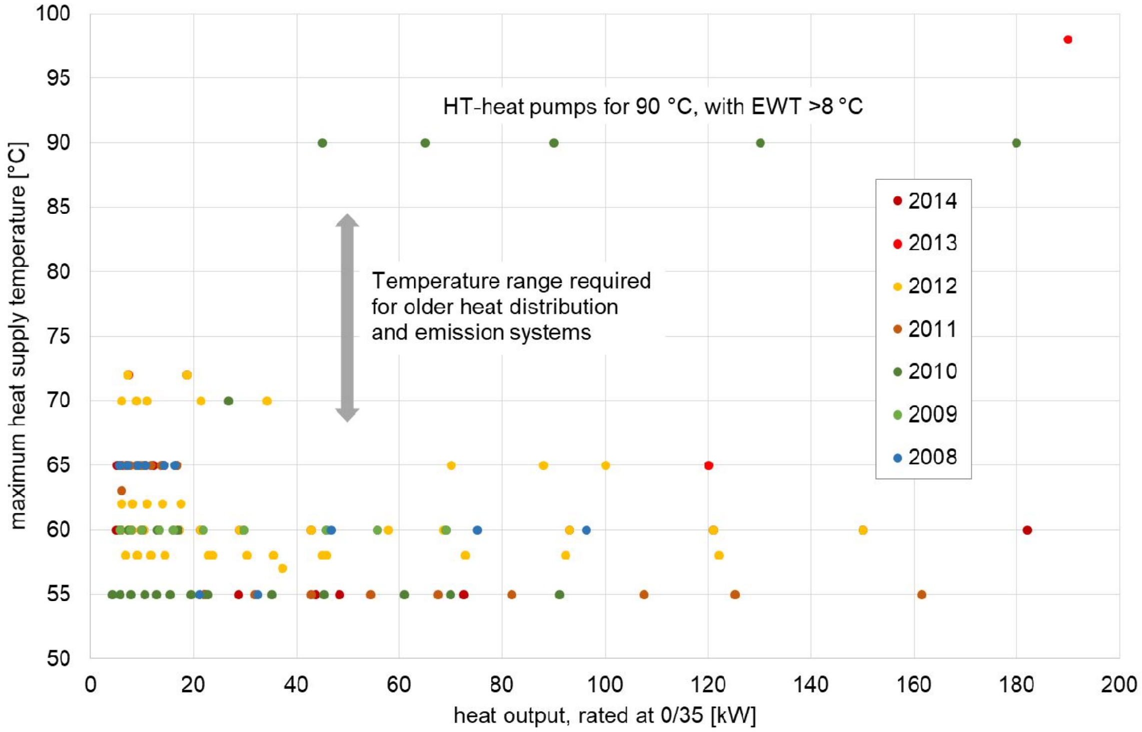

Figure 1.9 Availability of heat pumps in different capacity classes and related maximum supply temperature; EWT: Entering Water Temperature, i.e. heat source temperature for heat pump (after manufacturer´s data, from unpublished study by UBeG in 2017)

1.3.3 High thermal peak load and load balancing

Older buildings often have high thermal peak loads, which are difficult to meet directly with a geothermal system of economically feasible size. Also a high demand of thermal energy for DHW can be hard to meet for residential applications, not in office buildings as already mentioned. Buffer storages could help if spaces allow (cf. 1.3.1). As a matter of fact when increasing the storage, the peak power decreases. Sometimes this may be done by acting on the thermal inertia of the buildings as Thermo-Active Building Systems (TABS) do. However TABS are quite difficult to realize in existing buildings, due to high mass and structural problems. Work on TABS in connection with shallow geothermal was done in the European project GEOTABS (EraSME, 2011-2013, https://www.geotabs.eu/) and is debated since 2016 in the ongoing project GEOTABS^{hybrid} (H2020-723649, http://www.hybridgeotabs.eu/).

In Southern Europe, where cooling requirements are high, DHW is free during the summer period, therefore high DHW demand is an asset, not a market barrier. However, maximum heat loads during winter must be considered. In any case when cooling peak power is high this is even more difficult to handle with a GHEs field due to the fact that in heating the building thermal energy is partly covered by the compressor, while for dissipating the cooling energy in the ground the energy of the compressor has to be added to the building energy.

1.3.4 Constraints in electric power supply

Often the electric power supply to older buildings is just meeting the normal demand. Any further power consumer like an electrically driven heat pump could exceed the available capacity. Existing medium voltage electrical cabinets might not be sufficient for large plants. Solutions could be the (costly) upgrading of electric power supply, the use of thermally activated heat pumps (natural gas), or the reduction of the power demand of electric heat pumps. The latter might be achieved by additional power sources (PV, wind), by increased heat pump efficiency, or by load distribution over larger periods by using buffer storage either on the thermal side (cf. 1.3.3) or on the electrical side.

A further problem can arise in areas where power supply is not stable and voltage may fluctuate, triggering heat pump alarm and disrupting heat pump operation. Manual intervention may be required to return to operation (however, remote controls and access may help avoiding downtimes with minimum disturbances for the owners). Also additional electricity supply systems with renewable energy like PV, if equipped with storage managed by intelligent inverter and home automation for the control of loads, can avoid anomalous voltage flows and interruptions of heat pump operation.

1.3.5 Specific issues with some heat pump types

When using hybrid (dual-source-HP) solutions, it is necessary to check the acoustic impact of the air-source part; this is less an issue in Southern Europe, as the noise is at the same or even lower level than the widespread air-source cooling systems. There might also be possible problems related to fire protection with new, flammable heat pump refrigerants.

The main problem with dual-source hybrid heat pumps solutions is related to the maximum distance between the internal unit and the external coil. As a matter of fact, the external unit is part of the same circuit, and due to the maximum available pressures of the compressor, the maximum permissible distance between the internal water-to-water unit and the outdoor condenser/evaporator is limited.

2 Non-Technical Barriers

A number of non-technical barriers exist in addition to the technical ones.

2.1 Objections from stakeholders

The different stakeholders in a building project have different, partly contradicting interests, and in most cases are not familiar with SGE technology. Understanding their perceptions and communicating appropriately, addressing the concerns even if only imagined, is a key to overcome objections.

Generally, new technologies are associated with uncertainty. The key stakeholders will differ with regard to knowledge about the SGE technology. Thus, differences in perceptions partly might derive from asymmetry of information. In that case, providing information could lead to an approximation of views. If the parties involved have a different cultural, economic and social background it may be even more difficult to achieve an agreement on how the technological development and implementation should proceed.

It is important to ensure early involvement of SGE stakeholders right at the start of a project. Often SGE is considered later in the project and then conceptual design, drawings are already too much advanced and incorporating SGE becomes more difficult.

2.1.1 Owners

Owners here include real estate investors, housing associations etc. To avoid objections, it is important to communicate adequately and inform owners and final users of the convenience of SGE. It is them who decide which technology to adopt for their buildings, therefore they have to be convinced of its multiple advantages to request it to the builders. Building design engineers here play a key role with interfacing with the owner/client.

In cases where building owners are not residents and have the building for exploitation only, they tend not to install capital intensive heating/cooling systems but prefer instead the commonly used options of lower cost (fossil fuel boilers and/or split air conditioning units). Incentives or regulations (obligations) are required to make SGE economically interesting also in such circumstances.

The chief reason for most of the objections by owners is related to the cost of investment compared to the advantages of the new technology, in particular when considering only a short time period. In this respect, the opportunity to involve and interest ESCo's should be considered: they could be putting up the upfront capital, be a solution between the owner/resident issue and handle the complexity.

The correct dissemination of the information is important from the very beginning of the project. The presentation of the SGE technology will need to focus on long term advantages. Owners/clients want precise details about the product and its advantages and they want the commitment to hitting those dates. Meetings, conferences, presentations with different stakeholders can increase awareness and interest. The advantages of the new technology compared to the one used should always be pointed out.

2.1.2 Architects

Architects tend to be reluctant to SGE use from the point of view of the design, volume and dimensions of the new system which can impact on their creativity and limit creative choices. This reluctance can be attributed to a lack of understanding of design of systems, sizing and technical solutions that are available with SGE systems. A link to specialist designers and an increased awareness of the existence of specialist services could help in this field. On the positive side, the fact that SGE systems usually do not interfere with the building exterior can be an asset with architects.

A definite asset for architects is when GSE can help in building (energy) certification, like LEED, BREEAM, Minergie, Passivhaus, ZEB etc.). The implementation of the SGE on the market should be related also to the European (and national) strategy for mandatory targets for energy efficiency.

Architects should be made aware of the positive environmental impact that the new technology can bring in the long term, due to superior energy efficiency. Also aspects related to reduction of costs in long term exploitation should be pointed out during presentation meetings with architects.

2.1.3 Planners/installers of HVAC systems

In many countries there is a lack of experience in the execution of such projects and in using the SGE systems, exacerbated by low density of installations and of qualified contractors for installation. Only few countries already have existing certification schemes, where certificates mainly are required to make projects eligible to receive public grants (France, Switzerland), or as a prerequisite for BHE drilling permits (Germany). Previous projects like REGEOCITIES and Cheap-GSHPs have identified shortcomings on training and certification. A basic, European-wide training approach for the underground part exists in the form of GEOTRAINET (created through an IEE-project of the same name from 2008-2011, and now organised as an association) and in some related or independent national training activities; however, the scope of GEOTRAINET is limited, and training on the building side and specifics of SGE in refurbishment does hardly exist (yet).

2.1.4 General contractors for engineering and/or turn-key-construction

With general contractors for engineering and/or turn-key-construction, there is a basic, general reluctance to deviate from conventional systems. Many issues are encountered with the installation of ground heat exchangers in particular (less for building terminals), where a main/general contractor is inexperienced in GHSPs, and in particular with the installation of GHEs that do not fall under the remit of mechanical/electrical contract work where heat pumps are normally considered as part of the project. The facts that there is no direct contact of experienced specialists to the client, and that general contractors are responsible for interfacing with different aspects of the GHSP system installation, can constitute barriers too.

Adequate communication to the client is of great importance, in particular on SGE advantages over other solutions and heat pumps that can address the required demand, to keep the client properly informed about the advantages of SGE technology. Contractors and building companies often tend not to do what owners ask for, but make a case to the client as to what is easiest and most practicable to build and what they can sell more easily, resulting in GSHP getting left out. This even can lead to GSHP systems being deliberately designed out off a project in favour of other technologies.

The role of general contractors is quite different for the residential (SFH) sector versus the commercial/institutional sector. The sectors should thus be considered separately.

2.1.5 Administrators of apartment building blocks, facility managers

Administrators and facility managers need to understand the specifics of SGE systems. For them it can be a challenge to convert from a known, conventional system to a new, efficient installation they have no experience with. Hence main barriers here are lack of expertise, lack of deep know-how of heat pump technology, and inadequate risk perception, possibly leading to opposition of SGE planning by the people who are expected to run the final installation. This is a general issue in all types of larger buildings, but exacerbated in refurbishment because the respective people are already there, have experience with what is/was there, and need to trust in something unknown and learn its workings. The complexity of the controls and the large number of configurations possible in operation of larger systems is also a barrier for installers and the people responsible for the start-up; starting up and running a gas boiler is much more simple for them.

Efforts need to be made to properly inform this group of stakeholders, and it has to be identified what incentives might be there to convince them of the merits of a SGE system as part of their workplace.

2.1.6 Public authorities and policy makers

Generally there is a lack of understanding with public authorities and policy makers on how SGE can be an environmental game changer. Only in some countries (e.g. Greece) they are aware and supportive to SGE heating/cooling systems.

There are European or national grants four installing energy efficiency technology at the level of public authorities, in connection to the EU Directive on Energy Performance in Buildings. GSHP can support the path towards NZEB for public buildings as envisaged in the Directive. Presentation with responsible persons from public authorities should be organised.

2.1.7 Insurance companies

A correct evaluation of the real risk and impact of design deviations, suspensions of the system, etc. can be impossible due to lack of experience and know-how in the insurance companies. And insurance companies unable to assess the risks will not issue insurance policies that include and cover also the SGE system, as part of the correct functioning of the overall building system. This can lead to objections from stakeholders not able to get insurance coverage for SGE systems at reasonable premium.

2.1.8 Other stakeholders

Other important stakeholders are:

- Specialised lawyers in the field of energy law and various aspects of the energy sector, with experience and practice (typically concerning investments in the field of energy, exploitation of incentives, European funds for energy efficiency, etc.), are very important dissemination tools as they interfere directly with interested stakeholders.

- Certification bodies and Environmental Auditors (for all types of environmental certification), in particular in the field of industrial applications. Knowing SGE technology is a real value for Certification bodies and Environmental Auditors, allowing them to suggest SGE as improvement proposals for energy efficiency in HVAC systems. Lack of technical know-how might be substituted with these stakeholders by the high interest in energy efficiency improvement methods and in a high preparation and awareness of long time advantages of such products.

2.2 Regulatory issues

The regulatory framework for building and for SGE is complex and achieved through the implementation of different legislative and regulatory constraints for separate parts of the system. The ground heat exchanger and the building services aspects are commonly the responsibility of different (local/municipal/regional/national) authorities, making the integration of GHSP systems into existing buildings more difficult. Where these are considered in the context of old infrastructure and historical buildings, additional regulation on the preservation aspects and the restoration of these is also applicable. The technical constraints in designing (cf. 1.1) these types of systems is therefore further complicated.

In emerging markets for ground heat exchangers often no specific regulation at all is given. Although this seems to offer some freedom, in reality it can be a barrier because other regulation like for groundwater, mining, underground construction might apply. These regulations need to be known to the designer in order to avoid problems at a later stage, and the often are not easily applicable, being written for different purposes. Furthermore, a loosely regulated or unregulated environment does not give protection to the installation. In any case early contact to possibly relevant authorities is required in order to navigate the design and installation process through a legal environment with no specific regulations.

2.2.1 General licensing

The licensing conditions of GHSP systems are considered generally in the context of the below ground part of the system which includes the ground heat exchangers and the integration of the heat pump technology to the building. Licensing and regulation frameworks therefore generally deal with the ground heat exchangers and the above surface plants through separate legislation. The permitting process often covers several responsible authorities and results in the application of multiple permits with differing approval timeframes. The permits consider the energy performance of the system in buildings, the drilling and completion of the GHEs in the underground and the operational impact of the system.

2.2.2 Licensing of ground system

The licensing process in mature markets where GHSP technology is commonly used [6], typically requires separate permits to be obtained to complete ground heat exchangers works. These commonly include:

- GHE permits validating design and proposed operation
- Drilling and borehole completion (cf. 2.2.3)
- Planning Permission

The licensing process is rarely centralised, with applications and costs required from separate authorities. In less mature markets limited or simple registration process is implemented.

Permits for GHE are implemented in many European jurisdictions based the application of thresholds such as size and installed capacity of the system, heat extraction and injection temperatures (Italy), the depth of GHEs based on the presence of drinking water aquifers (Germany), the heat extraction rate of a system and the proximity to other nearby GHEs and underground users (Switzerland, Germany).

More restrictive conditions are applicable where GHEs penetrate aquifers resulting in limited deployment options for GSHP systems for planners and owners. In dense urban and historical city centre settings, the presence of multiple underground users, the proximity of other GSHP systems restricts the potential

This is even more the case where unusual circumstances prevail among existing buildings, or where bespoke solutions are required e.g. to overcome space restrictions (cf. 1.2.1). GHE designs requiring less space may not be possible e.g. in Greece due to regulation constraints in urban environment.

As part of GHE licensing and permitting process the operational impact of the system is required at the design stage and this increases the permitting costs where operational models of the system need to be approved by the relevant authorities reducing confidence for developers and system owners. Areas of restricted space where higher heating and cooling loads are applicable (historical buildings, high density residential accommodation and office buildings) are particularly vulnerable to this as restrictive regulation may be less favourable to large scale GHE fields.

There are limited cases in Europe where requirements for monitoring of closed loop GHEs are in place, which further increase the potential operational costs of large system.

2.2.3 Permitting of ancillary operations

Permitting might be required for the drilling operation. This will typically include consideration in the context of noise levels with respect to background condition in neighbourhoods and permits could limit the daily/weekly working time, and thus increase cost. In case drilling or material storage has to be done on passageways, sidewalks or streets, respective permits including possible traffic management solutions have to be obtained and implemented; this is much more likely for existing buildings than for new building.

Regulations concern also solid or liquid waste disposal (cf. 1.2.3), and permits can also be implemented in some cases and the associated costs of specific measures related to the completion of drilling operation are increased particularly in urban areas (cf. 2.4.2). Inappropriate work and missing permits can result in halting SGE installation by authorities; proper procedures must be followed for waste disposal, especially drilling liquid waste.

The requirement for planning permission for the installation of larger scale GHSP systems with multiple GHE fields has been highlighted as a requirement in some parts of Europe with the completion of an EIA as part of the planning process. This requires significant additional permitting time and cost.

Regulatory requirements based on the contributions expected from GSHP systems to the heating, cooling and domestic hot water demands in different building types vary across the EU Member States. A recent analysis demonstrates that the highest contributions set out in the regulations are a minimum of 50 % of the total heating and cooling demand (Belgium) with the lowest contribution of 20 %. However in most other parts of Europe the implementation of similar regulations is applied to heat pumps (in general) providing between 40 % to 70 % of sanitary hot water contributions only. The regulation often does not differentiate between air source and ground source and does not favour the use of ground source heat pumps.

2.2.4 Other regulatory issues

The implementation regulations dealing with heating and cooling plants and the application of international ISO and EN standards dealing with the design and installation of heating and cooling plant equipment, the certification of heat pumps and the use of HFC alternatives in the heat pumps technology, increase the permitting burden of GHSP system. This could be particularly the case where the use of dual cycle or high temperature heat pumps is considered in the refurbishment of historical buildings.

Spatial planning regulations embedded in local renewable energy strategies lack a clear objective for the inclusions of GSHPs at local level, where guidance on the potential for the underground use of GHEs and the integration of HPs does not exist. The use of the underground characteristics in terms of soil conditions, aquifers and potential restrictions usually is not considered in the context of the potential for deployment of GHEs.

Targets setting out clear contributions from GHSP systems to building regulations for new build and retrofit scenarios including in historical buildings is lacking. These are required to facilitate the uptake of GSHPs in the context of renewable energy targets set out in the Energy Package to 2030.

2.3 Economic issues

Economic viability for SGE is much less likely in existing buildings than in new buildings. Several factors contribute to this fact, as outlined below. An in-depth investigation and economic analysis is performed in task T1.4 and will be reported in the relevant deliverables of that task.

Determining the economic viability of new systems and technical buildings implements can be determined through the use of cost benefit approaches and analyses which encompass technical and economic KPIs related to the system, building characteristics and macroeconomic indicators. Generally, the most common methodologies applied for determining economic viability of renovations and retrofits are net present value/discounted cash flow analysis, return on investment and simple payback period. All of these use an important set of key economic principles and indicators that are crucial to evaluating the economic viability of SGE for any kind of building. The concepts in question are described as follows:

Performance decline and substitution of assets (OPEX): Within the formulas used for economic viability, technical performance and life span of the systems and implements have to be included through a decline in cash flows, or in this case energy savings over time as well as maintenance of the systems and their replacement (deconstruction costs included). These indicators tend to enter the operational expenses or OPEX category.

Opportunity cost and discount rates: Any resource has a real value equivalent to the return that could be obtained in the best alternative use of that resource. This is called the opportunity cost and it refers to the rate of return an investor could earn in the marketplace on an investment of comparable size and risk. Therefore, in terms of economic viability, discounted savings to the expected market rate of return for equivalent renovations must be calculated. This in itself should determine the economic viability of

SGE if a positive NPV (net present value) is obtained, taking into consideration the rest of the economic principles and concepts described here. In the particular case of shallow geothermal solutions, as pre-drill assessments of geothermal performance is subject to some uncertainty, the risk profile is higher compared to alternative sources of renewable energy.

Energy prices: Economic viability methodologies are all based on cash flow discounting or in this case energy savings brought about by the system. These energy savings are highly dependent on energy prices. The higher the price of energy, the higher will be the return on the investment in question.

Inflation rates: The rate at which prices increase over time, resulting in a fall in the purchasing value of money.

Energy performance of SGE: Determining the energy savings attributable to SGE in different building types will enable the calculation of savings or cash flows for the economic viability analysis. Of course, for new buildings the savings in question will simply be the amount of energy saved compared to other potential implements or systems in the market, whilst for existing buildings the amount of energy saved with SGE compared to current systems will be used.

Building characteristics: As mentioned at the beginning of this section with existing vs new buildings, different building typologies will lead to different results in energy savings.

Cost of installation (CAPEX): The initial capital outlay for implementing the system at time t_0 must be calculated. This includes the cost of the system itself as well as potential licenses, and other unforeseen costs.

The following NPV formula demonstrates how all these economic concepts and indicators are consolidated and exploited for determining the economic viability of SGE. Considering the discount rate used will reflect the potential returns of other solutions in the market, if the NPV is positive it means SGE is economically viable and a better solution to what is generally offered in the market.

$$NPV = \sum_{t=1}^{n} \frac{\Delta E_t}{(1+r)^t} - (I_0 + \sum_{j}^{N} \frac{C_m}{(1+r)^j} + \sum_{j}^{N} \frac{C_r}{(1+r)^j}) \qquad [1]$$

Benefit:

ΔE_t	Annual monetary energy gain (dependant on energy prices, energy performance of SGE and building typology)

Cost:

I_o	Investment cost (CAPEX)
C_m	annual maintenance cost (OPEX)
C_r	replacement cost (OPEX)

Of course, this formula is demonstrative at this phase and will most likely not be the chosen methodology for T1.4. Indeed, it is often difficult to distinguish the installation cost from the material/equipment cost. Therefore, those two categories will likely be aggregated. Moreover, because of lack of data on maintenance and operation costs, it is likely that the project focuses on the equipment/ installation cost as the principal cost for each solution or package.

Taking into consideration this demonstrative model for the evaluation of the economic viability of new building implements and systems, it is possible to foresee potential economic issues that may arise especially in terms of the viability of SGE in existing buildings compared to new buildings as suggested at the beginning of this section.

Indeed, existing buildings are more likely to bring about higher CAPEX and OPEX represented by I_0, C_m and C_r in the formula above, inevitably leading to lower NPVs, ROIs or simple payback periods. It will be necessary to see if the annual monetary energy gains for existing buildings will be sufficient to offset these expenses. Moreover, the ability to evaluate these expenses implies more uncertainties in existing buildings than new buildings, rendering the process for evaluating the economic viability of SGE more complicated.

With all of these potential issues in mind, the following sections will be dedicated towards making observations in terms of:

- Increased installation cost due to given constraints
- Increased operation cost
- Problems with cost-benefit analysis in retrofitting
- Other economic issues

2.3.1 Increased installation cost due to given constraints

SGE system are often not the first choice for heating and/or cooling in new buildings, and the situation is even worse in the building retrofit market due to more difficult drilling conditions and the need to change high temperature terminals.

The most critical areas are drilling and borehole heat exchanger connections, representing at least 50 % of the total system cost. Costs are function of the total metres to be installed, the soil conditions and the productivity level of the drilling system.

The use of the down-hole hammer (DTH) technology with compressed air, necessary to drill in hard rock, infers additional cost due to the purchase/rental and fuel consumption of the air compressor, as does the need for temporary casing in soft, unstable ground conditions. Furthermore, in both cases the additional equipment calls for sufficient space for placing and handling components. With the space restrictions in the built environment, drilling generally becomes more difficult and sometimes requires bespoke solutions that increase the costs.

2.3.2 Increased operation cost

Heat pump efficiency is reduced at higher supply temperatures, compared with systems for new buildings with lower supply temperatures in heating mode. Power consumption, and as a result the operating cost, thus can be higher for the existing building than for a new building of the same size.

Heat pumps can be optimised considering the base loads and the peak loads, especially in larger systems. In the built environments or in historical buildings, where the limited available space may restrict the extent of a GHE field, a combination with other heating/cooling equipment or a dual-source heat pump might be required to meet peak loads. This means that the heating/cooling appliances will be more expensive than a traditional single-source water-to-water HP.

Deeply retrofitted residential buildings (SFH) have a much lower heating or cooling demand, sometimes in the order of only 4-6 kW. The deep renovation requires on the one hand substantial upgrading of the building envelope, ventilation system etc., while on the other hand reduces both installation and operating cost for the heating/cooling equipment. Only thorough economic analysis can show in each case to what extend better insulation or more advanced energy technology will contribute to a cost-effective overall solution.

The typical electric power supply to older buildings is merely able to cover the normal household demand. Adding a heat pump as power consumer might exceed the available grid capacity, possibly requiring costly solutions for upgrading the supply lines. A further problem could arise where the power supply is not stable, causing disruption in the heat pump operation with respective loss of valuable data and increase of operational cost.

Even if the acoustic impact of a dual-source heat pump is considered less an issue in South Europe, there might nevertheless be a need for costly solutions for noise protection and avoiding problems related to fire protection with new flammable heat pump refrigerants.

2.3.3 Problems with cost-benefit analysis in retrofitting

For a new building, different options can be rather accurately compared in cost-benefit analysis. This is not the case in existing buildings with their numerous constraints and sometimes unknown properties. It will be necessary to set up bespoke methods for cost-benefit analysis in retrofitting a building with SGE.

Taking into consideration the model presented in section 2.3 it is possible to foresee potential economic issues that may arise especially in terms of the viability of SGE in existing buildings compared to new buildings. Undeniably, existing buildings are more likely to bring about higher CAPEX and OPEX inevitably leading to lower NPVs, ROIs or simple payback periods. It will be necessary to see if the annual monetary gains in energy cost for existing buildings will be sufficient to offset these expenses. Moreover, the ability to evaluate these expenses implies more uncertainties in existing buildings than new buildings, rendering the process for evaluating the economic viability of SGE more complicated.

The uncertainties related to the cost-benefits analysis in the case of retrofitted building depends on several aspects which affect the installation cost of the SGE system, including the time needed to install it (which is usually longer than for a new building). The most important of these aspects are problems with the available manoeuvre space for installation, which could be reduced by pre-existing equipment or building items. Unforeseen problems could be found during the installation of the underground part and GHE, due to in-terrain impediments. Adapting the SGE system to the current or new heating system could also incur some technical and practical delays or problems which would increase the final installation costs. Other possible aspect could be that the retrofitted building blueprints might jeopardize the SGE system installation, by not including it into the first design or heating/cooling system dimensioning. Also, problems adapting the technical rooms to host the new technology systems could be encountered, requiring some additional work which, consequently, would increase cost or even generate some serious problem for keeping the project going.

Even in cases where the economic benefits using a SGE systems have been demonstrated already (efficiency, lower operating costs in fuel and maintenance, a longer lifetime expectancy, etc.), the risks faced in a SGE installation project in a renovated building are still high due to the high level of uncertainties described before, which could increase the cost dramatically.

Further work on this issue will be done in task T1.4.

2.3.4 Other economic issues

The spreading of the SGE systems usage is nowadays limited by the current costs of natural gas; since it is extremely low, achieving short pay-back time (PBT) of the GSHP solution becomes more difficult. This situation could change in the future, as was already experienced with market fluctuation in fuel cost, due to politic and economic crisis, where consumers did (and might do again) face dramatic fuel cost peaks over long time periods. Fuel cost increase might also result from government strategies on climate change and urban quality air improvement, where actions on shifting taxes on electricity to taxes on fossil fuels or amending environmental taxes are discussed and proposed.

Talking about electrical power, even if not all the energy markets allow enough flexibility to purchase green electricity, its use could have a positive influence upon moving the buildings from natural gas to electric driven GSHP, and then managing and use Energy Certificates. In this sense also historical buildings could have the chance to move toward the target of Near Zero Energy Building (NZEB).

2.4 Environmental issues

SGE generally is a very environmentally friendly technology, contributing to cutting noxious emissions and CO_2-emissions. However, when installing technology in ground and groundwater, there is always a certain risk. For SGE this consists e.g. in pollution (leakage), changing flow patterns, long-term temperature changes, etc. Advantages and problems with SGE for existing buildings are evaluated in the following paragraphs.

2.4.1 Influence of energy efficiency

System efficiency of heat pumps can be reduced under the constraints in existing buildings (cf. 1.3.2). A lower efficiency and resulting higher power consumption means on the one hand higher overall CO_2-emissions compared to a new building, where the system efficiency is higher. On the other hand, compared to fossil fuel alternatives, even this lower efficiency might look favourable.

The electrical energy consumption of air source heat pumps (a competitor of SGE due to lower cost) is about 50 % higher than with GSHP, and using air source HP for cooling contributes to heat islands problems.

2.4.2 Environmental issues related to drilling and installation of GHE

The main environmental impacts considered as part of the drilling and installation of GHEs can be considered as follows:

- GHE/ BHE design in urban complex ground conditions.
- The local hydrogeological conditions and the protection of aquifers.
- Possible presence of contaminated land in urban environments and settings and its impact on borehole design and drilling operations.
- The noise related impacts of the drilling plant equipment compared to the neighbourhood baseline conditions.
- The impact of drilling vibration on nearby buildings, infrastructure and historical buildings.

- Traffic and transportation related impacts of the drilling plant and ancillary equipment on the local roads infrastructure.
- The presence of cultural heritage and archaeological artefacts in the city historical urban centres.

Whilst the construction related impacts are often perceived to be minor for most of the aspects described above as a result of the short timeframe and temporary nature of the works, the impacts require careful planning and the implementation of adequate mitigating measures.

The impacts of the construction operations on the ground and hydrogeological conditions require careful planning with the necessity for adequate borehole design, the selection of adequate drilling methodologies and drilling fluids that favour minimising the impact relating to subsidence in nearby ground and prevent either the penetration of important aquifers or the cross contamination of these.

The disposal of waste generated from the drilling in the form of solid cuttings and liquid waste needs to be carefully segregated and disposed of appropriately. Where disposal of drilling fluid to public sewer is considered, specific permission may be required. Fine particulate removal and treatment of the liquid before discharge is critical. In urban settings waste disposal is typically achieved through on-site storage that minimises any discharge to the ground and neighbouring properties. These measures typically require higher drilling and disposal costs that are not foreseen where piling or vibration-based drilling methods are used.

Other operational aspects including the need for noise restrictions during site operating hours, the use of sound barriers in areas where sensitive receptors are present, the levels of vibrations generated by the drilling operations, etc. need careful consideration. In dense urban settings historical buildings in close vicinity can be significantly impacted by air or water based drilling methods.

Site access and local road infrastructure has a considerable bearing on the potential deployment of drilling plant equipment. In historical urban centres, the use of small portable drilling rigs with minimal ancillary plant compared to other more conventional methods is more favourable.

2.4.3 Environmental issues related to working media

Several heat transfer fluids are circulated in GHEs, in some cases the use of pure water is favoured, however glycol (mono & ethylene) typically are used to prevent freezing. Glycol based compounds are listed in the REACH and other EU Directives as having a certain level of toxicity and as a consequence can have adverse environmental impact on groundwater aquifers and ecosystems. The risk of leakage from GHE and BHE thus must be minimised by using adequate mitigating measures. These are typically focussed on the requirements for using grouting materials to backfill the annular space of boreholes and installed ground heat exchangers when conventional drilling methods are used.

This use of piling-based drilling methods (e.g. with stainless steel coaxial heat exchangers) push the GHE in place without creating any openings, and thus in impermeable underground avoid the interconnection of subsurface layers.

2.4.4 Environmental issues due to normal operation

Also normal operation can have some impact, mainly related to heat exchanger operations and ground temperature changes. The operational impacts of GSHP systems is generally considered in the context of the following aspects:

- The impact of the GSHP system in terms of CO_2 saving compared to fossil fuel based technologies.
- Impact of SGE design and operation on existing aquifers where the GHEs are installed.
- Proximity of neighbouring heat exchangers and related temperature development.

The impacts on air quality for the operational phase of a GSHP system are generally considered as positive ones. Adequately designed GHSP system result in a considerable saving of CO_2 emissions over the lifetime of a heating and cooling plant compared to fossil fuel technologies and other renewables, even when the entire lifecycle of the system and its components is taken into account.

The heat exchange in the ground in the subsurface and aquifers where the GHEs are installed typically results in an increase in ground temperature when the system is operated in cooling mode and a decrease in heating mode. Where balanced loads can be achieved throughout the system operational profile, the net impacts to ground temperatures can be minimised. However regulatory restrictions on these fluctuations often dictate the energy extraction and injection rates that can be achieved by a GHE field.

In dense urban settings where potential users are in close proximity, the operational temperatures of a GHE system and its potential impact on nearby operating systems or other ground users (water supplies, underground infrastructure) is critical and can limit the peak load requirements that can be delivered by a GHE field in a confined space.

2.4.5 Other environmental issues

The visual effects during the construction and operation phase, prone to generate adverse effects on the character of the landscape, are among the main environmental impacts that should be taken into account.

Even though the temporary nature of the works precludes any long term impact from the visual standpoint, impacts on landscape as a result of the drilling operation could occur if receptors that have direct views to the construction site exist, but the effects could be greatly reduced if small size equipment is preferred on site (i.e. avoid high mast drilling machines).

Regardless of the particular environmental context and sensitivity of the landscape undergoing some change, the operational phase is considered to have little or no impact. In the case of GHEs the installations are mainly below ground, or in a mechanical room when the heat pump installation is considered. Only minimal impacts in the finished building are perceived in respect to heating and cooling terminals such as fan coils.

3 Particular constraints for SGE in historical buildings

This section is focused on the identification of the main typologies of barriers making the application of GEO4CIVHIC technologies in cultural heritage buildings difficult.

A general definition of “cultural heritage building” or “historic building” is required here: As to prEN 16883:2016, it is a building of heritage significance (in EN 15898:2011 described as “single manifestation of tangible cultural heritage”). A historic building does not necessarily have to be statutorily designated as cultural heritage. Further info is given in Appendix A.

In general, the integration of geothermal technologies in any type of building strongly depends on the characteristics of the building itself and its specific requirements on thermal energy, as well as on the characteristics of the ground and its thermal properties. In addition, in the case of historical buildings, it is very important to preserve the architectural aspect of the building, but also the archaeological aspect of the whole “site” where the building is located, including gardens and squares close to the building. Therefore, the installation of GEO4CIVHIC technologies in historical buildings has to be based on detailed studies to decide about the suitability of the project on a case by case basis.

Besides ideological barriers related to the suspiciousness towards the applicability of such systems in the field of Cultural Heritage, technical barriers will be described hereunder.

3.1 Barriers to SGE in non-listed buildings

Barriers in all historic buildings are e.g. linked to volumes and construction characteristics, not always suitable for the technical interventions required.

The integration of shallow geothermal systems in historical buildings is strongly influenced by the availability of free surface (e.g. gardens, cloisters, etc.) where those underground systems could be installed. In principle, these technologies could be more feasible when installed during important refurbishments of the building due to the needs of drilling and installing infrastructures in the underground. In fact, a refurbishment of sufficient magnitude would permit the access of the necessary drilling machinery and the use of available outdoor space (if any) to perform the installation of boreholes.

On the other side, inside an historical building dimensions of the heat pump could be a problem. In fact, it needs a room big enough to install the ground source heat pump, which is not always suitable, as deeply explained in section 1.1.4.

3.2 Barriers to SGE in listed buildings

In listed buildings, there can be additional barriers linked to the total respect of the aesthetical aspects (outside, and often also inside), and special permissions from the authorities might be required before any intervention. In most listed buildings it is impossible to intervene in the external façade, and sometimes even impossible to install radiant thermal panels or floor heating inside.

In any case, the special characteristics of the cultural heritage may make necessary to proceed with special care during the assembling and installation phases, in order to preserve the architectural and aesthetical value of the building itself, by avoiding the presence of external units or appliances.

The integration of GEO4CIVHIC geothermal systems for heating and cooling purposes does not affect the aesthetical aspects of the historical building because:

i) most of the infrastructure is buried;

ii) the existing terminal units for the thermal energy distribution associated to the innovative heat pump developed in the project do not need to be changed, avoiding an operation that is costly and often not feasible in historical buildings for conservation constraints.

The use of water source heat pumps is particularly useful in Cultural Heritage field as it can be easily combined with the terminals normally used in historical buildings, i.e., hydro-air fan coils and conventional radiators. In fact, even if the temperature drop is small, this pump provides water for heating at high temperatures (60/70 °C) as required by the kind of terminals often installed in heritage buildings, without being penalized in performance efficiency. Nevertheless, in case of huge refurbishment, it is necessary to select and place the terminal units in compliance with the conservation requirements of the historical building, related to its use and to the materials that are preserved.

In conclusion, the aesthetic impact of GEO4CIVHIC technologies on the building fabric (excluding the intervention outdoors) is very small, depending strongly on the availability of a room of suitable dimensions that can be used as technical room.

3.3 Underground situation and remains

In historic areas, underground conditions need specific attention. This means that a verification of the presence of historic remains needs to be performed using special scientific techniques before any action. If remains are evidenced, if possible, the recovery of artefacts etc. may have to precede any mechanical digging and drilling.

3.4 Possible conflicts with local regulations

Europe has the world’s greatest concentration of Cultural Heritage, including 440 cultural sites inscribed in the UNESCO World Heritage List, encompassing monumental buildings, districts of towns and cities and even whole EU member states ‘capitals’. The specific needs and standards related to cultural heritage protection pose many constraints and requirements for the application of mainstream sustainable energy solutions.

Despite the above major calls for applying renewable including geothermal, there are no specific national and EU standards to comprehensively implement renewable energy sources in built heritage. Heritage buildings are often completely excluded by new regulations on energy performance of buildings because it is believed that their cultural value should not be compromised or threatened [7].

A detailed analysis of the existing EU standards, building code and national legislation in force in GEO4CIVHIC partner countries indicates that no specific EU standards are applicable to Cultural Heritage properties dealing with geothermal power solutions. The applicability of geothermal technological solutions in the Cultural Heritage field depends on the different national normative frameworks related to the conservation of historical buildings. Hence, the conservation constraints and requirements have to be evaluated in each individual case, making it difficult to achieve an overall legal landscape in Europe related to the improvement of the energy efficiency in historical buildings, facilitating energy supply from renewable sources.

Indeed, as from the statements received by representatives of Cultural Heritage protection authorities of EU Member States, such as Italy, the National Renewable Energy Action Plan (NREAP) contains recommendations to consider the application of sustainable energy solutions also for historical buildings[5]. The regulations in force at the national level provide only the procedure to identify the need for energy improvements and the appropriate solutions that match the requirements for the historical building conservation. The contribution of built heritage to climate change mitigation policy by improving efficiency and installation of renewable including geothermal is, however, left to discretion of the heritage conservation authorities, which have to evaluate on a case by case basis the compatibility between heritage conservation and the application of sustainable energy solutions.

The heritage significance of a single cultural building or even a district is a rather fundamental element to reckon when energy management and production are at stake. The mainstreaming of retrofitting measures as well as the installation of renewable energy sources must be considered according to the differentiated impact they may exert on the heritage significance. The latter is also susceptible of a wide array of evaluation from a conservation perspective with a variable degree of impact according to the components and their significance, which might or might not be altered by the planned systems and their installations. Therefore, a heritage impact assessment should be undertaken to determine the acceptability of such measures in a balancing process between installations of some measures and impact on the integrity of the significance [8]. This is also dependent upon the categorization of the built heritage at stake, and to the magnitude of heritage significance pertained to its different components and locations according to the national or even international designations and enlistments (i.e., UNESCO World Heritage properties[6]). It is therefore upon the conservational authorities to

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[5] Posing the question of conservation of cultural heritage and sustainable energy in Europe has a major relevance since as notable known, approximately 25-30% of public buildings are protected and are considered cultural heritage while the building stock built before 1919 amounts to 14.3% of the total buildings, corresponding to about 65 million of European citizens. If we also include buildings built between 1919 and 1945, the percentage rises to 26.4% and the occupants reach the number of about 120 millions. Taking such figures into account, it has been calculated that a heating-demand in historic buildings and old towns has be estimated of 855 TWh corresponding to 240 Mt CO_2.

[6] UNESCO world heritage sites are defined as such because of their exceptional characteristics defined of “Outstanding Universal Value” and as such worthy of special regime of management and protection against threats. To ensure, as far as possible, the proper identification, protection, conservation and presentation of the world's heritage, the Member States of UNESCO adopted the *World Heritage Convention* in 1972. The World Heritage Committee, the main body in charge of the implementation of the Convention, has developed precise criteria for the inscription of properties on the World Heritage List. These are all included in a document entitled "Operational Guidelines for the Implementation of the World Heritage Convention". World Heritage properties have proved they have an important role to play in sustainability, in terms of education, management, and scientific knowledge to be regionally shared and possibly applied. Successful experience in the World Heritage properties can generate innovative solutions for other historic sites and cities and best practices may be possibly replicated both at the regional and at the global scale. In this context we can draw insights from the UNESCO-lead RENFORUS initiative (Renewable Energy Futures for UNESCO Sites), documenting with empirical evidence that properties inscribed in the World Heritage List and Biosphere Reserves are a testing ground for the prioritisation of energy efficiency retro-fit measures and renewable energy infrastructure, including examples of geothermal based

undertake a heritage significance assessment and decide in their full discretion to approve or reject specific measures.

However, these regulations are mandatory for the buildings statutorily designated as Cultural Heritage, whilst in historical building the normative are considered as recommendations.

The document EN 16883: *"Conservation of cultural heritage - Guidelines for improving the energy performance of historic buildings"* [9] is currently the only guideline at European level applicable on the subject of historical buildings. This standard, however, refers to the energy improvement of historical buildings without a specific reference to ground source heat pumps, describing and providing a systematic procedure for identifying and selecting appropriate measures to improve the energy performance of the buildings that match the requirements for the historical building conservation. It does not define general measures, but it points out the necessity to study each case individually and to collaborate with experts and technicians involved in buildings conservation. The final decision of the energy improvement in the historic building is made by the qualified authorities.

According to standard EN16883 all measures have to respect the heritage significance of the building evaluated at international, national and regional level. Accordingly, the requested refurbishment process should be carried out using a multidisciplinary approach. In one hand, the designers manage the process by identifying the solutions considered to be the most appropriate in each case**.** On the other hand, the relevant authorities responsible for heritage must verify the compliance with the constraints existing on the historical building(s), outlined in international charters and national guidelines. These constraints refer to the appropriate indoor environment useful for the conservation of the internal building fabric, the fixtures, the decorative surfaces of the interiors and the work of arts stored in it, as well as for the structural interventions. Following the EN 16883, the latter should respect the building's existing spatial configurations, appearance and exterior building fabric, then any measures that could cause damage to the structural elements should be avoided. This European standard underlines that the interventions should be additive, non-invasive and reversible, in order to minimize its impact on heritage significance and integrity. Furthermore, following this standard both the extent and depth of interventions should be minimised.

This balancing effort between heritage significance and conservation and the installation of sustainable energy infrastructure, may find a fair point of balance within the use of geothermal energy solution. Several studies (e.g. [10]) have notably indicated that ground source heat pumps are often among the best solutions to match the requirements of sustainable energy with the integrity and authenticity of the Cultural Heritage and its buildings, both in their interior and exterior features [11, 12]. The architectural impact is minimal with the most part of the system located underground without on-site combustion and any effect on the integrity of the building which make it suitable also to meet conservation stances. GHPs installation are, therefore, among the most elective solutions to implement sustainable energy policies into practices in cultural buildings and districts. Moreover, the conversion from traditional HVAC systems to a GHP system has been recorded significant and multiple achievements on the preservation of the integrity and the historical value of building, valuable economic benefits along with CO_2 emission reduction. This sounds particularly true when applied to monumental buildings, such as museums with high energy demand and, in several circumstances, with

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solutions with reference to the integrated energy system of Ferrara (Benchikh, O., Marin, C. Good Practices: Success Stories on Sustainable and Renewable energies in UNESCO Sites, UNESCO, 2013).

special requirements in the performance of heating and cooling systems, dictated by the very nature of the artefacts displayed.

3.5 Other barriers for SGE in historical buildings

Other aspects and constraints, related to items in chapters 1 and 2 and valid also for historical buildings, might have a higher significance in the context of historical buildings.

4 Conclusions

Any deep refurbishment of an existing building faces constraints given by the properties of the given building structure, site and space limitations, and in particular economic feasibility. This results in the wish to do refurbishment with well-known standard technologies, in order to avoid any further uncertainties and the need for bespoke – and thus costly – solutions. This approach can result in missing out on the opportunities offered by new and energy efficient technologies for providing heat, cold and DHW, like shallow geothermal energy (SGE).

In order to explore ways to overcome this attitude and to unleash the great potential SGE has for saving energy and avoiding emissions, this report presents the collection and analysis of barriers against SGE use in building refurbishment. The barriers are grouped into two main types, technical and non-technical barriers, with an extra section considering the specific problems posed by historic buildings.

Technical barriers are deemed to be overcome more easily, with development work ongoing since many years and new solutions found constantly. The ingenuity of the engineers and scientists in the wide-ranging disciplines required for SGE application can be trusted to deliver the necessary solutions – provided they can be demonstrated to be economically feasible. Section 1 of this report lists the many barriers and classifies them according to their place in the design and installation process, and to the technical nature of the constraints, be it limited available space or existing heat distribution systems not suited well for lower supply temperatures. Possible pathways how to overcome stated barriers are already hinted at in most cases, directing development work in GEO4CIVHIC towards relevant issues and possible solutions.

Dealing with the non-technical barriers is less straightforward and needs to address a large number of different aspects, ranging from the perception individual persons might have of SGE to questions of economic viability and environmental impacts. Changing negative perception of a SGE-based energy refurbishment in terms of feasibility, reliability and affordability can be a difficult task. Section 2.1 investigates all relevant stakeholders and looks at their possible objections, in order to allow for the creation of targeted information and communication strategies highlighting the possible advantages and debunking the perceived obstacles. Shortcomings in regulation and economic barriers are dealt with in Sections 2.2 and 2.3, respectively. Somewhat in a hybrid category is section 2.4, where environmental issues are addressed; these have both a technical and non-technical side, as technology can be employed to mitigate environmental influence.

Section 3 elucidates the specific barriers encountered with historic buildings. Many issues are similar to those in newer buildings, however, often exacerbated by the nature of the buildings considered, by the surroundings they usually are found in, and often also by specific regulations securing their historic integrity.

This report is destined not to be just a catalogue of barriers, but to provide guidance throughout the further development work in project GEO4CIVHIC. It can also provide the benchmark against which the progress achieved at the end of the project can be measured.

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[7] Draft (in German only) of new version published May 2015

Appendix A: Protection of historical buildings

Historical buildings often need protection and support, as their maintenance, modernisation etc. is more expensive, and usability and comfort might be limited. For buildings deemed as testimony of our culture, limitations to the rights of the owners can be stipulated, usually associated with some (financial) support to meet the requirements imposed. Most countries aligned their protection with the system of the “Hague Convention for the Protection of Cultural Property in the Event of Armed Conflict” of 1954, in force since 1956. The definition in Art. 1(a) of the convention reads:

> *For the purposes of the present Convention, the term "cultural property" shall cover, irrespective of origin or ownership:*
>
> *(a) movable or immovable property of great importance to the cultural heritage of every people, such as monuments of architecture, art or history, whether religious or secular; archaeological sites; groups of buildings which, as a whole, are of historical or artistic interest; works of art; manuscripts, books and other objects of artistic, historical or archaeological interest; as well as scientific collections and important collections of books or archives or of reproductions of the property defined above;*

In Art. 23, UNESCO is assigned to technically assist the convention.

An overview of the protection is given below for some countries:

In **Austria**, the regulation of listing and protecting historic buildings is handled on the federal level. There are about 16’000 listed buildings (out of some 60’000 objects basically deemed worth of protection), however, the protection is relatively weak.

In **Germany**, the regulation of listing and protecting historic buildings is handled on the level of the 16 states (Bundesländer). There are two main approaches among these states:

- system of declaration: All objects meeting the criteria stipulated in the respective law are automatically protected, no matter if they appear on lists or not. Listing only serves as supporting measure and does not constitute the legal protection.
- system of constitution: Only objects listed officially by the authorities, following criteria laid down in the respective law, are protected. Lists have to be updated continuously

In **Greece** Law N.3028/2002 (Government Gazette 153/A/28.06.2002) protects antiquities and cultural heritage establishing new criteria for recovery interventions in cultural heritage buildings. Furthermore, according to Law 4122/2013 and Ministerial Decision Δ6/B/5825 (407/2010) the minimum energy performance requirements are not applicable to the category of historic buildings. The historic / preserved buildings are recorded by the Ministry of Culture and Tourism as well as by the Ministry of Environment and Energy. For activities in registered buildings a permit is required from the Ministry of Culture and Tourism, from the Ministry of Environment and Energy as well as from the Architectural Committee.

In **Ireland** protected structures are considered as having special architectural, historical, archaeological, artistic, cultural, scientific, social or technical interest as defined in Section 57 of the Planning and Development Act, 2000. The Act places the legal responsibility on the owners or occupiers of protected structures to make sure that the structure does not become endangered through neglect, decay, damage or harm.

This is implemented by individual County Councils as the planning authority for any building listed in the Record of Protected Structures (RPS) that lists the relevant structures on a County by County basis. The structures are defined through County based surveys of buildings and gardens in the National Inventory of Architectural Heritage.

The protected structure status extends to the interior of the structure; to the land in its curtilage; and to any other structures on that land and their interiors. Curtilage means the land and outbuildings immediately surrounding a structure which is (or was) used for the purposes of the structure. This obligation also applies to all fixtures and features forming part of the interior and exterior of the protected structure or any structure on the grounds attached to it.

Planning permission is needed for work carried out on a protected structure that would materially affect its character. This means that many types of work, which in another building would be considered exempted development, may not be exempted where the building is a protected structure. Depending on the nature of the structure and the features of interest even work such as painting the interior or replacing windows could affect its character and require planning permission. The majority of energy efficiency improvement measures (both inside and outside the building) are affected by this.

The Department of Culture, Heritage and the Gaeltacht has a number of guideline publications including:

- energy efficiency in traditional buildings
- statutory guidelines for planning authorities and building owners
- conservation guidelines for architects, builders and owners

The owner occupier of a building can apply to the planning authority for a declaration under Section 57 of the Planning and Development Act 2000 about the structure and its curtilage (or grounds attached). This declaration states what types of work can be carried out without affecting the character of the structure. A declaration cannot exempt any works which would otherwise require planning permission. A planning authority will issue this declaration within 12 weeks of receiving a request.

In **Italy**, historic buildings could fall into the categories:

- non-listed building with complete demolition permission
- non-listed building without complete demolition permission
- classified building in historical town centre (not listed)
- listed building in historical town centre

In **Romania**, the entire normative approach is based on the concept of "Historic Monument", not "Historic Building". The "Historic Monument" approach is larger as can be seen below. At the national level there is the Historic Monuments List (LMI [8]) that was completed in 2010, after which it was updated in 2015. According to current regulation (the Order of the Minister of Culture 2260 / 2008 on the Methodology for ranking and inventory of historic monuments) the LMI has to be updated every 5 years. The Historic monuments are ranked or downgraded at the request of owners, institutions and organizations active in the field of patrimony by order of the Minister, published in the Official Gazette. The list of historical monuments is organized by

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[8] Lista Monumentelor Istorice

counties (see Annex B). The current list is an annex to the Order of the Minister of Culture 2828 / 2015 regarding the approval of the LMI, and has an official and legal character: http://www.cultura.ro/lista-monumentelor-istorice

In **Switzerland**, the regulation of listing and protecting historic buildings is handled on the level of the 26 cantons. Buildings can be declared "worthy of protection", and the important ones are listed in cantonal inventories.

Appendix B: Example of Regulations in Romania

Historic Monuments List (Lista Monumentelor Istorice, LMI)

In Romania, from a structural point of view, monuments are grouped into four categories, depending on their nature:

I. Monuments of archaeology
II. Architectural monuments
III. Public monuments
IV. Memorial and funeral monuments

From the value point of view, the LMI includes the following categories:

Group A - historical monuments of national or universal value

Group B - historical monuments representative of the local cultural heritage

The LMI Code includes:

XX - The County Acronym - 2 capital letters (in Romania there are 41 counties plus Bucharest Municipality). Bucharest Municipality has a "county" acronym the capital letter "B", meaning only one capital letter.

I - IV - a Roman numeral grouping monuments according to their nature (I-IV from above)

x - a minuscule letter
    m - for the monument
    a - for the historical ensemble
    s - for the archaeological site

X - a capital letter describing the monument from the point of view value (A / B from above)

99999 - a unique countrywide order number

The above components of LMI Code are separated by hyphens. For example, the Romanian Atheneum building has the LMI Code B-II-m-A-18789.

For the project GEO4CIVHIC the interest is only for all the ARCHITECTURAL MONUMENTS / BUILDINGS, meaning that included in the LMI Code:

"II" as the second component of the LMI code and

"m" as the third component of the LMI Code.

Unfortunately, in Romania the only accessible "data base" is a .pdf list in which buildings, funeral monuments, archaeological sites etc. are mixed together (with specific codes, indeed). All the items included in LMI are ranked and considered "protected" monuments. The whole list of applicable legislation is here:
http://cimec.ro/Legislatie/Legislatie-culturala.html#Monumenteistorice

Regulations of Interventions on historical monuments

Interventions on historical monuments shall be carried out only on the basis and in compliance with the approval issued by the Ministry of Culture and by the County Directorate for Culture, Cults and National Cultural Patrimony.

The interventions that are carried out on historical monuments are:

(a) all research, conservation, construction, extension, consolidation, restructuring, landscaping and rendering, which modify the substance or appearance of historical monuments;

b) execution of moldings on components of historical monuments;

c) permanent or temporary placement of fences, protective constructions, fixed furniture pieces, advertising panels, companies, logos or any sign on and in historical monuments;

d) changes in the function or destination of historical monuments, including temporary changes;

e) relocation of historical monuments;

f) arrangement of access roads, pedestrian and roadways, annex facilities, signs, including in the historical monument protection areas.

The building permit, the dismantling permit and the authorizations related to the interventions on historical monuments shall be issued only on the basis and in accordance with the opinion of the Ministry of Culture and the County Directorate for Culture, Cults and National Cultural Patrimony, according to the legal provisions in force.

Authorizations issued without the consent of the institutions empowered by law and without complying with their conditions are null and void.

Application file for the restoration / preservation of a historical monument

The application file for the restoration / preservation of the historical monument must have a certain form, as detailed below. Apart from the provisions of the Joint Order of the Ministry of Public Finance and of the Ministry of Transport, Constructions and Tourism 1013 / 2001, regarding the approval of the structure, the content and the use of the standard documentation for the elaboration and presentation of the tender for the public procurement of services, or other legal regulations in force, the content of the documentation regarding the restoration of the historical monuments is the following:

Chapter I. - DESIGN PHASES

1. The design phases of historical monument restoration documentation, capital repairs / consolidation are set out in Section III of the Joint Order of the Ministry of Public Finance and of the Ministry of Transport, Construction and Tourism 1013 / 2004.

These are as follows:

a) Pre-feasibility study including the Design theme, with or without preliminary technical report / expertise;

b) Feasibility study covering the design theme, with or without Technical Expertise;

c) The Technical Project and Task Book for the execution of the works;

d) Execution Details.

Preliminary Technical Report / Technical Expertise may be part of the Pre-feasibility Study or Feasibility Study, or may be set up in distinct phases of development.

Chapter II - THE CONTENT OF THE DOCUMENTATION

1. Forwarding letter:

   The letter / address for submission of the documentation, signed by the owner / holder, with any title of the historic monument building or its developer, provided that it is delegated by the owner / holder of the historic monument and can prove the delegation.

2. - Launching Sheet:

   a) - the name of the monument and the LMI code, according to the last update of Historical Monuments List; address

   b) - name of the owner / beneficiary / owner of the real estate, with any title, irrespective of the legal status of the monument;

   c) - name of the project;

   d) - project / contract number / year;

   e) - the design phase.

3. Elaboration team:

   a) the name of the general designer, the chief project manager, the designers (name, the quality / responsibility / profession / position they had in the elaboration team);

   b) the specialists / experts certified by the Ministry of Culture, designers, consultants or verifiers of the documentation, with their signatures and original stamp.

4. Documents included in the documentation:

   a) the urbanism certificate;

   b) a copy of documents evidencing the ownership of the monument;

   c) cadastral documentation;

   d) copies of the approvals of the Ministry of Culture previously issued for the same historical monument;

   e) other necessary documents, if appropriate.

5. Frame Content of each Design Phase:

   a) The general framework content for each design phase is provided in Section III of the Joint Order of the Ministry of Public Finance and of the Ministry of Transport, Construction and Tourism, 1013 / 2001.

6. Frame Content of Technical Expertise:

   a) The frame of the technical expertise is set by the Government Decision 1364 / 2001 on the reduction of seismic risk of existing constructions;

   b) Technical expertise for historical monuments, depending on the complexity of the damage, will be preceded by specialized studies and / or researches carried out on the basis of "technical documentation for preliminary research for the elaboration of technical expertise" previously approved.

   c) In the field of consolidation of historical monuments, the Technical Expert Development team consists of:

- Technical expert in engineering, certified by the Ministry of Construction and by the Ministry of Culture;
- Expert in the field of architectural restoration for monuments classified as "A" or expert / monument patron of "B" monuments, certified by the Ministry of Culture and Religious Affairs (see LMI Code);
- Expert in the restoration of artistic components, for monuments classified in the "A" group and / or expert / specialist for monuments classified in group "B", certified by the Ministry of Culture;

d) The conclusions of the Technical Expertise that develop a unitary concept of intervention on the historical monument, the maximum and minimum variants of intervention and the priorities of the works.

Chapter III. - CLARIFICATIONS TO FRAME CONTENT

In addition to the general framework content for the historical monument restoration projects, certain components must include specific details as follows:

1. Written parts:

a) The design theme, approved by the beneficiary, which will contain general data on the historical monument, its technical condition and its preservation, for the components: archeology, architecture, structure, artistic components, land characteristics and proposals for studies, investigations, investigations and design phases;

b) The justification / general memo: it will contain references to the design theme, detailing multi-disciplinary, all the historical, artistic, architectural, engineering, scientific and technical aspects of the historical monument; previous interventions according to documentary and archival research or the book of the historical monument / building book, the present conservation status, the unitary concept and the intervention proposals, in maximum and minimum variants, as well as the setting of the execution priorities, depending on the project stage ;

c) Specialized technical memos;

d) Considering that in the field of historical monuments protection the documentation is elaborated by multidisciplinary teams, the projects / documentation will include:

- Specialized reports with the signatures and stamps of the technical experts certified by the Ministry of Culture and / or the Ministry of Construction depending on the project field and the design phase;
- The specialized reports, the signature and the stamp of the project verifiers certified by the Ministry of Culture and / or the Ministry of Construction depending on the project field and the design phase;
- Specialized reports of specialists or experts certified by the Ministry of Culture in fields related to the subject area of the project, such as archaeology, architecture, engineering or artistic components, as appropriate.

2. Drawings:

- 1: 25,000 or 1: 5000 scale plan for the area, as appropriate;
- site plans at 1: 200, 1: 500, or 1:1,000 as appropriate;

- specific drawings depending on the scope of the project, marking all types of degradation or damage, as the case may be;
- plans, sections, facades on a convenient scale, specific to the field / phase of the project design, marking the proposals, intervention according to the proposed unitary restauration concept.

3. Other items, depending on the project field:

a) Historical, architectural / comparative / iconographic / archaeological studies, historical urban and / or other, as appropriate;

b) photographic documentary, explanatory / commented;

c) field studies: topographical, geotechnical and / or other, as appropriate;

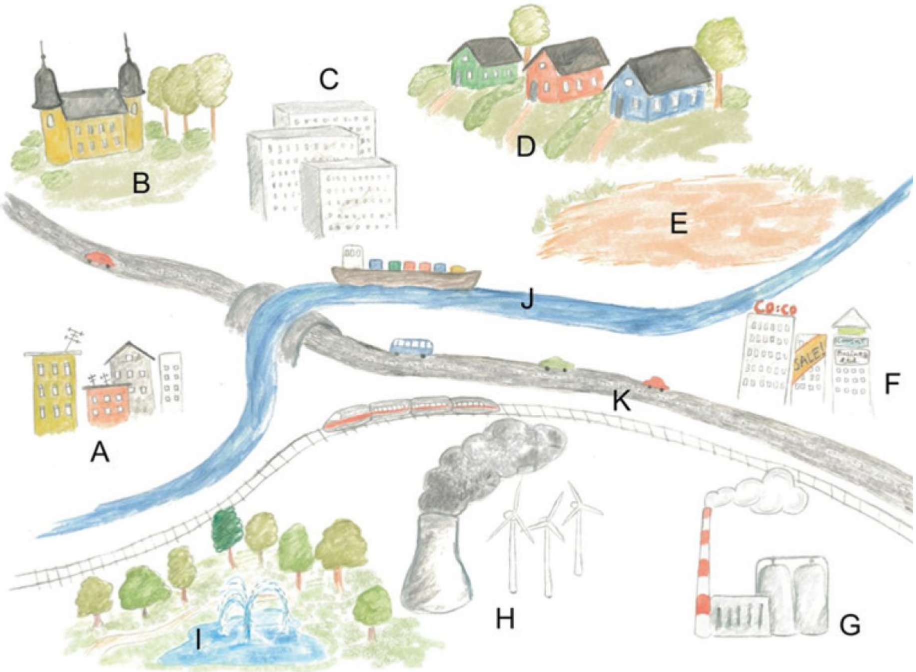
d) Physical, chemical, biological, petrographic or other investigations, as appropriate.

(Compiled and translated by Doina Cucueteanu, 19th June 2018)

Appendix C: ReGeoCities land area classification

A reference to city zones from ReGeoCities land area classification is suggested. For GEO4CIVHIC, the zones A-D and F might be relevant.

Below the original graph and list from the ReGeoCities final report:



	Zone	Explanation
A	Older settlements	Older areas of the city, but without special attention to preservation. Different sizes and ages of buildings.
B	Areas with special attention to preservation.	For example cultural areas, environmentally protected areas, water protection areas etc.
C	Dense urban settlements	Suburbs, multifamily houses, public services, hotels
D	Sparse urban settlements	Single family houses with gardens and two floor terraced housing
E	Urban development areas	Areas with potential for new buildings
F	Commercial operation areas	Office complexes, commercial buildings
G	Industrial area	Terminal areas with logistic zones and manufacturing industries (Handling of goods, containers and so on), industrial settlements
H	Areas for the technical sustainment of the city	Energy production, sewage plants etc.
I	Park areas	
J	Water areas with waterways	
K	Main roads and railroad tracks	