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Deliverable D4.1

Preliminary analysis and generation of possible different modular solutions description for civil and historical buildings

WP4

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Contents

Summary

The document D4.1, *"Preliminary analysis and generation of possible different modular solutions description for civil and historical buildings"* is a public document delivered in the context of WP4, Task 4.1: *"Preliminary analysis and generation blocks of different modular solutions to overcome the specific barriers and their associations for civil and historical buildings".*

This report contains the main conclusions of deliverables D1.1, D1.2 and D1.3 with which different scenarios are composed. These scenarios combine different thermal profiles of buildings according to their climate, drilling conditions according to the location and access conditions and the possibility of combination with other renewable energies (Chapter 1).

When confronting the scenarios with the identified barriers, the most appropriate solutions are chosen, creating a portfolio for a first analysis of the identified solutions. A visual diagram detailing the relationships between solutions, scenarios and barriers is included (Chapter 2).

Finally, from the analysis of Chapter 2, a catalogue of the most common blocks of solutions aimed at specific building renovation scenarios is developed to serve as input for the further GEO4CIVHIC DSS tool.

List of Figures and Tables

Abbreviations

AG	Historical Building
ASHP	Air Source Heat Pump
BF	BHE field
BHE	Borehole Heat Exchanger
BT	Building type
BTES	Borehole Thermal Energy Storage
CL	Climate
DHW	Domestic Hot Water
DSS	Decision Support System
DTH	Downhole Hammer (drilling)
EGDI	European Geological Data Infrastructure
GEO4CIVHIC	Most Easy, Efficient and Low Cost Geothermal Systems for Retrofitting Civil and Historical Buildings
GHE	Ground Heat Exchanger (general term, includes BHE)
GPR	Ground-Penetrating Radar (Geo-radar)
GSHP	Ground Source Heat Pump
HRV	Heat recovery ventilation
HVAC	Heating, Ventilation and Air Conditioning
PV	Photovoltaic electric power generation system
RES	Renewable Energy System
SGE	Shallow Geothermal Energy
TP	Thermal Profile
TS	Type of soil

Introduction

The project H2020 GEO4CIVHIC (Most Easy, Efficient and Low-Cost Geothermal Systems for Retrofitting Civil and Historical Buildings) seeks to overcome barriers and increase the market for geothermal heat pumps in the renovation of buildings in urban environments.

From the Deliverables D1.1 "Report on different kind of barriers for shallow geothermal in deep renovation", D1.2 "Drillability mapping and state of the art of the drilling methodologies" and D1.3 "Modelling energy demand and plant typology study for different levels of renovation in different types of buildings, climates and grounds" a series of critical conditions associated with the retrofitting actions of a building applying geothermal systems can be drawn.

The Task T4.1 consists in the conception of a catalogue of modular solutions, from a scenario configured with the information of the building according to its location, type of building, thermal load, drillability, access conditions, etc., and using the new technologies developed in the project. The proposed solution will overcome the identified barriers, using 100% renewable systems in which geothermal energy has a main role or is part of the system with other renewable energies. The most appropriate solution will be selected according to all the conditions analysed. These solution blocks will be used as a repository for the DSS (Decision Support System) developed in the project.

Therefore, the result of Task T4.1 will be a catalogue of the most common blocks of solutions oriented to a specific building rehabilitation scenario.

1 Description of the different scenarios

1.1 Classification of scenarios

1.1.1 Classification of scenarios according to different types of drilliability

"Drillability" is defined as the prediction of the most suitable drilling methods and related borehole heat exchanger types for a given underground, with the estimated installation time and cost in function of the rig and drilling technique types and the local geological constrains.

The drillability maps are produced both at European scale and at local municipal scale, with different purposes. The first aims at providing a first overview of the cheapest drilling technique applicable all-around Europe. It is addressed to interact with the applications for support of shallow geothermal workers to be developed in Task 4.4. The second kind of map, instead, further improve and complete the techno-economic maps already developed within the previous EU funded project Cheap-GSHPs, representing the feasibility of several kind of heat exchangers and the potential savings in terms of costs and efficiency. In this case, the drillability maps want to suggest a preferable drilling technique at local scale and provide a first evaluation of the drilling time and costs.

The drilling technology suitable on a given site is mainly determined on the local stratigraphy (kind of materials/rocks and their state of consolidation) and on the local hydrogeological conditions, that affect also the drilling times and costs.

For the installation of a BHE, the classic drilling techniques as applied for water wells, prospecting, geotechnical investigations etc. can be used. The basic distinction among the classical drilling methods is made into percussing, rotating, and combined percussion-rotation methods. The drilling techniques considered are the following:

- Rotary drilling tricone or chevron bit
- Traditional DTH with casing
- Traditional DTH without casing
- Easy drill piling without casing
- Easy drill with casing

The mapping method will be further implemented and verified during the next working period, in order to finally verify the maps by comparison with the measured drilling times and drilling costs and techniques applied in the real demonstration cases. This further work will be finalized and presented in the deliverable D 1.6 – *"Integration of the drilling developments in the implemented drillability mapping*", to be released at the 36th month.

The European drillability maps

The geological map of Europe (scale 1:5M) provided by the EuroGeoSurveys' European Geological Data Infrastructure (EGDI) with its simplified lithological definition (204 lithologies identified for all Europe) forms the basis for GEO4CIVHIC thematic maps. The EGDI Metadata Catalogue consists of a dataset realized in a standardized format in agreement with the INSPIRE Implementing Rules on interoperability of spatial data sets and services (IRs) and Technical Guidelines (Data Specifications). To this existing lithological catalogue, information related to the different drilling techniques previously described were added.

The association among drillability techniques and geological sequence was made considering the knowledge of the partners expert in drilling operations (FAU, GEOSERV, GEOGREEN, UBeG, HYDRA, in addition to UNIPD DG). Therefore, a datasheet file containing the list of all the lithologies considered in the EGDI map was shared between all of them. For each geological condition, each partner was asked to indicate the drilling technique that can be applied according to their experience, the expected drilling time and foreseen approximate cost. In addition, they were asked to specify in each case the casing requirement, in order also to consider this element in the evaluation of the time/costs. Even if hydrogeology could affect greatly the drillability of the underground, this parameter is not considered in the map at European scale, due to its high spatial variability and the lack of updated information and mapped data.

The answer of the partners about drilling methodology, time of drilling and cost of drilling for each lithology are not always in agreement and sometimes even greatly differ one from the other, due to the different personal experience of the partner and the extreme variety of geological conditions in Europe, from north to south and from east to west.

Therefore, at first, with regards to the inputs received from the 6 partners, the drilling methodology more suitable for a certain lithology was selected. Then, the following criteria were adopted:

- When 2 or more partners selected the same drilling method for a given lithology, more weight was assigned to this method.
- When there was no clear preference, the information provided by the most experienced drilling partners (Hydra, UbeG, GeoGreen, GeoServ,) was weighed more, trying to prefer the technique most representative at European and not at local level.
- Easy drill piling without casing technology, developed during the Cheap-GSHPs Project, was selected as preferred method when unconsolidated sediments are present, due to its lower costs and high speed, even if it is still not so widespread around Europe due to its novelty.

Once defined the drilling methodology for each lithology, the time and cost have been selected. In this case, a conservative approach was followed:

- When 2 or more partners shown the same drillability time and costs, expressed as minute per linear meter or euro per linear meter respectively, associated to the same drilling method, more weight was assigned to these time and costs.
- When different value and costs were described, the higher times and the higher costs were selected.
- Usually time and costs are expressed as range of values, to take into consideration the cost fluctuations in different countries related to the local market and local geology.

Finally, a map for each parameter (drilling method, drillability time, drillability cost) was produced (Figure 1.1 and Figure 1.2).

Concerning the cartographical representation, for the drillability time, the following classes have been recognized:

1. ≤ 7 min/m
2. 7 < x < 10 min/m
3. ≥ 10 min/m

Also, the drillability costs can be grouped in three main classes as follow:

1. ≤ 30 €/m

2. 30 < x < 40 €/m
3. ≥ 40 €/m

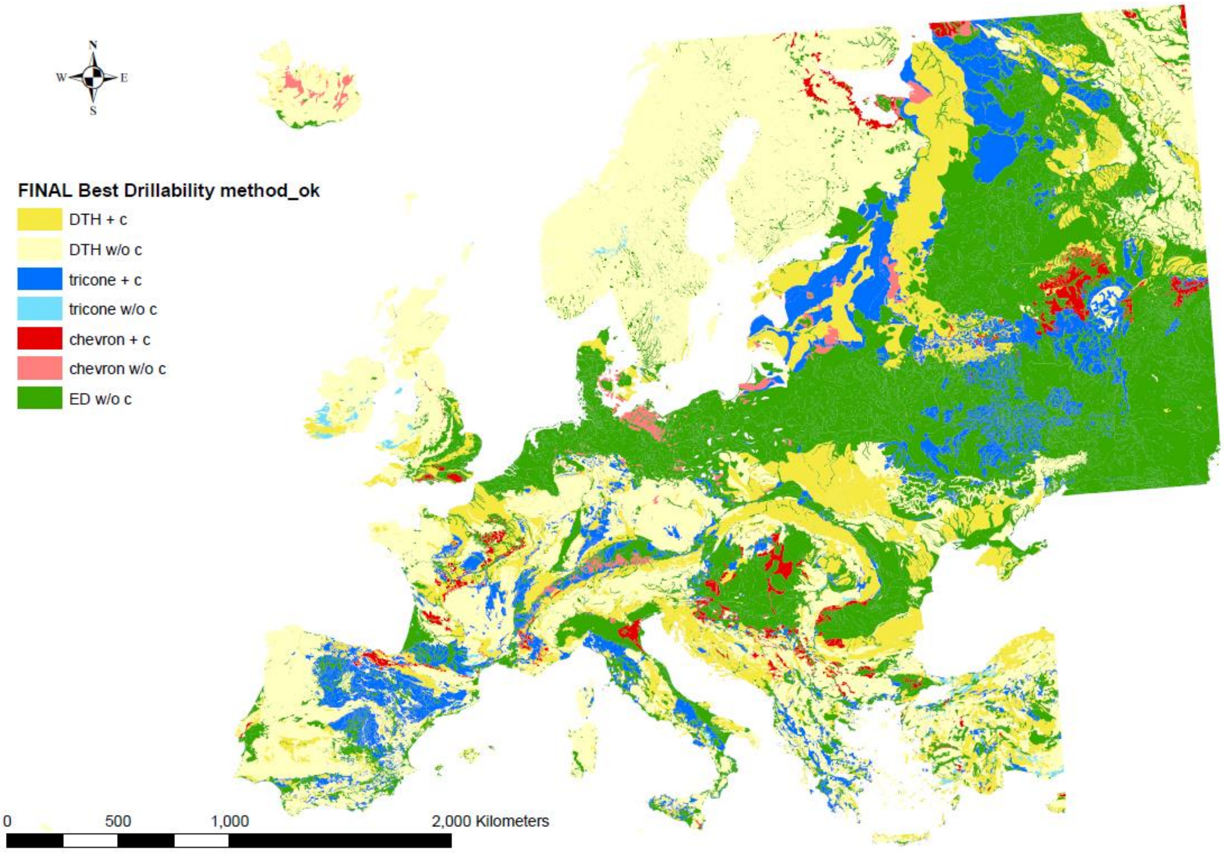

Figure 1.1 European map of drillability method

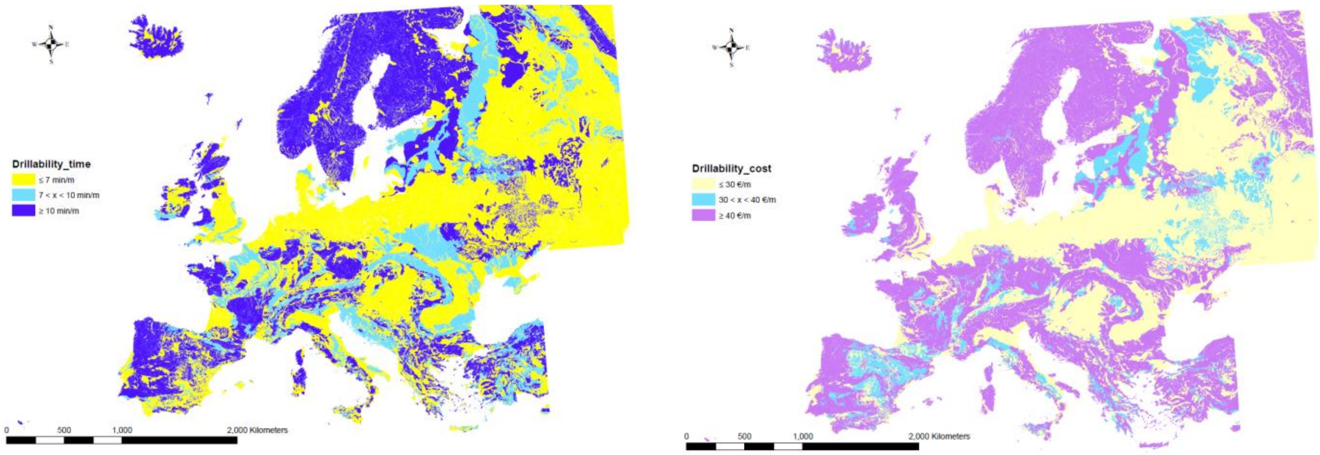

Figure 1.2 European map of drillability in terms of time (left) and cost (right)

Drillability maps at municipal scale

The thematic maps at municipal scale have to be very detailed (<= scale 1:25.000). The municipal scale maps are based on 3D data, in order to consider the whole elements affecting the local drillability, by considering also the hydrogeological conditions.

In addition, other thematic maps related to the local thermal conductivity and the undisturbed ground temperature can be produced, because these are key parameters to correctly sizing and designing new borehole fields. At local scale, these kinds of data can be defined by collecting

local stratigraphies (with high density - minimum 1 well/km^2), groundwater saturation levels, meteo data and TRT tests.
The local maps of GEO4CIVHIC project will be focused on the locations selected as demonstration sites:

- ✓ Dublin
- ✓ Malta
- ✓ Ferrara
- ✓ Mechelen

To date, the most part of the data have been collected for each demo sites, as shown in the following table (Table 1).

Demonstration site	Geological map	Stratigraphic sequence (to 100m)	Thermal conductivity	Hydrogeology information
Dublin	Map and shape of bedrock and of the superficial deposits	Some stratigraphies are available (superficial layers + bedrock depth) → already created the bedrock surface	Derived from stratigraphy (by considering also the water table depth)	*Bedrock considered impervious, *water table depth derived from water level measurements (1998-2006)
Malta	Map and shape	No		No
Ferrara	Only map			Only map
Mechelen	Only map		Thermal conductivity map already available (on 100m)	Water table: shape of areas with homogeneous water table + piezometric data measured in a well next to Putte

(blanks cells where information is not yet available)

Table 1 – Summary of the data collected till today in the demonstration case

In Dublin (Ireland) the quaternary alluvial cover (first 20m) consists mainly of black clay, sand, gravel size and cobble sized clasts of limestone (Figure 1.3, top left). The solid bedrock instead is characterised mainly by granite in the South and by dark limestone and shale of the Carboniferous aged Lucan Formation in the North. Due to the shallow bedrock and the presence of groundwater, the weighted thermal conductivity for the area of Dublin has been evaluated approximately equals to 2.6 W/mK.

The geology of Malta is quite homogeneous, mainly consisting of limestones. In La Valletta (Malta) test site, the available geological map shows a homogeneous geological setting formed by globigerina limestones (Figure 1.3, top right). The hydrogeological conditions suggest dry condition of the subsoil.

In Ferrara (Italy), the underground consists of a continuous succession of alluvial deposits mainly formed by fine sands, silts and clays, deposited alternatively by the Po river and Reno river (Figure 1.4, bottom left). The hydrogeological data show the existence of a multilayer aquifers system, where the water table of the associated unconfined or locally semi-unconfined aquifers can be found at 1 m depth from the ground surface.

In Mechelen (Figure 1.4, bottom right) the area is interested by the presence of fine-grained sediments such as silts, clays and sandy clays, creating a succession of aquifers and aquitards in the underground. With regards to the geological and hydrogeological characterization, the average thermal conductivity in the municipality of Mechelen until a depth of 100 m is expected to be in the range of 1.8-2.0 W/mK.

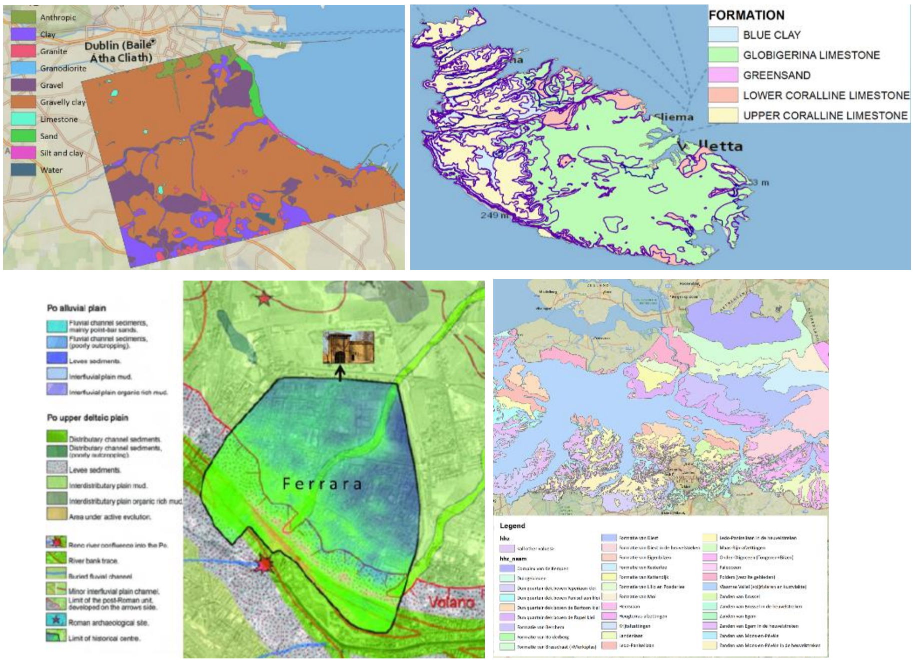

Figure 1.3 Geological maps of GEO4CIVHIC case studies: Dublin (top left), La Valletta (top right), Ferrara (bottom left), Mechelen (bottom right)

Conclusion

The drillability, defined as *the prediction of the most suitable drilling methods and related borehole heat exchanger types for a given underground with the estimated installation time and cost in function of the rig and drilling technique types and the local geological constrains,* has been conceptually defined and indicated for a wide group of different geological settings and lithologies. A first drillability map has been produced at European scale, and the main data and information needed for the drillability maps at local scale have been collected.

Both mapping methods will be further implemented and verified during the next working period (M36): the maps at European scale could be integrated considering the full potential of the new drilling methodology developed during GEO4CIVHIC, while those at municipal scale have to be validated by comparison with the real data collected in the demonstration cases.

To summarize, the following variables of type of soil have been defined:

- Sands
- Clays
- Gravels
- Limestones
- Sandstones
- Shales
- Marbles
- Conglomerates
- Gneiss, michashist
- Plutonic rocks

1.1.2 Classification of scenarios according to different types of building load profiles and climates

The Energy Performance of Building Directive (EPBD) states that buildings represent 40% of the final energy consumption in Europe [1-3]. In particular, 70% are residential buildings and 30% are commercial buildings. The most part is located in the urban city centre and needs to be renovated at different refurbishment level. However, the space availability for installing a borehole field for a GSHP installation represents one of the most important issues.

The definition of archetypes within the urban environments is usually given depending on a deep analysis of building characteristics which are grouped based on similarities, with the objective to represent in a proper way the most common typologies of buildings in the urban areas.

In the GEO4CIVHIC project, building archetypes have been defined as models representative of the European building stock that allow the evaluation of the energy demand in order to develop innovative strategies and technologies to increase the energy efficiency, therefore to reduce the energy consumption. The energy demand of existing buildings around Europe ranges from 150 kWh/(m^2 year) to 300 kWh/(m^2 year) based on recent studies [4].

Considering that, the aim of GEO4CIVHIC project is to increase the installation and application of GSHPs in the retrofit action within historical city centres, the analysis focused on climatic zone, period of construction and building typology in order to divide the building stock into different categories. More parameters have been collected to calculate the reference building energy profiles, such as geometry, envelope, heating and cooling systems, end-use and so on.

A first subdivision must be done between historic and non-historic buildings. Usually it is a well-established rule that buildings which have been built before 1960a are considered as “historical”, whereas construction between 1960 and 1990 are defined as “existing”.

Since no free databases regarding non-residential buildings are available in literature, a structure similar to apartment block has been considered, varying internal loads and time schedule according to the final end use (offices, rather than companies, etc.).

Analysing the European urban environment, the most representative types of buildings are linear buildings, subdividing them in two main types of archetype:

- Terraced House (TH), which contain more land-to-sky buildings with one or two floors (Figure 1.4a).
- Apartment Blocks (AB) represented by typical construction of the popular neighbourhood (Figure 1.4b)

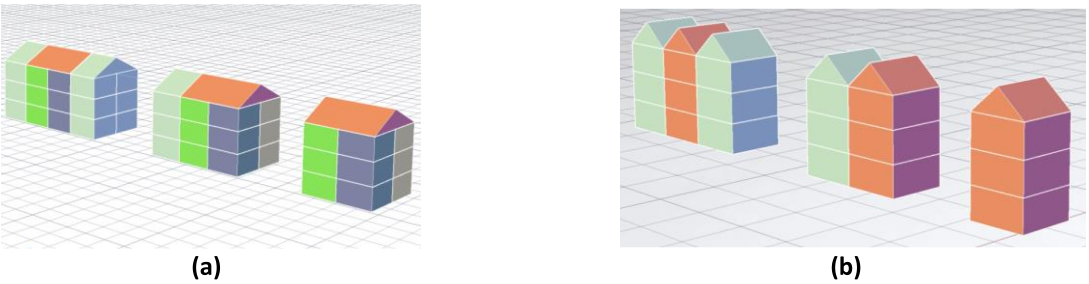
(a) (b)

Figure 1.4 Example of possible solutions for apartment blocks (a) and terraced house (b)

Single Family houses and Multi-Family houses have been excluded from the present work, because the object of the project is the installation of GSHPs in the urban city centre, where usually these typologies of building are not present.

Standard shape and orientation have been defined to obtain a generalized profile based on the building typologies; for example, the apartment block has been defined as a 5-floor building and a sum of single housing unit with common stairwells according to TABULA database [5].

Standard height for the ceiling in existing buildings has been set equal to 2.5 m, while in historical buildings an average height of about 3.15 m has been considered (25% higher than the height of existing buildings). According to literature data, the glazed/net floor surface ratio has been found to be typically in the range 12-24%, hence 19% has been considered as average value in existing buildings. In historical buildings an increased glazed surface has been considered according to the corresponding ceiling height, i.e. 22% as ratio between the glazed area and the net floor area.

Since archetypes must be grouped based on the climate to define the proper boundary conditions affecting energy in buildings, the Köppen-Geiger scale and the Degree-Days (DD) have been used as parameters [6] to group the archetypes of the 20 countries. This strategy is based on the previous analysis done for the project Cheap-GSHPs [7] where the climatic conditions have been defined based on the Köppen-Geiger scale and the Degree-Days (DD) defined for the heating season (DDH) and the cooling season (DDC).

Therefore, the European climatic conditions have been summarised into 3 main groups, identified by a reference city:

- Athens as representative of the warm climate, DDH = 995 and DDC = 1046;
- Strasbourg for a mild climate, DDH = 2746 and DDC = 115;
- Helsinki as a cold climate, DDH = 4597 and DDC = 23.

where DDH and DDC have been calculated according to [7].


(a) Athens (b) Strasbourg (c) Helsinki

Figure 1.5 Building typologies characteristics of the historical city centers

Using the energy profiles obtained by the dynamic building simulations, shallow geothermal systems have been sized considering three values of thermal conductivity and volume thermal capacity which correspond to the mostly common types of ground (defined in Task 1.2).

	Type 1	Type 2	Type 3
Thermal conductivity [W/m K)]	1.5	2.2	3
Thermal capacity [MJ/m^{3}K]	2	2.5	2.6

Table 2 – Thermal properties of the three considered types of ground.

The analysis of the common layout of urban environments was needed in order to verify limitations for installing GSHP systems in the urban area. In fact, the standard space occupied by the installation of borehole fields have to be limited according to the available space (Task 1.1), which depends both on already existing free space as gardens, parking lots, etc., and on the refurbishment level, considering that the deeper will be the retrofit, the lower the energy need, therefore the probes length and the space needed. Based on the layout of the city, different hypotheses of space availability have been decided, thus leading to different options either with GSHPs or hybrid solutions.

The building energy demand and the overall results obtained from the sizing of the probes will be used to develop a database of almost 108 cases, furtherly implemented considering three different heating and cooling terminal units to use the correct COP for the heat pumps: high temperature (radiators), medium temperature (fan coils) and low temperature (radiant systems). Moreover, the energy supplied either by the ground source heat pump or by the air to water heat pump has been calculated, in order to optimize the length of the probes that have to be installed.

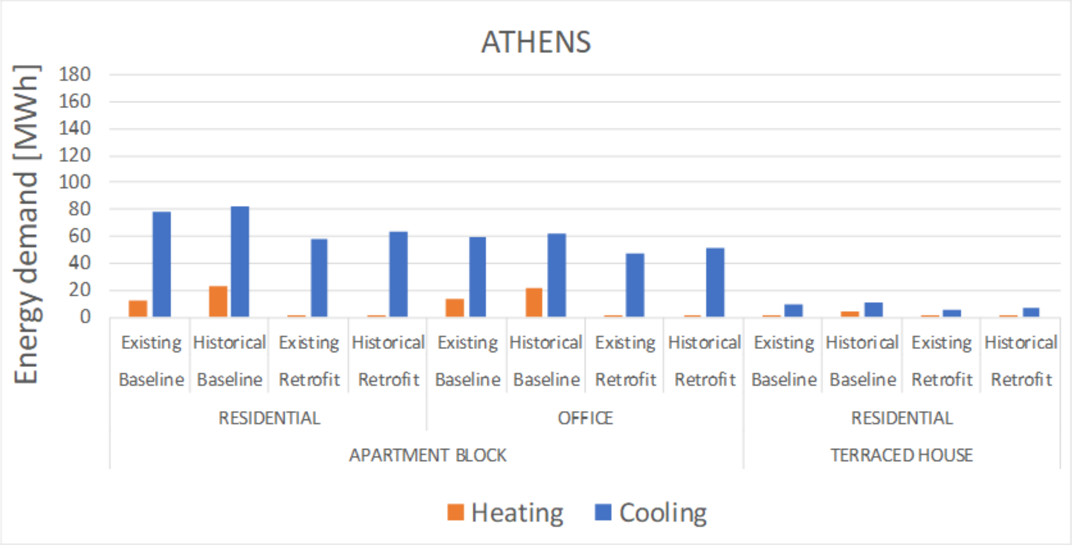

Figure 1.6 Energy demand for heating and cooling for Athens

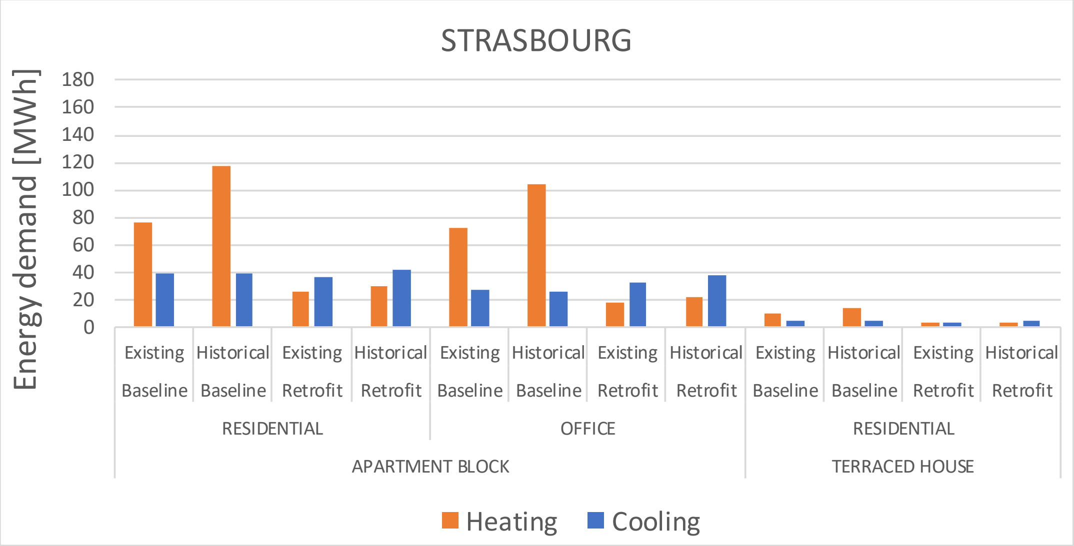

Figure 1.7 Energy demand for heating and cooling for Strasbourg

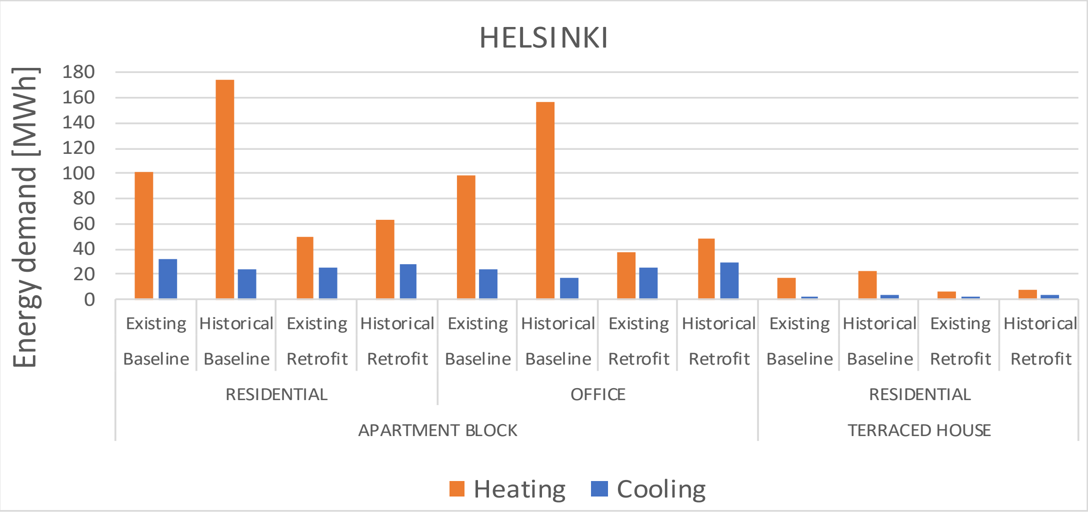

Figure 1.8 Energy demand for heating and cooling for Helsinki.

To summarize, the following variables have been defined:

- Building type (BT):
  - Terraced house
  - Apartment block
- Historical (AG) (Y/N, if not, the building is existing type).
- Existing HVAC system (HVAC)
- Climate (CL):
  - Cold
  - Mild
  - Warm
- Thermal Profile (TP)
- BHE field (BF):
  - Available space
  - Accessibility problems (Y/N)
  - Underground infrastructure (Y/N)
  - Urban location (Y/N)

1.2 Combination with other types of RES

A Ground Source Heat Exchanger (GSHE) system absorbs heat from the ground in winter (evaporation in the heat pump) and releases heat to the ground in summer (condensation in the heat pump).

It is possible to combine GSHPs with other renewable technology solutions such as:

- Photovoltaic system (PV)
- Thermal Solar system
- Hybrid PV & solar thermal collector
- Wind Turbine

They can also be combined with a water tank to reduce the consumption of the heat pump.

The heat pump system can integrate a part based on heat exchange with the surrounding ambient air, constituting a so-called Dual Source appliance.

Photovoltaic system
Photovoltaic systems can be integrated with a geothermal system to provide electric energy to the heat pump and auxiliary systems.

Thermal Solar system

Solar energy collectors are a special kind of heat exchangers that transform solar radiation energy to internal energy of the transport medium. The major component of any solar system is the solar collector. This is a device that absorbs the incoming solar radiation, converts it into heat, and transfers this heat to a fluid (usually air, water, or oil) flowing through the collector. The solar energy collected is carried from the circulating fluid either directly to the hot water or space conditioning equipment, or to a thermal energy storage tank from which can be drawn for use at night and/or cloudy days. The thermal solar system, therefore, can help the geothermal system with heating water (DHW) production.

Photovoltaic Thermal system

Photovoltaic systems (PV) can be integrated with solar thermal collectors and GHEs. Photovoltaic thermal collectors (PVT) are solar panels that allow producing electrical and thermal energy at the same time, through the direct conversion of solar radiation. They are considered as an attractive technology since they can produce both electricity and heat at an acceptable cost. Moreover, removing the excess heat leads to an enhanced average annual energy efficiency [8]. Figure 1.9 below shows the concept behind the PVT technology.

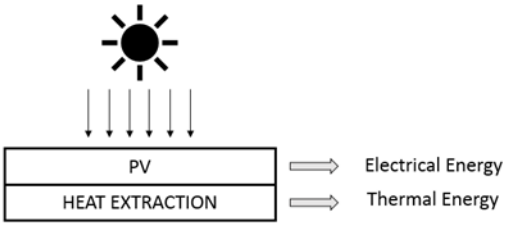

Figure 1.9 Simplest scheme of PVT concept

The photovoltaic cells generate electricity and, at the same time, absorb thermal energy that is recovered and transferred to a heat carrier fluid to be used for example to heat domestic hot water by means of a storage tank [9]. However, heat can also be used to be supplied to the source side of a heat pump, while the electrical energy produced by the photovoltaic cells can cover a part of the electrical energy consumption of the heat pump.

When speaking about a non-concentrated PVT (that means without concentrator technologies such as the Compound Parabolic Concentrators or the Fresnel Lenses), which heat carrier fluid is a liquid, the electrical and thermal efficiencies are in the range of 10–12% and 50–70% respectively. On the other hand, the electrical and thermal efficiencies of non-concentrated air type PVT systems are in the range of 9–12% and 40–60% respectively [10].

Wind Turbine

Micro-wind turbines are a renewable system that can be integrated with a ground source heat pump. Photovoltaic and wind systems are two sustainable energetic sources that can be used to produce the electric energy needed for the heat pump.

The micro-wind turbines can be installed on the roof of houses and offices and require small spaces (like a house’s balcony) to be installed.

Wind turbines installed on domestic roofs are between 90 and 140 cm high. Their small sizes facilitated the installation without sacrificing the efficiency. This type of wind turbines is silent and can produce electricity even if the wind velocity is not so high.

Water tank

The design and sizing of a heating and cooling system including a heat pump require the inclusion of a storage tank between the heat pump and the end-user. The function of the tank is to guarantee a certain amount of water into the system.

A low water amount means low thermal inertia of the system. If thermal inertia is low, the compressor in a heat pump will start and stop frequently, working for short periods. The amount of water in the system greatly influences the COP of the system, with a lower energy efficiency achieved if the water amount of the system is low.

1.3 Basic constrains identified

In the deliverable D1.1 *"Report on the different kind of barriers for shallow geothermal in deep renovation"*, the barriers were grouped into two main types, technical and non-technical barriers, with an extra section considering the specific problems posed by historic buildings. For the purpose of this D4.1, only the technical barriers (incl. those in historical buildings) are of relevance. However, a short summary of the non-technical issues is thought to be helpful. The investigation of non-technical barriers addressed 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, and hence all relevant stakeholders and their possible objections were investigated, 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 were also dealt with.

Somewhat in a hybrid category are environmental issues; these have both a technical and non-technical side, as technology can be employed to mitigate environmental influence. Examples of such issues that considered more in the technical category are B9 and B10 (see Table 3).

Technical barriers are deemed to be overcome more easily than non-technical ones, 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. The deliverable D1.1 listed the many barriers and classified 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.

Hence the technical barriers can be classified into those pertaining to the existing building (including heat pump integration into the building system) and those associated with BHE design and drilling. Furthermore, economic constraints have to be considered. Concerning 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. The relationship between the identified barriers and the variable data for the scenarios is presented in Table 3.

Identified Barrier	Related Variables
Barriers pertaining to the existing building	
B1 – Poor building thermal envelope	AG, TP
B2 – Existing high temperature terminals	HVAC, TP
B3 – Space for technical room	HVAC
B4 – Constraints in electric power supply	HVAC, TP
B5 – High thermal peak load and load balancing	TP
Barriers pertaining to BHE design and drilling	
B6 – Lack of space for BHE field	BF, TP, TS
B7 – Accessibility	BF
B8 – Underground infrastructure	BF
B9 – Drilling waste removal	BF, TS
B10 – Noise and vibrations	BF, TS
Other barriers	
B11 – Economic viability of GSHP system	TP, HVAC, AG, BF, TS

Table 3 – Basic barriers identified and related variable data for the scenarios

1.3.1 Barriers related to the conditions in the existing building

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.

B1 – Poor building thermal envelope

Old buildings are usually not well insulated, with single-glazed windows, resulting in high energy needs. When only the addition of a SGE system to such a building is contemplated, this could result in prohibitive capital costs for the SGE installation. 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. On the other hand, more recent buildings might already have acceptable insulation standards. The key variables here are the fact a building being historic or recent (AG) and the energy demand and temperature profile the building might require after an affordable improvement of the building envelope (TP). Constrains and costs of such interventions as well as potential benefits have to be considered against the costs and benefits of a SGE system.

B2 – Existing high temperature terminals

In most refurbishment projects the question has to be asked if existing distribution systems, emission units (terminals) etc. should be kept or replaced. 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. A general 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. Bringing temperature of heat supply down (or cold supply for space cooling up) allows for much better efficiency of a heat pump but could come with high cost. The resulting temperature requirements after affordable improvements to the terminals is provided in variable TP (temperature profile). These temperatures have to be met by innovative heat pump concepts; the efficiency and cost of operation of the SGE system have to be weighed against the cost for upgrading existing terminals.

B3 – Space for technical room

In a refurbishment the space constraints for a technical room is a valid question, since the spaces are quite reduced, especially in an urban context. In general, mechanical rooms usually are located in the basement, and/or in narrowly confined surroundings. Heat pump systems require a buffer vessel in the heating/cooling circuits in order to increase inertia and thus 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. The feasibility of conversion to SGE thus depends on the inside space required by different SGE solutions as a function of the peak power needed for heating and cooling. The key variable here is the availability of innovative, space-saving equipment for heating, ventilation and air conditioning (HVAC). The economic side is controlled by the cost for enlarging available space versus cost for smaller equipment (or cost for additional energy, when supplying only a smaller part of the demand from SGE).

B4 – 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. 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. The relevant variables here are improved equipment (HVAC) and an optimized thermal profile (TP).

B5 – 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, hotels etc. Buffer storages could help if space allows; when increasing the storage capacity, the peak power decreases. Sometimes this might even be done by acting on the thermal inertia of the building. The variable TP (thermal profile) is concerned here, and the economy can be analyzed by comparing the cost for measures to reduce the peak demands (storage) with the additional SGE installation required for covering higher peak loads.

1.3.2 Barriers related to BHE design and drilling

Space availability for installing the borehole field for a SGE installation is always considered a crucial issue due to the standard dimensions of a common BHE field. 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.). 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). 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.).

B6 – Lack of space for BHE field

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 for deeper boreholes; thermal interactions have to be considered as well. The required size of the BHE field for a given thermal load profile is determined by the thermal properties of the underground, which is part of the variable TD (type of soil), and the type of BHE used, including pipes, grout, depth etc., being included in variable BF (BHE field). While the type of underground cannot be changed on a given site, the type and layout of BHE can be optimized. The economic benefits of improved BHE can only be assed in the frame of total system design and operational behaviour.

B7 – Accessibility

Drilling rigs need a certain room to manoeuvre, 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. 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. Furthermore, accessibility of the area in certain historic city centers - e.g. Venice, Brugge, medieval cities - is even more difficult and sometimes not possible at all. All these issues are represented in variable BF (BHE field).

B8 – 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 sometimes do not have such drawings. However, the gardens behind the houses are normally free since the utilities are coming from the street. In the case of drilling in Historical Building areas, existence of underground infrastructure might include objects of archaeological interest, and the use of technologies like GPR (Geo-radar) may be appropriate to avoid incidents and perturbations. Caution is also 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. Investigations by dedicated authorities or specialized companies will need to precede drilling activities in affected areas. In any of the aforementioned cases, exact location and pathway for boreholes has to be kept. Variable BF (BHE field) contains these issues.

B9 – Drilling waste removal

Problems can arise from waste removal, mainly of drill cuttings or mud from rotary drilling. Also the possibility to get rid of possible higher amounts of water from the borehole is crucial. The problems involved here are dependent on the type of soil (TS) and the drilling methodology, including the type and geometry of the BHE (BF).

B10– Noise and vibrations

Drilling in the built environment always means drilling in the vicinity of people, 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. Again, the problems involved are dependent upon the type of soil (TS) and the drilling methodology, including the type and geometry of the BHE (BF).

1.3.3 Other barriers

The main remaining barrier is economic viability. In case of retrofitted buildings, cost-benefits analysis is complicated by uncertainties related to several aspects affecting the installation cost of the SGE system, including the time needed to install it (which is usually longer than for a new building). An important aspect are problems posed by the available 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 BHE, due to in-terrain impediments. Adapting the SGE system to the current or new heating system and existing technical rooms could also incur some delays or problems which would increase the final installation costs.

B11– Economic viability of GSHP system

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 meters to be installed, the soil conditions and the productivity level of the drilling system. With the space restrictions in the built environment, drilling generally becomes more difficult and sometimes requires bespoke solutions that increase the 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. All variables (TP, HVAC, AG, BF, TS) are concerned when evaluating economic viability, and some specific issues are mentioned above in the paragraphs on individual technical barriers.

2 Different solutions portfolio

2.1 Description of the solutions

This section defines the different solutions proposed to overcome the barriers identified in the previous chapter. The solutions have been categorized into four types: building retrofitting, GSHP system design, GEO4CIVHIC new developments and integration with other renewable energy sources.

2.1.1 Building retrofitting

Primary energy use in buildings represents approximately 40% of total energy consumption in the European Union (EU), 63% of which is attributed to domestic buildings [11]. Since buildings are estimated to account for approximately half of all annual energy and greenhouse gas emissions, one possible solution is design, construction and maintenance are environmentally sustainable [12]. The most commonly applied measures are installation of thermal insulation, limitation of thermal bridges, glazing replacement, improvement of the building's air tightness and introduction of mechanical ventilation with heat recovery [13] [14].

Acting on the envelope in the refurbishment of buildings has a direct impact on the energy demand, i.e. on the amount of energy needed to have the desired comfort conditions inside the building. Within this **thermal envelope**, the opaque parts (walls, floors and roof) and the glazed parts (**windows**) are differentiated.

The envelope of the building is the retaining air conditioned at the comfort temperature. Heat can pass through the envelope in two ways:

- **Conduction:** the way heat is transmitted through solid elements, depending on their conductivity coefficient. In the points where this conductivity is higher (different materials, moisture content, degradation, ...) and / or where the thickness is more reduced, we find a *thermal bridge*, points in the envelope where more heat is lost.
- **Convection:** Thermal envelopes are not sealed. When a house is heated, a higher-pressure zone is produced in the upper zone, so that the conditioned air escapes to the outside through fissures (exfiltrations), while in the lower zone the low pressures cause the outside air to penetrate (infiltrations) without conditioning. This circulation of air conditioned takes the interior energy out of our house, and the installed equipment have to constantly renew the energy of the wasted air, heating again the cold air that penetrates, increasing the consumption.
- **Heat transfer through radiation** (glazed surfaces): Radiant heat transfer - sun rays! - may have a significant role in the overal energy balance of a building. The ratio "glazed surface / opaque surface" of the buildings envelope is an important parameter. Shading devices may play an important role in diminishing the cooling needs - this must be analyzed in conjunction with the lighting needs.

A hermetic and sealed thermal enclosure is key to having an efficient building, as it blocks undesired air infiltrations through carpentries, encounters or poorly sealed ducts (thermal bridges) that produce greater energy consumption in the building.

Therefore, an important solution to consider in the rehabilitation of a building is the improvement of the thermal envelope, since this measure can drastically reduce the energy of the building in both winter and summer, which would result in a lower need for capacity in the new air conditioning system (reducing the cost of renovation works). However, the term «good insulation» should not be confused with «a lot of insulation», as from a certain thickness it is no longer profitable. The key is to find the point at which the investment in **insulation** and the energy savings (and renovation costs) it will provide is cost-effective.

Heat recovery ventilation (HRV) is a ventilation system that employs a backflow of heat between the inlet and outlet of the air flow. The heat recovery or heat exchange system allows to heat or cool the air from outside - depending on whether it is summer or winter - and to reuse the energy previously consumed. Suppose that the air inside a room is above 20ºC and it is winter. At the time of air renovation, to prevent cold air from entering, the heat recovery system puts the air extracted from the rooms in contact with the air entering from outside. In this contact the air is not mixed. In this way, the temperature and humidity of the air being exchanged is used. The cold air that enters from the street in winter will be heated, and during the summer it will be the other way around: the warm air will be cooled by passing through the heat exchanger. This allows energy savings depending on the quality of the windows and doors with respect to their permeability to the air. Heating and/or cooling the fresh air needed for ventilating the rooms is an important component of the energy balance of the building, which must not be disregarded. The heat recovery ventilation system is located downstream the fresh air inlet - meaning that the fresh air has already been "handled"/treated = heated or cooled, which means energy consumption. Indoor comfort means also indoor air quality.

2.1.2 GSHP system design

Ground Source Heat Pump (GSHP) technology has been extensively investigated over recent years being the most competitive Heating, Ventilation and Air Conditioning (HVAC) system compared to the more widely used Air Source Heat Pump (ASHP) system [15]. GSHPs use the ground as a source and extract/inject heat to the subsurface at low depth, subsequently called “shallow geothermal energy”, in order that it is usable for air conditioning buildings and domestic hot water (DHW) heating [16]. The installation of a ground source heat pump system in the retrofitting of a building will allow us a series of advantages that will help us overcome some of the barriers identified. It is always necessary a correct engineering design of the geothermal installation that allows an **accurate calculation** of the geothermal heat exchanger and a **good layout of the engine room**. In addition, it is also necessary to undertake a **feasibility study** checking whether there are problems of access to the work area, the existence of infrastructure in the underground or even if there is thermal interference with other adjacent geothermal installations.

2.1.3 GEO4CIVHIC new developments

In the GEO4CIVHIC project a **small-size geothermal heat pump named “Plug&Play”** is being developed**.** The machine of modular design will be very compact, equipped with on board control devices, pumps, buffer tanks for Domestic Hot Water and for the heating/cooling system if required. The system will be easy to install and connect to the distribution systems for terminals and SHW without the need for additional pumps and control devices. The layout will be designed for easy maintenance and accessibility to the components. Two versions with respectively inverter-driven and ON/OFF compressor will be tested in the field to define the one with the best performance factors. This solution may be applied in single family houses as well as decentralized solutions in multi-apartment buildings.

New generation heat pumps: dual source and high temperature heat pumps have been developed and demonstrated in H2020 projects (Cheap-GSHPs and GEOTeCH). The second generation of these pumps based on optimizations and, contributing to the overall efficiency of the geothermal system. These machines can be optimized considering the base loads and the peak loads.

- **Dual source low temperature heat pump** selects the most convenient source or sink in such a way that it can operate as an air-water heat pump using air as the source (aerothermal energy), or as a water-to-water heat pump using ground as the source (shallow geothermal energy). It is based on the heat pump developed in GEOTeCH project. The optimization in the control will be carried out by checking different operating conditions as a function of the temperature of the sources (i.e. the temperature of the water in the circuit of the GSHEs and the temperature of the outdoor air), of the actual load of the building, of the power sharing among air and water source, of the climatic conditions and of the ground thermal properties.
- Heat pumps with good performances usually operate at medium/high temperatures (50°C) and are usually avoided when retrofitting a building, due to the costly replacement of radiators (or unfeasible in historical buildings for preservation). Low-pressure heat pumps refrigerants (such as R134a) do not perform as the compressors on the market are not optimized for these working conditions. A **high temperature two-stage heat pump** using CO_2 as one of the refrigerants has been developed during the European Cheap-GSHPs project. The machine will be further improved on the basis of the lessons learned from the demonstration case in in particular the optimization of the control strategy. This second-generation machine will have a higher COP and will take care of the application in a partial retrofitting in historic buildings when some of terminals are replaced to low temperature, but the radiators stay at high temperature.

A new **grouting** composition and procedure to be used during the installation of the co-axial heat exchangers is being adapted in the case direct piling without the use of a casing within the GEO4CIVHIC project. To take advantage of the new technology, the best option would be to grout from the bottom using the drill bit as grout flushing device. This option requires very specific conditions to the grout mixture in terms of injection pressure, grout pumpability and solidification times. A grouting solution and procedure will be developed and tested in one of the demonstration cases.

The development of a **plastic coaxial pipe** is also being carried out within the project. A plastic pipe adapted to the new drilling techniques developed in the project would combine the advantages of the HDPE material with the advantages of the new drilling systems. In practice, HDPE-pipes dominate the market of geothermal probes in Europe. The main reasons are:

- Plastic pipes have superior corrosion resistance compared to plain metals in the same cost range and corrosion-resistant metals are much more expensive than plastic materials.
- Geothermal heat exchangers made of plastic pipes can be delivered to the drilling site in coils, factory-finished and for the full length.
- Most metals would mean sections of rigid steel tubes to be connected during installation on site, increasing costs, time and lack of reliability in the process. Corrugated metal tubes with thin walls (stainless steel) could also be pre-fabricated and coiled, but at much higher cost.

And finally, **new drilling techniques** will be developed in the project:

- One of the methods developed within Cheap-GSHPs also uses **piling** to push co-axial heat exchangers in the ground. The method uses a newly developed rotary head with moderate vibration power at low frequency and small amounts of water injected at the tip of the heat exchangers to loosen the soil. This method is an evolution of the drilling method called “vibrosond”.

- A smaller drilling head **VibroDrill (TKI)** that can be used inside buildings (low rooms, cellars, underground parking garages, etc.) and inner courtyards or gardens (like historical buildings with an inner square, new building complexes with green areas, etc.) is being developed within the project. The new VibroDrill head will be compact in overall dimensions (like length, width and height), in a “light weight version”. The head will run on a reduced hydraulic oil flow (to reduce the required kW of the power pack). With operating frequencies of more than 100 Hz (>7000 bpm) it will drill through nearly all ground conditions, even concrete floors in rooms and cellars and underground parking garages as well as layers of clay, gavel, sand and soft rock. Furthermore, they will reduce the required flow of the flushing media (like water, mud or air) to avoid flooding and contaminating sites, especially when drilling inside historical buildings. Two options will be developed:
    i. drill with internal rods, loosen and clearing the underground with the V-shaped drill bit whilst pulling down the external tube of a co-axial heat exchanger that is fixed on the drill bit. After drilling, grout through the internal hollow rods, disconnect the internal drill rods from the drill bit and remove them. Insert the inner plastic tube of the co-axial heat exchanger
    ii. drill with external drill rods having a larger diameter and using a sacrificial drill bit. Insert after drilling a steel or plastic co-axial heat exchanger. Then start grouting whilst pulling out the external drill string, after having left the lost drill bit behind at the bottom of the hole.

2.1.4 Integration with other renewable energies.

Integrating renewable energy into buildings improves energy efficiency [17]. In order to reduce energy dependence and greenhouse gas emissions from buildings, it is essential to take advantage of renewable energy sources such as solar energy, wind energy or geothermal energy. Thanks to its use we can obtain in the building domestic home water or/and air conditioning in the most efficient way possible.

The renewable energy sources that are considered most practicable in building are mini-wind energy, solar energy (thermal and photovoltaic), geothermal and biomass boiler. Therefore, any of these renewable energy sources can be used to retrofit a building and improve its energy efficiency.

Using of renewable energies in the construction or retrofitting of buildings should not be an added element but should always have to be taken into account.

In section 1.2 the main types of integrations with other renewable energies have been listed.

To conclude, Table 4 shows the matrix that relates the barriers identified in the previous chapter with the solutions proposed and described in this section. When a technological solution overcomes a specific barrier, it is marked in the matrix with the symbol •. The results of the Table 4 have been obtained from the contribution of the partners involved in task T4.1, selecting the most appropriate solutions to overcome the specific barrier.

Technological solutions

Main barriers identified		BUILDING RETROFITTING			GSHP SYSTEM DESIGN			GEO4CIVHIC NEW DEVELOPMENTS							Integration with other renewable energies
		Windows	Insulation	Heat recovery in ventilation	Accurate GHSE calculation	Feasibility study	Good layout technical room	New Generation High temperature HP	Compact heat pumps	New generation dual source heat pump	New grouting	Coaxial plastic	Piling (HYDRA machine)	VibroDrill head	
Barriers pertaining to the existing building	Poor thermal envelope	●	●	●						●					●
	Existing high temperature emission units							●							
	Space constrains for technical room						●		●						
	Constraints in electric power supply	●	●	●	●										●
	High thermal peak load and load balancing	●	●	●	●					●					●
Barriers pertaining to BHE design and drilling	Lack of space for GSHE installations				●					●	●	●			●
	Accessibility constraints at working area					●								●	
	Existing underground infrastructure					●									
	Drilling waste removal (muds, water)												●	●	
	Noise and vibrations					●									
Other barriers	Economic viability of GSHP system	●	●	●	●		●	●	●	●	●	●	●	●	

Table 4 – Barriers versus solutions matrix

2.2 Visual description of the different solutions

This section describes the process to develop the flowchart of the different of solutions. The Figure 2.1 presents both, a concept map for the contents of this document and the flow a designer will follow to detect which solutions are better for overcome the related barriers. As can be seen, the first step is to define the scenario by fulfilling the variables values that define it. These variables will be taken into account in the development of the Decision Support System (DSS), to obtain information from them during the data collection process. Then, based on those variables, the barriers that that scenarios presents are identified. Once the barriers are detected, designers can follow this flowchart to find blocks of modular solutions for their case study.

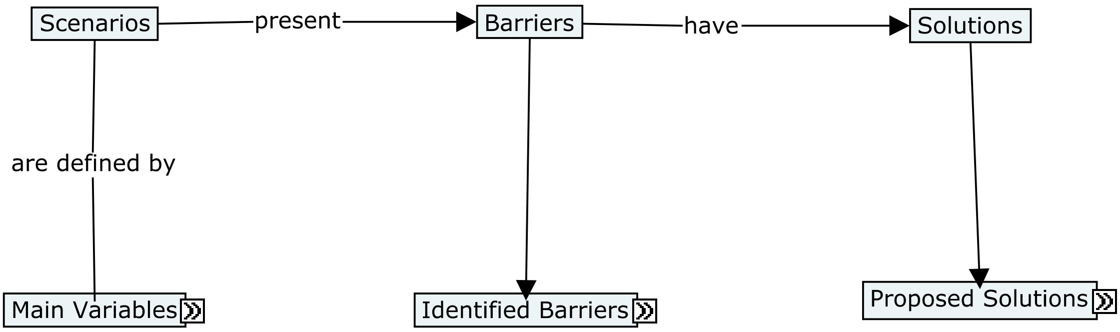

Figure 2.1 Concept map of the flowchart.

Firstly, the main variables that have to be defined in order to classify a scenario have been enumerated. In fact, the scenario is defined taking into account the target building. Figure 2.2 presents a summary of these variables and the acronyms we use for them.

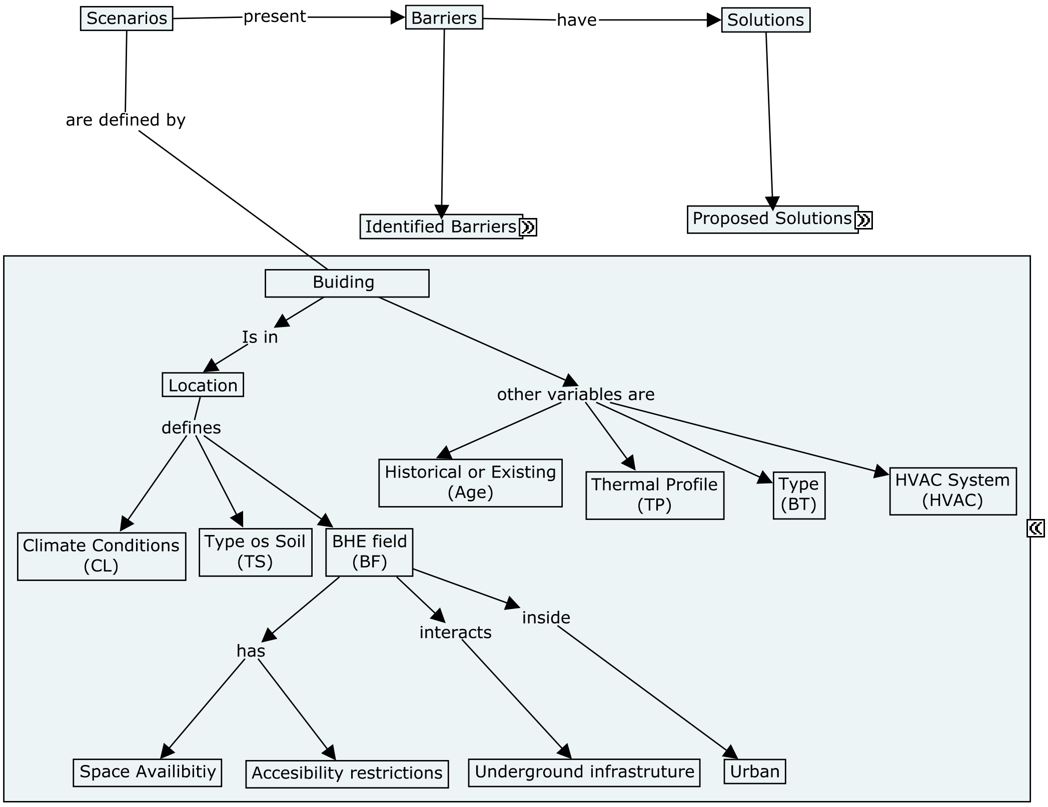

Figure 2.2 Flow to define the retrofitting scenario

The location of the building is important in order to define the climate conditions and type of ground we can be expected to find but also to define variables related to thermal profile and the borehole field that are significant at the beginning of the retrofitting assessment.

The characteristics of the building are mapped to other key variables such as whether the building is historical or existing, the thermal profile of the building, the type of building (apartment or block) and whether the building already has a HVAC system installed.

Once the scenario is defined, we can study the barriers triggered for that specific scenario. These barriers correspond to those identified in the deliverable D.1.1 and have been analysed in Section 1.3. Most of these barriers are relates to characteristic of the existing building or the installation of new GSHP system. Figure 2.3 shows these barriers.

After defining the variables that are describing the scenario (Figure 2.2) we will obtain the main barriers that we have to face for this case study (Figure 2.3). In order to overcome these barriers, different solutions have been defined and developed.

Figure 2.4 shows the different type of solutions. These solutions can be combined in different modular solutions (blocks) as described in the following Chapter 3.

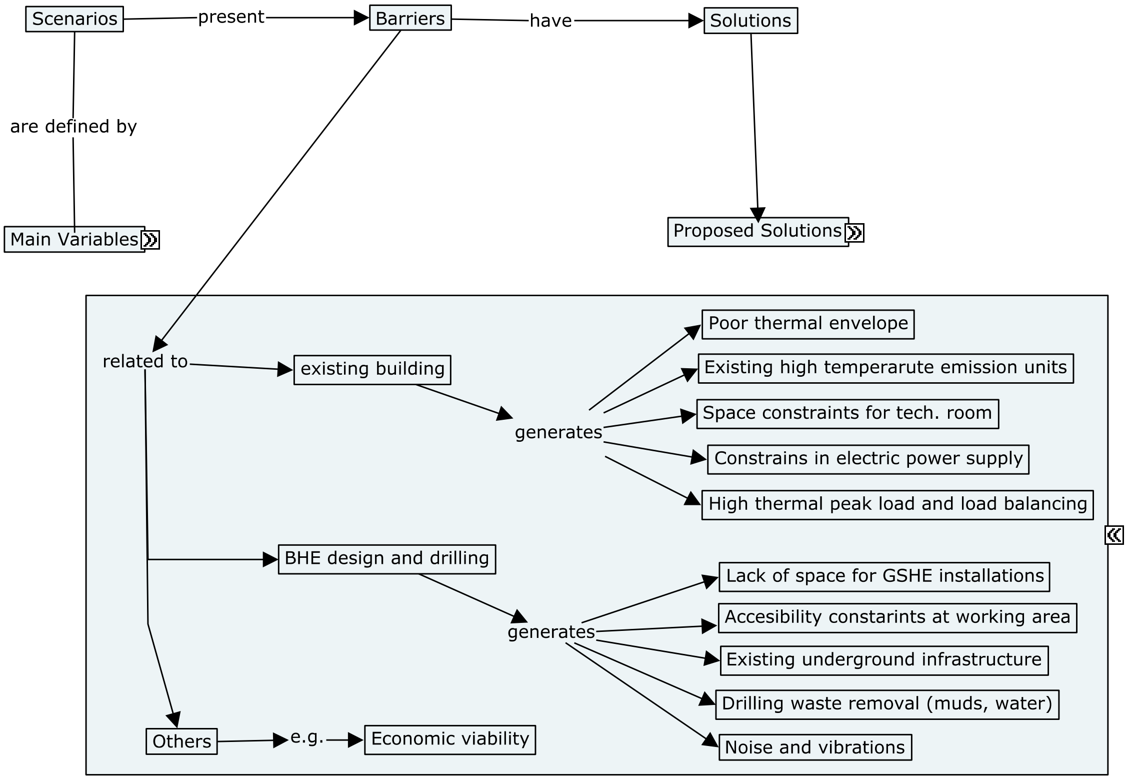

Figure 2.3 Diagram of main barriers identified for the scenarios

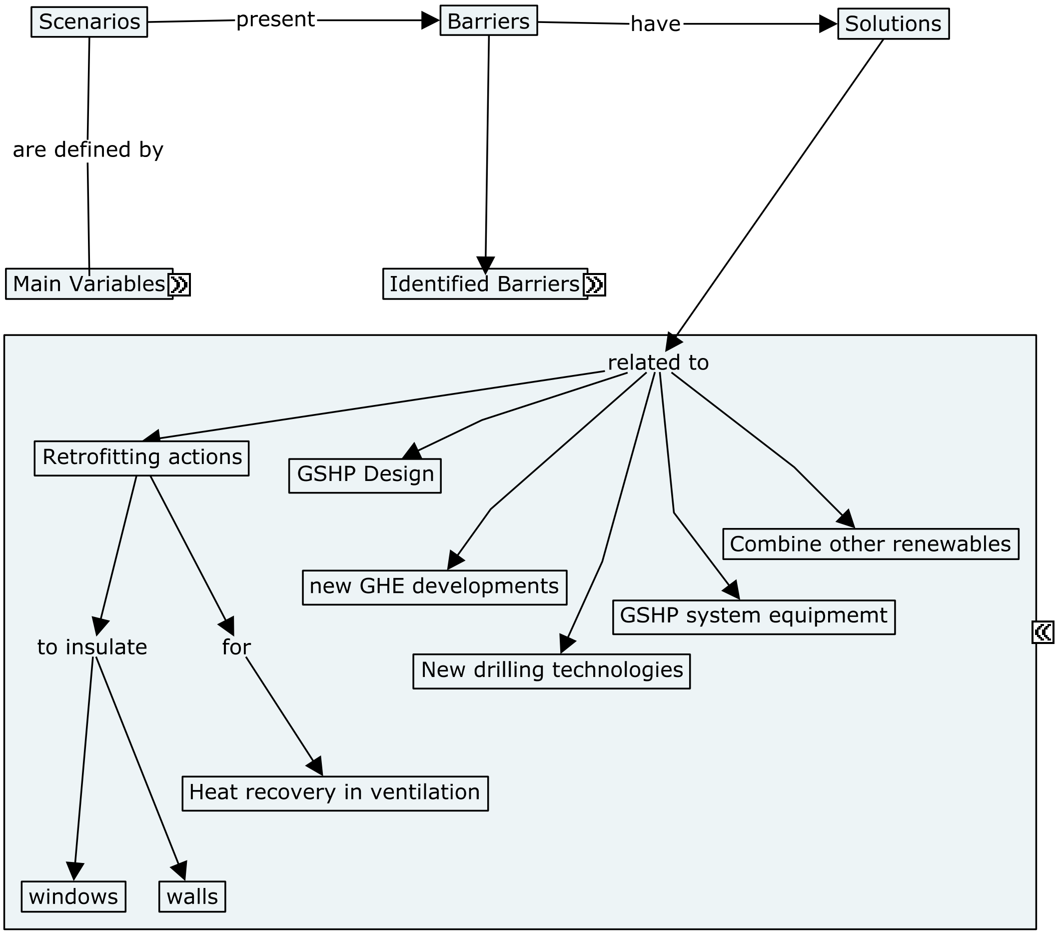

Figure 2.4 Diagram of the list of solutions

Finally, below is the flow diagram that relates the variables describing a scenario to the barriers to which it is related (left part of the image). On the right side, the relationship between these barriers and the solutions that best overcome them can be found. For better understanding of the diagram, it has been divided into three figures (Figure 2.5: barriers related to the building, Figure 2.6: barriers related to perforation and the field of perforations and other barriers, Figure 2.7).

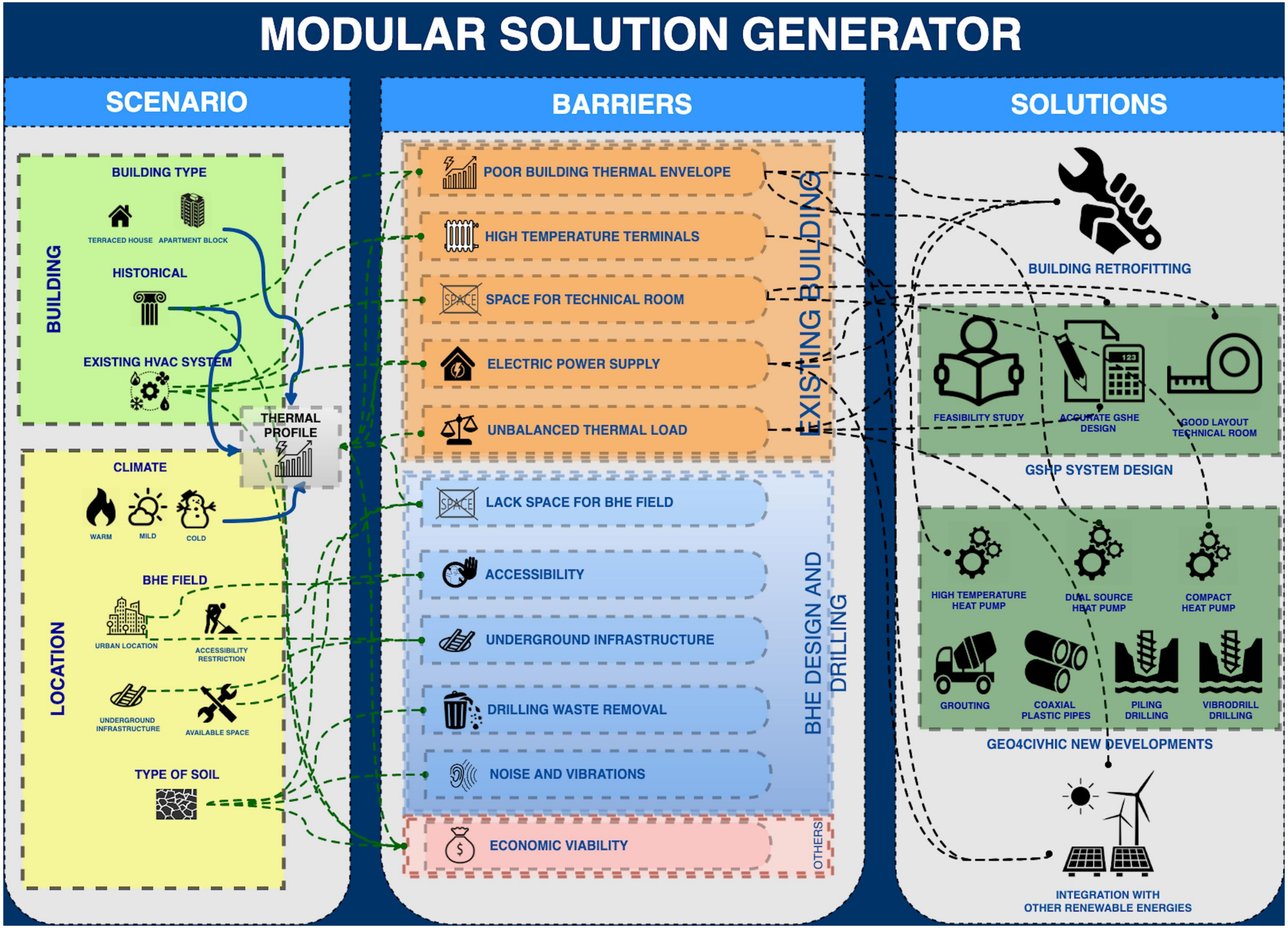

Figure 2.5 Flowchart diagram (relationship between existing building barriers and solutions)

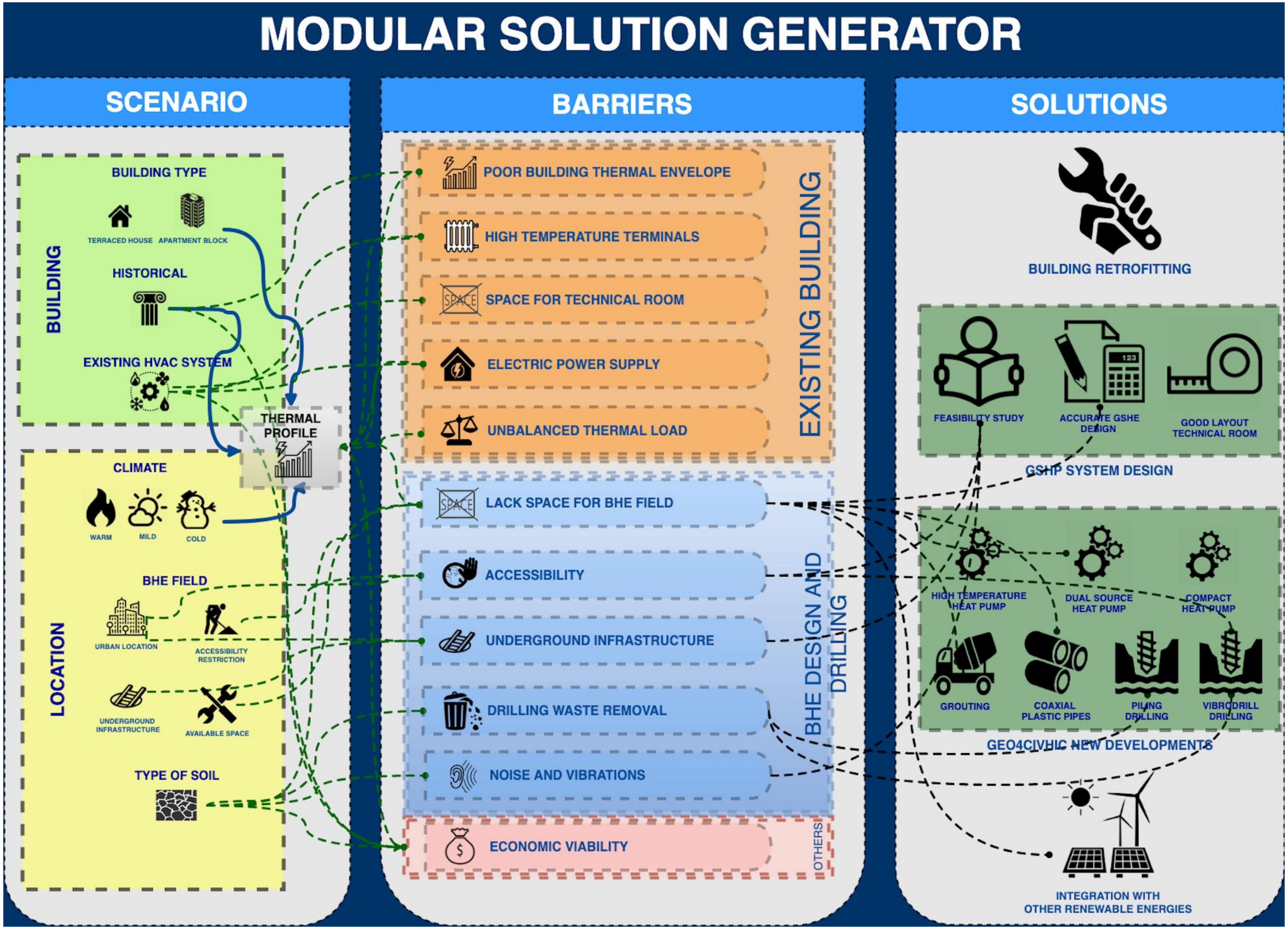

Figure 2.6 Flowchart diagram (relationship between BHE design and drilling barriers and solutions)

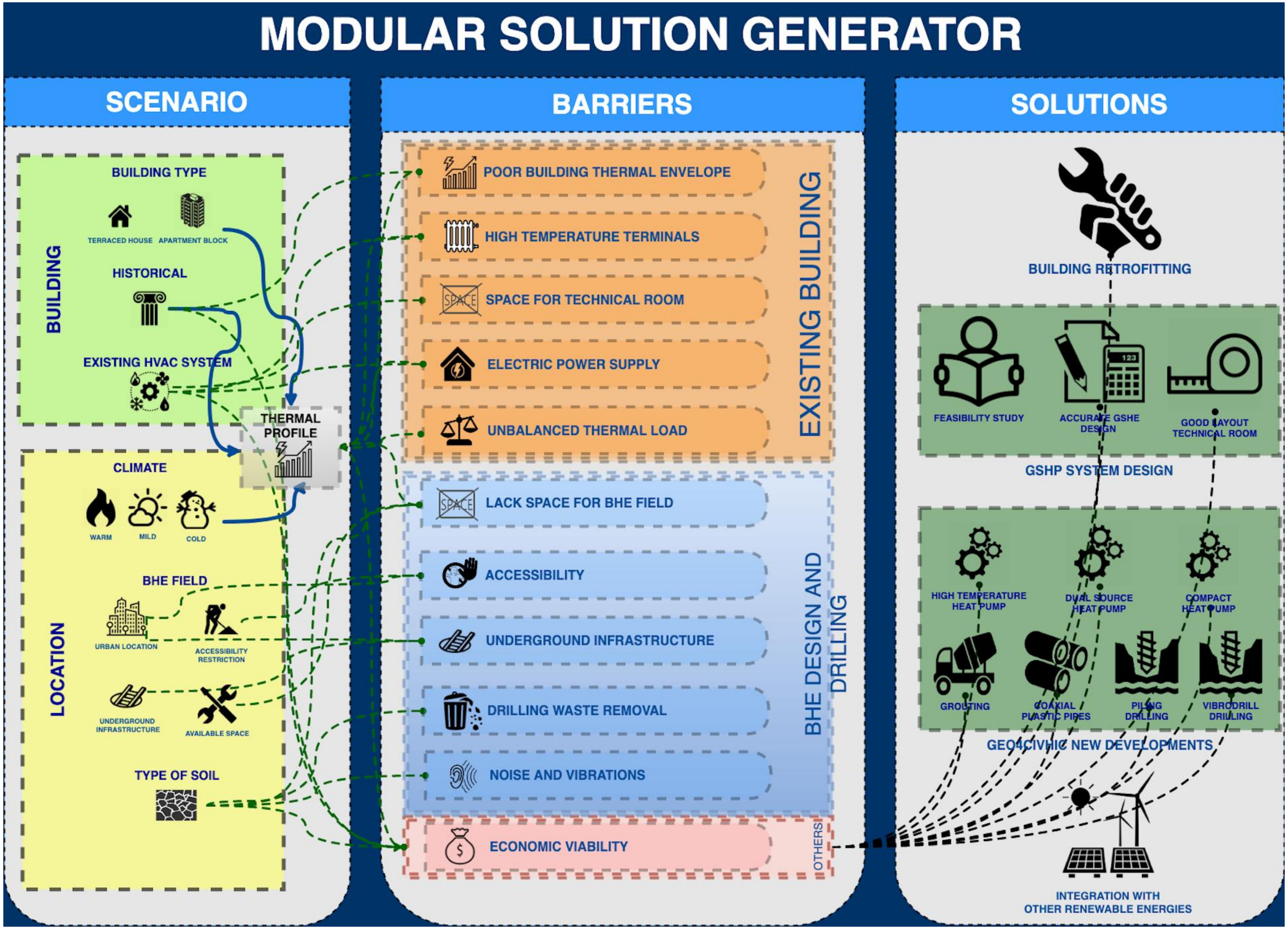

Figure 2.7 Flowchart diagram (relationship between other barriers and solutions)

3 Selection and description of the different modular solutions (blocks) for civil and historical buildings

To conclude the deliverable, the list of modular solutions for civil and historical buildings that would be obtained as a result of a rehabilitation study is drawn. The block of modular solutions will provide with the optimal solutions for the retrofitting case studied. These solutions will overcome the identified barriers of the specific scenario. In Figure 3.2 we have the diagram with all the possible solutions that our case can activate.

Example of a solution

For a better understanding of the process, below is a small case study sample. Suppose we are studying a case that after introducing all the input variables, triggers the following barriers:

- B1 – Poor building thermal envelope
- B2 – Existing high temperature terminals
- B7 – Accessibility
- B11 – Economic viability of GSHP system

In this case, a possible solution would be shown in Figure 3.1, where the solutions that are enabled in our solutions block are listed. These solutions would overcome the barriers activated during the analysis of our case study.

Figure 3.1 Sample solution

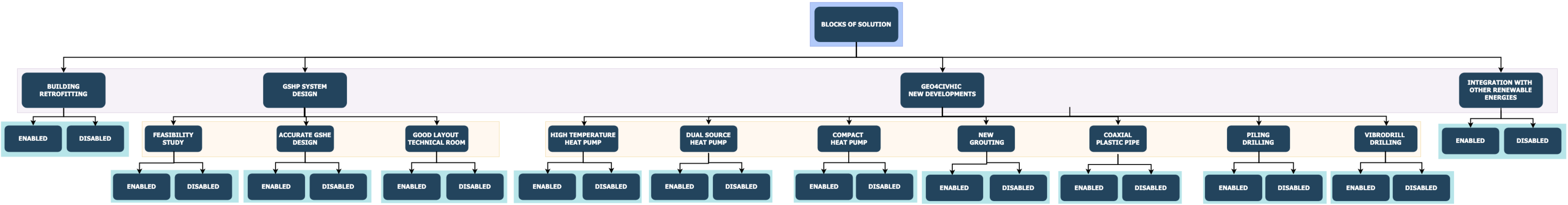

Figure 3.2 Blocks of solutions

4 Conclusions

In this deliverable a preliminary analysis and generation of possible different modular solutions description for civil and historical buildings is presented. Firstly, an exhaustive review of the deliverables D.1.1, D1.2 and D.1.3 has been done. From the deliverable D1.1 "Report on different kind of barriers for shallow geothermal in deep renovation", the main barriers related to a retrofitting process of a building have been obtained. From D1.2 "Drillability mapping and state of the art of the drilling methodologies" and D1.3 "Modelling energy demand and plant typology study for different levels of renovation in different types of buildings, climates and grounds" the variables to be taken into account in a renovation scenario have been determined, related to the type of building, construction features, location, type of soil and climate.

Subsequently, an analysis was carried out to determinate the relationship between the variables and the barriers identified. These relationships are shown in Table 3. Therefore, these variables should always be considered in order to identify in advance the barriers that can be found in a retrofitting process.

Finally, an analysis has been carried out to obtain the possible solutions that solve the identified barriers, focusing on the technological applications that are being developed in the context of the project. These relationships between the solutions and the barriers are shown in Table 4.

Figure 2.5, Figure 2.6 and Figure 2.7 show the flow diagram of the output of this deliverable. Starting from the variables identifying the case study scenario, the possible potential threats that may arise during the implementation process of the retrofitting are obtained and, as a result, a modular solution is obtained with the optimal solutions that counteract the identified constraints (Figure 3.1).

The results of this preliminary analysis will help in the development of the decision support tool (DSS) of the project and will help it provide the best modular solution to each case study analyzed.

5 References

[1] Directive 2002/91/CE of the European Parliament and of the Council of 16 December 2002 on the energy performances of buildings, L1/65, 2003.

[2] Directive 2010/31/EU of the European Parliament and of the Council of 19 May 2010 on the energy performances of buildings (recast).

[3] Directive (EU) 2018/844 of the European Parliament and of the Council of 30 May 2018 amending Directive 2010/31/EU on the energy performance of buildings and Directive 2012/27/EU on energy efficiency (Text with EEA relevance)

[4] Ballarini, I., Corgnati, S. P., Corrado, V., Use of reference buildings to assess the energy saving potentials of the residential building stock: the experience of Tabula project, Energy policy, 68:273-284, 2014.

[5] IEE Project TABULA (2009 - 2012). "Typology Approach for Building Stock Energy Assessment". http://episcope.eu/iee-project/tabula/. Accessed 25 Sep. 2019.

[6] Peel, M. C., Finlayson, B. L., McMahon, T. A., Updated world map of the Koppen-Geiger climate classification, Hydrology and Earth System Sciences, 11, 1633–1644, 2007.

[7] De Carli, M., Bernardi, A., Cultrera, M., Dalla Santa, G., Di Bella, A., Emmi, G., Galgaro, A., Graci, S., Mendrinos, D., Mezzasalma, G., Pasquali, R., Pera, S., Perego, R., Zarrella, A., A database for climatic conditions around europe for promoting GSHP solutions. GEOSCIENCES, vol. 8, 71, (2018). ISSN: 2076-3263, doi: 10.3390/geosciences8020071

[8] A. H. A. Al-Waeli, K. Sopian, H. A. Kazem, and M. T. Chaichan, “Photovoltaic/Thermal (PV/T) systems: Status and future prospects,” *Renew. Sustain. Energy Rev.*, vol. 77, no. November 2016, pp. 109–130, 2017.

[9] N. Aste, C. del Pero, and F. Leonforte, “Water flat plate PV-thermal collectors: A review,” *Sol. Energy*, vol. 102, pp. 98–115, 2014.

[10] S. S. Joshi and A. S. Dhoble, “Photovoltaic -Thermal systems (PVT): Technology review and future trends,” Renew. Sustain. Energy Rev., vol. 92, no. May, pp. 848–882, 2018.

[11] C. Balaras, A. Gaglia, E. Georgopoulou, S. Mirasgedis, Y. Sarafidis, D. Lalas. European residential buildings and empirical assessment of the Hellenic building stock, energy consumption, emissions and potential energy savings. Building and Environment, 42 (2007), pp. 1298-1314.

[12] Commission for Architecture and the Built Environment (2007). Sustainable design, climate change and the built environment, available at: https://www.designcouncil.org.uk/sites/default/files/asset/document/sustainable-design-and-climate-change.pdf. Accessed 25 Sep. 2019.

[13] H. Tommerup, S. Svendsen. Energy savings in Danish residential building stock. Energy and Buildings, 38 (2006), pp. 618-626.

[14] Y. Nikolaidis, P.A. Pilavachi, A.A. Chletsis. Economic evaluation of energy saving measures in buildings. Applied Energy, 86 (12) (2009), pp. 2550-2559.

[15] P. Bayer, D. Saner, S. Bolay, L. Rybach, P. Blum. Greenhouse gas emission savings of ground source heat pump systems in Europe: a review. Renew Sustain Energy Rev, 16 (2012), pp. 1256-1267.

[16] A.M. Omer. Ground-source heat pumps systems and applications. Renew Sustain Energy Rev, 12 (2008), pp. 344-371.

[17] Y. Chen, J. Chen, U. Berardi, B. Xu. A multi-integrated renewable energy system in a commercial building in Beijing: lessons learnt from an operating analysis. International Journal of Low-Carbon Technologies, 7 (3) (2012), pp. 192-198.