> Deliverable 16

Comparison of PT and EE with DE, FR and SE

➢ Report on the comparison of results obtained in Estonia and Portugal versus France, Germany and Sweden

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1. Introduction

The task of this report is to compare the results obtained under different conditions for

- climatic situation
- geology
- market environment.

While in France, Germany and Sweden some real installations have been investigated more closely, and the geothermal alternatives studied, the transfer of geothermal technology to Portugal and Estonia was done by theoretical considerations with the intention to check the applicability of the proposed solutions in the respective economic and climatic environment.

2. Comparison of general background

2.1 Climate

One aim of the project was to investigate geothermal solutions in different climatic conditions prevalent in Europe. The five countries concerned in the project cover everything from warm, Mediterranean climate (Portugal and Southern France) to very cold, Nordic climate (Estonia and Northern Sweden). Within some countries, both warm and moderate / cold and moderate can be found; the table below gives the key temperature data for some representative cities. Fig. 1 gives an impression of the distribution in Portugal and Sweden.

Table of temperatures average below 6 °C average above 14 °C

Country	City	average	Winter (Jan)	Summer (Jul)
Estonia	Tallinn	5.1 °C	-5.2 °C	16.3 °C
	Tartu	4.8 °C	-7.1 °C	16.5 °C
France	Brest	10.9 °C	6.3 °C	16.3 °C
	Paris	10.8 °C	3.5 °C	18.4 °C
	Belfort	9.2 °C	0.3 °C	17.9 °C
	Marseille	14.8 °C	6.7 °C	23.8 °C
Germany	Hamburg	9.0 °C	1.3 °C	17.4 °C
	Frankfurt/Main	10.1 °C	1.6 °C	19.4 °C
	Freiburg	11.1 °C	2.4 °C	20.3 °C
	Villingen (Black Forest)	7.0 °C	-1.7 °C	26.3 °C
Portugal	Braganca	12.2 °C	4.5 °C	21.1 °C
	Lisbon	17.1 °C	11.1 °C	23.8 °C
Sweden	Malmö	8.8 °C	0.5 °C	17.2 °C
	Stockholm	6.6 °C	-3,0 °C	17.0 °C
	Sundsvall	3.2 °C	-9.0 °C	15.3 °C
	Luleå	1.2 °C	-12.1 °C	15.5 °C

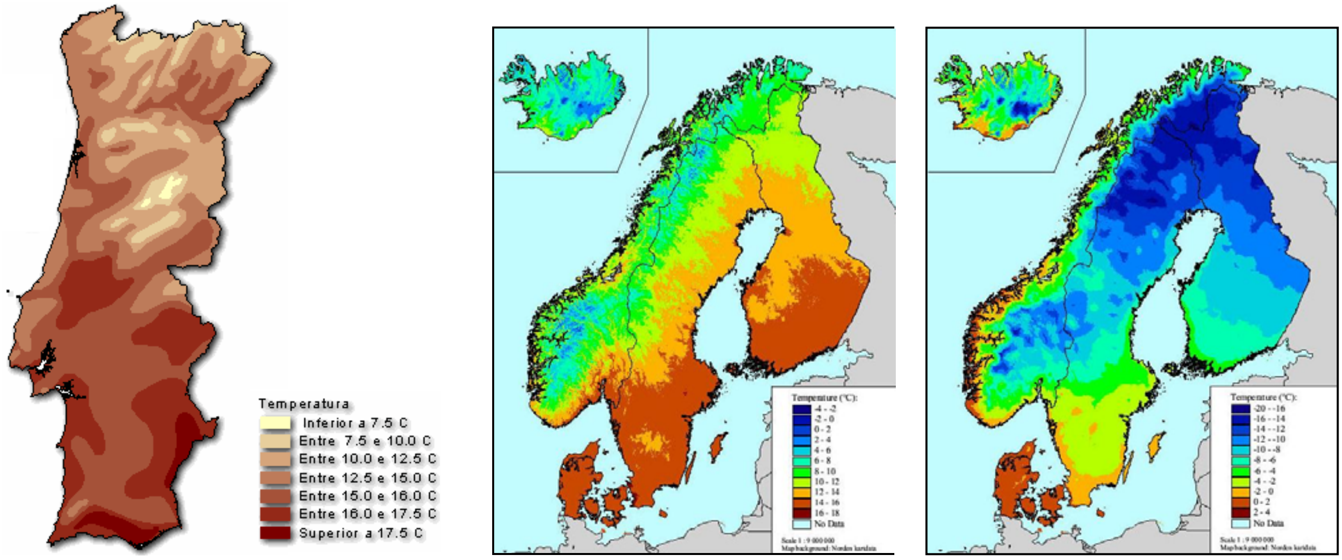

Figure 1: left: Average temperature in Portugal (continental) (Source: Instituto do Ambiente)
centre and right: Average temperature in Scandinavia in summer and winter

2.2 Geology

The geologic situation in the 5 countries is rather divers. While France, Germany and Portugal exhibit a variety of different rock types from every age (from old, metamorphic rocks to younger sediments), the situation in Sweden and Estonia is more uniform. In Sweden, most of the country consists of old, crystalline bedrock, mainly covered by glacial deposits (overburden); only the southernmost region of Scania is different, with younger sediments (typically Cretaceous limestones and marls). In Estonia, old (Paleozoic) sedimentary layers cover most of the country. This situation is also reflected in the geothermal heat flow, with low values in the Scandinavian-Baltic shield (Estonia and Sweden) and a mixture of average values in France, Germany and Portugal (Fig. 2). None of the countries comprises high heat flow areas (in Portugal, those are found on the Azores only).

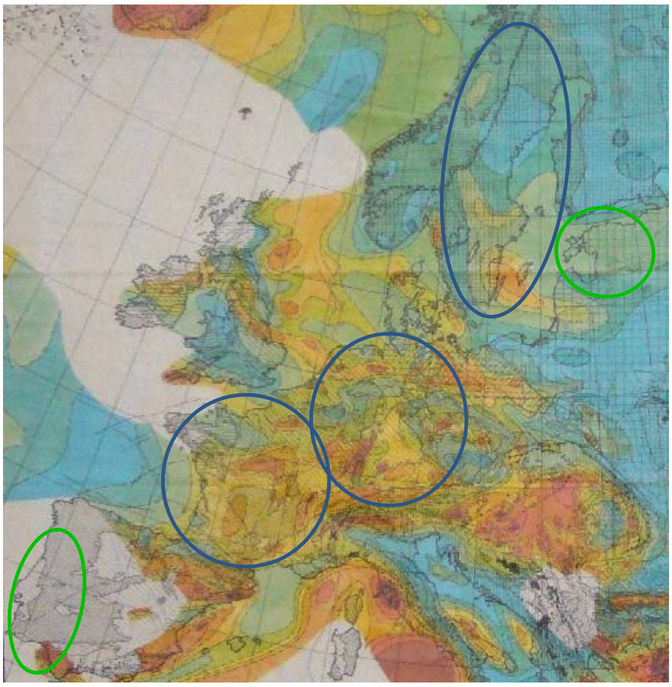

Figure 2: Geothermal heat flow in Europe (map from Cermak & Hurtig, 1978)

The geological situation controls the geothermal possibilities in two ways:

- The prevailing rock types have an impact on the type of ground coupling (open systems, BHE) and on the drilling techniques
- The geothermal heat flux controls the temperature increase towards depth

As a consequence, borehole heat exchangers (BHE) are the most common method of ground coupling in Sweden, typically with a rather unique open-hole-completion not used outside Scandinavia. For environmental reasons (groundwater protection), BHE have to be grouted in the rest of Europe, i.e. the borehole annulus around the BHE pipes has to be filled with a sealing material. In France and Germany, there are regions better suited for groundwater use (open systems) and others that are only suited for BHE (closed systems).

2.3 Cost

The investment cost for geothermal systems is controlled by the geology (drilling and completion) and by the economic situation of the countries (wages). The specific drilling and completion technique for BHE in Sweden allows for low cost for BHE, while the low cost in Estonia may be due to the low wages. The table below gives some specific values for groundwater wells, BHE and heat pumps.

Table of investment cost

Country	Cost of wells	Cost of BHE	Cost of heat pump
Estonia	no data	no data	400-500 €/kW_{heat}
France	400-500 €/m	Ca. 70 €/m	400 €/kW_{heat}
Germany	80-300 €/m	50-70 €/m	400 €/kW_{heat}
Portugal	no data	35 €/m	no data
Sweden	100-300 €/m	30 €/m	300-600 €/kW_{heat}

Also the energy cost vary widely throughout the countries investigated, with the lowest values in Estonia and the highest in Germany, and for fuel oil in Sweden, respectively. The table below gives the details.

Table of energy cost (highest red, lowest green)

Country	Electricity	Natural Gas	Fuel Oil
Estonia	65 €/MWh	25 €/MWh	50 €/MWh
France	70 €/MWh	40 €/MWh	50 €/MWh
Germany	100 €/MWh	70 €/MWh	70 €/MWh
Portugal	85 €/MWh	40 €/MWh	no data
Sweden	90 €/MWh	no data	120 €/MWh

2.4 Emissions

The reduction of emissions of greenhouse gases are a key reason for the use of renewable energies, and geothermal energy is no exception. As emission reductions have to be calculated against competing, conventional systems, the specific emissions of different energy sources have to be known (see table below). While obviously the factors for natural gas and fuel oil are quite similar, CO_2-emissions from electric power generation vary widely, according to the production mix (high share of hydropower in Sweden, mainly fossil fuel fired power plants in Estonia.

Table of CO_2-factors

Country	Electricity	Natural Gas	Fuel Oil
Estonia	ca. 1200 g/kWh	240 g/kWh	270 g/kWh
France	40-180 g/kWh	206 g/kWh	270 g/kWh
Germany	617 g/kWh	202 g/kWh	266 g/kWh
Portugal	348 g/kWh	103 g/kWh	103 g/kWh
Sweden	20 g/kWh	ca. 200 g/kWh	270 g/kWh

3. Examples of technical solutions

The basic idea was to repeat the detailed design studies done in France, Germany and Sweden in a more general way under the climatic and economic conditions of the two target countries Estonia and Portugal. In that framework, Estonia should serve as example for a more Northern climate within the EU new member states, while Portugal is deemed the example for Southern/Mediterranean Europe.

During the actual working on the studies, some more options evolved in the two target countries, and allowed to diversify the scope of applications. At the end, the applications as stated in the table below have been considered:

Table of technical applications investigated

Application	country of original study	target country/countries
Supermarkets	Germany	Estonia, Portugal
Shopping malls	France	Portugal
Industry (foundry)	Sweden	Estonia
Laboratories		Portugal
Swimming pool		Estonia, Portugal
Sports hall		Estonia
Culture House		Estonia
Greenhouse		Portugal

3.1 Supermarkets / Hypermarkets

The basic example here was investigated in Germany and is described in the relevant IGEIA publications D8 and D10 – Germany.

Beside space heating and cooling, the most important energy consumer in a supermarket is the cooling for food storage, consisting mainly of the following items:

- Cold for cold display cases in market area
- Cold for cold storage cells in storage area
- Cold at low temperature for deep freezers in market area
- Cold at low temperature for deep freezing storage in storage area

The heat and cold required for all of the thermal energy needs in the standardized supermarket is listed in the table below.

Table: Summary of thermal energy need of standardized supermarket, in arbitrary energy values EV for heating/cooling work (instead of kWh or MWh), and arbitrary power units PU for heating/cooling capacity (instead of kW)

	Annual work	Momentary output
Space heating requirement	14’690 EV per year	13.8 PU
Space cooling requirement	942 EV per year	6.9 PU
Food cooling, storage, freezing	73’370 EV per year	18.1 PU

The relevant heating and cooling loads now are transferred to the geothermal system, and the resulting energy flows are calculated. Table 2 lists the annual total, while fig. 5 shows the development over an average year. For space heating and cooling, both the actual demand (cf. tab. 1) and the part that has to be covered by the geothermal system are differentiated. Because heat pumps and chillers require some final energy input,

- the amount of heat from the ground is smaller in the heating mode (the additional energy becomes part of heating),
- and the amount of heat into the ground is larger in cooling mode (the additional energy becomes part of the waste heat to be rejected).

For the central refrigeration system, only the sum of waste heat from the condenser is shown, which keeps constant over the year. As with space cooling, the waste heat is larger than the cold demand. So the resulting energy flows from and towards earth are given below:

	Annual work
Heat from the earth (BHE), due to space heating	10’820 EV per year
Heat into the earth (BHE), due to space cooling	1’130 EV per year
Food cooling, storage, freezing condenser waste heat (into earth and air)	98’090 EV per year

The waste heat from the central refrigeration system (food cooling) exceeds by far the energy to be extracted from the ground for heating purposes. It is obvious that a certain balance of heat and cold towards the ground is impossible to achieve with rejecting 100 % of this waste heat. Thus a scenario is optimized to allow a safe operation over 25 years and beyond with maximum possible share from this waste heat, while the number and depth of BHE should be limited to an economically reasonable size. The waste heat from refrigeration still can be injected with the full thermal power over most of the time. For this scenario, the following BHE layout would be sufficient:

Number of BHE	16
Depth of each BHE	100 m
Pattern of BHE	2 parallel lines
Type of BHE	Double-U-tube

The heating and cooling load to be covered by that system would be:

Space Heating	14’690 EV (100 %)
Space Cooling	942 EV (100 %)
Waste heat from Refrigeration	30’500 EV (30 %)

The incremental construction cost over a conventional system has been estimated, as well as the possible energy savings due to the use of renewable energy and due to better system efficiency in the central refrigeration system when using geothermal cold for condenser re-cooling. The cost data are given in the table below, in arbitrary currency units (CU):

incremental investment cost	80’000 CU
annual operation cost savings	5’000 CU/year
simple payback time	16 years

The BHE system meanwhile has actually been built (fig. 3), in spite of the relatively long payback time, in order to verify these assumptions.

Figure 3: Drilling for a supermarket BHE project in Western Germany

Examples in Estonia and Portugal

Supermarket in Valga city, EE

Total heated space 4062 m²

Cooling and freezing load (electrical) 42 kW

Heat supply – from city DH system 250 MWh/y

Heat recovery from cooling and freezing systems through ventilation system

Geothermal system allows to store the excess heat during summer

Supermarket in Santa Maria da Feira, Aveiro, PT

Total heated space 8308 m²

Cooling load (thermal) 620 kW

Heating load (thermal) 256 MWh/y

Proposed geothermal system with 23 BHE at 150 m depth each

Cost for BHE at 35 €/m result in a total of 120'750 €

Economic Feasibility:

	Geothermal Energy option	Natural Gas Boiler and Chiller option	Annual saving
Heating costs (€/a)	3078	9415	6337
Cooling costs (€/a)	4873	6362	1489
BHE total costs (€)	120'750		
Payback (years)	15.5		

With 15.5 years of payback, this system might not be favourable for supermarkets that are based upon an economy looking at much shorter terms for profit.

3.2 Shopping Centres / Malls

The basic example here was investigated in France and is described in the relevant IGEIA publications D8 and D10 – France. The concrete example that was considered was a planned shopping mall "Au Carré d'Or", located in Perpignan. The following areas were desired (cf. fig. 4):

"world of dwelling" 25'000 m²

commercial area 20'000 m²

promenade area 3'000 m²

The climate in Perpignan is of mediterranean type, with hot summers and mild winters. The heating demand is much smaller than the cooling demand; nevertheless is a total installed heating and cooling capacity of >2 MW each necessary in order to cover the loads at all times; this capacity shall be distributed to 120 individual heat pumps. The summary of thermal energy need of the shopping mall is given below:

	Demand	Installed capacity
Space heating	366 kW	2848 kW
Space cooling	1492 kW	2213 kW

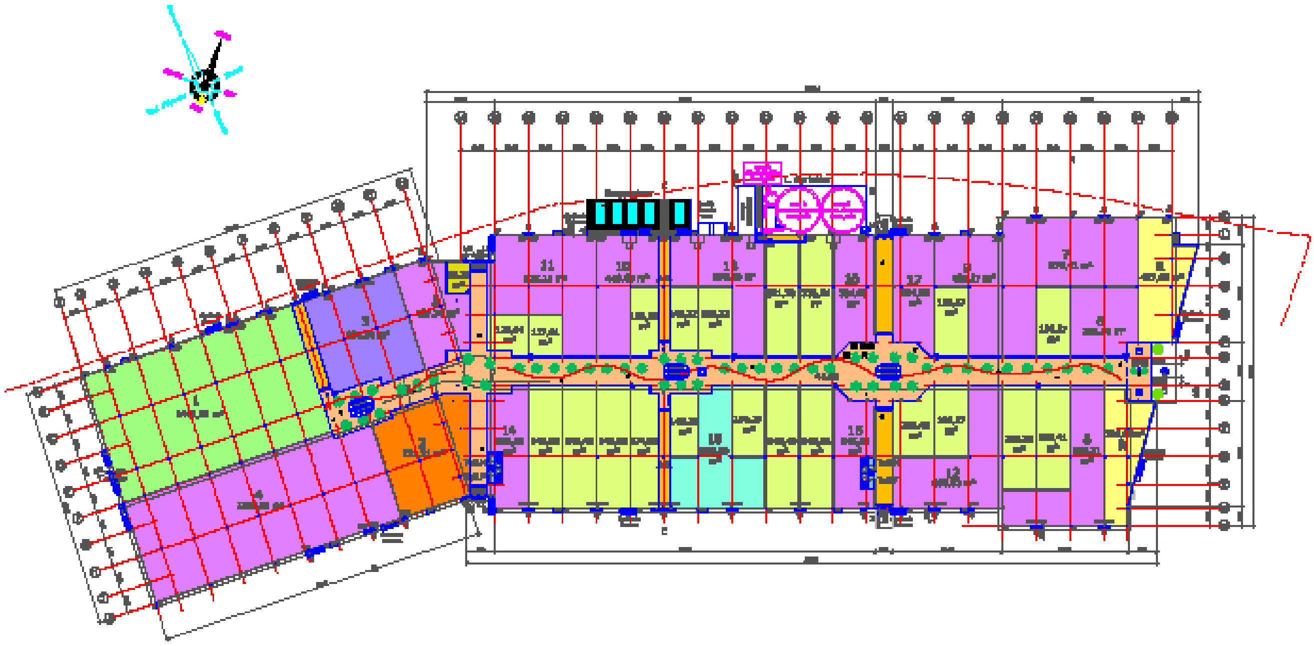

Fig. 4: Plan of the investigated shopping mall in Perpignan

The annual energy demands are calculated as:

Space heating	122,7 MWh/a
Space cooling	860,3 MWh/a

A conventional system would emit 99.1 t CO_2 per year, and create annual operational cost of 48’495 €/a; detailed cost are listed below:

	Annual consumption	Total cost	Specific cost
Gas (heating)	275 MWh/a	10’335 €/a	38 €/MWh
Electricity (cooling)	658 MWh/a	38’159 €/a	58 €/MWh

For the geothermal system, two wells each 190 m deep are planned, with 265 mm inner diameter. Due to the low groundwater table (ca. 35 m below ground) a pump of 55 kW electric power consumption at about 90 m depth would be required in the production well. A maximum amount of 100 m^3/h is required to supply enough heat or cold to the intermediate water loop connecting the heat pumps.

The additional investment for the geothermal facility has been calculated to 352’892 €. Annual energy cost savings are expected to be 6’868 €. The resulting payback time, including the annual savings in maintenance and operation, amounts to about 20 years, making the system uneconomic without subsidies.

The geothermal solution would emit only 57.9 t $C0_2$ per year. This represents a reduction of 41.6% in comparison with the reference solution.

Example in Portugal

Shopping mall in Santa Maria da Feira, Aveiro, PT

Total heated space	5607 m²
Cooling load (thermal)	106 kW
Heating load (thermal)	315 MWh/y

Proposed geothermal system with 10 BHE at 150 m depth each

Cost for BHE at 35 €/m result in a total of 52'500 €

Economic Feasibility:

	Geothermal Energy option	Natural Gas Boiler and Chiller option	Annual saving
Heating costs (€/a)	1079	3246	2167
Cooling costs (€/a)	1747	2550	803
BHE total costs (€)	52'500		
Payback (years)	17.7		

With 17.7 years of payback, this system might not be favourable for shopping malls that are based upon an economy looking at much shorter terms for profit.

3.3 Industry (foundry)

The basic example here was investigated in Sweden and is described in the relevant IGEIA publications D8 and D10 – Sweden.

The company ITT Flygt in Emmaboda is the worlds leading manufacturer of submersible pumps and mixers. The plant handles the whole production flow, from molten metal to finished products. As such it contains a foundry, an electric motor workshop and several product workshops (cf. fig. 5). The surface area is approx. 330'000 m^2 while the buildings occupy some 100'000 m^2.

Fig. 5: The ITT Flygt Emmaboda industrial area

Currently, ITT Flygt buys some 5’200 MWh of energy off the regional district heating network each winter. This indirectly contributes to a release of approximately 1’800 tons of CO_2 to the atmosphere each year. Currently, approximately 3’600 MWh of heat is recovered from the ovens within the local DH. There is a large potential within the site to increase this amount by constructing a seasonal thermal energy storage system operating together with heat pumps.

To allow for a better waste heat recovery, the existing system is planned to have some new components, which have been dimensioned as follows:

- HP1 for utilization of heat from the cooling. It will lift the temperature from +30-35 to +60-65°C .
- HP2 for utilization of heat from the water basin. It will lift the temperature from +20-35 to +60-65°C.
- The seasonal BTES system is designed for storage of 3 800 MWh annually at a temperature around +60-65°C (maximum +70°C). The temperature after recovery is +40°C.

A simulation with EED shows that it takes 140 boreholes of 150 m each with a rectangular shape and a borehole distance of 5 m to create a storage for 3’000 MWh.

Taken into account that the average time for storage is six months, and that the storage working temperature is +60/40°C, the storage losses will be in the order 1’200 MWh. Hence, 2’600 MWh will be recovered and utilized. The storage will be able to deliver a load capacity of some 1’100 kW at the start of the winter season. At the end of winter the capacity may drop down to some 100 kW. However, pulses of short term storage can drastically increase this number if required.

Compared to the conventional system a reduction of 1’700 t CO_2 per year can be expected, due to the fact that the required electricity has a rather small carbon footprint. This figure means a reduction of about 94 %. The net investment is 10’600 Thousand SEK and the annual savings 1’830 Thousand SEK. Using the net investment, the straight pay back time will be in the order of 5.8 years.

Example in Estonia

Industrial complex in Pärnu, EE

Total heated space	32’000 m²
Heating capacity	4 MW
Heat supply	9990 MWh/y
Cold supply	200 MWh/y

The geothermal system would allow to save oil, reduce CO_2 emission, store heat from the cooling system, and store heat from warm river water during summertime.

3.4 Other applications

Laboratory (Portugal)

Laboratory building in Sines, PT, with 8 laboratories of 66.8 m² of area each, used by new companies in different activities areas.

Total heated space 534 m²

Cooling load (thermal) 34,1 kW

Heating load (thermal) 46,1 MWh/y

Proposed geothermal system with 5 BHE at 130 m depth each

Cost for BHE at 35 €/m result in a total of 22’750 €

Economic Feasibility:

	Geothermal Energy option	Natural Gas Boiler and Chiller option	Annual saving
Heating costs (€/a)	1130	3386	2256
Cooling costs (€/a)	379	511	132
BHE total costs (€)	22’750		
Payback (years)	9.5		

With 9.5 years of payback, this system can be favourable for such an application.

Swimming Pool (Estonia, Portugal)

Swimming pool in Narva, EE

Total space 2688.7 m²

Electricity consumption 240 MWh/y

Heat consumption 1200 MWh/y
(incl. 281 MWh/y hot water)

Required heating capacity 400 kW,

It is possible to reduce the heating capacity 30% through heat recovery and energy saving measures. A Geothermal system can reduce the purchased amount of district heat and store the excess heat in summertime.

Swimming pool in Barreiro, Setubal district, PT

Total heated space 2263 m²

Dehumidification 130 kW

Heating load (pool water) 70 MWh/y

Proposed geothermal system with 18 BHE at 150 m depth each

Cost for BHE at 35 €/m result in a total of 94’500 €

A cost comparison was not done for this case, since this option will only be considered if the actual system has to be changed, being the equipment costs similar for both options, plus the borehole costs. The geothermal option could be also considered in the swimming pool implementation and can be used for other swimming pools with the same conditions.

Sport Hall (Estonia)

Sport hall in Narva, EE, with icefield

Total heated space	6798,5 m²
Electricity consumption	1200 MWh/y
Heat consumption	500 MWh/y
Required heating capacity	200 kW
Required cooling capacity	400 kW

A geothermal system allows to store excess heat in summertime and reduce cost of purchased heat.

Culture House (Estonia)

Culture House in Narva, EE

Total space	5982 m²
Electricity consumption	50 MWh/y
Heat consumption	650 MWh/y
Heating capacity	250kW

The building needs renovation. The heat demand can be reduced by 40%, implementing energy saving measures. A geothermal system reduces the purchased heat cost and allows to store excess heat from cooling.

Greenhouse (Portugal)

The greenhouse sits on Quinta do Monte Alegre, Taipadas, Canha on Montijo region, PT

Total heated space 46'900 m² (divided into 23 greenhouses)

Load per Greenhouse:

Space Loads	Design Heating Load	Design Cooling Load
Greenhouse Transmission Load	132 kW	64 kW
Infiltration – Continuous Load	59 kW	36 kW
Solar Heat Load		472 kW
Total Space Loads	191 kW	572 kW

Proposed geothermal system: for maximum heating, 17 BHE at 150 m depth each, and for maximum cooling, 64 BHE at 150 m depth each; resulting in cost of 89’250 € and 336’000 €, respectively

For an open loop system (groundwater), the cost would be 31’238 € and 117’600 €.

The closed loop systems would result in 13-62 years of payback, while the open loops could result in only 4-22 years.