This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 792355.

Deliverable D1.4

Preliminary cost and business analysis for different types of building, climates and underground conditions

WP1

Grant Agreement number	792355
Project acronym	GEO4CIVHIC
Project full title	Most Easy, Efficient and Low Cost Geothermal Systems for Retrofitting Civil and Historical Buildings
Due date of deliverable	30/09/2019 (M18)
Lead beneficiary	17 – SOLINTEL (Solintel Team)
Other authors	RED, UNIPD-DII, PIETRE, SUPSI, GALLETTI, CRES, DLH, GEOSERV

Dissemination Level

PU	Public	**X**
CO	Confidential, only for members of the consortium (including the Commission Services)	
CI	Classified, as referred to in Commission Decision 2001/844/EC	

Document History

Version	Date	Authors	Description
1	20/05/2019	Solintel	ToC of the document
2	20/06/2019	Solintel	Request of contributions
3	23/09/2019	All involved partners	Contribution of Partners
4	30/09/2019	Solintel	Implementing Contributions
5	2/10/2019	Solintel	Draft for reviewers
6	03/10/2019	UBeG	Reviewed draft
7	03/10/2019	UNIPD	Reviewed draft
8	04/10/2019	Solintel	Final version for Coordinator
9	04/10/2019	Coordinator (CNR-ISAC)	Final revision and upload in ECAS

Disclaimer

This document is the property of the GEO4CIVHIC Consortium.

This document may not be copied, reproduced, or modified in the whole or in the part for any purpose without written permission from the GEO4CIVHIC Coordinator with acceptance of the Project Consortium.

This publication was completed with the support of the European Commission under the *Horizon 2020 research and innovation programme*. The contents of this publication do not necessarily reflect the Commission's own position. The documents reflects only the author's views and the Community is not liable for any use that may be made of the information contained therein.

Contents

Figures

Tables

Summary

The present deliverable reports the activities related to the Task 1.4 – Preliminary cost and business analysis for different levels of renovation in different types of building, climates and undergrounds – aiming to define the investment gap between conventional solution (condensing boilers, direct exchange chillers) and actual geothermal solutions. Also a preliminary data base of investment costs at European level has been performed taking into account national costs to each project (material, installation and performance). This is a public document delivered in the context of WP1.

A preliminary analysis has been performed investigating first the most used conventional solutions for heating and cooling of buildings in Europe. A preliminary cost and business analysis has been made with the help of all partners from the different countries across Europe for levels of renovation, climates and undergrounds.

In parallel the same analysis has been performed for the buildings in Athens, Strasbourg and Helsinki which were modeled in Task 1.3. This Report is meant to serve as a tool to those interested in implementing geothermal technology throughout Europe and to assist in identifying and analyzing the relevant factors to determine if geothermal energy systems are a viable solution in a specific case.

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
DHW	Domestic Hot Water
GHE	Ground Heat Exchanger (general term, includes BHE)
GSHP	Ground Source Heat Pump
IP	Intellectual Property
NZEB	Near-Zero-Emission Building
PBT	Pay-back Time
RES	Renewable Energy Sources
SFH	Single Family House
SGE	Shallow Geothermal Energy
ZEB	Zero-Emission Building

Introduction

Purpose and target group

Main goal of the GEO4CIVHIC project is to accelerate the deployment of shallow geothermal systems for heating and cooling in retrofitting existing types of buildings, including historical buildings. It will be based on innovative technological solutions, improvements and enrichment of results obtained from previous EU projects.
GEO4CIVHIC project intends not only to develop and innovate a flexible drilling machine of reduced dimensions and ground heat exchanger technologies but also to develop hybrid heat pump technologies for both low and high temperature suitable for all buildings, climate and underground conditions.

In the framework of WP1 – Barriers identification, case study modelling and preliminary feasibility studies to define key performance indicators and the basis for the innovation – and specifically into the Task 1.4 – Preliminary cost and business analysis for different levels of renovation in different types of building, climates and undergrounds – the main objectives are related to the preliminary cost study with the help of all partners from different countries. This study will be based on the buildings selected for consideration in the project.

Contribution of Partners

Solintel is the task leader and responsible to deliver the present document. All partners, based on their expertise and knowledge, contributed to carry out activities needed for a detailed and complete document which is the D1.4.

Baseline

For the preparation of this deliverable a gathering of the required data involving type of buildings, level of renovation, climates, undergrounds and energy demand for heating and cooling have been performed. Most of this document is based on the considered buildings, climates and undergrounds modelled in the task 1.3.

Relation to other activities

Contributions from other related tasks mainly derive from Task 1.3 – Modelling energy demand and plant typologies for different renovation levels in different types of building, climate and undergrounds – The installation and drillability related costs will be provided by Task 1.2 – Mapping of ground eligibility for drilling methodologies and borehole heat exchangers –The outcomes of this activity will be used in DSS (WP4) as well as in the business models (WP7) supported by the demonstration experiences (WP5). Some results will be also used in WP6 in the development of recommendations for the use of GSHP system in retrofit scenarios and in historical buildings.

1 Overview of available geothermal systems for heating and cooling

A general characteristic of the European landscape is that the heating and cooling sector is very heterogeneous in its structure, in terms of technologies, actors, demand, sources, costs, etc. In this context, geothermal represents a renewable energy source with a very important potential of energy savings which can concern the air conditioning of different kind of buildings such as residential, commercial or industrial.

Shallow geothermal energy has the potential to save up to 70% of energy in comparison with the traditional heating and cooling (H&C) systems that use oil and gas, hence it is a technology that can be instrumental for decarbonising the overall heating sector. Furthermore, shallow geothermal systems can also cover the cooling demands, such as in commercial buildings all over the EU. However, the shallow geothermal sector is currently facing important challenges, such as regulatory barriers at different levels, which are able to affect the implementation of those systems in Europe.

It has to be noted that the EU is committed to achieve the following goals by the year 2020 [1]:

- A reduction of at least 20% in greenhouse gas (GHG) emissions compared to 1990 levels.
- 20% of the final energy consumption needs to come from renewable sources;
- An improvement of energy efficiency by 20%

Addressing these objectives, Shallow Geothermal Energy (SGE) represents a Renewable Energy Source (RES) with a large potential of energy savings and GHG emissions reduction.

This is the reason why SGE will be a key technology in order to contribute to achieve all major objectives of the EU's energy policy.

Additional benefits provided by using shallow geothermal energy technologies are:

- Reducing import dependency of fossil fuels and increasing security of energy supply
- Increasing local added value and creating jobs
- Potential integration of shallow geothermal technology in locally existing businesses, especially SMEs
- Bringing innovation to the building/installation sector
- Zero pollution systems, when using clean electricity
- Empowering consumers and contributing to provide affordable energy as it is relatively immune from price volatility typical of fossil fuels
- Suited for European-wide geology, hydrogeology, and climate
- Suitable for a variety of small as well as large applications
- High energy savings potential for both heating and cooling
- Integration through (thermal) storage potential as controllable load into smart electrical grids of small and large scale
- Practical implementation on large scale (proven technology with good track record)

1.1 Geothermal Technology

The following is a description of the different systems which constitute a geothermal facility: the thermal exchange with the ground, the heat pump, and at last, the hybridisation of the production system with other back-up technologies.

1.1.1 Exchange with the ground

The heat exchange with the ground depends on the different temperatures and underground depth and also on the different typologies of heat exchanger used (vertical, horizontal, or foundations).

The distinction between shallow and deep geothermal is not fixed. In general, shallow geothermal systems can be considered as those not pursuing the higher temperatures, typically found only at greater depth, but instead applying technical solutions to make use of the relatively low temperatures offered in the uppermost 100 to 200 m or more of the Earth's crust [2].

The Spanish Geothermal Technology Platform (GEOPLAT) classifies the geothermal resources depending on the temperature level in the ground. The most important characteristics of each one are listed below:

- ***High-Temperature Geothermal Resources***, with temperatures above 150ºC, used fundamentally for electricity generation and found at highly variable depths but frequently between 1,500 and 3,000 m
- ***Medium-Temperature Geothermal Resources***, with temperatures between 100 ºC and 150 ºC, usually used in power generation plants but also used for district heating and other thermal purposes. This type of geothermal resources can be found at depths lower than 1,000 m in areas with high geothermal gradient or at depths between 2,000 and 4,000 m in sedimentary basins
- ***Low-Temperature Geothermal Resources***, with temperatures between 30 ºC and 100 ºC, mainly used for thermal purpose in HVAC, found in areas with normal geothermal gradient at depths between 1,500 and 2,500 m or at depths lower than 1,000 meters in areas with high geothermal gradient
- ***Shallow or Very Low-Temperature Geothermal Resources***, with the energy stored in the Earth or in groundwater at temperatures lower than 30 ºC and used for thermal uses.

In order to use the constant low temperature of the ground, two options are available:

- Increase or decrease the temperature of geothermal heat to a usable level using heat pumps (**Ground Source Heat Pumps, GSHP**)
- Increase or decrease the temperature in the ground by storing heat or cold (**Underground Thermal Energy Storage, UTES**).

  All these SGE technologies can be classified in two main types:

- ***Open circuits***, where water is pumped from an aquifer, having a heat exchanger above ground

- ***Closed circuits***, where a heat exchanger is installed inside the ground to exploit the energy resource.

The various shallow geothermal methods to transfer heat out of or into the ground comprise:

- Horizontal ground heat exchangers (horizontal loops): 1.2 – 2.0 m depth
- Borehole heat exchanger (vertical loops - BHE): 10 - 250 m depth
- Energy piles (foundation heat exchanger): 5 - 45 m depth
- Screen walls (foundation heat exchanger)
- Basket systems: 2 – 6 m depth
- Ground water wells
- Water from mines and tunnels

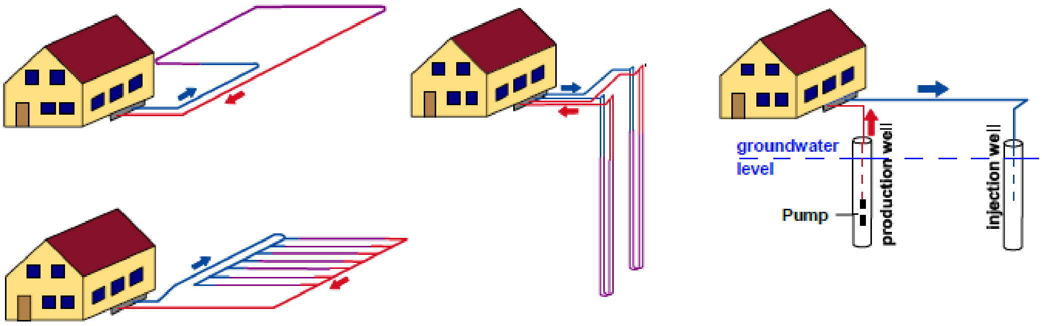


Figure 1.1 Schematic diagram of the most common ground-coupling methods (from left): horizontal loops, BHE, groundwater wells

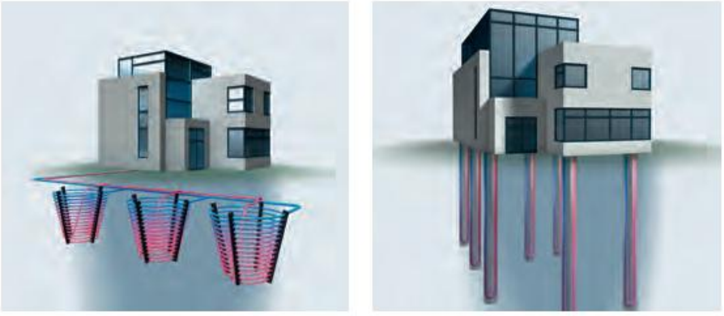


Figure 1.2 Basket systems (left); Energy piles (right) (Source: UPONOR)

1.1.2 Heat Pump

In the current market a lot of types of heat pumps exist, depending on their source of energy, application and coupled end-unit. Heat pumps can be categorised according to [3]:

- **Function**: heating, cooling, domestic hot water, ventilation, drying, heat recovery
- **Heat source**: ground, ground-water, air, exhaust air.
- **Working fluids**: (heat source/heat distribution) brine/water, water/water, direct-expansion/water, air/water, air/air, water/air.
- **Unit construction**: compact or split, installation location (indoor/outdoor), compression heat pump, absorption heat pump, drive power (electric, gas), number of compression stages.

Once the different categories of heat pumps have been described, it is important to clear out that **Ground Source Heat Pumps (GSHPs) are the type that uses the underground (ground or ground-water) as heat source**, as indicated by the name itself. There are other types in the sub-category Water Source Heat Pumps (WSHPs) that use surface water as source, like ponds, lakes, the sea, etc. They are often considered with GSHP (e.g. in the American term "Geoexchange") due to the fact that they are based on the same technology and obtain similar performance results. Usually terminology like geo-exchange, ground-coupled, geothermal, earth-coupled, ground water source, well water heat pumps etc. refers to GSHPs. This diversified nomenclature is sometimes used to describe more accurately the specific application, however, more often all of them work as synonyms for GSHPs.

1.1.3 Distribution H/C system

The most common type of HVAC systems using GSHP are the water-to-water system and the water-to-air system. Unlike air-to-air and air-to-water systems, these do not include an air-handling unit, and ventilation is effectuated independently through air vents. As for the terminal unit, fan coils, conventional radiators and radiating surfaces (e.g. floor heating) can be used, depending on the delivery media.

The building's energy efficiency is improved when GSHPs are combined with low-temperature heating and high temperature cooling systems like radiant floors or ceilings. Radiant surfaces require a small thermal difference to function, thereby offering better heat pump efficiency.

Indirect applications, as Thermally Active Building Systems (TABS), are less common but can be much more energy efficient. They usually do not match fully the building's demand in energy and they are therefore a complimentary heating and cooling technology. The heat transfer fluid is distributed through a loop system embedded in the central concrete core of a building's construction, meaning floors and, occasionally, walls. This technology utilises the heat storage capacity of the concrete and increases the thermal capacity of the building to neutralise peak loads. It works as follows: energy is produced at night, when the price of electricity is lower, and then stored in the structure of the building. During the day, energy is dissipated through the floor and ceiling. Conventional heating or cooling systems will only perform if the heat capacity of the heat pump system is not enough to provide the room temperature requirements for optimal comfort. This system is particularly suitable for buildings with temporal occupancy such as office buildings, universities and shopping centres, which have a very specific and stable energy demand. Comfort is warranted thanks to the optimal and stable temperatures offered by quiet equipment without air circulation, which means that air currents and fouling factor caused by dust are avoided.

2 Overview of the most used traditional systems for heating and cooling

Energy consumption intended for heating and cooling in the European Union represents half of total consumption. Looking at how such energy is distributed among the individual sectors, the percentages are shared as follows: 45% residential sector, 37% industry and 18% services [4].

In 2007, 48% of the final energy consumption in EU-27 took the form of heat and, specifically, heat accounted for 86% of the final energy consumption in households, 76% in commerce, services and agriculture and 55% in industry [5].

There is a trend of significant reduction in the heating demand in the EU whereas the cooling demand is growing exponentially. However, it is difficult to accurately estimate the impact on energy consumption of cooling demand, because it's hidden in data for the electricity demand of the residential and service sectors. An estimation of the expected evolution for the next years has been made and it is shown in [6]:

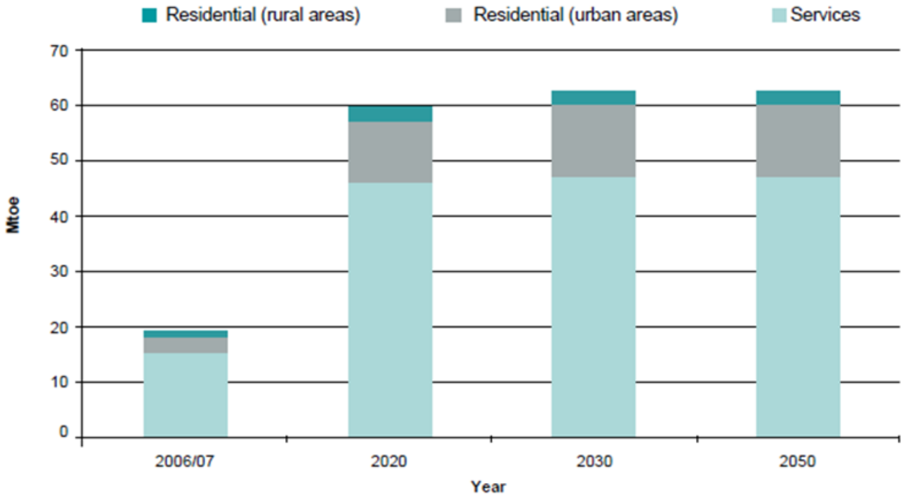


Figure 2.1 Expected evolution of cooling demand in EU

The following subchapters provide an overview of the existing and most used technologies for heating and cooling in buildings in the EU Member States, according to the EU Strategy for Heating and Cooling report presented to the European Commission in 2016.

Technologies for heating reach from small decentralised applications to large-scale industrial boilers and furnaces and large centralised generation units in district heating networks. Small decentralised technologies include gas and biomass boilers, heat-pumps, individual solar thermal panels and micro-small cogeneration units. Similarly, cooling can be produced in decentralised applications using technologies from small air-conditioning units to large chillers and heat pumps. The capacity used for thermal energy generation ranges from 1 kW or below to several hundred MW units.

The heating and cooling market is fragmented and no single sector has so far emerged either nationally or EU-wide. In its place, heat markets are local markets composed by many different technologies and economic agents (suppliers, installers and builders, engineering companies and energy advisors, energy utilities and energy service companies) selling the heat and cool as a commodity or service, often combined with other services, such as facility management, water and sewage and waste treatment. Heating and cooling are closely linked with other energy markets, in particular fuel and electricity, but also with non-energy markets like, for example, water, waste and technology.

2.1 Heating Technologies

2.1.1 Boilers

Boilers are water heaters that are special-purpose. While furnaces carry heat in the air, boiler systems disperse the heat in warm water, which gives up the heat as it moves through other devices or radiators in rooms throughout the home.. Residential boilers use fuel oil or natural gas for fuel. In steam boilers, which are only used in larger installations and are not common in the residential sector these days, the water is boiled and steam carries heat condensing as it warms to water in the radiators. Gas and oil are used.

Rather than a duct and fan system, a boiler uses a pump to circulate water. Some hot water systems circulate water through plastic tubing in the floor, a system called radiant floor heating. Boiler controllers include valves which regulate water and flow temperature, aquastats, and thermostats. Even though the cost isn’t trivial, it’s generally a lot easier to set up “zone” thermostats and controls for individual rooms with a hydronic system than with forced air. Some controllers are standard features in new boilers, while others may be added on to conserve energy.

2.1.2 Individual stoves and furnaces

They are still an important technology, and have some merits in combination with renewable fuels. Stoves are fuelled by gas, oil, coal and biomass and furnaces using coal, biomass and waste.

2.1.3 Heat Pumps

For climates with moderate heating and cooling needs, heat pumps offer an energy-efficient alternative to furnaces and air conditioners. Like your refrigerator, heat pumps use electricity to move heat from a cool space to a warm space, making the cool space cooler and the warm space warmer. During the heating season, heat pumps move heat from the cool outdoors into your warm house and during the cooling season, heat pumps move heat from your cool house into the warm outdoors. Because they move heat rather than generate heat, heat pumps can provide equivalent space conditioning at as little as one quarter of the cost of operating conventional heating or cooling appliances. There are three types of heat pumps: air-to-air, water source, and geothermal. They collect heat from the air, water, or ground outside your home and concentrate it for use inside.

2.1.4 Cogeneration

Heat- and Power-Cogeneration technologies constitute an important family of heating technologies, which include combined cycle and steam turbines and engines operated on gas, coal or biomass, internal combustion engines using gas, and emerging technologies, such as fuel cells, Stirling engines and Organic Rankine Cycle turbines. While cogeneration is usually applied in large capacities up to 150 MW and above, micro-CHP (often in form of fuel cells) is emerging in the residential sector supplying individual buildings and even apartments.

At the same time, there are emerging alternative fuels, such as biogases, synthetic gases and hydrogen or recovered waste heat, which expand the available range of energy carriers and sources for heating.

2.1.5 Complementary devices

Lastly, modern heating systems include other technologies that are complementary to boilers and are often used to provide more comfort to the users depending on specific needs; these complementary technologies are listed below:

- Heat storage and domestic hot water;
- Intelligent thermal control and communication instruments;
- Radiators and heat exchangers;
- Surface (floor) heating (and cooling);
- Passive heating (and cooling) elements;
- Smart metering and smart homes integrating heating (and cooling) with the wider;
- Technical systems of buildings.

2.2 Cooling Technologies

The cooling sector is quite heterogeneous regarding its technologies and actors. Cooling shows a strong interconnection with the electricity sector because, on the one hand, electricity is used as secondary energy in order to produce cooling (e.g. compression methods) or to satisfy the heat demand (e.g. heat pumps). On the other hand, there is an interaction of cooling with heating. One example of this occurs when heat is used to drive heat driven chillers for the generation of cooling (e.g. tri-generation applications), or when cooling is produced from the waste heat generated in electricity production or industrial processes. Moreover, it is also possible to recover the heat rejected in compression chillers for instance for the pre-heating of hot water. **Cooling** is **mostly supplied from electric devices** removing heat/moisture from air. Conventional cooling technologies include the following

2.2.1 Central air – conditioning units

Can be distinguished as follows:

- *Packaged air conditioning equipment (PAC)*: it includes all direct expansion (DX) systems. PAC are standardised products, with a packaged central unit containing the heat exchanger and compressor – and sometimes the evaporator and condenser as well – all in one cabinet, usually placed on a roof. Multiple split systems, ducted packaged systems and roof-tops are also defined as packaged plants;
- *Central plant air conditioning equipment*: these are usually larger systems based on Chillers. One or more chillers, either water- or air-cooled, are located in a central place and produce cold water. This cold water can be piped either to air handling units, which distribute the cold air within the building through the ventilation system, and/or to individual fan coils, inductor or beams located throughout the building.

Thermally driven "adsorption or absorption" chillers (using fossil fuels, solar thermal, waste energy, biomass, etc.) are a mature technology and use a similar cycle to that of conventional air conditioners. Their efficiencies are lower than electrically driven heat pumps (with coefficients of performance typically in the range 0.7-1.2). High-efficiency absorption chillers, which use mixtures of water and ammonia (or lithium bromide) with natural gas or cogenerated heat sources, could replace traditional electric chillers in buildings with a high demand for cooling and/or heating and air conditioning.

Therefore, the **European market is dominated by electric cooling machines**. However, thermal cooling machines operated with district heating and cooling or waste heat are also present to a limited extent in the high performance, large-scale classes.

2.2.2 District cooling

This technology allows using locally available sources. Often district cooling uses the direct thermal energy, converting heat into cold using waste heat from industry and waste incineration (often via tri-generation) to produce cooling, using heat driven sorption chillers and heat pumps. Electric compression chillers represent also a large portion of many of the existing systems.

The so-called *free cooling,* whereby cold from rivers, lakes and seas is transported directly, or enhanced with heat pumps through pipes, to the end-users (mainly tertiary and public buildings sectors) has been in use since the early nineties and, using ATES (Aquifer Thermal Energy Systems), it is the standard cooling technology used in the Netherland and also in other countries with suitable aquifers (UK, Germany, France) for large scale applications such as airports, hospitals, large offices, etc. (currently district heating is under consideration). Free cooling is best established in Finland, France, Sweden and Spain. District cooling still represents a small portion with a total installed capacity of only 2.4 GW, which is less than 1% of the total installed district heating capacity of 301.5 GW in EU-28 [7].

2.3 Heating and Cooling Technologies

Costs and performance vary widely among heating and cooling technologies and also for each individual technology, because of differences in equipment prices, installation and running costs, different end-use applications, climate, technology specifications, user requirements and building occupation profiles.

The old heating (using coal, oil and wood) and cooling (electrical) equipment installed raise concerns for the air quality and associated health problems that it can cause. In fact, in some parts of Europe, up to three quarters of outdoor fine particulate matter pollution is attributable to household heating with solid fuels (including coal and biomass) [8].

To overcome such problem, Eco-design and energy labelling requirements for space and water heaters came into application in 2015 and the sale of inefficient boilers is now banned. Moreover, consumers can be informed about efficiency ratings, both for single technologies and for packages that include the use of renewables.

The new Regulation 517/2014 on fluorinated greenhouse gases will also accelerate the refurbishment of heating and cooling technologies, pushing towards the use of alternative refrigerants. Indeed, climate-friendly refrigerants offer great energy saving potentials, even though they require, for some applications, an update of the existing standards to ensure their safe use.

A good time to replace an old heating system is when a building is refurbished: transformation to an efficient building makes it possible to shift to heat pumps, solar or geothermal heating or waste heat. These appliances save costs. In addition, there is a number of innovative highly efficient technologies that quickly approach market-readiness, such as stationary fuel cells.

Hence, a wide range of renewable heating and cooling solutions is available and scaling-up the market would reduce their price. The Energy Labelling Directive (2010/30/EU) states that Member State incentives for products, such as heaters, need to reach the highest performance levels.

Cooling comes mostly from electric devices, although there are promising innovative low energy cooling technologies. A recently adopted Eco-design regulation covering cooling products completes the set of requirements for heating and cooling and it will bring fuel savings of 5 Mtoe per year in 2030, corresponding to 9 million tonnes of CO_2 [9].

3 Geothermal GEO4CIVHIC system

3.1 Short description of the stand-alone technologies

Drilling technology

The most promising methodology is the rotary, vibration piling of steel co-axial ground source heat exchangers at depths between 50 – 80 m using a lost drill bit in combination with small quantities of water. Good drilling speed is achieved in soft to medium formations, using small machines with moderate torque. This methodology and the co-axial heat exchangers efficiencies are studied in H2020 projects Cheap-GSHPs and GEOTeCH with several GEO4CIVHIC consortium partners participating. Results are encouraging but with some limitations in gravel type undergrounds. The objective now is to progress this technique further by developing a small but more powerful vibration-rotation drilling head to increase the drilling speed and extend the application to almost all soil types. This new head will be integrated in a compact drilling machine to facilitate operation in confined spaces. Additional operator aids will reduce the dead times inherent to the mounting/dismounting of casings and shafts. These developments will aim to a further reduction of drilling costs by at least 30 %.

Co-axial heat exchangers

Co-axial heat exchangers have higher thermal performances than state of art double U's. Co-axial heat exchangers out of stainless steel with their lower borehole resistance extract 10 – 20 % more energy from the underground. Design improvements (larger diameter, insulated inner tube, helicoidally shaped vanes) are further increasing this gap. An increase in diameter from 50 mm to 80 mm has shown in simulations a yield increase of 12 – 13 % and is being tested under real load conditions in the field. It is now possible with the powerful vibration-rotation method to increase the tube diameter further up to 100 mm and the borehole diameter to 130–150 mm without impacting much on installation speed and possibly depth. There are positive (larger heat exchange surface, higher thermal capacity) and negative aspects (laminar versus turbulent flow, larger pumps and electrical consumption, higher material costs, depth).

The outcome of running projects (i.e. internally insulated tube and helicoidally shaped vanes from GEOTeCH and Cheap- GSHPs; plastics and grout with higher thermal conductivity from GEOCOND and use of Phase Change Materials from TESSE2b) will be integrated in the design based on the results from field demonstrations. Finally, the most recent high conductivity grout will further enhance the thermal performance since there is no danger of thermal bridging losses with co-axial heat exchangers.

Dual source heat pump for high and low temperatures

Condensing gas boilers are usually installed today in renovations. They have low initial costs, but do not use renewable energy and cannot provide cooling (direct expansion air-conditioners are used instead). The heat pump uses renewable energies and provides cooling as well. Cooling demand is on the rise, even in more Northern climates due to much better insulated buildings (internal heat gains), demand for comfort and climate change. Heat pumps are one of the main solutions in the drive to use more renewable energy for heating and cooling. Air to water heat pumps sales exceed in a ratio 2/1 the sales of water to water types from water or ground sources. The reason is the lower investment cost for the entire system despite higher operation costs due to a lower energy efficiency.

In deep retrofits reaching NZEB status, the stakeholders ask for low cost, compact, easy to install HVAC plants of low capacity (3-6 kW). Such heat pumps are not readily available on the market due to the lack of appropriate components, mainly compressors. The available space in city centers and the lower efficiencies may limit the use air-to-water heat pumps especially in multi-user buildings. Therefore, GEO4CIVHIC will develop a small-size geothermal heat pump named “Plug&Play”. 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.

Heat pumps operating at medium/high temperatures (50 – 70 °C) with good yields is another topic in renovations to avoid costly replacement of radiators (or not feasible in historic buildings for conservation reasons). Heat pumps using low-pressure refrigerants (like R134a) do not have good yields since the compressors on the market are not optimized for these working conditions. A two-step heat pump using CO2 as one of the refrigerants was developed and is being tested in Cheap-GSHPs. The machine will be improved further based on the learnings from the demonstration case in Cheap-GSHPs, in particular the control strategy optimization. This second generation machine will have a higher COP and address the application in a partial retrofit in historical buildings and others when part of the terminals are changed to low temperature but the radiators remain at high temperature.

Dual source pumps (i.e. air and ground) were recently introduced to reduce demand from the soil and to increase overall efficiency. Its application is still limited since the concepts and controls for their design are not yet very well known. This dual source heat pump will be operated and analysed in the heat pump research center of Galletti, which is also a demo site in GEOTeCH. The second generation of these pumps will thus have improved controls.

Finally, the both heat pump concepts, dual source and high temperature will be combined in a solution to reduce installation costs (less geothermal demand, hence less drilling costs) and to achieve good performances at high temperature.

3.2 Integrated GEO4CIVHIC system

Market and business innovations will be defined in further documents to exploit the main stand-alone products developed within the project. This is however not enough to really assess the GEO4CIVHIC added value. In fact, considering that all the GEO4CIVHIC technologies are designed to be easily integrated, one important added value of the GEO4CIVHIC is to provide the market with an integrated shallow geothermal system, suitable for heating/cooling of existing and historical buildings analysed in this project.

4 Typology and characteristics of European buildings

Buildings in Europe vary remarkably in terms of their function type. They can be broadly divided into residential and non-residential sectors where each sector alone consists of multiple types. The general tendency is to seek larger floor spaces over time, especially under favourable economic conditions. With increasing trends in floor space, the energy demand associated with buildings is also increasing, which in turn highlights the need for improving the energy efficiency of our current stock, especially that of older stock.

4.1 Residential buildings

The residential sector is the biggest segment with an EU floor space of 75% of the building store (Figure 4.1). Within the residential sector, different types of single family houses (e.g. detached, semi-detached and terraced houses) and apartment blocks are found.

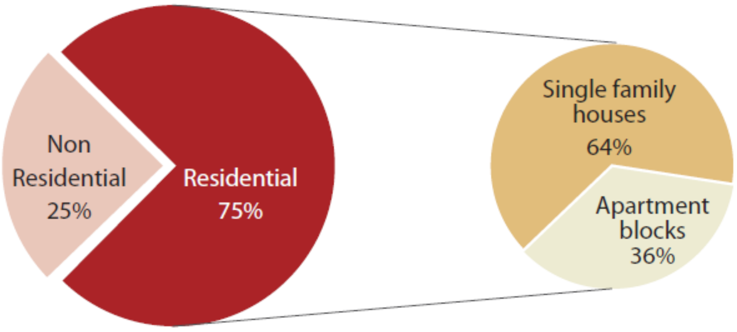


Figure 4.1 Floor space of residential building store in Europe

Energy in households is mainly consumed by heating, cooling, hot water, cooking and appliances where the dominant energy end-use in homes is space heating. The strong correlation between heating degree-days and fuel consumption emphasises the link between climatic conditions and use for heating as the year-to-year fluctuations in heating consumption largely depend on the climate of a particular year. The significant increase in use of appliances in households is also evident through the steady increase in electricity consumption.

Gas is the most common fuel in Europe. The highest use of coal in the residential sector is found in Central & Eastern Europe where the largest share is used in Poland. Oil use is highest in North & West Europe where Germany and France are the biggest consumers (inevitably due to the size of these countries). District heating is most common in Central & Eastern Europe. Space heating is the most energy intense end-use in EU homes and accounts for around 70% of our total final energy use. The energy mix for heating consumption is an indicator for the overall performance of a building and the breakdown of the heating energy.

Heating system and building envelope, climatic conditions, behavioural characteristics (e.g. typical indoor temperatures) and social conditions (e.g. fuel poverty meaning that not all buildings are used at maximum capacity). Despite different improvements in, for instance, heating systems, there is still a large saving potential associated with residential buildings that has not been exploited. These technologies are easily implemented in new buildings, but the challenge is mostly linked to our existing stock which forms the vast majority of our buildings.

The oldest part of the building stock contributes greatly to the high energy consumption in the building sector. Older buildings tend to consume more due to their low performance levels.
It is clear that the largest energy saving potential is associated with the older building stock. This is a trend observed in all countries where in some cases buildings from the 1960s are worse than buildings constructed in the years before that.

Moreover, although heating needs in Southern countries such as Portugal and Italy are lower due to milder winters, the energy use in these countries is relatively high, which can be an indication of lack of sufficient thermal envelope insulation in their building stocks. For those countries, cooling becomes an important contributor to the overall consumption, where homes are, in many cases, equipped with air-conditioning systems.

In addition to the lack of sufficient thermal insulation, gaps at connection points between different elements of a building envelope (e.g. window frame and surrounding wall) can lead to considerable energy wastage. This highlights the importance of appropriate air tightness levels in a building. A building with high air tightness levels typically suffers from high energy consumption levels while a building with very high air tightness levels can cause unhealthy conditions for its occupants, especially if there is inadequate ventilation. Establishing the appropriate level of air tightness in buildings is, therefore, a key aspect from the viewpoints of energy usage and comfortable occupant conditions.

4.2 Non-Residential buildings

The diversity in terms of typology within the non-residential sector is vast. Compared to the residential sector, this sector is more complex and heterogeneous. It includes types such as offices, shops, hospitals, hotels, restaurants, supermarkets, schools, universities and sports centres while in some cases multiple functions exist in the same building. In addition to this, differences are also pronounced within this sector where there is no homogeneity in terms of size, usage pattern (use hours) and construction style.
Office buildings are the second biggest category with a floor space corresponding to ¼ of the total non-residential floor space. Offices have similar heating and cooling conditions to residential buildings although they are of shorter use. Similar usage pattern as offices are found with educational buildings which count for less than 20% of the entire non-residential floor space. Hospitals have continuous usage patterns, where energy demand can vary substantially depending on the services provided (from consultation rooms to surgery rooms).
Understanding energy use in the non-residential sector is complex as end-uses such as lighting, ventilation, heating, cooling, refrigeration, IT equipment and appliances vary greatly from one building category to another within this sector.

Over the last 20 years in Europe electricity consumption in European non-residential buildings has increased by a remarkable 74%. This is compatible with technological advances over the decades where an increasing penetration of IT equipment, air conditioning systems etc. means that electricity demand within this sector is on a continuously increasing trajectory.

Construction techniques of non-residential buildings are in large similar to those in residential buildings. While the energy performance discussion for the residential buildings above applies also to the non-residential sector (hence similar renovation measures should be considered), the installation of smart energy management systems in non-residential buildings becomes more important due to their high share of electricity use.

4.3 Characteristics of buildings

In addition to typology, buildings vary greatly in terms of age, size and location. These are discussed in more detail below.

Age

Buildings across Europe are associated with different time periods dating even before the 1900s. Historical buildings certainly have a significant heritage value while construction techniques and building regulations such as building codes imposed at the design phase have a great influence on the energy performance of a building built in a specific period.

In the residential sector, the age of a building is likely to be strongly linked to the level of energy use for the majority of buildings that have not undergone renovation to improve energy performance. The BPIE survey has classified buildings in different age bands (specific chronological periods) for each country. In order to allow some comparison between the age profiles of the residential building stock of different countries, the floor area data for each country has been consolidated into three representative age bands:

- Old: typically representing buildings up to 1960
- Modern: typically representing buildings from 1961 to 1990
- Recent: typically representing buildings from 1991 to 2019

The specific energy use within these age bands is likely to differ between countries in different regions of Europe due to a number of political, economic and social factors. The variations in the age profile between the regions appear to be small where older buildings (before 1960) have the biggest share in the North & West region of Europe. In particular, the countries with the largest components of older buildings are the UK, Denmark, Sweden, France, Czech Republic and Bulgaria. It is also evident that all countries experienced a large boom in construction in the 'modern' period (1961-1990) and with a few exceptions, the housing stock more than doubled in this period.

According the International Existing Building Code (IEBC) an historic building is any building or structure that is one or more of the following:

- Listed, or certified as eligible for listing, by the state historic preservation officer or the keeper of national register of historic places, in the national register of historic places
- Designed as historic under an applicable state or local law
- Certified as a contributing resource within a national register, state designated or locally designed historic district.

Defining renovation levels and associated costs

Type of Renovation	Reference	Definition/Measures
Minor	BPIE [10]	It reduces final energy consumption up to 30% implementing from one to three improvement measures (e.g., new boiler plant, wall/roof insulation, windows), with an average total project cost of 60 €/m^2.
Moderate	BPIE	It involves from three to five retrofit improvements resulting in energy reductions in the range 30%–60%, with an average total project cost of 140 €/m^2.
Deep	EED [11]	It reduces both the delivered and the final energy consumption by a significant percentage compared with the pre-renovation level leading to a very high energy performance.
	European Parliament Report 2012 [12]	It reduces both the delivered and the final energy consumption of a building by at least 80% compared with the pre-renovation level.
	Commission SWD (2013) [13]	Significant efficiency improvements, typically more than 60%.
	GBPN [14]	Reduction in energy consumption for heating, cooling, ventilation and hot water of 75% or more.
	Entranze Consortium [15]	Renovation level implementing high-grade refurbishment packages (e.g., 30, 20 and 15 cm of insulation on roof, walls and basement; very efficient heating/cooling generators; heat recovery strategies).
	Zebra 2020 Project [16]	Deep thermal renovation with more than two improved thermal solutions (e.g., efficient heating plus insulation of wall/roof, etc.)
	BPIE	It adopts a holistic approach, viewing the renovation as a package of measures working together, resulting in energy reductions in the range 60%–90%, with an average total project cost of 330 €/m^2.
Major	EPBD [17]	Renovation of a building where: (a) the total cost of the renovation relating to the building envelope or the technical building systems is higher than 25% of the value of the building, excluding the value of the land upon which the building is situated; (b) more than 25% of the surface of the building envelope undergoes renovation.
NZEB	EPBD	Renovation that leads to a building that has a very high energy performance. The nearly zero or very low amount of energy required should be covered to a very significant extent by energy from RES, including energy from RES produced on-site or nearby.
	BPIE	It leads to more than 90% final energy saving, with an average total project cost of 580 €/m^2.

Table 1 Definition of renovation level and associated costs

Ownership and tenure

The ownership of buildings have a bearing on the rate at which renovations are undertaken and the depth of the energy savings measures that may be included in renovation projects. Arguably, the public sector should be taking the lead in 'deep renovations' and its large portfolio of buildings provides many opportunities for economies of scale. Private owners may be reluctant to act early and may require encouragement, incentives and regulations to stimulate reasonable rates and depths of renovation. Data was sought on the division of ownership in residential and non-residential buildings between the public and the private sector of the EU27 together with Switzerland and Norway. Analysis of the data provided on the split between public and private ownership of residential buildings revealed that across the 23 countries from which data was available the largest share is held in private ownership while 20% is allocated to 'pure' public ownership.

Location

The location of buildings is of interest as typically the willingness and ability to take up renovation measures to improve energy performance can be affected by a number of factors including the location of a building. In the urban environment, economies of scale will come into play with large-scale renovation programmes able to act on streets, districts and localities. In rural environments, projects may be more widespread and hence benefit from economies of scale to a lesser extent while labour rates are often lower in these areas.

These findings should be considered in conjunction with the relevant occupancy patterns for rural and urban areas as rural areas are typically less populated meaning that the permanent occupancy rate in these areas is lower.

5 Climates

Climate is the average or general weather conditions of an area, taken over a long period of time. To know about climate, you have to look over a large area and watch that area over many years. In the same way, climate change is about weather patterns occurring over multiple decades.

Europe is a huge area of land. It might look small on a map, but map projections can be deceiving. Europe is 3.931 million square miles. Since it's such a huge area, it's also similarly varied in climate: there are at least eight distinct climates in Europe. These climates include semiarid, Mediterranean, humid subtropical, marine, humid continental, subarctic, tundra and highland climates. In general terms the climate of Europe varies from subtropical (warm) to polar (cold). The Mediterranean climate of the south is dry and warm. The western and northwestern parts have a mild, generally humid climate, influenced by the North Atlantic Drift. In central and eastern Europe the climate is of the humid continental-type with cool summers. In the northeast subarctic and tundra climates are found. All of Europe is subject to the moderating influence of prevailing westerly winds from the Atlantic Ocean and, consequently, its climates are found at higher latitudes than similar climates on other continents. The Köppen climate classification is one of the most widely used climate classification systems and it is presented in the following figure.

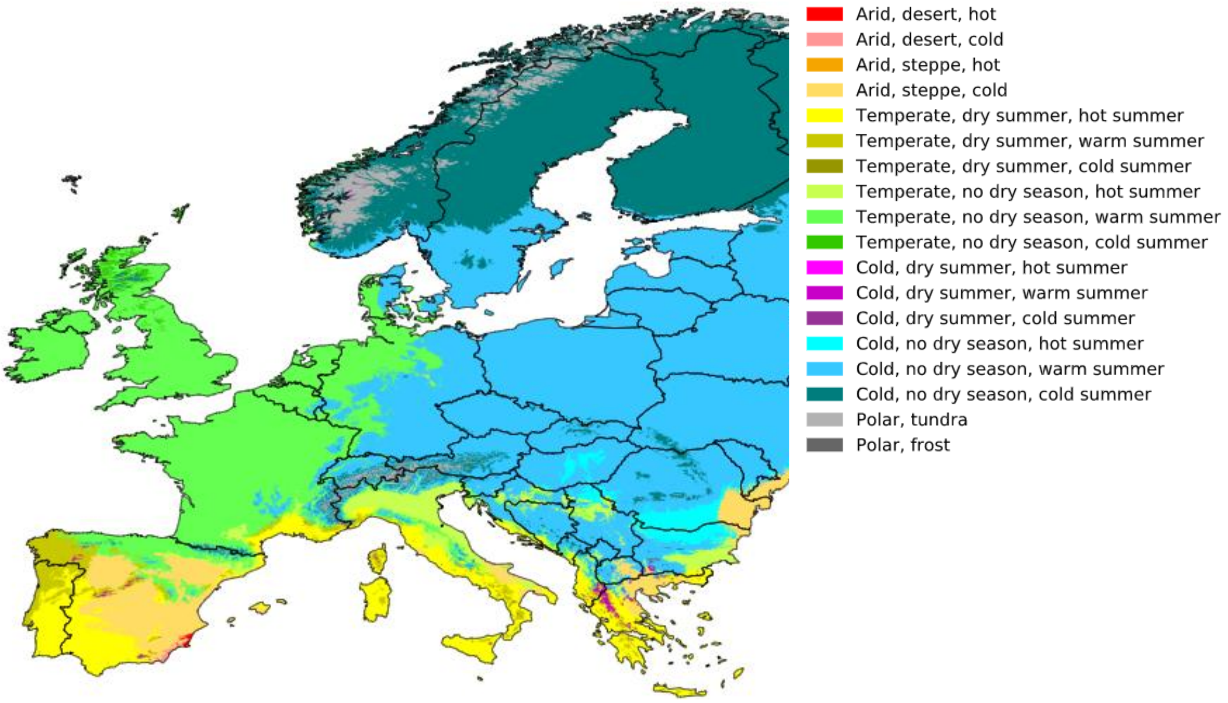


Figure 5.1 Köppen-Geiger climate classification map for Europe (1980-2016), Source: Beck H. E., *et al.* 2018

The Köppen climate classification divides climates into five main climate groups, with each group being divided based on seasonal precipitation and temperature patterns. The five main groups are A (tropical), B (dry), C (temperate), D (continental), and E (polar).

Group A: Tropical (megathermal) climates

This type of climate has every month of the year with an average temperature of 18 C or higher, with significant precipitation.

Group B: Dry (arid and semiarid) climates

This type of climate is defined by little precipitation.

Multiply the average annual temperature in Celsius by 20, then add

a) 280 if 70% or more of the total precipitation is in the spring and summer months (April–September in the Northern Hemisphere, or October–March in the Southern), or
b) 140 if 30%–70% of the total precipitation is received during the spring and summer, or
c) 0 if less than 30% of the total precipitation is received during the spring and summer.

If the annual precipitation is less than 50% of this threshold, the classification is arid: desert climate; if it is in the range of 50%–100% of the threshold, the classification is semi-arid: steppe climate.

Group C: Temperate (mesothermal) climates

This type of climate has the coldest month averaging between 0 C or −3 C and 18°C and at least one month averaging above 10 C.

Group D: Continental (microthermal) climates

This type of climate has at least one month averaging below 0 C or −3 C and at least one month averaging above 10 C.

Group E: Polar and alpine (montane) climates

This type of climate has every month of the year with an average temperature below 10 C.

<u>Climatic zones in Europe regarding the energy performance of buildings</u>

The energy behaviour of the building unit follows in general terms the trend indicated by the amount of Heating Degree Days (HDD) and Cooling Degree days (CDD). The classification of climatic zones on the basis of both heating and cooling degree days leads to more realistic results, since nowadays cooling needs form a substantial part of the energy balance of the building, especially in the Mediterranean regions. HDD and CDD are a measure to estimate energy demand for heating/cooling building interiors. The indicator is calculated based on accumulated difference between outdoor air temperatures below (above) some reference base temperature. Although the approach is based solely on the amount of heating and cooling degree days and is mainly building orientated, its application in the examined cities (Figure 5.2) leads to a classification with significant similarities with the maps produced on the basis of Köppen climate classification found in relevant literature [18].

Figure 5.2 The geographical distribution of selected cities and their classification into climatic zones on the basis of CDD and HDD approach. Source: K. Tsikaloudaki et al. Energies 2012, 5.

6 Undergrounds

6.1 General information

The initial base maps of surface geological units were taken from the *EuroGeoSurveys' European Geological Data Infrastructure - EGDI* web portal (www.europe-geology.eu), which collects and expands the information previously contained in the *OneGeologyEurope webportal* (www.onegeology-europe.org). The EGDI provides access to pan-European and national geological datasets and services from the Geological Survey Organizations of Europe.

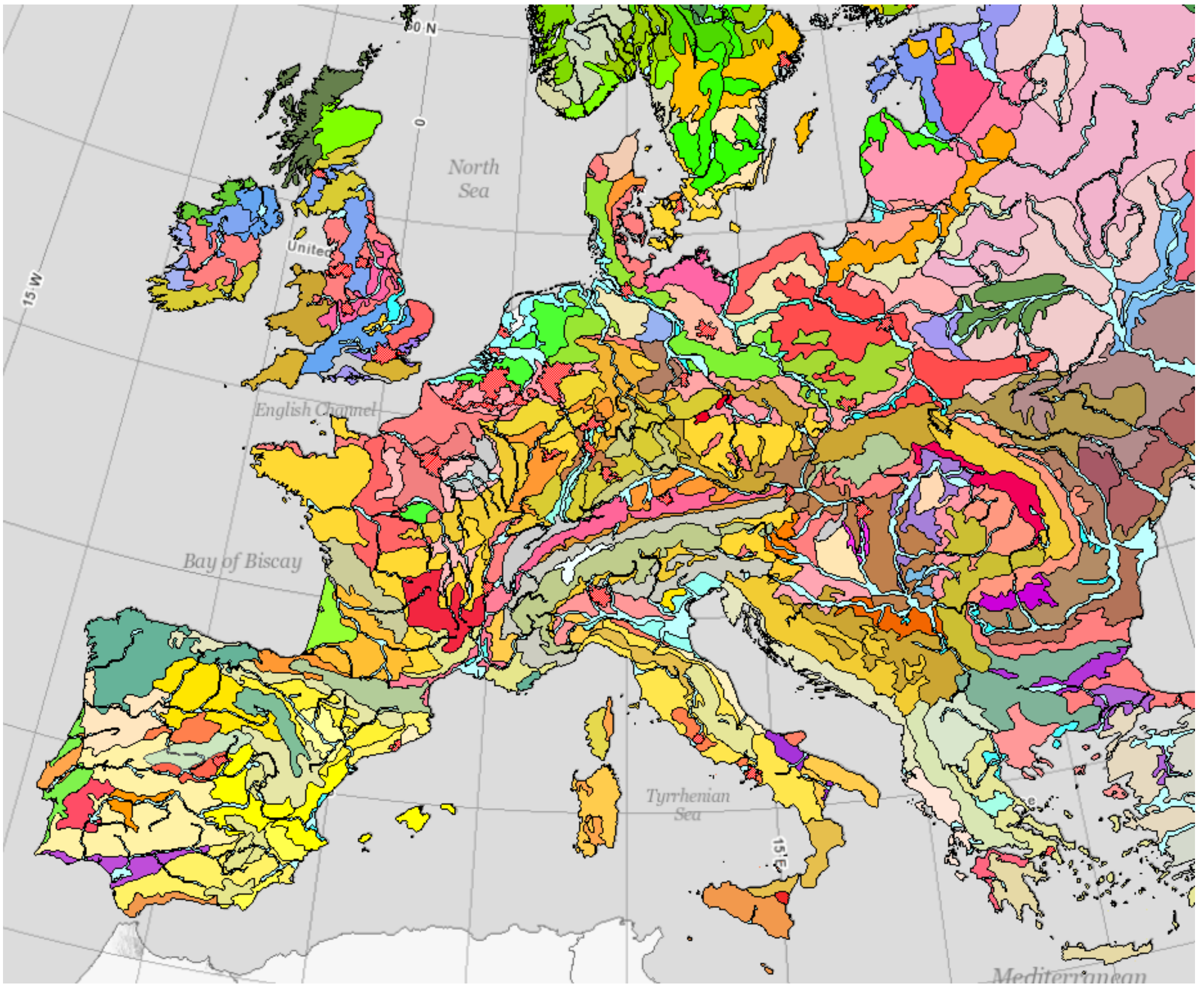


Figure 6.1 Map of the soil regions of Europe (1: 5M). Source: EuroGeoSurveys' European Geological Data Infrastructure (EGDI)

The complete set of colours identifying the different geological units presented in the geological maps is presented in Table 2 below.

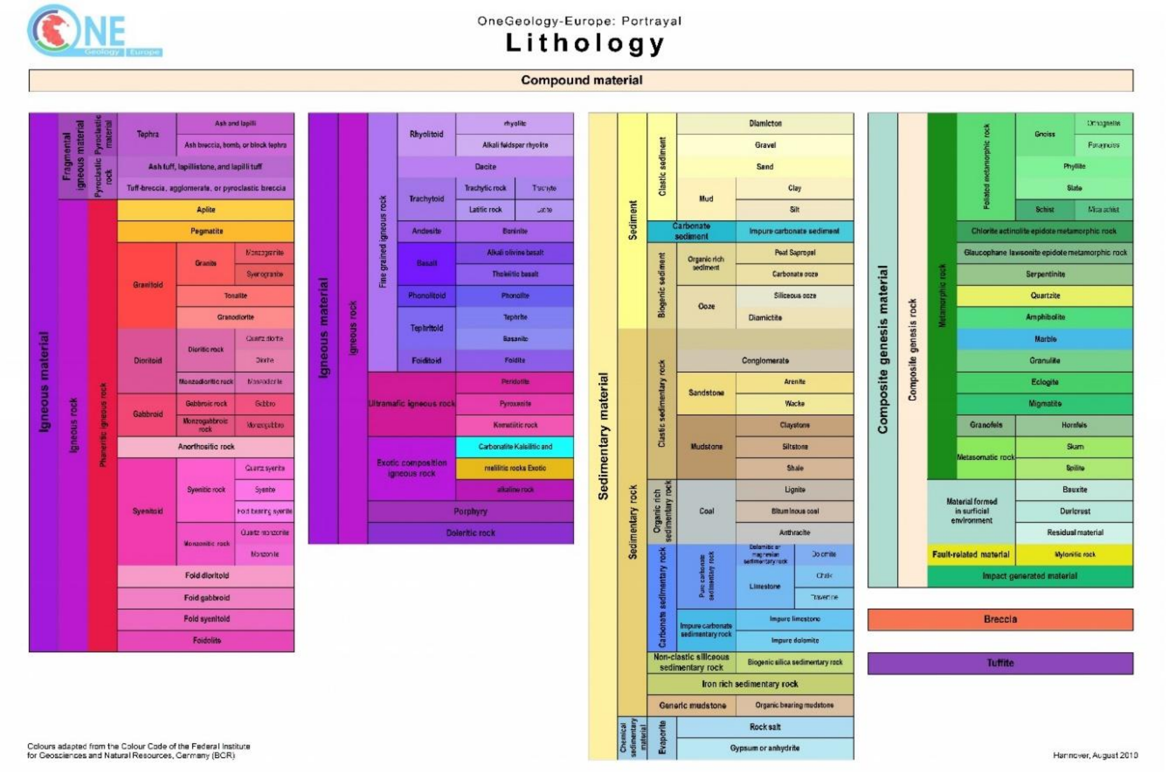


Table 2 Set of colours identifying lithology used in OneGeology-Europe webmaps.

Hydrology

The hydrogeology information influences both the drillability of auger technology in sediments and rocks and the heat transfer between the ground and innovative ground heat exchangers. Quantitative hydrogeological data (static and dynamic levels of European aquifers) is considered too fragmented and collected at different working scales (province and district levels). The following Information in this work derives from the published International Hydrogeological Map of Europe 1:1.500.000 (IHME1500) (BGR&UNESCO, 2014).

The dataset geolocalizes and classifies the aquifers in the following manner:

- Highly productive porous aquifers;
- Low and moderately productive porous aquifers;
- Highly productive fissured aquifers (including karstified rocks);
- Low and moderately productive fissured aquifers (including karstified rocks);
- Locally aquiferous rocks, porous or fissured;
- Practically non-aquiferous rocks, porous or fissured.

Inland water and snow field/ice field are two additional classification possibilities in the presence of lakes, rivers or glaciers.

The Hydrogeological map of Europe (*Figure 6.2*) does not include the northern part of Scandinavia or some zones of European Cyprus.

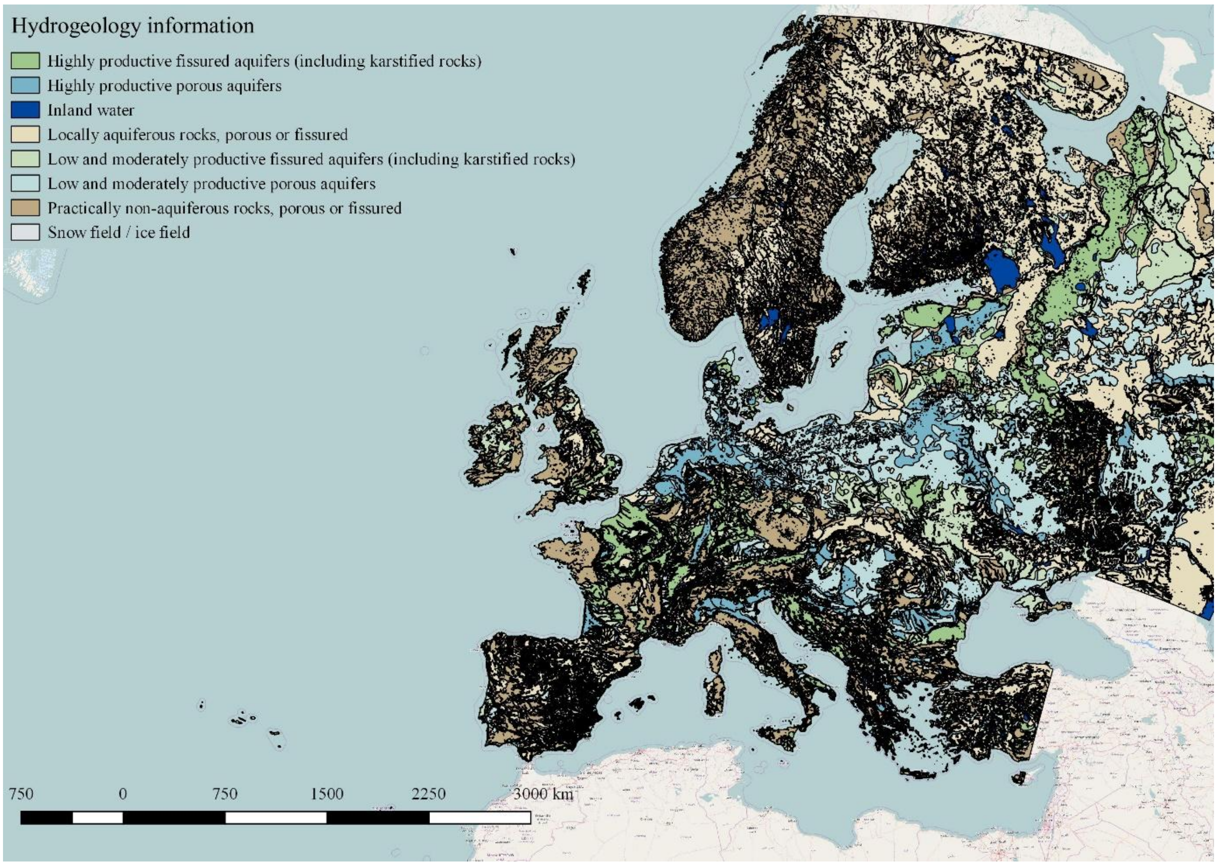


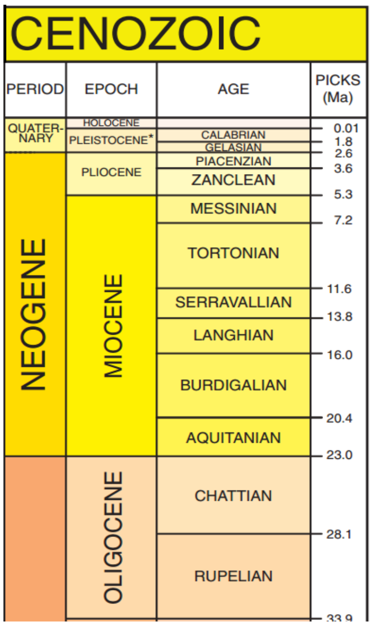
Figure 6.2 Hydrogeological Map of Europe (Redrawn from BGR&UNESCO, 2014)

Bedrock depth

The subsurface layers of the earth can be divided into soil, intact regolith (unconsolidated materials) and un-weathered bedrock. These layers are affected by different parameters such as hydrogeology, biochemical processes, climate and geomorphology. Accurate land surface modelling of the energy, water, carbon cycle and dynamic vegetation requires information on subsurface layer thickness and bedrock depth (Pelletier et al., 2016). Bedrock depth can be identified from the age of the geological layers and/or the type of materials. For the purposes of the GEO4CIVHIC project, bedrock depth is important because it provides:

- A preliminary indication of the hypothetical drilling depth of the auger.
- A preliminary indication of heat transfer between the ground and the heat exchanger.

Sedimentary deposit thickness maps were gathered from a gridded global dataset of soil (~1 × 1 km), intact regolith, and sedimentary deposit thicknesses for regional and global land surface modelling (https://daac.ornl.gov/, [19]) on the basis of both the geological age of the bedrock layers and the type of materials. Unconsolidated materials (including soil on upland hill slopes and sedimentary deposits in valley bottoms) were allocated an average value in order to define the depth-of-bedrock map, distinguishing between unconsolidated and consolidated deposits. The boreholes used for mapping were those that penetrated Miocene or younger geological units to reach the head of the bedrock. Other boreholes penetrating geological units older than Miocene units (the bedrock) were also used in the calculation. Table 3 below reports the geological ages used to identify the thickness of sediments and bedrock depth.



CENOZOIC

PERIOD	EPOCH	AGE	PICKS (Ma)
QUATER-NARY	HOLOCENE		0.01
	PLEISTOCENE*	CALABRIAN	1.8
		GELASIAN	2.6
NEOGENE	PLIOCENE	PIACENZIAN	3.6
		ZANCLEAN	5.3
	MIOCENE	MESSINIAN	7.2
		TORTONIAN	11.6
		SERRAVALLIAN	13.8
		LANGHIAN	16.0
		BURDIGALIAN	20.4
		AQUITANIAN	23.0
	OLIGOCENE	CHATTIAN	28.1
		RUPELIAN	33.9

Table 3 Geological time scale considered to identify sediment thickness

In sedimentary thickness maps, the layer over the bedrock is considered unconsolidated material with a higher porosity than the bedrock. Figure 6.3 shows the sedimentary thickness map as indicated above, i.e. based on soil thickness, intact regolith, and sedimentary deposits up to 50 m in thickness.

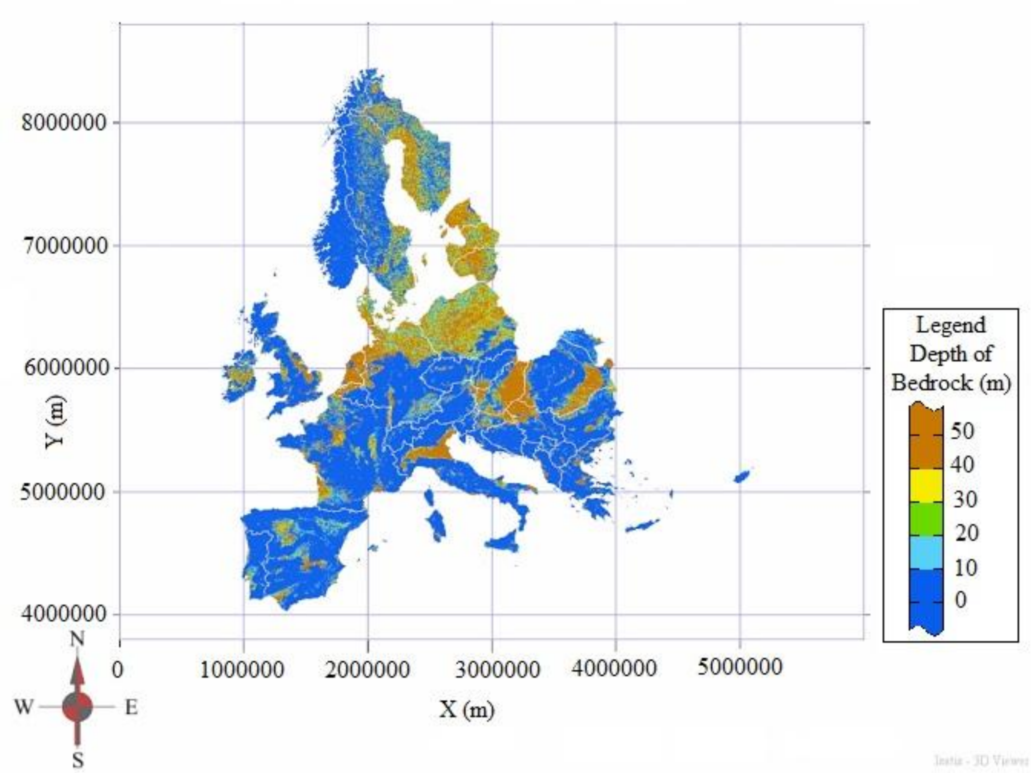


Figure 6.3 Sedimentary thickness map (Pelletier et al., 2016), redrawn for Europe

7 Countries and archetypes under study

In order to perform a preliminary cost study across Europe this document has taken into account information provided by different partner from different countries regarding levels of renovation, buildings, climates and undergrounds.

Related Costs (material and installation as well as running operational and maintenance costs) to each installed solution (one design for traditional solution and one for GSHP solution) have been provided by related partners and they are presented in the following tables.

7.1 European countries' description

This report have considered the following countries that the consortium comes from and they cover all the different type of climes described previously and on the top of this all these countries reflects the types of building which the project is interested on.

Country	Type of Building	Surface [m2]	Status	Renovation Level	Climate
Spain	Multifamily Residential	807	Existing	Moderate	Zone B
Italy	Non-Residential	16654	Historic	Deep	Zone B
Belgium	Non-Residential	170	Existing	Deep	Zone D
Greece	Non-Residential	450	Existing	None	Zone D
Malta	Non-Residential	64,79	Historic	Deep	Zone A
Ireland	Single family Residential	165	Historic	Minor	Zone C
Netherlands	Multifamily residential	4176	Existing	Deep	Zone E

Spain

Most of Spain's area is located in southwestern Europe on the mainland of the country that is south of France and the Pyrenees Mountains and east of Portugal. Most of the topography of Spain consists of flat plains that are surrounded by rugged, undeveloped hills. The northern part of the country, however, is dominated by the Pyrenees Mountains.

The climate of Spain is temperate with hot summers and cold winters inland and cloudy, cool summers and cool winters along the coast. Madrid, located inland in the center of Spain, has an average January low temperature of 3˚C and a July average high of 31˚C. The building characteristics taken into account in this study is presented on the tables below.

Building Characteristics	Building Type	Multifamily House	
	Building Use	Residential	
	Building Status	Existing Building	
	Heating/Cooling surface	807	m2
	Existing Heating Technology	Gas Boiler	
	Existing Cooling technology	Electric elements	

Intervention	Renovation Level	Installation System	Heating	Cooling
Pre-Intervention	NONE	Gas Boiler	✓	
		Electric elements		✓
Post-Intervention Traditional System	Moderate	Gas boiler	✓	
		Electric elements		✓
Post-Intervention GSHP System	Moderate	GSHP	✓	✓

Italy

Italy is a Mediterranean country located in southern Europe. Italy is known for its Mediterranean climate, which is found mainly on the coast. Inland it is generally cooler and wetter but usually hotter during the summer. Southern Italy has a hot and mostly dry climate while the north has more of an Alpine climate, getting lots of snow in winter. The building characteristics taken into account in this study is presented on the tables below.

Building Characteristics	Building Type	Class rooms and Offices	
	Building Use	Non-Residential	
	Building Status	Historic Building	
	Heating/Cooling surface	16654	m2
	Existing Heating Technology		
	Existing Cooling technology		

Intervention	Renovation Level	Installation System	Heating	Cooling
Pre-Intervention	NONE			
Post-Intervention Traditional System	Deep	Gas Boiler	✓	
		Heat Pump		✓
Post-Intervention GSHP System	Deep	GSHP	✓	✓

Belgium

Belgium is situated in the west of Europe, the geography of Belgium shows it to have three major areas: lower Belgium (up to 100m above sea level), central Belgium (between 100 and 200m above sea level) and upper Belgium (from 200 to over 500m above sea level). Belgium has a temperate maritime climate influenced by the North Sea and Atlantic Ocean, with cool summers and moderate winters. Since the country is small there is little variation in climate from region to region, although the marine influences are less inland. The building characteristics taken into account in this study is presented on the tables below.

Building Characteristics	Building Type	Office building/laboratories	
	Building Use	Residential	
	Building status	Existing building	
	Heating/Cooling surface	170	m2
	Heating Technology	Gas Boiler	
	Cooling technology	N/A	

Intervention	Renovation Level	Installation System	Heating	Cooling
Pre-Intervention	NONE	Gas Boiler		
Post-Intervention Traditional System	Deep	Condensing Gas Boiler	✓	
		Fan Coils		✓
Post-Intervention GSHP System	Deep	GSHP	✓	✓

Greece

Greece is located in Southern Europe, bordering the Ionian Sea and the Mediterranean Sea, between Albania and Turkey. It is a peninsular country, with an archipelago of about 3,000 islands. Greece is a mostly mountainous country with a very long coastline, filled with peninsulas and islands. The climate can range from semi-desert to cold climate mountain forests. The building characteristics taken into account in this study is presented on the tables below.

Building Characteristics	Building Type	Museum	
	Building Use	Non-Residential	
	Building status	Existing building	
	Heating/Cooling surface	465	m2
	Heating Technology	Electric Elements	
	Cooling technology	Heat pump	

Intervention	Renovation Level	Installation System	Heating	Cooling
Pre-Intervention	NONE			
Post-Intervention Traditional System	Moderate	Electrical elements	✓	✓
Post-Intervention GSHP System	Moderate	GSHP	✓	✓

Malta

Malta is dominated by water. Malta is an archipelago of coralline limestone, located in the Mediterranean Sea. The country is approximately 316 km2 in area. Numerous bays along the indented coastline of the islands provide harbours. The landscape of the islands is characterised by high hills with terraced fields. Malta has a Mediterranean climate according to the Köppen climate classification, with very mild winters and warm to hot summers. Rain occurs mainly in winter, with summer being generally dry. The building characteristics taken into account in this study is presented on the tables below.

Building Characteristics	Building Type	Museum	
	Building Use	Non-Residential	
	Building status	Historic building	
	Heating/Cooling surface	64,79	m2
	Heating Technology	Electric Elements	
	Cooling technology	Heat pump	

Intervention	Renovation Level	Installation System	Heating	Cooling
Pre-Intervention	NONE			
Post-Intervention Traditional System	Deep	Electric Elements	✓	✓
Post-Intervention GSHP System	Deep	GSHP	✓	✓

Ireland

Ireland is an island in Northwestern Europe in the North Atlantic Ocean. The island lies on the European continental shelf, part of the Eurasian Plate. The island's main geographical features include low central plains surrounded by coastal mountains. The climate of Ireland is mild, moist and changeable with abundant rainfall and a lack of temperature extremes. Ireland's climate is defined as a temperate oceanic climate, a classification it shares with most of northwest Europe. The building characteristics taken into account in this study is presented on the tables below.

Building Characteristics	Building Type	Single family house	
	Building Use	Residential building	
	Building status	Historic building	
	Heating/Cooling surface	165	m2
	Heating Technology	Gas Boiler	
	Cooling technology		

Intervention	Renovation Level	Installation System	Heating	Cooling
Pre-Intervention	NONE			
Post-Intervention Traditional System	Minor	Gas Boiler	✓	
Post-Intervention GSHP System	Minor	GSHP	✓	✓

Netherlands

The Netherlands is a very flat country with almost 25% of its land at, or below sea level. Low rolling hills cover some of the central area, and in the far south, the land rises into the foothills of the Ardennes Mountains. Vaalserberg, the country's highest point is located there, rising to 322 m. The Netherlands have a temperate maritime climate influenced by the North Sea and Atlantic Ocean, with cool summers and moderate winters. Daytime temperatures varies from 2°C-6°C in the winter and 17°C-20°C in the summer. The building characteristics taken into account in this study is presented on the tables below.

Building Characteristics	Building Type	Apartment block	
	Building Use	Residential	
	Building status	Existing	
	Heating/Cooling surface	4176	m2
	Heating Technology	Gas Boiler	
	Cooling technology	Fan Coil	

Intervention	Renovation Level	Installation System	Heating	Cooling
Pre-Intervention	NONE			
Post-Intervention Traditional System	Minor	Gas boiler	✓	
		air to water chiller		✓
Post-Intervention GSHP System	Minor	GSHP	✓	✓

7.2 Archetypes' description

In parallel this study is based on the considered buildings selected in Task 1.3, on a design which will consider different insulation levels and HVAC system, based on indications of national costs and on energy results from Deliverable D1.3.

Statistical analysis of the most significant parameters defining the building allow the definition of the archetypes, grouping them based on similarities. Archetypes' definition must be representative of the most common typology of buildings in the urban environment for all European countries, in order to define the barriers and the problems related to the built environment.

The objective of these models is the rapid evaluation of the energy demand of a wide building stock to allow the development of new strategies and technologies to reduce the energy consumption and increase the energy efficiency. The GEO4CIVHIC project focuses on the European urban areas, considering a typical range of energy demand of existing buildings from 90 kWh/(m^2 year) to 300 kWh/(m^2 year) depending on the climate.

The first definition clarifies the difference between "existing buildings", which regards the ones which are neither historical nor buildings of heritage significance built after 1960s, and "historical", built before 1960s that usually (but not always) allow only partial retrofit. Moreover, buildings dated later than 1990 have not been included in the analysis because they are either not present or limited present in urban and confined environments, which are the target of the project to increase the installation and application of GSHPs in retrofit strategies for buildings.

The same boundary conditions have been chosen concerning geometry, envelope, orientation, heating and cooling energy systems, end-use and so on, in order to obtain comparable results as output of the energy analysis. For example, the apartment block has been defined as a sum of single housing unit with common stairwells.

Once this information had been collected, the extrapolation of the archetypes has been based on the most frequent type of construction, defining the geometric characteristics as average between all the buildings associated within that archetype.

According to European building stock in an urban context the main representative types of buildings are linear buildings, which have been divided for our purpose in two main archetypes [20].

- Terraced House (TH), which contain more land-to-sky buildings with one or two floors (Figure 7.1a).
- Apartment Blocks (AB) represented by typical construction of the popular neighborhood (Figure 7.1b)

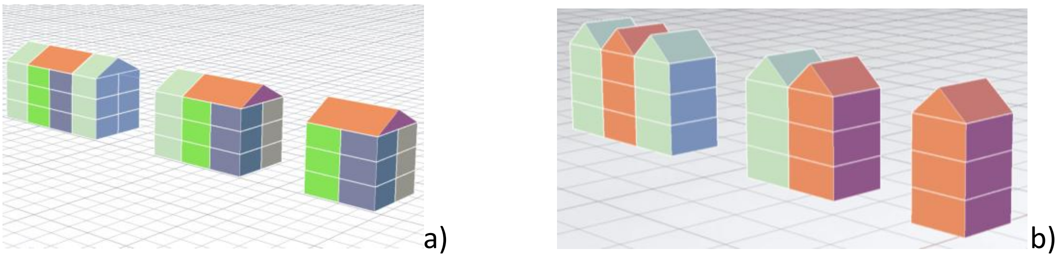


Figure 7.1 Possible solutions for apartment blocks (a) and terraced house (b)

Even if in literature four different building typologies have been found (apartment block, single family house, multi-family house and terraced house), Single Family houses and Multi-Family houses have been excluded from the present work since the main area of interest of the Geo4Civhic project is the urban city centre, where usually these typologies of building are less frequently present.

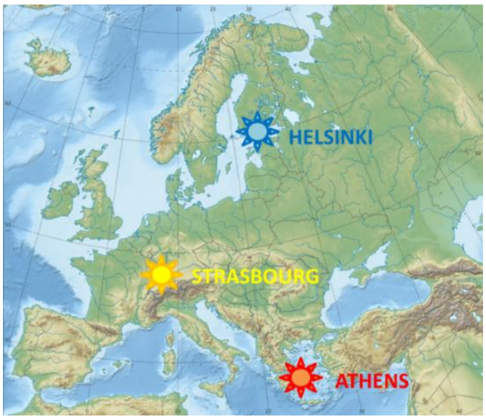
Figure 7.2 shows the geometry and the layout of the residential plan, representing the multifamily archetype. The office building has been considered with a similar structure with respect to the residential apartment block, due to the absence of data regarding non-residential uses. Therefore, the same configuration with 4 offices of the same size of the apartments has been used, varying internal loads and time schedule, which will be adapted according to the final end-use (offices, rather than companies, etc.).

Figure 7.2 Layout of the residential unit in the Apartment Block

Since the climates and the related boundary conditions affect the building performance, archetypes have been grouped based on the analysis carried out in Cheap-GSHPs [21], 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).

To limit the climatic analysis, three different climates and related most representative city have been chosen according to EN 14825 [22] (Figure 7.3):

- Athens (C1) as representative of warm climate (the BWh and BSk European climates), DDH = 995 and DDC = 1046;
- Strasbourg (C2) for a mild cold climates (including Cfb and Cfc European climates), DDH = 2746 and DDC = 115
- Helsinki (C3) as a cold climate (including Dfb and Dfc European climates), DDH = 4597 and DDC = 23.



Average annual temperature:
- Athens, 17.9 °C
- Strasbourg, 10.3 °C
- Helsinki, 5.2 °C

Figure 7.3 Representative locations considered for the analysis

As for the sizing of the boreholes for heating and cooling the archetypes, the ASHRAE method has been used to calculate the lengths of the probes, considering the limited area available for each building typology. A simplified conceptual framework of this procedure is given in Figure 7.4, where the inputs are framed in red and the outputs in green.

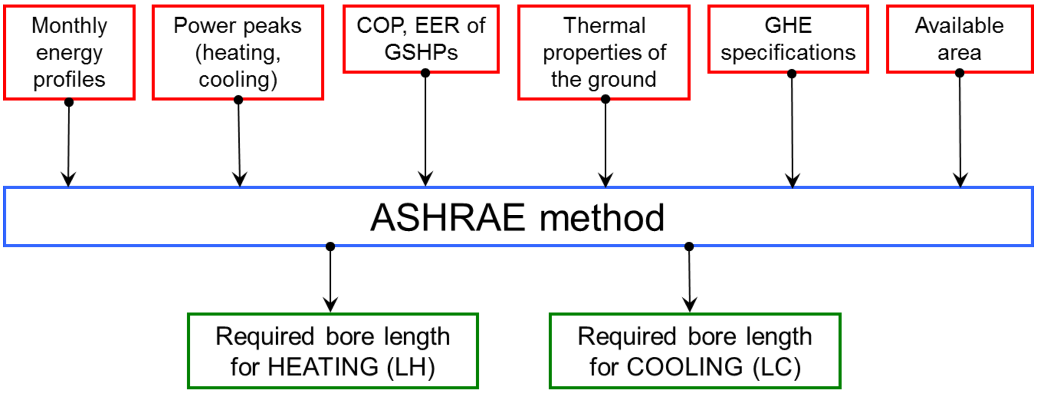


Figure 7.4 Simplified conceptual framework of the applied procedure.

The simulations have been performed considering the three values of thermal conductivity and volume thermal capacity specified in Table 4 which correspond to the mostly common types of ground.

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

Table 4 Thermal properties of the three considered types of ground.

The considered borehole heat exchanger is a double U-tube characterised by the following specifications (Table 5). The two U-loops are coupled in parallel as all the borehole heat exchangers.

Pipe	Internal diameter	26 mm
	External diameter	32 mm
	Thermal Conductivity	0.35 W/(m K)
Grouting material	Borehole diameter	120 mm
	Thermal conductivity	1.5 W/(m K)

Table 5 Specifications of the considered double U heat exchanger.

In conclusion, the output obtained from these energy analyses and already presented in Deliverable 1.3 are the energy demand of the buildings, the peak loads for heating and cooling, correlated with the optimal sizing of the borehole heat exchangers, as a function of the installed terminal unit inside the building, the available space and thermal load.

The following table indicates the different cases and their respective I.D.

Nº	**I.D. Case**	**Building Type**	**Building Use**	**Status**	**Climate**
1	**AB_HI_C1**	Apartment Block	Residential	Historical	Warm
2	**AB_HI_C2**	Apartment Block	Residential	Historical	Average
3	**AB_HI_C3**	Apartment Block	Residential	Historical	Cold
4	**AB_EX_C1**	Apartment Block	Residential	Existing	Warm
5	**AB_EX_C2**	Apartment Block	Residential	Existing	Average
6	**AB_EX_C3**	Office Building	Residential	Existing	Cold
7	**OB_HI_C1**	Office Building	Non-Residential	Historical	Warm
8	**OB_HI_C2**	Office Building	Non-Residential	Historical	Average
9	**OB_HI_C3**	Office Building	Non-Residential	Historical	Cold
10	**OB_EX_C1**	Office Building	Non-Residential	Existing	Warm
11	**OB_EX_C2**	Office Building	Non-Residential	Existing	Average
12	**OB_EX_C3**	Office Building	Non-Residential	Existing	Cold
13	**TH_HI_C1**	Terrace House	Single Residential	Historical	Warm
14	**TH_HI_C2**	Terrace House	Single Residential	Historical	Average
15	**TH_HI_C3**	Terrace House	Single Residential	Historical	Cold
16	**TH_EX_C1**	Terrace House	Single Residential	Existing	Warm
17	**TH_EX_C2**	Terrace House	Single Residential	Existing	Average
18	**TH_EX_C3**	Terrace House	Single Residential	Existing	Cold

Table 6 Specification of the different cases.

8 Preliminary cost and business analysis

There are a number of potential benefits to using geothermal as part of a project's energy management approach. Geothermal energy is clean and renewable heat from the Earth. In addition to reducing emissions, the use of geothermal can provide building owners with energy cost savings, increased reliability, and reduced exposure to market energy price fluctuations.

A business case analysis is one that diligently examines many aspects of a decision to demonstrate a project's value in the strongest manner. The costs accounted for in the Report's business case analysis include capital costs and operation and maintenance costs.

The purpose of this Section is to show the typical economic factors that are considered when a developer is analyzing if geothermal is a worthwhile investment for their project. This Report analyzes the preliminary cost for geothermal for existing/historical and retrofitted buildings. As well, based on the geology characteristics, different location and different climates across the Europe.

A preliminary cost and business analysis has been made with the help of all partners from the different countries across of Europe for levels of renovation, climates and undergrounds.

In parallel the same analysis has been performed for the buildings in Athens, Strasbourg and Helsinki which were modeled in the Task 1.3. This Report is meant to serve as a tool to those interested in implementing geothermal technology throughout Europe and to assist in identifying and analyzing the relevant factors to determine if geothermal energy systems are a viable solution.

8.1 European Countries' cost Analysis

A preliminary cost study for the different countries for the levels of renovation, climates, and undergrounds has been done in this report. The different related partners have provided the national costs related to each item such as material and installation as well as running operational and maintenance cost. This document takes the type of buildings presented in the previous Section 4. The energy cost takes into account the energy consumption of the building (gas and/or electricity) and the involved prices of them is taking from Eurostat 2018.

The running cost represents the operational and maintenance of the systems. On the other hand the one-off cost involves the costs of the implementation of the technology in each different studied building (i.e. Drillability, materials, heat pumps, etc.). The table below shows the preliminary costs calculations for different countries across the Europe involving different climates, undergrounds and levels of renovations. Calculations in the table below will serve as input to make a preliminary Cost Benefits Analysis (CBA) for some of the cases presented in this report.

For this preliminary cost study, we have included initial cost benefit analysis considerations in the form of net present value formulas using the data on cost and savings obtained from partners and the following theoretical formula and approach:

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

Benefit:

$$\Delta E_t = Annual\ monetary\ energy\ gain\ (dependant\ on\ energy\ prices,$$
$$energy\ performance\ of\ solution\ and\ building\ typlogy)$$
$$r = discount\ rate\ (opportunity\ cost)$$

Cost:

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

Within this formula, the following KPIs and indicators may influence the NPV and help us understand dynamics at play between CBA results and solutions used, building typologies and country specific macro-economic trends such as energy prices.

More specifically, the following economic indicators and principles can influence results:

Performance decline and substitution of assets (OPEX): Within the NPV formula, technical performance and life span of the systems and implements **have to be included through a decline in 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 he or she could obtain 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 solutions simply through obtaining a positive NPV discounted at the appropriate rate. Moreover, discounting is also a method for reflecting the perceive value of money over time. Cash and returns in the present are more valuable than cash flows years down the line.

- Discounting is the process of determining the present value of a future payment or stream of payments.
- An Euro is always worth more today than it would be worth tomorrow, according to the concept of the time value of money.
- A higher discount indicates a greater the level of risk associated with an investment and its future cash flows.

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. Moreover, on top of this comes the actual energy mix at hand. Heating is covered either through natural gas or electricity which both have different prices per kWh. Depending on systems chosen and energy prices, different energy mixes can yield higher or lower savings.

Energy performance of solutions: Determining the energy savings attributable to solutions in different building types will enable the calculation of savings or cash flows for the economic viability analysis. **Of course, for existing buildings the amount of energy saved is calculated from post retrofit consumption compared to current systems.**

Cost of installation (CAPEX): The initial capital outlay for implementing the system at time t0 must be calculated.

At this stage in the project, the consortium has been able to gather a myriad of costs in relation to pre-intervention yearly energy costs, post-intervention yearly energy costs for both traditional and geothermal solutions (enabling the calculation of ΔE_t energy gain) and initial capital expenditures (CAPEX) for installing the systems. Because the breadth of our data is focused on these indicators, the NPV formula will reduced to the following:

$$NPV = \sum_{t=1}^{n} \frac{\Delta E_t}{(1+r)^t} - I_0$$

Benefit:

$$\Delta E_t = Annual\ monetary\ energy\ gain\ (dependant\ on\ energy\ prices,\\ energy\ performance\ of\ solution\ and\ building\ typlogy)$$

$$r = discount\ rate\ (opportunity\ cost)$$

Cost:

$$I_o = Investment\ cost\ (CAPEX)$$

Discount rates will either be reflected at different levels through NPV profiles or set at specified levels reflecting at least 2.5 times the level of the highest risk free rates.

As the project moves on, it will be important for the consortium to integrate more cost data and indicators related to OPEX and integrate them in the NPV calculations for more precise CBA assessments.

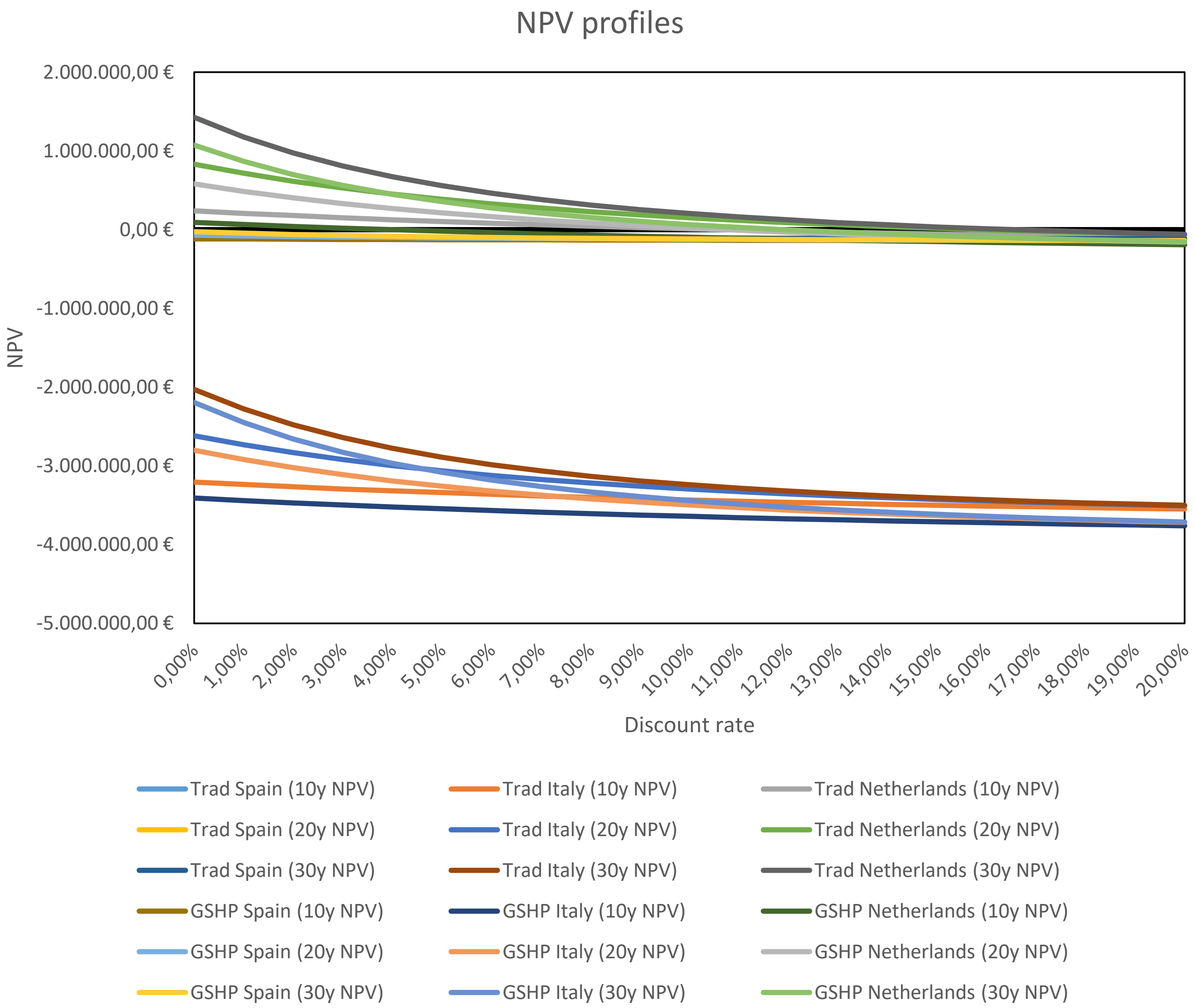
The following table presents the cost data results for the European cases described prior to this section. As stated, in the current form, focus has been given towards pre and post intervention energy consumption and costs as well as initial capital outflow for implementing the new systems.

Country	Status	Renovation Level	Climate	Preliminary Total Costs [€/m2]					
				Post-Intervention Traditional System			Post-Intervention GSHP System		
				Energy Costs [€/Yr/m2]	Running Costs [€/Yr/m2]	One-Off Costs [€/m2]	Energy Costs [€/Yr/m2]	Running Costs [€/Yr/m2]	One-Off Costs [€/m2]
Spain	Existing	Moderate	Zone B	8,88	6,69	154,89	5,69	5,45	200,74
Italy	Historic	Deep	Zone B	0,29	6,07	227,87	0,19	3,96	241,02
Belgium	Existing	Deep	Zone D	10,79	44,12	147,06	6,26	26,47	223,53
Greece	Existing	None	Zone D	2,82	44,12	43,86	2,82	5,23	144,74
Malta	Historic	Deep	Zone A	30,64	59,87	59,87	18,90	38,59	596,16
Ireland	Historic	Minor	Zone C	6,95	22,86	118,98	27,75	8,74	152,73
Netherlands	Existing	Deep	Zone E	3,86	5,05	85,01	3,23	5,89	95,31

Table 7 Preliminary total costs for European countries for traditional and GSHP systems

What is important when observing this data is understanding the dynamics at play behind each case which can increase CBA results. Observing the dynamics between pre and post intervention energy costs and the required initial capital outflow for implementing the solution can give an idea on whether or not annual cash flows represented in energy savings will be sufficient in order to obtain satisfying return on investment and payback periods. In order to reflect these trends, we have decided to calculate NPVs according to the previously discussed methodology over 10, 20 and 30 year time horizons for Spain, Italy and the Netherlands. Different discount levels will be reflected as an NPV profile graph will be introduced. This approach is interesting as discount rates can differ highly according to the opportunity costs of the investing party, which country they live in and their investment preferences and behaviour meaning they may require different threshold rates of return for the investment to be of interest to them.

The results of this analysis are presented in the following table and graph (for the graph: “trad” refers to traditional system and “GSHP” to the GSHP system):


NPV profiles
2.000.000,00 €
1.000.000,00 €
0,00 €
-1.000.000,00 €
-2.000.000,00 €
-3.000.000,00 €
-4.000.000,00 €
-5.000.000,00 €
NPV
0,00%
1,00%
2,00%
3,00%
4,00%
5,00%
6,00%
7,00%
8,00%
9,00%
10,00%
11,00%
12,00%
13,00%
14,00%
15,00%
16,00%
17,00%
18,00%
19,00%
20,00%
Discount rate
Trad Spain (10y NPV)
Trad Italy (10y NPV)
Trad Netherlands (10y NPV)
Trad Spain (20y NPV)
Trad Italy (20y NPV)
Trad Netherlands (20y NPV)
Trad Spain (30y NPV)
Trad Italy (30y NPV)
Trad Netherlands (30y NPV)
GSHP Spain (10y NPV)
GSHP Italy (10y NPV)
GSHP Netherlands (10y NPV)
GSHP Spain (20y NPV)
GSHP Italy (20y NPV)
GSHP Netherlands (20y NPV)
GSHP Spain (30y NPV)
GSHP Italy (30y NPV)
GSHP Netherlands (30y NPV)

	Traditional									GSHP								
	10 year NPV			20 year NPV			30 year NPV			10 year NPV			20 year NPV			30 year NPV		
Dicount rate	Trad Spain (10y NPV)	Trad Italy (10y NPV)	Trad Netherlands (10y NPV)	Trad Spain (20y NPV)	Trad Italy (20y NPV)	Trad Netherlands (20y NPV)	Trad Spain (30y NPV)	Trad Italy (30y NPV)	Trad Netherlands (30y NPV)	GSHP Spain (10y NPV)	GSHP Italy (10y NPV)	GSHP Netherlands (10y NPV)	GSHP Spain (20y NPV)	GSHP Italy (20y NPV)	GSHP Netherlands (20y NPV)	GSHP Spain (30y NPV)	GSHP Italy (30y NPV)	GSHP Netherlands (30y NPV)
0%	-105.572,00 €	-3.206.654,02 €	238.713,42 €	-86.144,00 €	-2.618.308,04 €	832.426,83 €	-66.716,00 €	-2.029.962,06 €	1.426.140,25 €	-116.868,21 €	-3.408.224,60 €	92.000,00 €	-71.736,42 €	-2.802.449,21 €	582.000,00 €	-26.604,63 €	-2.196.673,81 €	1.072.000,00 €
1%	-106.599,15 €	-3.237.759,61 €	207.324,06 €	-89.941,10 €	-2.733.297,15 €	716.388,69 €	-74.860,78 €	-2.276.613,86 €	1.177.238,26 €	-119.254,31 €	-3.440.251,67 €	66.093,92 €	-80.557,19 €	-2.920.844,80 €	486.232,10 €	-45.525,20 €	-2.450.632,53 €	866.577,70 €
2%	-107.548,63 €	-3.266.513,22 €	178.308,12 €	-93.232,44 €	-2.832.969,99 €	615.806,54 €	-81.488,17 €	-2.477.313,54 €	974.707,62 €	-121.459,99 €	-3.469.857,10 €	42.146,67 €	-88.203,06 €	-3.023.470,40 €	403.220,23 €	-60.920,79 €	-2.657.277,82 €	699.426,32 €
3%	-108.427,52 €	-3.293.128,95 €	151.449,59 €	-96.096,04 €	-2.919.689,75 €	528.295,64 €	-86.920,26 €	-2.641.815,91 €	808.704,50 €	-123.501,67 €	-3.497.261,30 €	19.979,94 €	-94.855,30 €	-3.112.759,18 €	330.996,27 €	-73.539,70 €	-2.826.653,49 €	562.421,63 €
4%	-109.242,15 €	-3.317.798,71 €	126.554,76 €	-98.596,71 €	-2.995.418,61 €	451.875,91 €	-91.405,04 €	-2.777.630,17 €	671.651,22 €	-125.394,08 €	-3.522.661,89 €	-566,11 €	-100.664,43 €	-3.190.731,47 €	267.925,99 €	-83.957,96 €	-2.966.491,17 €	449.309,63 €
5%	-109.998,21 €	-3.340.694,83 €	103.449,76 €	-100.788,42 €	-3.061.790,86 €	384.898,15 €	-95.134,40 €	-2.890.568,02 €	557.683,04 €	-127.150,43 €	-3.546.236,30 €	-19.634,99 €	-105.755,82 €	-3.259.069,96 €	212.648,31 €	-92.621,38 €	-3.082.774,74 €	355.250,10 €
6%	-110.700,82 €	-3.361.972,24 €	81.978,24 €	-102.716,24 €	-3.120.171,80 €	325.984,61 €	-98.257,69 €	-2.985.151,69 €	462.236,49 €	-128.782,61 €	-3.568.144,03 €	-37.355,73 €	-110.234,19 €	-3.319.180,39 €	164.026,14 €	-99.876,86 €	-3.180.160,39 €	276.476,73 €
7%	-111.354,59 €	-3.381.770,40 €	61.999,46 €	-104.417,95 €	-3.171.705,43 €	273.980,84 €	-100.891,71 €	-3.064.919,05 €	381.741,42 €	-130.301,32 €	-3.588.528,71 €	-53.844,50 €	-114.187,32 €	-3.372.240,68 €	121.106,70 €	-105.995,78 €	-3.262.290,82 €	210.043,02 €
8%	-111.963,65 €	-3.400.215,06 €	43.386,54 €	-105.925,30 €	-3.217.353,24 €	227.916,58 €	-103.128,38 €	-3.132.652,84 €	313.389,70 €	-131.716,20 €	-3.607.519,78 €	-69.206,01 €	-117.688,94 €	-3.419.240,79 €	83.089,22 €	-111.191,61 €	-3.332.031,18 €	153.631,38 €
9%	-112.531,77 €	-3.417.419,69 €	26.024,95 €	-107.265,06 €	-3.257.925,69 €	186.974,00 €	-105.040,34 €	-3.190.553,69 €	254.960,62 €	-133.035,96 €	-3.625.234,09 €	-83.534,77 €	-120.801,24 €	-3.461.015,16 €	49.298,74 €	-115.633,16 €	-3.391.647,31 €	105.409,05 €
10%	-113.062,34 €	-3.433.486,86 €	9.811,19 €	-108.459,85 €	-3.294.107,90 €	150.461,70 €	-106.685,39 €	-3.240.371,28 €	204.688,56 €	-134.268,47 €	-3.641.777,24 €	-96.916,21 €	-123.576,76 €	-3.498.269,26 €	19.164,62 €	-119.454,65 €	-3.442.940,71 €	63.918,81 €
11%	-113.558,40 €	-3.448.509,40 €	-5.348,39 €	-109.528,85 €	-3.326.480,79 €	117.793,47 €	-108.109,70 €	-3.283.504,21 €	161.162,13 €	-135.420,84 €	-3.657.244,81 €	-109.427,63 €	-126.060,08 €	-3.531.601,17 €	-7.796,92 €	-122.763,36 €	-3.487.351,44 €	27.995,84 €
12%	-114.022,75 €	-3.462.571,40 €	-19.538,68 €	-110.488,36 €	-3.355.538,29 €	88.470,89 €	-109.350,39 €	-3.321.076,49 €	123.247,08 €	-136.499,53 €	-3.671.723,39 €	-121.139,07 €	-128.289,07 €	-3.561.519,48 €	-31.997,26 €	-125.645,51 €	-3.526.036,77 €	-3.295,99 €
13%	-114.457,89 €	-3.475.749,15 €	-32.836,64 €	-111.352,31 €	-3.381.701,56 €	62.068,93 €	-110.437,44 €	-3.353.996,24 €	90.027,00 €	-137.510,39 €	-3.685.291,52 €	-132.114,07 €	-130.296,04 €	-3.588.457,83 €	-53.787,17 €	-128.170,78 €	-3.559.931,76 €	-30.712,98 €
14%	-114.866,13 €	-3.488.111,93 €	-45.312,22 €	-112.132,58 €	-3.405.330,78 €	38.224,15 €	-111.395,22 €	-3.383.001,07 €	60.757,56 €	-138.458,74 €	-3.698.020,55 €	-142.410,33 €	-132.108,63 €	-3.612.787,05 €	-73.466,60 €	-130.395,72 €	-3.589.795,84 €	-54.869,46 €
15%	-115.249,54 €	-3.499.722,77 €	-57.028,97 €	-112.839,37 €	-3.426.734,75 €	16.624,91 €	-112.243,61 €	-3.408.693,23 €	34.831,02 €	-139.349,40 €	-3.709.975,34 €	-152.080,34 €	-133.750,52 €	-3.634.825,10 €	-91.292,76 €	-132.366,56 €	-3.616.249,11 €	-76.267,00 €
16%	-115.610,01 €	-3.510.639,00 €	-68.044,80 €	-113.481,45 €	-3.446.179,03 €	-2.996,76 €	-112.998,94 €	-3.431.567,01 €	11.748,56 €	-140.186,78 €	-3.721.214,97 €	-161.171,85 €	-135.242,08 €	-3.654.845,41 €	-107.486,80 €	-134.121,20 €	-3.639.800,51 €	-95.317,27 €
17%	-115.949,26 €	-3.520.912,93 €	-78.412,45 €	-114.066,37 €	-3.463.892,57 €	-20.871,90 €	-113.674,66 €	-3.452.030,21 €	-8.901,32 €	-140.974,89 €	-3.731.793,25 €	-169.728,42 €	-136.600,88 €	-3.673.083,70 €	-122.239,40 €	-135.690,92 €	-3.660.869,92 €	-112.359,91 €
18%	-116.268,89 €	-3.530.592,24 €	-88.180,07 €	-114.600,68 €	-3.480.073,31 €	-37.200,26 €	-114.281,95 €	-3.470.420,94 €	-27.459,83 €	-141.717,38 €	-3.741.759,31 €	-177.789,77 €	-137.842,10 €	-3.689.743,79 €	-135.715,42 €	-137.101,67 €	-3.679.805,47 €	-127.676,51 €
19%	-116.570,32 €	-3.539.720,51 €	-97.391,62 €	-115.090,05 €	-3.494.892,83 €	-52.154,97 €	-114.830,11 €	-3.487.020,98 €	-44.211,31 €	-142.417,61 €	-3.751.158,00 €	-185.392,19 €	-138.978,90 €	-3.705.002,32 €	-148.057,76 €	-138.375,05 €	-3.696.897,27 €	-141.501,74 €
20%	-116.854,87 €	-3.548.337,59 €	-106.087,31 €	-115.539,38 €	-3.508.500,23 €	-65.886,52 €	-115.326,92 €	-3.502.066,28 €	-59.393,87 €	-143.078,62 €	-3.760.030,36 €	-192.568,87 €	-140.022,72 €	-3.719.012,84 €	-159.390,59 €	-139.529,17 €	-3.712.388,28 €	-154.032,12 €

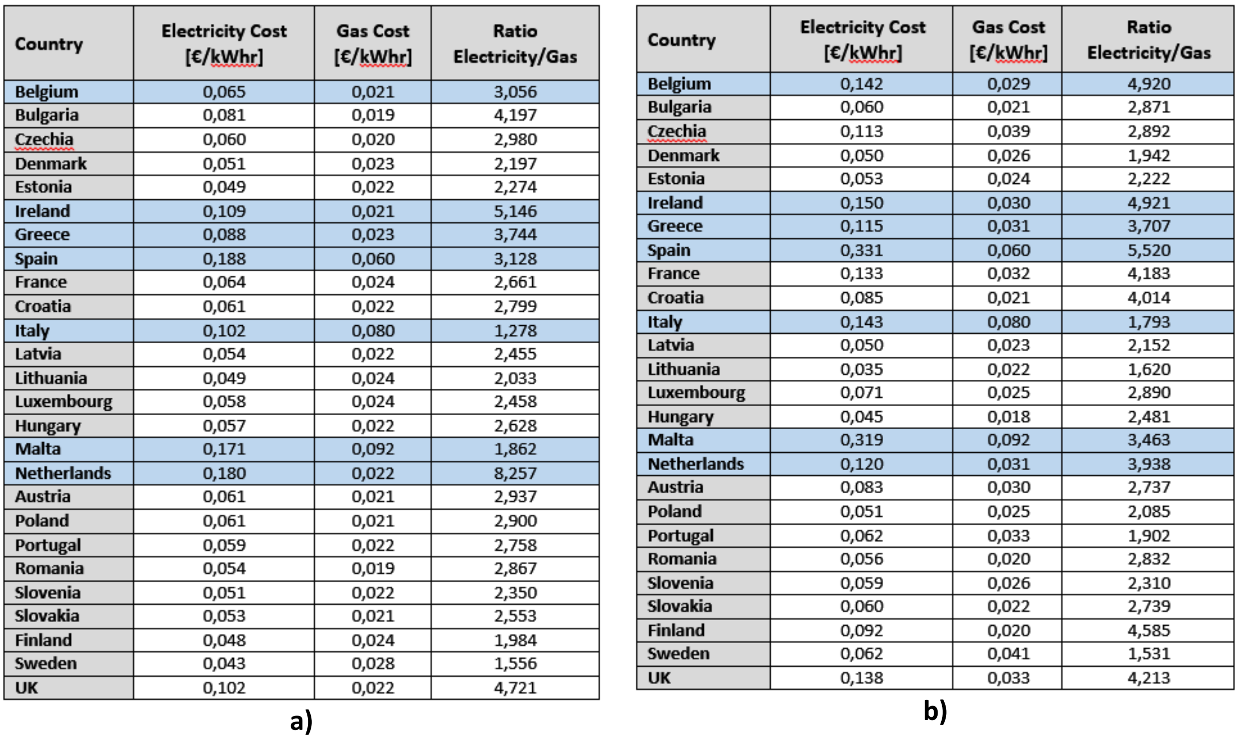
Table 8 Cost benefit analyses over 10, 20 and 30 year time horizons for Spain, Italy and the Netherlands

Observing the tables and pictures above, we can see that the involved implements are mainly profitable in the case of the Netherlands. Analysing more deeply, this seems to be due to insufficient energy savings which are unable to cover the initial investment costs in the case of Spain (at around 2000 € a year for a 125’000 € initial investment) or very high CAPEX costs for instance in the case of Italy (almost 4 million euros in CAPEX for 58-60 thousand euros saved annually). The reasons for these costs may be the prices of natural gas vs electricity in each country which will be presented later in this document, or high licences, material and labour agreements costs as well as difficulties in drilling for the high CAPEX.

Moreover, from a general point of view, it is possible to see that the higher the discount rate the lesser the NPV as future cash flows used to amortize the CAPEX are further discounted, while the longer the time period (10 vs 30 years) the higher the NPV as there is logically more time for the annual energy gain to compensate for the CAPEX.

For the calculation of the preliminary energy costs presented in the table above, this study has taken into account the following gas and electricity prices published in Eurostat in 2018. These prices are separated by Non-household and household consumers. Countries in blue are those analysed in the present document.

Gas and Electricity prices components **for non-household** consumers corresponding to 2018.



Country	Electricity Cost [€/kWhr]	Gas Cost [€/kWhr]	Ratio Electricity/Gas
Belgium	0,065	0,021	3,056
Bulgaria	0,081	0,019	4,197
Czechia	0,060	0,020	2,980
Denmark	0,051	0,023	2,197
Estonia	0,049	0,022	2,274
Ireland	0,109	0,021	5,146
Greece	0,088	0,023	3,744
Spain	0,188	0,060	3,128
France	0,064	0,024	2,661
Croatia	0,061	0,022	2,799
Italy	0,102	0,080	1,278
Latvia	0,054	0,022	2,455
Lithuania	0,049	0,024	2,033
Luxembourg	0,058	0,024	2,458
Hungary	0,057	0,022	2,628
Malta	0,171	0,092	1,862
Netherlands	0,180	0,022	8,257
Austria	0,061	0,021	2,937
Poland	0,061	0,021	2,900
Portugal	0,059	0,022	2,758
Romania	0,054	0,019	2,867
Slovenia	0,051	0,022	2,350
Slovakia	0,053	0,021	2,553
Finland	0,048	0,024	1,984
Sweden	0,043	0,028	1,556
UK	0,102	0,022	4,721

a)

Country	Electricity Cost [€/kWhr]	Gas Cost [€/kWhr]	Ratio Electricity/Gas
Belgium	0,142	0,029	4,920
Bulgaria	0,060	0,021	2,871
Czechia	0,113	0,039	2,892
Denmark	0,050	0,026	1,942
Estonia	0,053	0,024	2,222
Ireland	0,150	0,030	4,921
Greece	0,115	0,031	3,707
Spain	0,331	0,060	5,520
France	0,133	0,032	4,183
Croatia	0,085	0,021	4,014
Italy	0,143	0,080	1,793
Latvia	0,050	0,023	2,152
Lithuania	0,035	0,022	1,620
Luxembourg	0,071	0,025	2,890
Hungary	0,045	0,018	2,481
Malta	0,319	0,092	3,463
Netherlands	0,120	0,031	3,938
Austria	0,083	0,030	2,737
Poland	0,051	0,025	2,085
Portugal	0,062	0,033	1,902
Romania	0,056	0,020	2,832
Slovenia	0,059	0,026	2,310
Slovakia	0,060	0,022	2,739
Finland	0,092	0,020	4,585
Sweden	0,062	0,041	1,531
UK	0,138	0,033	4,213

b)

Table 9 Gas/Electricity ratio for a) Non-Household and b) Household consumers. 2018

The main problem observed is the relative extremely low cost of gas compared to electricity in almost all countries. If we focus on the countries under analyses we can observe that in the case of Belgium, Ireland and Spain this difference is remarkable (for household case). Even though you increase the efficiency of the building the operational costs are higher with a heat pump due to the costs. As an example the following:

- Belgium: gas 0.029 €/kWh; electricity 0.142 €/kWh; this leads to a ratio 0.142/0.029=4.92. This means that if the heat pump has a SPF > 4.92 the costs are lower with a Heat Pump.
- Spain: gas 0.06 €/kWh; electricity 0.331 €/kWh; this leads to a ratio 0.331/0.06=5.52. This means that if the heat pump has a SPF > 5.52 the costs are lower with a Heat Pump.

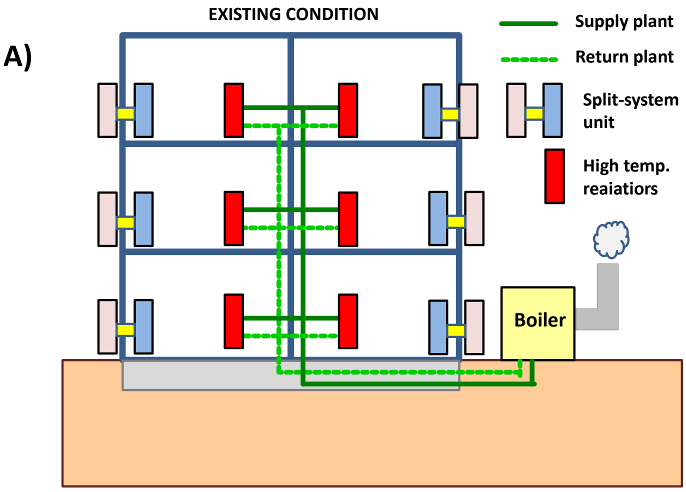
If so, the market exploitation may be thought will experience some critical conditions which have to be underlined, i.e. barriers related to the diffusion of heat pumps in general and as a consequence GSHPs.

8.2 Archetypes' cost Analysis

The costs included in the analysis regard the retrofit of the envelope, the emission systems and the generation system. Different solutions with the combination of possible retrofit levels have been considered. The estimated values of operating and investment costs have been considered.

Among the different possible sets of cases here the case of a deep retrofit solution is presented. Hence the retrofit costs consider both more performing opaque elements (walls, roof, floor) and transparent elements (windows). It has been supposed that radiators are the traditional emission system present in the stock of buildings and radiant heating and cooling systems have been considered in the retrofit case, as they represent the best solution to be integrated with ground source heat pumps, due to the lower operating temperature in winter (30/35°C) and high temperature in summer (17°C), i.e. LTH/HTC (Low Temperature Heating, High Temperature Cooling).

Concerning the generation system, the existing condition has been considered to be a boiler (with a seasonal generation efficiency of 85%) with split-system solution. Two different options of retrofit solutions have been considered: a the traditional solution with condensing gas boiler and air-to water chiller and a retrofit solution with GSHP or hybrid or bivalent heat pump, i.e. a heat pump which may use the water in the ground circuits or the air as source (in winter) or sink (summer). The hybrid solution can be applied either when the available space for the borehole is not sufficient or when the thermal seasonal load in the ground is not balanced. Figure 8.1 shows the concepts of the three cases for a multi-user building. The analysis has been carried out for the multi-user residential building (AB, Apartment Block), for the office multi-user building (OB, Office Building) and for the single user building (TH, Terrace House). The analysis has been done for both existing (EX) and historical (hi) buildings. As already said, the three reference climates have been considered: Athens (C1), Strasburg (C2), and Helsinki (C3). The overall summary with the explication of the different cases is reported in Table 6.



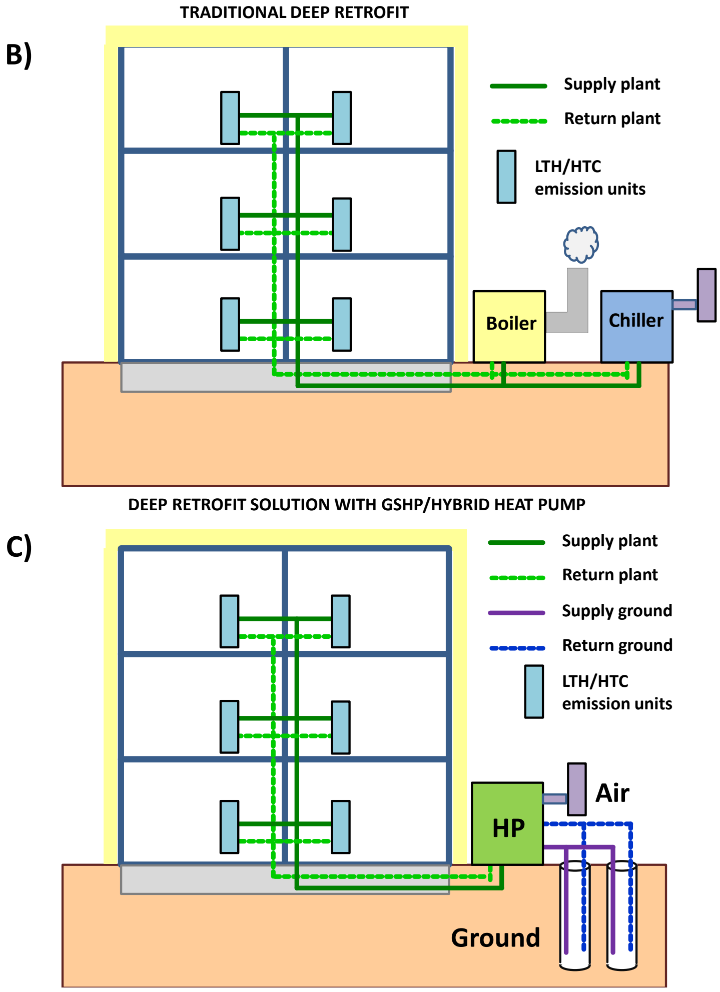


Figure 8.1 Cases analysed: baseline existing condition (a), deep retrofit standard solution (b), GSHP or hybrid solution for the deep retrofit.

8.2.1 Preliminary Energy costs

Cost analysis has been considered for the investment in the retrofit solutions and in running energy costs summing up the heating and cooling seasonal costs, so as to get the yearly value. The costs have been considered for the three countries (Greece, Germany and Finland). Although in some countries the reference generation plant may be different (e.g. in Finland gas boilers are not the most used generation typology), in the analysis the same generation systems have considered to have a direct comparison between the different cases. As a matter of fact, natural gas is the most used energy carrier in Europe as shown in Figure 8.2 and one can make the analysis on a cold climate taking as reference Helsinki.

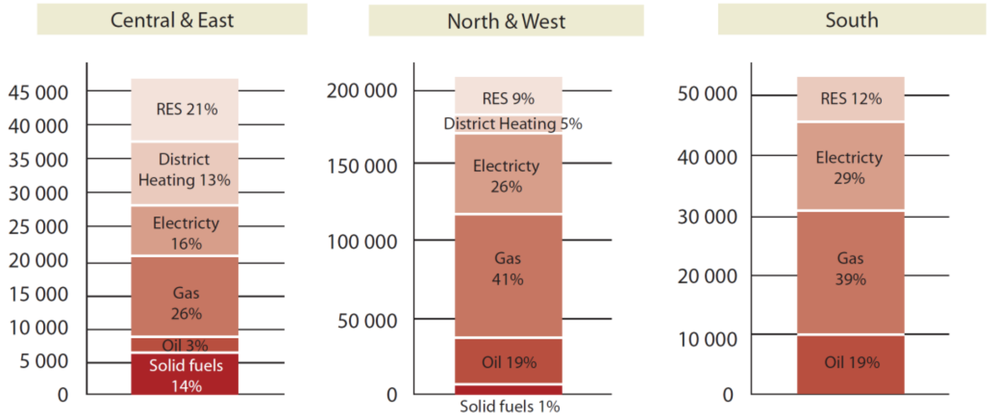
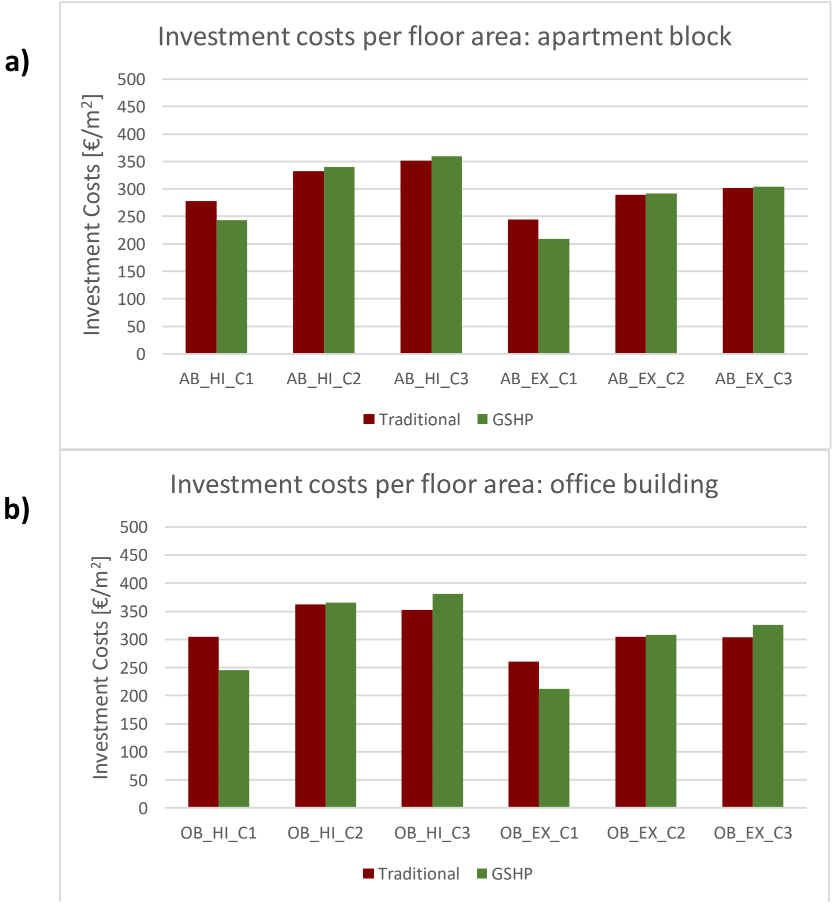


Figure 8.2 Final energy mix in residential buildings (thousand toe) by region [23]

The comparison between the investment costs is presented in Figure 8.3. As might be seen for the multi-user buildings (AB and OB) the difference between the estimated investment costs is reduced due to the fact that the increase in the investment of the BHEs field is counterbalanced by the double plant (boiler and air to water chiller). When looking at the single-family house the costs for the GSHP solution are usually higher compared to the traditional solution: the difference between the investment on a standard deep retrofit and a retrofit with a GSHP or a hybrid solution is usually in the range of 10%÷15% in the single-family house archetype.



c)

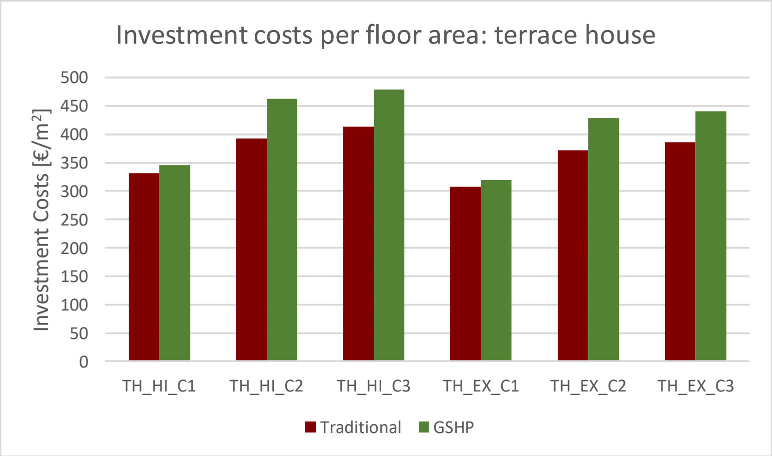


Figure 8.3 Investment costs per net floor area for the deep retrofit standard solution versus a deep retrofit with GSHP or hybrid solution for the apartment block (a) for the office building (b) and for the terrace house (c).

The energy operating costs are related to the national market and the costs related to the energy used for heating and cooling the buildings. For the thermal energy the unitary costs for Greece is 0.062 €/kWht, for Germany is 0.068 €/kWht, for Finland is 0.08 €/kWht. For the electricity the unitary costs have been considered as 0.16 €/kWhe for Greece, 0.30 €/kWhe for Germany and 0.16 €/kWhe for Finland.

Table 10 summarizes the results for the energy operating costs, showing the costs for heating and cooling before the retrofit and after the retrofit in the different cases. In parallel it is also useful to look at Figure 8.4 which represents the energy use in before and after renovation with a standard deep retrofit and the retrofit with GSHP and hybrid heat pumps.

As can be seen, in Greece the energy costs are similar in the case of standard retrofit and with GSHP and/or hybrid solution after renovation. The operating energy costs reduce 31% for multi-user historical buildings and 35% in the multi-user existing buildings, while for the terrace house costs reduction is 21% for the historic building and 28% for the existing one. In Greece there is a very small difference between the final energy use after renovation with traditional generation system and with the use of GSHP or hybrid heat pumps. This is related to the small amount of heating energy need in winter period after renovation.

Nª	**Type of Building**	**Baseline** **Energy cost per floor area** **[€/m²]**	**Traditional** **Energy cost per floor area** **[€/m²]**	**GSHP** **Energy cost per floor area** **[€/m²]**	**Energy cost reduction per floor area (GSHP Vs. Baseline)** **[%]**
1	**AB_HI_C1**	5.23	1.62	1.63	31%
2	**AB_HI_C2**	11.80	3.28	3.07	26%
3	**AB_HI_C3**	15.96	4.34	2.38	15%
4	**AB_EX_C1**	4.31	1.48	1.50	35%
5	**AB_EX_C2**	8.68	2.82	2.65	30%
6	**AB_EX_C3**	9.74	3.49	1.92	20%
7	**OB_HI_C1**	4.24	1.30	1.31	31%

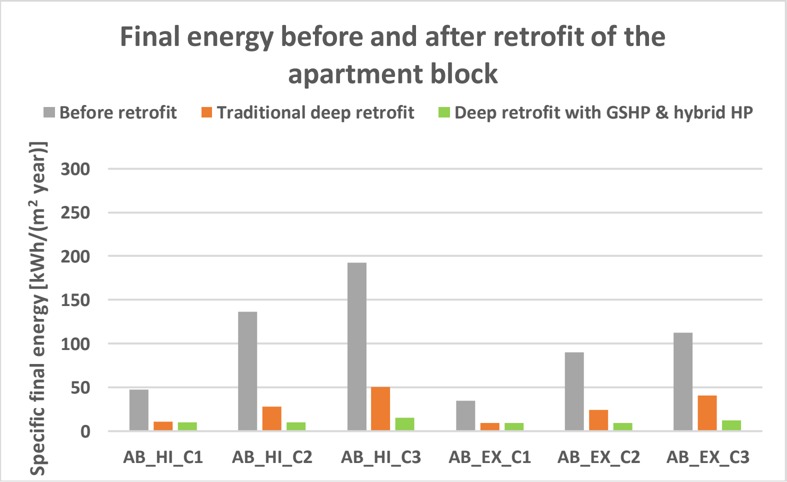
Nª	Type of Building	Baseline Energy cost per floor area [€/m^2]	Traditional Energy cost per floor area [€/m^2]	GSHP Energy cost per floor area [€/m^2]	Energy cost reduction per floor area (GSHP Vs. Baseline) [%]
8	**OB_HI_C2**	9.61	2.67	2.49	26%
9	**OB_HI_C3**	14.00	3.47	1.94	14%
10	**OB_EX_C1**	3.53	1.19	1.21	34%
11	**OB_EX_C2**	7.30	2.26	2.11	29%
12	**OB_EX_C3**	9.05	2.75	1.55	17%
13	**TH_HI_C1**	8.17	1.83	1.81	22%
14	**TH_HI_C2**	15.19	3.79	3.57	23%
15	**TH_HI_C3**	20.99	5.02	2.77	13%
16	**TH_EX_C1**	5.70	1.58	1.61	28%
17	**TH_EX_C2**	11.26	3.19	3.00	27%
18	**TH_EX_C3**	16.31	4.10	2.24	14%

Table 10 Specific energy cost per net floor area for the technologies analysed

In Germany the energy costs are 5% higher in the case of standard retrofit than with GSHP and/or hybrid solution after renovation, although the final use of energy strongly reduces in all cases (on average 35%). This is due to the cost of natural gas which is very low compared to electrical cost. The operating energy costs reduce 26% for multi-user historical buildings and 30% in the multi-user existing buildings, while for the terrace house costs reduction is 23% for the historic building and 27% for the existing one.

In Finland the energy costs are 55% higher in the case of standard retrofit than with GSHP and/or hybrid solution after renovation, although the final use of energy strongly reduces in all cases (on average 30%). The operating energy costs reduce 15% for multi-user historical buildings and 18% in the multi-user existing buildings, while for the terrace house costs reduction is 13% for both the historic building and the existing one.

a)



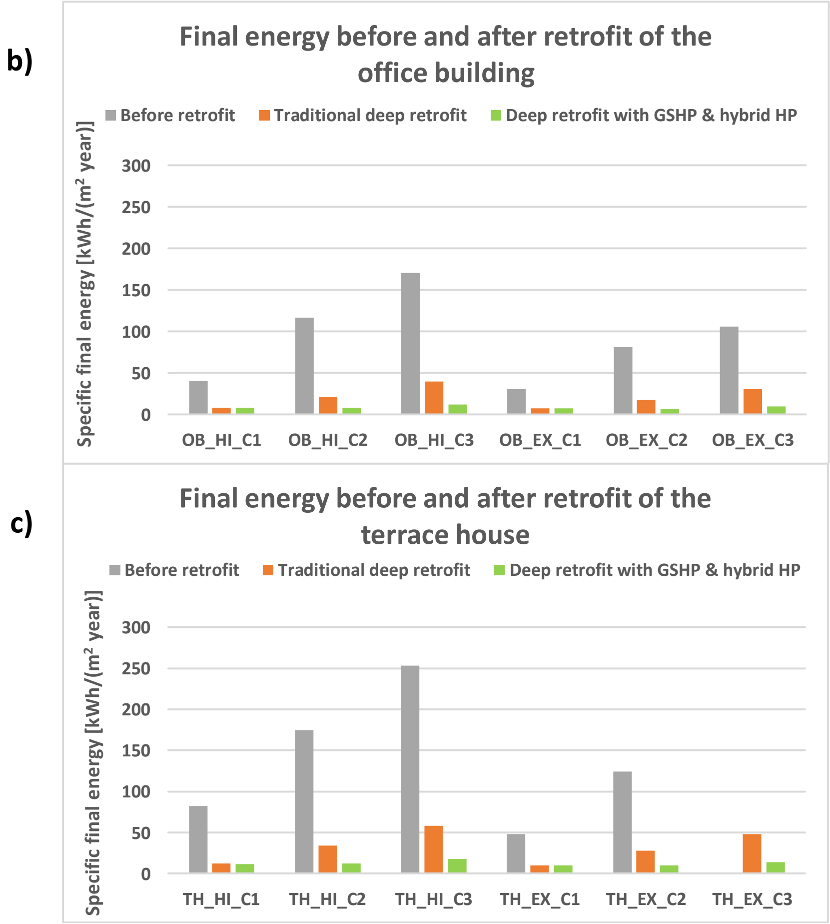


Figure 8.4 Specific final energy (per net floor area) in the different climates for the apartment block (a) for the office building (b) and for the terrace house (c).

Observing the dynamics between pre and post intervention energy costs and the required initial capital outflow for implementing the technologies can give an idea on whether or not annual cash flows represented in energy savings will be sufficient in order to obtain satisfying return on investment and payback periods. In order to reflect these tendencies, we have decided to calculate NPVs according to the previously discussed methodology over 1, 2, 5 and 10 year time horizons for the archetype cases modelled in Task 1.3. A 7% of discount levels is assumed for this analyses since this value reflects at least 2.5 times the level of the highest risk free rates.

The result of this analysis is presented in the following Table 11 and graph ("Trad" refers to traditional system and "GSHP" to the GSHP system):

№ Case	**I.D.**	**Area [m2]**	**Total energy cost pre-intervention [€/Yr]**	**Total Energy Cost Post-Intervention [€/Yr]**		**Investment Cost [€]**		**5 year NPV**		**10 year NPV**		**20 year NPV**		**30 year NPV**	
				traditional	**GSHP**	**traditional**	**GSHP**	**traditional**	**GSHP**	**traditional**	**GSHP**	**traditional**	**GSHP**	**traditional**	**GSHP**
1	AB_HI_C1	1417	7410	2292	2304	343849	394214	-322.864,19 €	-343.510,96 €	-307.902,31 €	-358.351,59 €	-289.628,84 €	-340.120,96 €	-280.339,53 €	-330.853,44 €
2	AB_HI_C2	1417	16714	4642	4348	481579	470346	-432.081,42 €	-391.417,20 €	-396.790,32 €	-383.492,39 €	-353.688,06 €	-339.340,42 €	-331.777,05 €	-316.895,80 €
3	AB_HI_C3	1417	22616	6147	3366	509333	498379	-441.806,85 €	-482.039,71 €	-393.661,64 €	-363.175,06 €	-334.860,18 €	-294.444,23 €	-304.968,50 €	-259.504,96 €
4	AB_EX_C1	1417	6109	2100	2124	296373	346131	-279.935,31 €	-311.086,61 €	-268.215,46 €	-318.142,03 €	-253.901,60 €	-303.913,85 €	-246.625,15 €	-296.680,97 €
5	AB_EX_C2	1417	12296	4003	3749	413741	410781	-379.738,06 €	-365.375,41 €	-355.494,44 €	-350.750,45 €	-325.884,84 €	-320.233,96 €	-310.832,82 €	-304.720,93 €
6	AB_EX_C3	1417	13801	4948	2727	430380	427026	-394.080,95 €	-410.026,58 €	-368.200,23 €	-349.246,86 €	-336.591,19 €	-309.707,89 €	-320.522,76 €	-289.608,28 €
7	OB_HI_C1	1417	6003	1837	1857	347230	432537	-330.148,58 €	-391.182,41 €	-317.969,76 €	-403.417,23 €	-303.095,34 €	-388.614,22 €	-295.533,93 €	-381.089,12 €
8	OB_HI_C2	1417	13613	3785	3527	517652	512892	-477.355,26 €	-442.819,63 €	-448.624,24 €	-442.052,16 €	-413.534,03 €	-406.040,77 €	-395.695,94 €	-387.734,41 €
9	OB_HI_C3	1417	19839	4920	2749	540581	499489	-479.410,15 €	-485.974,75 €	-435.796,19 €	-379.455,99 €	-382.528,90 €	-318.437,30 €	-355.450,51 €	-287.418,49 €
10	OB_EX_C1	1417	5009	1691	1713	300927	368431	-287.322,54 €	-338.261,75 €	-277.622,76 €	-345.281,28 €	-265.776,06 €	-333.513,13 €	-259.753,80 €	-327.530,80 €
11	OB_EX_C2	1417	10343	3205	2985	436629	431092	-407.361,79 €	-387.556,10 €	-386.494,67 €	-379.412,49 €	-361.008,93 €	-353.141,24 €	-348.053,26 €	-339.786,27 €
12	OB_EX_C3	1417	12819	3897	2201	461540	430450	-424.958,04 €	-426.850,03 €	-398.875,61 €	-355.873,61 €	-367.020,20 €	-317.962,76 €	-350.826,53 €	-298.690,80 €
13	TH_HI_C1	138	1128	252	250	47697	45789	-44.105,23 €	-39.212,28 €	-41.544,34 €	-39.622,30 €	-38.416,64 €	-36.487,46 €	-36.826,68 €	-34.893,86 €
14	TH_HI_C2	138	2096	523	492	63808	54193	-57.358,39 €	-43.885,10 €	-52.759,91 €	-42.927,18 €	-47.143,62 €	-37.200,20 €	-44.288,58 €	-34.288,90 €
15	TH_HI_C3	138	2896	693	382	66059	57097	-57.026,27 €	-54.784,49 €	-50.586,05 €	-39.439,72 €	-42.720,39 €	-30.463,65 €	-38.721,88 €	-25.900,67 €
16	TH_EX_C1	138	786	219	222	44081	42448	-41.756,19 €	-37.773,77 €	-40.098,63 €	-38.486,70 €	-38.074,19 €	-36.472,98 €	-37.045,07 €	-35.449,30 €
17	TH_EX_C2	138	1554	441	414	59191	51336	-54.627,48 €	-43.377,52 €	-51.373,75 €	-43.329,12 €	-47.399,86 €	-39.258,82 €	-45.379,74 €	-37.189,69 €
18	TH_EX_C3	138	2250	566	309	60796	53220	-53.891,27 €	-53.220,00 €	-48.968,29 €	-39.587,23 €	-42.955,68 €	-32.657,02 €	-39.899,17 €	-29.134,05 €

Table 11 Cost benefit analyses (5, 10, 20 and 30 years) for the archetypes' cases

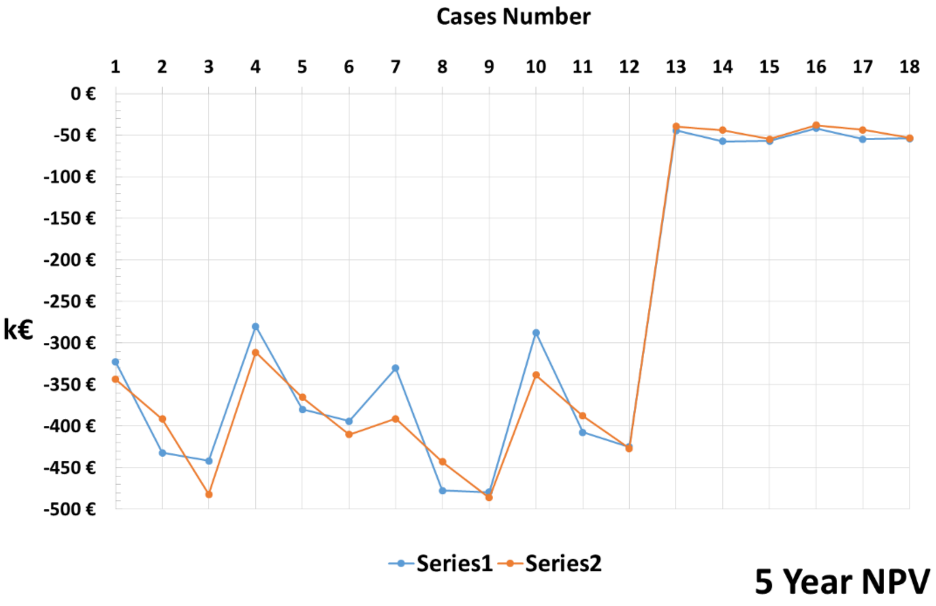
Observing the table above, we can see that we obtain negatives NPVs for all the cases, systems and in timeframes. This can be explained by the fact that the energy savings achieved through the implementation of the said systems are not sufficient in order to absorb the high initial CAPEX. In order to observe schematically we present the following pictures (Figure 8.5) which show the NPVs values for 5, 10, 20 and 30 year horizon for different cases and different systems analysed in this report.

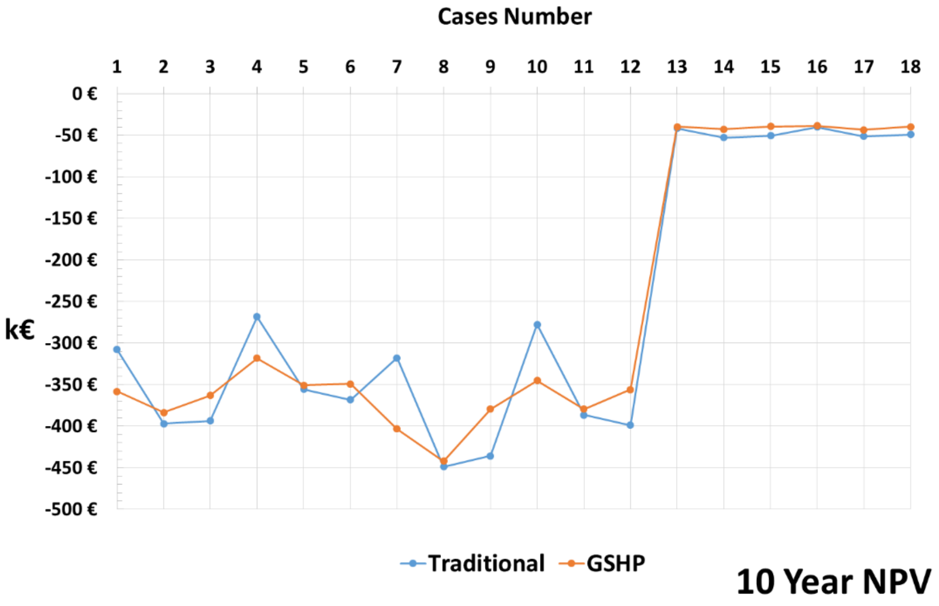
Observing the figures below (Figure 8.5), we can figure out first that for the cases number 13-18 (TH_HI_C2 – TH_EX_C3). These cases corresponding to the terraced house, single residential for historical and existing buildings. This is explained by the fact that the lowest initial inversion for installing the said systems. Even that the energy savings achieved through the implementations are not sufficient to absorb the initial inversion. For the same cases, it seems that the GSHP solution is a little more profitable compare to the traditional solution over the all years horizon analysed here.

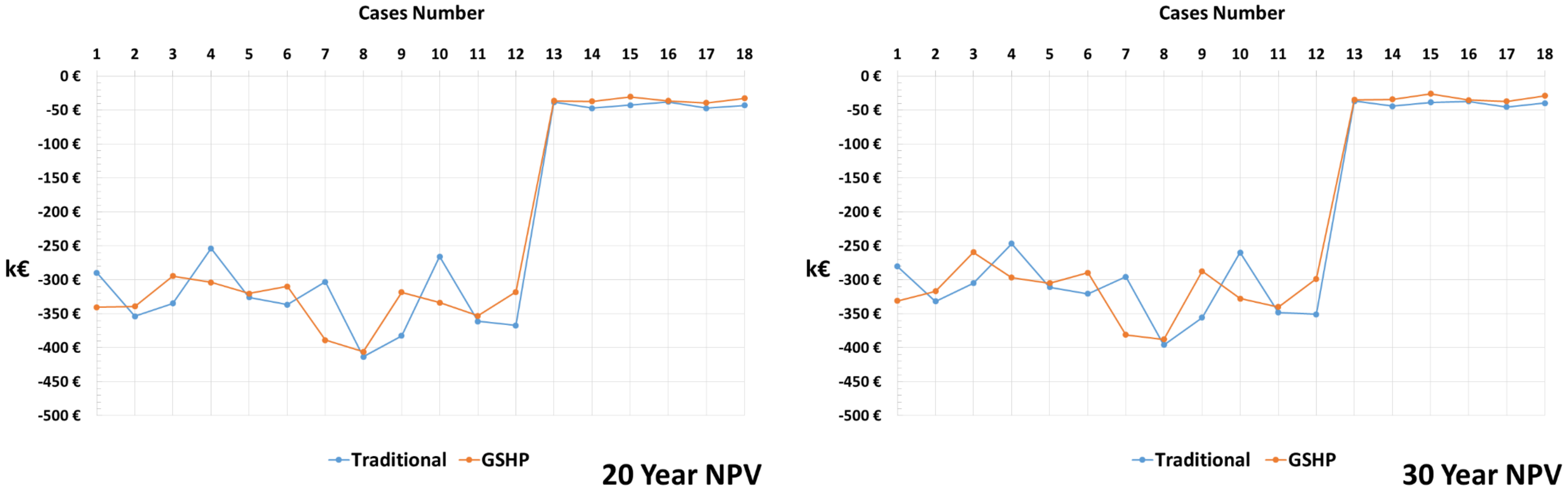
Taking a look over the following cases:

- Case 1: AB_HI_C1 → Apartment block, Existing building ,**Warm** climate
- Case 4: AB_EX_C1 → Apartment block, Existing building, **Warm** climate
- Case 7: OB_HI_C1 → Apartment block, Historical building, **Warm** climate
- Case 10: OB_EX_C1 → Apartment block, Existing building, **Warm** climate

We can see the involved traditional implementations are more profitable than the GSHP overall the years horizon. This can be explained by the fact that the lower initial investment of the traditional solution than the GSHP implementation.







20 Year NPV

30 Year NPV

Figure 8.5 Cost benefit analyses (5, 10, 20, and 30 years) for the archetypes' cases

If we take a look over the following cases:

- Case 2: AB_HI_C2 → Apartment block, Historical building ,**Average** climate
- Case 5: AB_EX_C2 → Apartment block, Existing building, **Average** climate
- Case 8: OB_HI_C2 → Apartment block, Historical building, **Average** climate
- Case 11: OB_EX_C2 → Apartment block, Existing building, **Average** climate

We can see the involved GSHP implementations has almost the same profitability than the traditional systems overall the years horizon and for all the cases.

If we focus on the following cases:

- Case 3: AB_HI_C3 → Apartment block, Historical building , **Cold** climate
- Case 6: AB_EX_C3 → Apartment block, Existing building, **Cold** climate
- Case 9: OB_HI_C3 → Apartment block, Historical building, **Cold** climate
- Case 12: OB_EX_C3 → Apartment block, Existing building, **Cold** climate

We can see the involved traditional solution are more profitable than the GSHP installation over the first 5 years horizon. But from the 10 years horizon the NPVs value increase for the GSHP resulting in a more profitable solution compared with the involved traditional one. This can be explained by the fact that the lower initial investment of the GSHP system than the traditional solution.

Generally speaking and thinking loud, it looks like that the traditional solutions is more profitable than GSHP in warm climates and the opposite thing in a cold climates for all the cases analysed here. For the average climates the two involved solutions have almost the same profitability.

9 Conclusions

A preliminary cost and business analysis has been made with the help of all partners from the different countries across of Europe for levels of renovation, climates and undergrounds. In parallel the same analysis has been performed for the buildings in Athens, Strasbourg and Helsinki which were modeled in the Task 1.3. This Report is meant to serve as a tool to those interested in implementing geothermal technology throughout Europe and to assist in identifying and analyzing the relevant factors to determine if geothermal energy systems are a viable solution.

What is important when observing the preliminary total cost of the some European countries (Table 7) is understanding the dynamics at play behind each case which can increase CBA results. Observing the Table 7, we can see that the involved implements are mainly profitable in the case of the Netherlands. Analysing more deeply, this seems to be due to insufficient energy savings which are unable to cover the initial investment costs in the case of Spain (at around 2000€ a year for a125000€ initial investment) or very high CAPEX costs for instance in the case of Italy (almost 4 million euros in CAPEX for 58-60 thousand euros saved annually). The reasons for these costs may be the prices of natural gas vs electricity in each country which will be presented later in this document, or high licences, material and labour agreements costs as well as difficulties in drilling for the high CAPEX. Moreover, from a general point of view, it is possible to see that the higher the discount rate the lesser the NPV as future cash flows used to amortize the CAPEX are further discounted, while the longer the time period (10 vs 30 years) the higher the NPV as there is logically more time for the annual energy gain to compensate for the CAPEX.

The costs related to the investment due to renovation in the archetypes modelled in Task 1.3 has been carried out. The costs analysis has been considered for the three climates (warm, average and cold) with the local costs (Greece, Germany, Finland) and for two possible deep retrofit solutions which are common for the envelope and the installation of radiant systems, by changing only the generation system: in one case condensing boilers and air to water chiller (named traditional) have been considered and GSHP or hybrid/bivalent reversible heat pump have been analysed. The interventions of deep retrofit range from 220 €/m^2 to 400 €/m^2 in the case of multi-user buildings. On average, the costs of the GSHP or hybrid solutions are similar due to the presence of a double generation system in the traditional systems and due to a scale factor. For the terrace house the costs are in the range 300 €/m^2 ÷ 470 €/m^2. The specific costs are always higher for the GSHP or hybrid/bivalent solution compared to the traditional solution by 10%÷15%. About the running energy costs in Greece are similar for the two proposed deep retrofit solutions, due to the fact that the energy demand in heating is very limited. In Germany, despite the strong reduction of final energy required by the GSHP or hybrid/bivalent solution, the costs are only slightly lower than the traditional solution, due to the lower cost of the thermal energy compared to the electrical energy. In Finland both the final energy and the costs are lower in the case of deep retrofit with GSHP or hybrid/bivalent solution than for the traditional deep retrofit.

In general terms, it looks like that the traditional solutions is more profitable than GSHP in warm climates and the opposite thing in a cold climates for all the cases archetypes analysed here. For the average climates the two involved solutions have almost the same profitability.

10 References

---

[1] As in the 2020 climate & energy package of the EU from 2007 and 2009 (“20-20-20 by 2020”)

[2] Geotrainet Training Manual for designers of shallow geothermal systems. GEOTRAINET. Brussels, 2011

[3] Karl Ochnser, Geothermal Heat Pumps. A guide for Planning and Installing, Earthscan, UK 2007

[4] EU Strategy for Heating and Cooling. Brussels, 2016

[5] Common vision for the Renewable Heating&Cooling sector in Europe. 2020-30-50. RHC Platform.Brussels, 2011

[6] Common vision for the Renewable Heating&Cooling sector in Europe. 2020-30-50. RHC Platform.Brussels, 2011.

[7] Fraunhofer 2015. EU Strategy for Heating and Cooling. Brussels, 2015.

[8] An Eu Strategy on Heating and Cooling. Brussels, 2016. European Commision. Final Report

[9] An Eu Strategy on Heating and Cooling. Brussels, 2016. European Commision. Final Report

[10] Buildings Performance Institute Europe (BPIE)

[11] Directive 2012/27/EU of European Parliament and of the Council of 25 October 2012 Energy on Efficiency, Amending Directives 2009/125/EC and 2010/30/EU and Repealing Directives 2004/8/EC and 2006/32/EC. Off. J. Eur. Union 2012, 4, 202–257.

[12] European Parliament. Proposal for a directive of the European Parliament and of the Council on Energy Efficiency.

[13] Report from the Commission to the European Parliament and the Council—Financial Support for Energy Efficiency in Buildings.

[14] Global Buildings Performance Network (GBPN)

[15] Entranze. Cross-Analysis on Member-States’ Plans to Develop Their Building Regulations Towards the NZEB Standard.

[16] Zebra 2020. Nearly Zero Energy Building Strategy 2020—Strategies for a Nearly Zero-Energy

[17] Directive 2010/31/EU of the European parliament and of the council of 19 May 2010 on the energy performance of building.

[18] K. Tsikaloudaki et al. Energies 2012.

[19] Pelletier et al. 2016

[20] M. De Carli, L. Carnieletto, A. Di Bella, S. Graci, G. Emmi, A. Zarrella, N. Baseggio, M. Belliardi, L. Rossi, L. Mulè Stagno, B. Badenes, J. Urchueguía, B. Sanner, G. Cadelano, A. Bernardi. Archetype definition for analysing retrofit solutions in urban areas in Europe, Proceedings of CLIMA 2019 Conference, Bucharest, May 2019.

[21] 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., ZarrellaA. (2018). A database for climatic conditions around Europe for promoting GSHP solutions. GEOSCIENCES, vol. 8, 71, ISSN: 2076-3263, doi: 10.3390/geosciences8020071.

[22] EN 14825 2016. Air conditioners, liquid chilling packages and heat pumps, with electrically driven compressors, for space heating and cooling - Testing and rating at part load conditions and calculation of seasonal performance.

[23] M. Economidou, B. Atanasiu, C. Despret, M. Economidou, J. Maio, I. Nolte, O. Rapf. Europe’s buildings under the microscope. A country-by-country review of the energy performance of buildings. Buildings Performance Institute Europe (BPIE). 2011. ISBN: 9789491143014.