Ground Source Heat Pumps in Europe: An analysis of the Geothermal Heat Pumps market

Deliverable D4.1

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Abbreviations

1U, 2U – configuration of heat exchanger with one respectively two loops made of polypropylene pipe.

ASHP – air source heat pump

BHE – borehole heat exchanger

BTES – Borehole Thermal Energy Storage

CAPEX – Capital Expenditure

CDH – Cooling degree hours

DH – District heating

DTH – down the hole drilling technique

DHW – Domestic hot water

EED – Earth Energy Designer

EG – ethylene glycol

EHPA European Heat Pump Association

GeoBOOST – Project that promote geothermal heating and cooling

GHP – geothermal heat pump

GHE Ground Heat Exchangers

GSHP – ground source heat pump

HDH – Heating degree hours

ICMS – International cost management standard

LCCA/LCC – Life-cycle cost analysis/Life-cycle cost

LCOE – levelized cost of energy

MPG – monopropylene glycol

NGO – non-governmental organization

NPV – Net present value

OPEX – Operational expenditures

SGU – Swedish Geological Survey

SKVP – Svenska Kyl&Värmepumpsföreningen (Swedish heat pump organisation)

WACC - Weighted Average Cost of Capital

Introduction

These are the instructions as set out for Task 4.1.

A set of economic evaluation schemes will be applied on a crosscut of representative GHP utilization concepts to demonstrate the true financial value of this technology to investors.

The outcomes of WP2 and WP5 will be used to define a set of technological GHP typologies, which will be populated with real case studies

The defined portfolio should reflect the current market situation in Europe and emerging future trends and will be completed with alternative, non-GHP based concepts reflecting the current market and actual trends

In a second step, life cycle cost analyses will be applied on the selected portfolio leading to comparisons of levelized costs of energy (LCOE) and net present values (NPV)

Our delivery

We have identified the numerous advantages that GSHP-energy solution has compared to other heating methods; it is gathered in the Chapter "Advantage Ground source Heat Pump".

We have gathered information regarding the market in the EU as it is for heating systems. It can be found in the chapter "Overview of heating and cooling systems in some EU countries". The input for that has been provided the other participants in the GeoBOOST project.

We have identified a country where the GSHP solution is very successful and analyzed the reason for that. Chapter "Description of a mature market, the Swedish example".

We have identified a number of evaluation tools for evaluating different energy solutions, it can be found in the chapter "Different evaluation tools".

We have developed an LCC tool an made several simulations for typical energy solutions in Europe and compared the outcome. It is an Excel file and comes separately.

We have done several standard calculations in the LCC-tool but also a number of simulations described separately in the chapter: "Some calculations examples". The purpose of these was to investigate the sensitivity of fuel prices, drilling cost, and financial cost for Capex.

Advantage of Ground Source Heat Pups

As the global community increasingly prioritizes sustainability, innovative technologies are emerging to offer more eco-friendly and efficient heating solutions. Among these, Ground Source Heat Pumps (GSHP) stand out due to their remarkable efficiency and environmental benefits. While traditional heating methods, such as oil, gas, and electric heating systems, have been the norm for decades, GSHPs offer several values that make them an attractive alternative. This chapter explores these benefits, highlighting why GSHPs could be a smarter choice for modern heating needs.

1. **Unmatched Energy Efficiency** . GSHPs harness the stable temperatures of the ground to heat and cool buildings, providing a highly efficient energy transfer process. Traditional heating systems, which rely on burning fossil fuel or electric resistance, often waste a significant amount of energy. GSHPs, on the other hand, can achieve efficiencies of 300-600%, meaning they produce three to six units of energy for every unit of electricity consumed. This efficiency translates into substantial energy savings and lower operational costs over time.

1. **Environmental Impact and Sustainability**
   One of the most compelling values of GSHPs is their minimal environmental impact. Traditional heating methods typically rely on fossil fuels, contributing to greenhouse gas emissions and environmental degradation. GSHPs, however, use renewable geothermal energy, drastically reducing carbon footprints. By switching to GSHPs, homeowners and businesses can significantly lower their greenhouse gas emissions, contributing to a healthier planet. Especially if they use certified, fossil free electricity, i.e. electricity produced by not using fossil fuels.

2. **Long-Term Cost Savings**

While the initial installation cost of a GSHP system usually is higher than traditional heating systems, the long-term financial benefits are significant. The high efficiency of GSHPs results in lower energy bills, which, over time, offsets the initial investment. Additionally, GSHPs have longer lifespans—typically 20-25 years for the indoor unit and over 80-100 (or even forever when it comes to the borehole) years for the ground loop—reducing the need for frequent replacements and repairs associated with traditional systems.

3. **Reliability and Low Maintenance**
   GSHPs offer unparalleled reliability due to their simple and durable design. The underground components are protected from weather extremes and physical damage. This protection leads to fewer breakdowns and lower maintenance requirements. Moreover, the consistent underground temperature ensures a stable and reliable heat source, irrespective of weather conditions.

4. **A local energy source**
   Most of the energy used by a GSHP-system is extracted from the ground around the building. It makes a very robust energy source since that part of the energy provisioning is not dependent on transports or external provisioning.

5. **Quiet Operation** Traditional heating systems, especially those that rely on combustion, can be noisy during operation. GSHPs, conversely, operate quietly, as the noisy components are typically located outside the living space, in the basement. Also no part of the GSHP is located in the open outside the building. This quiet operation enhances the comfort of the living environment, making GSHPs an attractive option for residential areas.

6. **Versatility and Year-Round Use**
   GSHPs are versatile systems capable of providing both heating and cooling, along with hot water. This all-in-one functionality eliminates the need for separate heating and cooling systems, simplifying home management and reducing overall costs. Traditional heating systems, in contrast, often require additional air conditioning units, leading to higher installation and maintenance costs.

7. **Government Incentives and Rebates**
   To promote sustainable energy solutions, many governments offer incentives and rebates for the installation of GSHPs. These financial incentives can significantly reduce the initial installation costs, making GSHPs more accessible and affordable. Traditional

heating systems rarely benefit from such extensive government support, making GSHPs a financially savvy choice in the long run.

9. Safety

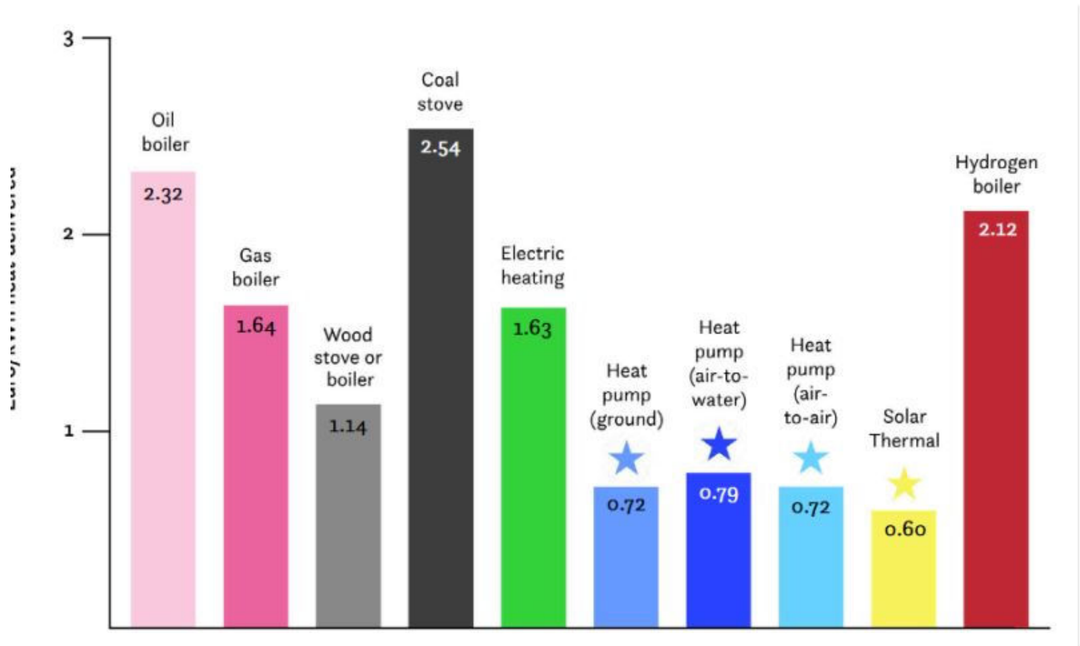
Safety. A Heat Pump operates at relatively low temperatures and has no open flame nor any needs for containers or pipings with flammable liquid or gas.

10. Other Heat Pump solutions

One could argue that Heat Pump solution with other heat sources like ambient air has most of these advantages. It is true but they are less efficient, lower COP, needs more electricity per unit produced since the temperature of air in wintertime is usually much lower than the underground temperature which will demand mor energy to be raised to useful levels. Also, unlike for GSHP-solutions, since a part of the Air Heat pumps must be outside for collecting the air, means that it is affected by wear and tear from the weather, rain and frost, and will have a shorter life span.

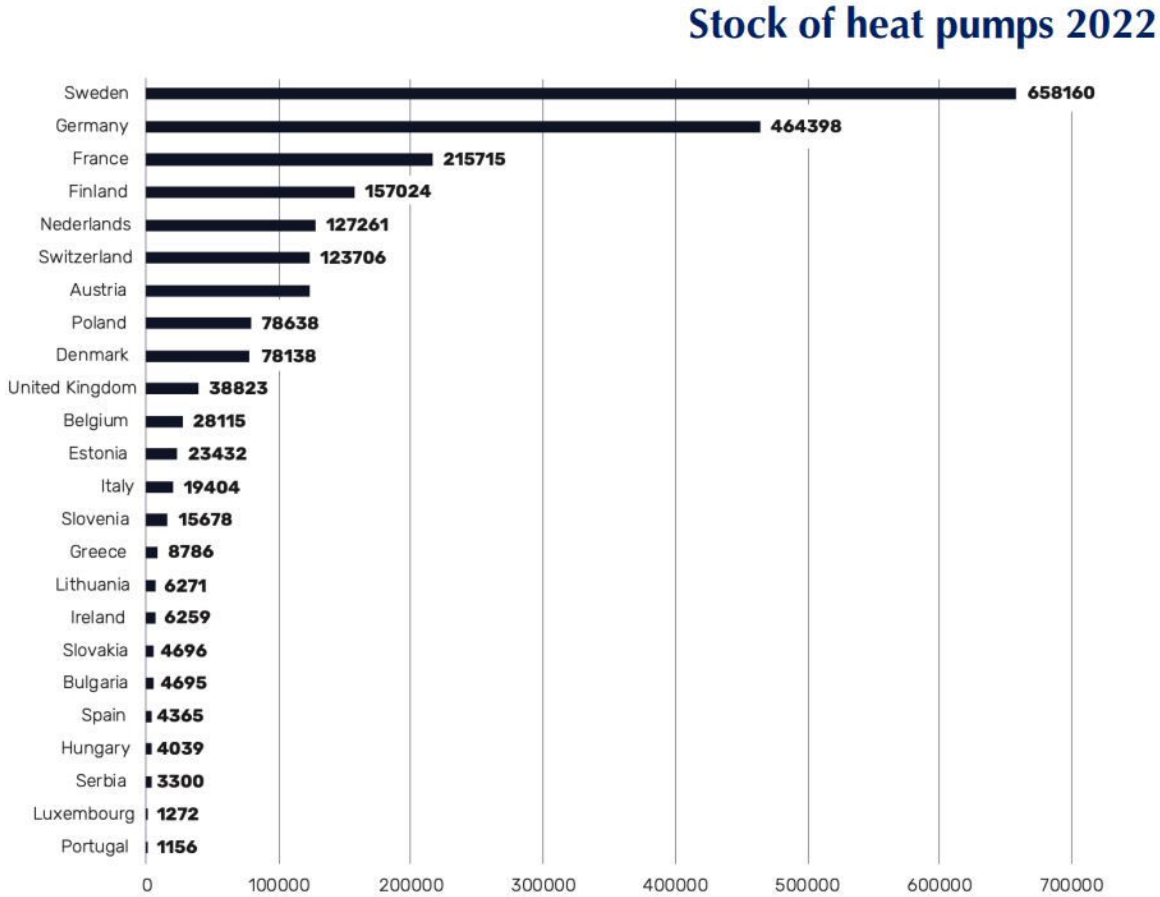
11. Levelized cost of heating in EU overall

Figure 6. Total cost of ownership by heating technology, 2030-2040 (EUR/kWh heat delivered)



Source: Mixed scenario with hydrogen produced domestically, from ECF et al. (2022).

The number of installed GSHPs in Europe



From http://www.geothermica.eu/media/about-geothermal/Presentation-Slovenia-Prospects-of-Geothermal-Energy-in-Europe-PD.pdf

Conclusion

Ground Source Heat Pumps offer a plethora of real values that make them a superior choice compared to traditional heating methods. From unmatched energy efficiency and environmental benefits to long-term cost savings, safety and enhanced comfort, GSHPs present a forward-thinking solution for modern heating needs. As the world moves towards sustainability, adopting GSHP technology can provide both immediate and long-lasting benefits for homeowners and businesses alike. Embracing this innovative technology not only supports a greener future but also offers practical advantages that extend far beyond the initial investment.

Description of a mature GSP market, the Swedish example

Foreword

Each and every country has its own unique situation when it comes to climate, geology, industrial, economic, social and political prerequisite to introduce and expand GSHP as a heating solution. The following chapter describes the Swedish situation based on its unique prerequisite and is not necessary a blueprint for other countries. But hopefully it can give some inspiration.

Introduction

The total heated area in Sweden 2022 was 704 million m2.

The year 2002 it was 574 million m2. See appendix.

In spite of this increase the primary energy used for heating and tap water decreased from 2002, when it was 89,2 TWh, to 74,2 TWh in 2022. (Appendix.)

Some reasons for this are more efficient building technology, refurbishments like more efficient windows, attic insulations and a general awareness focused on energy savings. But the most important reason is the vastly increased usage of heat pumps during this period. An estimation based on the number of sold heat pumps gives “free” heat energy produced from air/soil/lake/bedrock to about 40 TWh. Thus about 114 TWh is really used for heating and hot water production.

Sweden has some 1,7 million heat pumps (1) installed. As of 2022 about 660 000 of those are ground source (6) heat pumps

The ground source heat pumps produce around 28 TWh of heat energy. Extrapolated from (2) and based on verbal communication with ground source heat pump expert Ph D Signhild Gehlin, head of Svenskt Geoenergicentrum, who closely monitor this and is a coauthor of (2)about 24 percent of heating energy is provided by ground source heat pumps.

This figure is somewhat contested and other estimates are that “only” about 20 % of the total heating energy comes from ground source heat pumps.

Main drivers

What are the main drivers for this?

In the 70s Sweden was heavily dependent on oil for heating buildings. Since the 50s Sweden had systematically switched most heating systems from coal to oil. Most individual houses had oil burners and larger buildings in urban areas were often served by local plants producing heat using large oil burners and disposing of hot gases through high chimneys. The heat and hot water produced were distributed by pipes to buildings nearby. For buildings erected on public land it was mandatory to connect to this local heat production plants.

The vastly increased oil price in the years 1974 and 1978 hit Sweden very hard and triggered a number of actions. One was to build nuclear power-plants. In a few years at the end of the 70s Sweden built and commissioned 12 nuclear reactors. Together with lots of hydropower this kept Swedish electricity prices low for a long time. Six of the nuclear plants are still running as of today. The decommissioning of the other six has been based on political decisions.

Another action was to build district heating systems. The first one in Sweden was built already in 1948 but by the time of the oil crises it was still not widely spread. But the oil price crises spurred a fast buildup of district heating networks. Today virtually every township in Sweden has one, all in all there is about 580 of them. Originally many of them used fossil fuels like oil and coal and even electricity which was very cheap at the time.

But fossil fuels have nowadays largely been phased out for heat production in district heating plants. Only about 1,9 % of the fuel is fossil. Instead, sources like waste, peat, biofuel and waste heat from industrial production are used. The CO2-emissions from district heating is still a not negligible 51,4 g/kWh on average, most of it from burning waste. (3)

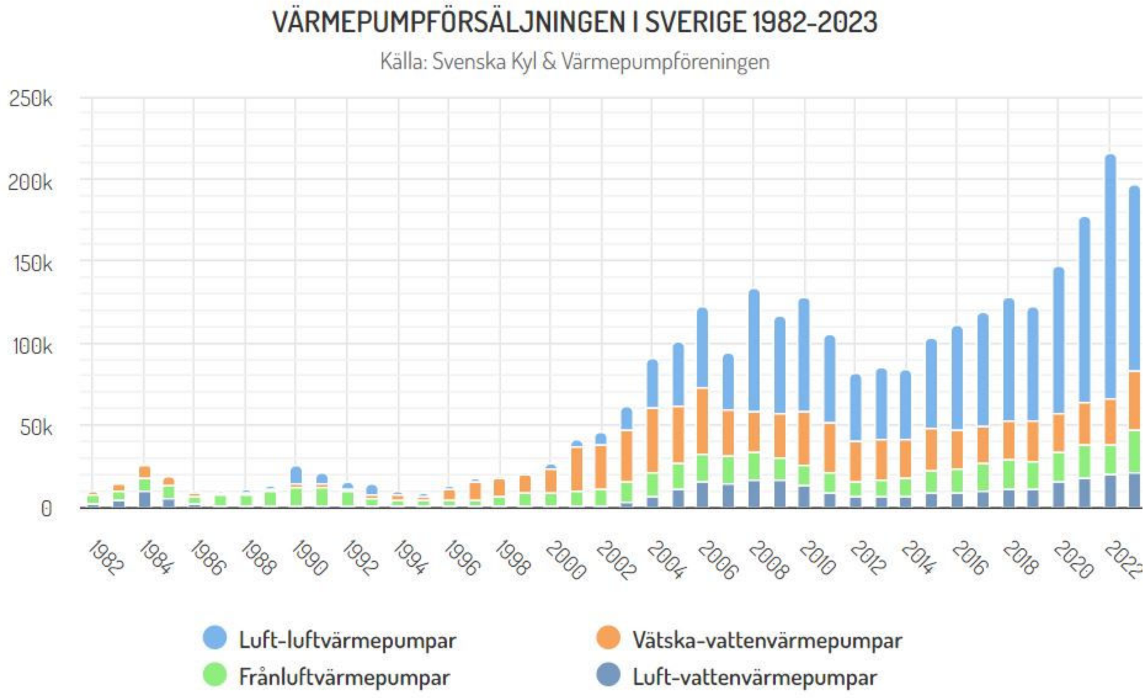
If we look only at primary energy about 60 % of total heating is provided by district heating but it shrinks to 40 % when the "free" energy from the heat pumps is taken into consideration. Penetration for larger buildings in urban areas is about 90 %.

Also, in individual small buildings oil has largely been phased out. Less than 1 % still uses oil. The oil burners have mainly been replaced by heat pumps.

Gas has never been a major source for heating in Sweden, and nowadays, less than 1 percent of the building stock by floor area use gas for heating.

The third major action caused by the oil price increases was to stimulate research and development of heat pump technology. Sweden already had a strong industrial sector when it comes to heat pump technology. Sweden was a pioneer developing the modern refrigerator based on an invention made by Munters and von Platen. A refrigerator is a heat pump though the purpose is the reverse. A heat pump/refrigerator is moving heat from one place to another. Decreasing the temperature on one side, increasing it at another.

The first heat pumps for buildings were developed by pioneering companies like NIBE and IVT in the 80s. But effective ground source heat pumps were first developed in the 90s. At the same time theoretical analysis tools and software for simulating effect of extracting and injecting heat in the bedrocks were developed at a few Universities in Sweden, Germany and USA. Public financing supported the academic research.



Above can be seen sales statistics for heat pumps in Sweden. (4) The first ground source heat pumps (light brown) were deployed already in the 80ties. They were open source based, using ground water directly. They were not very efficient, and the solution got a bad reputation, effectively stopping all sales. As mentioned, effective ground source heat pumps were developed in the 90ties and used with close loop systems which are easier to install and maintain compared to open-source systems. In the beginning of the century, driven by high oil prices, government subsidies (there is still some subsidies for private house-owners) and cheap electricity the number of systems really started to soar as can be seen in the diagram.

In the segment small houses, the ground source heat pumps soon were meeting stiff competition from air based heat pumps (blue colours in graph above, and also illustrated here

from (2)

But it was compensated by a fast growth of larger heat pumps (which means more drilling) as can be seen from graph below. (2)

A perfect storm

Several factors contributed to the strong development for ground source heat pumps in Sweden.

Four factors are already mentioned above:

A strong industrial and technological base, with basic knowledge about heat pumps already around.

Academic research publicly funded. Methods and software developed puts calculating borehole fields on a more accurate base, ensuring sustainable solutions. E.g. Earth Energy Designer is and easy to use software tool for simulating bore hole fields with a proven accuracy. It was developed in the 90ss through a collaboration between Lund Institute of Technology (Sweden) and Giessen University (Germany)

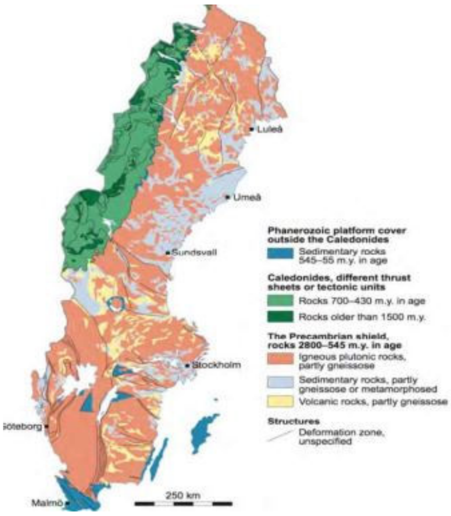
Government subsidies in the beginning of the century.

Cheap electricity.

Geology and drilling

A large part of Sweden the bedrock consists of the so-called Baltic shield. The Baltic shield consists of old (pre-Cambrian), predominantly crystalline igneous and metamorphic rocks suitable for drilling and as a heat source and sink since it is giving stable holes for mounting collectors and with good heat conductivity due to high quartz content. The most common diameter for the holes is 114 mm, even if 139 mm is sometimes used for deeper boreholes and the collector is normally a single U-collector 40-50 mm in outer diameter with SDR 17. Material is PolyEthylene (PE100 is common) Sometimes double-U collectors are used, and the pipes then are 32 mm, SDR 17 mm. Boreholes with less diameter is cheaper to drill since less energy is needed for smashing the rocks and for transporting the crushed rock to the surface.

The high conductivity normally found in Swedish rocks means less amount of drilling meter per produced heat unit, which of course also keeps the cost down. Overview of the geology below by Swedish Geological Survey. From (2).



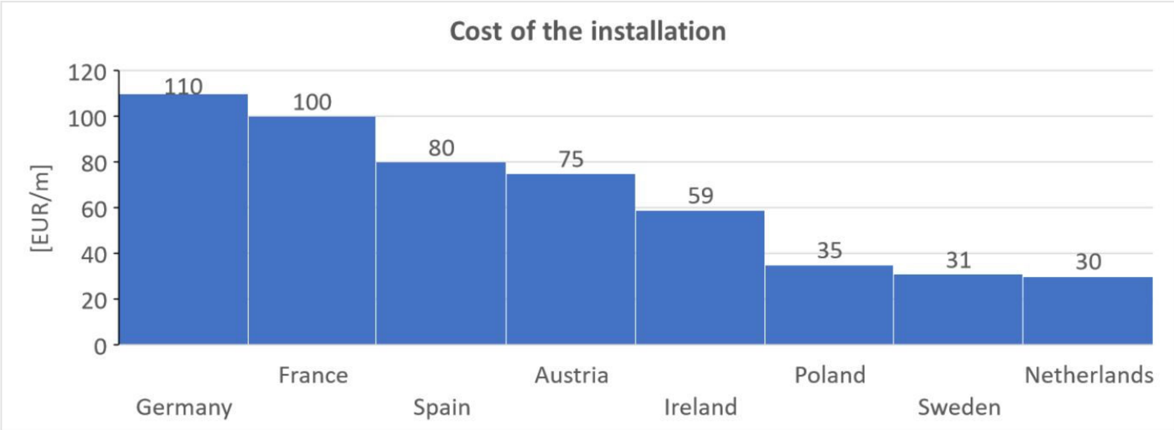
An important contributor to the fast spread of borehole-based ground source heat pumps were efficient, therefore relatively cheap, drilling methods. Sweden has a long history of mining in hard rocks. Due to that efficient drilling methods and machinery; rigs, tools and compressors already were developed by companies like Sandvik and Atlas Copco. And could be used for drilling for ground source heating. Cost comparison in (5) shows that Sweden drilling methods are efficient and therefore cheap, compared to other countries.

In Swedeen there is usually no demand for grouting, since there is plenty of ground water almost everywhere and this keeps the cost down. Ground water level is usually found at depths between 4 and 6 meters. The protection of the ground water is regulated in a number of (strong) recommendations how to drill to protect the ground water, as stated in the document Normbrunn 16 (translated to English it can be found at (10)) by the Swedish Geological Survey.

High ground water levels mean grouting is not necessary since heat is transferred between the bedrock and the collector through the ground water.

Finally, another factor keeping the cost down, is that the soil (sand, moraine, etc) overburden covering the bedrock is usually quite shallow keeping the need to drill with steel pipes to a minimum. It is rarely thicker than 6 meters. And drilling with pipes is much more expensive compared to drilling in solid rocks.

From (5)



Since heat pumps is a commoditized market, the price does not differ much between EU-countries and labor-cost are also quite equal (with the exception of Poland) the cost in the above graph (5) is mainly reflecting drilling cost.

Serving the ground source heat pumps in Sweden is some 670 000 drilled bore holes (vertical and closed loop), 150 000 soil/lake based (horizontal and closed loop) heat pumps and around 12 000 open-source (direct usage of ground water) systems. Extrapolated from (2).

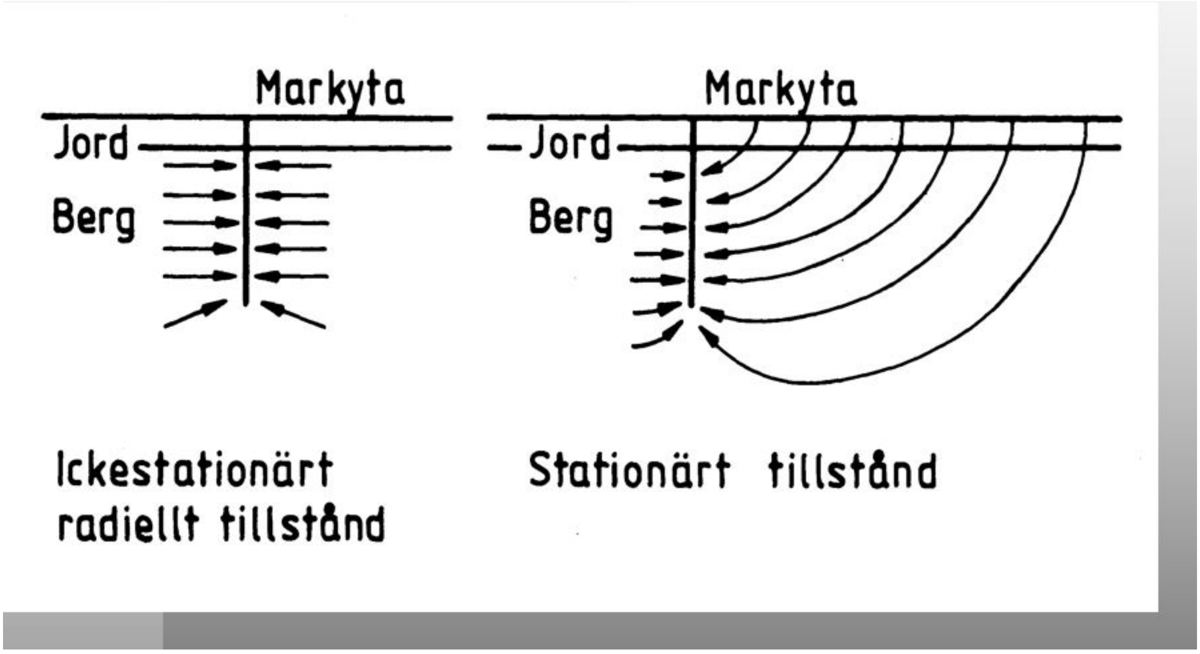
Drilled boreholes with closed loop system is thus by far the biggest heat source for liquid based heat pumps in Sweden. The reason is that in urban area there is no space for soil-based system and even if some 13 percent of Swedish ground holds enough water for open loop systems (2) it is a complicated process to get permission to drill there, since it is often used for freshwater extraction and thus highly protected. The permission procedure is also more complicated compared to drilling for closed systems.

Drilling 114 mm borehole and mounting a single-U collector is a standardized routine and therefore efficient and cost-effective, and together with an abundance of drilling companies that makes it a highly competitive sector, are factors keeping the cost for drilling and mounting collectors and pipes, down.

Climate

Sweden has a continental climate with cold to very cold winters and warm summers, this means there is a great need for efficient warming solutions to handle the winter cold and that there is some need for cooling in the summer and the bedrock can be used as a source and sink for both needs.

Since most of the heat energy stored in the upper crust derives from the sun, warm summers is favourable for long term extraction of heat energy as illustrated below (from 7). The heat from the interior of the earth is very negligible in Sweden due to thick continental crust (the Baltic Shield) that isolates the upper crust from the hot mantle.



Right part of the picture illustrates the situation when you have a steady temperature around the borehole(s) and thus a sustainable ground source heat installation. To the left is the initial situation when temperature is dropping in the bedrock.

Simple permission management

All 290 municipalities in Sweden have an environmental department (sometimes together with other municipalities). The environmental department is the entity that gives the permission of installing a ground source heat pump, including drilling (or digging).

The process is simple, a simple form needs to be filled in and sent to the department. Provided there is no issue with neighbours' being too close (at least 20 meter from adjacent boreholes), water protection issues or drilling applied for is on contaminated ground the permission is practically always granted. And normally within a few weeks' time.

Every drill must be reported on a simple form, it can be done interactively, and sent to the Swedish Geological Survey, it is a quick procedure.

This light bureaucracy also facilitates the spread of ground source heat pumps.

Conclusion

Factors like advanced and early development of technologies for heat pumps and drilling equipment, a favorable geology and climate, early development in academia, cheap electricity, timely government subsidies and simple permission procedures all created a "perfect storm" for the fast and thorough spread of ground base heat pumps in Sweden.

In absolute numbers Sweden (the most recent figure is 660 000, from (6) is only surpassed by China and USA when it comes to absolute numbers of ground source heat pumps installations. The only country in Europe near the number of installations that Sweden has, is Germany (460 000 units installed (6). When it comes to number of ground source heat pumps installations per capita and share of heating used for buildings there is no country even close to Sweden. With one exception. Iceland, a volcanic island sitting on top of the mid Atlantic ridge is having a whooping amount of 90 percent of heating from buildings coming directly from warm and hot ground water, mostly without the need for a heat pump.

In contrast, and unlike most European countries one cannot even find any warm water reservoir, within a reasonable depth, in Sweden with a temperature above 25 degC.

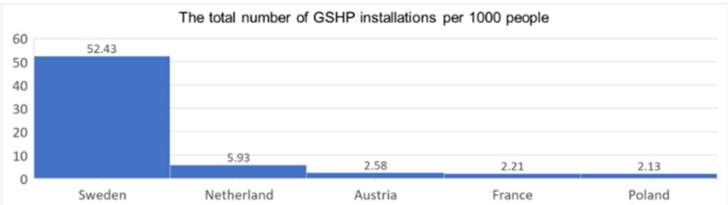
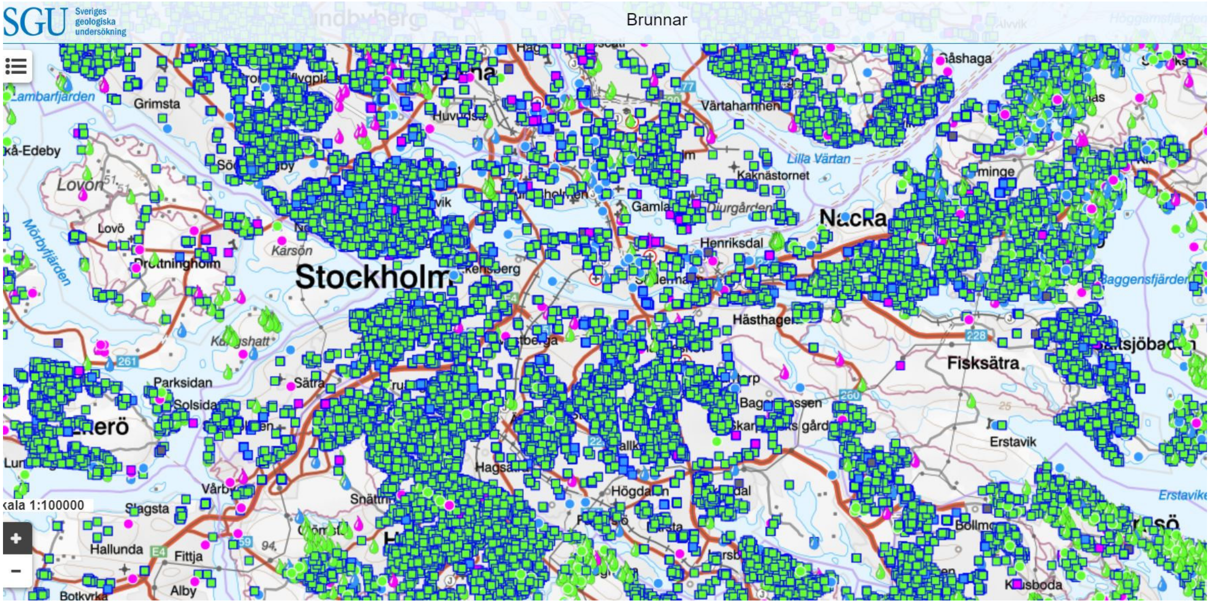


Figure 4. Total number of GSHP installations per 1000 people

Graph above from (4)

Below is an excerpt from "Databasen brunnar" (generally referred to as Brunnsarkivet. (8)

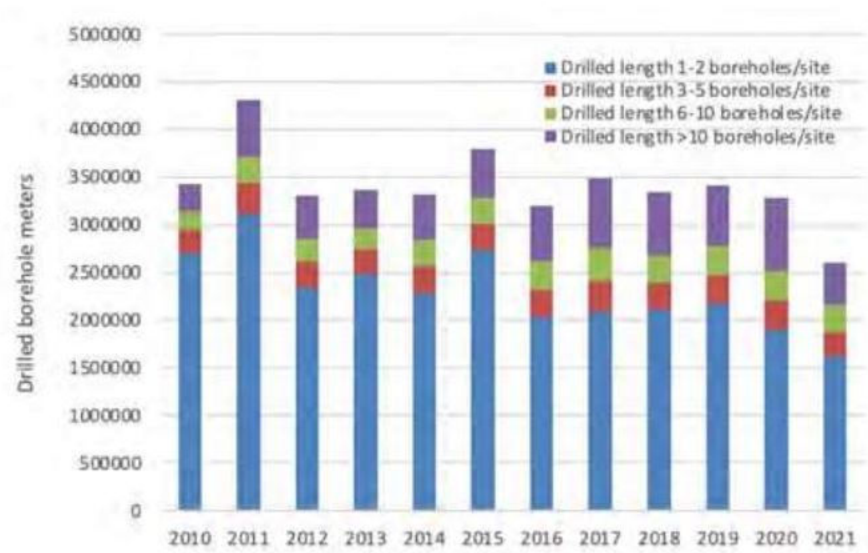
Every green square is one or several borehole(s), even a hundred boreholes on a property is represented with only one green square on the map, it has to be clicked in order to find out the number of boreholes and other details about the boreholes. As can be seen the penetration is indeed high!



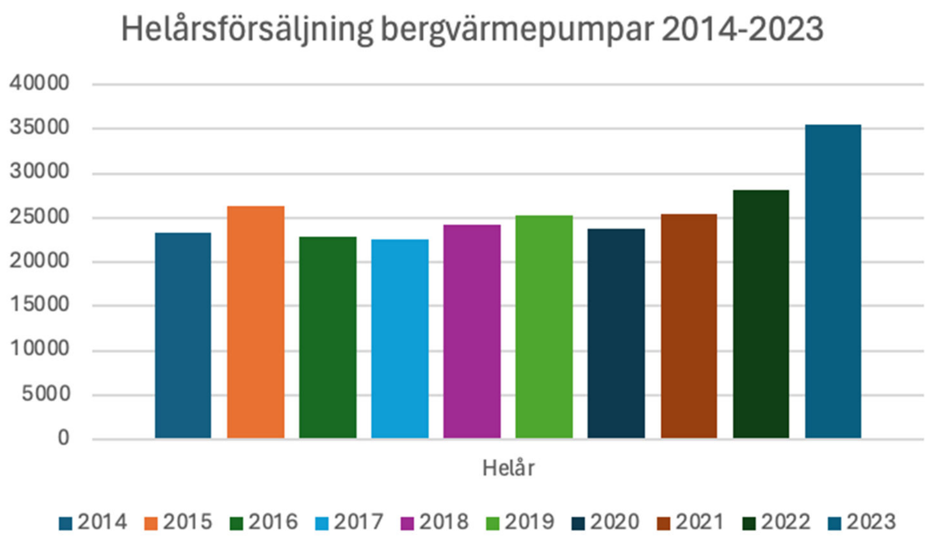
This is a great tool since each borehole is documented with distance to bedrock, distance to ground water, abundance of groundwater, bigger cracks and generally gives some information about the bedrock. It facilitates planning and cost estimation for drilling.

Future

The market for ground source heat pumps has been quite stable for many years. The decrease in sales towards the small house segment is offset by an increase of larger systems. Thus, the drilling has been quite stable, about 3,3 million drilled meters per year as can be seen in the graph below. Not even the pandemic changed that. (2) 2021 is underreported due to lag in the reporting,



This graph also shows a stable market. Ground source heat pumps sales in Sweden. (4)



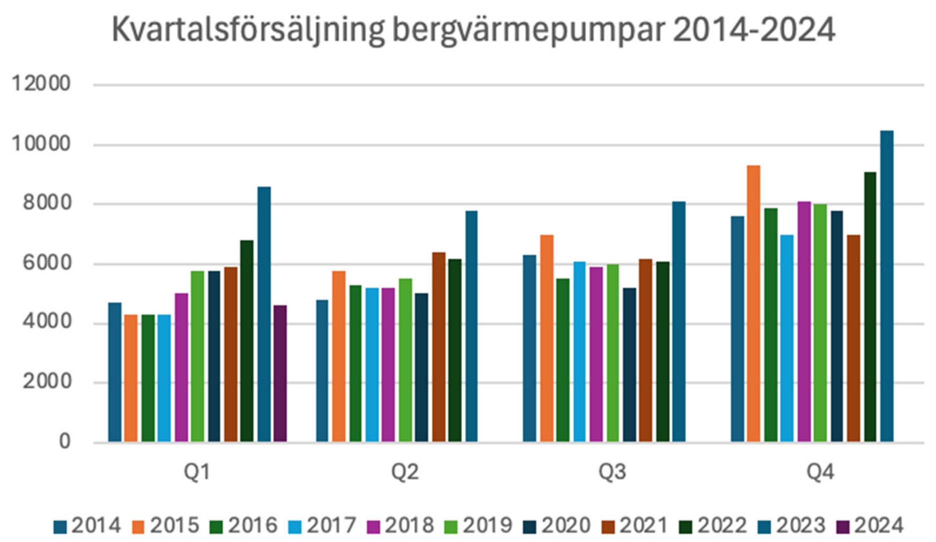
However ,the Russian invasion of Ukraine and all the effect and actions it causes created problems for the market.

The increase of the interest rate made it more expensive to invest in a ground source solution due to its high capex. The electricity price increased more than the District heating prices making comparisons with district heating less favourable. For larger installations in urban areas district heating is always an alternative to ground source heat pumps.

The increase in sales for ground source heat pumps the year 2023 is a little hard to explain since it was not followed by an increase in drilling demand.

An explanation is the very optimistic forecast from EU (9) regarding sales of heat pumps in Europe and the need for weaning of gas boilers somehow spilled over to the Swedish installers and they invested in increasing their inventories, anticipating a surge in sales. A surge that never came.

And, predictably, in Q1 2024 the sales took a sharp dip as can be seen in this graph (4),



It is a fact that Sweden is in a recession at the moment and most larger building projects has been cancelled or put on hold, and that of course reflects as a shrinkage of the ground source heat market.

However, there is light in the tunnel since Sweden is soon coming out of the recession, interest rates are on its way down and the building market will rebound.

And for larger buildings with need for both heating and cooling an LCC will most of the time show that ground source heat solutions are less expensive in the long run compared to the alternative, district heating.

And, also more sustainable, with less CO2-emission if certified electricity is used.

(1) https://pxexternal.energimyndigheten.se/pxweb/sv/Bost%c3%a4der%20och%20lokaler/Bost%c3%a4der%20och%20lokaler__Samlingsrapport/EN0112_6_ts.px/table/tableViewLayout2/?rxid=b1ada2ab-5fc9-4c72-a2e1-f429a1644466
(2) Geothermal energy use, Country update for Sweden. Gehlin, Andersson, Rosberg 2022
(3) https://www.energiforetagen.se/statistik/fjarrvarmestatistik/miljovardering-av-fjarrvarme/
(4) https://skvp.se/nyheter-o-statistik/statistik/varmepumpforsaljningen
(5) Geoboost- Deliverable D2.1 Ground Source Heat Pumps in Euro

(6) http://www.geothermica.eu/media/about-geothermal/Presentation-Slovenia-Prospects-of-Geothermal-Energy-in-Europe-PD.pdf
(7) Prof. Bo Nordell / Göran Hellström, Avd. för förnyelsebar energi, Luleå tekniska universitet. Lecture material extract.
(8) https://apps.sgu.se/kartvisare/kartvisare-brunnar.html
(9) https://setis.ec.europa.eu/heat-pumps-european-union_en
(10) https://resource.sgu.se/dokument/publikation/ovriginfo/ovriginfo08broschyr/well-standard-16.pdf

Overview of heating and cooling technologies in some EU-countries

Foreword. Information, unless otherwise stated, is from the members in the GeoBOOST project.

Germany

Germany is considered to be a Mature market according to definition in GeoBOOST project.

Private Consumers/Single Houses

Dominating Heating Methods:

The dominant heating methods in private homes in Germany are natural gas around (50%) oil (about 25%), and district heating (10%). Recently, there has been an increase in the use of renewable energy such as heat pumps, wood pellets and other biomass (15%).

Average Price for Purchase and Installation:

Gas heating system: 6 400 €

Oil heating system: 9 300 €

Heat pump system:

Air source HP 12 000 € per 6kW and 18 000 € per 12kW

Geothermal HP 11 000 € per 6kw to 17500 € per 20kW

Geothermal HP 31 000-32 000 € per the whole installation including planning , borehole, HP and installation. (6kw) (The price per meter of borehole is 139 €/m)

Pellet heating system: 31 700 € –fully automatic system.

Price for Heat Sources:

Natural gas: €0.06 - €0.07 per kWh

Heating oil: €0.08 - €0.10 per kWh

Electricity: €0.30 - €0.35 per kWh

Wood pellets: €0.05 - €0.06 per kWh

District heating: €0.07 - €0.10 per kWh

-

Heating Requirement per Square Meter:

- Old modernized buildings 90 kWh per square meter annually
- Old buildings 225 kWh per square meter annually
- New buildings 60 kWh per square meter annually
- The higher standard is the Maximum Heating requirement 40 kWh per square meter annually

Efficiency:

- Gas boilers: 85-95%
- Oil boilers: 85-95%
- Heat pumps: 300-400% (COP of 3-4 for the renewable electricity),

  (if the efficiency of fossil fuel powerplants is counted as well, the results will be different)

- Pellet boilers: 85-90%

- Hydronic systems (radiators or underfloor heating) are most common.

Cooling Systems:

Cooling is not very common in single-family homes, but when present, it is usually delivered by reversible heat pumps or air conditioning units. Energy usage can vary significantly but typically ranges from 50-100 kWh per square meter annually.

Tenant Buildings

Dominating Heating Methods:

- Similar to single houses, natural gas is the most common, followed by district heating and oil. Heat pumps and electric heating are less common but growing.

Prices for Heat Sources:

We do not know the prices for the bigger customers.

Heating Requirement per Square Meter:

- Old buildings 180 kWh per square meter annually
- New buildings 50 kWh per square meter annually
- The higher standard is the Maximum Heating requirement 40 kWh per square meter annually

Efficiency:

- Similar to private homes with gas and oil boilers around 85-95%, and district heating systems typically around 80-90%. And up to 30 percent loss during the transportation.

Heat Distribution:

- Hydronic systems, primarily radiators, and underfloor heating in the new houses.

Cooling Systems:

- There is no cooling system in the tenant houses.

Office Buildings

Dominating Heating Methods:

- District heating and natural gas are the most common. Heat pumps are also becoming more common in new build houses.

Heating Requirement per Square Meter:

- Modernized old office houses typically, 300 kWh per square meter annually.
- New offices 210 kWh per square meter per year.)

Efficiency:

- Gas boilers and district heating systems have efficiencies around 85-95%.
- The heat pumps might be more efficient that the same counterparts from the multifamily houses, because they do not produce the warm water.

Heat Distribution:

- Often a combination of hydronic systems and ventilation systems.

Cooling Systems:

- Cooling is common, usually provided by centralized air conditioning systems or reversible heat pumps. Energy use can range significantly, often around 100-200 kWh per square meter annually.

In General

CO2 Emissions per kWh:

- Natural gas: ~200-250 g CO2/kWh
- Heating oil: ~270-300 g CO2/kWh
- Electricity (grid average): ~400-500 g CO2/kWh
- Wood pellets: ~20-40 g CO2/kWh - The numbers for wood pellets are much lower than the fossil fuel, which probably mean, that pellets are from the renewable source.
- District heating: Varies widely depending on the energy mix, but generally around 150-250 g CO2/kWh.

Trends:

- Increasing replacement of gas and oil boilers with heat pumps.
- Growing use of district heating, especially in urban areas.
- Rising demand for cooling systems, driven by climate change and increasing comfort expectations.
- Enhanced focus on energy efficiency and reduction of CO2 emissions, with government incentives supporting renewable energy and efficient technologies.
- CO2 pricing increase the prices of the heat.
- 2024 – 45 €/ton
- 2025 – 55 €/ton

Figure 5. Monthly operating costs of an electric heat pump in Germany

Source: Miara, 2021.

Sweden. See [Description of a mature market for Ground Source Heat Pump based heating solution the Swedish example]

The Netherlands

The Netherlands is considered a Transitional market according to GeoBOOST definition.

Questionaire Heating system

Answers pertaining to cost / energy per m2 etc are based on a recent study "Cost and benefit analysis ground source energy systems. CE Delft, 2023.

Private consumers/single houses

What is/are the dominating heating method(s) for private consumers? How large part in percentage are using that/those method(s)?

Gas fired boilers: 70 oC, GHSP: Underfloor heating (35 oC) is the standard. There are 8 x 10^6 houses in the Netherlands and about 120.000 ground source energy systems. Last couple of years about 25% of new build uses ground source heat pump.

What is the average price for a normal house for purchase and installation for the heating system?

In the netherlands this is not considered part of the ground source system. For the ground source system, including the heat pump (space heating, tap water and free cooling) the price for a single family house ranges probably between 10.000 – 20.000 euro (gas boiler cost around 5000 euro).

What is the price, inclusive non-deductible taxes (i.e. real cost) for the heat "source"? (Coal, oil, gas, electricity, pellets (wood)), district heating per suitable unit (liter, kilo, cubic meter, kWh).

Especially the last period this varies wildly. Currently (2024) between 0.55 and 0.80 / kWh (consumer price, not including connection cost etc). Gas between 1,14 and 1.36 / m3 depending on contract.

How much is typically needed for heating per square meter? What is the efficiency in percentage for the fuel and heating method, (how much is wasted in the form of hot gas etc?

First number existing build, second number new build using ground source energy system: Heating 0.143 – 0.113 GJ/m2, domestic hot water 0 – 0.06 GJ/m2, cooling 0.013 – 0.046 GJ/m2

How is the heat typically distributed in the house (hydronic, ventilation, fans, radiator)?

Hydronic

Is cooling systems common. How is it delivered in that case and how much energy in kWh is used? (I assume inverters or reversed heat pump).

Yes, free cooling if ground source energy system installed.

Tenant buildings

What is/are the dominating heating method(s) for tenant buildings? ? How large part in percentage are using that/those method(s)?

Gas fired boilers: 70 oC, GHSP: Underfloor heating (35 oC) is the standard. There are 8 x 10^6 houses in the Netherlands and about 120.000 ground source energy systems. Last couple of years about 25% of new build uses ground source heat pump.

What is/are the price(s), inclusive non-deductible taxes (i.e. real cost) for the heat "source(s)"? (Coal, oil, gas, electricity, pellets (wood), district heating) per suitable unit (liter, kilo, cubic meter, kWh).

Especially the last period this varies wildly. Currently (2024) between 0.55 and 0.80 / kWh (consumer price, not including connection cost etc). Gas between 1,14 and 1.36 / m3 depending on contract.

How much is typically needed for heating per square meter? What is the efficiency in percentage for the fuel and heating method, (how much is wasted in the form of hot gas etc?

First number existing build, second number new build using ground source energy system: Heating 0.139 – 0.131 GJ/m2, domestic hot water 0 – 0.072 GJ/m2, cooling 0.009 – 0.046 GJ/m2

(1 GJ is 277 KWh)

How is the heat typically distributed in the building (hydronic, ventilation, fans, radiator)?

Hydronic

Is cooling systems common? How is it delivered in that case and how much energy in kWh is used? (I assume inverters, cooling compressor or reversed heat pump).

Yes, free cooling if ground source energy system installed.

Office buildings

What is/are the dominating heating method(s) for office buildings?

Gas fired boilers, open loop ground source energy systems. I do not know the numbers, but GSHP is small fraction of total.

How much is typically needed for heating per square meter? What is the efficiency in percentage for the fuel and heating method, (how much is wasted in the form of hot gas etc.

First number existing build, second number new build using ground source energy system: Heating 0.406 – 0.081 GJ/m2, domestic hot water 0.004 – 0.005 GJ/m2, cooling 0.087 – 0.077 GJ/m2

How is the heat typically distributed in the building (hydronic, ventilation, fans, radiator)?

Hydronic / air

Is cooling systems common? How is it delivered in that case and how much energy in kWh is used? (I assume inverters, cooling compressor or reversed heat pump).

Yes, air conditioning. In office with open-loop system also free cooling. In some instances with heat pump, reversible on refrigerant or water side.

In general

The dominating heat source/s, how much CO2 in gram is generated per kWh or other suitable unit?

Typical is for electricy generation around 0.350 - 0.450 kg/kWh

Do you see any trend in the heating/cooling market. E.g. gas boilers being replaced by heat pumps, district heating making inroads, demand for cooling increases etc.

In retrofit hybridization with air source heat pump.

Ireland

Ireland is considered an enfent according to GeBOOST definition.

Sources:

SEAI National Heat Study 2022: https://www.seai.ie/data-and-insights/national-heat-study/

Energy in Ireland 2023 Report: https://www.seai.ie/publications/Energy-in-Ireland-2023.pdf

Heating and Cooling in Ireland today 2022 report: https://www.seai.ie/publications/Heating-and-Cooling-in-Ireland-Today.pdf

SEAI Energy Price Stats: https://www.seai.ie/data-and-insights/seai-statistics/key-statistics/prices/

SEAI National Energy Balance Stats Summary: https://www.seai.ie/data-and-insights/seai-statistics/key-publications/national-energy-balance/

SEAI Energy Use Overview Stats: https://www.seai.ie/data-and-insights/seai-statistics/key-statistics/energy-use-overview/

Private consumers/single houses

What is/are the dominating heating method(s) for private consumers? How large part in percentage are using that/those method(s)?

- Dominating heating methods for single houses are oil boilers
- In Ireland the SEAI divide the residential sector by housing archetypes (Apartment, terraced house, semi-detached house, and detached house)
- 90% of Ireland's buildings are in the residential sector
- In terms of this section which refers to private consumers and single houses this consists of Terraced homes, semi-detached homes, and detached homes.
- Apartments will be discussed in the next section which refers to tenant buildings
- Heating in the residential sector represents 18% of Ireland's total final energy use and has an annual fuel use of 26.3 TWh and negligible cooling demand.
- The predominant heating systems across building types are oil and gas boilers.
- Oil boilers dominate in detached homes; in all other building types, gas boilers are the dominant technology.
- Detached homes make up 43% of all homes but are responsible for 56% of all heating demand, indicating that oil is largest contributor to heating in the residential sector. Oil contributed to 67% of fuel used for space heating in detached homes.
- The annual heating demand in detached homes is more than the combined total for all other archetypes, indicating that they tend to have heating demands higher than those for other house types.
- In other housing types oil contributes to 39% of fuel consumption for heating in semi-detached homes, 26% in terraced homes and 11% in apartments.
- In housing archetypes where oil is not the dominant type of fuel used, gas boilers dominate. Gas contributed to only 10% of fuel consumption for heating in detached homes, 49% in semi-detached homes, 55% in terraced homes and 47% in apartments.

Heating and Cooling in Ireland today 2022 report: https://www.seai.ie/publications/Heating-and-Cooling-in-Ireland-Today.pdf - please note that the 2023 report is not yet published (probably mid 2024)

What is the price, inclusive non-deductible taxes (i.e. real cost) for the heat "source"? (Coal, oil, gas, electricity, pellets (wood)), district heating per suitable unit (liter, kilo, cubic meter, kWh).

Residential & Commercial Fuel prices in Ireland are reported on a quarterly basis every year. We have included the latest data (fuel prices 2024):

Residential

https://www.seai.ie/publications/Domestic-Fuel-Cost-Comparison.pdf

- According to the SEAI, in 2022 oil prices peaked at 15.49 €cent/kWh, this was the highest cost recorded in over 10 years
- At the end of 2023 prices dropped to 13.73 €cent/kWh

SEAI Energy Price Stats: https://www.seai.ie/data-and-insights/seai-statistics/key-statistics/prices/

How is the heat typically distributed in the house (hydronic, ventilation, fans, radiator)?

Older non refurbished homes tend to be high temperature radiator emitters, these are the most common in Ireland. Newer residential buildings will have mostly underfloor heating, mechanical heat recovery ventilation.

Is cooling systems common. How is it delivered in that case and how much energy in kWh is used? (I assume inverters or reversed heat pump).

Cooling demand in the residential sector is currently statistically very low. There are low requirements for residential cooling and there is also no domestic cooling data available.

Heating and Cooling in Ireland today 2022 report: https://www.seai.ie/publications/Heating-and-Cooling-in-Ireland-Today.pdf

However, the completion of increased energy efficient homes, cooling, especially using GHSPs is becoming more popular especially where ventilation systems or underfloor is installed.

Tenant buildings

What is/are the dominating heating method(s) for tenant buildings? How large part in percentage are using that/those method(s)?

See above

What is/are the price(s), inclusive non-deductible taxes (i.e. real cost) for the heat "source(s)"? (Coal, oil, gas, electricity, pellets (wood), district heating) per suitable unit (liter, kilo, cubic meter, kWh).

See above

How much is typically needed for heating per square meter? What is the efficiency in percentage for the fuel and heating method, (how much is wasted in the form of hot gas etc?

See above

How is the heat typically distributed in the building (hydronic, ventilation, fans, radiator)?

See above

Is cooling systems common? How is it delivered in that case and how much energy in kWh is used? (I assume inverters, cooling compressor or reversed heat pump).

See above

Office buildings

The SEAI report on office buildings of two archetypes: Offices (commercial) and offices (public).

What is/are the dominating heating method(s) for office buildings?

Electricity accounts for 65% of the energy used for heating in commercial offices.

Gas accounts for 73% of the energy used for heating public offices.

Heating and Cooling in Ireland today 2022 report: https://www.seai.ie/publications/Heating-and-Cooling-in-Ireland-Today.pdf

What is/are the prices, inclusive non-deductible taxes (i.e. real cost) for the heat "source(s)"? (Coal, oil, gas, electricity, pellets (wood), district heating) per suitable unit (liter, kilo, cubic meter, kWh).

Residential & Commercial Fuel prices in Ireland are reported on a quarterly basis every year. We have included the latest data (fuel prices 2024):

Commercial

https://www.seai.ie/publications/Commercial-Fuel-Cost-Comparison.pdf

Electricity

The SEAI reports that the average cost of electricity for business in 2023 was 23.3 €cent/kWh which was a decrease in prices from 2022 which peaked at 28.4 €cent/kWh. This was a significant rise in costs from 14.27 €cent/kWh in 2021. Price is per kWh ex-VAT

Gas

The SEAI reports that the average cost of gas for business in 2023 was 7.21 €cent/kWh which was a decrease in prices from 2022 which peaked at 8.45 €cent/kWh. This was a significant rise in costs from 3.5 – 5.16 €cent/kWh in 2021. Price is per kWh ex-VAT

SEAI Energy Price Stats: https://www.seai.ie/data-and-insights/seai-statistics/key-statistics/prices/

Is cooling systems common? How is it delivered in that case and how much energy in kWh is used? (I assume inverters, cooling compressor or reversed heat pump).

Similarly to the residential sector office buildings have a much lower cooling demand than heating demand. According to the SEAI, commercial offices have a total annual cooling demand of 765 GWh and public offices 297 GWh.

Heating and Cooling in Ireland today 2022 report: https://www.seai.ie/publications/Heating-and-Cooling-in-Ireland-Today.pdf

In general

The dominating heat source/s, how much CO2 in gram is generated per kWh or other suitable unit?

- The dominating heat source in Ireland is oil and gas

- In 2022 heating contributed to 36.5% of Ireland's final energy usage with ~4.42 Mtoe of energy used
- According to the SEAI's National Energy Balance, in 2023, more than three quarters of Ireland's energy came from oil and gas. Oil contributed to 48.8% of Ireland's energy for refining, heating and transport.
- According to the SEAI's Heating and Cooling in Ireland today report 2022, total fuel use for heating of all buildings and industrial applications is ~60TWh. This is around 42% of Ireland's final energy usage in a typical year.
- According to the SEAI's Heating and Cooling in Ireland today report 2022, total CO_2 emissions from fossil fuel consumption for the heating of all buildings (residential and non-residential) and from industrial applications in Ireland is 14.1 $MtCO_2$. This represents 38% of total energy-related CO_2 emissions, or 24% of total national greenhouse gas emissions
- 39% of emissions from the heat energy is from gas and 36% is from oil

SEAI National Energy Balance Stats Summary: https://www.seai.ie/data-and-insights/seai-statistics/key-publications/national-energy-balance/

Heating and Cooling in Ireland today 2022 report: https://www.seai.ie/publications/Heating-and-Cooling-in-Ireland-Today.pdf

SEAI Energy Use Overview Stats: https://www.seai.ie/data-and-insights/seai-statistics/key-statistics/energy-use-overview/

Do you see any trend in the heating/cooling market. E.g. gas boilers being replaced by heat pumps, district heating making inroads, demand for cooling increases etc.

There are rising trends in the uptake of heat pumps however they are growing at a slow rate. According to SEAI National Energy Balance the use of renewable ambient from heat pumps increased by 19% in 2023 with over 32,000 installations in Irish homes. This brought the national total to around 120,000 homes with heat pumps. Ireland's climate action plan (CAP) has a target of 215,000 by 2025 and 680,000 by 2030.

SEAI National Energy Balance Stats Summary: https://www.seai.ie/data-and-insights/seai-statistics/key-publications/national-energy-balance/

The Climate Action Plan targets in Ireland ban the installation of fossil fuel fired boilers for new buildings by 2025.

Annual heating demand from detached homes exceeds the combined total for all other types of home. Comparing this with the stock distribution shows that detached houses tend to have heating demands higher than those for other house types.

This is given that detached homes are 43% of all homes, but are responsible for 56% of all heating demand; for example, there are 45% more detached houses than semi-detached houses, but the total heating demand in detached houses is 129% higher than in semi-detached houses. The total annual useful heating demand by building type shows detached houses use 11,022GWh, semi-D 4816GWh, Terraced 2463GWh and apartment 1109GWh.

Heating in the residential sector represents 18% of Ireland's total final energy use and has an annual fuel use of 26.3 TWh and negligible cooling demand. The predominant heating systems across building types are oil and gas boilers. Oil boilers dominate in detached homes; in all other building types, gas boilers are the dominant technology. Detached homes make up 43% of all homes but are responsible for 56% of all heating demand, indicating that oil is largest contributor to heating in the residential sector. Oil contributed to 67% of fuel used for space heating in detached homes. The annual heating demand in detached homes is more than the combined total for all other archetypes, indicating that they tend to have heating demands higher than those for other house types. In other housing types oil contributes to 39% of fuel consumption for heating in semi-detached homes, 26% in terraced homes and 11% in apartments. In housing archetypes where oil is not the dominant type of fuel used, gas boilers dominate. Gas contributed to only 10% of fuel consumption for heating in detached homes, 49% in semi-detached homes, 55% in terraced homes and 47% in apartments.

Due to low current requirements for residential cooling, and no significant projected demand increase. there is no domestic cooling demand data, so any attempt to quantify the domestic cooling demand in Ireland would be ineffective.

Residential page SEAI

In 2022 the average home used 17.15 MWh of energy — split into 74% from direct fuel (non-electric) and 26% from electricity.

For 2020 we estimate that 61% of all energy used in households was for space heating, 20% for water heating, 16% for lighting & appliances, and 2% for cooking.

In 2020 1314.73ktoe of oil was used in the residential sector, of that amount 1014.04ktoe was used for space heating and the remainder used in water heating. Total fuel usage in space heating was 1908.5ktoe and of that oil contributed 1014.04 which is around 50% of all fuel consumed in space heating in 2020.

Energy in residential report

36% of energy used in Irish households is from oil, the highest proportion of any EU member state except for Cyprus. Oil is less carbon intensive than coal but more carbon intensive than gas.

Energy in Ireland

In 2020 80.39TWh of oil contributed to the total primary energy in Ireland. This was around 57% of the 140.26TWh used in Ireland. 31.5 TWh was used in the residential sector

Austria

Austrias is considered to be a transitional market according to GeoBOOST project.

Private consumers/single houses

What is/are the dominating heating method(s) for private consumers? How large part in percentage are using that/those method(s)?

Primary heating system by predominant energy source and type of heating system 2021/2022 – Results for Austria

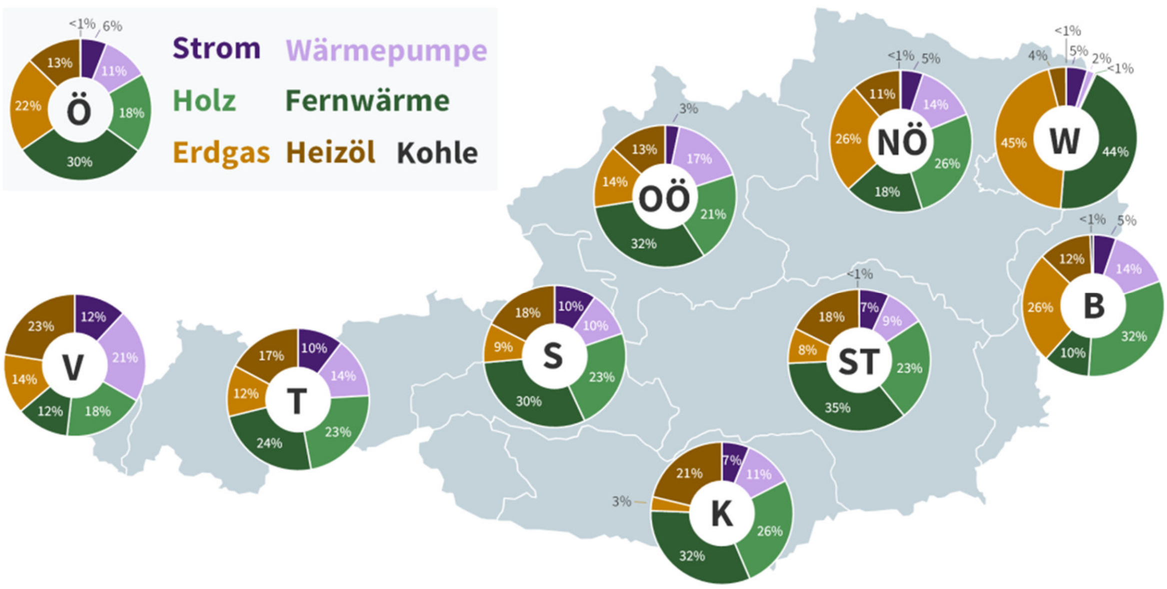
Fuel	Number of apartments ("main residences") in total	Type of heating system				
		Single furnace	Gas convec tors	Electric heating	Central heating and equal	District heating[1]
Fuel wood, wood chips, wood pellets, wood briquettes	733,972	74,329	-	-	659,643	-
Coal, coke, briquettes[2]	3,469	873	-	-	2,596	-
Fuel oil, liquified petroleum gas	521,306	6,115	-	-	515,191	-

Electricity	241,072	-	-	241,072	-	-
Natural Gas	878,319	-	15,160	-	863,159	-
Solar, heat pumps	429,143	-	-	-	429,143	-
District heating	1,226,819	-	-	-	-	1,226,819
Total	4,034,100	81,317	15,160	241,072	2,469,732	1,226,819

S: STATISTICS AUSTRIA, Energy statistics: Micro census energy consumption of households 2021/2022. Compiled on 1 September 2023. Updated on 22 September 2023.
1) Central heating systems with unknown fuel are defined as district heating. – 2) Values for hard coal, lignite, lignite briquettes and coke are subject to very high statistical uncertainties. Lignite will no longer be published from 2021/2022 due to a lack of sufficient reporting figures.

- There are around 4 million main residences in Austria.
- 35% of these are heated with fossil fuels: 22% heat with natural gas, 13% with heating oil, coal makes 0.1%.
- Around half of district heating in Austria is based on renewable energies and is the most widespread form of heating alone, accounting for 30%.
- Direct electricity heating such as night storage heaters, electric underfloor heating or infrared heating are used in 6% of main residences.
- Heat pumps (including air source and GHPs) are in almost 11% of all main residences.
- Wood heating systems are also traditionally widespread in Austria. Pellets, wood chips or logs are used as the primary heating system in 18% of main residences.

Note that there are big differences between the Federal States.



Statistics Austria 2023 (microcensus, 2021/2022). Primary heating system in apartments ("main residences") based on the primary energy source used. The district heating category also includes other forms of heating that cannot be assigned. Strom – electricity, Wärmepumpe – heat pump, Holz – wood, Erdgas – Gas, Heizöl – Oil, Kohle – Coal, Fernwärme – District heating.

What is the average price for a normal house for purchase and installation for the heating system?

We did not find official sources with these numbers. However, it expected that the cost of purchasing and installing a heating system in Austria can evidently vary a lot depending on the type of heating system and brand. There are also several sub-system types, each with its own cost. The following are very general prices:

- Gas heating with standard/conventional boiler
  - Total: ~ €3,000 and €7,000
- Oil heating with standard/conventional furnace
  - An oil condensing boiler with sufficient output for a typical single-family home costs between €4,000 and €7,000. Because economical operation is easier to achieve with a hot water tank, homeowners have to expect additional costs of €800-1,500.
- Pellets
  - Depending on the design, system size and complexity, a new pellet heating system costs ~ €17,000 and €24,000 for a typical single-family home,

including pellet storage (fabric tank), conveyor technology, hot water preparation, assembly and commissioning.
    - To convert an oil heater to a pellet heater, the actual costs for a single-family home are ~ €5,000 and €12,000.
    - Pellet prices: https://www.oekofen.com/de-at/aktueller-pelletspreis/

- District heating:
    - Total: ~ €2,000 if a connection is existing or ~ €6,000 if there is a line nearby.

- Heat Pump:
    - **Air-Source**: ~ €3,000 to €9,000.
    - **Geothermal**: ~ €10,000 and €60,000 or even more, depending on the type of geothermal system and size of the system. Note that the lower end may be related to horizontal systems where only digging is needed. The upper end may be related to larger installations with quite a few drilled boreholes.
    - Here you can find typical heat pump prices: https://gruenes.haus/waermepumpen-hersteller/

What is the price, inclusive non-deductible taxes (i.e. real cost) for the heat "source"? (Coal, oil, gas, electricity, pellets (wood)), district heating per suitable unit (liter, kilo, cubic meter, kWh).

Prices for gas and electricity you can find at the national level for all countries in Europe as Eurostata bi-annual data here:

https://ec.europa.eu/eurostat/databrowser/view/nrg_pc_204__custom_7886640/bookmark/table?lang=en&bookmarkId=38d079fe-d389-4b10-8e8b-6a414e1e53bc

https://ec.europa.eu/eurostat/databrowser/view/nrg_pc_202__custom_7886729/bookmark/table?lang=en&bookmarkId=9ed6d6af-ff76-48b9-9b07-3de43fb08b04

You can also find more from Statistik Austria here (see also table in the next page):

https://www.statistik.at/en/statistics/energy-and-environment/energy/energy-prices-taxes

The biomass prices were not be found in these databases given above. However, there is information here:

- Pellet prices: https://www.oekofen.com/de-at/aktueller-pelletspreis/

District heating: The prices are dependent on the provider and therefore can vary regionally. For Vienna (*Fernwärme Wien*), the tariff for heating is divided into two parts. The basic price (consumption-independent part) is currently € 0.3845/m2/month net; the working price (consumption-dependent part) is currently € 134.1410/MWh (megawatt hour) net, i.e. excluding value added tax (VAT).

Year	2023				
Values	Net price	Energy fees and taxes	VAT	Overall taxes	Gross price
Energy products					
Heavy fuel oil (Industry)/t	584.31	175.23	-	175.23	759.53
Heavy fuel oil (Power plants)/t	599.05	7.70	-	7.70	606.75
Gas oil (Industry)/1000 l	560.33	109.18	-	109.18	669.51
Gas oil (Households)/1000 l	818.67	193.26	202.39	395.65	1,214.32
Diesel (Comm. consumption)/l	1.03	0.41	-	0.41	1.44
Diesel (Private consumption)/l	0.88	0.49	0.27	0.76	1.64
Gasoline 98 Octan/l	-	-	-	-	-

Year	2023				
Values	Net price	Energy fees and taxes	VAT	Overall taxes	Gross price
Energy products					
Gasoline 95 Octan/l	-	-	-	-	-
Gasoline 98 Octan (Comm. consumption)/l	0.94	0.56	-	0.56	1.50
Gasoline 98 Octan(Private consumption)/l	0.94	0.56	0.30	0.86	1.80
Gasoline 95 Octan (Comm. consumption)/l	0.77	0.56	-	0.56	1.33
Gasoline 95 Octan (Private consumption)/l	0.77	0.56	0.27	0.83	1.59
Regular gasoline/l	-	-	-	-	-
Regular gasoline (Comm. consumption)/l	0.77	0.56	-	0.56	1.33
Regular gasoline(Private consumption)/l	0.77	0.56	0.27	0.83	1.60
Hard coal (Industry)/t	220.57	50.00	-	50.00	270.57
Hard coal (Power plants)/t	-	-	-	-	-
Natural gas (Industry)/10^7 kcal GCV	-	-	-	-	-
Natural gas (Households)/10^7 kcal GCV	-	-	-	-	-
Natural gas (Industry)/kWh	0.08	0.00	-	0.00	0.08
Natural gas (Households)/kWh	0.13	0.01	0.03	0.04	0.16
Electricity (Industry)/kWh	0.23	-0.01	-	-0.01	0.22
Electricity (Households)/kWh	0.27	-0.04	0.05	0.00	0.27

How much is typically needed for heating per square meter? What is the efficiency in percentage for the fuel and heating method, (how much is wasted in the form of hot gas etc?

You can find this information in this link (see also tables in the next page):

https://statcube.at/statistik.at/ext/statcube/jsf/tableView/tableView.xhtml

Fuel consumption per m2 in GJ (contributing HH)	Fuel consumption per m2 in GJ (contributing HH)				
Austria and Laender (provinces)	Austria in total				
Purposes	Space heating				
Year	2013/2014	2015/2016	2017/2018	2019/2020	2021/2022
Fuels					
Hard Coal	0.1651	0.1401	0.2747	0.1488	0.1430
Lignite	0.1073	0.0309	0.0313	0.1789	-
Brown Coal Briquettes	0.0866	0.0926	0.2056	0.1667	0.1031
Coke	0.3621	0.4307	0.2814	0.2453	0.2957
Fuel Wood	0.3390	0.3206	0.3359	0.3794	0.3471
Wood pellets and briquettes	0.4724	0.4689	0.4657	0.5542	-
Wood Pellets	0.3526	0.3431	0.3479	0.4093	0.4439
Wood Briquettes	0.1198	0.1257	0.1178	0.1449	0.1240
Wood Chips	0.5031	0.5341	0.5055	0.6202	0.6343
Fuel Oil	0.4066	0.4011	0.4164	0.4306	0.5133
LPG	0.3138	0.2777	0.3027	0.3445	0.3015
Natural Gas	0.5731	0.6024	0.5909	0.5174	0.4215
District Heating	0.2895	0.2854	0.3237	0.3458	0.3070
Electricity	0.1801	0.1581	0.1621	0.1580	0.0420
Power consumption from grid	-	-	-	-	-
self supply	-	-	-	-	-
Solar Heat	0.0692	0.0708	0.0737	0.0831	0.0338
Ambient Heat	0.1309	0.1239	0.1505	0.1532	0.1546
All Fuels (sum/average)	-	-	-	-	-

Fuel consumption per person in GJ (contributing HH)	Fuel consumption per person in GJ (contributing HH)				
Austria and Laender (provinces)	Austria in total				
Purposes	Water heating				
Year	2013/2014	2015/2016	2017/2018	2019/2020	2021/2022
Fuels					
Hard Coal	1.6475	1.4658	4.8381	0.4417	-
Lignite	1.2208	0.6592	-	4.3164	-
Brown Coal Briquettes	2.4059	0.7615	1.5237	1.8769	0.0712
Coke	2.8368	2.8598	1.8560	0.7827	0.6862
Fuel Wood	5.2912	5.3354	5.4734	5.0518	1.3601
Wood pellets and briquettes	6.1501	6.2222	6.8688	6.2572	-
Wood Pellets	4.6062	4.7019	4.4696	3.9379	3.0021
Wood Briquettes	1.5439	1.5204	2.3991	2.3193	0.1602
Wood Chips	4.6924	4.7912	4.7088	4.8739	4.3801
Fuel Oil	4.0336	3.9020	4.0027	3.3607	3.0303
LPG	3.1697	2.7258	3.4957	2.8038	2.1161
Natural Gas	4.1018	3.7449	3.9590	3.4664	3.2731
District Heating	3.5607	3.5350	3.6865	3.6278	2.4872
Electricity	3.0621	3.0053	3.0617	3.0450	1.5589
Power consumption from grid	-	-	-	-	-
self supply	-	-	-	-	-
Solar Heat	2.8923	2.8808	2.8510	2.9032	2.7030
Ambient Heat	1.7125	1.7165	1.9131	2.0390	1.3908
All Fuels (sum/average)	-	-	-	-	-

How is the heat typically distributed in the house (hydronic, ventilation, fans, radiator)?

Radiators are the standard for older buildings, although some have floor heating too. New ones use radiators too, but mainly wall/floor heating.

Is cooling systems common in Austria. How is it delivered in that case and how much energy in kWh is used? (I assume inverters or reversed heat pump).

No. Even though in big cities like Vienna, cooling becomes more and more important. In the private sector there are already some private houses that use GHPs for heating AND cooling (free cooling in that case). ACs are not common in Austria.

Tenant buildings

What is/are the dominating heating method(s) for tenant buildings? ? How large part in percentage are using that/those method(s)?

Databases with official data do not distinguish between the different types of buildings asked for in this questionnaire. Especially for "tenant buildings", we are afraid this information is not readily available. However, it could be expected that the dominant heating methods and their shares are more or less similar to the residential sector mentioned above.

What is/are the price(s), inclusive non-deductible taxes (i.e. real cost) for the heat "source(s)"? (Coal, oil, gas, electricity, pellets (wood), district heating) per suitable unit (liter, kilo, cubic meter, kWh).

The official databases we are aware of do not distinguish as precisely between the different types of buildings specified in the questionnaire. Especially for "tenant buildings", we are afraid this information is not available.

As mentioned before, for natural gas and electricity for example, these prices can be obtained from Eurostat as country averages (bi-annual data). However, the prices in this dataset are given for different bands (see legend of Fig. 2 of Deliverable 2.2). It is not straightforward to separate the band-related price values for the buildings categories asked.

How much is typically needed for heating per square meter? What is the efficiency in percentage for the fuel and heating method, (how much is wasted in the form of hot gas etc?

See table above for a reference.

How is the heat typically distributed in the building (hydronic, ventilation, fans, radiator)?

Radiators are the standard for older buildings, although some have floor heating too. New ones use radiators too, but mainly wall/floor heating.

Is cooling systems common? How is it delivered in that case and how much energy in kWh is used? (I assume inverters, cooling compressor or reversed heat pump).

No. Even though in big cities like Vienna, cooling becomes more and more important. Talking to planners for affordable housing, they still state that cooling is a luxury and not included, even though it would increase the efficiency of GHPs. On the free market, new buildings sometimes already offer free cooling, but it’s not standard. ACs are not common in Austria.

Office buildings

What is/are the dominating heating method(s) for office buildings?

Databases with official data do not distinguish between the different types of buildings. Especially for “tenant buildings”, we are afraid this information is not readily available. However, it could be expected that the dominant heating methods and their shares are more or less similar to the residential sector mentioned above.

What is/are the prices, inclusive non-deductible taxes (i.e. real cost) for the heat “source(s)”? (Coal, oil, gas, electricity, pellets (wood), district heating) per suitable unit (liter, kilo, cubic meter, kWh).

The databases with official data that we are aware of do not distinguish between the different types of buildings asked in the questionnaire so precisely. Especially for “office buildings”, we are afraid this information is not available.

How much is typically needed for heating per square meter? What is the efficiency in percentage for the fuel and heating method, (how much is wasted in the form of hot gas etc.

See table above for a reference.

How is the heat typically distributed in the building (hydronic, ventilation, fans, radiator)?

Radiators are the standard for older buildings, although some have floor heating too. New ones use radiators too, but mainly wall/floor heating.

Is cooling systems common? How is it delivered in that case and how much energy in kWh is used? (I assume inverters, cooling compressor or reversed heat pump).

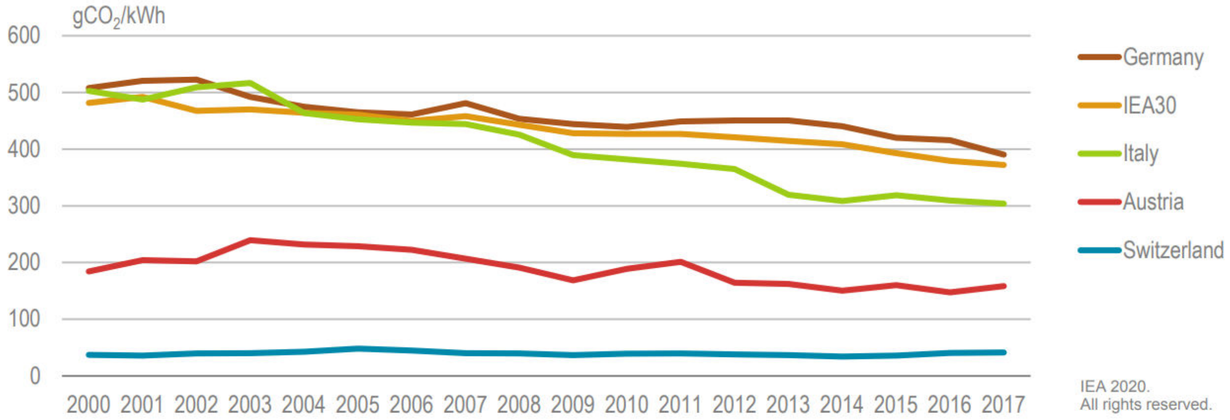
I would say in offices cooling is more prevalent than in the private sector, however still not very common. The increasing cooling demand will become a problem, eventually, because Austria is not prepared for this (Austria is in the list of 10 most affected countries for future cooling demand https://www.nature.com/articles/s41893-023-01155-z)

In general

The dominating heat source/s, how much CO2 in gram is generated per kWh or other suitable unit?

We only found the following information from an IEA report :

Figure 6.5 CO_2 intensity of power and heat generation in Austria and in selected IEA member countries, 1990-2017



Austria has low CO_2 emissions per kWh heat and power, mostly thanks to the large share of hydropower, although electricity generated by hydro has been flat in recent years.

Source: IEA (201a*CO_2 Emissions from Fuel Combustion 2019*, www.iea.org/statistics.

Do you see any trend in the heating/cooling market. E.g. gas boilers being replaced by heat pumps, district heating making inroads, demand for cooling increases etc.

Low temperature heating and cooling grids are getting more and more important. Gas boilers are being replaced more and more by heat pumps (mostly by air source heat pumps, but also GHPs). As Austria is very dependent on Russian gas, we want to decrease that dependency and get out of gas – since the Ukraine war.

Furthermore, promoting the replacement of fossil fuel-based heating systems goes hand in hand with a predisposition to increase federal funding for the thermal renovation of buildings. Another emerging trend is the expansion of federal funding specifically targeted at low-income households.

Poland

Poland is considered a transitional market in the GeoBOOST definition.

Private consumers/single houses

What is/are the dominating heating method(s) for private consumers? How large part in percentage are using that/those method(s)?

Solid fuel boilers – 55%

Gas boilers – 24%

Electric boilers – 12%

District heating – 3%

Solar-thermal heating – 3%

Heat pumps – 2%

Oil boilers – 1%

https://www.kfch.pl/aktualnosci/baza-ceeb-dane-na-dzien-1-stycznia-2023

What is the average price for a normal house for purchase and installation for the heating system?

Own estimation

Normal house – 120 m2

Heating system (heat source incl. installation) with:

- Gas boiler incl. installation (no access to network) – 2.000 EUR
- A/W Heat pump incl. installation – 6.500 EUR
- G/W heat pump incl. installation – 9.000 EUR
- Pellet boiler incl. installation – 3.500 EUR

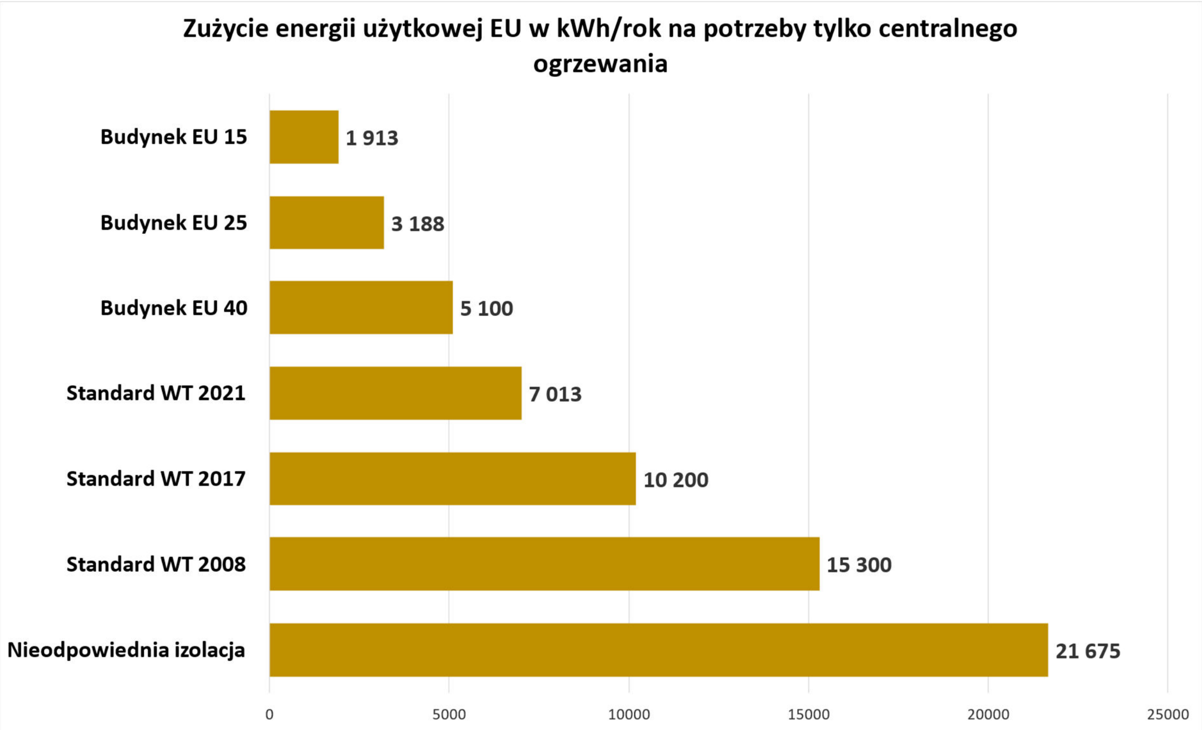
What is the price, inclusive non-deductible taxes (i.e. real cost) for the heat "source"? (Coal, oil, gas, electricity, pellets (wood)), district heating per suitable unit (liter, kilo, cubic meter, kWh).

Fuel	Unit cost of fuel or energy carrier with VAT [PLN/unit]	Unit cost of fuel or energy carrier with VAT [EUR/unit]	Unit	Source	link
E high-methane natural gas	30,8	7,2	kWh		
Electricity from the G12w tariff	109,6	25,5	kWh		
Pellet	140,9	32,8	kg	Własne	https://polskialarmsmogowy.pl
Firewood (beech)	87,8	20,4	kg	Własne	https://polskialarmsmogowy.pl
Fine coal peas (so-called eco-powder)	154,1	35,8	kg	Polski Alarm Smogowy	https://polskialarmsmogowy.pl
Propane	238,0	55,3	l.	cdc24.pl	https://www.cdc24.pl/srednie-ceny-detaliczne
Heating oil	554,0	128,8	l.	cdc24.pl	https://www.cdc24.pl/srednie-ceny-detaliczne

http://pobe.pl/kalkulator-pobe-koszty-ogrzewania-w-typowych-budynkach/

How much is typically needed for heating per square meter? What is the efficiency in percentage for the fuel and heating method, (how much is wasted in the form of hot gas etc?

Building standard	EU usable energy for heating the building in kWh/m^2 year
Wrong or lack of insulation	170
Standard WT 2008	120
Standard WT 2017	80
Standard WT 2021	55
Budynek EU 40	40
Budynek EU 25	25
Budynek EU 15	15



Solid fuel boilers – 64-84%

Gas boilers – 91-94%

Electric boilers – 96%

Heat pumps – SCOP:

- AWHP – 3-3,5
- GSHP – 3,5-4,4

How is the heat typically distributed in the house (hydronic, ventilation, fans, radiator)?

Hydronic (radiator) – 70%

Hydronic (underfloor heating) – 25%

Ventilation/fans – 5%

Is cooling systems common. How is it delivered in that case and how much energy in kWh is used? (I assume inverters or reversed heat pump).

Own estimation – around 15%

Mainly aircon and rarely HPs with cooling – 900-1800 kWh per year (typical 120m2 house)

Tenant buildings = Multi-family houses

What is/are the dominating heating method(s) for tenant buildings? ? How large part in percentage are using that/those method(s)?

Own estimation:

District heating – 40%

Central heating with solid fuel boiler – 30%

Central heating with gas boiler – 30%

What is/are the price(s), inclusive non-deductible taxes (i.e. real cost) for the heat "source(s)"? (Coal, oil, gas, electricity, pellets (wood), district heating) per suitable unit (liter, kilo, cubic meter, kWh).

See above – single houses

How much is typically needed for heating per square meter? What is the efficiency in percentage for the fuel and heating method, (how much is wasted in the form of hot gas etc?

See above – single houses

How is the heat typically distributed in the building (hydronic, ventilation, fans, radiator)?

Hydronic (radiator) – 92%

Hydronic (underfloor heating) – 5%

Ventilation/fans – 3%

Is cooling systems common? How is it delivered in that case and how much energy in kWh is used? (I assume inverters, cooling compressor or reversed heat pump).

Rarely – around 5%

Aircon (only in 1-2 rooms) – 900-1200 kWh per year

Office buildings

What is/are the dominating heating method(s) for office buildings?

Own estimation:

District heating – 40%

Central heating with solid fuel boiler – 10%

Central heating with gas boiler – 49%

Heat pumps – 1%

What is/are the prices, inclusive non-deductible taxes (i.e. real cost) for the heat "source(s)"? (Coal, oil, gas, electricity, pellets (wood), district heating) per suitable unit (liter, kilo, cubic meter, kWh).

See above – single houses

How much is typically needed for heating per square meter? What is the efficiency in percentage for the fuel and heating method, (how much is wasted in the form of hot gas etc.

See above – single houses

How is the heat typically distributed in the building (hydronic, ventilation, fans, radiator)?

Own estimation:

Hydronic (radiator) – 70%

Hydronic (underfloor heating) – 10%

Ventilation/fans – 20%

Is cooling systems common? How is it delivered in that case and how much energy in kWh is used? (I assume inverters, cooling compressor or reversed heat pump).

Own estimation:

Very common – around 70%

Mainly Aircon – energy usage depending on office size

In general

The dominating heat source/s, how much CO_2 in gram is generated per kWh or other suitable unit?

No data

Do you see any trend in the heating/cooling market. E.g. gas boilers being replaced by heat pumps, district heating making inroads, demand for cooling increases etc.

All above examples are true +

- solid fuel boilers being replaced by gas boilers or heat pumps
- more electric heating with PV
- district heating replaced by HPs (small extend)

Spain

Spain is considered an enfent according to GeoBOOST definition.

Questionnaire Heating system

Private consumers/single houses

- What is/are the dominating heating method(s) for private consumers? How large part in percentage are using that/those method(s)?

In Spain, the dominant heating methods for private consumers are mainly natural gas, electricity, and to a lesser extent, heating oil (diesel) and biomass. Here is a breakdown of the heating methods and their prevalence:

1. **Natural Gas**: This is the most common heating method, especially in urban areas where the natural gas network is well-developed. Approximately **35-40%** of households use natural gas for heating.

2. **Electricity**: Many households use electric heating, particularly in regions where the winters are milder. Electric heating is used by about **25-30%** of households.

3. **Heating Oil (Diesel)**: This is more common in rural areas and regions where the natural gas network is less extensive. Around **10-15%** of households use heating oil.

4. **Biomass (wood pellets, firewood)**: Biomass heating has gained popularity, particularly in rural areas and among environmentally conscious consumers. This method is used by about **5-10%** of households.

5. **Heat Pumps (Air-source or Ground-source)**: Heat pumps are gaining popularity due to their energy efficiency and environmental benefits. They are used by about **10-15%** of households. This category includes both air-source and ground-source heat pumps (although air source heat pumps represents for 99% of heat pumps).

- What is the average price for a normal house for purchase and installation for the heating system?

The cost of purchasing and installing a heating system in a typical house in Spain varies depending on the type of heating system chosen. Here are the average costs for the most common heating systems:

1. **Natural Gas Heating**:

- *Purchase and Installation*: The average cost ranges from **€2,000 to €5,000**.

- This includes the cost of a natural gas boiler, radiators, and installation. Costs can be higher if the house needs to be connected to the natural gas network.

2. **Electric Heating**:

- *Purchase and Installation*: The average cost ranges from **€500 to €2,500**.

- This includes electric radiators or convectors, which are relatively easy and inexpensive to install compared to other systems.

3. **Heating Oil (Diesel)**:

- *Purchase and Installation*: The average cost ranges from **€3,000 to €7,000**.

- This includes the cost of an oil-fired boiler, storage tank, radiators, and installation. Prices can vary depending on the size of the house and the complexity of the installation.

4. **Biomass Heating (wood pellets, firewood)**:

- *Purchase and Installation*: The average cost ranges from **€4,000 to €8,000**.

- This includes the cost of a biomass boiler or stove, storage for the fuel, and the necessary installation work. Biomass systems can be more expensive upfront but may offer savings on fuel costs over time.

5. **Heat Pumps (Air-source or Ground-source)**:

- *Purchase and Installation*: The average cost for an air-source heat pump ranges from €4,000 to €7,000, while a ground-source heat pump can range from **€10,000 to €20,000**.

- Heat pumps are highly efficient but can be expensive to install, especially ground-source systems due to the need for ground excavation.

- What is the price, inclusive non-deductible taxes (i.e. real cost) for the heat "source"? (Coal, oil, gas, electricity, pellets (wood)), district heating per suitable unit (liter, kilo, cubic meter, kWh).

1. **Natural Gas**:

- Price per kWh: €0.08 - €0.15

2. **Electricity**:

- Price per kWh: €0.15 - €0.25

3. **Heating Oil (Diesel)**:

- Price per liter: €1.10 - €1.30

- Price per kWh: Approximately €0.10 (considering 10 kWh per liter)

4. **Wood Pellets**:

- Price per ton: €250 - €300

- Price per kWh: €0.05 - €0.06

5. **District Heating**:

- Depending on the source.

6. **Coal**:

- Price per ton: €300 - €400

- Price per kWh: €0.04 - €0.05

- How much is typically needed for heating per square meter? What is the efficiency in percentage for the fuel and heating method, (how much is wasted in the form of hot gas etc?

The amount of energy needed for heating per square meter and the efficiency of various heating methods can vary depending on the insulation, climate, and specific heating system. However, here are some general figures and efficiency percentages for common heating methods in Spain:

- **Heating Energy Requirement**

1. **Typical Energy Needed**:

- *Energy Requirement*: On average, about 100 to 150 kWh per square meter per year is needed for heating in a moderately insulated house in Spain.

- **Efficiency and Waste for Heating Methods**

1. *Natural Gas Heating*:

- Efficiency: 85-95%

- Wasted Energy: 5-15% (mainly in the form of exhaust gases)

2. *Electric Heating*:

- Efficiency: 95-100%

- Wasted Energy: 0-5% (very minimal losses, mainly due to electrical resistance)

3. *Heating Oil (Diesel)*:

- Efficiency: 80-90%

- Wasted Energy: 10-20% (mainly in the form of exhaust gases)

4. *Wood Pellets*:

- Efficiency: 70-90%

- Wasted Energy: 10-30% (mainly in the form of combustion gases and ash)

5. *District Heating*:

- Efficiency: 80-90%

- Wasted Energy: 10-20% (losses in distribution and heat exchange)

6. *Coal*:

- Efficiency: 60-80%

- Wasted Energy: 20-40% (mainly in the form of combustion gases and ash)

7. *Heat Pumps*:

- Efficiency (COP): 300-400%

- Wasted Energy: 0-5% (due to electrical resistance and some thermal losses)

To heat a house in Spain, you typically need 100 to 150 kWh per square meter per year. The efficiency of heating systems varies widely, with electric heating and heat pumps being the most efficient, while traditional methods like firewood and coal have higher waste percentages. Heat pumps, in particular, offer a highly efficient solution, providing more heat energy than the electrical energy they consume, thanks to their high COP.

- How is the heat typically distributed in the house (hydronic, ventilation, fans, radiator)?

In Spain, the typical methods of heat distribution within homes vary depending on the type of heating system used. Here are the most common heat distribution methods:

1. **Radiators (Hydronic Systems)**: In hydronic systems, hot water or steam generated by a boiler (using natural gas, oil, or biomass) circulates through pipes to radiators located in different rooms. This is a very common method, especially in homes with natural gas or oil-fired boilers.

2. **Electric Radiators and Convectors**: These devices use electrical resistance to generate heat, which is then distributed through convection or radiation. Common in homes that rely on electric heating due to ease of installation and lower initial costs.

3. **Underfloor Heating (Hydronic or Electric)**: In hydronic underfloor systems, heated water circulates through pipes embedded in the floor. In electric systems, electric cables or mats are installed beneath the floor surface. Increasingly popular in new buildings and renovations due to the uniform heat distribution and comfort.

4. **Air-source Heat Pumps**:

Ducted Systems: Heat pumps use ducts to distribute warm air throughout the house via a network of ducts and vents. Increasingly popular due to efficiency and ability to provide both heating and cooling.

Split Systems: Outdoor units connected to indoor units, distributing heat through fans. Common for flexible and efficient heating and cooling.

5. **Ground-source Heat Pumps**: Extract heat from the ground via a network of pipes (ground loops) and distribute it through hydronic systems (radiators or underfloor heating) or forced-air systems. Gaining popularity for their high efficiency and environmental benefits, though the installation cost is higher compared to air-source systems.

6. **Fireplaces and Stoves (Biomass or Wood):** Heat from burning wood or pellets is distributed directly into the room where the fireplace or stove is located. Some advanced systems can distribute heat to other rooms via ducts or water-based systems. Common in rural areas and among environmentally conscious consumers.

- Is cooling systems common. How is it delivered in that case and how much energy in kWh is used? (I assume inverters or reversed heat pump).

Cooling systems are becoming increasingly common in Spanish homes, especially in regions with hot climates, such as southern Spain. The most common method for cooling is through the use of air-conditioning systems, which often utilize inverters or reversed heat pumps for efficient operation. Here is an overview of cooling systems and their energy usage:

Air-Conditioning Systems: These systems use refrigerants to transfer heat from indoors to outdoors, cooling the indoor air. Inverter technology or reversed heat pumps allow for variable-speed operation and increased energy efficiency. Cooling is typically delivered through indoor units such as wall-mounted, ceiling-mounted, or ducted units.

- *Energy Usage*: On average, a residential air-conditioning system might consume considering medium insulation, varies based on the climate zone from **25 (interior, dry climate, continental) to 75 (coast, mediterranean climate) kWh/m^2** per year for cooling in Spain, though this can vary widely.

For this and the following options: **Geothermal cooling** systems offer significant advantages by balancing the dissipated heat load in the geothermal field. This balance is achieved because the system uses the temperature of the cold extracted during the winter from the geothermal heat exchanger to heat the building during the summer. Unlike traditional air conditioning systems that release heat into the air, geothermal systems transfer this heat to the ground. This process enhances the efficiency of the cooling system, reduces energy consumption, and minimizes the environmental impact by leveraging renewable energy stored in the earth. Additionally, the balanced heat load in the geothermal field ensures long-term sustainability and operational efficiency of the system.

Tenant buildings

- What is/are the dominating heating method(s) for tenant buildings?? How large part in percentage are using that/those method(s)?

In tenant buildings in Spain, the dominating heating methods are often similar to those in private residences. However, in tenant buildings, the prevalence of certain heating methods can be influenced by factors such as building regulations, infrastructure availability, and the preferences of building owners or managers. Here are the dominating heating methods for tenant buildings and their approximate prevalence:

1. **Centralized Heating Systems**: Many tenant buildings, especially larger ones, are equipped with centralized heating systems. These systems typically use natural gas boilers or district heating networks to provide heat to multiple units within the building. Centralized heating systems are quite common, especially in multi-unit buildings and apartment complexes. They can serve a significant portion of tenant buildings, potentially reaching up to **70-80%** in some urban areas.

2. **Electric Heating**: Electric heating systems, including electric radiators or convectors, are another option for tenant buildings, particularly in units where individual control over heating is preferred. While not as prevalent as centralized systems, electric heating may still be found in a notable percentage of tenant buildings, accounting for approximately **10-20%** of the total.

3. **District Heating**: Some tenant buildings, especially in urban areas, may be connected to district heating networks. These networks distribute heat generated from centralized sources to multiple buildings. The prevalence of district heating in tenant buildings can vary depending on the availability of such networks in the area. In cities with well-established district heating infrastructure, it may serve a significant portion of tenant buildings, potentially up to **10-20%**.

4. **Other Methods**: Other heating methods such as heating oil or biomass may be used in some tenant buildings, though they are less common compared to the options mentioned above. These methods are typically less prevalent in tenant buildings, often chosen in specific circumstances or regions where alternative heating sources are more common.

- What is/are the price(s), inclusive non-deductible taxes (i.e. real cost) for the heat "source(s)"? (Coal, oil, gas, electricity, pellets (wood), district heating) per suitable unit (liter, kilo, cubic meter, kWh).

1. **Natural Gas**:

   - Price per kWh: €0.08 - €0.15

2. **Electricity**:

   - Price per kWh: €0.15 - €0.25

3. **Heating Oil (Diesel)**:

   - Price per liter: **€1.10 - €1.30**

   - Price per kWh: Approximately **€0.10** (considering 10 kWh per liter)

4. **Wood Pellets**:

   - Price per ton: **€250 - €300**

   - Price per kWh: **€0.05 - €0.06**

5. **District Heating**:

   - Price per kWh: **€0.08 - €0.12**

6. **Coal**:

   - Price per ton: **€300 - €400**

   - Price per kWh: **€0.04 - €0.05**

These prices are indicative and can vary based on the specific circumstances of purchase, including location, supplier, and any applicable delivery charges. Additionally, market conditions, such as global energy prices and local demand, can influence these costs.

- How much is typically needed for heating per square meter? What is the efficiency in percentage for the fuel and heating method, (how much is wasted in the form of hot gas etc?

The energy needed for heating per square meter and the efficiency of heating methods can vary based on factors such as insulation, climate, and the specific heating system used in tenant buildings in Spain. Here's an overview:

- **Heating Energy Requirement**

1. **Typical Energy Needed**:

- *Energy Requirement*: In tenant buildings, the typical energy needed for heating can range from 100 to 150 kWh per square meter per year. This varies depending on factors such as building insulation, climate, and the efficiency of the heating system.

- **Efficiency and Waste for Heating Methods**

1. *Natural Gas Heating*:

- Efficiency: 85-95%

- Wasted Energy: 5-15% (mainly in the form of exhaust gases)

2. *Electric Heating*:

- Efficiency: 95-100%

- Wasted Energy: 0-5% (minimal losses due to electrical resistance)

3. *Heating Oil (Diesel)*:

- Efficiency: 80-90%

- Wasted Energy: 10-20% (mainly in the form of exhaust gases)

4. *Wood Pellets*:

- Efficiency: 70-90%

- Wasted Energy: 10-30% (mainly in the form of combustion gases and ash)

5. *District Heating*:

- Efficiency: 80-90%

- Wasted Energy: 10-20% (losses in distribution and heat exchange)

6. *Coal*:

- Efficiency: 60-80%

- Wasted Energy: 20-40% (mainly in the form of combustion gases and ash)

- How is the heat typically distributed in the building (hydronic, ventilation, fans, radiator)?

In tenant buildings in Spain, the distribution of heat typically involves a combination of hydronic systems (radiators or underfloor heating), ducted systems (for air-source heat pumps or centralized air conditioning), radiant panels, and fan coil units. The choice of distribution method depends on factors such as the type of heating system installed, building design, and individual preferences for comfort and energy efficiency.

1. **Hydronic Systems (Radiators)**: In buildings equipped with central heating systems, hot water or steam generated by a central boiler is circulated through a network of pipes to individual radiators in each unit. The radiators release heat into the rooms through convection and radiation. Hydronic systems with radiators are common in tenant buildings, especially those with centralized heating systems using natural gas or district heating.

2. **Underfloor Heating**: Some tenant buildings may have underfloor heating systems installed, either using hydronic or electric systems. With hydronic underfloor heating, hot water circulates through pipes installed beneath the floor, while electric underfloor heating utilizes electric cables or mats. Underfloor heating systems, particularly hydronic ones, are becoming more popular in new constructions and renovations due to their comfort and even heat distribution.

3. **Ducted Systems (Air-Source Heat Pumps)**: In buildings equipped with air-source heat pumps or centralized air conditioning systems, warm air is distributed to individual units through ductwork connected to central air handling units. These units may also include fans for air circulation. Ducted systems are common in buildings with centralized air conditioning systems, providing both heating and cooling as needed.

4. **Radiant Panels**: Radiant panels installed on walls or ceilings emit heat directly into the room through radiation. They can be electric or hydronic and offer a comfortable heating solution with minimal air movement. Less common compared to radiators or underfloor heating but may be found in some modern or renovated buildings.

5. **Fan Coil Units**: Fan coil units are often used in buildings with centralized heating and cooling systems. These units contain a fan and a heat exchanger through which hot or cold water circulates,

providing heating or cooling to individual rooms. Common in buildings with centralized HVAC systems, offering individual control over temperature in each room.

- Is cooling systems common? How is it delivered in that case and how much energy in kWh is used? (I assume inverters, cooling compressor or reversed heat pump).

Cooling systems, especially air-conditioning systems with inverter technology or reversed heat pumps, are common in tenant buildings in Spain, particularly in regions with warm climates. These systems provide efficient cooling while minimizing energy consumption. Energy usage for cooling can vary widely depending on factors such as system efficiency, building size, insulation, and climate conditions. Regular maintenance and proper use can help optimize energy efficiency and reduce overall energy consumption.

Air-Conditioning Systems: Air-conditioning systems use refrigerants to transfer heat from indoors to outdoors, cooling the indoor air. Inverter technology or reversed heat pumps allow for variable-speed operation and increased energy efficiency. Cooling is typically delivered through indoor units such as wall-mounted, ceiling-mounted, or ducted units.

- *Energy Usage*: On average, a residential air-conditioning system might consume considering medium insulation, varies based on the climate zone from **25 (interior, dry climate, continental) to 75 (coast, mediterranean climate) kWh/m^2** per year for cooling in Spain, though this can vary widely.

Office buildings

- What is/are the dominating heating method(s) for office buildings?

In general, the choice of heating method can depend on factors such as the building's size, location, age, and the specific climate of the region within Spain.

1. **Central Heating Systems**: Many office buildings use central heating systems, which distribute heat through radiators or underfloor heating. These systems are often powered by natural gas, though in some cases, oil or biomass may be used.

2. **Heat Pumps**: Heat pumps, including air-source and ground-source heat pumps, are increasingly popular due to their energy efficiency. They can provide both heating and cooling, making them a versatile choice for office buildings.

3. **Electric Heating**: While less common due to higher operating costs, electric heating systems (such as electric radiators and underfloor heating) are used in some office buildings, particularly in areas with mild winters or where central heating systems are not feasible.

4. **District Heating**: In some urban areas, office buildings may be connected to district heating networks, which provide heat from a centralized plant. This method is efficient and can reduce the carbon footprint of heating.

5. **Renewable Energy Sources**: There is a growing trend towards the use of renewable energy sources for heating. Solar thermal systems, for instance, can provide hot water and contribute to space heating, especially in combination with other systems.

- What is/are the prices, inclusive non-deductible taxes (i.e. real cost) for the heat "source(s)"? (Coal, oil, gas, electricity, pellets (wood), district heating) per suitable unit (liter, kilo, cubic meter, kWh).

The prices for heating sources in Spain, including non-deductible taxes, can vary based on several factors such as market fluctuations, region, and the supplier. However, as of the latest data available, here are approximate prices for different heating sources in Spain:

1. **Natural Gas**:

- Price per kWh: €0.08 - €0.15

2. **Electricity**:

- Price per kWh: €0.15 - €0.25

3. **Heating Oil**:

- Price: Approximately **€1.00 - €1.20** per liter

4. **Pellets (Wood)**:

- Price: Approximately **€0.20 - €0.25** per kg

5. **District Heating**:

- Price: Varies significantly by provider and region, typically around **€0.05 - €0.10** per kWh

6. **Coal**:

- Price: Approximately **€0.15 - €0.20** per kg (though coal is less common and often subject to environmental regulations that may affect availability and price)

- How much is typically needed for heating per square meter? What is the efficiency in percentage for the fuel and heating method, (how much is wasted in the form of hot gas etc.

The amount of energy required for heating per square meter in office buildings in Spain and the efficiency of different heating methods can vary widely based on building design, insulation, local climate, and usage patterns. However, general estimates and typical efficiencies for various heating methods are as follows:

➢ **Energy Requirement per Square Meter**

On average, office buildings in Spain may require around **70-100 kWh** per square meter per year for heating, though this can be lower in milder regions and higher in colder areas.

➢ **Heating Methods and Efficiencies**

Central Heating Systems (Natural Gas)

Energy Requirement: ~70-100 kWh/m²/year

Efficiency: Approximately **85-95%**

Wastage: **5-15%** of energy can be lost through exhaust gases and system inefficiencies.

Heat Pumps (Air-Source and Ground-Source)

Energy Requirement: ~70-100 kWh/m²/year

Efficiency (Coefficient of Performance (COP)): Approximately **300-400% (COP: 3-4)**

Wastage: **Minimal direct wastage**, as they transfer rather than generate heat; however, electrical energy used has upstream losses depending on electricity generation mix.

Electric Heating

Energy Requirement: ~70-100 kWh/m²/year

Efficiency: **Close to 100%** at the point of use

Wastage: Electrical energy used has upstream losses in generation and transmission (typically around **30-40%**).

District Heating

Energy Requirement: ~70-100 kWh/m²/year

Efficiency: Approximately **80-90%**

Wastage: **10-20%** due to distribution losses and system inefficiencies.

Pellets (Wood)

Energy Requirement: ~70-100 kWh/m²/year

Efficiency: Approximately **70-85%**

Wastage: **15-30%** through exhaust gases and incomplete combustion.

Coal

Energy Requirement: ~70-100 kWh/m²/year

Efficiency: Approximately **70-80%**

Wastage: **20-30%** through exhaust gases and ash residue.

- How is the heat typically distributed in the building (hydronic, ventilation, fans, radiator)?

In Spain, the typical methods for distributing heat in office buildings include a combination of hydronic systems, ventilation, fans, and radiators. The choice of distribution method can depend on the building's design, age, and specific heating requirements. Here are the common methods used:

1. **Hydronic Systems**: Hydronic heating is a popular method in Spain for distributing heat in office buildings.

2. **Radiators**: Radiators connected to a central heating system (often hydronic) are common in many office buildings.

3. **Underfloor Heating**: Underfloor heating systems are also used, particularly in modern office buildings. These systems can be hydronic or electric.

4. **Ventilation Systems**: Ventilation-based heating systems, including HVAC (Heating, Ventilation, and Air Conditioning) systems, are widely used in office buildings.

5. **Heat Pumps with Air Distribution**: Heat pumps, which are becoming increasingly popular due to their efficiency, often distribute heat through ducted air systems or fan coils.

6. **Fan Coils**: Fan coil units are used in conjunction with central heating and cooling systems, also common in the office buildings in Spain.

7. **Combination Systems**: Many office buildings use a combination of the above methods to optimize heating efficiency and comfort. For example, a building might use hydronic radiators in individual offices and an HVAC system for common areas and larger open spaces.

- Is cooling systems common? How is it delivered in that case and how much energy in kWh is used? (I assume inverters, cooling compressor or reversed heat pump).

Yes, they are common for office buildings in Spain, as follows.

1. Inverter-based Air Conditioning Systems

Energy Consumption: Typically uses about **0.3 to 0.5 kWh** per square meter per month during peak cooling months (approximately **20 to 60 kWh** per square meter annually).

2. Reversible Heat Pumps

Energy Consumption: Similar to inverter-based systems, using around **0.3 to 0.5 kWh** per square meter per month (approximately **20 to 60 kWh** per square meter annually).

3. Chilled Beam Systems

Energy Consumption: Generally more efficient, using about **0.2 to 0.4 kWh** per square meter per month (roughly **15 to 50 kWh** per square meter annually).

4. Fan Coil Units

Energy Consumption: Similar to other centralized systems, using around **0.3 to 0.5 kWh** per square meter per month (approximately **20 to 60 kWh** per square meter annually).

In general

- The dominating heat source/s, how much CO_2 in gram is generated per kWh or other suitable unit?

The CO_2 emissions generated per kWh for different heating sources in Spain can vary widely based on the type of fuel used. Below are typical CO_2 emission factors for common heating sources:

Natural Gas: **200-250 grams** of CO_2 per kWh

Electricity: **70-100 grams** of CO_2 per kWh (depending on average grid mix)

Heating Oil: **270-300 grams** of CO_2 per kWh

Pellets (Wood): **20-30 grams** of CO_2 per kWh (net emissions considering sustainable practices)

District Heating: **100-150 grams** of CO_2 per kWh (depending on suerce/fuel mix)

Coal: **340-360 grams** of CO_2 per kWh

- Do you see any trend in the heating/cooling market. E.g. gas boilers being replaced by heat pumps, district heating making inroads, demand for cooling increases etc.

Yes, there are several notable trends in the heating and cooling market in Spain, reflecting broader European and global shifts towards more sustainable and efficient energy solutions:

- **Rise of Heat Pumps**: Increasingly replacing gas boilers for heating and cooling due to higher efficiency. Heat pump technology is significantly developing, manufacturing much more economical and efficient equipment than in the last 5 years.
- **Expansion of District Heating (and cooling)**: Growing interest in urban areas for its efficiency and use of renewable energy sources. (although subsidy support is still needed)
- **Growing Cooling Demand**: Driven by climate change and the need for better indoor comfort.
- **Renewable Energy Integration**: More use of PV solar, biomass, and geothermal energy for heating and cooling. (although subsidy support is still needed)
- **Focus on Energy Efficiency**: Retrofitting buildings for reduced energy consumption.
- **Adoption of Smart Technologies**: Use of smart systems for better energy management.

➢ **Government Support**: Policies and incentives promoting sustainable heating and cooling solutions.
➢ **Decline in Fossil Fuels**: Decreasing use of coal and oil in favor of cleaner alternatives.

These trends illustrate a shift towards sustainability, efficiency, and technological advancement in Spain's heating and cooling sector.

Different evaluation methods

Forword

In order to demonstrate that GSHP many times is the best solution some kind of evaluation tool needs to be used. We will focus on Life Cycle Cost Analysis but there are several other methods that can be used and in the following there are short description of them plus examples how to calculate.

Evaluating the cost of heating solutions in a building involves several methods that take into account not just the initial investment, but also the operational, maintenance, and replacement costs over the system's lifecycle. Here are some of the most commonly used evaluation methods:

1. Life Cycle Cost Analysis (LCCA)

Description: LCCA is a comprehensive method that considers the total cost of ownership over the system's lifespan, including initial costs, operating costs, maintenance costs, and end-of-life disposal costs.

Steps:

1. Identify all relevant costs.
2. Determine the lifespan of each heating solution.
3. Choose an appropriate discount rate.
4. Calculate the present value of all costs.
5. Compare the total costs for each option.

Example: For a heating system with an initial cost of €10,000, annual maintenance costs of €500, annual fuel costs of €1,000, and a lifespan of 20 years, the LCCA would sum the discounted costs over the 20-year period. In this case it would be 34 527 EUR in total cost discounted to present day.

2. Net Present Value (NPV)

Description: NPV calculates the present value of the cash inflows and outflows associated with a heating solution, discounting future cash flows to reflect the time value of money.

Steps:

1. Estimate future cash flows (savings, costs).
2. Choose a discount rate.
3. Calculate the present value of each cash flow.
4. Sum the present values.

Example: For a heating system that saves €1,200 per year in energy costs, has an initial cost of €10,000, and a discount rate of 5%, the NPV would discount the annual savings over the system's lifespan, say 20 year, and subtract the initial cost. Result 4955€ in savings. Formula:

$$NPV = \frac{Cash\ Flow_1}{(1+r)^1} + \frac{Cash\ Flow_2}{(1+r)^2} + \frac{Cash\ Flow_n}{(1+r)^n} - Initial\ Investment$$

3. Simple Payback Period

Description: The simple payback period is the time it takes for the savings generated by the heating system to cover the initial investment.

Steps:

1. Calculate the annual savings (energy savings minus operating costs).
2. Divide the initial investment by the annual savings.

Example: If a heating system costs €10,000 and saves €2,000 annually, the payback period would be €10,000 / €2,000 = 5 years.

4. Return on Investment (ROI)

Description: ROI measures the profitability of an investment as a percentage of the initial cost.

Steps:

1. Calculate the total net savings over the system's lifespan (total savings minus total costs).
2. Divide the net savings by the initial investment and multiply by 100 to get a percentage.

Example: If a heating system costs €10,000 and generates €25,000 in savings over its lifespan, the ROI would be (€25,000 - €10,000) / €10,000 * 100 = 150%.

5. Levelized Cost of Energy (LCOE)

Description: LCOE calculates the average cost per unit of energy produced by the heating system over its lifetime, considering all costs.

Steps:

1. Sum all costs over the lifespan (initial, O&M, fuel, replacement).
2. Divide by the total energy produced over the lifespan.

Example: If a heating system costs €10,000 initially, has €500 annual O&M costs, produces 1,000 MWh over 20 years, the LCOE would be calculated as the total costs divided by the total energy produced.

6. Internal Rate of Return (IRR)

Description: IRR is the discount rate at which the NPV of the cash flows (savings minus costs) equals zero. It helps to identify the efficiency of an investment.

Steps:

1. Estimate the cash flows (savings, costs).
2. Use financial software or iterative methods to find the discount rate that makes the NPV zero.

Example: If a heating system generates varying annual savings and costs over its lifespan, the IRR would be the discount rate where the present value of these cash flows equals the initial investment.

7. Total Cost of Ownership (TCO)

Description: TCO includes all direct and indirect costs of owning a heating system over its entire life.

Steps:

1. Sum initial, operating, maintenance, and any indirect costs.
2. Compare the TCO of different systems.

Example: If a heating system has an initial cost of €10,000, annual operating and maintenance costs of €1,500, and an expected life of 20 years, the TCO would include all these costs.

8. Cost-Benefit Analysis (CBA)

Description: CBA compares the costs and benefits of different heating solutions, monetizing all benefits to compare with costs.

Steps:

1. Identify and monetize all benefits and costs.
2. Compare the net benefits (benefits minus costs) of each option.

Example: If a heating system costs €10,000 but provides €30,000 in benefits (energy savings, increased property value) over its life, the CBA would highlight the net benefit.

9. Energy Performance Contracting (EPC)

Description: EPC involves a third-party contractor who finances and installs the heating system, with payments tied to the energy savings achieved.

Steps:

1. The contractor guarantees energy savings.
2. Payments are based on actual savings, ensuring cost-effectiveness.

Example: An EPC might install a heating system for €0 upfront but take a portion of the energy savings over a 10-year period.

Conclusion

Choosing the best evaluation method depends on the specific context and objectives. Combining multiple methods can provide a more comprehensive analysis, ensuring that decision-makers have a well-rounded view of the costs and benefits associated with different heating solutions.

Introduction to life-cycle cost analysis

Life cycle cost analysis (LCCA) is a comprehensive and widely used concept used to analyse the total cost of an investment throughout its entire life cycle. In a detailed life-cycle cost analysis the costs are usually divided into different key categories depending on when they occur, and why. The international cost management standard (ICMS) uses the following key cost categories (ICMS 2021): Acquisition Costs (AC), Construction Costs (CC), Renewal Costs (RC), Operation Costs (OC), Maintenance Costs (MC) and End of Life Costs (EC).

The Acquisition costs are generally related to the procurement of land, property or asset and excludes any physical construction. AC is deemed a redundant category for this study, all non-construction costs related to installing a heating and cooling system such as permit fees and pre-studies of building energy demand is considered as either equal regardless of choice of heating and cooling method, or easily included as part of the construction costs.

There are three important dates in an LCCA, as illustrated in **Error! Reference source not found.**.

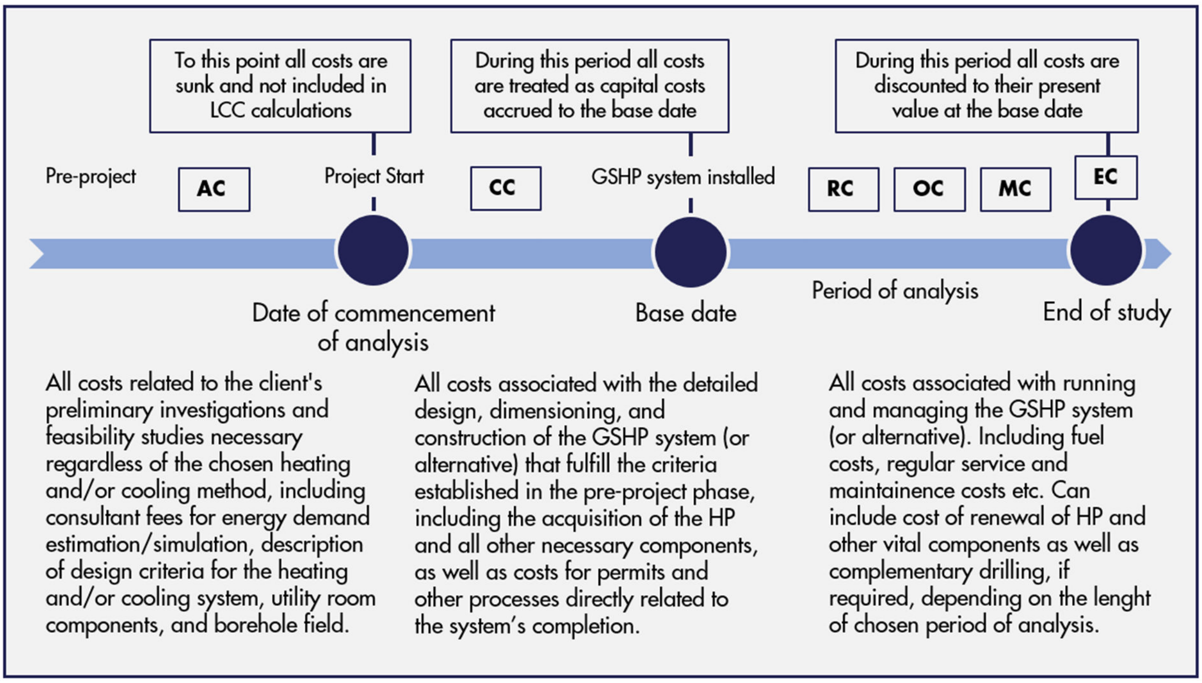


Figure 1. Illustration of important dates in a LCCA, and how different costs are treated in relation to them.

Description of life-cycle cost assessment tool

This section gives a detailed description of the life-cycle cost assessment tool developed in MS Excel for comparison of GSHP systems and other commonly used heating and cooling technologies. The tool calculates the net present value (NPV) and the levelized cost of energy (LCOE) for four main types of heating technologies:

- Ground source heat pumps (GSHP)
- Air source heat pumps (ASHP)
- Heat only boilers
- District heating (DH)

Input parameters and pre-sets.

System size parameters

The first input parameters are related to the size of the heating and cooling system, i.e. the energy requirements of the building, see Figure 2. The tool does not do any energy calculations; however, the tool has eight different presets, one each for the countries involved in GeoBOOST. As forementioned, the climate and geological conditions vary within each country, but the presets were deemed necessary for three main reasons:

- GSHP systems are generally characterised by high CAPEX and low OPEX. The installed peak capacity of the system is the dominating factor that drives up the CAPEX, but the energy delivered by systems with the same peak capacity varies depending on climate.

- The cost of installing GSHP system or any of the alternatives varies depending on country, as well as the price of fuel or electricity, and thus the OPEX of any heating and cooling technology.

- To take into account the variations in expected performance of both GSHP and ASHP, which are rated depending on climate conditions as defined in the EN14825 standard.

The country dependent preset used in the LCCA are chosen from the drop down list. Depending on the installed capacity in kW entered in the corresponding cell the energy delivered for space heating (Heating Delivered SH), the domestic hot water (DHW) consumption as well as the peak demand in kW and energy demand for cooling will change automatically (as indicated by the red colour). If you already know the energy demand of the building you can override the preset energy demand estimation by typing in the correct demand in the dark grey cells.

Country	Sweden

System Size Parameters				
Heating				
Installed Capacity	15	kW	Override:	
Heating Delivered SH	56,5	MWh/yr		MWh/yr
DHW	14,5	MWh/yr		MWh/yr
Supply Temperature of heating system	35	°C		
Cooling				
Peak Demand	8,8	kW		
Cooling Delivered	3	MWh/yr		MWh/yr

Figure 2. LCCA-tool input parameters interface: Country depending preset definition and system size parameters.

The red colour in the cells with white background indicates that the number presented is linked to a formula within the presets, and changes automatically. If an override value is typed in it only replaces the value of the corresponding cell. In conclusion, the only cell that determines the system size within the presets are the installed peak capacity for heating. Since this value needs to be defined by the user, the option to override it is redundant. The other cell that needs to be defined by the user is the supply temperature of the heating system, since it has a considerable influence on the performance of any type of heat pump solution. Two options are available, 35 °C and 55 °C.

The presets are only applicable to residential energy demand load profiles since the load profile of other types of buildings are not only determined by the climate but also strongly influenced by what type of activity takes place in said building.

The energy demand for space heating linked to the different countries has been estimated by choosing an arbitrary position within each country and using typical meteorological year (TMY) climate data to determine the number of heating degree days/hours (HDD/HDH), cooling degree days/hours (CDD/CDH) as well as the peak demand for cooling. The climate data was gathered from PVGIS[1]. The calculations of HDD/HDH and CDD/CDH is done using a 16 °C ambient temperature threshold for heating demand and an 18 °C ambient temperature threshold for cooling demand. The HDD and CDD is used to categorize each location into the three climatic zones used when rating heat pump performance according to the EN 14825 standard.

Table 1 presents the resulting HDD and CDD as well as the resulting climatic zone used for each location.

Table 1. HDD and CDD for each preset location.

[1] Photovaltaic Geographical Information System (PVGIS) [JRC Photovoltaic Geographical Information System (PVGIS) - European Commission (europa.eu)]

	HDD	CDD	Climatic Zone	Temperature °C	
				Min	Max
Austria	2395	297	Average	-18	32
France	2162	313	Average	-5	32
Germany	2406	356	Average	-11	31
Ireland	2167	89	Average	-3	23
Netherlands	2044	246	Average	-5	30
Poland	2572	385	Average	-12	31
Spain	926	891	Warm	1	36
Sweden	3659	194	Cold	-21	29

Since GSHP systems are CAPEX intensive and the predominant factor driving up the initial investment cost is the installed peak capacity of the heat pump (and the corresponding size of the borehole field) it is commonplace (recommended) to install a complementary heating solution with low CAPEX and higher OPEX cover the peak demand during the coldest hours of the year. In the presets the energy delivered by the analysed options is estimated using a peak demand coverage of 60 %. Table 2. below presents the resulting energy delivered by the investigated heating solutions for each preset location for three system size categories: Small <15 kW, Medium 15-100 kW, Large 100-250 kW.

The estimated peak demand of cooling is relatively high compared to the analysed solutions in all presets. Keep in mind that the actual peak demand at the dimensioning outdoor temperature for heating is at 25 kW in a scenario where a 15 kW installation covers 60 % of the peak demand. The cooling demand for the preset representing Spain is adjusted so that the investigated installations does not cover the entire cooling demand, which will be further explained in the section describing the GSHP parameters. The DHW demand for each preset is estimated through country specific statistics on average household energy consumption gathered from Eurostat (nrg_d_hhq). The relationship between the share of space heating and the share of domestic how water demand is used together with the space heating requirement derived from climate data to estimate the DHW use in each preset.

Table 2. Space heating and domestic hot water delivered in preset depending on capacity of analyzed solution. Source: Disaggregated final energy consumption in households-quantities Eurostat (nrg_d_hhq)

	Size Category X (kW)	SH Delivered MWh/yr	SH energy demand covered [%]	Share of final energy consumption in the residental sector (2022) SH [%]	DHW [%]	DHW Delivered MWh/yr	Cooling demand [kW]	Cooling demand [MWh/yr]
Austria	S (15)	50	91,3	68,6	14	11	13	6,9
	M (100)	336				75	87	45,7
	L (250)	841				188	218	114,3
France	S (15)	49	98,5	67,3	10,3	7	16	7
	M (100)	328				50	105	48
	L (250)	819				125	263	120
Germany	S (15)	53	96,1	66,1	16,7	14	15	8
	M (100)	356				90	98	55
	L (250)	890				225	245	137
Ireland	S (15)	50	99,6	57,9	21	18	7	2
	M (100)	332				120	47	14
	L (250)	830				301	118	34
Netherlands	S (15)	47	99,2	60,6	19	15	14	6
	M (100)	312				98	90	38
	L (250)	780				245	225	94
Poland	S (15)	56	94,7	62,8	18	16	14	9
	M (100)	375				107	96	59
	L (250)	937				269	241	148
Spain	S (15)	36	91	39,5	19,1	19	32*	38*
	M (100)	241				128	211*	255*
	L (250)	602				320	528*	636*
Sweden	S (15)	57	97,7	56,2	14,5	15	9	3
	M (100)	376				97	59	20
	L (250)	941				242	147	51

The values of the energy demand in residential buildings in the arbitrarily chosen locations within each country presented in Table 2 should not be regarded as anything but rough estimates.

Period of analysis and discount rate

There are two standard parameters that need to be included in all types of life-cycle cost analyses: the period of analysis and the discount rate. As illustrated in **Error! Reference source not found.** the period of analysis begins at the LCCA base date. When studying different heating and cooling solutions the reasonable base date is the first day the GSHP system or the investigated alternative is up and running. The period of analysis ends when the person doing the analysis sees fit for the purpose of the study, at the end of study date. A discount rate is used to take the time value of money into account in economic assessments. In an LCCA all costs occurring between ***the date of commencement of analysis*** and the ***base date*** is treated as capital cost accrued to the base date, similar to what is commonly referred to as capital expenditures (CAPEX). All costs occurring after the ***base date*** up until the ***end of study date***, i.e. during the ***period of analysis***, are discounted to their ***present value*** at the base date using a ***discount rate***.

To our knowledge, there is no recommended method of determining the appropriate period of analysis in an LCC study. It is evident that the longer the period of analysis, the less accurate the results. In this case, where the primary objective of the study is to investigate and compare the life-cycle cost of different heating systems where the expected lifetime of the main components differs the choice becomes particularly difficult. Some guidance can be found in different definitions used to describe the time during which a component fulfill certain requirements such as:

- Functional life: The period until a component or a system ceases to function for the initially intended purpose
- Physical life: The period until a component breaks down and needs to be replaced
- Technological life: The period until a component or system is no longer technically superior/competitive to alternatives.

As previously presented, the expected physical life of the different heat producing units in this study varies, and theoretical physical lifespan of a borehole field is in a completely different order of magnitude. Once you have decided what period of analysis you deem suitable, our recommendation is to try the sensitivity of the result if you add a few years to investigate any effect potential renewals have on the results. **Error! Reference source not found.** below shows the cells in the LCC-tool where the values of the period of analysis and discount rate is entered. An upper limit of a 100 years is set, since a longer period of analysis is deemed ludicrous. No lower limit is set, but a too short of a period of analysis defeats the purpose of doing an LCCA in the first place.

Standard LCC Parameters				
Period of analysis	**25**	Years		
Inflation (e)	**2**	%		
Discount (i)	**5,5**	%	Override:	
Real discount rate (r)	**3,43**	%	**3,50**	%
WACC Calculator				
Portion of Equity (Pe)	**50**	%		
Portion of Debt (Pd)	**50**	%		
Total Cost of Debt (Rd)	**4**	%		
Tax rate (Td)	**25**	%		
Total Cost of Equity (Re)	**5,5**	%		
WACC (r)	**4,25**	%		

Figure 3. LCCA-tool input parameters interface: Period of analysis and discount rate.

The input interface allows the user to calculate the real discount rate using two methods:

By changing the inflation rate (e) and discount rate (i) which is used to calculate the real discount rate through formula **Error! Reference source not found.**.

$$r = \frac{1+i}{1+e} - 1 \quad (1)$$

Or by calculating the Weighted Average Cost of Capital (WACC) through formula 2 below

$$WACC(r) = P_e \times R_e + P_d \times R_d(1 - T_d) \quad (2)$$

The real discount rate used in the LCCA can be changed by typing in the desired real discount rate in the dark grey cell overriding the discount rate automatically used otherwise, which is the real discount rate calculated through equation (1).

Since the expected life span of the different components varies, their potential residual value is incorporated into the final estimation of the NPV. Residual values represent any value of an asset at the end of the period of analysis. The tool uses the straight line method of depreciation to estimate the residual values, which is the common method (RICS 2016). Any residual value of a renewed asset is depreciated using the same method but starting from the discounted present value of the renewal cost of the asset (not including the cost of installation).

The input interface of the fuel cost is presented in Figure 4. As indicated by the red font colour in the cells with the white background, the fuel costs are linked to the preset of the chosen country. However, since the price of fuel is constantly changing the preset costs of fuel will be outdated before you have reached the punctuation mark. The dark grey cells allow the user to change the costs in order to reflect the current market at the time of analysis, or to conduct a sensitivity analysis on the effect of fuel costs.

Fuel Costs			Override:	
Electricity	0,18	EUR/kWh		EUR/kWh
District Heating	0,102	EUR/kWh		EUR/kWh
Pellets	0,106	EUR/kWh		EUR/kWh
Natural Gas	0,2	EUR/kWh		EUR/kWh
Coal		EUR/kWh		EUR/kWh
Other		EUR/kWh		

Figure 4. LCCA-tool input parameters interface: Fuel Cost.

GSHP Specific Parameters

The input interface of the GSHP specific parameters is presented in Figure 5 The number of input parameters reflects the purpose of this project, and the complexity of estimating the life-cycle cost of something as complex as a GSHP system. Neither the physical life of the ground source heat pump or the physical life of the boreholes is linked to any preset and can be changed at the discretion of the user. The tool has a set minimal value on the physical life of the heat pump of 5 years. In the presets developed the sensitivity of the CAPEX and OPEX of the GSHP system to important factors can be investigated. The presets are adapted for closed loop systems. The user can override all key costs if the investigated system is not a closed loop system.

GSHP-Specific Parameters				
Physical Life Heat Pump:	20	Years		
Physical Life Boreholes:	100	Years		
CAPEX				
Borehole field				
Thermal Conductivity (Lambda):	3	W/(mK)		
Total Drilling Depth:	680	m		
Drilling Cost:	32	EUR/m		
Drilling Cost:	21760	EUR		
Digging/Horisontal piping:	6963	EUR		
Other:		EUR	Override:	
Total Cost:	28723	EUR		EUR
Building/Utility Room				
Heat Pump:	900	EUR/kW		
Heat Pump:	13500	EUR		EUR
Heat Pump Installation:	870	EUR		EUR
Passive Cooling:	2600	EUR		EUR
Active Cooling:		EUR		EUR
Total Cost:	16970	EUR		EUR
OPEX				
SCOP SH:	4,9	-		-
SCOP DHW:	3	-		-
SEER:	20	-		
Regular Service/Maintenence:	220	EUR/yr		EUR/yr
Interval of major repairs:	0	Years		
Average cost major repair:	0	EUR		
Decomissioning/Renewal				
Decomissioning HP:	870	EUR		EUR
Renewal				
Borehole field renewal:		EUR		
Heat Pump:	13500	EUR		EUR
Installation:	870	EUR		EUR

Figure 5. LCCA-tool input parameters interface: GSHP specific parameters.

The cost of the borehole field is estimated using the price of drilled meter, presented in work package 2, deliverable D2.1, Figure 7 and the total depth of the borehole field required to meet the system needs.

The required total depth of the borehole field is sensitive to a number of factors, one of which is the thermal conductivity along the borehole. The user can choose between three different values of the thermal conductivity: 2,3,4 W/mK. Another important factor is the SCOP value of the heat pump installed since it is directly linked with the amount of energy extracted from the ground. The SCOP value used in the presets changes depending on the supply temperature of the heating system and the climatic zone.

The required total borehole depth for each preset has been investigated by simulating the system using the software Earth Energy Designer (EED). The input parameters for the EED simulations are based on, again, the findings in deliverable D2.1 where the most commonly used borehole diameters, collectors and circulation medias among the different countries are presented. The load profile of the space heating for each preset is derived from the typical meteorological year.

18 different simulations have been conducted for each size category for each country investigating the borehole depth required depending on supply temperature of the heating system (SCOP), the three values of the thermal conductivity listed above, and if the system only produced SH, SH + DHW, or SH + DHW + Cooling.

The values of the installation cost is derived from a survey of the current market for each participating country.

The presets use the assumption that the cost of decommissioning is the same as the cost of installing the heat pump, discounted to the present value. The same assumption is made about the cost of renewal, the same cost for the heat pump and installation is used but discounted to the present value. There are no major repairs included in the presets, but it can be included in the analysis. The shortest possible interval of major repair is set to 5 years. If the need for repair is deemed more frequent, this should be included in the regular service and maintenance cost.

ASHP Specific parameters

The input interface of the ASHP specific parameters is presented in Figure 6. The physical life of the heat pump is one of three parameters not connected to a preset. Apart from the minimal value of 5 years imposed, it is up to the user to choose a feasible physical life of the heat pump. There are no major repairs included in the presets, but it can be included in the analysis. The shortest possible interval of major repair is set to 5 years. If the need for repair is deemed more frequent, this should be included in the regular service and maintenance cost.

Air Source Heat Pump Solution				
Physical Life Heat Pump:	15	Years		
CAPEX				
			Override:	
Heat Pump:	1100	EUR/kW		
Heat Pump:	16500	EUR		EUR
Heat Pump Installation:	870	EUR		EUR
Active Cooling:	2600	EUR		EUR
Total Cost:	19970	EUR		EUR
OPEX				
SCOP SH:	3,8	-		-
SCOP DHW:	2,7	-		-
SEER:	6,2	-		-
Regular Service/Maintenence:	220	EUR/yr		EUR/yr
Interval of major repairs:	0	Years		
Average cost major repair:	0	EUR		
Decomissioning/Renewal				
Decomissioning:	435	EUR		EUR
Renewal				
Installation:	870	EUR		EUR
Heat Pump:	16500	EUR		EUR

Figure 6. LCCA-tool input parameters interface: ASHP specific parameters.

Heat Only Boiler specific parameters

The input interface of the parameters specific to a heat only boiler solution is presented in Figure 7. The input parameters are pretty much the same as for the ASHP described above. The physical life of the boiler as well as the parameters related to major repairs are not linked to any presets and needs to be defined by the user. Again, the physical life of the boiler and the interval of major repairs both have a minimal value of 5 years. There are two OPEX related parameters specific to the heat only boiler solution: boiler efficiency and fuel cost.

HO Boiler solution				
Physical Life Boiler:	15	Years		
CAPEX				
Boiler:	330	EUR/kW	Override:	
Boiler:	4950	EUR		EUR
Installation:	1090	EUR		EUR
Total Costs:	6040	EUR		EUR
OPEX				
Boiler efficiency	0,95	-		
Fuel Cost	0,106	EUR/kWh		
Regular Service/Maintenence:	400	EUR/yr		EUR/yr
Interval of major repairs:	0	Years		
Average cost major repair:	0	EUR		
Decomissioning/Renewal				
Decomissioning:	1090	EUR		EUR
Renewal				
Installation:	1090	EUR		EUR
Boiler	4950	EUR		EUR

Figure 7. LCCA-tool input parameters interface: Heat Only Boiler specific parameters.

Boiler efficiencies vary depending on a range of factors (such as fuel type and fuel quality, the make and model of the boiler etc.), so no value of the boiler efficiency is linked to any preset. Given the fluctuating and often unpredictable nature of the price of different types of energy sources, the country specific fuel cost presented by the presets will most likely be outdated by the time this report is published. Consequently, the fuel cost used in the analysis is thus not linked to any preset and needs to be defined by the user. The tools can only analyse one type of heat only boiler at a time.

District heating specific parameters

The input interface of the parameters specific to a district heating solution is presented in Figure 8. No presets are available for the district heating solution. District heating networks are local, and in many cases not an option since there simply is no network available. If district heating is an option, the CAPEX and OPEX varies significantly depending on the network. Presenting any presets depending on country alone would be highly misleading and a serious attempt of doing so is definitely outside the scope of this project.

As for the LCC-tool, the value of the input parameters needs to be defined by the user. The physical life of the heat exchanger and the interval of major repairs both have a minimal value of 5 years. The red colour of the total cost in the CAPEX section indicates that a simple summation of the specified costs is done automatically if detailed information of the cost of the heat exchanger (representing all utility room components), connection to the network and installation cost are defined. If no such information is available, the user can use the grey cell to override the total CAPEX.

District Heating Solution				
Physical Life Heat Exchanger:	20	Years		
CAPEX			Override:	
Heat exchanger/Central:	3915	EUR		EUR
Connection to network:	4698	EUR		
Installation:	435	EUR		
Total Costs:	9048	EUR		EUR
OPEX				
DH Energy Cost	0,102	EUR/kWh		
Regular Service/Maintenence:	110	EUR/yr		
Interval of major repairs:	0	Years		
Average cost major repair:	0	EUR		
Decomissioning/Renewal				
Decomissioning:	435	EUR		EUR
Renewal				
Heat exchanger/Central:	3915	EUR		EUR
Installation:	435	EUR		EUR

Figure 8. LCCA-tool input parameters interface: District Heating specific parameters.

The cost of decommissioning assumed to be is the same as the cost of installation, discounted to the present value. The same assumption is made about the cost of renewal, the same cost for the heat exchanger and installation is used but discounted to the present value. If the grey box to override the total CAPEX cost is used, the cost of the heat exchanger is estimated using the user-defined installed capacity and a cost of 270 EUR/kW for the heat exchanger. If this value is deemed unfeasible, the user can specify the total cost of the heat exchanger in the dark grey cell. If any of the cells used to override the previously described costs is in use, the cost of decommissioning is roughly estimated to be 10 % of the cost of the heat exchanger.

Complementary Cooling

Both GSHP and ASHP can provide both heating and cooling, district heating and heat only boilers can't. In order to highlight this distinction between the types of technologies included in the LCC-tool, the cost of installing (and using) a complementary cooling solution has been added. If a cooling solution are to be installed, it is recommended to add the cost of a solution that produces the equivalent amount of cooling as the GSHP to the cost of the district heating or heat only boilers solution. If cooling is deemed irrelevant, the cost related to cooling for both heat pump solutions should be set to zero. The input interface of the parameters to a potential complementary cooling solution is presented in Figure 9.

Complementary Cooling Solution		
Physical Life:	12	Years
CAPEX		
Cooling components cost:	4000	EUR
Installation:	500	EUR
Total Costs:	4500	EUR
OPEX		
Fuel Cost	0,18	EUR/kWh
SEER	8	-
Regular Service/Maintenence:	220	EUR/yr
Interval of major repairs:	0	Years
Average cost major repair:	0	EUR
Decommissioning/Renewal		
Decommissioning:	250	EUR
Renewal		
Installation:	500	EUR
Cooling components cost:	4000	EUR

Figure 9. LCCA-tool input parameters interface: Complementary Cooling specific parameters.

The complementary cooling solution is not added to any preset, and all parameters need to be defined by the user.

Results presented by the LCC-Tool

The result of the LCC is presented in a separate sheet. This section aims to clarify and describe how to interpret the plots and tables provided. The main focus points are summarized in a table; see Table 3 for an example.

The initial investment cost is the total sum of all costs related to the various heating and cooling technologies occurring between the date of commencement of analysis and the base date. The future renewal cost represents the expense of replacing any heating solution that has reached the end of its physical life and been substituted with a new unit (of the same type) within the analysis period. This could occur multiple times if a short physical life is assigned to a solution or if a long analysis period is used. The cost of future renewal is discounted to its present value. The costs related to operation and maintenance are presented by their respective present values.

Table 3. Table of result generated by the LCC-Tool.

Cost Distribution in EUR Period of analysis: 25 Years	GSHP	ASHP	HO Boiler	District Heating	HO Boiler + Equivalent Cooling	District Heating + Equivalent Cooling
Initial Investment:	45693	19970	6040	9048	10540	13548
Future Renewal Cost:	7222	10368	3605	2186	8554	7135
Fuel:	48991	61477	124040	119359	125152	120472
Regular Service:	3626	3626	6593	1813	10219	5439
Major Repairs:	0	0	0	0	0	0
Decomission:	368	184	461	184	567	290
Residual:	-26959	-3456	-1202	-2936	-3008	-4743
Total NPV:	**78942**	**92169**	**139537**	**129654**	**152024**	**142141**
LCOE [EUR/MWh]:	65	76	119	111	125	117

The end of life cost is represented by the cost of decommissioning the heating and cooling solution at the time when the period of analysis ends. The post "residual" represents any residual value of the analysed solutions using the straight line method of depreciation as described in the section *Period of analysis and discount rate*. At the bottom of the table the net present value and the levelized cost of energy for all analysed solutions is presented.

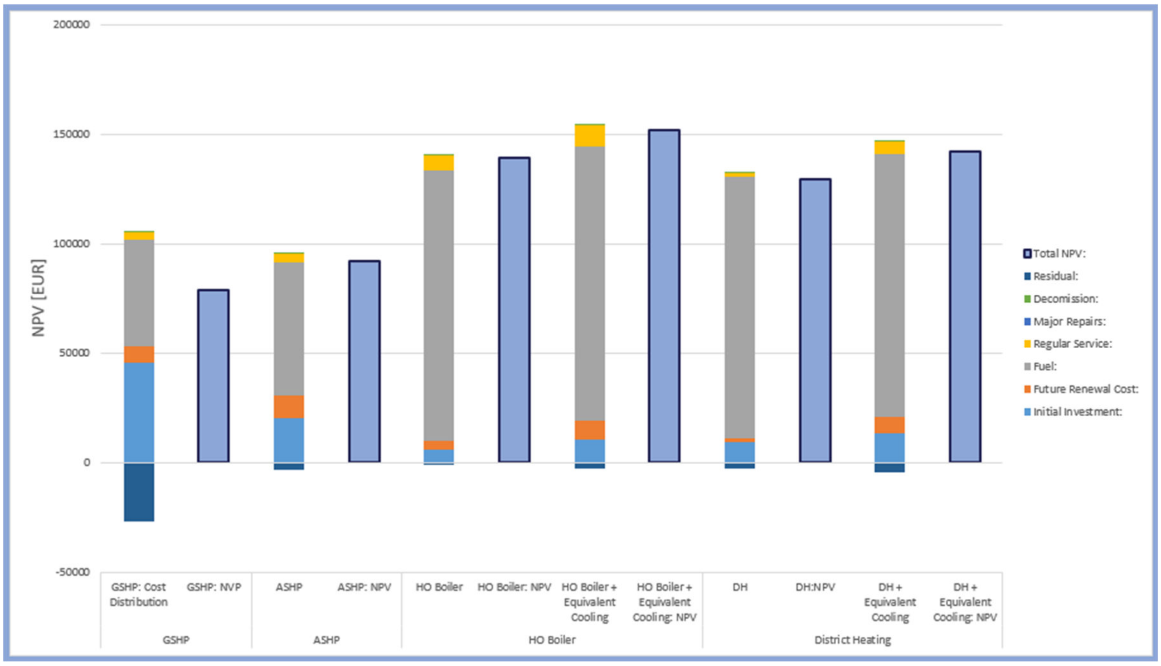


Figure 10. Illustration of heating and cooling solution cost allocation presented by the LCC-tool.

The same results that are presented in Table 3 are also illustrated in a stacked column chart see Figure 10. In this particular example, the residual value of the GSHP solution has a substantial impact on its NPV, which can be explained by the tool using the straight line method of depreciation and a physical life of 100 years of the borehole field. Since the period of analysis was set to 25 years, the residual value of the borehole field is 75 % of the initial investment cost. In addition to that, the ground source heat pump was set to have a physical life of 20 years, which means that the residual value of the heat pump is 75 % of discounted value of installing a unit 20 years into the future.

The progression of the net present value of the different heating and cooling solutions are illustrated by a scatter chart, see Figure 11 for an example.

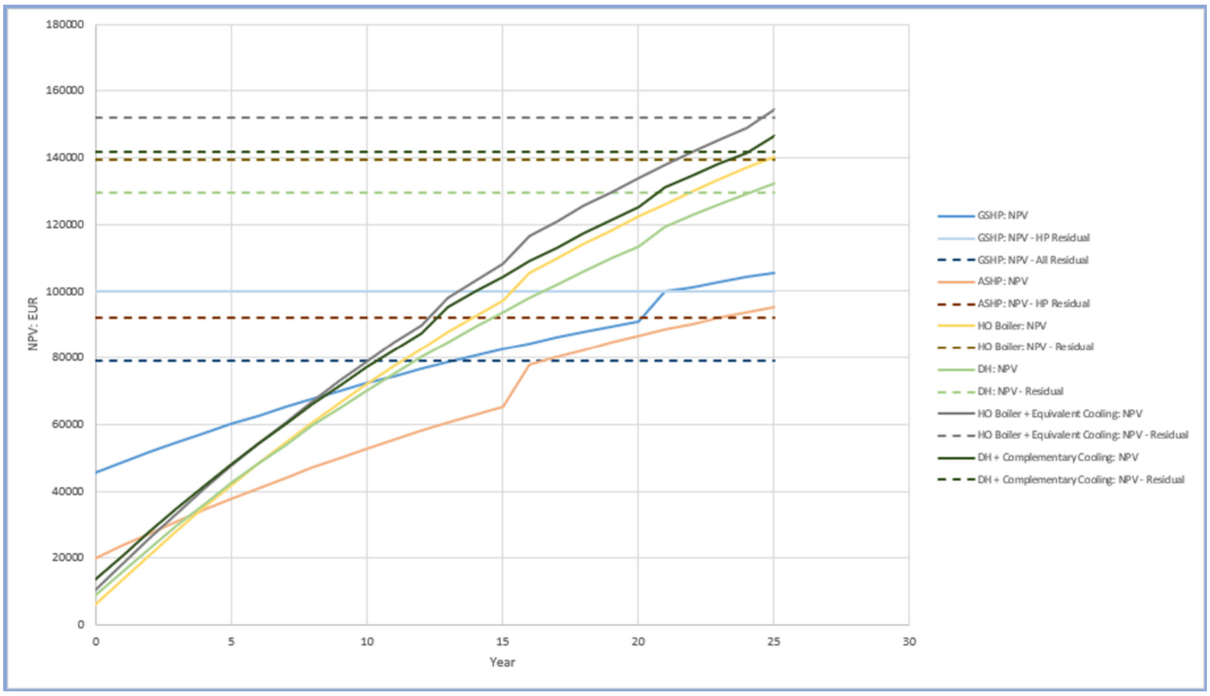


Figure 11. Progression of the NPV of the analyzed heating and cooling solutions generated by the LCC-tool.

Examining the progression of the NPV of the ASHP solution one can see a sudden increase in the NPV, which is due to the cost of renewal occurring after 15 years (in this example). The horizontal dotted lines represent the NPV of the different heating and cooling solutions at the end of study date, including their respective residual values and decommissioning cost.

Since assessing the value of a GSHP solution is prioritized in this project, the payback time of choosing a GSHP solution compared to any of the other alternatives is estimated, and the progression of the NPV using a cash-flow approach is illustrated, see Figure 12 for an example.

Using this approach, a negative value indicates that the investment of a GSHP is profitable compared to the alternative.

	ASHP	HO Boiler	DH	HO Boiler + Equivalent Cooling	DH + Equivalent Cooling
GSHP Paybacktime* [Years]:	38	10	10	8	8

*Without residual value

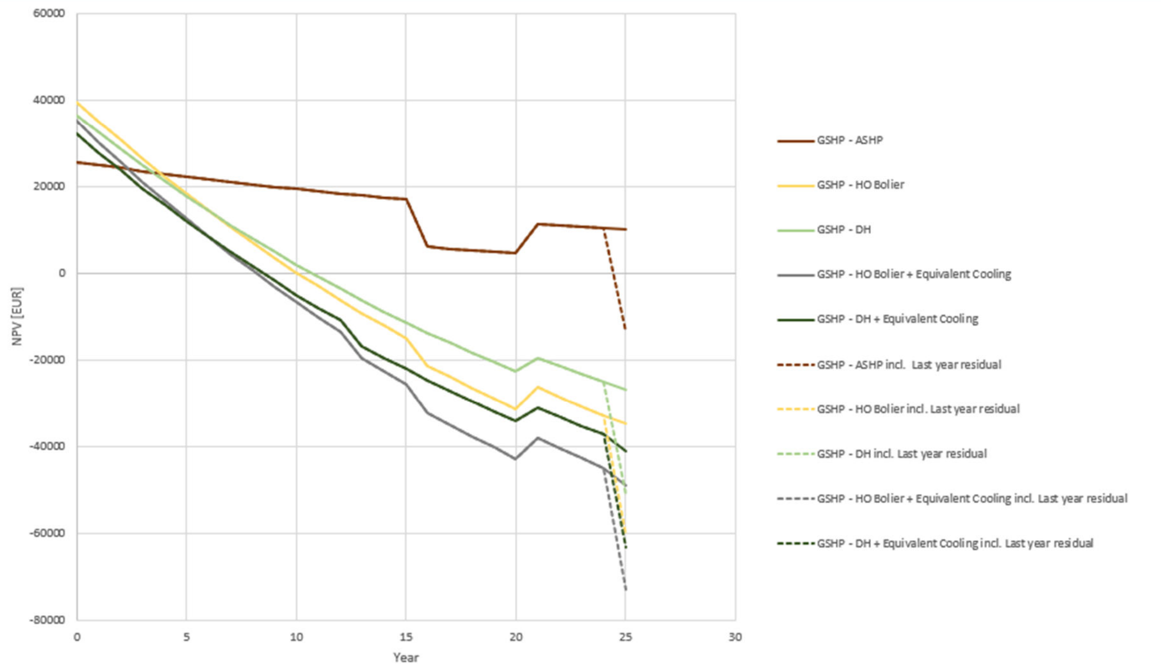


Figure 12. Illustration of the progression of the NPV using a cash-flow approach comparing GSHP to other heating solutions generated by the LCC-tool.

Again, the dotted lines represent the NPV of the different heating solutions, taking their residual values into account. In this case, the residual values are negative for all alternatives since the residual value of the GSHP option is higher at the end of the analysis period. In this example, the payback time for the ASHP extends beyond the analysis period, resulting in a positive NPV compared to the GSHP solution if the difference in residual values is not considered.

Some calculation examples

Following is a number of calculations for fictive heating solutions. It is intended to give a feeling what parameters are important.

Basic for all calculations is 2 % discount interest, 20-year calculation period.

GSHP 12 500 EUR inc installation, AWHP (air, water)11 000 EUR inc. installation and a Gas boiler 3 500 EUR inc. installation. The GSHP is considered having 25-year longevity, the other 20 year. It gives a residual value of 2 500 EUR for the GSHP. The other solution will have a useful time at 20 year and thus zero residual value. All systems are supposed to produce 40 MWh of heating with COP 4 respective 3,5 for GSHP and AWHP and with a 90 % efficiency of the Gas boiler.

For the GSHP two costs for drilling the necessary meters are considered, cost 10 000 respectively 20 000 EUR giving the GSHP a Capex of 22 500 respectively 32 500 EUR. The borehole and outdoor piping are assumed to not loose its value after 20 year, so NPV will be the same as todays cost.

Gas price is set to 0,1 EUR per kWh and electricity prices to 0,25 respectively 0,4 per kWh. Average electricity price for a medium sized household 2023 is 0,293 EUR according to EUROSTAT. It is also used as can be see below.

https://ec.europa.eu/eurostat/databrowser/view/ten00117/default/table

Financial cost (Weighted Average Cost of Capital) is set to yearly interest for Capex to 3,4 respective 5 % in the examples.

Discussion.

An electricity price 4 times of gas per kWh makes the gas boiler solution cheapest due to relatively similar Opex considering COP and efficiency. It is of course due to lower Capex.

A high drilling cost, combined with higher financial cost, will make a GSHP more expensive than a AWHP even if Opex is lower due to higher COP.

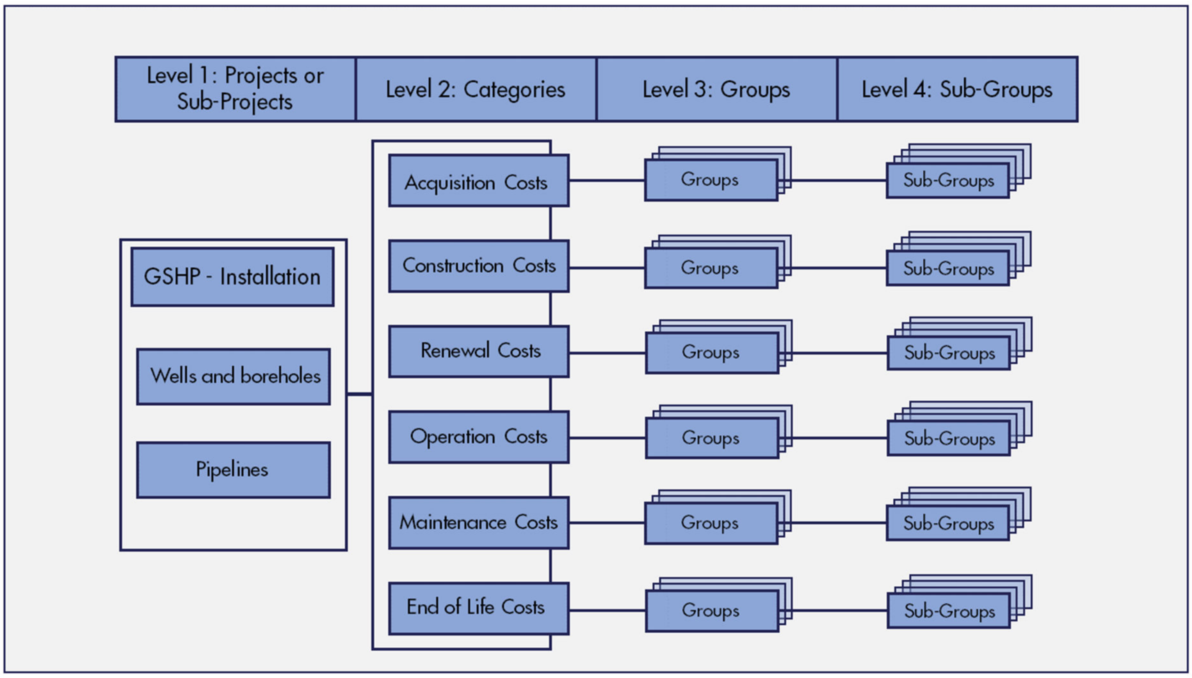
These simple examples high light the necessity to have not too high electricity prices compared too gas prices.

Also, as can be seen in the examples below, having an efficient, and thus relatively low-cost drilling process and finding reasonably low-priced financing solutions. If drilling cost are high and financial cost as well the AWHP will be more economical. AWHP will have a higher operating cost since it has a lower COP (using more electricity per unit of heat produced) but is soon “eaten up” of financial costs for the Capex.

Type	Investment EUR	Discount int. %	Financial cost %	Price KWh EUR	NPV a 20 year
GSHP	22500	2	3	0,25	61 916
AWHP	11000	2	3	0,25	63 112
Gas B.	3500	2	3	0,1	77 890
GSHP	32500	2	3	0,25	66 822
AWHP	11000	2	3	0,25	63 112
Gas B.	3500	2	3	0,1	77 890
GSHP	22500	2	5	0,25	69 274
AWHP	11000	2	5	0,25	66 709
Gas B.	3500	2	5	0,1	79 035
GSHP	32500	2	5	0,25	77 450
AWHP	11000	2	5	0,25	66 709
Gas B.	3500	2	5	0,1	79 035
GSHP	22500	2	3	0,4	83 802
AWHP	11000	2	3	0,4	91 142
Gas B.	3500	2	3	0,1	**77 890**
GSHP	32500	2	3	0,4	93 802
AWHP	11000	2	3	0,4	94 379
Gas B.	3500	2	3	0,1	**79 035**
GSHP	22500	2	5	0,4	93 801
AWHP	11000	2	5	0,4	94 739
Gas B.	3500	2	5	0,1	**77 890**
GSHP	32500	2	5	0,4	101 977
AWHP	11000	2	5	0,4	94 739

Gas B.	3500	2	5	0,1	**79 035**
GSHP	22500	2	5	0,293	76 305
AWHP	11000	2	5	0,293	**74 744**
Gas B.	3500	2	5	0,293	79 035
GSHP	32500	2	5	0,293	84 421
AWHP	11000	2	5	0,293	**74 744**
Gas B.	3500	2	5	0,293	79 035
GSHP	22500	2	4	0,293	**72 676**
AWHP	11000	2	4	0,293	72 946
Gas B.	3500	2	4	0,293	78 462

Appendix A. LCC with the ICMS adjusted for GSHP systems



LCC with the Internaltional Cost Measurement Standard (ICMS) Adjusted for GSHP systems			
LEVEL 1: Projects or Sub-Projects.			
Code			
08.	Pipelines		
09.	Wells and boreholes		
LEVEL 2: Categories - ACROME			
	Code	Acronyme	Name
	1.	AC	Acquisition Cost [Part of Non-Construction Costs]
	2.	CC	Construction Cost
	3.	RC	Renewal Cost
	4.	OC	Operation Cost
	5.	MC	Maintenance Costs
	6.	EC	End of Life Costs
LEVEL 3: Groups			
	1.	AC	Acquisition Cost [Part of Non-Construction Costs]
		02.	Administrative, finance, legal and marketing expenses
		02.010	Client's preliminary investigations/Feasibility studies - client's in-house project management and design team - Energy demand estimation/simulation - Consultant fees - Conceptual design/ description of design criteria of utility room components - Conceptual design/ description of design criteria of borehole field
		02.020	General project planning
		02.030	Required Documents and descriptions
		02.040	Accommodation and travelling expenses for in-house team and external parties
		02.050	Interest and finance cost
		02.060	Tendering process
		02.070	Taxes and statutory charges
		02.080	License and permit charges
		02.090	Preliminary dimensioning and design of borehole field

2.	CC	Construction Costs
Adjusted list from Appendix C. Table C-1: Construction | Renewal | Maintenance Sub-Groups: Civil Engineering Works		
	01.	Demolition, site preparation and formation
	01.010	Site survey and ground investigation
	01.020	Test hole drilling
	01.030	Field measurements and analysis
	01.040	Dimensioning and design of borehole field
	02.	Substructure
08.	02.010	Excavation and trenching: - Excavation - Asphalt removal - Rock removal/blasting - Removal of paving/temporary storage - Top-soil removal - Trenching - Backfilling - Beds and surrounds to underground pipes - Backfilling - Restoration to original condition
09.	02.020	Boreholes: - Drilling from surface to bedrock - Casing and casting - Bedrock drilling - Grouting - Removal of drill cuttings - Treatment of drilling water
09.	02.030	Energy wells - Collector - Collector installation - Protective well caps - Brine (for energy wells and horizontal piping)
	03.	Structure
	03.010	Civil pipeworks (horizontal pipes)
	03.020	Manifolds, valves and fittings (inside and outside of utility room)
	03.030	Seperate substation / utility room structure
	04.	Non-structural works
	04.010	Refurbishment of heating system
	04.020	Refurbishment of ventilation system
	04.030	Signage, markings and the like
	05.	Services and equipment
	05.010	Heat pump
	05.020	Other utility room components related to heat and DHW production: - Accumulator tanks - External circulation pumps - Control systems and instruments - Signaling system - Telecommunications systems - Other storage vessels, knobs, bults, pipes and so on and so forth
	05.030	Other utility room components related to passsive/active cooling - Heat exchangers, fans and so on and so forth
	05.040	Installations and work done related to HVAC-system

08.	Preliminaries | Constructors' site overheads | general requirements
08.010	Construction management including site management staff and support labour
08.020	Temporary access roads and storage areas, traffic management and diversion (at the constructors discretion)
08.030	Temporary site fencing and securities
08.040	Workpeople living accommodation
08.050	Other temporary facilities and services
08.060	Technology and communications: telephone, broadband, hardware, software
08.070	Constructor's submissions, reports and as-built documentation
08.080	Quality monitoring, recording and inspections
08.090	Safety, health and environmental management
08.100	Insurances, bonds, guarantees and warranties
08.110	Constructor's statutory fees and charges
08.120	Testing and commissioning
08.130	Extras for extreme climatic or working conditions (if priced seperately according to local pricing practice)
09.	Risk Allowances
09.010	Design development allowance
09.020	Construction contingencies
09.030	Price level adjustment until tendering
09.040	Exchange rate fluctuation adjustments
10.	Taxes and Levies
10.010	Paid by the constructors
10.020	Paid by the Client in relation to construction payments
11.	Work and utilities off-site (including related risk allowances, taxes and levies)
11.010	Diversion of and capacity enhancement of public utility mains or sources off-site up to mains connections on-site: - Electricity
12.	Production and loose furniture, fittings and equipment (including related risk allowances, taxes and levies)
12.010	Drilling equipment (Drilling rig, Compressor, Hammers, part of contractor's operational costs)
12.020	Trucks and other logistics vehicles (part of contractors operating costs)
13.	Construction-related consultants and supervision (including related risk allowances, taxes and levies)
13.010	Consultants' fees and reimbursable: - Civil Engineers - Electrical Engineers - Plumbing, Heating, Water and sanitation - Project managers - Surveyors - Specialist consultants
13.020	Charges and levies payable to statutory bodies or their appointed agencies (in connection with planning, design, tender and contract approvals, supervision and acceptance inspections)
13.030	Site supervision charges (including their accommodation and travels)
13.040	Payments to testing authorities or laboratories

4.	OC	Operations Costs (OC)
	02.	Utilities
	02.010	Fuel: - Electricity
	04.	Security
	04.010	Physical security and routine checks
	04.020	Remote monitoring
	05.	Information and communications technology
	05.010	Communication system / internet for remote monitoring
	06.	Operators' site overheads | general requirements
	06.010	Administration
	06.020	Insurance
	07.	Risk Allowances
	07.010	Operation related
	08.	Taxes and Levies
	08.010	Taxes
	08.020	Levies
5.	MC	Maintenance Costs
	05.	Services and equipment
	05.010	Routine check and controll - check and adjust brine levels - inspect ground loops for leaks - clean or replace air filters - check and tighten electrical connections - inspect and lubricate moving componens such as fans, bearings and the like - test the thermostat calibration and accuracy - verify that safety monotoring systems are functioning - inspect piping for leaks, corrosion or insulation damage
	05.020	Major repairs not covered by insurance

6.	EC	End of Life Costs
	01.	Disposal inspection
	01.010	Indoor inspection and overwiev
	01.020	Outdoor inspection and overwiev
	02.	Decommisioning and decontamination
	02.010	Shutdowns and decommissioning
	02.020	Decontamination
	03.	Demolition, reclamation and salvage
	03.010	Demolition
	03.020	Reclamation
	03.030	Salvage
	06.	Risk Allowances
	06.010	End of life specific
	06.020	Abnormal risks
	07.	Taxes and Levies
	07.010	Taxes
	07.020	Levies
	07.030	Credit for grants

Discussion

As pointed out in the chapter "Advantage Ground Source Heat Pumps" there is many advantages with Ground Source Heat Pumps compared to other heating solutions, and maybe in the long run it is the zero contribution (together with certified electricity) of CO2 to the atmosphere and thus being very important for the goal of having a CO2 carbon neutral housing market to 2050 in EU, that is the most important from a societal view.

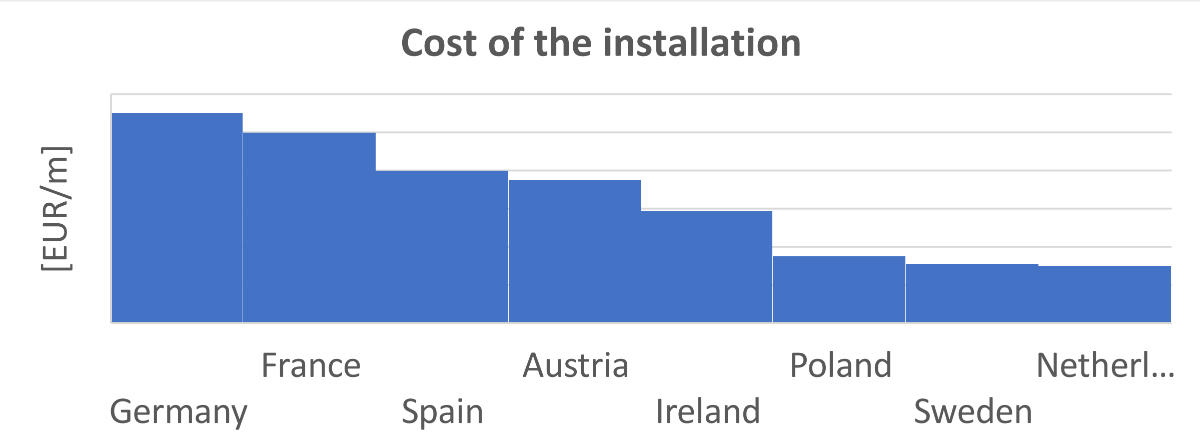
However for most private persons and companies the economic aspect will be the most important factor when choosing an heating (and cooling) solution. Since Capex is high for a GSHP installation it is a deterrent for deciding on a GSHP solution; awareness of all the advantages with a GSHP solution needs to be raised and the use of an LCC tool can demonstrate that over time it is the most economic solution.

Apart from the obvious action for states to subsidize GSHP to bring down Capex, it is important to bring down the financial cost for the Capex, e.g. low interest loans and easily accessible loans and bring down the cost for drilling. Equipment (Heat pump) and installations should automatically be reasonably priced in a competetive market. Also drilling unless burdened with a lot of regulations and fees. As can be seen in the data and graph from "Geoboost- Deliverable D2.1 Ground Source Heat Pumps in Euro" the price for drilling varies a lot between states in EU:

General cost of the installation per meter (EUR/m).

Austria	**70 – 80** for singular family homes (lower costs for bigger installations)
France	**100**
Germany	**90 - 130** (drilling, probe and grouting)
Ireland	**56 - 62**
Netherlands	**25 - 35**
Poland	**35** (drilling, grouting, probe and glycol)
Spain	**75 - 85** borehole complete (borehole, probe and backfill) (without lost casing)

Sweden	**30-32** for drilling (collector, ground install., digging not included, add 10-15€)



In order for GSHP to be competitive, especially to other Heat Pump solutions, the prices for drilling probably need to go down to the level we find in The Netherlands, Sweden and Poland. It is obviously possible and the path to get there should be to carefully study the "good examples", ease the regulatory burdens, encourage competition, e.g. making it easy for foreign drilling companies to enter their markets, even encouraging them to do so.

There is an example on how a new actor lowered the price for the whole market by introducing new drilling standards. When Rototec entered the Finnish market the dominating drilling methods were 139 mm borehole and truck mounted drilling rigs no always easy to manouver to the right spots. Rototec entered the market, (around 2010) using Swedish experience how to conduct efficient drilling, a.o.t. with selfgoing drilling rigs that was much easier to manoeuvre and usually drilling 114 mm boreholes which enabled them to be very competitive on pricing and they could take a substantial market share within a few years. Most of the other drilling companies had to adapt to the "Rototec way" of drilling and the price level for drilling dropped substantially and Finland had a rapid growth of GSHP solution and now being one of the biggest markets in Europa with a penetration the second highest in Europe after Sweden for GSHP-installations.

As he Swedish examples shows, described in the chapter: "Description of a mature GSHP market, the Swedish example" GSHP solutions is meeting the stiffest competition from other Heat Pump solutions on the villa market, especially in he smaller segment. And those solutions are also fossil free and are relatively cheap to install thus being a natural choice for many villa owners. From a societal aspect the most desirable HP solutions should be those with ground source since they use less electricity per unit of heat produced. That is especially significant on peak cold days when the demand on the electric grid is the highest.

When it comes to large buildings in Urban areas the stiffest competition in Sweden comes from District Heating which is very well developed in Sweden, with a network in practically every towns over a certain size. All in all 580 of them in 290 kommuner, the smallest regulatory entity in Sweden, usually with one major town and a number of smaller.

However District heating in Sweden only delivers heat and most and the demand for cooling is growing even in Sweden with moderately warm summers, especially in the segments of office buildings, hospitals and schools. Since a GSHP solution also can deliver "free cooling" most of the time the GSHP comes out as a winner in a LCC calculation since there is virtually no fuel cost for an additional cooling solution. Air based Heat Pumps are usually not used for larger buildings.

It is also a fact that the District Heating solutions usually are not free of CO2 emission, the average in Sweden being around 50 g/kWh. So even there the GSHP comes out as a winner.

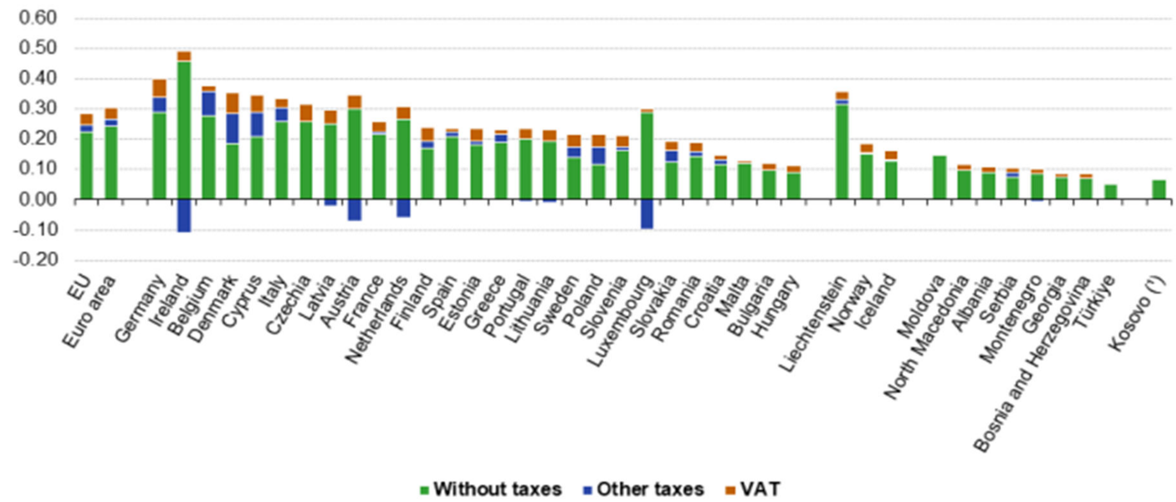
The most common heating solution in EU is gasboilers. Natural gas is relatively cheap and so is the boiler. But natural gas has a high CO2 content, some 470 g/kWh, admittedly much lower than for coal or oil but still significant and need to be phased out if the goal of zero emission for the real estate sector to 2050 is to be met.

From a LCC perspective, economic perspective, the calculations show that the price of electricity per kWh needs to be not to high compared to price for natural gas per kWh in order for the Opex to be so much lower for GSHP in order to compensate for the higher Capex. It is demonstrated in the chapter "Some calculation examples".

One way is of course carbon tax to increase the cost of using natural gas. It can be done through carbon tax. The carbon tax varies a lot in EU with Sweden having the highest with 115 EUR per ton and Estonia the lowest with 2 EUR per ton of carbon emitted. https://taxfoundation.org/data/all/eu/carbon-taxes-in-europe-2023/

But there is also an obvious need for the electricity price to be reasonable low if GSHP is to take of. Below is a chart of current electricity prices in Europe.

Electricity prices for household consumers, second half 2023
(€ per kWh)

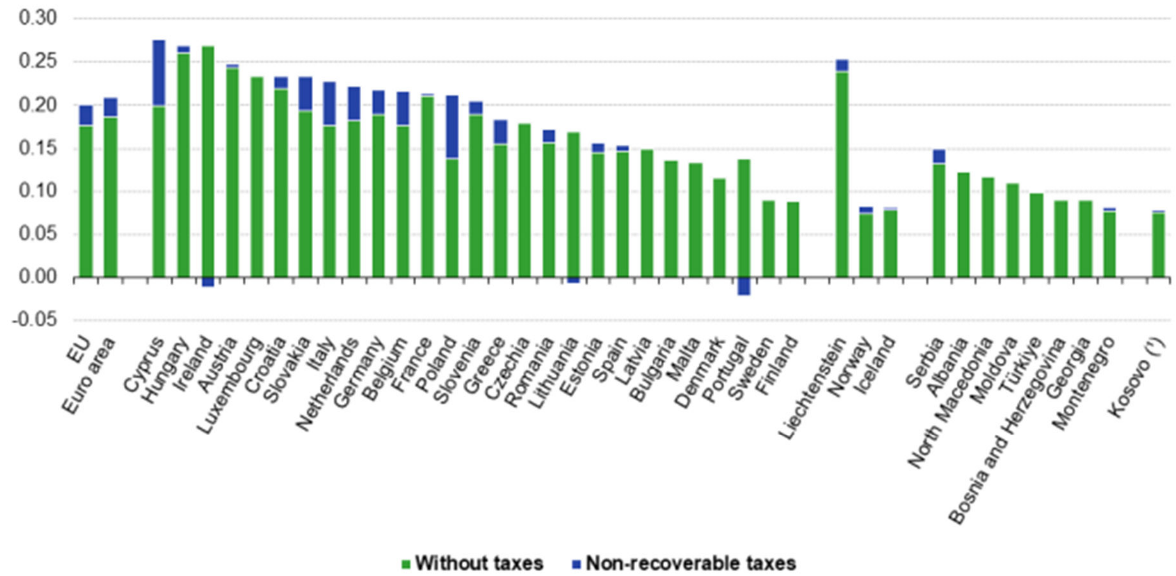


(¹) This designation is without prejudice to positions on status, and is in line with UNSCR 1244/1999 and the ICJ Opinion on the Kosovo Declaration of Independence.
Source: Eurostat (online data codes: nrg_pc_204)

eurostat

From https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Electricity_price_statistics

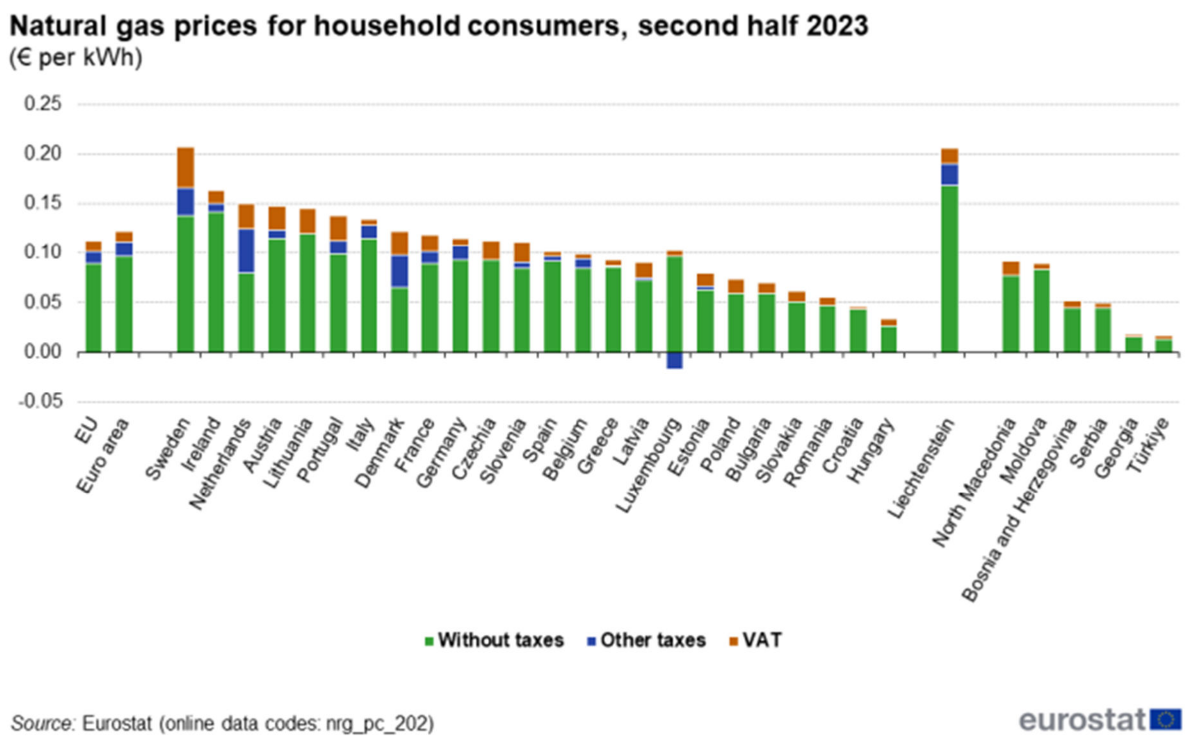
Electricity prices for non-household consumers, second half 2023
(€ per kWh)



(¹) This designation is without prejudice to positions on status, and is in line with UNSCR 1244/1999 and the ICJ Opinion on the Kosovo Declaration of Independence.
Source: Eurostat (online data codes: nrg_pc_205)

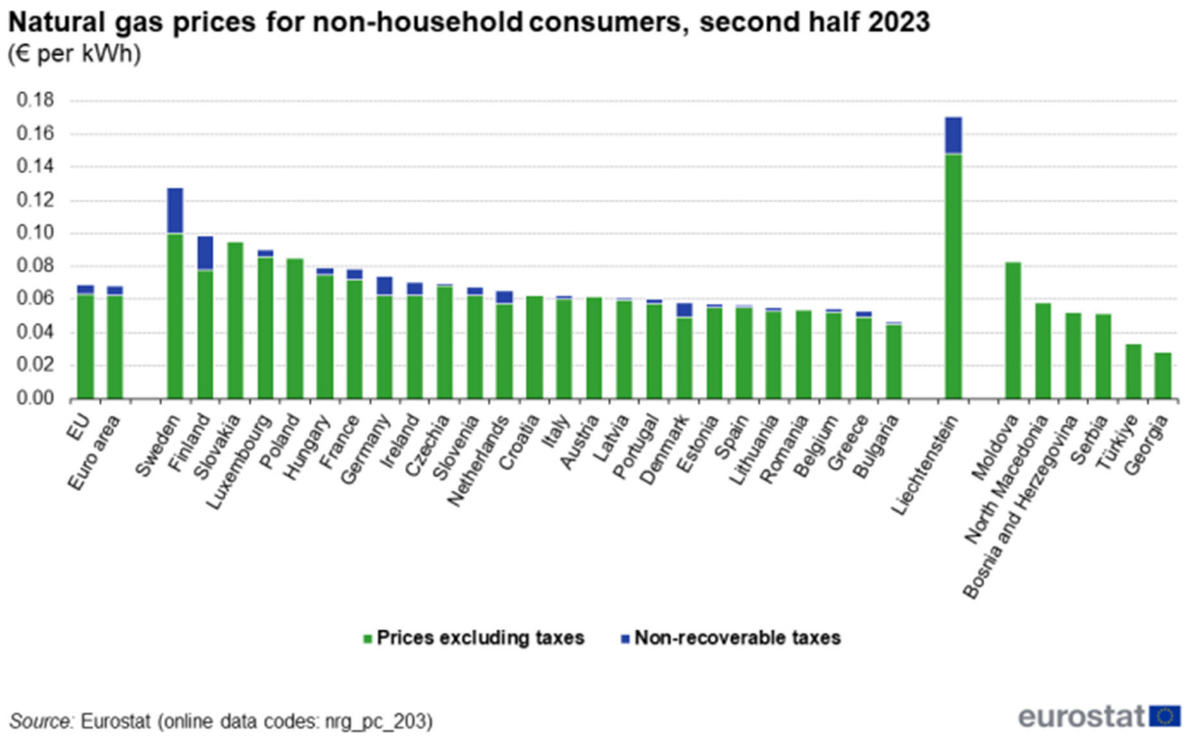
eurostat

From From https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Electricity_price_statistics#Electricity_prices_for_non-household_consumers



From https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Natural_gas_price_statistics#Natural_gas_prices_for_household_consumers

Gas prices for non-households.



From https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Natural_gas_price_statistics#Natural_gas_prices_for_non-household_consumers

These are the average prices for electricity and natural gas for households and non-housholds:

Average electricity price for households in EU is 0,2847 EUR/kWh and the average gas price is 0,1125 EUR/kWh. The ratio is 2,53.

Average electricity price for non-housholds in EU is 0,1771 EUR/kWh and the average gas price is 0,0689 EUR/kWh. The ratio is 2,57.

The ratio between electricity and gas prices should be below 3 in order for the Opex of gasboiler solutions to be "eaten up" by GSHP solutions. Also the drilling cost and the financial cost of Capex needs to be reasonable.

When it comes to comparisons between GSHP solutions and other Heat Pump solutions a higher electricity price is advantageous for the GSHP since they consume less electricity due to higher COP (efficiency). The CAPEX is obviously much higher for the GSHP solution but over a reasonable calculation time like 20-25 years the value of boreholes and outdoor piping is not depreciated much, if anything at all. An LCC will thus show that the cost is lower for the

GSHP solution compared to other Heat Pump solutions. Again, provided a reasonable drilling cost and financial cost for the Capex.

Conclusion. From a societal standpoint a GSHP solution is the best heating and cooling solution since it is emission free (with certified electricity) and less power consuming than other HP solutions.

For households and businesses an LCC can demonstrate that GSHP over time is the most economical solution in spite of its high Capex. As always provided the drilling cost and financial cost of the Capex are reasonable.

References

ICMS. 2021. Global Consistency in Presenting Construction Life Cycle Costs and Carbon Emissions. 3rd edition, November 2021. International Cost Management Standard | International standards and data for a global construction industry (icms-coalition.org)

RICS. 2016. Life cycle costing, 1st edition, April 2016. Lifecycle Costing, 1st edition (rics.org)

Appendix: Printout of LCC Excel tool

LCC Inputs

Country	Sweden

System Size Parameters			Override:	
Heating				
Installed Capacity	15	kW		
Heating Delivered SH	56,5	MWh/yr		MWh/yr
DHW	14,5	MWh/yr		MWh/yr
Supply Temperature of heating system	35	°C		
Cooling				
Peak Demand	8,8	kW		
Cooling Delivered	3	MWh/yr		MWh/yr

Standard LCC Parameters			Override:	
Period of analysis	25	Years		
Inflation (e)	2	%		
Discount (i)	5,5	%		
Real discount rate (r)	3,43	%	3,50	%
WACC Calculator				
Portion of Equity (Pe)	50	%		
Portion of Debt (Pd)	50	%		
Total Cost of Debt (Rd)	4	%		
Tax rate (Td)	25	%		
Total Cost of Equity (Re)	5,5	%		
WACC (r)	4,25	%		

Fuel Costs			Override:	
Electricity	0,18	EUR/kWh		EUR/kWh
District Heating	0,102	EUR/kWh		EUR/kWh
Pellets	0,106	EUR/kWh		EUR/kWh
Natural Gas	0,2	EUR/kWh		EUR/kWh
Coal		EUR/kWh		EUR/kWh
Other		EUR/kWh		

GSHP-Specific Parameters			Override:	
Physical Life Heat Pump:	20	Years		
Physical Life Boreholes:	100	Years		
CAPEX				
Borehole field				
Thermal Conductivity (Lambda):	3	W/(mK)		
Total Drilling Depth:	680	m		
Drilling Cost:	32	EUR/m		
Drilling Cost:	21760	EUR		
Digging/Horisontal piping:	6963	EUR		
Other:		EUR		
Total Cost:	28723	EUR		EUR
Building/Utility Room				
Heat Pump:	900	EUR/kW		
Heat Pump:	13500	EUR		EUR
Heat Pump Installation:	870	EUR		EUR
Passive Cooling:	2600	EUR		EUR
Active Cooling:		EUR		EUR
Total Cost:	16970	EUR		EUR
OPEX				
SCOP SH:	4,9	-		-
SCOP DHW:	3	-		-
SEER:	20	-		
Regular Service/Maintenence:	220	EUR/yr		EUR/yr
Interval of major repairs:	0	Years		
Average cost major repair:	0	EUR		
Decomissioning/Renewal				
Decomissioning HP:	870	EUR		EUR
Renewal				
Borehole field renewal:		EUR		
Heat Pump:	13500	EUR		EUR
Installation:	870	EUR		EUR

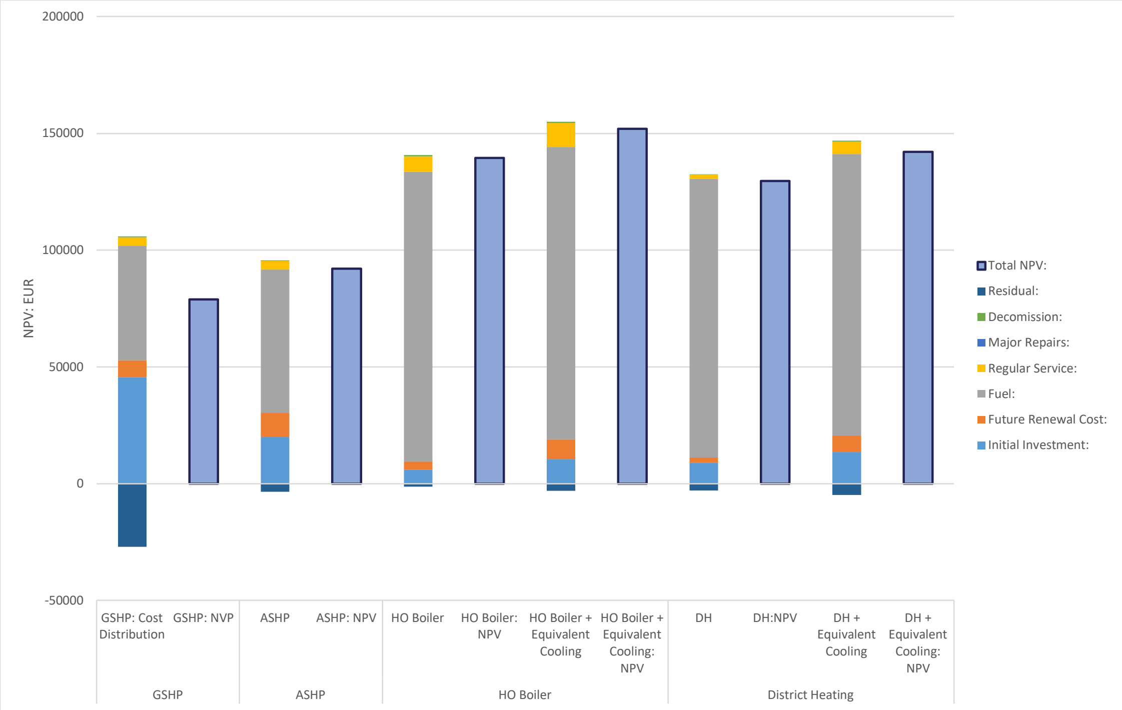
Air Source Heat Pump Solution			Override:	
Physical Life Heat Pump:	15	Years		
CAPEX				
Heat Pump:	1100	EUR/kW		
Heat Pump:	16500	EUR		EUR
Heat Pump Installation:	870	EUR		EUR
Active Cooling:	2600	EUR		EUR
Total Cost:	19970	EUR		EUR
OPEX				
SCOP SH:	3,8	-		-
SCOP DHW:	2,7	-		-
SEER:	6,2	-		-
Regular Service/Maintenence:	220	EUR/yr		EUR/yr
Interval of major repairs:	0	Years		
Average cost major repair:	0	EUR		
Decomissioning/Renewal				
Decomissioning:	435	EUR		EUR
Renewal				
Installation:	870	EUR		EUR
Heat Pump:	16500	EUR		EUR

District Heating Solution			Override:	
Physical Life Heat Exchanger:	20	Years		
CAPEX				
Heat exchanger/Central:	261	EUR/kW		
Heat exchanger/Central:	3915	EUR		EUR
Connection to network:	313,2	EUR/kW		
Connection to network:	4698	EUR		EUR
Installation:	29	EUR/kW		
Installation:	435	EUR		EUR
Total Costs:	9048	EUR		EUR
OPEX				
DH Energy Cost	0,102	EUR/kWh		
Regular Service/Maintenence:	110	EUR/yr		EUR/yr
Interval of major repairs:	0	Years		
Average cost major repair:	0	EUR		
Decomissioning/Renewal				
Decomissioning:	435	EUR		EUR
Renewal				
Heat exchanger/Central:	3915	EUR		EUR
Installation:	435	EUR		EUR

HO Boiler solution			Override:	
Physical Life Boiler:	15	Years		
CAPEX				
Boiler:	330	EUR/kW		
Boiler:	4950	EUR		EUR
Installation:	1090	EUR		EUR
Total Costs:	6040	EUR		EUR
OPEX				
Boiler efficiency	0,95	-		
Fuel Cost	0,106	EUR/kWh		
Regular Service/Maintenence:	400	EUR/yr		EUR/yr
Interval of major repairs:	0	Years		
Average cost major repair:	0	EUR		
Decomissioning/Renewal				
Decomissioning:	1090	EUR		EUR
Renewal				
Installation:	1090	EUR		EUR
Boiler	4950	EUR		EUR

Complementary Cooling Solution			Override:	
Physical Life:	12	Years		
CAPEX				
Cooling components cost:	4000	EUR		EUR
Installation:	500	EUR		EUR
Total Costs:	4500	EUR		EUR
OPEX				
Fuel Cost	0,18	EUR/kWh		
SEER	8	-		
Regular Service/Maintenence:	220	EUR/yr		EUR/yr
Interval of major repairs:	0	Years		
Average cost major repair:	0	EUR		
Decomissioning/Renewal				
Decomissioning:	250	EUR		EUR
Renewal				
Installation:	500	EUR		EUR
Cooling components cost:	4000	EUR		EUR

Preview of result

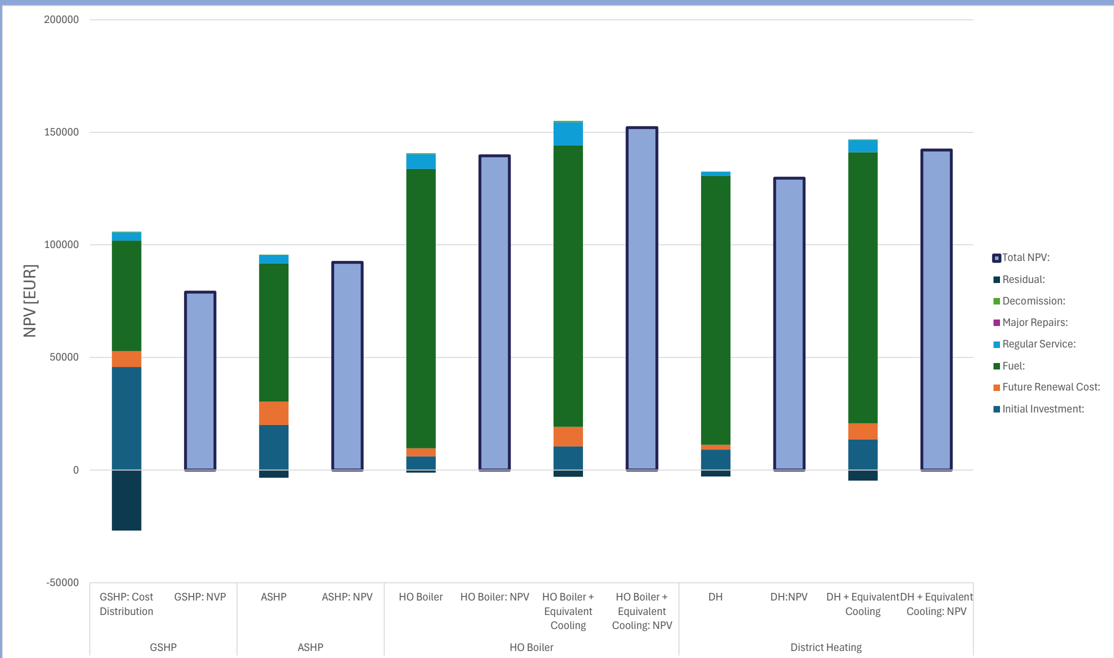


For further details go to Results sheet.

Cost Distribution in EUR

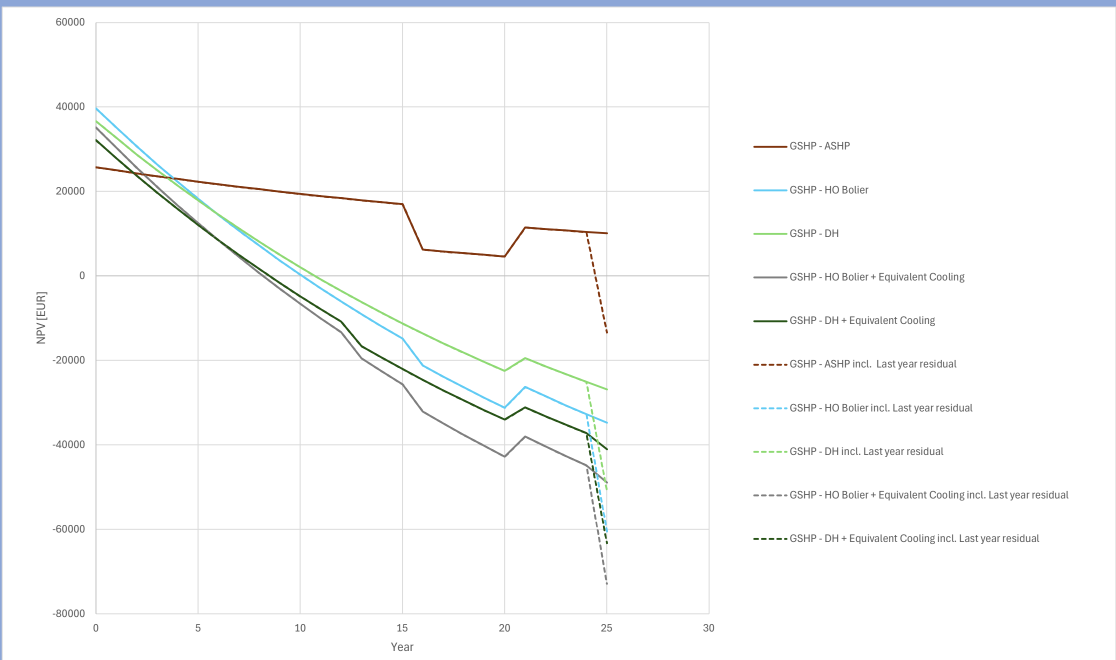
Period of analysis: 25 Years

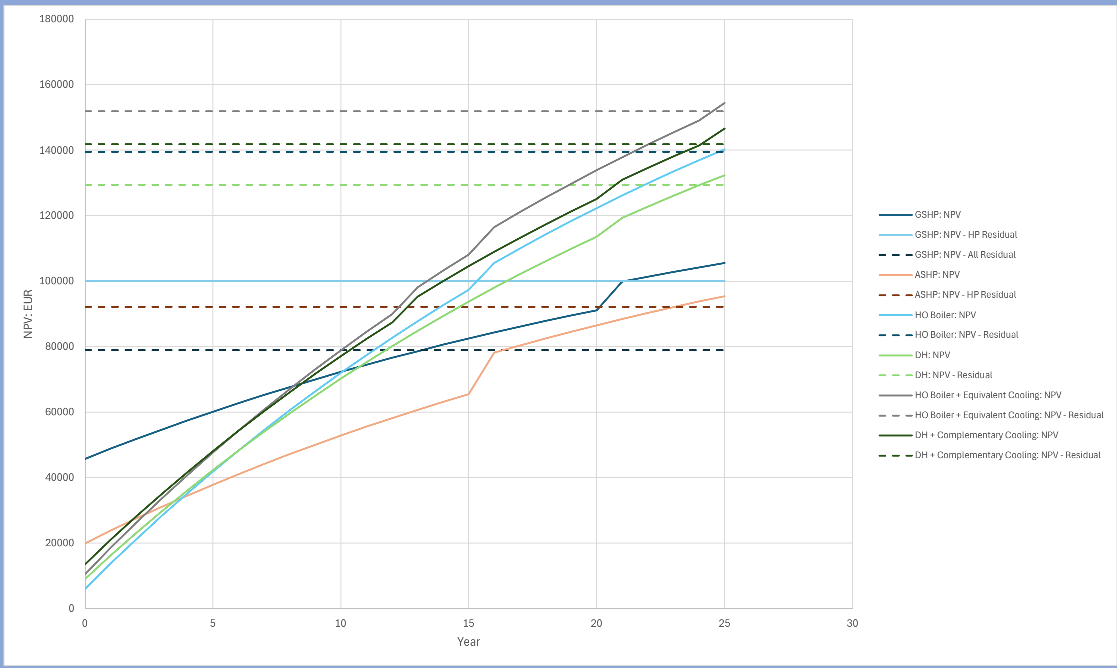
	GSHP	ASHP	HO Boiler	District Heating	HO Boiler + Equivalent Cooling	District Heating + Equivalent Cooling
Initial Investment:	45693	19970	6040	9048	10540	13548
Future Renewal Cost:	7222	10368	3605	2186	8554	7135
Fuel:	48991	61477	124040	119359	125152	120472
Regular Service:	3626	3626	6593	1813	10219	5439
Major Repairs:	0	0	0	0	0	0
Decomission:	368	184	461	184	567	290
Residual:	-26959	-3456	-1202	-2936	-3008	-4743
Total NPV:	**78942**	**92169**	**139537**	**129654**	**152024**	**142141**
LCOE [EUR/MWh]:	65	76	119	111	125	117



	ASHP	HO Boiler	DH	HO Boiler + Equivalent Cooling	DH + Equivalent Cooling
GSHP Paybacktime* [Years]:	38	10	10	8	8

*Without residual value





180000
160000
140000
120000
100000
80000
60000
40000
20000
0
NPV: EUR
0
5
10
15
20
25
30
Year
GSHP: NPV
GSHP: NPV - HP Residual
GSHP: NPV - All Residual
ASHP: NPV
ASHP: NPV - HP Residual
HO Boiler: NPV
HO Boiler: NPV - Residual
DH: NPV
DH: NPV - Residual
HO Boiler + Equivalent Cooling: NPV
HO Boiler + Equivalent Cooling: NPV - Residual
DH + Complementary Cooling: NPV
DH + Complementary Cooling: NPV - Residual

LCC with the Internaltional Cost Measurement Standard (ICMS) Adjusted for GSHP systems			
LEVEL 1: Projects or Sub-Projects.			
Code			
08.	Pipelines		
09.	Wells and boreholes		
LEVEL 2: Categories - ACROME			
	Code	Acronyme	Name
	1.	AC	Acquisition Cost [Part of Non-Construction Costs]
	2.	CC	Construction Cost
	3.	RC	Renewal Cost
	4.	OC	Operation Cost
	5.	MC	Maintenance Costs
	6.	EC	End of Life Costs
LEVEL 3: Groups			
	1.	AC	Acquisition Cost [Part of Non-Construction Costs]
		02.	Administrative, finance, legal and marketing expenses
		02.010	Client's preliminary investigations/Feasibility studies - client's in-house project management and design team - Energy demand estimation/simulation - Consultant fees - Conceptual design/ description of design criteria of utility room components - Conceptual design/ description of design criteria of borehole field
		02.020	General project planning
		02.030	Required Documents and descriptions
		02.040	Accommodation and travelling expenses for in-house team and external parties
		02.050	Interest and finance cost
		02.060	Tendering process
		02.070	Taxes and statutory charges
		02.080	License and permit charges
		02.090	Preliminary dimensioning and design of borehole field
	2.	CC	Construction Costs
Adjusted list from Appendix C. Table C-1: Construction | Renewal | Maintenance Sub-Groups: Civil Engineering Works			
		01.	Demolition, site preparation and formation
		01.010	Site survey and ground investigation
		01.020	Test hole drilling
		01.030	Field measurements and analysis
		01.040	Dimensioning and design of borehole field
		02.	Substructure
08.		02.010	Excavation and trenching: - Excavation - Asphalt removal - Rock removal/blasting - Removal of paving/temporary storage - Top-soil removal - Trenching - Backfilling - Beds and surrounds to underground pipes - Backfilling - Restoration to original condition
09.		02.020	Boreholes: - Drilling from surface to bedrock - Casing and casting - Bedrock drilling - Grouting - Removal of drill cuttings - Treatment of drilling water
09.		02.030	Energy wells - Collector - Collector installation

	- Protective well caps - Brine (for energy wells and horizontal piping)
03.	Structure
03.010	Civil pipeworks (horizontal pipes)
03.020	Manifolds, valves and fittings (inside and outside of utility room)
03.030	Seperate substation / utility room structure
04.	Non-structural works
04.010	Refurbishment of heating system
04.020	Refurbishment of ventilation system
04.030	Signage, markings and the like
05.	Services and equipment
05.010	Heat pump
05.020	Other utility room components related to heat and DHW production: - Accumulator tanks - External circulation pumps - Control systems and instruments - Signaling system - Telecommunications systems - Other storage vessels, knobs, bults, pipes and so on and so forth
05.030	Other utility room components related to passsive/active cooling - Heat exchangers, fans and so on and so forth
05.040	Installations and work done related to HVAC-system
08.	Preliminaries | Constructors' site overheads | general requirements
08.010	Construction management including site management staff and support labour
08.020	Temporary access roads and storage areas, traffic management and diversion (at the constructors discretion)
08.030	Temporary site fencing and securities
08.040	Workpeople living accommodation
08.050	Other temporary facilities and services
08.060	Technology and communications: telephone, broadband, hardware, software
08.070	Constructor's submissions, reports and as-built documentation
08.080	Quality monitoring, recording and inspections
08.090	Safety, health and environmental management
08.100	Insurances, bonds, guarantees and warranties
08.110	Constructor's statutory fees and charges
08.120	Testing and commissioning
08.130	Extras for extreme climatic or working conditions (if priced seperately according to local pricing practice)
09.	Risk Allowances
09.010	Design development allowance
09.020	Construction contingencies
09.030	Price level adjustment until tendering
09.040	Exchange rate fluctuation adjustments
10.	Taxes and Levies
10.010	Paid by the constructors
10.020	Paid by the Client in relation to construction payments
11.	Work and utilities off-site (including related risk allowances, taxes and levies)
11.010	Diversion of and capacity enhancement of public utility mains or sources off-site up to mains connections on-site: - Electricity
12.	Production and loose furniture, fittings and equipment (including related risk allowances, taxes and levies)
12.010	Drilling equipment (Drilling rig, Compressor, Hammers, part of contractor's operational costs)
12.020	Trucks and other logistics vehicles (part of contractors operating costs)
13.	Construction-related consultants and supervision (including related risk allowances, taxes and levies)

	13.010	Consultants' fees and reimbursable: - Civil Engineers - Electrical Engineers - Plumbing, Heating, Water and sanitation - Project managers - Surveyors - Specialist consultants
	13.020	Charges and levies payable to statutory bodies or their appointed agencies (in connection with planning, design, tender and contract approvals, supervision and acceptance inspections)
	13.030	Site supervision charges (including their accommodation and travels)
	13.040	Payments to testing authorities or laboratories
3.	RC	Renewal Cost
Adjusted list from Appendix C. Table C-1: Construction | Renewal | Maintenance Sub-Groups: Civil Engineering Works		
	01.	Demolition, site preparation and formation
	01.010	Site survey and ground investigation
	01.020	Test hole drilling
	01.030	Field measurements and analysis
	01.040	Dimensioning and design of borehole field
	02.	Substructure
08.	02.010	Excavation and trenching: - Excavation - Asphalt removal - Rock removal/blasting - Removal of paving/temporary storage - Top-soil removal - Trenching - Backfilling - Beds and surrounds to underground pipes - Backfilling - Restoration to original condition
09.	02.020	Boreholes: - Drilling from surface to bedrock - Casing and casting - Bedrock drilling - Grouting - Removal of drill cuttings - Treatment of drilling water *
09.	02.030	Energy wells - Collector - Collector installation - Protective well caps - Brine (for energy wells and horizontal piping)
	03.	Structure
	03.010	Civil pipeworks (horizontal pipes)
	03.020	Manifolds, valves and fittings (inside and outside of utility room)
	03.030	Seperate substation / utility room structure
	04.	Non-structural works
	04.010	Refurbishment of heating system
	04.020	Refurbishment of ventilation system
	04.030	Signage, markings and the like
	05.	Services and equipment
	05.010	Heat pump
	05.020	Other utility room components related to heat and DHW production: - Accumulator tanks - External circulation pumps - Control systems and instruments - Signaling system - Telecommunications systems

		- Other storage vessels, knobs, bults, pipes and so on and so forth
	05.030	Other utility room components related to passsive/active cooling - Heat exchangers, fans and so on and so forth
	05.040	Installations and work done related to HVAC-system
	08.	Preliminaries | Constructors’ site overheads | general requirements
	08.010	Construction management including site management staff and support labour
	08.020	Temporary access roads and storage areas, traffic management and diversion (at the constructors discretion)
	08.030	Temporary site fencing and securities
	08.040	Workpeople living accommodation
	08.050	Other temporary facilities and services
	08.060	Technology and communications: telephone, broadband, hardware, software
	08.070	Constructor's submissions, reports and as-built documentation
	08.080	Quality monitoring, recording and inspections
	08.090	Safety, health and environmental management
	08.100	Insurances, bonds, guarantees and warranties
	08.110	Constructor's statutory fees and charges
	08.120	Testing and commissioning
	08.130	Extras for extreme climatic or working conditions (if priced seperately according to local pricing practice)
	09.	Risk Allowances
	09.010	Design development allowance
	09.020	Construction contingencies
	09.030	Price level adjustment until tendering
	09.040	Exchange rate fluctuation adjustments
	10.	Taxes and Levies
	10.010	Paid by the constructors
	10.020	Paid by the Client in relation to construction payments
	11.	Work and utilities off-site (including related risk allowances, taxes and levies)
	11.010	Diversion of and capacity enhancement of public utility mains or sources off-site up to mains connections on-site: - Electricity
	12.	Production and loose furniture, fittings and equipment (including related risk allowances, taxes and levies)
	12.010	Drilling equipment (Drilling rig, Compressor, Hammers ... part of contractor's operational costs?)
	12.020	Trucks and other logistics vehicles (part of contractors operating costs?)
	13.	Construction-related consultants and supervision (including related risk allowances, taxes and levies)
	13.010	Consultants' fees and reimbursable: - Civil Engineers - Electrical Engineers - Plumbing, Heating, Water and sanitation - Project managers - Surveyors - Specialist consultants
	13.020	Charges and levies payable to statutory bodies or their appointed agencies (in connection with planning, design, tender and contract approvals, supervision and acceptance inspections)
	13.030	Site supervision charges (including their accommodation and travels)
	13.040	Payments to testing authorities or laboratories
4.	OC	Operations Costs (OC)
	02.	Utilities
	02.010	Fuel: - Electricity
	04.	Security
	04.010	Physical security and routine checks

	04.020	Remote monitoring
	05.	Information and communications technology
	05.010	Communication system / internet for remote monitoring
	06.	Operators' site overheads | general requirements
	06.010	Administration
	06.020	Insurance
	07.	Risk Allowances
	07.010	Operation related
	08.	Taxes and Levies
	08.010	Taxes
	08.020	Levies
5.	MC	Maintenance Costs
	05.	Services and equipment
	05.010	Routine check and controll - check and adjust brine levels - inspect ground loops for leaks - clean or replace air filters - check and tighten electrical connections - inspect and lubricate moving componens such as fans, bearings and the like - test the thermostat calibration and accuracy - verify that safety monotoring systems are functioning - inspect piping for leaks, corrosion or insulation damage
	05.020	Major repairs not covered by insurance
6.	EC	End of Life Costs
	01.	Disposal inspection
	01.010	Indoor inspection and overwiev
	01.020	Outdoor inspection and overwiev
	02.	Decommisioning and decontamination
	02.010	Shutdowns and decommissioning
	02.020	Decontamination
	03.	Demolition, reclamation and salvage
	03.010	Demolition
	03.020	Reclamation
	03.030	Salvage
	06.	Risk Allowances
	06.010	End of life specific
	06.020	Abnormal risks
	07.	Taxes and Levies
	07.010	Taxes
	07.020	Levies
	07.030	Credit for grants

Introduction

LCC_tool v5.2

This tool for calculating life cycle cost (LCC) was developed as part of Deliverable
more detailed information, please refer to the D4.1 deliverable report.

The tool has been developed to evaluate the total cost of ownership for differen
throughout their entire life cycle. It is primarily designed to assess ground sourc
includes other types of heating and cooling solutions.

The tool calculates:

- **Net Present Value (NPV)** - the total discounted cost over time.
- **Levelized Cost of Energy (LCOE)** - the average cost per unit of energ

These metrics help users understand both the upfront and long-term economic
cooling solutions.

Cost categories Included

- AC (Acquisition Costs): Pre-studies, design work
- CC (Construction Costs): Installation, borehole field, heat pump etc.
- RC (Renewal Costs): Component replacements during the analysis per
- OC (Operation Costs): Cost of fuel/electricity
- MC (Maintenance Costs): Service and repairs
- EC (End-of-Life Costs): Decommissioning
- Residual Value: Remaining value of components at the end of the peri

Technology Comparison

The tool enables side-by-side analysis of:

- Ground source heat pumps (GSHP)
- Air source heat pumps (ASHP)
- Heat-only boilers
- District heating
- Complementary cooling systems (optional)

The tool covers relevant cost categories, including investment, operation, mainte
and residual value for each technology.

Adaptability & Sensitivity Analysis

Users can modify key parameters such as:

- System size and energy demand
- Climate presets (based on country)
- Discount rate and analysis period
- Lifespan and performance of components
- Fuel prices and installation costs

This flexibility allows sensitivity analyses to evaluate how changes in assumption
the tool suitable for both preliminary assessments and more detailed feasibility s

While tailored for residential buildings, the tool can be adapted for other types o

Results & Visualization

The tool presents results in both table and graphical formats:

- Cost breakdowns for each technology
- NPV progression over time
- Cash-flow comparisons between GSHP and alternatives
- Payback time estimation, comparing GSHP to alternatives

These visulizations help users interpret the results.

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D4.1 of the GeoBOOST project. For

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