MSc Program
Renewable Energy in Central and Eastern Europe

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Utilization of shallow geothermal energy in Slovakia focused on Ground Source Heat Pump domestic installations

A Master's Thesis submitted for the degree of
"Master of Science"

supervised by
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Bratislava, September 2009

Affidavit

I, **Dipl. - Ing. Jana Mária Obernauer**, hereby declare

1. that I am the sole author of the present Master's Thesis, "Utilization of shallow geothermal energy in Slovakia focused on Ground Source Heat Pump domestic installations", 116 pages, bound, and that I have not used any source or tool other than those referenced or any other illicit aid or tool, and
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Abstract

The geological setting of the Slovak Republic favours the occurrence of geothermal energy resources, especially low enthalpy geothermal resources (temperature in the range 20℃ – 100℃). The total thermal-energy poten tial of geothermal waters in prospective areas (proven, predicted and probable) is 5 538 MWt. Up to now, geothermal water has been used only for recreation (swimming pools, spa), agriculture (greenhouse heating, fisheries) and district heating.

The low-enthalpy aquifers suitable for district heating system are limited and occur only in regions with a specific geological structure. Nevertheless, shallow geothermal resources up to the depth of 400 m are suitable for heat extraction and utilization virtually everywhere.

The most geographically extensive use of geothermal energy in the world and the most localized in use is ground source heat pump (GSHP) technology which can utilise the moderate temperatures just beneath the earth's surface.

An immense amount of energy has been accumulated in the surrounding air, ground and water, which constitutes an almost inexhaustible supply of absolutely free energy.

The heat pump technology required to extract heat accumulated in the air, earth and water has been known for more than a hundred years. The most common heat pump systems, determined by the type of cooled and heated medium, are: air-to-water, water -to-water and ground-to-water.

Due to the fact that shallow ground temperatures are relatively constant, GSHP can be effectively used almost anywhere. GSHP is commonly used for the space and domestic water heating of a wide range of building types and sizes. GSHP are particularly suitable for new buildings as well as for older existing buildings, especially in conjunction with reduced demand for heat..

The most significant direct benefits of appropriately designed GSHP systems are the reduced energy requirements and the use of a sustainable energy source. In addition, the indirect benefits of GSHP systems include a low environmental impact with a significant reduction of emissions of CO_2 and other pollutants.

Slovakia's geological and hydrogeological conditions are very favorable to the installation of GHP water-to-water and earth-to-water systems. This is due to the high average heat flow (78 mW/m^2) compared to the central European average heat flow - the energy yield is in the range of 50 W/m. So far, the number of heat pump installations does not reflect these conditions. It is estimated that at present only app. 100 units of heat pumps are in operation and the Slovak GSHP market is still

very flat. Barriers to growth in the geothermal heat pump market in Slovakia can be overcome. By far the most significant one is the high installation cost of GSHP systems. Well-designed incentives could help to overcome the higher installation cost of a GSHP and reduce the payback time to a period comparable with other available RES heating systems. The breakeven point can typically be accelerated by favorable government and utility energy incentives. The most important market barriers to GSHP implementation in Slovakia are definitely limited public awareness and low familiarity with technology on the part of practitioners. Generally, there are a number of misconceptions and myths about GSHP technology mainly due to the unprogressive approach of the authorities. Wider general education would improve the reputation of GSHP and enable misconceptions to be challenged.

The case study of the installation of a GSHP system in a historical building can be used to promote shallow geothermal technology and challenges the common public misconception that heat pump utilization is predominately applicable only to new and low-energy buildings.

The successful implementation of the proposed GSHP system could provide further evidence of the reliability and practicality of utilizing shallow geothermal energy with GSHP despite complicated regional geology, and the official restrictions placed on reconstruction.

In combination with building renovation, the implementation of a GSHP system is also feasible for older buildings. Reduction of specific heat demand and the most up to date high efficiency GSHP permit the application of GSHP in bivalent mode with an additional energy source even in historical buildings. This argument is supported by the evidence of the numerous heat pump installations completed in existing older houses and historical buildings.

Executive summary

The objectives of the present study involved determination of geothermal potential in Slovakia, focusing on shallow geothermal and low-potential resources, with a view to implementation of GSHP in the heating sector. On the basis of the available results of research on the outlook and current status of GSHP utilization in Slovakia, limitations on the Slovak market were identified. The key barriers and obstacles which inhibit GSHP market growth were shown to be: higher installation costs, lack of public awareness, the general public's unfamiliarity with technology and limited participation by utilities and main market players (manufacturers, installers, supplier, contractors, etc.) in encouraging adoption of GSHP systems.

This study makes the following proposals to overcome the identified market barriers:

1. Reduction of capital costs of GSHP systems:

If transparent and consistent government support becomes available and heating fuel costs continue to rise rapidly, it is likely that there will be an increase in the use of heat pumps in the near future. Higher fuel bills, may well be the main driver of more effective use of GSHP in Slovakia, in spite of the high initial costs of these systems.

The most expensive and complicated stage of GSHP installation is the building of the primary circuit, including drilling works and final completion of the borehole heat exchanger. The reliable and efficient performance of drilling work is closely associated with sizing and system dimension. Borehole completion is a key design factor for low-temperature GSHP systems.

The efficiency of an individual borehole is never perfect. The drilling contractor must construct the borehole in accordance with local regulations. Indeed, there does not exist any single and universal solution for all geological and hydrogeological conditions. Drilling a test borehole makes a positive contribution to the design process. The test borehole should be provided by wire-line core drilling technology. The core recovery obtained will be used for logging of all drilling intervals and detailed description of samples. The collected samples and subsequent analysis have significant informative value. Interpretation of the results of core sampling, logging and analysis, provide information on drilling conditions and native ground heat transfer properties. Precise data is essential for the design of the complex ground loop and desirable for the selection of an appropriate drilling method and tooling. Finally, when the test borehole is positive, it may be converted into a vertical closed borehole heat exchanger.

At first sight, the proposed procedure may seem to be a costlier solution. Ultimately, however, a superior installation technique can reduce costs and have a marked impact on the thermal efficiency of the entire GSHP system.

2. A general improvement in familiarity with GSHP technology should be promoted through a systematic educational framework widely available to all those wishing to participate in the use of GSHP.

Recently, a broad range of heat pumps from reputable brand manufacturers as well as cheaper un-branded alternatives have become available, even in Slovakia. Therefore the current challenge is to train enough knowledgeable sales staff, designers, installers, maintenance technicians and drilling contractors to ensure that GSHP are correctly sold, specified, designed, installed and commissioned. To build a profitable and sustainable GSHP market in Slovakia, it is essential to avoid GSHP installations developing a reputation for poor quality.

The available manufacturers´ data sheets and technical guidelines do not provide sufficient educational background for any practitioner aiming to become involved in the GSHP market. This approach does not guarantee high quality GSHPs installations which meet customers´ requirements and expectations.

Manufacturers´ main concerns should be the establishment of training and workshop courses aimed at the different professionals involved: geologists, designers, installers and drillers. The theoretical and practical courses could cover geothermal resources and ground source temperatures of different regions, soil and rock identification for thermal conductivity, regulations on the use of geothermal resources, determination of the most suitable GSHP system, system arrangement, drilling technologies, installation of borehole heat exchangers, borehole construction, pressure testing, building law and safety and, last but not least, environmental protection.

3. The global GSHP market is growing faster than the overall market for building climate control technologies. Heat pumps have recently become widely distributed in Slovakia, but GSHP are often confused with the more familiar air-source heat pump installations. GSHP have never had a strong market penetration in Slovakia while the general public continues to have very limited knowledge of the technology and its availability. This clean, safe, renewable and proven technology has a greater chance of adoption if the public become more aware and better informed.

As potential costumers are looking for comfortable and reliable substitutes for existing natural gas heating, GSHP are an excellent alternative. Customer appreciation of the potential of GSHP is possible only if GSHP suppliers take an open and transparent approach. Generally, it is difficult to find any available data about successful installations of GSHP or standard statistics about salability of GSHP systems. As a result of the obscure legal framework governing GSHP installations and trade competition among players on the GSHP market, it is standard practice to treat all relevant and useful data as confidential. The key players in the GSHP market are unaware of the undesirable impact which this has on market growth.

The suggestion that a standard register of GSHP installations, authorized by the Ministry of the Environment, should be established, should shed light on the legal procedures. At present there is a legal duty to report all ground surveys and interferences with the Earth’s crust. In practice, this obligation is frequently ignored by the majority of GSHP contractors. Therefore, Slovakia currently lacks a reliable information base dealing with ground sources exploration for the purpose of GSHP applications. The utilization of ground water or ground source heat for energetic purposes is an exploitation of mineral resources and must be strictly supervised and monitored. The data obtained from exploration and exploitation of ground water or ground source heat should be collected in a publicly accessible database.

The proposed measure could appear to be an administrative obstacle to GSHP implementation. However, it could contribute to increased public awareness and improved expert familiarity with GSHP technology. GSHP systems offer a geographically unlimited and practically inexhaustible source of heat. Nevertheless, it is extremely important to have regard to environmental impacts where such interference with the Earth’s crust is irreversible.

This summary of proposals to overcome the main market barriers acting as a brake on the further development of GSHP utilization in Slovakia constitutes an extensive answer to the core question posed: **Under what conditions could utilization of shallow geothermal resources by Ground Source Heat Pump domestic installations improve the diversity of heating resources in Slovakia?**

Proper appreciation of GSHP technology, increased public awareness, improvement of specialist familiarity, reduction of capital costs through government measures, active participation of the utility companies and the market players involved, could definitely be beneficial to the diversification of the Slovak heating industry in the near future. However, from a strategic point of view, the development of the GSHP market in Slovakia must take place with an emphasis on environmental compatibility and with a view to sustainable development.

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Acronyms

ASHP Air Source Heat Pump
AVTČ Czech Heat Pump Association
BHE Borehole Heat Exchanger
COP Coefficient of Performance
CZ Czech Republic
EER Efficiency of Energy Recovery
EGEC European Geothermal Association
EHPA European Heat Pump Association
EU European Union
GHC Geo-Heat Center
GHP Geothermal Heat Pump

GSHP	Ground Source Heat Pump
IGSHPA	International Ground Source Heat Pump Association
IRR	Internal rate of return
HP	Heat Pump
HT	High Tariff
LT	Low Tariff
NW	Northwest
N	North
N	Number
NPV	Net present value
PE	Polyethylene
RACE	Slovak Association for Refrigeration and Air Conditioning Engineers
RES	Renewable Source of Energy
SPF	Seasonal Performance Factor
SR	Slovak Republic
SSE	Stredoslovenská Energetika (Central Slovakian Energy Corp. Inc.)
SWMB	State Water Management Balance
TDS	Total dissolved solids
TRT	Thermal Response Test
VAT	Value Added Tax
VSE	Východoslovenská Energetika (Eastern Slovakian Energy Corp. Inc.)
ZSE	Západoslovenká Energetika (Western Slovakian Energy Corp. Inc.)

Introduction

Slovakia is one of the European countries which utilizes a very low proportion of renewable sources of energy (RES) and a relatively high proportion of fossil fuel consumption in primary energy production. Due the fact that Slovakia has very small reserves of fossil fuels, energy progress must be focussed on the diversification of primary energy sources with increasing use of domestic renewable sources of energy and a continuing decrease of energy intensity. As Slovakia has domestic energy sources this would reduce the current dependence on imported energy.

Under the terms of an energy and climate change package presented by the EC at the end of January 2008, Slovakia is required to increase the share of RES in total consumption to 14% by 2020.

The relative domestic potential of RES is about 4 % of the primary energy sources usable in 2010. The potential of geothermal energy is 17,5% and represents the second most significant domestic potential of RES in Slovakia

The geological setting of the Slovak Republic is favourable to the occurrence of geothermal energy resources and there are 26 geothermal areas or structures, covering 27 % of Slovak territory.

However, of all the available alternative domestic energy options, geothermal energy may be the best option for Slovak energy security. It is clean, renewable, abundant, domestically available and dependable which makes this energy source a highly attractive option for fulfillment of Slovakia's current demanding energy needs.

In contrast to the direct use of deep geothermal energy, shallow geothermal technology can be utilized virtually anywhere as it is not dependent on accessing the extremely hot water and steam deeper inside the earth. Geothermal heat pumps (GSHP) utilize the shallow nearby earth. Ground source heat pump (GSHP) can access the moderate and nearly constant temperature during the year and use it to heat and cool homes or commercial buildings.

Due to the fact that geothermal heat pumps have almost no geographic limitations and are perfectly suited to single-building applications, in comparison with traditional energy technologies, utilization of GSHP systems offers many economical and environmental advantages.

GSHP is a proven and well-established technology, widely spread throughout Europe. Nowadays this is one of the most dynamic growing sectors of implementation of RES. Despite all the advantages, the potential of GSHP is still not properly appreciated in Slovakia. Although increasing in popularity in neighboring countries with comparable potentials, GSHP are less known than comparable conventional systems utilizing fossil fuels.

Despite the undoubted benefits, the utilization and promotion of GSHP is overshadowed by the more popular alternative energy options, such as wind, sun and biomass. Though RES implementation is increasingly popular, GHSP technology is still very unfamiliar to the general public and successful installations of GSHP system are still rare.

Meeting the challenge of increasing the adoption of GSHP technology in Slovakia should involve increasing public awareness, improving the emphasis on technology and encouraging utility company participation and government support.

Methodology

The main goal of the present study is to determine the potential of and prospects for utilization of shallow geothermal resources by ground source heat pumps (GSHP) in Slovakia.

The key question addressed by this study is:

Under what conditions could the utilization of shallow geothermal resources by Ground Source Heat Pump domestic installations improve the diversity of heating sources in Slovakia?

Nowadays the Slovak market for GSHP applications is very flat and the share of heat pump installations in the heating market is still negligible. Hence the aim of this study is to examine the advantages of GSHP technology and outline the prospects for its further development in Slovakia. GSHP technology needs to be more accessible to all the market players concerned as well as to the general public.

In order to achieve these objectives, the present study is structured as follows:

- The introductory part explores the geothermal potential of Slovakia, focusing on the description of geological settings, geothermal potential and resources, the current status of and future prospects for the utilization of geothermal resources. A geothermal overview of Slovakia is presented, based on literature research in the Geological archives of the Geofond and Geological Institutes. Comprehensive information about geothermal exploration and hydrogeothermal characteristics is available in “Atlas of geothermal energy in Slovakia” and “Landscape Atlas of Slovak republic” in the section on “ Geothermal and mineral water sources”.
- The definition of shallow geothermal resources, surrounding energy and the general principle of heat pump technology are described in the second general and theoretical part. The various classifications of GSHP are described. The fundamental principles of GSHP installations are explained and guidance offered on the general design of GSHP systems. This part has been prepared on the basis of accessible expert literature and information resources.
- The low-potential energy resources available in Slovakia are quantified in the third part of this study. The particular sources (ambient air, groundwater, soil, ground) are analyzed in detail on the basis of extensive research in the databases of the Hydrometeorology Institute (climate conditions, ambient air), Water management and Research Institute (hydrogeological conditions – groundwater), Geological Institute (geothermal resources, ground conditions) and Geofond (geological maps, ground physical characteristics,

ground thermal conductivity, etc.). The resultant research provides a comprehensive overview of available sources of low-potential energy in Slovakia from the point of view of heat pump implementation.

- The fourth chapter elaborates the legislative framework and administrative aspects of GSHP installations in Slovakia. There are defined institutional frameworks and administrative procedures in respect of GSHP installations. As there is no integrated legislation in this field, this chapter considers the various regulations impacting on GSHP installations.
- The technical performance of borehole heat exchangers is described in detail in the fifth chapter. Traditional and modern methods for the design and sizing of BHE are explained. As it is difficult to find GSHP applications sized using sophisticated methods (numerical simulations, software programs) the main focus is on operational dimensioning and provision of technical works. Considerable attention is paid to drilling technologies, completion techniques, BHE sounding and grounding. State of the art drilling techniques and enhanced equipment which could significantly improve further development in the field of GSHP applications are discussed.
- The following two chapters are dedicated to a description of the GSHP market . A brief overview of the GSHP market in the EU (statistical data from Geothermal Energy Barometer by EurObserver) is followed by a more extensive analysis of the GSHP market in Slovakia and the Czech Republic. Taking into account market research findings, the study examines the potential for extension of GHSP applications (current status of heating sector), government support and utilities initiatives. The need for advanced vocational education and quality labeling systems if the main market barriers are to be overcome is shown. Promotions and initiatives applied in the Czech Republic (government support schemes, the activities of the Czech Heat Pump Association) which can serve as a model for the further, successful development of the Slovak market, are described.
- The study of the economic aspects of heat pump utilization in Slovakia focuses on analysis of the capital and operational costs of various kinds of heat pump application. Comparative economic evaluations are carried out, based on the technical parameters of particular heat pump systems (described in manufacturers' specifications) and current Slovak energy prices. Heat pumps are commonly associated with air-source heat pump installations, therefore the more popular air-to-water heat pump systems as well as conventional heating systems have been included in the comparative

evaluations. The final evaluation incorporates the standard economic indicators and technical parameters which are meaningful for the customer decision making process.

- The last part of the study applies theoretical information to a real case study. This is a model study of a GSHP application in a historical building – a private manor house situated in Central Slovakia. The objective is to identify a practicable and profitable heating system which meets the investor's requirements. The proposed solution has had to take into consideration the local settings (climate, geology, hydrogeology conditions) and statutory limitations (Historical Office restrictions). The design and dimensioning of the GSHP system are specified on the basis of hydrogeological data and technical and financial specifications provided by heat pump suppliers. Economic profitability is evaluated on the basis of calculations of specific indicators (using economic software EKONOMIC 4,75 produced by the company 5PSOFT). The conclusion of the case study summarizes and interprets all available data and considerations relevant to the final decision and makes recommendations for the implementation of a suitable GSHP heating system.

1. Potential of geothermal energy in Slovakia

Geothermal energy can be effectively used in the regions and localities as a local available source of heat in the case of lack of other energetic sources or increase of fossil flues prices. In the case of favorable conditions geothermal energy can be also used as a source of the direct electric energy generation (waters over 140 ℃). According to the sustainable resources management and environmental protection, sources of geothermal energy were declared as one of the partial solutions which can substitute for fossil fuels.

Geological setting of the Slovak Republic is favorable for occurrence of geothermal energy resources and represents 26 geothermal areas or structures, covering 27 % of the Slovak territory.

Geothermal resources of the Slovak Republic occur in territory in low enthalpy (temperature in the range 20℃ – 100℃), medium ent halpy (100℃ – 150℃) and high enthalpy (higher than 150 ℃) The most frequen t of these are low enthalpy geothermal resources. The Slovak Republic belongs to the countries where total geothermal energy installation is over 100 MWt.

Temperature of geothermal waters at a depth of 1000 m varies from 20 to 74 ℃ with the average value of 45 ℃. The average value of th e heat flow density is 82,1 mW/m^2 ± 20,5 mW/m^2, with the minimum value of 40,6 and maximum value of 121,6 mW/m^2. The total amount of thermal-energy potential of geothermal waters in prospective areas (proven, predicted and probable) represents 5 538 MWt. Geothermal wells up to now verified 4,5 % of the total thermal-energy potential of the geothermal sources in the Slovak Republic, but only 2,3 % of the potential are utilized. Only 53 % of proven geothermal energy potential is utilized until now.

Table 1: Thermal - energy potential of geothermal waters in Slovak Republic[1]

Resources (MWt)			Reserves (MWt)		
Proven	Predicted	probable	proven	predicted	probable
147	85	321	29	445	4511
553			4985		
Total amount: 5 538 MWt					

[1] Franko O., Remšík A., and Fendek M., Eds.: Atlas of Geothermal Energy of Slovakia. Dionýz Štúr Institute of Geology, Bratislava 1995

Due to favorable geological conditions Slovakia is the country rich in low enthalpy sources occurrences. The state policy support new renewable ecological energy sources, among which the geothermal energy belongs. The geothermal water is used for recreation (swimming pools, spa), agriculture (greenhouses heating, fishery) and district heating. Obtained results and assumed possibilities create the real conditions for the feasible geothermal energy utilization in the territory of the Slovak Republic in the near and future.

1.1. Geology background

The geological structure of the Western Carpathians in Slovak territory and favorable geothermic conditions create a suitable setting for the occurrence of geothermal energy resources. The Western Carpathians are classified according to the age of development of the Alpine nappe structure as the Outer – with Neo-Alpine nappes and the Inner with Paleo-Alpine – Pre-Paleogene nappe structure. The Klippen Belt marks the boundary between them. The structure of the Western Carpathians is characterized by zoning. The Mesozoic and Tertiary formations, arrayed in a series of arcuate belts, have been tectonically transformed form qualitatively and temporally different sedimentary basins into the fold-nappe ranges, which may either be composed of sedimentary filling alone, or may include the original basement. The geological setting is favorable for the occurrence of geothermal waters with temperature higher than 20 °C only to the south of the Klippen Belt. Geothermal waters are largely associated with Triassic dolomites and limestones of the Krížna and Choč nappes (Fatricum and Hronicum), less frequently with Neogene sands, sandstones, conglomerates, andesites and related pyroclastics.

1.2. Geothermal resources and potential

Geothermal research on the territory of the Slovak Republic started in seventies of the last century. Results gained during more then 20 years were for the first time evaluated and summarized in the Atlas of geothermal energy of Slovakia[2]. Knowledge on geothermal resources of selected parts of Slovakia became a part of

[2] Franko O., Remšík A., and Fendek M., Eds.: Atlas of Geothermal Energy of Slovakia. Dionýz Štúr Institute of Geology, Bratislava, 1995

the Atlas of geothermal resources in Europe[3]. Brief hydrogeothermal characteristic of Slovakia together with evaluation of prospective areas was included into the Atlas. More detailed evaluation was done for Liptov basin and Central depression of the Danube basin[4]. The text is complemented by thematic geothermal map of Slovakia, map of temperature distribution at the depth of 500 m, map of geothermal resources of Slovakia and by eight maps characterizing hydrogeothermal conditions of the Liptov basin (for Choc and Krížna nappes). Accordingly, eight maps show hydrogeothermal conditions of the Central depression of the Danube basin (for Pontian and Panonian sequences). The latest graphical review of geothermal and mineral water occurrence in Slovakia was published in 2002 as a map in the scale 1:500 000 under heading "Geothermal and mineral water sources" [5], which is a part of the Landscape Atlas of the Slovak Republic[6].

The tectonic geothermal map of Slovakia (Appendix 1) shows geological structure of the area, main geothermal aquifers, prospective areas or structures of geothermal waters, yields and temperatures of respective sources, as well as thermal power of geothermal waters in respective areas.

1.3. Geothermal resources

Geothermal resources for direct use can be classified according to their temperature into three following types:

- **Low temperature** with water temperature in the range of 20 – 100 ℃. They occur in Komarno high block, Danube Basin central depression, Banovce Basin, Topolcany embayment, Trnava embayment, Piestany embayment, Central Slovakian Neogene volcanic (NW part), Central Slovakian Neogene volcanics (SE part), Upper Nitra Basin, Turiec Basin, Zilina Basin, Skorusina Basin, Liptov Basin, Levoca Basin (W and S parts), Horne Strhare – Trenc Graben, Rimava Basin, Trencin Basin, Ilava Basin, Levice marginal block, Komarno marginal block, Vienna Basin, Komjatice depression, Levoca Basin (N part), Humenne ridge, Kosice Basin, Besa-Cicarovce structure, Dubnik depression. All determined areas have favourable conditions for low temperature geothermal waters occurrence in depths of 150 – 3500 m.

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[3] Hurter, S. and Haenel, R., Eds.: Atlas of Geothermal Resources in Europe, Luxembourg, European Communities, 2002

[4] Remsik, A., Fendek, M., Kral, M. and Mello, J.: National geothermal resource assessments Slovakia. Atlas of Geothermal Resources in Europe, 2002

[5] Fendek, M., Porazikova, K., Stefanovicova, D. and Supukova, M.: Geothermal and mineral water sources, Map 1:500 000. In: Landscape Atlas of the Slovak Republic, 2002

[6] Landscape Atlas of the Slovak Republic. 1st edition. Bratislava – Ministry of environment of the Slovak Republic, SEA, Banska Bystrica 2002

- **Medium temperature** with water temperature in the range of 100 – 150 ℃. They occur in Besa-Cicarovce structure, Kosice Basin, Danube Basin central depression, Humenne ridge, Levoca Basin (N part), Zilina Basin, Trnava embayment, Piestany embayment, Central Slovakian Neogene volcanic (NW part), Vienna Basin. Favourable conditions for medium temperature geothermal waters occurrence are in the depth of 2500 – 4500 m.
- **High temperature** with water temperature higher than 150 ℃. They occ ur in Besa-Cicarovce structure, Central Slovakian Neogene volcanics (NW part) and in Vienna Basin at the depth of 3500 – 5500 m.

Geothermal waters in Slovakia were documented by wells in 22 prospective areas. Totally, 117 geothermal wells are registered in Slovakia, only 5 of them were negative. The amount of app. 1690 l/s of geothermal water were documented by geothermal wells. The temperature on the well head reaches 18 – 129 ºC. Geothermal waters were reached by wells 92 – 3616 m deep. Free outflow of the wells ranged from 0,1 up to 100 l/s, Na-HCO_3-Cl, Ca-Mg- HCO_3 and Na-Cl chemical type of water with the TDS (Total dissolved solids) value of 0,4 – 90,0 g/l prevails.
Classification of geothermal resources based on hydrogeothermal regionalisation is presented in the Appendix 3.

1.4. Utilization of geothermal energy

1.4.1 Historical background

The history of utilization of geothermal energy in the area of Slovak Republic is mainly the history of utilization of thermal springs. Many archaeological finds discovered at the site and in the surroundings of thermal springs indicate that man was attracted to settle in these friendly areas. Most admired in the literature of past centuries were the well-known spas: Piestany, Trencianske Teplice, Rajecke Teplice, Turcianske Teplice, Sklene Teplice, Vyhne, but also Svaty Jur, Pezinok, Lipovce, Rudno, etc.
Though thermal springs were known as early as in the Middle Ages, the first geothermal well drilled in the territory of the Slovak Republic as the well in Ganovce drilled to the depth of 183 m in the year 1879. The value of free out flow from the well was 13,5 1/s of geothermal water with temperature of 24 ℃. the second geothermal well followed in 1899 in Kovacova. The free outflow from the depth of 473 m was 12,5 l/s with temperature of 40,5 ℃ [7].

[7] Fendek M. and Fendeková M. : Country Update of the Slovak Republic, Proceedings World Geothermal Congress 2005, Antalya, Turkey, 24-29 April 2005

The first utilization of geothermal waters for energetic purpose is connected with space heating in spas and can be dated to the year 1958. Three systems of direct utilization of geothermal waters were tested [8]:

- direct space heating in spas Piestany, Kovacova, Sklene Teplice,
- utilization of heat pumps in Piestany and Turcianske Teplice,
- space-heating and heating of hot service water through heat exchangers in Piestany, Turcianske Teplice and Kovacova.

These first steps created conditions for more extensive research in the field of geothermal energy utilization for direct use in Slovak Republic.

1.4.2. Current trends

Geothermal water in Slovak Republic is used just for direct use in agricultural farms, for space heating, fish farming and for recreational purposes. In 12 agricultural farms geothermal water is used for greenhouse heating and soil heating. Utilization of heat in agriculture provides great possibilities for early production of vegetables (cucumber, tomatoes, peppers, aubergines, etc.) and flowers. The total area covered by greenhouses is about 27,6 ha. The number of localities where geothermal water is used for space heating has increased importantly – from 6 in 1999 to 13 in 2004. Geothermal water is utilized for heating of service buildings in Galanta, Topolniky, Komarno, Besenova, Liptovsky Trnovec and Poprad, for hotels heating in Besenova, Velky Meder, Podhajska and Sturovo and for block of flats and hospital in Galanta. For sport hall heating it is used in Topolniky, in Novaky-Kos it is utilized for heating of miner's dressing rooms and air heating in brown coal mine. Geothermal water is utilized for fish farming on Vrbov and Turcianske Teplice. In 32 localities geothermal water is used for recreational purposes, mainly in swimming pools.

The total amount of geothermal energy utilized in 27 localities represents thermal power of 88,52 MWt and 764 l/s of geothermal water. The thermal power verified by realized geothermal wells totals 314,3 MWt (using them up to the reference temperature of 15 ºC). In Tables 2 and 3 are listed detail utilization of geothermal energy for various kinds of utilization and direct heating in Slovakia (on the date 31.12.2004)[9].

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[8] Fendek M. and Fendeková M., : Country Update of the Slovak Republic, Proceedings World Geothermal Congress 2005, Antalya, Turkey, 24-29 April 2005

[9] Fendek M. and Fendeková M., : Country Update of the Slovak Republic, Proceedings World Geothermal Congress 2005, Antalya, Turkey, 24-29 April 2005

Table 2: Utilization of geothermal energy for direct heating

Locality	Type of utilization	Maximum utilization			Capacity	Average annual utilization	
		Flow rate	Temperature ℃			Flow rate	Energy use
(31.12.2004)		l/s	Inlet	Outlet	MWt	l/s	TJ/yr
Komarno	B	5	40	33	0,15	4	3,7
Sturovo	B/D	70	40	28	3,51	15	23,7
Kralova pri Senci	B/G	13	52	41	0,59	5	7,2
Topolniky	D/B/G	23	74	35	3,75	12	61,7
Galanta-1	B	10	61	35	1,09	10	34,3
Galanta-2,3	D	50	80	40	8,37	20	105,5
Tvrdosovce	B/G	20	70	34	3,01	15	71,2
Horna Poton	G	20	68	36	2,68	16	67,5
Vlcany	G	10	58	22	1,51	6	28,5
Dunajska Streda-1	G/B/D	15	91	40	3,2	10,5	70,6
Dunajska Streda-2	B	23	55	30	2,41	16	52.8
Velky Meder-1	G/D	10	73	44	1,21	8	30,6
Velky Meder-2	B	16	57	30	1,81	16	57
Diakovce	D/B	12	63	30	1,65	10	43,5
Nove Zamky	B	4	59	27	0,54	4	16,9
Sala	B	3	42	28	0,17	3	5,5
Cilizska Radvan-1	G	6	82	32	1,25	6	39,6
Cilizska Radvan-2	G	17	64	32	2,28	12	50,6
Topolovec	G	10	61	35	1,08	10	34,3
Dunajsky Klatov	G	10	74	33	1,72	10	54,1
Podhajska	D/B/G	45	80	41	7,34	20	102,9
Besenova	D/B/G	27	62	40	2,48	18	52,2
Vrbov-1	F/B	28	55	33	2,58	20	58
Vrbov-2	F/B	33	59	33	3,59	15	51,4
Ban. n/Bebravou	B	23	46	20	2,5	15	51,4
Oravice	B	110	56	30	11,96	10	34,3
Liptovsky Trnovec	B/D	31	60	18	5,45	25	33,1
Poprad	B/D	47	48	20	5,51	35	30,9
Novaky-Kos	D	22	59	23	3,31	4,5	5,1
Chalmova	D/B	15	36	22	0,87	8	3,5
Male Bielice	B	8	36	19	0,57	6	3,2
Partizanske	B	18	20	15	0,38	7,8	1,2
TOTAL		**764**			**88,52**	**395,8**	**1 294,70**

Note: F – fishing farming; D – district heating, B – Bathing and swimming; G – Greenhouses and soil heating

Table 3: Geothermal heat direct utilization

District GT heat utilization (on the date 31.12.2004)	**Installed Capacity [MWt]**	**Annual Energy Use [TJ/year]**	**Capacity Factor**
Individual Space Heating	0,0	0,0	0,0
District Heating	31,6	576,9	0,579
Greenhouse Heating	31,8	502,3	0,501
Fish Farming	4,6	72,4	0,499
Bathing and Swimming	118,3	1 870,3	0,501
Subtotal	186,3	3 021,9	0,514
Geothermal Heat Pumps	1,4	12,1	0,274
Total	**187,7**	**3034**	**0,512**

1.4.3. Future development

At present, hydrogeothermal evaluation has been performed in three prospective areas, namely in Upper Nitra basin (2001 – 2004), Topolcany embayment and Banovce basin (2002 – 2006), in Humenne ridge (2003 - 2006) and in Lučenec and Rimava Basin (2004 - 2008).

2. Shallow geothermal resources

Slovakia has favorable geothermal and hydrogeological conditions but not sufficient for direct electricity generation. Low-enthalpy aquifers suitable for district heating system are limited and available only in regions with specific geological structure. Nevertheless, shallow geothermal resources up to the depth of 400 m are suitable for heat extraction and utilization virtually everywhere and are not depend on accessing the extremely hot water and steam deeper inside the earth.

The most geographically extensive use of geothermal energy in the world and the most individual use is geothermal heat pump (GHP) technology which can access the moderate temperatures just beneath the earth's surface. This technology often called a "ground-source heat pump" (GSHP) usually to distinguish them from air-source units. The terminology for GHP and GSHP is interchangeable. Geothermal heat pumps should not be confused with air-source heat pumps, the common system used on buildings for the past few decades. Air-source heat pumps are much less efficient than GHP.

The shallow ground around us, the upper 5 m of the Earth, maintains a nearly constant temperature between 10°-16℃ during all se asons of the year. From 5m to 12-14 m temperatures decrease to 10-14℃. From ther eon to approximately 100 m, the temperature remains between 10 and 12℃. With f urther depth temperatures increase according to the geothermal gradient (average 3 ℃ for each 100 m of depth).

The use of shallow geothermal energy depends on the physical, thermal, and hydrogeological properties of the ground sources: density and porosity of the soil, thermal conductivity and thermal capacity of soils, natural field of temperature in ground, temperature gradient, groundwater level and direction and velocity of groundwater flow.[10] In the Central Europe the geothermal heat flow is in the range of 0,05-0,12 W/m^2, and is constant over 8760 h/year. The solar radiation can reach values above 1000 W/m^2, but only for a limited number of hours.

2.1. Heat pump technology

Energy of surrounding accumulated an immense amount of energy in the air, ground or water. These energy sources are from our point of view almost inexhaustible and absolutely free. Due to low level of their heat, they are in common way unusable for

[10] Katzenbach Rolf, Clauss Frithjof, Waberseck Thomas: "Geothermal Energy – Sustainable and Efficient Energy Supply and Storage in Urban Areas", The Sixth China Urban Conference, Bejing, China, March 2007

space heating and hot water heating. We can transfer that low temperature heat by means of so called heat pump to a higher level suitable for domestic and industrial use. The heat pump technology required to extract heat accumulated in the air, earth and water has been known for more than a hundred years.

2.1.1. Heat pump principle

The heat pump principle is based on the second law of thermodynamics formulated by Sadi Carnot, a French mathematician (1796-1832). The law says that heat naturally flows from an area with higher temperature to an area with lower temperature and not vice versa.

To be able to pump heat following this law from low-temperature source, the heat must be first absorbed into a low temperature stuff which is then transferred on a higher temperature level. Also we can define the heat pump like this:

The heat pump is a device which withdraws heat from surroundings (so called low-temperature sources) normally unusable and transfers it to a higher temperature usable for space heating and/or hot water heating[11].

2.1.2. Heat pump operation

Based on the principle, heat pumps can be divided into three kinds: compression, absorption and hybrid types. Most heat pumps work on the principle of a vapour compression cycle. The main components in such a heat pump are a compressor, an expansion valve, and two heat exchangers referred to as an evaporator and condenser.

The components are connected to form a closed circuit through which a coolant (working fluid) circulates. Firstly, in the evaporator the temperature of the liquid working fluid is kept lower than the temperature of the heat source, causing heat to flow from the heat source to the liquid. This makes the coolant evaporate. Next, vapour from the evaporator is compressed by the compressor resulting higher pressure and temperature. After that, the hot vapour comes into the condenser, where it condenses giving off useful heat. Finally, the high-pressure coolant is expanded to the evaporator pressure and temperature in the expansion valve. The coolant is returned to its original state and again enters the evaporator.

[11] ENERSOL EU Project: “Energy Saving and renewable energy in vocational education”, Centrum odborné přípravy technické, Praha, 2004

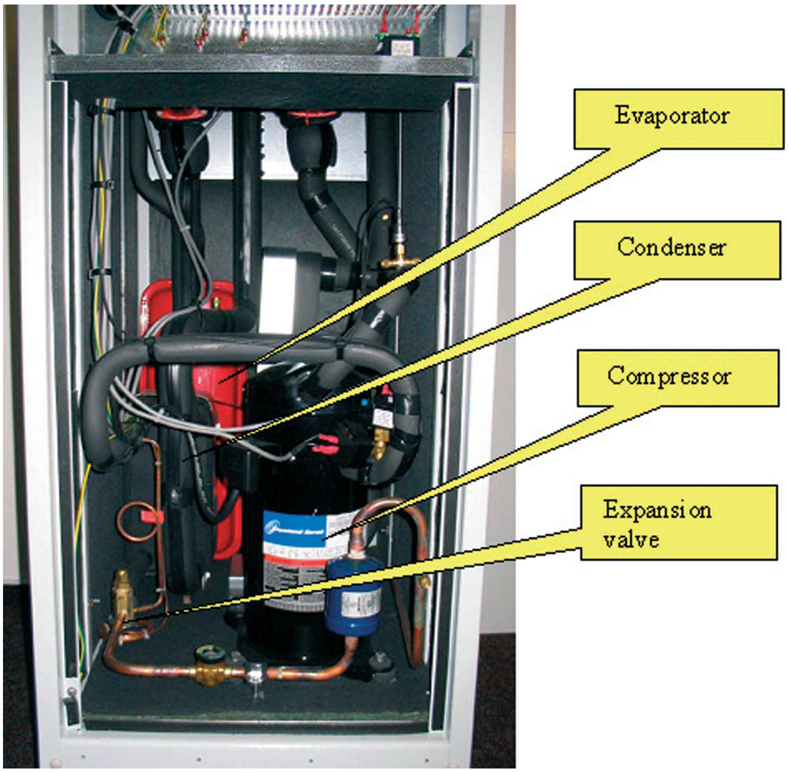

Figure 1: Principle of the vapour compression heat pump [12]

Absorption heat pumps are not very widespread. They are thermally driven which means that heat is used to supply working cycle rather than mechanical energy. Hybrid heat pumps are mixed systems and are tailored to match needs of a specific customer.

2.3. Heat pump parameters

We can rate heat pumps according to the following parameters.

Coefficient of performance (COP) - energy consumption necessary to ensure circulation of coolant depends first of all on the amount of transferred heat and on the temperature difference between the heating system and the low-temperature heat source. Coefficient of performance is a ratio between the heat power and the driving (electrical) energy necessary to operate the heat pump. Generally the COP varies between 2.5 and 4, i.e. 1 kWh of electrical energy consumed by the heat pump produces 2.5 – 4 kWh of heat.

COP = delivered heat energy (kW)/electrical input to compressor (kW) [13]

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[12] ENERSOL EU Project: "Energy Saving and renewable energy in vocational education", Centrum odborné přípravy technické, Praha, 2004
[13] Ochsner Karl: „Geothermal Heat Pumps, A guide for Planning & Installing", Earthscan London, 2008

The COP value depends on input temperature from the low-temperature heat source, final temperature of the heating system, chemical and physical qualities of the coolant and technical parameters of the heat pump.
The higher the temperature of the low-temperature heat source and the lower the temperature of the heating medium are, the higher the COP is. Conversely, the heat pump performance decreases with increasing gap between both temperatures.

Seasonal Performance Factor (SPF) - operating performance of an electric heat pump over the season is called Seasonal Performance Factor. It is defined as a ratio of the heat delivered and the total energy supplied over the season. It takes into consideration variable heating and/or cooling demands, variability of the heat source and temperature minima over the year.

Heating power is a sum of both input energy (heat moved from the evaporator to the condenser and heat developed in the compressor by transformation of electrical driving energy).

Cooling efficiency EER (efficiency of energy recovery) describes the cooling capacity of GSHP. The energy efficiency, as well as the operation costs of an air conditioning system or a heat pump in cooling operation, depends mainly on the required temperature difference. The EER is the corresponding performance coefficient:

EER = Cooling Capacity/Required Electrical Power [14]

In practice, ground source climate heat pumps require only a small temperature difference. In long-term operation, the collector area reaches a maximum of 25℃. The temperature difference between the cooling supply (15℃) and the brine ground collector (25℃) is only 10 K, which allows for a h igh COP and EER.

Operating modes - The heat pump can work in several operating modes.

Monovalent mode

The heat pump is the only source of heat. This mode is suitable for low-temperature heating with water temperature up to 65℃. Mostly t he heating system is not designed to cover all heat demand even at the lowest outside temperatures because the installation would be too large and the investment cost worthless high.

[14] Ochsner Karl: „Geothermal Heat Pumps, A guide for Planning & Installing“, Earthscan London, 2008

Bivalent mode

The heat pump is designed to cover needed heat demand up to a certain outside temperature (so called a bivalent point) and at lower temperatures another supplementary heat source „ helps“ (e.g. electrical boiler). This way the optimal ratio between investment and operating cost can be achieved.

2.4. Heat pump types

The heat pump system is determined by the kind of cooled and heated medium. The most common systems are: air-to-water, water (antifreeze)-to-water, ground-to-water.

2.4.1. Air-to-water heat pump

This type extracts energy directly from air which is either outdoor air or waste air from a ventilation system. There are two designs of air-to-water heat pumps: split (outdoor unit - the exchanger and the ventilator; indoor unit) or compact (all component in common case) (Figure 2.).

Figure 2: Principle of the air-to water heat pump (outdoor unit).

Heat pumps of this kind can operate usually at ambient temperatures up to – 20 °C and lower. But their performance significantly decrease with descending temperature. Air-to-water heat pumps have lower installation cost because no expensive adaptations of the surrounding are required. The dependence of performance on outside temperature heat pumps are sized to cover 60 – 70 % of a building heat loss, provided that at low temperature the heat demand is covered by supplementary source of heat (electric boiler or the original gas boiler).

2.4.2. Water-to-water heat pump

Distinguished according to possible water source (surface water, underground water).

2.4.2.1. Surface water

- Direct extraction of flowing water is possible. A suitable circulation pump is necessary to ensure water circulation.
- Indirect extraction heat from flowing water realizes via a system of collectors (1) (Figure 3) laid at the bottom of a watercourse. The primary circuit utilizes antifreeze, most often a brim, flow.
- Indirect extraction from still water - the heat exchanger down at the bottom (pond).

Figure no.3: Principle of the heat pump using a system of collectors

2.4.2.2. Underground water

The systems use two wells (Figure 4). From the suction well (1) water is pumped up and after cooling down (heat extracted) it is returned to the absorption well (2), which should be located at least 10 meters far from the suction well, or to a surface water. The cooled water must not be returned to the same well or to sewerage. Drilled wells in depth interval from 10 to 30 meters represent the biggest cost of investment.

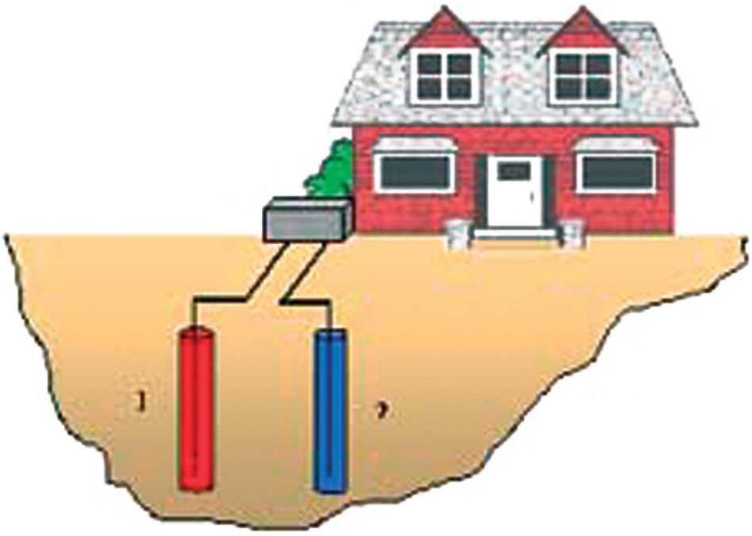

Figure 4: Heat pump using two wells

2.4.3. Ground-to-water heat pump

Utilization of energy penetrating toward the earth surface from the core and energy accumulated in surface by sunshine. The system is equipped either with ground (horizontal) collectors or drilled bore holes (vertical collectors).

2.4.3.1. Ground horizontal collectors

The source of heat is surface soil up to a depth of 2 meters (Figure 5). Paramount is the heat accumulated through direct sunshine, transfer of air, or rainfall. Heat from deeper ground layers is negligible due to its very low density (0.05 – 0.12 W/m^2). Usable amount of heat depends on sunshine, which is determined by the local climate, composition and quality of the soil. Ability of heat accumulation and thermal conductivity of soil increase with increasing moisture content in the ground, increasing amount of minerals, and decreasing number of air pores. Soil ability to give off heat varies from 10 to 4 W/m^2. Extracted power adequate to one meter of the pipe ranges from 10 W in sandy soil to 35 W in enough moisturized clay. Energy extracted should not exceed 50 – 70 kWh per year to ensure natural supply of energy. The ground collectors require a relatively large area – about triple of the heated area is needed.

Figure 5: Heat pump using ground collectors

2.4.3.2. Vertical borehole exchanger

Vertical arrangement is a suitable choice in locations where the area surface is limited such as in suburban residential areas. Vertical collectors are inserted to drilled holes deep up to 150 m and wide 100 – 150 mm. For each required 1 kW we need 10 – 30 of borehole length depending on the kind of subsoil (rock with underground water – dry sediments).

2.5. Classification of GSHP installations

The ground system links the heat pump to the underground and allows for extraction of heat from the ground or injection of heat into the ground. These systems can be classified generally as open or closed systems. In open systems the groundwater is used as a heat carrier, and is brought directly to the heat pump. In the closed systems heat exchangers are located in the underground (either in a horizontal, vertical or oblique fashion), and a heat carrier medium is circulated within the heat exchangers, transporting heat from the ground to the heat pump (or vice versa). A special case of vertical closed systems are "energy piles", i.e. foundation piles equipped with heat exchanger pipes.

The comprehensive scheme describing utilization of shallow geothermal energy for heating purposes is presented in Figure 6.

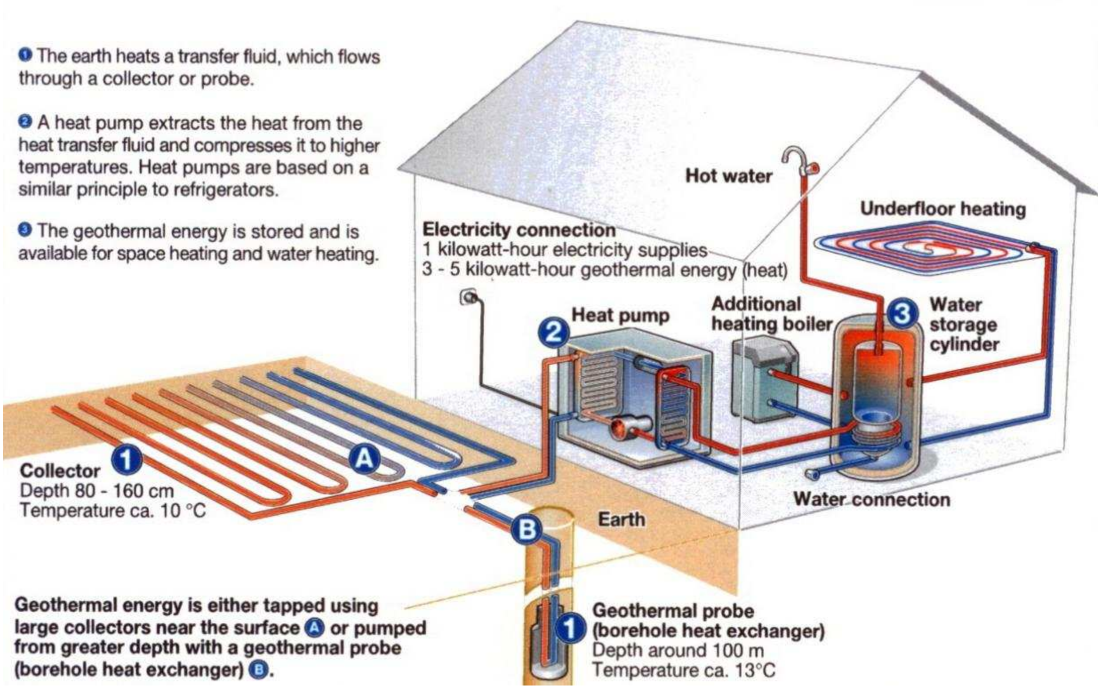

Figure 6: Heat from the earth – utilization of shallow geothermal energy

2.5.1. Groundwater wells

Main technical part of open systems are groundwater wells, to extract or inject water from/to water bearing layers in the underground "aquifers". In most cases, two wells are required "doublette", one to extract the groundwater, and one to re-inject it into the same aquifer it was produced from.

With open systems, a powerful heat source can be exploited at comparably low cost. On the other hand, groundwater wells require some maintenance, and open systems in general are confined to sites with suitable aquifers. The main requirements are sufficient permeability (production of the desired amount of groundwater) and appropriate chemistry (mineralization). Open systems tend to be used for larger installations.

2.5.2. Horizontal loops – surface heat collectors

The closed system easiest to install is the horizontal ground heat exchanger. Due to restrictions in the area available, in Western and Central Europe the individual pipes are laid in a relatively dense pattern, connected either in series or in parallel. For exploitation a smaller area at the same volume, these collectors are best suited for heat pump systems for heating and cooling, where natural temperature recharge of

the ground is not vital. Spiral forms, mainly in the form of the so-called "slinky" collectors are placed horizontally in a wide trench or vertically in a narrow trench.
The main thermal recharge for all horizontal systems in heating-only mode is provided for mainly by the solar radiation to the earths surface. It is important not to cover the surface above the ground heat collector.

2.5.3. Vertical loop – Borehole Heat Exchangers (BHE)

Due to the fact that temperature below the "neutral zone" (ca. 10-20 m) is relatively constant over the year, vertical ground heat exchangers - borehole heat exchangers are widely favored (Figure 7). The standard borehole heat exchanger is equipped by plastic pipes (polyethylene or polypropylene) which are installed in boreholes. The remaining space in the hole is grouted with a pump-able material.

- U-pipes, consisting of a pair of straight pipes, connected by a 180°-turn at the bottom. One, two or even three of such U-pipes are installed in one hole. The advantage of the U-pipe is low cost of the pipe material,
- Coaxial (concentric) pipes, either in a very simple way with two straight pipes of different diameter, or in complex configurations.

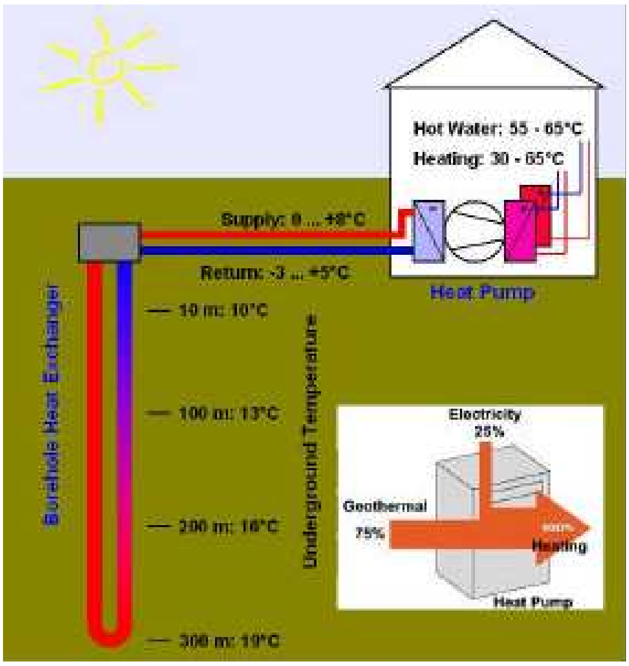

Figure 7: Basic scheme of BHE installation

2.6. Site evaluation for GSHP

Due to the fact that shallow ground temperatures are relatively constant, GSHP can be effectively used almost anywhere. However, the specific geological, hydrological, and spatial characteristics of particular land will help to local system supplier and installer determine the best type of ground loop for one site:

2.6.1. Site Investigation

One factor in the choice of system selected is the ground conditions beneath the site, in particular the nature of the soils and rock, groundwater and the potential of contamination (and cross- contamination). Therefore, it is prudent to undertake an appropriate ground investigation prior to the installation phase in order that the correct system can be selected and the ground array designed (e.g. Cone Penetration Testing). Such information can also be used to optimize the design and construction of the proposed development. This can often offset the costs of the installation and help in reducing the potential risk of construction downtime due to 'unforeseen' ground conditions experienced in some 25% of conventional ground works and construction projects.

2.6.2. Ground Temperatures

Traditional geothermal systems have utilized 'true' geothermal heat derived from extracting water from or pumping water down into 'hot' rocks. In general, the average mean ground surface temperature is exhibited by the subsurface ground conditions normally to depths of up to 100 m. Typically, from round level to 5 m depth vary seasonally between 12 and 15℃. From 5 m to 12-14 m temperatures decrease to 10-14℃ [15]. From thereon to approximately 100 m, the temperature remains between 10 and 12℃. Regardless, there is t herefore little advantage in installing systems to extract heat from great depth.

2.6.3. Geology

Factors such as the composition and properties of soil and rock parameters (which can affect heat transfer rates) require consideration when designing a ground loop. For example, soil with good heat transfer properties requires less piping to gather a certain amount of heat than soil with poor heat transfer properties. The amount of soil available contributes to system design as well — system suppliers in areas with

[15] McCray Kevin, Guidelines for the construction of vertical boreholes for closed loop heat pump systems, , National Ground Water Association, 2004

extensive hard rock or soil too shallow to trench may install vertical ground loops instead of horizontal loops.

2.6.4. Hydrology

Ground or surface water availability also plays a part in deciding what type of ground loop to use. Depending on factors such as depth, volume, and water quality, bodies of surface water can be used as a source of water for an open-loop system, or as a repository for coils of piping in a closed-loop system. Ground water can also be used as a source for open-loop systems, provided the water quality is suitable and all ground water discharge regulations are met.

Before installation of open-loop system, the system supplier, installer and contractor must fully investigate local hydrology. It is necessary to avoid potential problems such as aquifer depletion and groundwater contamination. Antifreeze fluids circulated through closed-loop systems generally pose little to no environmental hazard.

2.6.5. Land Availability

The amount and layout of surveyed land, landscaping, and the location of underground utilities or sprinkler systems also contribute to the system design. Horizontal ground loops (generally the most economical) are typically used for newly constructed buildings with sufficient land. Vertical installations or more compact horizontal installations are often used for existing buildings because they minimize the disturbance to the landscape.

The thermal conductivity of the ground also needs to be determined as part of the investigation to provide realistic energy profiles for the design of the ground array.

2.7. General design of GSHP system

The field of application of GSHP commonly comprises the space and domestic water heating and if required, space air-conditioning to a wide range of building types and sizes. GSHP are particularly suitable for newly built as the technology is most efficient when used to supply low temperature distribution systems such as underfloor heating. They can also be used for retrofit especially in conjunction with measures to reduce heat demand. They can be particularly cost effective in areas where natural gas distribution is not available or for developments where there is an advantage in simplifying the infrastructure provided.

2.7.1. Source of heat selection

The starting point for the choice of the system is always the output, i.e. the heat to be extracted from the ground or, for cooling, the heat to be dissipated in the ground. During planning, the most appropriate heat source for the site must be selected and the heating system and auxiliary equipment chosen according to this. The two most frequently used are horizontal or vertical ground heat exchangers. The choice of horizontal or vertical ground heat exchangers is dependent on the geological conditions of the site and the required space, or by constructional circumstances. A good knowledge of geology and hydrogeology allows the thermal and hydraulic properties of the substrate to be determined and thereby allows the most suitable energy extraction technique to be chosen.

2.7.2. Heat pump sizing

The main technical criteria for the equipment are:

- designed output of the heat source system
- output of the heat pump
- annual operating hours and full load hours
- peak load of the heat source

Projecting of GSHP system comprehends many factors which must be taken into account in order to determine the required length of the ground loop. The first and the most important step in the design of a GSHP installation is accurate calculation of the building heat loss, annual energy consumption profile and the domestic hot water requirements. This should estimate the design load i.e. peak demand - the coldest winter period for heating season and hottest summer season for air-conditioning. The ‘balance point’ of system should respect also the heat gain. Design should be based on the loads of the whole not just peak heat or cooling times. The calculation must make provision indoor conditions, distribution temperature and climate conditions.

2.7.3. Distribution systems

Typical GSHP input water temperature range from -5°C to + 12℃ for pumps delivering heat, with maximum output come up to 65°C.

The efficiency of a heat pump is a function of the difference between the temperature of the source and the output (i.e. the temperature of the distribution system). The smaller this temperature difference, the higher the coefficient of performance (COP) of the heat pump will be. For example, if the distribution temperature required falls from 60℃ to 40℃, the C OP can increase by more than 40%. It is therefore important to use the temperature distribution system with the lowest requirement.

2.7.4. Space heating

Table 4 shows the supply temperatures required for a range of domestic heating distribution systems[16].

Table 4: Typical delivery temperatures for various heating distribution systems

Distribution System	Delivery Temperature ℃
Underfloor heating	30 – 45
Low temperature radiators	45 – 55
Conventional radiators	60 – 90

For new buildings where high insulation levels result in low heating demand, possible distribution options include low temperature air distribution systems, low temperature water-based systems or underfloor heating. The most efficient type of space heating to use with a GSHP system is underfloor heating. Ideally the system should be designed to give floor surface temperatures no higher than 26℃ and should be sized using a water temperature difference of about 5℃.

2.7.5. Cooling

Most water-to-air heat pumps are reversible so a forced air distribution system can readily be adapted to provide cooling as well as heating. A reversible water-to-water heat pump coupled to an underfloor distribution system can also be designed to supply space cooling in summer. Even with water/water heat pumps designed for heating only, a limited amount of ‘passive’ summer cooling can be provided by direct use of the ground loop, for example by bypassing the heat pump and circulating fluid from the ground coil through a fan convector.

2.7.6. Design overview

The most significant direct benefits of GSHP systems are the reduced energy requirement and the use of a sustainable energy source. If the system is designed appropriately, the mode of operation can be reversed to cool the building and

[16] BRE´s Sustainable Energy Center: Domestic Ground Source Heat Pumps: Design and installation of closed-loop systems, Housing Energy Efficiency Best Practice Program, London, 2004

replace the energy previously taken from the ground. However, most GSHP systems can only have limited cooling capacity because the main heat delivery system includes the use of underfloor or radiator heating.

In addition, indirect benefits of GSHP systems include low environmental impact with a significant reduction of emissions of CO_2 and other pollutants. As well as reducing purchased energy consumption and resulting in low CO_2 emissions, GSHP have a number of other environmental and operational advantages: high reliability (few moving parts, no exposure to weather), high security (no visible external components to be damaged), long life expectancy (typically 20-25 years), low noise, low maintenance costs (no regular servicing requirements), no boiler or fuel tank, no combustion or explosive gases within the building, no air flue or ventilation.

3. Resources of low-potential energy

The term “low-potential energy” in relation to heat pumps refers to all environmental energy which, in normal conditions, cannot be further utilised by classical systems. The low-potential environmental energy sources, suitable for utilization by heat pump systems in Slovak conditions are air, surface water, ground water, geothermal water and soil[17].

3.1. Ambient air

Ambient air is available everywhere, although it varies with location and time. The temperature level fluctuates with climate and season. Changes of temperature during the year, but also during the day, are significant. The disadvantage is that in winter time, when demand for heating increases, the temperature of the source decreases, with the risk of ice coating in the evaporator, necessitating automatic defrosting. Regulation is complicated due to large temperature changes and the system can be noisy as an air-fan is needed for the external heat exchanger[18].

Slovakia has a continental climate, with four seasons. Winters are typically cold and dry, while summers tend to be warm and humid (Maps of annual temperatures, Appendix 4). The average daily temperature e.g. in Bratislava ranges between -3° to 2 °C in January and 16° to 26 °C in July[19].

3.2. Surface Waters

Availability depends on particular climate conditions. Daily temperature level ranges from 0 to +15 °C; temperature fluctuations are more pronounced during the year. Surface waters cannot be used in temperatures lower than 3 to 4 °C, since there is a probability of their freezing on the heat pump evaporator. Another problem is the risk of corrosion and inadequately low temperature level in winter months necessitating the installation of an additional heat source for heating[20].

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[17] ENERSOL EU Project: “Energy Saving and renewable energy in vocational education”, Centrum odborné přípravy technické, Praha, 2004

[18] VÍGLASKÝ, J.: Možnosti pre extenzívne uplatnenie biomasy v sektore energetiky Slovenska, prezentácia v rámci konferencie Vykurovanie 2005, Tatranské Matliare

[19] MATEJ P., PETRAS D.: Possibilities of Applying Heat Pumps in Slovakia, “8th IEA Heat Pump Conference”, Las Vegas, USA, May/June 2005

[20] MEČÁRIK, K.., HAVELSKÝ, V., FÜRI, B.: Tepelné čerpadlá, ALFA SNTL, Bratislava 1988

Where surface waters are utilised, it is necessary to consider the ecological impact of cold water returning to the flow (for biological reasons, a minimum of approx. +2 ℃ is required), as well as the growth of ecological sedimentary deposits on heat exchangers and the potential for corrosion and incrustation.

3.3. Groundwater

Slovakia has favourable hydrogeological conditions with large supplies of groundwater. It has groundwater of all types, which creates a constant water level.

Groundwater is the fundamental source of natural resources and the most important source of drinking water supplies. Utilization of groundwater resources must be regulated to ensure their continuous renewal.

The basic unit for evaluation of groundwater balance is the hydrogeological region with its subsequent classification into sub-regions. According to the accepted hydrogeological regionalization, the territory of Slovakia is divided into 141 hydrogeological regions (areas with similar hydrogeological conditions, type of aquifer and groundwater cycle). A map of utilizable groundwater volumes in hydrogeological regions of Slovakia in 2002 is presented in Appendix 5.

There are 101 groundwater bodies identified in Slovakia including 16 bodies in Quaternary sediments, 59 bodies in pre-Quaternary sediments and 26 geothermal water bodies[21].

The largest groundwater resources are located in the quaternary sediments of the upper region of "Žitný Ostrov" and in the limestone - dolomite rocks of the mountains in Central Slovakia and the Slovak Karst (Slovenský Kras). Considerably lower amounts can be found in East Slovakia and southern Central Slovakia.

The largest available groundwater resources in the whole of Europe (24.8 $m^3.s^{-1}$) [22] are documented in the Danube Lowland (Žitný Ostrov), consisting of massive quaternary-pliocene layers of gravel and sand, where the highest drinking water abstraction is recorded. This water is distributed through long-distance distribution

[21], [22] Water Research Institute Bratislava: Report on Water Management in the Slovak Republic in 2007, MINISTRY OF ENVIRONMENT OF THE SLOVAK REPUBLIC, Bratislava 2008

systems to the regions of Central Slovakia. Based on water management balance data, the natural resources of Slovakia amount to 146.7 $m^3.s^{-1}$. Groundwater resources represent 76,830 $l.s^{-1}$, i.e. more than 52 % of natural resources[23].

Recently, long-term maximum water levels and maximum well capacities have been exceeded more frequently and well capacities and water levels have more often fallen below the minimum. This may be a result of extreme weather events (droughts, floods and storm rainfalls).

As far as groundwater quality is concerned, the most polluted areas are lowlands. The least polluted is the water in the alluvial deposits of the upper and middle parts of the Váh, Hron, Poprad nad Hornád river basins and the groundwater accumulated in the Mesozoic carbonates of mountain ranges.

Basic information on the groundwater regime in Slovakia is included in the Hydrological Yearbook produced by the Slovak Hydrometeorological Institute Bratislava (State Water Management Balance (SWMB) – section Groundwater) based on monitoring of groundwater level and well yields at monitoring sites in the Institute's network.
Most of the monitoring facilities are situated in quaternary sediments and only a minority of them are located in pre-quaternary rock formations from sedimentary neogene up to crystalline complex.

Ground water resources include ground water designated as natural healing water resources, natural mineral water resources or mining water under the special provisions. The basic register of mineral springs lists more than 1600 mineral springs. A specific group of natural mineral waters includes natural healing waters used for balneal-therapeutic purposes, in health care facilities and natural spas (managed by the Ministry of Health - Spas and Mineral Springs Inspectorate).

The need to protect important natural healing waters has led to the establishment of protection zones where activities with potentially negative effects are restricted or prohibited. In the Stage II and III protected zones utilization of ground waters for energy purposes, including heat pump installations is significantly restricted.

[23] Water Research Institute Bratislava: Report on Water Management in the Slovak Republic in 2007, MINISTRY OF ENVIRONMENT OF THE SLOVAK REPUBLIC, Bratislava 2008

The suitability of a water-water heat pump depends on the characteristics of a particular location.

For HP purposes the mineralization of ground water must not exceed limit 300 mg/l (Table 5). The concentration of certain substances has a significant influence on the corrosion resistance of heat exchangers (distribution heat exchanger copper or nickel brazing).

Table 5: Mineralization requirements of ground water for HP purposes [24]

Index	Unit	Heat exchanger copper brazing	Heat exchanger nickel brazing
pH value		7 – 9	6 – 10
SI – saturation index	δ	-0,2 <0<+0,2	unspecified
Total water hardness	°dH	6 – 15	6 – 15
Conductivity	µS/cm	10 … 500	unspecified
Filterable substances	mg/l	> 100 °C chlorides are i naccessible	
Free chlorine	mg/l	< 0,5	< 0,5
Sulphureted hydrogen H_2S	mg/l	< 0,05	unspecified
Ammonia (NH_3/NH_{4+})	mg/l	< 2,0	unspecified
Sulphate	mg/l	< 100,0	< 300,0
Hydrogen carbonate	mg/l	< 300,0	unspecified
Hydrogen carbonate/sulphate	mg/l	> 1,0	unspecified
Sulphide	mg/l	< 1,0	< 5,0
Nitrate	mg/l	< 100,0	unspecified
Nitride	mg/l	< 0,1	unspecified
Soluble iron Fe	mg/l	< 0,2	unspecified
Manganese Mn	mg/l	< 0,2	unspecified
Free agresive CO_2	mg/l	< 20,0	unspecified

[24] Pinka J., and Jágerová B.,: Možnosti využitia tepelných čerpadiel pre vykurovanie rodinných domov a bytov (The possibilities of heat pumps utilisation for family houses and flats fumigation), In: Acta Montanistica Slovaca Ročník 11 (2006), mimoriadne číslo 1, s. 133-136

Ground water is especially suitable as a heat source for heat pumps because it has a constant temperature of 8 to 12 ℃ even where outside temperatures are low. Because of this pumps can achieve an average yearly coefficient of performance of app. 4[25].

To operate a heat pump, the yield of the groundwater source must be within the minimum range from 0,5 to 1,5 l/s. In some locations a sufficient source of ground water with a balanced yield throughout the year could be a crucial factor. Table 6 presents required yield of groundwater sources depending on heat pump capacity.

Table 6: Required yield of groundwater sources depending on HP capacity.[26]

Output from water demand	**HP COP 3,0**	**HP COP 4,0**	**Flow of water, cooled in 4 K**		**Flow of water, cooled in 6 K**	
[kW]	**[kW]**	**[kW]**	**[l/min]**	**[m^3/hour]**	**[l/min]**	**[m^3/hour]**
3	4,5	4	11	0,6	7	0,4
5	7,5	6,7	18	1,1	12	0,7
8	12	10,7	29	1,7	19	1,1
10	15	13,3	36	2,2	24	1,4

There can be one or two drills (two where water is returned to the ground). The drill through which the water is re-injected into the ground must be situated along the stream of the flowing groundwater above the drill from which the groundwater is drawn.

Water/water heat pumps use well water as the heat source and are the most efficient solution and offer the fastest return on investment costs.

3.4. Geothermal Waters

Geothermal water is groundwater which serves as a medium for the accumulation, transport and exploitation of heat from a rock environment. Geothermal water has its

[25] Pinka J., and Jágerová B.,: Možnosti využitia tepelných čerpadiel pre vykurovanie rodinných domov a bytov (The possibilities of heat pumps utilisation for family houses and flats fumigation), In: Acta Montanistica Slovaca Ročník 11 (2006), mimoriadne číslo 1, s. 133-136

[26] Bříza K., Bujok P., Ryška J., and Kunz A.,: Tepelná čerpadla - jedna z možností alternativních zdrojů energie k vytápění objektů (Geothermal heat pumps as one ofpossibilities of an alternative energy used for objects heating objects in Czech Republic), In: Acta Montanistica Slovaca Ročník 12 (2007), číslo 2, 163-167

own specific features that makes it different from ordinary groundwater. It is primary and almost only quality is its thermal-energetic potential.

The results of geological research and surveys show Slovakia to be an above average region for geothermal activity. According to the Muffler classification[27], the territories of the central part of the Inner Western Carpathian Mountains, together with the Slovak Ore Mountains (Slovenské Rudohorie), the peri-klippen zone in Western and Central Slovakia, and the western part of Outer Western Carpathians are regions with normal (average) density of thermal flow and geothermal gradient. The northern part of the Pannonian basin (the Danube, South-Slovak, and East-Slovak Basins, and central-Slovak neovolcanites) are linked to recent volcanism. Their geothermal activity is above average. Measured by the average density of thermal flow ($q \approx 82$ mW/m^2), the territory of Slovakia has exceptional geothermal activity. Similarly, also the average value of the geothermal gradient is higher here than the world average (approx. 38 °C/km). The temperature at a depth of 1000 m is less than 20 °C in the Komárno Reverse Fault and more than 70 °C in the South Slovakian and East Slovakian Basins.

So far in the territory of Slovakia has been registered 132 geothermal sources (drills, wells, etc.) with water temperature from 15,7 to 126,0 °C. Geothermal drills have been carried out in vertical intervals of 40,0 to 3 700 m, while geothermal water reservoirs occur at depths ranging between 200 and 5 000 m (with exception of welling areas). The temperature of these waters ranges from 20 to 240 °C.

Based on the available information, 26 potential areas with geothermal energy – geothermal water occurrence have been located in Slovakia. Between 1971 and 1991, were carried out 61 geothermal drills in 14 areas. Between years 1991 to 1999 were made 5 drills. The majority of drills (34) were performed in the central depression of the Danubian Basin.

A total of 58 drills have examined around 218 MW, which represents approximately 1 190 l/s of geothermal waters with temperature of 20 to 126 °C at usage of temperature gradient to the referential temperature of +15 °C. Approximately 390,5 MW remains to be explored by drillings for renewed usable volume, and approx. 4 868,2 MW for non-renewed usable volume, which together accounts for 5 258,7 MW. The overall energy potential of geothermal waters in the given areas (verified, probable, and prognostic) represents around 5 538 MW. At 50 % effectiveness of utilisation it corresponds to circa 2 769 MW of thermal power potential. In spite of

[27] Atlas of Geothermal Energy of Slovakia. Dionýz Štúr Institute of Geology, Bratislava, 1995

the fact that this potential is dispersed, it is still significant. Geothermal waters are used in geothermal energy systems in 14 locations for agricultural purposes – as heat supply for heating of greenhouses, plastic greenhouses, and for warming soil; in 6 locations as heat supply for space heating of housing estates, flats, public buildings, sport halls and restaurants; in 3 locations for preparation of technological water for fish farming; and in 30 locations for heated pools for recreational purposes.

The total volume of geothermal energy used in 36 locations represents a heating capacity of 132,30 MW at 846,4 l/s yield of geothermal water. The overall area of greenhouses and plastic greenhouses heated by heat from geothermal drills represents app. 27,6 ha [28].

Suitability of geothermal heat pumps depends on a location with a constant temperature level between 15 and 90℃. They are sui table for usage in place, or in the vicinity. A disadvantage is the possibility of corrosion and incrustation, depending upon mineralisation. The advantages are simple regulation of the heat pump´s circuit and achievement of high power values [29].

3.5. Soil – underground collector

This type of HP utilization is suitable only for locations with open space nearby. The temperature level ranges between –5 to +15℃ with r elatively small variations. Fitness for mass utilisation is limited by geological conditions (eg unusable in rocky soils). Problematic issues include repairs to spiral tubes buried underground and the impact of temperature reduction on vegetation.

Thermophysical features of soil[30], such as density, specific thermal capacity, and heat conductivity index vary with soil types. The difference in the heat conductivity index value between dry and humid soil can be very large – from 0.25 W./m.K to 2.5 W/mK. If the soil freezes due to a fall in the temperature near the exchanger, an air gap may be created around the evaporator pipeline when defrosting occurs. This negative impact can be reduced by making pipelines from elastic material, which adapt to movements of the soil

[28] PETRÁŠ, D. a kol.: Nízkoteplotné vykurovanie a obnoviteľné zdroje energie, Jaga, Bratislava 2001

[29] MEČÁRIK, K.., HAVELSKÝ, V., FÜRI, B.: Tepelné čerpadlá, ALFA SNTL, Bratislava 1988

[30] Sidorová M., and Wittenberger G.,: Využitie nízko-potenciálnej tepelnej energie Zeme v tepelno-čerpadlových systémoch (Low-potencial Earth Thermal Energy Utilization in Heat Pump Systems), In: Acta Montanistica Slovaca Ročník 11 (2006), No. 1, 166-171

mass, or by placing the pipelines in a gel mass with high water content, such as bentonite. Underground collectors are laid 1 to 2 m under the surface. For transmission of 1 kW of heat input approximately 125 m of spiral tubes are needed; with humid soil this length reduces to 40 m; with usage of bentonite it is circa 13 m. Or, by a different evaluation: from 1 m^2 of soil it is possible to gain 10 to 40 W, depending upon the soil type[31]. Table 7 illustrate relation between area of surface collector and soil thermal conductivity.

Table 7: Relation between area of surface collector and thermal conductivity of soil

Type of soil	Heat intake of extraction site (W/m^2)	Required area of surface collector (m^2) (HP output 5kW)
Clay (heavy water-bearing bed)	30-40	165-125
Gravels, sands (waterlogged rocks)	25-30	200-165
Extra moist adhesive soil	20-25	250-200
Moist adhesive soil	15-20	330-250
Dry mould soil	10-15	500-330

The output of heat pumps with a surface collector is very similar to heat pumps using a drill hole. However, the cost of their installation is much lower as the price of the excavation work for surface collectors is much lower than the price of hole drilling. Ground/water type heat pumps using areal ground collectors are in particular demand due to their good price/performance ratio.

3.6. Ground – vertical loop

A heat pump using a vertical borehole has a higher efficiency and is particularly suitable for houses with less available land. In places where the land dimensions do not permit the use of areal collectors, vertical heat exchangers known as boreholes are used. The number of holes depends on the size of the building to be heated. The depth of vertical borehole exchangers depends on the required COP of the installed HP, the thermal conductivity of the rocks and the surface heat flow.

The average value of heat flow on the majority of Slovak territory is 78 mW/m^2. The highest anomalous regional values are found in the Eastern Slovakian basin and the Central Slovakian neovulcanite structure (average heat flow over 100 mW/m^2).

[31] Sidorová M., and Wittenberger G.,: Využitie nízko-potenciálnej tepelnej energie Zeme v tepelno-čerpadlových systémoch (Low-potencial Earth Thermal Energy Utilization in Heat Pump Systems), In: Acta Montanistica Slovaca Ročník 11 (2006), No. 1, 166-171

Heat flow density has so far been calculated in 136 wells[32]. The mean value calculated as an arithmetic mean of all data is 82,1 ± 20,5 mW/m^2. (Table 8).The distribution of heat flow density values is illustrated in map and histogram of surface heat flow density (Appendix 7).

Table 8: Heat flow density in main province, sub-provinces and areas

Main province Sub-provinces and areas	Heat flow (mW/m^2)				
	N	Q_{min}	Q_{max}	Q_{mean}	SD
West Carpathians	136	40,6	121,6	82,1	20,5
Outer Flysch Belt	2	56,8	72,5	64,7	11,1
Slovenske rudohorie	3	50,7	68,3	62,0	9,8
Core mountains	5	52,7	80,0	69,9	11,2
Intramountane basins	18	52,0	79,4	65,9	8,3
Central Slovakian Neovolcanites	11	74,0	109,0	94,3	12,6
Southern Slovakian Basin (E-part)	4	59,9	63,4	62,2	1,6
Vienna Basin	11	40,6	69,0	44,0	10,2
Danube Basin	43	61,2	99,0	78,5	8,8
Trnava embayment	3	61,0	67,9	65,2	3,7
Topoľčany embayment	1	-	-	67,8	-
Eastern Slovakian basin	30	82,1	121,6	110,9	9,5
Košice basin	4	87,6	109,9	94,9	10,5
Eastern Slovakian Neovolcanites	1	-	-	73,3	-

The length of underground collectors ranges between 70 to 120 m depending on the local geological structure and ground conditions. Generally, the deeper the boreholes and the more stable the ground temperature is the higher the thermal efficiency, however the higher the installation cost as well. Hence it is preferable to provide deeper boreholes (140 – 150 m) with a minimum distance of 10 m between single boreholes to avoid thermal interference.

The technology of drilling works varies, depending on the borehole type and geological conditions. The drilling diameter of water well boreholes is usually more than 220 mm and for geothermal heat exchangers a minimum diameter of about 120 – 140 mm is usual.

The most suitable drilling technology is rotary percussion drilling using down-the-hole hammers with airlift. For large diameter water wells, the reverse rotary method

[32] Atlas of Geothermal Energy of Slovakia, Bratislava 1995

is well suited. This technique allows reliable removal of drill cuttings through the pipe and helps to keep the borehole wall stable.

Heat pumps using the ground heat from a drill hole are one of the most efficient types of heat pumps and their yearly coefficient of performance is 3 – 3,5. The only disadvantage of this solution is the higher initial investment due to the higher cost of drilling works. The installation can also be more expensive in certain geological conditions e.g. where the subsoil is rocky. However, this type of heat pump is convenient, especially in colder areas.

Table 9 presents the parameters for borehole depth dimensioning according to rock formations and required COP of heating system.

Table 9: Parameters for dimension of borehole depth regarding to rock formations is Slovakia and required COP of heating system.[33]

Parameters for dimension of borehole depth	Thermal conductivity	Specific output	Depth of borehole for HP with COP 3	3,5
Rock	[W/(m.K)]	[W/m]	[m/kW]	[m/kW]
Dry soft rocks	<1,5	20	33	36
Firm rocks or water logged	1,5 to 3,0	50	13	14
Firm rocks with high thermal conductivity	>3,0	70	9,5	10
Dry gravels and sands	0,4	<20	>33	>33
Watered gravels and sands	1,8-2,4	55-65	10-12	11-13
Moist loams and clays	1,7	30-40	17-22	18-24
Massive limestone	2,8	45-60	11-15	12-16
Sandstone	2,3	55-65	10-12	11-13
Granites	3,4	55-70	9,5-12	10-13
Basalt	1,7	35-55	12-19	13-20
Gneisses	2,9	60-70	9,5-11	10-16

[33] Ryška J.,: Dimenzování vrtů pro tepelná čerpadla (Dimensioning of Boreholes for Geothermal Heat Pumps) , In: Acta Montanistica Slovaca Ročník 9 (2004), No. 3, s. 269-273

4. The legislative framework and administrative aspects of GSHP installations

The utilization of ground source energy recovered through horizontal trenches or vertical boreholes as a primary source of low-potential energy is subject to legislation.

The legislative framework covering heat pump systems using ground water resources and GSHP extraction the heat of the earth includes:

a) Mining legislation – drilling of boreholes deeper than 30 m e.g. The provisions of the Mining Act[34] apply whatever the hydrogeological and ground source exploited by the borehole.

b) Geological legislation – covers planning, provision and evaluation of hydrogeological works. The Geological Act[35] applies to complex hydrogeological survey procedures including drilled water wells, hydrodynamic testing, chemical analysis of waters and final interpretation of results.

c) Legislation covering water management – treatment underground using underground water. The Water Act[36] applies to the utilization of underground waters as well as utilization of the energy potential of waters.

d) Building legislation – Under the terms of the Water Act it is compulsory to obtain building permission for "water constructions" for water pumping or energy purposes.

The administrative procedures, fall under the responsibility of various official bodies consist of the following statutorily required procedures:

1. Permission for ground water abstraction for special utilization including ground water heat pump installations.

a) Relevant legislation: Water Act
Responsible authority: District office of Environmental Protection, governed by Ministry of Environment

c) Scope of application: The definition of water management includes water management of all ground waters which occur below the surface in the saturated zone in proximate contact with soil or sub-soil. This definition also includes groundwater serving as a medium for the accumulation, transport and exploitation of heat from the surrounding rock (geothermal waters).

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[34] Mining Act no. 44/1988 Coll.
[35] Geological Act no. 569/2007 Coll.
[36] Water Act and Decree of the Ministry of Environment No. 221/2005 Coll.

d) Coverage: installation of ground water heat pumps.

e) Application submitted by: designer employed by contractor (supplier of HP installation) empowered by the owner of the property (customer).

f) Applicant duties: presentation of hydrogeolgical study conducted by an authorized hydrogeologist. The Geological Act stipulates that the hydrogeological study must include exploratory research, showing the frequency of ground water occurrence and its circulation, description of aspects of the hydrogeological conditions, and the results of hydrodynamic tests, laboratory works and sampling. The conclusion must contain a quantification of the underground water inlet, and describe quality requirements, risk indications and state how other problems and considerations will be addressed (protective zones, infrastructure collisions, etc.).

2. Permit for drilling works performed for utilization of thermal (heat) energy of the earth for the purposes of heating and cooling.

a) Relevant legislation: Mining Act.

b) Responsible authority: Regional Mining Office governed by Ministry of Economy

c) Scope of application: Drilling works at depths greater than 30 m are defined as a permanent interference with the Earth's Crust. Surface exploration and exploitation drilling works using mining methods are also covered.

d) Coverage: vertical boreholes for water and ground heat pumps.

e) Application submitted by: drilling contractor (supplier of drilling services).

f) Applicant duties: Informing relevant authority prior to the start of technical works, presentation of technical plan for drilling works and a report on termination of the drilling works.

3. Permission for building a water construction (water well) to allow inlet of water for energy purposes.

a) Relevant legislation: Regional planning and building code [37]

[37] Regional planning and building code no. 50/1976 Coll.

b) Responsible authority: Municipal Office under the supervision of the District Office of Environmental Protection governed by Ministry of Regional Development.

c) Scope of application: Approval of building works, modification to structures and final building designs on the basis of project documentation completed by an authorized person as prescribed in the Water Act regulations.

d) Coverage: ground (surface) water heat pumps

e) Application submitted by: contractor (supplier of HP installation) empowered by the owner of the property (customer).

f) Applicant duties: Under the terms of the Water Act it is obligatory to obtain permission to build a water construction for ground water abstraction. The fee for using a water inlet for energy abstraction is 0,0012 EUR/m^3 with the exception of close cycle systems (discharging ground water to the same underground aquifer).

5. Borehole heat exchangers

Traditional primary energy source for heat pumps are vertical geothermal boreholes. In Central Europe, drills for heat pumps are the most common technique of low-potential geothermal energy extraction. In spite its higher purchase price most investors are persuaded by the fact that this is a source absolutely independent of any weather impact. Another assured advantage of drills is the possibility to use their constant temperature (8 – 12 ℃) for building cooling in summer season. By cooling the drills we also supply them with higher thermal energy, which is re-evaluated in form of regeneration of these drills in winter season. In fact, we can speak about interesting settlement of thermal energy for utilisation in winter months.

To construct the geothermal drill correctly and from material designed to this, the whole work must comply with European norms and regulations. Adhering to the qualitative level is – so far – responsibility of each realisation company. It is therefore important that both layman and expert know the possibilities which usage of drills could bring for obtaining energy. Differences in execution and economic return of drills are considerable due to the different performance and material utilization.

5.1. Design principles

The design of borehole heat exchangers for residential installations or smaller commercial applications is commonly provided by the empirical values, available table data or guidelines. For defined power output required length of vertical ground source exchanger depend upon thermal properties of properties of ground. The main underground parameter for design of borehole heat exchanger is the thermal conductivity. This value can be estimated from the type of rock at the particular site or can be measured directly in situ. Typical value of the specific heat extraction range between 40 – 70 W/m[38] and depend upon geology (thermal conductivity), operating factor (hours/year), number of existing boreholes, etc. According to determined capacity of the heat pump evaporator, the required length can be calculated:

[38] Sanner B. and Andersson O.,: Drilling methods for shallow geothermal installations, International Summer School of Direct Application of Geothermal Energy, Oradea/Romania, 2001

Length (m) = HP evaporator capacity (W)/specific heat extraction rate (W/m) [39]

In the case of spacious borehole heat exchangers for heating, cooling and hot water delivery (overall annual operation more than 2000 hours), calculations must determine required number and depth of particular boreholes and total length of vertical loops. For this application it is recommended to provide deeper borehole exchangers with smaller distance between boreholes.

The modern and most sophisticated designs tools - numerical simulation and computer methods are also available but still infrequent in Slovak market. In USA and Western Europe special PC programs and software are very common for massive commercial and industrial installations. Numerical models and simulations solve the most difficult design problems for ground water applications.

There are a variety of proprietary software packages available for detailed modeling of heat demands and correct sizing of the ground array (Table 10).

Table 10: Review of software packages for modeling and sizing of GSHP[40]

Software product	**Vendor**
CLGS	Intl. Ground-Source Heat Pump Assoc., Stillwater, OK, USA
ECA	Elite Software, Inc., Bryan, TX, USA
Earth Energy Designer (EED)	University of Lund, Sweden
GEOCALC	Ferris State University, Big Rapids, MI, USA
GeoDesigner	ClimateMaster, Oklahoma City, OK, USA
GchpCalc	Energy Information Services, Tuscaloosa, AL, USA
GL-Source	Kansas Electric Utility, Topeka, KS, USA
GLHEPRO	Intl. Ground-Source Heat Pump Assoc., Stillwater, OK, USA
Ground Loop Design	GBT, Inc., Maple Plain, MN, USA
GS2000	Buildings Group, Natural Resources Canada
Lund Programs	University of Lund, Sweden
RIGHT-LOOP	Wrightsoft, Lexington, MA, USA
WFEA	Water Furnace Intl., Fort Wayne, IN, USA

39 Sanner B. and Andersson O.,: Drilling methods for shallow geothermal installations, International Summer School of Direct Application of Geothermal Energy, Oradea/Romania, 2001

40 McCray Kevin, Guidelines for the construction of vertical boreholes for closed loop heat pump systems, National Ground Water Association, 2004

The precise sizing and design is essential and key factors are energy load, building requirements, specification of the locality, borehole layout and used material for borehole equipment.

Recently there are available three relevant technical tools[41]:

- Thermal Response Test (TRT) – determination of the underground thermal parameters in situ. Measurement is provided based on to defined heat load in BHE and the changing temperature of the circulating fluid. Technology is now available also in Czech Republic for large plant installations.
- Grouting material with enhanced thermal conductivity - now is available in different brands and is used routinely.
- Direct extension systems – utilization of heat pipes (with ammonia) as borehole heat exchanger. These systems are commercially built and a good alternative in small to medium plants with heating demand only, however they can not replace the BHE with water/antifreeze in all applications.

5.2. Operational sizing of BHE

The advantages of underground drills are obvious: little spatial demandingness, preservation of the site, excellent heat profit during winter months. However, also here apply principles of good dimensioning, and mainly of appropriate usage of materials. The necessary depth of the boreholes is determined by a hydrogeologist, who has at their disposal hydrogeological maps with characteristics of the base. Ideally chosen total length of the drills, in reference to the location's base composition, will secure for operation without limitations. As with ground surface collectors, the most precise possible dimensioning is crucial. At high heat off-takes under-dimensioning leads to strong cooling of the ground, sometimes even to freezing around the drilling column. This not only decreases the heat pump's performance, but in summer periods also disables proper regeneration of lower layers due to limited heat flow. If the project engineer makes a mistake and proposes shorter drills, lower output values of the whole system could be expected in 3 – 7 years. In such case the balance between basement heat transmission and its mining is not guaranteed.

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[41] Sanner Burkhard: "Shallow geothermal systems, ground source heat pumps", Proceeding of the Conference International Geothermal Day Slovakia 2009, 26. – 28.05.2009

Sizing of BHE lengths for small installation to 30 kW of capacity is determined guide values possible maximum load of borehole by refrigerating capacity of HP (table 11). The initial values – refrigerating output per 1 meter of borehole depth are valid for particular borehole or boreholes in the line. Values relates to the duplex equipment of borehole (4 X 32).

Table 11: The guide values for sizing borehole depth (capacity to 30 kW).[42]

Structure of the ground	**Feasible heat extraction**	
General guide values	1800 hours	2400 hours
The worse bedrock - dry sediments (λ< 1,5 W/(m.K))	25 W/m	20 W/m
Standard firm rock or water saturated sediment (λ =1,5 – 3,0 W/(m.K))	60 W/m	50 W/m
Firm rock with high thermal conductivity (λ >1,5 – 3,0 W/(m.K))	84 W/m	70 W/m
Dry gravels and sands	< 25 W/m	< 20 W/m
Firm rocks or water saturated	65 – 80 W/m	55 – 65 W/m
Watered gravels and sands (ground water)	80 – 100 W/m	80 – 100 W/m
Moist loams and clays	35 – 50 W/m	30 – 40 W/m
Massive limestone	55 – 70 W/m	45 – 60 W/m
Sandstone	65 – 80 W/m	55 – 65 W/m
Acid eruptive rocks – Granites	65 – 85 W/m	55 – 70 W/m
Alkaline eruptive rocks – Basalt	40 – 65 W/m	35 – 55 W/m
Gneisses	70 – 85 W/m	60 – 70 W/m

Higher number of heat pumps with capacity over 30 kW require individual approach with utilisation of technique for measurement of drills´ capacity. Only in this way it is possible to take into account all anomalies of the base, groundwater moves, faults, and mutual relations during the whole drilling.

5.3. Geophysical methods for GSHP dimensioning

Applied geophysics has an important position in complex geological exploration process in order to determine potential aquifers of low temperature waters.

[42] Karlík Robert: „Tepelné čerpadla pro Váš dum“ (Heat pumps for your house), Grada Publishing a.s., Praha 2009

All geophysical exploration methods are focused on discovering anomalies in various and different measured geophysical fields based on different physical properties of rocks. According to this they are divided into six basic groups – geoelectric, geomagnetic, gravimetry, seismics, radiometry and well logging where a combination of particular above mentioned methods are used. For exploration of shallow waterbearing layers prevailingly geoelectric, geomagnetic, microgravity, shallow seismic and well logging methods are applied.

Geoelectric methods are based on different electric resistivity and/or conductivity of rocks. For information about vertical model of certain geological formation, vertical electric sounding (VES) is applied. For terrestrian special information a combined electric profiling is used (CEP). Measuring of geoelectric and electromagnetic parameters are applied in georadar exploration – ground penetrating radar (GPR).

Geomagnetic methods are based on registration and interpretation of magnetic properties of rocks – susceptibility, permeability, determination of vectors of remanent magnetization.

Gravimetry and microgravimetry measurements are based on different bulk (mineralogical) density of rocks.

Seismic refraction and reflection in microseismic modification (engineering seasonic) is based on measuring of acoustic running time in function of velocity. These methods are able to distinguish very thin geological layers, their position, structure, tectonic features and extension of defected structures.

Well logging using combination of geophysical methods is very precise techniques on determination of particular geological layers, different resistivities, permeability porosity, density etc. These measurements are more expensive. Measured data from field are evaluated and complexly interpreted. Presentation of final results are two dimensional geological cross setions or three dimensional models of geological structures.

Application of 2 – 3 physically independent methods and their results makes exploration time short, significantly contributes for effective localization of expensive technical work (drilling) and decreasing expences.

The review of different method of shallow geophysical exploration to GSHP design is shown if table 12.

Table 12: Different methods of shallow geophysical exploration applicable to GSHP design[43].

Method	Depth interval	Target	Remarks
Geoelectric	3 m – 100 m	Layers of different resistivity (sand, clay, etc; water table)	Easy field work, relatively low cost. Frequent ununique solutions.
Electromagnetic	5 m – 200 m	Layers of different conductivity (sand, clay, etc; water table)	Easy field work, relatively low cost. Sensitive for outside interference (electric cables, terrain, etc.)
Seismic Refraction	1 m – 50 m	Layers with different acoustic velocities (bedrock, structures, aquifers etc.)	Skilled field work required, medium cost. Sensitive for outside interferences (noise: traffic, cattle, etc.)
Seismic Reflection	>50 m – some kilometers	Layers with different acoustic velocities (aquifers, structures)	Complicated field work, high cost. Several long processing steps are needed.
GPR (Ground Penetrat,Radar)	1 m – 10 m	Shallow heterogeneities	Easy field work, low cost. Highly sensitive for outside effects (electric cables, terrain, etc.)
Well Logging (electric)	according to well depth	Layer differentiation based on resistivity	Medium complications in field work. High cost.
Well Logging (SP)	according to well depth	Distinction of permeable and impermeable layers	Medium complications in field work. High cost
Well Logging (radioactive)	according to well depth	Identification of clay layers and water content	Medium complications in field work. High cost

[43] Burkhard Sanner and Abbas Mohamed Abbas, How can geophysical exploration help to determine GSHP ground properties, Justus-Liebig-University, 2005

5.4. Drilling technology

Usual depth of drills ranges between 70 – 140 m; in some cases also 160 m is possible. The depth of drill depends on local conditions and availability of drilling technique. In case of more drills, the total length is divided into more drills of the same length. If the geological conditions or drilling technology disable reaching of 50 m, it is possible, in extreme case, to drill also shorter boreholes. However, in such case it is recommend to increase the total length of drills by minimum 10 %. At higher number of shorter drills it is always possible to connect two drills into one loop. In such case, it is advisable to carry out an even number of drills. The connecting pipeline of serial boreholes must have an air-outlet valve. At higher number of loops, aim for reaching their approximately same length, including connectors. Thus, it allows much easier regulation of flows by particular loops. The distance between drills should not be less than 10 m. In case of only two drills, it is possible to decrease their mutual distance up to 7 m.

Drills are performed by rotary percussion drilling method. Down-the-hole hammer is propelled by compressed air, which at the same time carries out the drilled material from the hole. This technology is used in most cases. If the base is unfitting for this type of drilling, drilling with flushing is used, where the air is replaced by water and other mixtures which then carry out the material from the borehole even in case of strong weathering of the base or at unstable borehole wall.

Modern drilling rigs are equipped by technology of controlled off-take of debris aside the drilled area, into prepared sewage storage deposits or waterproof containers. Drilling can be carried out almost without negative impacts on cleanness at the drilling site.

Drilling rigs are placed on terrain truck chassis or on a caterpillar chassis. The weight of these machines, including chassis, ranges between 6 – 20 tons. The compressor, which propels the down-the-hole hammer and debris off-take by air, can be put aside to a more remote area. For faster drilling and manipulation around the rigs it is necessary to secure for a place for location of drilling rods.

Tube drilling equipment (polyethylene sounds, double -U-, coaxial sounds, etc.) are installed into boreholes of 125 – 165 mm diameter.

The summary of recommended drilling methods for shallow geothermal applications is listed in Table 13.

Table 13: Recommended drilling methods for shallow geothermal applications[44]

Soil/Rock-type	Method	Recommendations
soil, sand/gravel	Auger Rotary	sometimes temporary casing required temporary casing or mud additives required
soil, silty/clayey	Auger Rotary	mostly best choice temporary casing or mud additives required
rock, medium hard	rotary DTH [1]	roller bit, sometimes mud additives required large compressor required
rock, hard to very hard	Rotary DTH [1] top hammer	with rock bit, hard-metal insert button bit, very slow large compressor required special equipment, depth range to app. 70 m
rock under overburden	ODEX [2]	similar in combination with DTH

[1] Down-the-Hole-Hammer

[2] Overburden Drilling Equipment; ODEX is a trademark of Atlas Copco

5.5. Groundwater well drilling and completion

Groundwater wells are drilled by the drilling methods mentioned earlier. For large diameter wells, the reverse rotary method is well suited. While in normal rotary the fluid is pumped downwards inside the drill pipe and rises through the annulus, the sense of motion here is reversed. This allows for reliable removal of drill cuttings through the pipe and helps to keep the borehole wall stable.

The basic ways for construction of a water-well are natural completion (lost filter completion) and gravel pack. For natural completion, the formation has to be sand and gravel with suitable grain-size distribution.

The well screen is inserted, and then through strong pumping fine material is removed, thus forming a kind of natural gravel filter around the screen. If the formation does not exhibit the composition required for natural completion, a gravel pack (or sand pack) has to be installed in the annulus around the screen, to avoid continuing production of fine material.

For a ground source heat pump, the type of well (production or injection) is always the same. In aquifer storage, wells may have to be operated as production well half of the year and as injection well for the other half.

After drilling of groundwater wells based on the information gained during drilling must be realized pumping test. By pumping this well and observation of groundwater

[44] Sanner B. and Andersson O.,: Drilling methods for shallow geothermal installations, International Summer School of Direct Aplication of Geothermal Energy, Oradea/Romania, 2001

level in the well (and in surrounding wells, if available), the hydraulic properties of the aquifer can be determined. Hydrodynamic tests – intake, elevation and absorbing tests are examined quantification of water discharge. Duration of hydrodynamic tests is app. 7 days for pumping boreholes, 3 days for absorbing boreholes. In the case of water pumping more than 4 l/sec or more than 2 pumping boreholes on one locality is necessary to conduct tests 21 days duration for pumping test and 9 days duration for absorb test.

5.6. Borehole heat exchangers sounding

Drills for heat pumps can never be repaired after installation of a sound. Therefore, usage of such support of boreholes, which was not designed for this purpose, is compared to cost of drilling works an expensive hazard, which will not pay off. For example, only the static pressure in a 120-meter deep borehole is 12 bars at the bottom. And another increase by 4 bars at pressure test of the system´s tightness should be kept in mind. Therefore it is recommended to use geothermal sounds from pipes, which are produced specifically as drilling equipment. It cannot be replaced by pipelines for water, gas, or canalisation. Parallel effect of implementation of the tube into a borehole is lengthwise scratches on the outer surface of the tube. The norm dealing with tube defects specifies that tubes with scratches deeper than 10 % of the width of the tube wall must be replaced. That means that with tube equipment of 32 X 2,9 mm the maximum allowed scratch can be 0,29 mm. At laying into horizontal cuts, a sand bed is needed to provide for environment for placement of the tube without risk of scratches or point pressure. A sand bed cannot be secured for at vertical drills to 150 m. The only solution is to use material, which is resistant to scratches and does not support their further spreading. One of the possibilities is material PE 100 RC (polyethylene tube with resistance to crack), which proves 10 times more resistant at drills than usual PE 100+ (polyethylene tube plus quality)[45].

Another underestimation can appear at realisation of the bottom part of equipment, which is the most stressed one during installation and operation.

The equipment is a closed circuit of pipelines. To secure for regulation of the media flow upwards at 130 mm diameter borehole there is a return U bend, a very small part of crucial importance, at the end of equipment. This part is tested during the whole operation of the system. Also this part is dealt with by EU norm; drilling

[45] Karlík Robert: „Tepelné čerpadla pro Váš dum“ (Heat pumps for your house), Grada Publishing a.s., Praha 2009

equipment can be considered a whole with a return U bend of a proved pressure loss less than 10 mbar at 1 m/s flow speed. Equipment with higher pressure loss cannot be considered as economic and suitable for implementation into systems with heat pumps. Development of return U bends includes numerous models, beginning at welded blocks with slot milling to newer ones produced by technology of injection.

Installation of drilling equipment must be carried out with usage of winding drum, which is usually lifted above the borehole; then the equipment is slowly sunk into the borehole. For easier installation, the sound is equipped by a drill stem at the end. The equipment is filled with water to level the buoyancy of water in the borehole.

Together with drilling equipment, another fifth tube is inserted between two circuits and then used as drill tamponing. The tube fills the borehole pressure-wise from bottom up (if the geologist approves of it), thus securing for push-out of unwanted air, which would obstruct transmission of heat energy between the equipment and rock.

At each drill the mined rock must be replaced. If various horizons of groundwater are drilled, there can appear leakage of deep-seated water under pressure with content of e.g. iron elements into upper horizons, from where drinking water is drawn in numerous areas. By filling the borehole is prevent to these irreversible ecological catastrophes. At the same time, by injecting it secures for important thermal contact of the drill with the base in locations with lack of groundwater.

On the very drill tamponing there are plentiful opinions. Technical realisation and safeguarding of the drill is in charge of a hydrogeologist. Method and realisation of injection can modify his/her proposal.

Considerable role has the very material for tamponing. It is possible to use common mix of cement, water and bentonite. The market offers special mixtures with lower pore content and mineral addition, which significantly influence heat transmission and profit from the drill.

Description of BHE construction with geothermal sound equipment GERO*top* Co. equipment is presented in Figure 6.

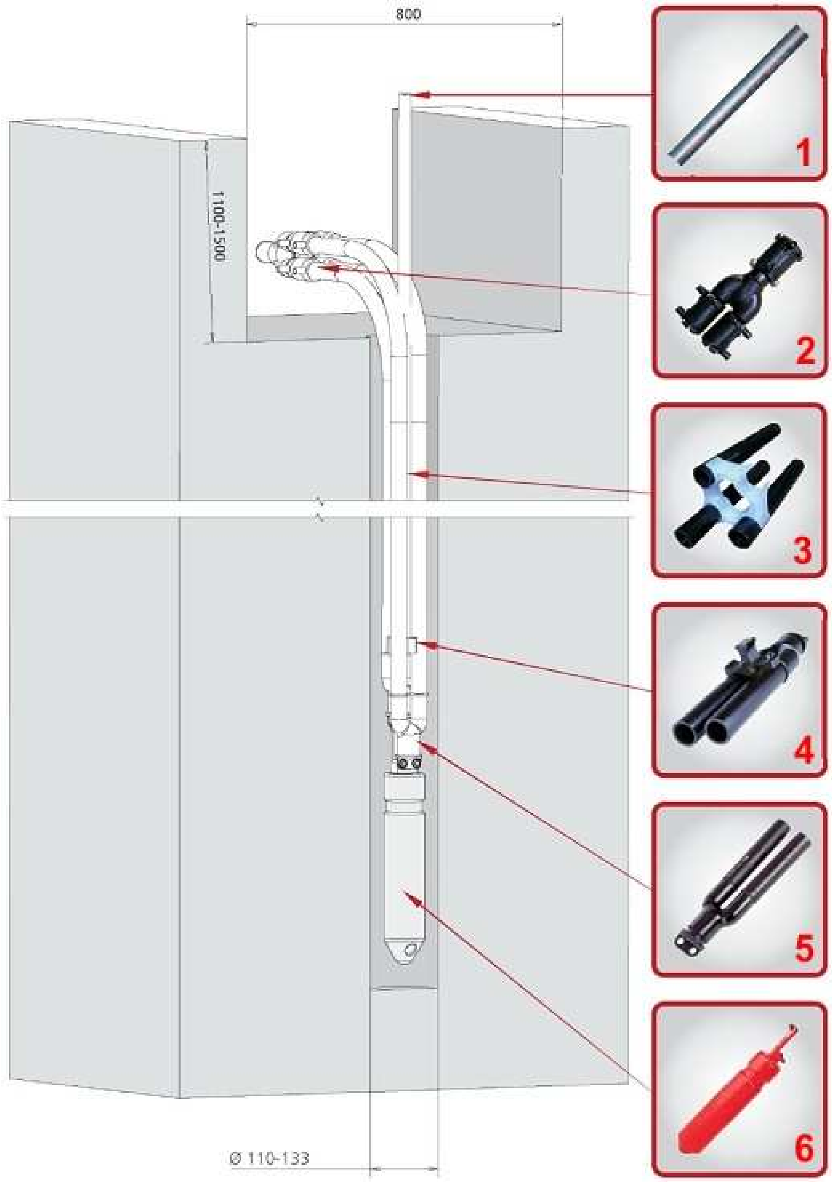

Figure 6: Construction of BHE with geothermal sound equipment GERO*top* Co. [46]

1 – Compressive grouting of borehole

Grouting ensures contact of sub-ground with borehole equipment. For installation is used grouting pipes driving in to the hole together with the sound. Borehole is filled by these pipes from below to above. Special grouting thermo-mixture STÜWATHERM ensures more effective heat penetration. COP of heat pump increase by using this special mixture from 3,5 to 3,8 up to 4 (10 – 15% energy saving).

2 – Reduction of amount of PE 100 fork

[46] http://www.gerotop.cz/cz/produkty/komponenty-pro-tepelna-cerpadla/vystrojeni-vrtu/

For installation of higher amount of boreholes it is possible to reduce higher amount of forks. Borehole equipped by pipeline 4 X 32 mm is concerted to pipeline 2 X 40 mm. Reducing sink is suitable for minimal hydraulic losses and long-term operation. T-fitting is not allowed and together with another improvisation effect decline of operation effectiveness.

3 – Gauge-piece DIHA

For limitation of distances between pipelines inside of borehole is providing by gauge-piece DIHA. The proper application of this part increase borehole performance up to 15 %. The advisable segment separation is 2 m. Investment in DIHA segment return within 2 years of GSHP operation.

4 - CENTRIFIX

For installations in complicated geological structures in necessary the equipment “push back” by means of drilling rods of drilling column. CENTRIFIX is spacer cross for installation of sound by grouting rod and driving of equipment inside of hole. Geothermal vertical sounds with CENTRIFIX gear are available in diameters of 32 and 40 mm. It is possible to use these sounds with or without sinker.

5 – Reversible U-elbow GERO*therm* Co.

This segment is the most stressed within installation and operating time. Reversible U-elbow provides return flow of medium.

6 – Sinker for Geothermal vertical sounds

Sinker (12,5 – 24 kg) is utilise for simpler installation and drifting Geothermal vertical sounds with plumb effect (load to the bottom of the borehole).

5.7. Grouting of borehole heat exchangers

A good thermal contact between the pipes and the ground is paramount for the performance of the BHE. In Scandinavia, in hard, crystalline rock the borehole often is just filled with water. With increasing temperature (e.g. for borehole heat storage), the water shows convection, and heat transport is increased, as measured during thermal response tests.

In the case of groundwater protection, the borehole annulus has to be filled with a suitable material. This grouting material has to be pumpable and is pressed through a tremie (concreting) pipe to the bottom of the hole, from where it rises to the borehole mouth (Table 14). Grouting from bottom to the top that way is the only method to guarantee perfect filling of the hole..[47] Reasonable ranges of thermal conductivity of the finished grout are λ = 1.6 - 2.0 W/m/K.

Table 14: Properties of BHE grouting materials

Material	Thermal conductivity [W/m/K]	Hydraulic conductivity	Pump-ability	Impact due to freezing
Sand, water saturated	1,7 - 2,5	good	-	-
Sand, dry	0,3 - 0,6	good	-	-
Clay	0,9 - 1,4	low	poor	exists
Bentonite 1.3 g/cm3	0,7	very low	good	high
Bentonite with sand	1,4 - 1,8	very low	poor	medium
Bentonite/cement	0,6 – 1,0	very low	good	low
Thermal enhanced Grout	1,6 – 2,0	very low	good	low
for comparison:	Air 0,03 Water 0,60			

The economy of drilling shallow holes is completely different than that of deep oil- or gas wells. Very easy methods - drilling with hammer equipment is far from cost and time required for deep holes. Light, mobile rigs, suitable for both rotary and DTH, ensure cost-effective drilling.

The comparative review of summary costs for BHE (100 m) is given in Table 15. [48]

Table no. 15: Cost comparison for different BHE designs – each 100 m

BHE systems	Drilling costs EUR	Price per tube EUR	Grouting material EUR	Antifreeze fluid	Summary EUR
Double-U-tube 4 X 32	3 750	677	237,5	432	5 097
Single-U-tube 2 X 40	4 000	426	309,4	334,4	5 070
Simple coaxial 63/32	3 750	439	240,6	362,4	4 792
Simple coaxial 63/40	3 750	478	240,6	340	4 809

[47] Sanner B. and Andersson O.,: Drilling methods for shallow geothermal installations, International Summer School of Direct Aplication of Geothermal Energy, Oradea/Romania, 2001.

[48] EWS Erdwärme-Systemtechnik GmbH & Co. KG: „GROUNDHIT project - brief report on deliverable No. 8“, Lichtenau, 27.04.2006

The realistic drilling cost including BHE and grouting in Europe are from 40-55 €/m for holes from 50-100 depth, resulting in 4000 - 5500 € for the 100 m deep hole. Only in very unfavorable geologic conditions, where temporary casing etc. may be required, the cost will be higher.

In Czech and Slovak market due to the less competitiveness the prices for drilling works are little bit higher and reflecting quantity of services and geological risk (unpredictable geological difficulties).

5.8. Future development in drilling technology BHEs

Today's drilling requirements is to get the hole drilled quicker and cheaper than ever before that where Sonic Drilling technology[49] differ from other drilling technologies nowadays use for borehole heat exchangers. The drilling contactor can get in drill the holes and get out at minimal cost demonstrating best value to the customer.

Sonic Drilling's main principle focus is getting the right equipment and solution to the right location to enable the drilling contactor to carry out their work with lowest cost of ownership. Sonic drilling rigs are new drilling technique which is gaining popularity with the ability to drill 'bad ground' quicker and cleaner than conventional drilling machines. The Sonic Drilling machines have been in operation for 20 years but have only been in operation in Europe for the past 5 years. With the ability to increase production and reduce the cost of operation these Sonic Drilling machines are now a cost effective equipment solution for any drilling contactor.

5.8.1. Sonic drilling technology

Sonic drilling technology provides the fastest drilling method on earth for geothermal installations. It also provides continuous core samples that can be used to create an accurate geological site profile before the final design of the geothermal loop field. Using patented drilling technology developed by the Sonic Drill Corporation geothermal holes are drilled 3-5 times faster than any other method. In gravel and boulder ground, where other rigs experience great difficulty, sonic technology can easily penetrate tough terrain to provide an economical geothermal installation. By using Sonic drilling, time-on-site is measured in days, not weeks (Table 16).

A sonic drill is more precisely identified as a rotary vibratory drill. It is capable of high drilling speeds as well as accomplishing tasks, such as continuous coring that cannot be carried out by any other equipment. At first glance, a sonic drill rig looks

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[49] http://www.sonicdrilling.co.uk/sonic-drilling-brochures.htm

very much like a conventional air or mud rotary drill rig. The biggest difference is in the drill head, which is slightly larger than a standard rotary head. The head contains the mechanism necessary for rotary motion, as well as an oscillator, which causes a high frequency force to be superimposed on the drill string. The drill bit is physically vibrating up and down in addition to being pushed down and rotated. These three combined forces allow drilling proceed rapidly through most geological formations including most types of rock.

While the principle behind the sonic drill appears complicated, the machine is actually very simple to operate. The driller only adds vibratory energy to the normal rotary motion. He simply chooses a frequency that gives him the best drilling rate or best core recovery, as the case may be.

Table 16: Drilling methods cost/time comparisons with Sonic drilling technology[50].

Well number	Actual depth	General Startigraphy of borehole	Time comparison, estimated days to drill and install well		
Actual days to complete			Cable tool	SONIC	Time reduction
1	117	Sand and silty clay with cobbles	11	3	73
2	305	Silty clay	28	7	75
3	127	Sand and silty clay with gravel	12	2	83
4	249	Silty clay, sand	23	3	87
5	270	Silty clay	25	4	84
6	150	Sand and silty clay with cobbles	14	3	79
7	180	Plastic clay, sand and silt	16	2	88
8	360	Plastic clay, sand and silt	33	10	70
9	140	Sand and silty clay with cobbles	13	2	85
10	289	Sand and silty clay with cobbles	26	2	92
11	307	Sand and silty clay with cobbles	28	6	79
		TOTAL	**229**	**44**	**81**

[50] http://www.sonicdrilling.co.uk/sonic-drilling-brochures.htm

5.8.2. GeoJetting technology

Geothermal energy is one of the most environmentally-friendly and sustainable sources of energy for the future. Heat stored within the Earth is not dependent on the climate or time of day/year and as such is an ideal source of energy and suitable for producing both heat and electricity. It can also be used to cover the energy base load. But there is one problem: it is necessary to dig down hundreds of metres underground in order to tap into this endless source of heat. Special drills and specialist know-how are therefore required.

The Metropole Ruhr is very well set-up when it comes to mining and drilling technology. A new type of drilling process has been developed in Bochum which makes mining technology applicable to geothermal energy: ‘GeoJetting’ is based on the cutting properties of water under high pressure (approx. 1000 bar). Rock completely disintegrates when subjected to the cutting power of the water, provided by water jets in the drill head. This increases the drilling speed by a factor of three to five, depending on the rock type. An additional advantage: the patented drill-bit can be retrieved after drilling thanks to the system of rods. This means that ground heat exchangers can be incorporated directly into the drill string, which also serves as a protective tube, thereby saving a whole stage of work. The system uses high-pressure water, will be employed for the installation of energy-saving and environment-friendly heat pumps.

‘GeoJetting’ was awarded a patent in May 2008 in a joint venture with Vaillant GmbH and was developed at the Bochum Geothermal Centre.[51] The team of inventors was led by Prof. Rolf Bracke from the University of Bochum and was awarded the Ruhr2030 Award for the invention in June 2008. This was the first time the prize had been awarded by the Initiativkreis Ruhrgebiet initiative for an excellent invention in the ‘meta-competence field of energy, materials and logistics’.

[51] TUhttp://www.vaillant-geosysteme.de/de/produkte/bohrungen/geojetting.htmlUT

6. GSHP market overview

Installations of GSHP are one of the fastest growing applications of renewable energy in the world, with annual increases of 10% in about 30 countries over the past 10 years. The review of leading countries using GSHP is listed in Table 17

Table 17: Leading countries using GSHP[52]

Country	MWt	GWh/yr	Installed number
Austria	275	370	23.000
Canada	435	600	36.000
Germany	640	930	46.400
Sweden	2.300	9.200	230.000
Switzerland	525	780	30.000
USA	6.300	6.300	600.000

6.1. European situation

In western and central European countries, the direct utilization of geothermal energy to supply heat through district heating to a larger number of customers so far is limited to regions with specific geological settings. In this situation, the utilization of the ubiquitous shallow geothermal resources by decentralized GSHP systems is an obvious option. Correspondingly, a rapidly growing field of applications is emerging and developing in various European countries. A rapid market penetration of such systems is resulting; the number of commercial companies actively working in this field is ever increasing and their products is recently significant in Czech Republic.

Total worldwide heat pump capacity has considerably increased in the last five years. Their total installed capacity is estimated to be 13 815 MWth at the end of year 2004 (1,15 million units with mean capacity of 12 kWth each) vs. 5 275 MWth capacity in 2000.[53]

The European Union is one of the main regions of the world to have developed this technology. The total number of geothermal heat pumps is estimated at more than 379 000 units, equivalent to 4 531 MWth.[54]

The review and quantification of GSHP market in EU is listed in Tables 18 and 19.

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[52] Geothermal Energy Barometer – September 2007, "EurObserv'ER" 2007

[53] Lund J., Sanner B., Rybach L., Curtis R., Hellström G.,: Geothermal (Ground-source) heat pumps – A World Overview, GHC BULLETIN, September 2004

[54] Geothermal Energy Barometer – September 2007, "EurObserv'ER" 2007

Table 18: Main GSHP markets* in the EU countries (number of installed units).[55]

Countries	2003	2004	2005	2006
Sweden	31 564	39 359	34 584	40 017
Germany	7 349	9 593	13 250	28 605
France	9 000	11 700	13 880	20 026
Austria	3 633	4 282	5 205	7 235
Finland	2 200	2 905	3 506	4 506
Estonia	n.a.	1 155	1 310	1 500
Czech Republic	n.a.	600	1 027	1 446
Belgium	n.a.	n.a.	1 000	1 000
Poland	n.a.	n.a.	100	200
Slovenia	n.a.	35	97	120
Hungary	n.a.	n.a.	80	120
Total	**53 746**	**69 629**	**74 039**	**104 775**
Switzerland**	3 558	4 380	5 128	7 130

*Estimate

**Not in European Union, for information

Table 19: Quantity and installed capacity of geothermal heat pumps* in the EU countries in 2005 and 2006.[56]

Countries	2005		2006	
	Number	**Capacity (in MWth)**	**Number**	**Capacity (in MWth)**
Sweden	230 094	2 070,8	270 111	2 431,0
Germany	61 912	681,0	90 517	995,7
France	63 830	702,1	83 856	922,4
Denmark	43 252	821,2	43 252	821,2
Finland	29 106	624,3	33 612	721,9
Austria	32 916	570,2	40 151	664,5
Netherlands	1 600	253,5	1 600	253,5
Italy	6 000	120,0	7 500	150,0
Poland	8 100	104,6	8 300	106,6
Czech Republic	3 727	61,0	5 173	83,0
Belgium	6 000	64,5	7 000	69,0
Estonia	3 500	34,0	5 000	49,0
Ireland	1 500	19,6	1 500	19,6
Hungary	230	6,5	350	15,0

[55] Geothermal Energy Barometer – September 2007, "EurObserv'ER" 2007
[56] Geothermal Energy Barometer – September 2007, "EurObserv'ER" 2007

United Kingdom	550	10,2	550	10,2
Grrece	400	5,0	400	5,0
Slovenia	300	3,4	420	4,6
Lithuania	200	4,3	200	4,3
Slovakia	8	1,4	8	1,4
Latvia	10	0,2	10	0,2
Potrugal	1	0,2	1	0,2
Total EU25	**493 236**	**6 158,0**	**599 511**	**7 328,3**
Bulgaria	19	0,3	19	0,3
Total EU 27	**493 255**	**6 158,3**	**599 530**	**7 328,6**

**Estimate*

6.2. GSHP Industry

The heat pump industry is by far the most dynamic of the three geothermal sectors. Europe counts several dozen manufacturers, the largest of which are found on the principal markets, in Sweden, Germany, Switzerland and France. Strong heat pump market growth has had important consequences on the industrial strategies of the main heating market actors who have sought to benefit from the present popularity of geothermal heat pumps.

The market is controlled more and more by large industrial groups that are buying out companies specialized in geothermal heat pump production. Three main categories of factors can therefore be distinguished today: independent small and medium businesses specialized in production of heat pumps, big firms specialized in heat pump production but controlled by large industrial groups and some generalist heat engineering companies that have historically developed a geothermal heat pump production activity (Table 20).

The IVT Industrier company, a Swedish origin manufacturer, is the biggest heat pump manufacturer in Sweden. The company's growth potential should increase considerably after having been purchased by BBT Thermotechnik, a subsidiary of the German firm Bosch, in November 2004. IVT Industrier's turnover has already gone from 77 M€ in 2003 to 92 M€ in 2004 thanks to a sizeable increase in the level of sales (26 000 units in 2004 vs. 20 000 in 2003). IVT Industrier should take advantage of BBT's international sales network to increase its share of exports that represented 15% in 2004.

Table 20: Representative geothermal heat pumps manufacturers in EU.[57]

Company	Country	Power Range (in kW)
Nibe Heating	Sweden	From 6 to 40
IVT Industrier	Sweden	From 4 to 65
Thermia Värme AB	Sweden	From 4 to 45
Ochsner Värmepumpen	Austria	From 2,4 to 950
Thermatis Technologies (Sofath)	France	From 2,3 to 31
France Géothermie	France	From 2,6 to 47
Satag Thermotechnik (Viessmann group)	Switzerland	From 4,8to 106,8
Alpha-Innotec	Germany	From 5 to 107*
Stiebel Eltron	Germany	From 5 to 44
Waterkotte	Germany	From 4,6 to 485

*Up to 800 if 5 machines are combined

In the Western Europe GSHP technology is no longer exotic. Number of applications has increased steadily over the years, and the technology is well understood. Optimization and further development will be required to keep GSHP efficiency in line with the advancements of competing heating and cooling systems. The main goals currently are:

- cost reduction without decrease of efficiency and longevity quality certification not only for the heat pump, but for the ground coupling system also
- further increase in efficiency and design accuracy
- proliferation of GSHP into regions with no or low market penetration (e.g. Eastern Europe and the Mediterranean).

[57] Sanner Burkhard: "Development of Geothermal heat pumps", Proceeding of the Conference International Geothermal Day Slovakia 2009, 26. – 28.05.2009

7. GSHP market in Slovakia

In general, various factors affect the growth of demand for heat pumps. Based on the experience of developed HP markets these forces include natural geographical potentials, energy policy, economic benefits, comparative costs, government policy and assistance, public utilities incentives, market barriers and environmental approach.

7.1. Present status on Slovak market

More or less successful experimental heat pump devices were constructed in Slovakia after World War II. However, moderate energy prices due to plentiful and cheap energy supplies, discouraged large-scale utilization of heat pumps. Heat pump technology was used only in specializes applications for the chemical and petrochemical industries. The global energy crisis of the 1970s and socioeconomic changes after 1990 encouraged the expansion and progressive spread of heat pump applications.

Slovakia's geological and hydrogeological conditions are very favorable for the installation of GHP water/water and earth/water systems. This is due to the high average heat flow (78 mW/m^2) compared to the central European average heat flow - the energy yield is in the range of 50 W/m.

So far the number of heat pump installations does not reflect these conditions. It is estimated that at present only app. 100 units of heat pumps are in operation, mainly for space heating and hot water preparation. Table 21 presents utilization of GSHP on the date 21.12.2004 in Slovakia.

Table 21: Geothermal (ground source) heat pumps utilization [58]

Locality	Temp. ground or water	Heat pump rating or capacity	Number of unites	Type	COP	Equivalent Full Load	Thermal Energy Used
(31.12.2004)	°C	kW	Pcs.			Hr/Yr.	TJ/yr.
Podhajska	40	20	1	W/W	3,8	3360	0,153
Bojnice	38	40	1	W/W	4,2	4350	0,273
V.Ruzbachy	19	778	2	W/W	3,7	11390	6,845
Gbely	9	23	1	W/W	4	4550	0,115
Raj.Teplice	34	489	3	W/W	4,5	7600	4,725
TOTAL		**1350**	**8**			**31250**	**12,111**

[58] Fendek M. and Fendeková M., : Country Update of the Slovak Republic, Proceedings World Geothermal Congress 2005, Antalya, Turkey, 24-29 April 2005

Recently, heat pump installations became widely distributed in Slovak market, but often confused with more familiar air-source heat pump installations. Only available and relevant statistical data documented sale of heat pumps in Slovakia in 2007 prove that most popular and best selling are air/water systems actually air-conditioning devices (Table 22).

Table 22: Sale of heat in Slovakia (2007).[59]

Type of HP	Output	Sale in 2007 (pcs.)	Share in %
air/water	6,1kW – 81,2kW	80	14,70%
air/water	5,3kW – 91,2kW	20	3,60%
air/water	5,2kW – 114,8kW	70	12,90%
air/water	6,2kW – 485,1kW	50	9,00%
air/water	5,8kW – 69kW	60	10,80%
air/water	5,9kW – 67,8kW	60	10,80%
air/water	5,2kW – 63,6kW	50	9,00%
air/water	4,8kW – 16,76kW	65	11,90%
air/water	5,3kW – 34kW	25	4,50%
Borehole/water	**4,7kW – 33kW**	**25**	**4,50%**
Borehole/water	**5,1kW – 36kW**	**15**	**2,70%**
water/water	5,4kW – 109,2kW	7	1,30%
water/water	6,6kW – 96,3kW	9	1,60%
water/water	7,2kW – 143kW	15	2,70%
	Totally	**551**	

7.2. Heating sector

Generation, supply and consumption of heat are significant parts of Slovak energy industry. According to the statistical data of the Statistical Office of SR for the year 2007, the greatest demand for final consumption of heat was for household heating (22.768 TJ in 2006). The final consumption of heat in the trade and services sector was 9.068 TJ and heat consumption of the industry sector was only 2.761 TJ.[60]

[59] Annual report 2007, Slovenský zväz pre chladiacu a klimatizačnú techniku, 2008
[60] BOLDIŠ, T.: Kombinované systémy elektrického vykurovania, Písomný projekt dizertačnej skúšky, Bratislava 2004

From the latest population census (2001) by the Statistics Authorities of the Slovak Republic, shown in Table 23, follow that the most widespread fuel for space heating is natural gas due to the established and advanced gas pipeline distribution system. However, due to the excessive dependence of the heating sector on natural gas imports, Slovakia is among the most gas-dependent countries in the world.
In Appendix no. 8 is presented map of heating season and duration of period with average daily air temperature bellow 12 ℃ – the mo st significant parameters for local quantification of heating demand.

Of all locally-heated households in Slovakia, approximately 73,500 use electric energy for space and hot-water heating, 565,000 use liquid fuels, and 222,000 use solid fuel. Together this represents 860,500 households. At the same time this figure contains the potential for future rationalisation, e.g. by replacing fossil fuel energy systems with renewable energy sources. Heat pumps are systems which use renewable energy sources and their operation in buildings can result in considerable primary energy saving.

Table no.23: Forms of heating in permanent residential flats in the SR in 2001

Form of heating	Number of Flats	Number of people in flats
Transmission central heating	689 480	1 991 347
Local central heating	581 708	2 088 291
On solid propellant	98 458	391 050
On gas	442 215	1 559 790
Electric	29 641	100 642
Floor heating		
On solid propellant	13 399	47 301
On gas	77 145	245 474
Other	9 046	28 057
Stove		
On solid propellant	110 271	341 715
Electric	3 602	9 462
Gas	45 144	117 325
Other	3 339	10 347
Different	132 402	419 618
Total	**1 665 536**	**5 298 937**

7.3. GSHP Market Barriers

Barriers to growth in the geothermal heat pump market in Slovakia can be overcome. By far, the most significant one is the high installation cost of GSHP systems. Well-designed incentives could help to overcome the higher installation cost of a GSHP and reduce the payback time to a period comparable with other available RES heating systems. However the lower, long-term operating cost may factor into the purchase decision depending on the particular financial situation of decision-makers.

The breakeven point can typically be accelerated by favorable government and utility energy incentives. The most generous measures implemented include tax credits or deductions, rebates, special financing, and special electricity rates. In addition, many electric utilities provide assistance with GSHP, including rebates, special electricity rates, or assistance with finding qualified contractors to design and install a system.

A final barrier to growth opportunities is the lack of public awareness. As the market expands, this will change, yet there is limited public knowledge about using the ground around a building to heat and cool it. The concept requires public education and the heat pump industry is still building the critical mass that will result in more widespread news reports about the technology. The situation is improving with the increased emphasis on environmentally compatible technology systems. But if regional climate control associations and unions do not offer GSHP, the prospective buyer may never hear of that option unless they do their own research.

7.3.1. Government support scheme

The Approved Energy Efficiency Action Plan for the years 2008 to 2010[61] sets an intermediate national indicative energy savings target for the third year (2010) of cumulative savings of 3% of final energy consumption (12 405 TJ). To achieve this goal it is important to support heat pump installations. These lead to savings in primary energy sources (fossil fuels), and hence to a reduce in CO_2. The Action Plan proposes to support the installation of heat pumps and energy-efficient air-conditioning systems in non-production buildings. Finance for this support is included in the Slovak state budget 664.000 EUR in 2009 and 996.000 EUR in 2010.

[61] Energy Efficiency Action Plan for the year 2008 – 2008, Ministry of Economy of SR, 2007

One of the tasks of the approved Action plan efficiency is determination the procedure for assessing the technical, environmental and ecological utilization of RES for heating and cooling, including heat pumps devices.

Table 24: Targets for utilization of low-potential heat according to Energy Security Strategy

Heat production	2010	2015
Heat pump	200 TJ	800 TJ

EU legislation stipulates that heat pumps should be included in the Strategy for higher utilization of RES. This stipulation appeared only marginally, in the context of geothermal energy exploited in the upper layers of the earth. The strategy includes support for all kinds of RES such a biomass, wind, geothermal and hydropower and solar energy.

Comparison of the efficiency of utilization of heat pumps and other RES for the production of thermal energy, shows heat pump systems to be more effective in achievable energy efficiency and on a number of economic comparators.

The proposed government support for the installation of heat pumps in 2009 and 2010 totaling 1,66 mil. EUR may stimulate the market. Given the technical potential for more than 3300 installations of heat pumps for heating and hot water preparation in the years 2008 to 2010 (3) the average amount of subsidy for one installation is only 500 EUR. Support at this level will not encourage residential installations.

The lack so far of a stable statutory measure to support implementation of HP systems is having a fundamental impact. Inadequate government support can be seen as the main obstacle to widespread use of this technology. The government is considering a future compromise measure which will provide some financial resources from the state budget. The subsidy proposed is exemption from VAT (19%) but only on the cost of the heat pump device. On the face of it, this suggestion is transparent and applicable without administrative obstacles. It is advantageous for manufacturers and HP suppliers and finally for potential consumers. To date, the macro-economic and strategic consequences of this proposal have not been authoritatively interpreted and evaluated.

7.3.2. Utilities initiative

Because of the constant consumption of electricity throughout the year, utilization of heat pumps promotion of heat pump applications for heating and air-conditioning are attractive to electricity suppliers and distribution network operators. Since 2008 the dominant regional distributors have offered separate tariff groups for electric energy take-off for electrically-powered heat pumps.

Under the terms of valid legislation[62], the household customers are divided into two tariff groups according to electricity consumption::

- Small households tariff for customers whose electricity consumption in the previous year was between 5,000 kWh and 20,000 kWh
- Large households tariff for customers who do not meet the consumption criteria for small household tariff rate

Advantageous two-band tariffs are available for points of delivery with a heat pump. The tariff rate EKO DOM (VSE), D37 (SSE) and D11 (ZSE) is offered to points of delivery where a heating system with a heat pump is installed and used, and the total sum of the installed input power of the heat pump, the input power in the direct heating during the preparation of warm water and in the air conditioning is at least 60 % of the total installed input power of the point of delivery. These facts have to be proved in a trustworthy way (e.g. audit report).

The low tariff (LT) applies for 22 hours per day and the high tariff (HT) for 2 hours daily with continuous length of maximum 1 hour. Pauses between HT validity should not be shorter than 1 hour.

Table 25: Review of all advantaged tariff group for electricity take-off

Distributor of electricity	Tariff	Tariff rate for small households			Tariff rate for large households		
Prices incl. 19 % VAT		Monthly flat rate	LT kW/€	HT kW/kW	Monthly flat rate	LT kW/€	HT kW/€
VSE – Eastern Slovakian region	EKO DOM	4,6611	0,1094	0,1410	7,2287	0,1367	0,1778
SSE – Central Slovakian region	D37	14,8128	0,0908	0,1979	15,7608	0,1126	0,2650
ZSE – Western Slovakian region	D11	16,0618	0,0905	0,3675	16,0618	0,1174	0,5365

On Slovak energy market the adequate and conceptual government subsidy system for promotion of heat pump applications is still missing. However, dominant electricity distributors have taken initiatives to increase consumer awareness of the benefits of heat pump systems.

[62] Decree of the Regulatory Office for Network Industries of July 28, 2008 No. 2/2008

Regional power distributor Vychodoslovenska Energetika, a.s. (VSE) has started a project “Saving Energy” in April 2008. Through this marketing initiative the distributor showed a level of commitment far beyond that required by legislation. VSE has shown a responsible approach to customers and to the environment through energy saving. VSE has introduced several measures to raise customer awareness of energy effectiveness.

Within the project Saving Energy, VSE will contribute 670 EUR to the first fifty customers who decide to buy a heat pump. Furthermore, it guarantees a 10% discount on purchase of this device from VSE contract partners and a free analysis of the advantages of a heat pump for households and enterprises, which VSE staff will prepare at any of the company’s contact points. VSE is the first power distributor in Slovakia to offer a 22-hour low tariff EKO DOM (households) and EKO (corporate entities) and offers the lowest electric power tariffs available for use of heat pumps. In April 2008 VSE also launched an Internet web site www.SetrimeEnergiu.sk with practical advice and tips for the effective use of electric power focusing on reduction of fuel consumption of its cars, cutting its own energy consumption through investments in upgrading of technological equipment and putting emphasis on reduction of losses in power distribution.

This initiative was commercially successful and other competitor distributors are struggling to follow this suggestion by offering similar commercial – educational programs.

SSE (Central – Slovakian distributor) in co-operation with their business partners (renowned manufacturers and distributors) has designed advantageous offers of discounts for the use of heat pumps and air-conditioning to make customer life more comfortable all year long. SSE promotes heat pumps as a state-of-the art and efficient technology which minimises operating costs. Heat pumps can save up to 3/4 of the costs of heating and provide a more comfortable and environmentally friendly method of heating, air-conditioning and hot water preparation.

Ultimately, all the above-mentioned initiatives and campaigns increase customer awareness and knowledge of energy saving and efficient heat pump technologies. However, this approach has increased sales of air-conditioning devices and made visible air/water types of heat pumps. There has been considerably less interest in other types of heat pumps, particularly ground- water and ground source heat pumps. This often leads to misconceptions on the part of potential customers about cooling systems for air-conditioning and space heating. These cooling and heating systems may be energy efficient devices but do not use renewable sources of energy.

7.3.3. Vocational education and networking

Challenges to the increased adoption of heat pump technology fall into three major areas: unfamiliarity with the technology, higher installation costs, and, sometimes, limited participation by utilities in measures to encourage adoption of the technology.

Consumers, contractors and installers are often unfamiliar with geothermal technology. Suppliers and installers of air-conditioning systems are reacting to increasing demand by consumers for more efficient and environmentally friendly climate control equipment. They may include heat pump systems in their product portfolio without having adequate knowledge of the technology. GSHP technology is, in any case, an innovation in residential, commercial and public buildings.

To overcome the knowledge barrier and increase public awareness, it would be very helpful to create vocational associations and unions at regional and national levels. Professional umbrella bodies operate at EU and international levels. The most prestigious and well-established associations for the promotion of heat pump technology are European Heat Pump Association (EHPA), International Ground Source Heat Pump Association (IGSHPA), Geo-Heat Center (GHC), European Geothermal Energy Council (EGEC), Geothermal Heat Pump Consortium – GEOEXCHANGE.

The Slovak Association of Refrigeration and Air Conditioning Engineers (RACE) was established in 1997. At the beginning of 2008 it had more than 500 members, predominately from the area of refrigeration and air-conditioning. This professional association organizes individual members of all professions in the field of refrigeration (e.g. designers, technicians, engineers, service technicians, assembly, etc.) and members of organizations (design- assembly firms, service centre operators, manufacturers, state testing institutions, high school training centers, research institutes, etc). In order to improve specialized services, sections have been created for manufacturing, training and education, air-conditioning equipment and, most recently, heat pump applications. The association's main activities include technical, professional and economic assistance. The Information center and vocational education center offer fairly comprehensive internal databases. The external availability of expert information from each sphere is limited. A weakness of the association is the lack of publicity and promotional material targeted at consumers and members of the public. The development of customer awareness in the field of HP implementation is only a marginal activity. The association does not engage in lobbying at governmental level. Its influence and impact on decision-making authorities is questionable.

The main contributions of RACE are certification services, technical standard procedures, fair trade arrangements and cooperation with foreign associations (AREA, EHPA, etc.). RACE regularly organizes certificated workshops and courses for heat pump installers. Nevertheless, the scope of training is mostly limited to direct installation procedures. Training in geothermal, geological and hydrogeological fundamentals and environmental heat sources offers only background information. The importance of the sizing and dimensions stages in the design process are often underestimated. Training does not give appropriate attention to the building of the primary circle of a GSHP system by ground and drilling works.

7.3.4. Quality market

Despite of very slow grow of GSHP installation in Slovakia on that market are penetrate new players. Regional sale representatives of well-established manufacturers of GSHP are not able to arrange turn-key installation of particular GSHP systems. The distributors of technology can provide complete installation by external subcontractors – installers, engineers and drillers. Local suppliers of ground or drilling works are obviously newcomers on this market with very poor experience in GSHP technology. Ultimately, unprofessional installations effect disrepute of GSHP and damages public confidence to this technology[63].

The most common qualitative defections are system planning and installing without appropriate practice and reliable approach. Mistakes in design process may cause failure of the complete installation.

The success of GSHP applications depends primarily on geothermal drilling operations which are very expensive and have strong influence on very long payback time. Moreover, drilling contractors with inefficient equipment, limited experience and poorly trained drilling staff are common. The weakness of Slovak

[63] Sanner Burkhard: “Development of Geothermal heat pumps”, Proceeding of the Conference International Geothermal Day Slovakia 2009, 26. – 28.05.2009

contactors is wrong technical conditions of drilling machines and equipment. Often drilling works for vertical boreholes are provided with inadequate drilling rigs or technology (quarry drill rig with limited capacity and under-designed parameters). Also usage of wrong drilling additives or possible leakage of fuels due to bad technical conditions of drilling equipment represents dangerous threat to the environment.

To maintain a good public image of GSHP application, strong quality assurance and relevant Training and Certification programs will be necessary in Slovakia in near the future.

A quality label or technical certification for drilling contractors for GSHP applications already exist in some countries of EU. So far, Slovak associations and chambers have not any ambition and legislative frameworks to follow this initiative.

Slovak republic does not participate on the new European initiative for training and education of planners, drillers and installers of GSHP – GEOTRAINET. The experience from Sweden, Switzerland, Germany and Austria shows that one of the barriers to a sustainable and profitable GSHP market the appropriate skilled personnel, and quality of design and drilling works are not always satisfactory. To increase quality of GSHP workforce certification program is essential.

The European Federation of Geologists coordinates project for the training of professionals to implement GSHP across Europe. The objective of the project “Geo-Education for a sustainable geothermal heating and cooling market”, GEOTRAINET, is to promote geothermal energy in training of the professionals involved GSHP installations. The duration of the project is 30 months from the 1st of September 2008. The complete education program and training courses are develop in e-learning platform to train workforce involved in geothermal application. Information will be available publicly, free and online.

The group of partners of GEOTRAINET represents: the European industry in the sector, the European Geothermal Energy Council; the European professionals, European Federation of Geologists; research centers, Arsenal Research Austria and BRGM France; private companies, GT Skills, Ireland and Geoexchange Society Romanian; and Universities, Universidad Politécnica de Valencia, Spain, University of Lund, Sweden, and Newcastle University, UK.[64]

GEOTRAINET project is focused on target groups of professionals: designers and drillers. The EU certification scheme included in this program is provided via training programs for designers, drillers and installers. The advantage of certification

[64] GEOTRAINET program: www.geotrainet.eu

procedure is to help in increase competitiveness on the GSHP market and may become a requirement with respect to environmentally friendly drilling and installation.

7.4. Comparison with the Czech heat pump market

In order to build and develop a functioning and profitable market for HP applications there is an evident effort to follow the schemes successfully applied in the Czech Republic and to benefit from the Czech experience. Despite the division of the former Czechoslovakia, both independent countries still have very strong historical, social, economic and commercial connections. The power industry, building energy efficiency sector and bilateral traders in the field of HP application are no exceptions. Both countries have comparable potential and favorable conditions for strong market development. However, actual comparison of the spread of HP shows a marked difference in the number of installations – ten thousand in the Czech Republic and less than a hundred in Slovakia.

Thanks to an advanced subsidy scheme and government support, the Czech Republic is enjoying a boom in energy efficient and energy saving applications including HP installations. The "green revolution" is a continual priority in Czech government policy and not just a response to the global economic down-turn. Due to the substantial development of the Czech HP market, the major Czech HP manufacturers and contractors are trying to penetrate the Slovak market through Czech commercial representation or subsidiary corporations

In the Appendix 9 is presented review of distributors and manufacturers of HP, operating in the Czech and Slovak markets.

7.4.1. The current market situation in the Czech Republic

There was no HP market in the Czech Republic before 2000. There were fewer than a hundred single installations a year. After 2001, noticeable annual growth could be observed due to rising energy prices, particularly for natural gas, a considerable amount of which is used for heating domestic houses. At the same time, the development shows the positive impact of state subsidies on HP installations in family houses and of subsidies and low interest rates for credit for HP installations in commercial and industrial buildings. This trend of annual growth, (approx. 80%), fell in 2003 and 2004. The main reasons were new highly restrictive rules for subsidy allocation that were in practice impossible to meet. Taking into consideration both the cost of high HP investment and purchasing power in the Czech Republic, receiving a subsidy amounting to approx. 30% of the total investment and installation costs is relatively important. Using the actual price level of fuels for calculation, the simple payback period of HP installations in the absence of any subsidy is far longer than 10 years. This is the main reason why those interested in HP systems are hesitating and waiting for a reduction in HP prices. This situation works to the advantage of those companies which offer cheap systems which are often of poor operating quality and consequently damage the reputation of heat pump technology.

Currently, about 10,000 HP systems of all types based on various principles are installed in the Czech Republic.

There is currently available a special electricity rate for households (or companies) with heat pump installations, which makes it possible to use a low tariff for 22 hours per day. There is also the opportunity to obtain support for installation from a government program (State Environmental Fund), or from a local electricity distribution company.

Heat pump technology is relatively well known to the public. Information about this technology has spread rapidly. Basic information is issued mainly by companies producing, importing or installing HP systems.

The majority of installed HP applications feature ground/water systems. A change has been observed in recent years, whereby demand for and supply of other HP systems, mainly air/water, and the number of installations of such systems began to increase. Air/air systems are not so common as warm air heating is not very often installed in the Czech Republic. Water/water systems are relatively rare due to the complicated hydro-geological situation and the time-consuming licensing process.

Installations of particular HP systems are classified as follows: ground/water (45%), air/water (40%), air/air (8%), water/water (5%), others (2%).

The majority of HP systems are installed in family houses which represent app. 90% of the market. The rest are in commercial, industrial, sport and other buildings. Waste heat utilization is not very frequent; only a few installations are known.

7.4.2. The Czech Heat Pump Association

The Czech Heat Pump Association (AVTČ)[65] is the only professional organization which brings together companies dealing with heat pump technology. Membership of AVTČ includes all the major producers and importers of heat pumps in the Czech Republic and their services cover almost 80 % of market activity.

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[65] Czech heat pump Assocciation: www.avtc.cz

The principal aims of the Association's activities are promotion of heat pumps, cooperation with public institutions and authorities, guaranteeing installation quality, information and consulting services and provision of certified vocational education and training.

AVTČ activities are divided into the following departments:

- **Educational section** – organizes professional workshops, courses and training on installation and after-sale service for contractors installing and maintaining HP heating and cooling systems. Educational tutorials are arranged by academic experts and practicing engineering specialists. In order to increase customer awareness, the educational section performs makes presentations and other promotions of HP technology targeted at the general public.

  Since 2006 AVTČ has expanded accreditation for EU educational certification EU_CERT HP approved by EHPA. This training covers theoretical knowledge of heat resources and their economic recovery, geological, ecological and environmental impacts, building energy efficiency, economics and marketing and the legislative background. Practical training includes dimensions, design, installation, inspection, and maintenance and warranty services.

- **The technical section** deals with quality appraisal of completed installations, technical expertise, collaboration between members and membership extension. AVTČ certifies its members and grants quality certificates based on actual installations.

- **The drilling section** comprises companies providing drilling and technical works related to GSHP installations. Compliance with the regulations and code of rules of the drilling section will ensure the responsible operation of a primary circle GSHP system.

  The major responsibilities of the drilling section include observation of qualitative performance of drilling and ground works in accordance with valid legislative, informing the general public and authorized bodies about procedures, and fostering the collaboration of drilling experts and geologists in the dimensioning and performing processes. Particular attention is paid to environmental protection and security of work.

- **Partnership of AVTČ with EU and international organizations**
  AVTČ is a member of EHPA (European Heat Pump Association). EHPA is consortium of national HP associations and unions of important manufacturers of HP in Europe. This partnership extends to support of research and development in the field of HP technology at the international level.
  The objectives of international organizations of which AVTČ is a member and of AVTČ itself have led to greater awareness of and a significant increase in HP applications.

7.4.3. Government support and initiatives in Czech Republic

In April 2009 the Czech Ministry of the Environment launched "the biggest environmental subsidy program in Czech history"[66]. The "Green for Savings" program is focused not only on supporting heating installations using renewable sources of energy, but also on investment in energy savings during reconstructions and in new-built houses. The program supports top-quality thermal insulation of family houses and non-prefabricated apartment houses, replacement of non-environmentally -friendly heating with low-emission biomass boilers and efficient heat pumps, installation of these sources in low-energy houses and new construction to a passive energy standard.
The State Environmental Fund summarized the benefits of the "Green For Savings" program as: "Millions of tons of emissions, which will not have to be released into the atmosphere, millions of gigajoules of heat, which will not have to be generated, millions of tons of coal which will not have to be mined and billions of crowns, which will remain in the purses of households throughout the Czech Republic"[67].

The general intention of the Ministry of Environment was "to solve the economic crisis while helping to avoid climate changes"**.** The proposed financial aid to over 250,000 households will help to create or maintain up to 30 000 jobs, primarily in small and medium-sized enterprises operating in the regions. Annual emissions of the main greenhouse gas (CO_2) in the Czech Republic could be reduced by 1 100 000 tons. Dust emissions could be 2 200 000 kg lower each year. Czech households will be able to maintain the same comfortable level of heating while

[66] Program Ministry of Environment of CR GREEN SAVINGS: www.zelenausporam.cz
[67] Ministry of Environment of CR: Dotační program "Zelená úsporám", April 2009

using 6 370 000 GJ less heating energy annually, resulting in savings of 185 000 000 m^3 of natural gas.

The registration of applications for aid started on Wednesday 22nd April 2009 – Earth Day. Applications can be submitted to the State Environmental Fund regional offices, or to branches of those banks taking part in the program. Banks administering these applications also offer loans to cover the remaining amount of the investment.

The amount of subsidies for particular energy – saving measures related to the implementation of HP are:

- Replacement of non-ecological heating sources of solid and liquid fuels fossil fuels and electric heating in new building or retrofitting in old building – application of heat pump systems ground – water or water – water 75 000 Kč (app. 2 900 EUR)/installation
- Replacement of non-ecological heating sources of solid and liquid fuels fossil Replacement of non-ecological heating sources of solid and liquid fuels fossil fuels and electric heating in new building or retrofitting in old building – application of heat pump systems air – water 50 000 Kč (app. 1 900 EUR)/installation

To date, the Board of the State Fund of the Environment (Státní fond životního prostředí – SFŽP) has approved 107 applications from the program "Green for Savings" which aims to reduce the energy demands of housing. An initial app. 14 billion CZK (540 mil EUR) was allocated from the total amount of 25 billion CZK (970 mil. EUR) which the state received from sale of emission permits to Japan. If citizens do not claim the money from the fund, through the program offered by the state, within three years the unused funds will go back to Japan (from which the Czech Republic acquired the money for the permits).

8. Economical perspective of heat pumps in Slovakia

Heat pump is becoming ever more wide-spread source of heat, mainly in households. The reason of this growing interest in heat pumps is rise of energy prices together with decline of technology prices. It is especially smaller or medium-size family houses, where utilisation of this technology is the most profitable. At low-energy buildings with very low heat consumption for space heating large investment into heat source with low usage can be non-effective. On the other hand, heat pumps with high capacity for coverage of big heat consumptions are very expensive. Economical valuation of these marginal cases is always specific and cannot be generalised.

8.3.1. Capital costs

For economic evaluation of capital costs of heat pump installation is essential confrontation with conventional fuels which are available for coverage of heat requirements (brown coal, wood, wood briquettes, wood pellets, natural gas, electricity - direct heating and accumulation, etc.).

Choice of fuel depends on availability and capacity of natural gas, electric energy connections or possible connection into the district heating network, plus on investor's user requirements (operating difficulties of device, etc.). Selection of particular fuel influences also cost of investments connected with installation of the heat source, i.e. a technological device for space heating, air-conditioning and hot water supply.

Table 26 compares the capital costs of the various systems for space heating a single family house.

Table 26: Comparison of capital costs of the various types of space heating

Item	HP ground/ water	HP air/ water	electrical boiler	condensing gas boiler	pellet boiler
Source of heating	8 111,00	5 869,00	596,00	1 836,00	3 154,00
Boiler incl. connection	built in	1 520,00	686,00	1 070,00	1 222,00
Equithermic regulator	built in	517,00	176,00	451,00	429,00
Accumulator incl. connection	not needed	445,00	not needed	Not needed	725,00
Primary circuit incl. fitting, transport and building works	2 139,00	built in	not needed	Not needed	not needed
Secondary circuit of external parts incl. fitting and transport	not needed	758,00	not needed	Not needed	not needed
Gas connection incl. building coupling	not needed	not needed	not needed	1 175,00	not needed
Chimney	not needed	not needed	not needed	548,00	313,00
Heating system connecting	968,00	1 136,00	1 121,00	960,00	1 050,00

Establishment	235,00	157,00	98,00	98,00	117,00
Electrical installation	255,00	451,00	196,00	137,00	137,00
Totally in EUR	**11 708,00**	**10 853,00**	**2 873,00**	**6 275,00**	**7 147,00**
Totally in EUR incl. VAT	**13 932,52**	**12 915,07**	**3 418,87**	**7 467,25**	**8 504,93**

Comparison of the capital costs of the variants of heat pump systems for space heating of a single family house with thermal losses 7,5 kW in shown the following Table 27.

Consequently, in Table 28 in presented Comparison of capital cost various types HP systems according their capacity.

Table 27: Summary of initial costs of variety heat pump systems for heating of single family house

Item	**air/water HP**	**soil/water HP surface collector**	**Ground /water HP borehole**	**soil/water HP surface collector**	**ground/ water HP, borehole**
Heating mode	Bivalent	Bivalent	Bivalent	Monovalent	Monovalent
Heating source	5 869,00	8 111,00	8 111,00	8 542,00	8 542,00
Electrical boiler	1 520,00	built in	built in	built in	built in
Boiler incl. connection	517,00	built in	built in	built in	built in

Equithermic regulator	445,00	not needed	not needed	748,00	748,00
Accumulator including connection	built in	2 139,00	4 063,00	3 197,00	5 873,00
primary circuit incl. fitting, transport and building works	758,00	not needed	not needed	not needed	not needed
secondary circuit of external parts incl. fitting and transport	1 136,00	968,00	968,00	1 168,00	1 168,00
secondary circuit of internal parts incl. fitting and transport	157,00	235,00	235,00	235,00	235,00
Establishment	451,00	255,00	255,00	255,00	255,00
electrical installation	not needed	not needed	494,00	not needed	494,00
HG expertise and drilling project	11 830,00	12 761,00	15 395,00	15 418,00	18 874,00
Total in EUR	**22 683,00**	**24 469,00**	**29 521,00**	**29 563,00**	**36 189,00**
Total in EUR incl. VAT	**26 992,77**	**29 118,11**	**35 129,99**	**35 179,97**	**43 064,91**

Table 28: Comparison of Capital cost various types HP systems according their capacity.

Type of heat pump	**Air /water**	**Soil /water**	**Ground /water**	**Soil /water**	**Ground /water**
HP output (kWh)	6,3	5,9	5,9	8,4	8,4

Capital costs (EUR)	12 200,00	12 600,00	15 300,00	12 203,00	12 204,00
Price for 1 kWh (EUR)	1 937	2 136	2 593	1 453	1 453

Consequently to previous economic evaluation of various heating system and modification follows:

- the cheapest solution is an air/water heating system,
- the price of a bivalent mode of soil/water system with surface collector almost approximates to that of an air/water system, but consumes 16 % less electricity
- the price of a monovalent soil/water surface collector system is very similar to that of a bivalent ground/water system (vertical borehole), but the vertical borehole system has a lower electricity demand at 8,6 %
- the price of a monovalent ground/water system is 22% higher than the same system in bivalent mode and also has an 8 % higher energy demand. It is clear that a monovalent ground/water system is uneconomic.

8.3.2. Operational costs

Although heat pump systems are much less expensive over the life of the unit than other systems, the upfront cost is substantial. The high installation cost quickly recovered by the following years operational savings. The biggest benefit of heat pumps is lower operating cost for the home or building. The high efficient types of heat pump utilize for heating almost 75 % of the required energy from the environment. The cost-free environmental energy comes from the ambient air, underground water, soil or ground. Heating with HP offers the highest possible living comfort and easy operation.

Implemented distribution systems low temperature radiant heat floor or wall heating minimizes overheating and improving living climate.

Responsible selection of appropriate type of HP system, correctly implemented heat pumps can be the heating system with the lowest operation and maintenance costs. With each increase in fossil fuel price, the cost of heating with heat pumps becomes even more competitive when compared to oil, gas or wood. The savings will increase because with HP 75 % of the energy if free even if electricity costs increase.

Table 29: Comparison of operational costs of various kinds of heating sources

Item	HP air /water	HP ground /water	electrical boiler	Condens-ing gas boiler	pellet boiler
consumption of electricity in LT (heating, hot water)	7 176 kWh	6 005 kWh	19 250 kWh	-	-
gas consumption (heating, hot water)	-	-	-	20 960 kWh	-
Pellet consumption (heating, hot water)	-	-	-	-	4 406 kg
other energy demand in LT	4 140 kWh	4 140 kWh	4 040 kWh	4 500 kWh	4 500 kWh
other energy demand in HT	360 kWh	360 kWh	460 kWh	-	-
price of electricity in LT	11 316 x 0,090585 =	10 145 x 0,090585 =	23 290 x 0,094058 =	4 500 x 0,112572 =	4 500 x 0,112572 =
	1 025,06 €	918,98 €	2 190,61 €	506,57 €	506,57 €
price of electricity in HT	360 x 0,367545 =	360 x 0,367545 =	460 x 0,142990 =	-	-

	132,32 €	132,32 €	65,77 €		
fixed tariff for circuit breaker	12 x 16 =	12 x 16 =	12 x 13 =	12 x 8,8319 =	12 x 8,8319 =
	192,00 €	192,00 €	156,00 €	105,98 €	105,98 €
fuel price	-	-	-	20 960 x 0,0393 =	4 406 x 0,18 =
				823,73 €	793,08 €
fixed tariff for gas meter	-	-	-	12 x 7,87 =	-
				94,44 €	
total operation costs	**1 349,38 €**	**1 243,30 €**	**2 412,38 €**	**1 530,72 €**	**1 405,63 €**
Saving of operational costs versus electrical boiler	1 063,00 €	1 169,08 €	0,00 €	881,66 €	1 006,75 €
Saving %	44,1%	48,5%	0%	36,6%	41,7%

A Comparison of the operational costs of the various heating sources (Table 29) shows the payback period of heat pump systems (assuming a 7 % annual increase in energy prices) to be:

- heating system air/water – 5,5 years
- bivalent heating system soil/water (space collector) – 5,8 years
- bivalent heating system ground/water (vertical borehole) – 7,9 years.

For mutual comparison operation costs of feasible type of HP system is necessary to take into consideration electricity consumption of particular HP. Energy efficiency of various types of HP can be derived from the basic parameters of HP device determined by manufacturer.
Evaluation of various types of HP systems from energy demand point of view is listed in Table 30.

Table 30: Comparison of energy demand of the most common HP systems

Item / HP type Heating mode	Unit	Air /water Bivalent	Ground /water Bivalent	Ground /water Monovalent
Consumption of heat for heating	kWh	14 250	14 250	14 250
Consumption of heat for hot water	kWh	5 000	5 000	5 000
Coverage of heat production for heating	%	97	96	100
Coverage of heat production for hot water	%	100	100	100
HP electricity demand for heating incl. circulating pump of primary circuit	kWh	4 449	3 439	3 740
Electricity demand for electric boiler	kWh	434	603	0
HP electricity demand for heat water incl. circulating pump of primary circuit	kWh	1 904	1 787	1 774
Overall consumption	kWh	6 788	5 830	5 514
Electricity demand ratio	%	122,5	108,6	100,0
Average COP for heating	-	3,11	3,97	3,81
Average COP for hot water heating	-	2,64	2,80	2,82

From energy evaluation result that HP air/water has in this case higher energy demand of 16 % respectively 22,5 % than both HP ground/water systems. It is clear that utilizaton of bivalent mode of ground/water system has higher energy demand (8,6%) than in case of monovalent mode.

The sharp rise in the prices of all kinds of energy and the increasing instability and unreliability of energy supply in the last 3 years has meant that of heat pumps are no longer uneconomic devices which add little value but are now a profitable and reliable source of energy. Payback period for the capital cost of heat pump systems range from 3 to 9 years, depending on the type of application.

8.3.3. Interpretation of economic evaluation

The detail economic evaluation capital costs, maintenance and operational costs all available HP system on Slovak market indicate that from long-term point of view investment in installation in GSHP applications are more reasonable and profitable than more wide-spread and popular air-source HP installations. In table 31 is presented comparison between air-sources HPs and different types of GSHPs.

Table 31: Comparison between air-sources HPs and different types of GSHPs

		ASHP	GSHPs		
			Vertical	Horizontal	Ground-water
Efficiency		•	•••	••	••
Design Criteria	Feasibility	••	•	•	•
	Construction Difficulty	•	•••	••	••
Life Cycle Cost	Installation	•	•••	••	••
	Operation	••	•	•	•
	Maintenance	••	•	•	•
	Total	••	•	•	•
Environ-mental	CO_2 Emissions	••	•	•	•
	Land Disturbance	no	••	•	•
	Water contamination	no	no	no	•
Durability		•	••	••	••
Practical Issues	Operating Restrictions	••	•	•	•
	Aesthetics	•	••	••	••
	Quietness	•	•••	•••	•••

	Vandalism	•	no	no	No
	Indoor Comfort ability	•	••	••	••
	Safety	••	••	••	••

Note: The more • means more efficient, more feasible, more difficult, higher cost, longer durability, more restrictions, more beautiful, quieter, more comfortable, and much safer.

Regarding to the detailed comparisons between GSHP and air-source HP is clear that GSHP has several advantages over air-source HP from following aspects: higher efficiency; lower life cycle cost; lower impact on environment; better reliability and other practical convenience.

However, air-source HP are suited if customer’s criteria for cost-effectiveness is depending on short payback periods, the local climate is mild, or there are difficulties in earth connection.

From long-term perspective GSHP is recommended to be considered a priority choice under new construction, especially for large buildings where the capital cost is not a pressure to the owners and are qualified construction team is available; the local climate indicating large seasonal variation in temperature; with feasible soil or water condition.

Finally, no matter air source or ground source heat pump, they are far more efficient, environmental friendly than conventional heating/cooling systems. In addition, under the current trends, with a global focus on climate change and energy resources depletion, heat pumps are one of the most potential green technologies.

9. GSHP projection for model case study Manor House Dolná Mičiná

The model case is provided as an example of the complete process of designing, sizing and project management of GSHP in comparison with alternative solutions. The aim of the guide is to promote shallow geothermal technology and to challenge social and public opinion that heat pump utilization is predominately applicable only to low-energy buildings. GSHP applications are a suitable, reliable and efficient technology for the majority of constructions, geological and climatic conditions regardless of existing technical conditions. The case study of GSHP installations in historical buildings provides evidence of its reliability despite complicated regional geology, and the official restrictions placed on reconstruction.

9.1. Setting of selected location and facilities

9.1.1. Sitting of building

The renaissance manor house is located on a raised plot above Dolná Mičiná village, 10 km southeast of Banská Bystrica, in the Central Slovakian Region.

The fortified manor house Dolná Mičiná house has built in the second half of the 16th Century in the Gothic style. Presumably, it was the manor-house or country house settled and rebuild in renaissance style by Tomáš Benický and his wife Katarína Mervaldo in 1667. It has three floors with a tower at each of the 4 corners.

The late baroque modifications have been dated to the end of 18th Century. In 1970 the manor house was partially reconstructed and the latest interior reconstruction was performed in the 1990s.

At present only the renaissance and baroque arches are partially preserved. Nowadays the manor house is abandoned (Appendix 10).

9.1.2. Disposition

Access to the manor house is currently through the western stone portal which has a trench for a drawbridge. Building is a 3-floored, 3-block property with 2 above-ground storeys and a rectangular basement. The 4 corner bastions have round section plans. On the western side is an arcade loggia and on the on the eastern side a 4-floored stair tower. Saddle roof is covered in shingles (Appendix 11).

Total area of land of belongs to the facility is app. 20 000 m^2 on the hilly landscape. A development of single family house was built in the south of the manor house in an area previously occupied by outhouses. At the present there is no connection to basic infrastructure (natural gas, electricity, drinking water). In the near future will be build electricity networking and water supply system. So far, natural gas distribution network is not disposal in this locality.

The only other historical structure which has been preserved is a masonry water well southwest of manor house. It is proposed to use existing 80 m meters deep water well for pumping test for preliminary hydrogeological survey.

Table 32: Heating surface of entire facility

Description	Heated/cooled space (m^2)	Build-up area (m^2)
Basement floor	186,16	284,71
Ground floor	258,45	395,32
First floor	275,93	395,32
Second floor	231,51	342,13
Attic (second mezzanine)	18,85	37,35
Totally	970,90	1.454,83

9.1.3. Legislative regulation of the reconstruction

On the basis of historical survey and specification of the manor house, the Historical Office made biding recommendation about the reconstruction and conservation of the historical landmark which restrict the technical solutions available:

- Façade heat isolation is excluded – building energy efficiency (according to the Act about building energy efficiency no. 555/2005) is defined in a package of procedures and provisions for increasing construction energy economy. In the case of historically protected buildings, observance of energy economy criteria is unacceptable. Reconstruction must not change characteristic historical architecture. The conservation of a historical landmark has priority over energy efficiency.

- During interior and exterior reconstruction prefer classical and original materials and art-craft elements. Utilization of modern materials is prohibited.
- Installation of modern double-glazing windows is prohibited.
- Building of infrastructure and distribution systems must not disrupt interior disposition of space.
- Heating distribution system must be situated on the floor base. Different forms of heating system are excluded.
- The distribution of heating and air-condition systems must not destroy renaissance ceiling arches.
- Building of new spaces, sanitary facilities and storage must not change the original construction and such facilities must be inserted in existing spaces within the house.

After complete reconstruction the new owner intend to utilize manor house partly as family house and partly for high standard guest accommodation. This purpose of manor house is acceptable and corresponds to original utilization of the historical landmark.

It is assumed that the energy demand and consumption of the reconstructed building will be extremely high. For that reason the investor has decided to apply an appropriate renewable source of energy in accordance with a reconstruction program which fulfills the requirements laid down by the Historical Office.

9.2. Hydrogeological study Dolná Mičiná
Evaluation of available source of water for heating purposes of manor house by GSHP

The main goal of an HG study is an appreciation of the hydrogeological conditions of the selected locality for the purpose of underground water intake. The specification of the available quantity of underground water was prepared in order to suggest an appropriate technique for water source abstraction.

9.2.1. Geomorphologic terms

Area of interest it is a part of Zvolen basin and is located on the boundary line sub-units Zvolen highlands and Bystrica upland. The landscape has hilly and downy landform.

9.2.2. Climatic conditions

The area is in a relatively warm basin zone with average annual air temperatures ranging from 7,1 to 8,7 °C. The average long-term annual aggregate precipitation in the locality is in the approximate range 650 – 700 mm. Snow cover usually lasts 60 – 80 days and the soil freezes to a depth of 1,4 m (170 frosty days). The by-pass regime is snowy-rainy with accumulation from December to February and with high levels of water flow during March and April. North-western and northern winds prevail in the Zvolen basin.

Long-term average month aggregate precipitation from meteorological stations Sliač and Môťová are referred in the Table 33.

Table no. 33: Long-term average aggregate precipitation, meteorological stations Sliač (mm)

Month	**I.**	**II.**	**III.**	**IV.**	**V.**	**VI.**	**VII.**	**VIII.**	**IX.**	**X.**	**XI.**	**XII.**	**Yearly**
Rainfall (mm)	43	45	44	40	74	87	79	68	47	55	68	53	703

The selected area is hydrographically integrated to the Hron river basin. A separate area is drained by the Lukavica stream. The regime of surface flows is characterized by maximal overflow when the spring snow melts and by lower levels of overflows during the summer and autumn seasons. Minimal levels occur in the winter season. The by-pass regime is snowy-rainy with accumulation in the December – February period. The highest levels of water flow occur in the March – April period.

9.2.3. Geological conditions

The geological structure of the selected area located in northern part of Zvolen basin has extremely complicated tectonic and lithological formations (Mesozoic, Neogene and Quarter rocks).

9.2.4. Hydrogeological conditions

According to the hydrogeological regionalization of Slovakia, the locality lies on the border line of hydrogeological zones MG-078 “Mesozoic and pre-mesozoic formations of north-eastern part of the Zvolen basin and north-western part of the Vepor Mountains” and MP-079 “Mesozoic Kremnica Mountains and western part of Zvolen basin”.

9.2.5. Protection of natural wells and mineral waters

The surveyed area is situated in III. Stage of protection zone of natural healing resources (NHR) and natural resources of mineral table waters (NRMTW) in localities Sliač – Kováčová – Čerín – Čačín. On the area of protection zone of III. Stage are common occurrence of following types of underground waters:

- ordinary underground waters – with CO_2 content, cold (acidulous water)
- mineral underground waters – with CO_2 content, cold
- thermo-mineral underground waters
- thermo-mineral underground waters – with CO_2 content

The afore-mentioned hydrogeological structure, is very complicated and open (with infiltration, accumulative and outflow zones).This structure fills naturally and drainage occurs through hidden outflows and wells.

In order to obtain a detailed understanding of the described hydrogeological structure, exploration boreholes were drilled. The majority of the testing boreholes were situated in the accumulative zone beyond existing outflow sites.

9.2.6. Evaluation of reservation of possible water sources

For the purpose of space heating the manor house at Dolná Mičiná using heat extraction from underground water, it was assumed that a well yield of 10 – 15 l/s would be required. The proposed system requires a particular quality of underground water.

Mineralization of underground water for direct utilization of heat pump may not exceed limit 300 mg/lit.

It is obvious that only natural underground fresh water (non-mineralised) match qualitative requirements. Therefore assessment is focused especially on reviewing the interception of possible fresh underground waters by hydrogeological borehole or water well, situate in immediate vicinity the manor house.

For assessment of eventuality was arranged in Table 34 with basic information about hydrogeological boreholes realized in surroundings of surveyed locality:

Table 34: Realized hydrogeological boreholes and wells in the surveyed locality.

Borehole	Locality	Depth borehole (m)	Perforated interval (m)	Results of hydrodynamic testing (pumping tests)				
				Water-table(m)	**Q (l/s)**	Water lowering (m)	Filtration Coefficient (m/s)	Geological description
HVH-1	Dolná Mičiná	150	32 - 150	+ 0,50	**0,25**	10,5	1,27 E-7	0 – 2 m loams (Quarter) 2 – 32 m sands, boulders, clays (Neogéne) 32 – 150 m clay a sandy shales, calcific breccia (Mesozoic – Triassic)
					0,54	35,5	9,53 E-8	
HVH-2	Dolná Mičiná	150	48 - 150	28,15	**0,37**	4,85	5,22 E-7	0 – 7,3 m loams 7,3 – 36 m calcite (lias) 36 – 53,3 m dolomites (keuper) 53,3 – 55,5 m clay shales (keuper) 55,5 – 150 m relay of dolomites and shales (keuper)
					0,75	9,85	5,55 E-7	
HVH-3	Dolná Mičiná	138	86 - 134	17,90	**0,33**	7,1	6,96 E-7	0 – 86 m clay 86-97 m clay shales and sandstones 97 – 116 m calcite, dolomite, dolomite breccia 116 – 117 m conglomerate 117 – 138 m dolomite calcite to dolomites
					0,79	17,1	7,45 E-7	
ČEM- 1	Čerín	55	Eruption of water, influence of Sliač Spa, plugging of the borehole					0 – 5 m clays (Quarter) 5 – 55 m tuff, tufity a andesite (Neogéne)
ČAM- 1	Čačín	154	?	Overflow 0,38 l/s	**2,0**	4,96	?	0 – 5 m Quarter 5 – 154 m breccia dolomites (krížňan nappe)
HVH-4	Horná Mičiná Môlča	150	4 - 37	20,14	**-**	-	1,96 E-6	0 – 6 m fluvial deposits (Quarter) 6 – 90,5 m calcite, dolomite calcite to dolomites (middle Triassic) 90,5 – 150 m clay calcite (necomian)
			51 - 150	20,03	**3,3**	6,5	2,35 E-6	

HVH-5	Horná Mičiná Môlča	135	7 – 50	5	**0,27**	-	3,60 E-5	0 – 7 m fluvial deposits (Quarter) 7 – 50 m calcite dolomite (neocomian) 50 – 135 m crystalline clay limestone (doger – malm)
			50 - 135	4,05	**0,17**	-	3,3 E-5	
HVH-6	Horná Môlča	81	4 - 59	0,76	**-**	-	1,0 E-5	0 – 4 m loam (Quarter) 4 – 81 m clay limestone (krížňan nappe)
STHm-1	Malá Môlča	151	117 - 135	Tap 117,13 Steady 113,85	**0,10** **0,30**	6,36 9,15	3,53 E-6	0 – 4,2 m loam (Quarter) 4,2 – 22,2 m clay, sandstone (neogéne) 22,2 – 151 m dolomite with calcite lay, from 117 m to 135 m tektonic fault (mezozoikum – trias)

The data presented in Table 34 indicate that it is possible to obtain resources of fresh underground water with water yield to 1 l/s by drilling boreholes to a depth of app. 150 m. The fresh underground water intercepted by the proposed borehole has mineralization from 282 to 465 mg/l, water temperature 9,5 – 10,0 ^{O}C, type of mineralization Ca-Mg-HCO_3, with pH 7,8 – 8,0. With the exception of the total mineralization, the available underground water resources satisfy the defined quality criteria. However, hydrogeological conditions do not preclude the possible tapping of mineral water (borehole ČEM-1). In that case the water yield will apparently be more than 10 l/s, and would thus be satisfactory to meet the proposed water demand for heating the manor house. There would be significant inconvenience if the level of water – mineralization in the borehole ČEM-1 was more than 4000 mg/l. A more important problem is the question of possible influence on natural healing resources and/or natural resources of mineral table waters protected by the protective zone in which the surveyed area is situated (Appendix 12).

9.2.7. Resolution suggestion

On the basis of the given data and analysis of the surveyed area the drilling of a hydrogeological borehole or well to extract underground water for space heating is recommended with significant reservations. It is possible to create a water well to ensure a source of fresh drinking water or a water supply. The Region of Central – Slovakian neovulcanites is characterised by geothermic activity with variable thermal ground. Based on a mathematic thermal model (Lizoň, 1985) in the area of the Sliač basin at the depth 1000 m the temperature is 65℃, geothemic grade 18,18 m/℃ a thermal gradient of 0,055 ℃/m. Specific he at extraction of geological bedrock water-saturated gravels and sands with occurrence of ground water steam ranges from 80 to 100 W/m. The data presented for the surveyed Dolná Mičiná locality are appropriate for an alternative heating system using extraction of ground heat without underground water.

Collision of interests

The area of interest is situated in a III. Stage of protection zone of natural healing resources (NHR) and natural resources of mineral table waters (NRMTW) on localities Sliač – Kováčová – Čerín – Čačín and a II. Stage of protection zone of natural resources of mineral table waters on locality Čerín – Čačín.

The protection zone of II. Stage protects an accumulative area. Its western boundary passes the left bank of Lukavica stream near the bridge before the village of Dolná Mičiná. It then turns to the north-east to the mountain-ridge (ground elevations 434 and 450), crossing the country road to the east of Dolná Mičiná. The boundary of protection zone of II. stage passes the manor house at a distance of 500 m. The protection zone of III. Stage protects the infiltration area. The entire village of Dolná Mičiná as well as the manor house are situated within the Protection zone III. Stage.

9.3. Feasibility study GSHP system proposal for the manor house Dolná Mičiná

Subject of the feasibility study is a proposal of GSHP heating/cooling system. All calculated values and technical and economical parameters of the suggested system are included.

9.3.1. Heat Balance of Building

Based on the afore-mentioned groundwork a preliminary calculation of heat losses for the given climate area has been made. The data on volume of heat losses and hot-water consumption are initial data for the suggested system of heating via heat pumps. Input data for the proposed system of heat-pump heating are the building's heat losses and hot-water consumption, which will be up to 1 000 liters daily. The assumed heat loss of the building is 94,5 kW. The total necessary heating capacity is then 96,4 kW.

9.3.2. Suggested solution

9.3.2.1. Heat pump

A heat pump, used as the only heat energy source, is capable of operating even when external environmental temperatures are very low. The use of the ecological energy of water temperature is under consideration. This alternative ecological energy source is available in the given location. The ecological heat source on the primary side of heat pump will be used. The energy gained will be transformed into usable heating water temperatures. The heat pump will be separated on its primary side from the primary source circuit by a superposed stainless steel plate exchanger. In the closed primary circuit of the heat pump there will be a flow-securing circulation pump, impurity filter, and a membrane expansion container for elimination of water expansion in the primary circuit. In the primary circuit there will also be a flow rate regulator to protect the heat pump. The required primary source (primary water) flow rate will be secured by the buyer.

On the secondary side of the heat pump there will also be a closed, "boiler" circuit. The forced circulation via the boiler circuit secures the circulation pump. Furthermore, the boiler circuit will also contain a filter, membrane expansion container, and accumulation container. Energy gained in this way is available in various forms, but always free of charge and will provide 65 – 80 % of the total heat capacity. Electric energy needs to be supplied only for the remaining 20 ÷ 35 %, for compressor drive.

Out of the heat pumps production line we have chosen as the most suitable the following heat pump:

Alt. I: HEAT PUMP WATERKOTTE DS 5109.3

At a supposed outlet temperature of **50 °C**, this heat pump's capacity is **101,8 kW**. Although there are no verified values of heat losses from the manor house's walls and future windows, doors and glass areas, this capacity is considered to be the maximum which may be required. If conditions are better than those on which the figure has been calculated, it can drop by approx. 30 – 40 %.

Alt. II: HEAT PUMP WATERKOTTE DS 5162.4

At a supposed outlet temperature of **70 °C**, this heat pump's capacity is **80.8 kW.** At the outlet temperature of **50 °C**, this heat pump's heating capacity is **97.6 kW.** The temperature solution to 70 °C is calculated for possible purposes of future air-conditioning requirements.

As working medium – coolant, the proposed heat pumps use ecologically friendly Freon R 134a, which enables a higher outlet temperature of heating water to be achieved than is the case with standard heat pumps. The outlet temperature can be 65 to 70 °C, depending on type of the heat pump. Alt. II: DS 5162.4 is up to 70 °C. This heat pump features as standard a microprocessor equithermal regulator with a display, operation diagnostics, and many other user functions. Usage of ecological coolant, which does not violate the ozone layer, is automatic.

9.3.2.2. Source of low-potential heat

The heat source will make use of outside environment heat. On the basis of the preliminary geological and hydrogeological review, we suggest direct usage heat pumped by groundwater. This is, however, conditioned by its yield. According to necessary flow rate and hydrogeological conditions, we estimate that two or three pumping wells and two absorbing wells will be needed. The required yield must be verified in a pumping test.

alt. I – Standard of 5.25 l/s and minimal of 3.5 l/s

(alt. II – Standard of 5.33 l/s and minimal of 3.55 l/s)

9.3.2.3. Bivalent source

The suggested ground source heat pump system be complemented by a bivalent source – an electric boiler (or direct heating system can be maintained), which means operational connection of two heat sources – a heat pump and a subsidiary source. Heat capacity of the electric boiler will be known after evaluation of the source with reference to its operational economy and will be dealt with in operational project. A bivalent source operates so that the heat pump always works whenever heat is needed. If the outside temperature is lower than the calculated one, the electric boiler will switch on. The proposed heat pump itself can cover minimum 89 % of the total annual heat consumption. The bivalent source is a fully automated and self-operated service. (The electric boilers already installed would be kept as a back-up heating system.)

9.3.2.4. Heating system

The proposal assumes either use of the existing central heating distribution system (albeit with modifications), or a much better and more economic version with construction of a new floor heating system via capillary mats, where the existing heat transfer surface will certainly suit the proposed low-temperature system of heating via heat pumps. No definite decision has yet been made due to lack of sufficient background documentation and an adequate time horizon for the calculation of heat losses, etc. The calculated values are therefore maximal.

9.3.2.5. Hot-water service

The heat pump will also secure for year-long hot-water service. We recommend usage of hot-water reservoirs of 1 000 litres volume with special inside coating of elastic duroplast. This reservoir is highly durable, hygienic, long-lasting, and resistant to activity of aggressive liquids and water scale sedimentation. The reservoir can be equipped by an exchanger and electric heating spiral.

9.3.2.6. Measurement and regulation

The heat pump is supplied equipped with a microprocessor equithermal regulator, which secures for regulation of heating water temperature depending upon outside temperature. The regulator also provides for preferential hot-water service. For an extra charge the regulator can be supplemented by a modem for distant data reading.

9.3.2.7. Operating life of device

The part of the system with the shortest operating life is the compressor, which is part of the heat pump. Manufacturers claim that new types of compressors have a minimum life of 15 years. After this period it is possible to renew the compressor if needed. The price of the compressor represents approx. 15 % of the price of a heat pump. The operating life of other system parts is several times longer than that of the compressor.

9.3.2.8. Heat distribution in building

No system for heat distribution has been installed in the building

9.3.2.9. Air-conditioning

If the owner of the property wishes to install air-conditioning in the building , an ideal solution would be installation of G-Therm capillary mats, which are capable of cooling as well as heating. They work noiselessly without air movement and create a pleasant natural environment. The close spacing of individual capillaries guarantees a steady surface temperature, and hence the balanced cooling of rooms. They can be installed into ceilings, walls, or floors.

The main advantages of G-Therm capillary mats in air-conditioning systems are that they are silent, draft-free, and react quickly to required temperature changes. They are installed immediately under the surface, thus taking up a minimum of space and creating optimal comfort.

Technical parameters

Table no. 35: Technical parameters – alternative I.

Climate conditions:			
Local environmental temperature:	-15 °C	Maximal outside temperature:	30 °C
User requirements:			
Total heated space:	970,90 m^2	To core temperature of 20 °C	365 days/year
Hot-water service daily:	1,000 l	To temperature of 50 °C	365 days/year
Calculated onto energy parameters	**Capacity**	**Energy consumption**	**Annually**
Space heating:	94.5 kW	201,323 kWh	725 GJ
Hot-water service (24 hours):	1.9 kW	16,977 kWh	61 GJ
Total needed heat capacity:	**96.4 kW**	**218,300 kWh**	**786 GJ**
Proposed solution GSHP usage		**Primary energy source:**	**Groundwater**
Heat pump Waterkotte	**DS 5109.3**	Power consumption	109,2 kW
Dimensions (HxWxD) m:	1,3x 1,1x0,85	Power delivery W10/W35	21,2 kW
Outlet heating water temperature	50 °C	Primary medium temperature	10 °C
Operational mode	Monovalent	Input power of primary side circulating pump	1,3 kW
Heating capacity of HP	101,8 kW	Subsidiary heat source	Elec.boiler
Energy balance of proposed solution		Covered heat consumption	Annually
Heating capacity of heat	101.8 kW	By heat pump (kWh)	218.300 kWh

pump:			
Heating capacity of subsidiary source:	9.0 kW	By subsidiary source:	0
Cooling capacity of heat pump:	72.3 kW	Input power of heat pump:	29.5 kW
Input power of subsidiary source	0	By subsidiary source:	0 kWh
Annual energy consumption by heat pump, including primary side circulation pump:			62,303 kWh
Annual energy consumption without usage of heat pump:			218,300 kWh
Annual energy savings with usage of heat pump:			155,997 kWh

Table no. 36: Technical parameters – alternative II.

Climate conditions:			
Local environmental temperature:	-15 °C	Maximal outside temperature:	30 °C
User requirements:			
Total heated space:	970,90 m^2	To core temperature of 20 °C	365 days/year
Hot-water service daily:	1,000 l	To temperature of 50 °C	365 days/year
Calculated onto energy parameters	**Capacity**	**Energy consumption**	**Annually**
Space heating:	94.5 kW	201,323 kWh	725 GJ
Hot-water service (24 hours):	1.9 kW	16,977 kWh	61 GJ
Total needed heat	**96.4 kW**	**218,300 kWh**	**786 GJ**

capacity:			
Proposed solution – GSHP usage		**Primary energy source:**	**Groundwater**
Heat pump Waterkotte	**DS 5162.4**	Power consumption	110,7 kW
Dimensions (HxWxD) m:	1,5x 1,4x0,85	Power delivery W10/W35	21,7 kW
Outlet heating water temperature	65 °C	Primary medium temperature	10 °C
Operational mode	Bivalent	Input power of primary side circulating pump	3 kW
Heating capacity of HP	85,0 kW	Subsidiary heat source	Elec.boiler
Energy balance of proposed solution		Covered heat consumption	Annually
Heating capacity of heat pump:	89.2 kW	By heat pump (kWh)	216.895 kWh
Heating capacity of subsidiary source:	9.0 kW	By subsidiary source:	605 kWh
Cooling capacity of heat pump:	62.6 kW	Input power of heat pump:	29.5 kW
Input power of subsidiary source	26.6 kW	By subsidiary source:	0 kWh
Annual energy consumption by heat pump, including primary side circulation pump:			69,820 kWh
Annual energy consumption without usage of heat pump:			218,300 kWh
Annual energy savings with usage of heat pump:			155,997 kWh

9.3.4. Calculation of proposed system

Table no. 37: Calculation of proposed systems (alt. I. and II.)

1. Technological Part	**DS 5109.3**	**DS 5162.4**
* Heat Pump Waterkotte	25 030,00 €	34 320,00 €
* Flow switch	809,00 €	809,00 €
* Hot water sensor	21,00 €	21,00 €
* Submersible pump(s)		
* Primary side circulation pump		
Secondary side circulation pump		
* Primary side plate exchanger - prim. water 10°/6° C		
Hot-water plate exchanger		
Fittings from DN 60 to DN 120		
Pipelines from DN 60 to DN 121		
* Anti-freezer		
Thermal insulations, coating		
Accumulation container including insulations		
Hot-water reservoir - use the existing one		
Connecting and fixing material		
* Pipeline for inlet and outlet of primary water		
Engine room assembly (estimation)	33 830,00 €	33 830,00 €
Back-up power supply - e.g. electric boiler		
Total:	**59 690,00 €**	**68 980,00 €**
2. Measurement and Regulation		
Supply of the device, software, implementation	7 550,00 €	7 550,00 €

Assembly	1 760,00 €	1 760,00 €
Total	**9 310,00 €**	**9 310,00 €**
3. Heavy-current Distribution		
Engine room - swichgear, cables, IE, lightning rod ...	12 820,00 €	12 820,00 €
Assembly	1 730,00 €	1 730,00 €
Take-off measurement	0,00 €	0,00 €
Total	**14 550,00 €**	**14 550,00 €**
4. Project Works		
Heat source - technology with heat pump	4 180,00 €	4 180,00 €
Electric heavy-current, traffo station, intelligent electric installation, lightning rod	4 950,00 €	4 950,00 €
Measurement and regulation	1 896,00 €	1 896,00 €
Total	**11 026,00 €**	**11 026,00 €**
5. Audit Reports - electric	**699,00 €**	**699,00 €**
6. Stoking Test and Final Regulation of Heating System	**999,00 €**	**999,00 €**
7. Transport of device, building site equipment	**1 162,00 €**	**1 162,00 €**
Total Costs (without VAT)	**97 436,00 €**	**106 726,00 €**
Total cost including 19% VAT	**115 950,00 €**	**127 000,00 €**

9.3.5. Energy Savings

Energy savings achieved through the operation of heat pumps result from the principle on which they function. The energy saved is the heat which the heat pump takes from the outside environment. Operational cost savings can be calculated in comparison with various other sources (solid fuels, fuel oil, natural gas, bottled gas, direct electric heating), but it is their availability that is decisive. For our case, a comparison with all common ways of heating has been made. The energy prices given here assume regular monthly payments for electric energy.

Table no. 38: Calculation of energy savings

Operational costs	Consumption kWh	Tariff *	Net Amount	Net Saving	Gross Amount	Gross Saving
Electrical bioler	218 300,00	0,119	25 977,70	0,00	30 913,46	0,00
HP alt. I	62 303,00	0,119	7 414,06	18 563,64	8 822,73	22 090,74
HP alt. II	69 820,00	0,119	8 308,58	17 669,12	9 887,21	21 026,25

* (transmission tariff 0.089 € + force tariff 0.03 € = total 0.119 €)

9.4. Proposal of drilling works

9.4.1. Technology of drilling works

Because of the possible eruption of gas-out mineral waters during drilling of borehole – heat exchangers, it is essential to observe the conditions for carrying out drilling works in a protected zone of healing, mineral and thermal waters. The most important procedure is to ensure and immediate borehole closure in the case of water or gas eruption. In practice, it means cementation of the introductory column to a depth of app. 30 m and installing special equipment for borehole closure before continuing to drill.

Due to the complicated geological structure and technical and technological restrictions, the drilling contractor recommended installation of a vertical loop of borehole heat exchangers (a so-called "dry-borehole"). Because of this, the drilling engineer discontinued the preparation of hydrogeological water wells.

Drilling works will be performed using a rotary percussion drilling rig HUTTE-II. with Down-The-Hole hammer. This rig is mounted on a caterpillar chassis. The drilling diameter will be ∅ 133,0 mm, casing by 3 m long PE casing pipes ∅ 100,0 mm. Total length of vertical loop is 1200 m, with 12 collectors, each of 100 m depth. The construction of each borehole involves: installation of geothermal vertical sound GERO*therm* RE-RC, bentonite injection, compressive obturation testing and final technical completion of the borehole head. High pressure water will be used to clean the borehole.

Calculation of total length of vertical loop – borehole heat exchanger:

$$\textbf{Length (m)} = \frac{\textbf{HP evaporator capacity (W)}}{\textbf{specific heat extraction rate (W/m) *}} = \frac{\textbf{110.000}}{\textbf{90}} = \textbf{1.220 m}$$

Specific heat extraction based on the results of the hydrogeolgical study for bedrock watered gravels and sands (ground water) (80 – 100 W/m) was calculated at 90 W/m. Total number of collector is 12, each of 100 m depth.

9.4.2. Calculation of drilling works

Table no. 39: Calculation of drilling costs and compete installation of primary circuit

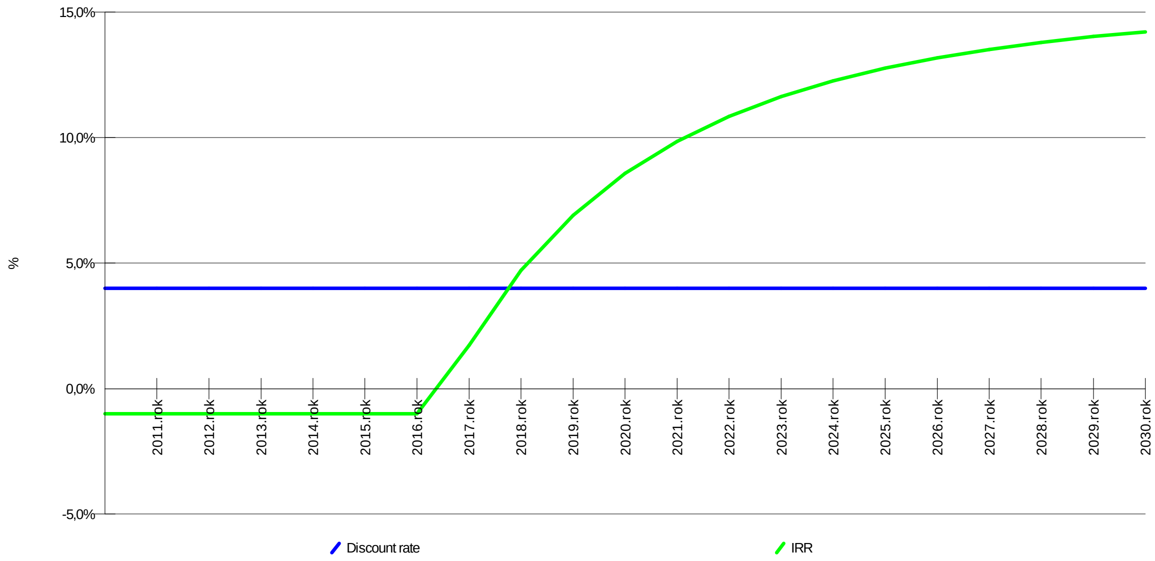
Description	Unit	Quantity	Unit price	Totally
Transportation, preparation and manipulation:				
Operation works on the locality	hour	4	20,00 €	80,00 €
Transportation of drill rig to the locality	km	197	1,00 €	197,00 €
Transportation of drilling equipment and compressor	km	197	1,00 €	197,00 €
Transportation of drilling disposal material	km	197	0,80 €	157,60 €
Transportation and manipulation totally:				631,60 €
Drilling works:				
Drilling diameter Ø133mm, casing pipes Ø110mm	m	1200	25,00 €	30 000,00 €
Drilling works totally:				30 000,00 €
Construction of boreholes:				
Manipulation with geothermal sound	m	1200	1,50 €	1 800,00 €
Compressive injection of boreholes (increase of thermal conductivity)	m	1200	1,50 €	1 800,00 €
Constructions totally:				3 600,00 €
Construction material:				
Geothermal vertical sounds GEROtherm PE-Rc	m	1200	7,50 €	9 000,00 €

Bentonite mixture, injection tubes	m	1200	1,50 €	1 800,00 €
Construction material totally:				10 800,00 €
Realization of primary circuit:				
Installation	hour	0	20,00 €	0,00 €
Transportation of sectional system	km	0	1,00 €	0,00 €
Realization of primary circuit totally:				0,00 €
Compressive obturation test:				
Pressure tests before and after installation	collector	12	10,00 €	120,00 €
Pressure test for tightness, compressive optimalization	system	0	15,00 €	0,00 €
Compressive tests totally:				120,00 €
Geology and technical works:				
Mining office notification	hour	2	20,00 €	40,00 €
Operation, control, calculation and evaluation of technical works	km	0	20,00 €	0,00 €
Elaboration of technological progress of works	km	8	20,00 €	160,00 €
Field reconnaissance, locality inspection	km	197	0,30 €	59,10 €
Geological and technical totally:				259,10 €
Total gross amount including rebate (without VAT)				**42 000,00 €**
Total costs including 19 % VAT				**49 980,00 €**

9.5. Economic evaluation

Table no. 40: Global criteria review

Item	Criteria	Abbreviation	Unit	I.alt.	II.alt.
1	Investment lifetime		year	20	20
2	Discount rate of interest		p.a.	4,0%	4,0%
3	Average inflation		p.a.	1,0%	1,0%
4	Total investment charges (5+6)		EUR	139 500,00	148 800,00
5	- of it – investment		EUR	139 500,00	148 800,00
6	- others		EUR		
7	Total revenues from investment		EUR	388 500,00	387 700,00
8	Total Cash-Flow (7-4)		EUR	249 000,00	238 900,00
9	Discount total expenses (10+11)		EUR	139 500,00	148 800,00
10	- of it – investment		EUR	139 500,00	148 800,00
11	- others		EUR		
12	Discount total revenues		EUR	248 270,96	247 470,96
13	Discount total Cash-Flow (12-9)	NPV	EUR	108 770,96	98 670,96
14	Present value (12-11)	PV	EUR	248 270,96	247 470,96
15	Net present value (13, 14-10)	NPV	EUR	108 770,96	98 670,96
16	Internal rate of return	IRR	p.a.	14,2%	12,9%
17	Profitability index (14/10)	PI		1,780	1,663
18	Payback time	PB	year	7	8
19	Discount payback time	DPB	year	9	9
20	Nominal rate of interest	NRI	p.a.	5,0%	5,0%
21	Real rate of return	RRR	p.a.	13,1%	11,7%



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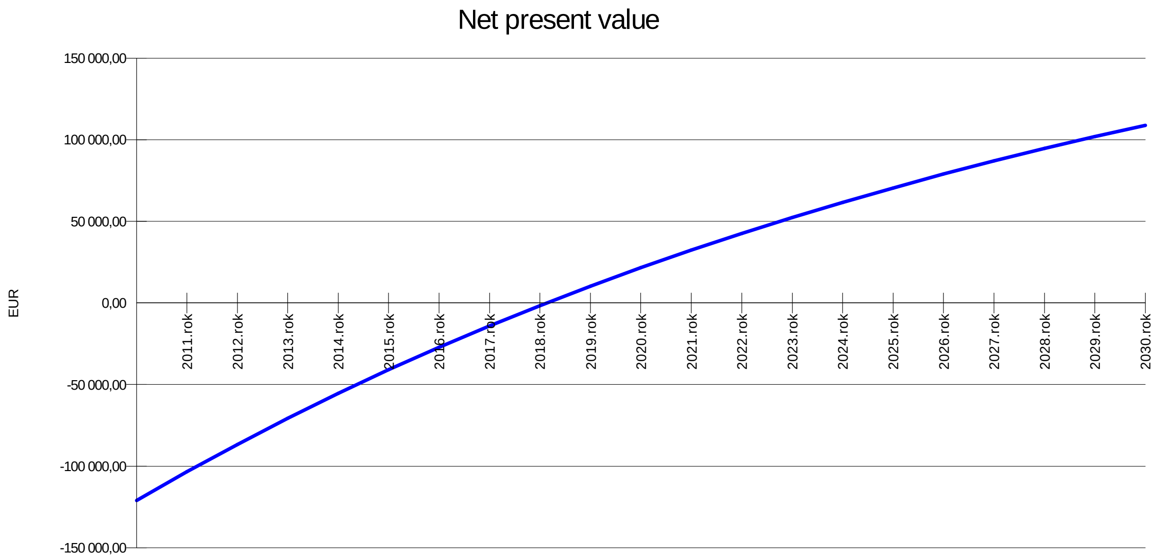
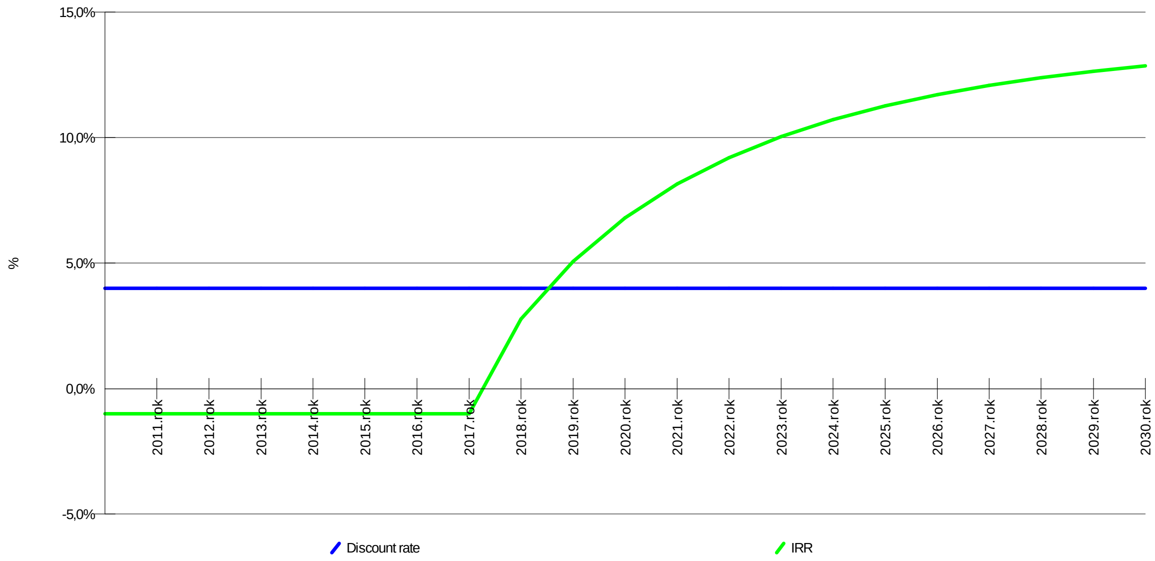


Figure 9: Graphs – IRR and Discount, NPV – I.alt.



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Discount rate
IRR

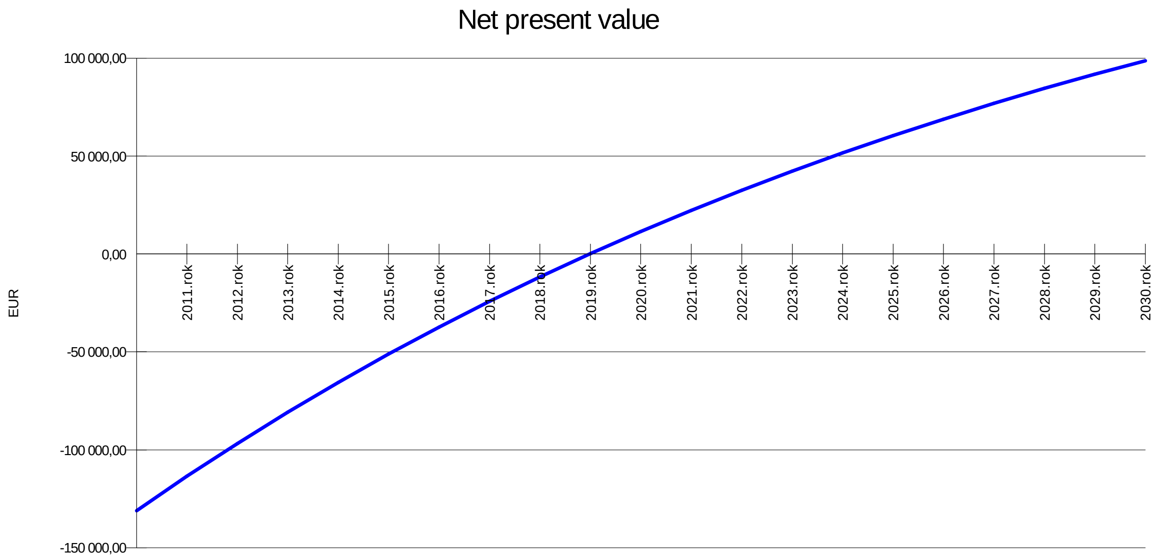

Figure 10: Graphs – IRR and Discount, NPV – II.alt

The final economic evaluation demonstrates that the proposed project is technically feasible and economically profitable. Although the proposal presented is energy demanding and capital intensive, the final economic indicators are acceptable. Total capital costs are 135 500 EUR for alternative I. almost 30 % of which is represented by drilling costs (42 000 EUR). Payback time is 7 years for alternative I. and 8 years for alternative II. Accordingly, the decisive indicators NPV and IRR are more favorable for the monovalent heating mode proposal, due to the higher energy saving.

9.6. Conclusion of the case study

The objective of the model case study was to propose a GSHP system to meet the energy needs of an historical building. At present, the 16th century manor house is ruined and abandoned. After complete reconstruction, respecting the conditions imposed by the Historical Office, the owner intends to utilize the manor house as a family house and high standard guest accommodation. The owner’s intention is to combine historic architecture with state-of-the-art environmentally friendly energy technologies. Due to his enthusiasm for renewable energy sources, designing an energy efficient, profitable and locally feasible energy system presented a difficult challenge.

The selection of an appropriate source of heat for a GSHP application was constrained by the technical and legal restrictions imposed by the conservation requirements of the historic building. The only possible heat distribution system is floor and ceiling heating. The final selection of the heat source was determined by the hydrogeological study. Although the, surveyed locality has sufficient hydrogeological potential, it is not possible to use ground water as the heat source. In view of the risk of gas eruption from the mineral water, a vertical loop of BHE of total length of 1200 m was designed to extract heat for the GSHP installation. The specified collectors are equipped with geothermal vertical sound GEOthem, a well-attested and widely-used technology in GSHP applications. The energy yield of ground source heat is sufficient for the energy requirements and for the designed heating and cooling system. A WATERKOTTE heat pump device was selected from the range of heat pumps currently in production. This type of heat pump is reliable and has proven effective in similar large-scale applications in historical buildings (Castles Tomášov, Tonkovce). For heating and cooling distribution well-established systems of capillary mats, which are acceptable to the Historical Office, have been proposed.

Despite the high capital intensity of the project, the final economic evaluation demonstrates that the proposed GSHP system is viable from both economic and technical points of view. Due to the high level of energy savings in comparison with electrical heating systems, the payback period is relatively very short. Moreover, other reliable economic indicators (Net present value, Internal rate of interest) are satisfactory to the owner and prospective co-investors.

Finally, the designed GSHP system is a feasible solution for a historical building taking onto consideration the legal constraints (restrictions imposed by the Historical Office) and the availability of local energy and heating sources (in particular, limited access to natural gas distribution). The successful implementation of the proposed GSHP system could provide further evidence of the reliability and practicality of utilizing shallow geothermal energy with ground source heat pumps.

10. Recommendations and conclusions

10.1. Recommendations

The problems with GSHP applications lie mainly in the lack of information about their potential, technical parameters, quality of products and investment costs. Negligible government support has resulted in generally higher costs for GSHP, but implementation of subsidies, grants or low credits for users could make this RES technology available at a reasonable price to the general public.

The most important market barriers to GSHP implementation in Slovakia are definitely limited public awareness and low familiarity with technology on the part of practitioners (specialists). Generally, there are a number of misconceptions and myths about GSHP technology. This is mainly due to the limited spread of GSHP systems and the unprogressive approach of the authorities. Wider general education would improve the reputation of GSHP and enable misconceptions to be challenged.

1. *A GSHP system is not able to meet all the heat requirements of a building.*

If the performance of GSHP is equal to the heat losses of the building and the heating system is low-temperature, it is possible to fully cover heat requirements. For economic and technical reasons a bivalent operation mode is recommended. GSHP systems are usually designed within the range of 70 – 85 % of the building load. The remainder of the thermal power requirements will be provided by additional heat sources (electric or gas boiler). Purchase of a less powerful GSHP system is a cheaper solution and, in addition, the energy consumption of the supplementary heat source is very small.

2. *GSHP are overpriced, uneconomic equipment which does not make a return on capital.*

Over the last 10 years the initial costs of GSHP have decreased markedly. The main reason is not reduction in the purchase price itself, but in the excessive rise in energy prices, decreasing energy requirements (energy demand) and energy intensity (energy consumption) of existing buildings. There have recently been significant improvements in the thermal-insulation properties of new buildings due to innovative construction technologies. The usual heat loss of a standard single-family house 10 years ago was app. 18 kW at least. The current figure is app.10 kW. In these respects, lower capacity GSHP has become preferable to alternatives and more available. The purchase price of a GSHP system for a single family house is about 10 000 EUR, which is higher than that of e.g. a natural gas heating system. However, with GSHP utilization it is possible, through lower running costs, to achieve an annual energy saving of more than 1 000 EUR. The payback period of GSHP investment (barring unstoppable energy price increases) is about 6 – 8 years. From the investment point of view, the investment of 10 000 EUR returns an annual saving of 1.000 EUR which represents an excellent capital profit with annual interest rate higher then 12 %.

3. *The more powerful the GSHP, the higher the energy savings.*

By installing a more powerful GSHP system it is possible to achieve a marked reduction in running costs. But this is offset by the lower durability of the compressor and higher initial costs. A comparison of achieved energy savings, capital costs, maintenance and service charges shows that a higher capacity (overlarge) GSHP system is not advisable. The optimal capacity of a GSHP system is between 70 – 80 % of energy building load.

4. *Air-source HP is cheaper and more profitable than GSHP.*

At first glance ASHP seems to be preferable due to its lower initial costs. GSHP are expensive because of the necessary ground and drilling works. Ultimately, however, ASHP itself is a more complicated and costly device. The relatively low capital costs of ASHP are counterbalanced by higher energy consumption, greater noise and significant reduction in the customer’s comfort.

5. *An air-conditioning unit is a full-value replacement for GSHP.*

Some distributors of HP systems have recently been positioning air-conditioning as an alternative to GSHP systems in their marketing activity. Air-source heat pumps are primarily designed for cooling and the heating mode is only a side effect of their operation. In some southern countries utilization of air-conditioning to provide a moderate increase in the temperature for short periods could be a feasible solution. However, climatic conditions during the winter season in southern Europe are not comparable with winter season temperatures in Central Europe. Even though it is a very common trade practice to offer “air-conditioning heating” in southern Slovakian locations with mild climate conditions, this solution is acceptable only as a back-up source of heating in case of emergency (e.g. shortage of natural gas, etc.)

6. *The life of a GSHP system is only 10 years*

The life of GSHP depends mainly on the life of the compressor which primarily depends on the number of compressor starts. This factor can be positively influenced by proper dimensioning of GSHP performance. The higher the output of the system (higher value of COP) the more frequent compressor starts. High-quality regulation is the key factor in running a compressor so as to minimize the number of compressor starts. Based on the experience of developed markets (Sweden, Germany, Austria), with superior and certified GSHP systems, compressor life can be 20 years. The life-cycle of the borehole heat exchanger itself is several decades.

7. *It is not possible to drill into rock*

In fact, the opposite is true – drilling into consolidated rocks is the most favorable drilling environment. In consolidated formations the borehole is not backfilled, the borehole wall is stable and utilization of casing pipe is not necessary. The most complicated structures for drilling and final BHE completion are unconsolidated sand, gravel formations and alternating soft and hard ground layers.

8. *The costs of drilling works can be reduced by using a greater number of boreholes with reduced depth and large diameter.*

The BHE completion is a key design factor for low-potential GSHP systems. The parameters calculated in the design process include total length loop requirement, individual borehole depth, piping and borehole diameters and final circuit arrangement. Most of these parameters can be determined on the basis of proven practice or available drilling equipment.

The diameter of the borehole is a constructional question determined by heat transfer and available drilling equipment. In general, the smaller the diameter of the borehole, the greater the thermal exchange efficiency of whole system. A smaller drilling diameter ensures protection against contamination. In contrast, large diameter boreholes are less resistant to long-term changes in ground temperature and larger distances must be kept between individual boreholes to avoid the mutual intersection of entire boreholes.

Borehole network configuration must take into account the depth of boreholes, drilling and geological conditions and drilling methods. In general, the deeper the borehole, the greater the heat extraction and the stability of the thermal efficiency of the complete system. The optimal single borehole depth is about 150 m and the optimal drilling diameter 130 mm. The borehole should be equipped with pipes for the entire borehole depth. This optimal proposal requires a stronger drilling rig and more precise drilling tooling. Using this relatively costly approach ensures long-term reliable and sustainable thermal exchange efficiency and environmental protection (protection against corrosion and the risk of antifreeze leakage).

9. *GSHP systems are appropriate heating methods in new buildings and houses.*

The autonomous heating sectors in single and multi-family houses in Slovakia represent an important potential for applications of GSHP systems. Nevertheless, it is clear that GSHP is not a versatile source of energy for every building. Most modern buildings in Central Europe recently built according to current construction standards are suitable candidates for GSHP application. Some limitations can arise in older existing buildings with poor insulation where the traditional boiler system has a very high working temperature (70° - 90 ℃). Nowadays, renovation of older buildings and houses often includes the installation of additional thermal insulation to reduce heating costs and bring the building's frame up to modern standards. This is the appropriate time to consider a new heating system. The original heating systems (solid fossil fuels, natural gas or electric boilers) were usually over-designed and are now compatible with a new GSHP system. In many cases, the existing heat distribution system can easily be modified into bivalent operation with larger radiators, convection fans, floor or wall heating systems.

In combination with building renovation, the implementation of a GSHP system is also feasible for older buildings. Reduction of specific heat demand and the most up to date high efficiency GSHP (with heating supply temperatures in the range of 55℃ to 65℃) permits the application of GSHP in bivalent mode with an additional energy source even in historical buildings. This argument is supported by the numerous heat pump installations completed in existing older houses and historical buildings.

10.2. Conclusions

The main objective of the presented study was to specify the potential of and outlook for shallow geothermal resources, focusing on the implementation of GSHP in Slovakia.

The key elements of the study were to identify the overall geothermal potential of Slovakia and to determine the resources of shallow geothermal energy and low-potential sources of heat. Heat pump technology, classification of GSHP installations, the fields of application, and the technical process of GSHP dimensioning and complete installation were described. Market research in Slovakia was used to identify the market opportunities, barriers and potential for further development and to highlight the market's strengths and weaknesses.

On the basis of extensive investigation, it has been possible to give a comprehensive answer to the core question:

Under what conditions could utilization of shallow geothermal resources by Ground Source Heat Pump domestic installations improve the diversity of heating resources in Slovakia?

Optimizing the contribution of GSHP applications to the improvement of the heating sector and diversification of energy first requires a proper appreciation of the technology itself.

The advantages of geothermal heat pumps over conventional climate control systems include:

- The absence of geographical limitations on accessibility. The various configurations of GSHP systems could satisfy all energy needs through horizontal loop, vertical loops – vertical borehole exchanger or groundwater wells applications.
- Earth-friendly and renewable source. GSHP systems utilize the heat of the earth or groundwater, a few meters under the ground. These sources of heat are continuously renewed and do not contribute to the exhaustion of other resources. Installed units have no adverse effects on the ambient air, land or water.
- Environmental compatibility. GSHP helps to reduce the need for fossil fuels, No additions to the greenhouse effect arise from its use .
- Clean and safe operation without any steam, odour, fumes or other environmental allergens.
- Reliable components. GSHP systems are durable and space-saving. Compressors and fans are noise-free. Extreme weather conditions do not influence the lifespan or maintenance requirements of the system.
- Improved environmental comfort. GSHP heat and cool more evenly than traditional systems. The heat cycle is not required to generate hot, dry air like that of a conventional system. Interior humidity also becomes easier to control.
- Parallel production of hot water. Many GSHP installations can also either provide, or contribute to, the energy needed for a building's hot water supply.

The disadvantages include:

- High capital costs. The initial installation costs of GSHP are higher than those of traditional heating systems. Without governmental support and utility company incentives it is difficult to reduce the capital-intensity of the technology.
- Potential environmental threats. Pollution of groundwater can occur due to leakage of additive chemicals used in the system. An inaccurately designed GSHP system could cause undesirable temperature changes in the aquifer or interactions between particular collectors (unacceptable hydraulic connections between water beds).
- Increased cost and complexity of service. The installation of GSHP requires several types of subcontractor services – the system supplier, installer, drilling contractors, electrical and maintenance contractors. There is a risk of incompatible performance of different services or overcharging for the complete turnkey contract.

The potential customer for a GSHP system must weigh all of these factors and make a decision on the feasibility of a GSHP system instead of a conventional system on the basis of their particular situation.

Acknowledgements

I would like to thank all the individuals who provided valuable contributions and important feedback during the development of this Master's Thesis. I particularly appreciate the contribution and support of my supervisor, Dr. Gábor Milics of the University of West Hungary.

I would especially like to thank OMV Group Austria, and in particular Mr. Walter Böhme, for providing financial assistance which enabled me to undertake the MSc Program - Renewable Energy in Central and Eastern Europe.

Last but not least, I would like to thank Dušan, my husband, for his patience, recognition and support throughout my studies.

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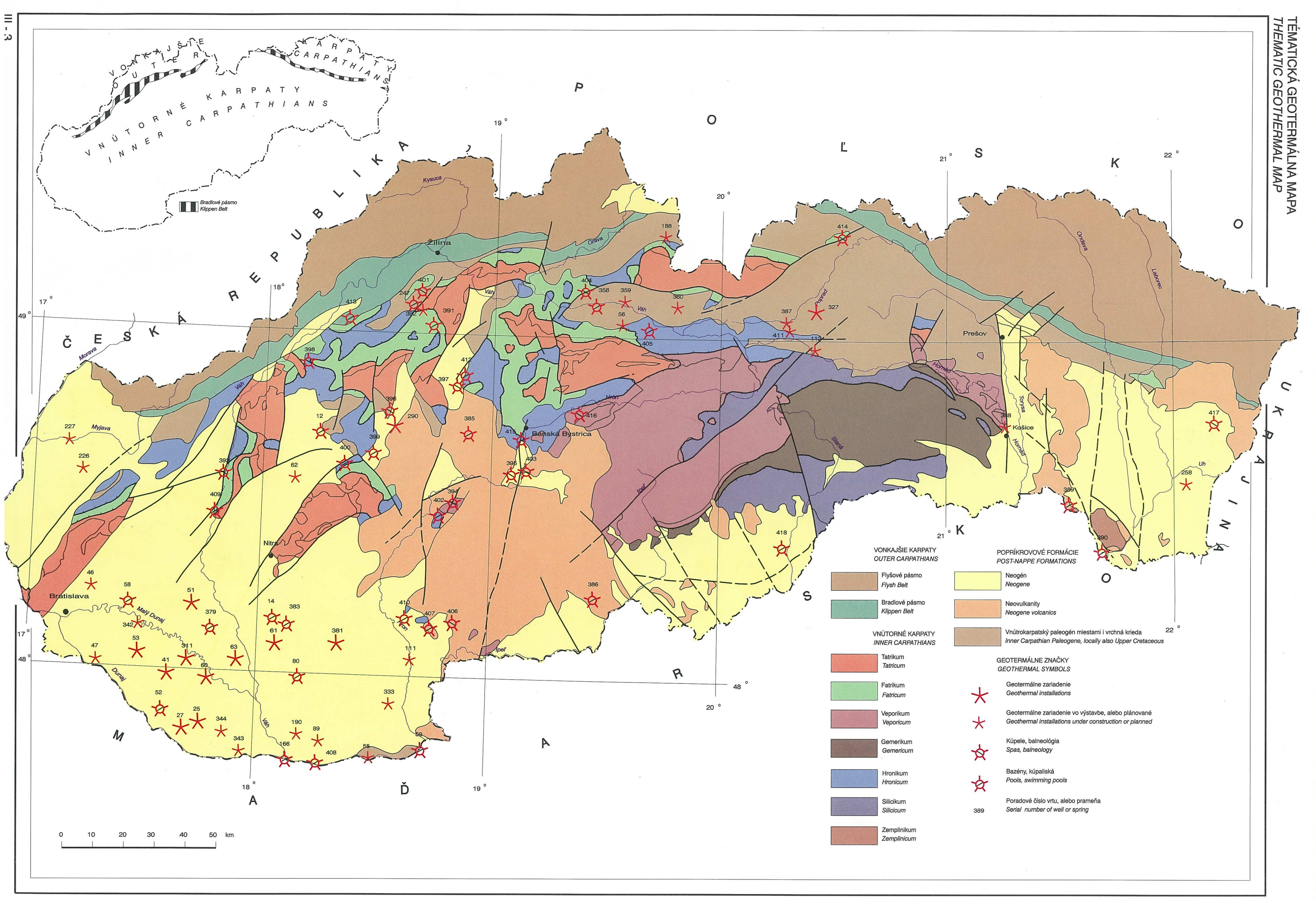
Appendix 1: Tectonic geothermal map of Slovakia



Appendix 2: General legend to the geothermal map of Slovakia

VŠEOBECNÁ LEGENDA
GENERAL LEGEND

izolínie, odpovedajúce dostatočnému množstvu údajov, resp. ich rozloženiu
isolines based on sufficient amount of data and data distribution

izolínie, odpovedajúce nedostatočnému množstvu údajov, resp. ich rozloženiu
isolines based on insuffiecient amount of data or data distribution

GEOTERMÁLNE ZNAČKY
GEOTHERMAL SYMBOLS

Po - 1 — Geotermálne zariadenie v prevádzke, označenie vrtu
Active geothermal installation, well designation

RGI - 1 — Geotermálne zariadenie vo výstavbe alebo plánované, označenie vrtu
Geothermal installation under construction or planned, well designation

BR - 1 — Kúpele, balneológia, označenie vrtu
Spas, balneology, well designation

FGŠ - 1 — Bazény, plavecké bazény, označenie vrtu
Pools, swimming pools, well designation

35 — Izoterma v °C, t.j. teplota v hĺbke pod terénom, izočiary tepelného toku v mW.m^{-2}
Isotherm in °C, i. e. temperature at depth below earth's surface, heat flow isolines in mW.m^{-2}

Di - 1 — Vrty s geotermickými meraniami, označenie vrtu
Wells with geothermic measurements, well designation

C - 1 — Geologické vrty, označenie vrtu
Geological drillholes, well designation

GEOLOGICKÉ ZNAČKY
GEOLOGICAL SYMBOLS

Hranice medzi litostratigrafickými vývojmi
Boundaries between lithostratigraphic units

Zlom, prešmyk
Fault, reverse fault

Príkrovová línia
Nappe line

1 — 1' Línia rezu
Section line

a) vrt v reze
b) vrt s perforáciou v reze
a) well in section
b) well with perforated interval in section

HLAVNÉ KOLEKTORY
MAIN COLLECTORS

piesky (neogén)
sands (Neogene)

zlepence, piesky (neogén)
conglomerates, sands (Neogene)

zlepence (neogén)
conglomerates (Neogene)

brekcie až zlepence (neogén)
breccias and conglomerates (Neogene)

andezity (neogén)
andesites (Neogene)

vulkanoklastiká (neogén)
volcanoclastics (Neogene)

zlepence (paleogén)
conglomerates (Paleogene)

dolomity a vápence vo východoalpských jednotkách (ötscherský, frankenfelský príkrov)
dolomites and limestones in Eastern Alpine Units (Ötscher, Frankenfels nappes)

dolomity a vápence triasu v silickom príkrove
triassic dolomites and limestones in Silica nappe

dolomity a vápence triasu v chočskom a vyšších príkrovoch
triassic dolomites and limestones in Choč and higher nappes

dolomity a vápence triasu v križňanskom príkrove s troskami chočského príkrovu
triassic dolomites and limestones in Križna nappe with Choč nappe outliers

dolomity a vápence triasu v križňanskom príkrove
triassic dolomites and limestones in Križna nappe

dolomity a vápence triasu v obalovom mezozoiku (tatrikum, veporikum)
triassic dolomites and limestones in envelope Mesozoic (Tatricum, Veporicum)

dolomity a vápence triasu vo vnútrokarpatskom mezozoiku (šupiny obalového mezozoika, križňanského a chočského príkrovu)
triassic dolomites and limestones in Inner Carpathian Mesozoic (scales of envelope Mesozoic, scales of Križna and Choč nappes)

dolomity a vápence triasu v maďarskom stredohorí
triassic dolomites and limestones in Central Hungarian Mts.

HYDROGEOLOGICKÉ ZNAČKY
HYDROGEOLOGICAL SYMBOLS

PK - 11 — prirodzený vývér (prameň, vrt v prirodzenej vývěrovej oblasti), označenie vrtu
natural spring (spring, well in natutal spring areas), well designation

LŠH - 1 — prirodzené vývery (pramene, vrty v prirodzenej vývěrovej oblasti), označenie vrtu
natural springs (springs, wells in natural spring areas), well designation

HG - 1 — umelý vývér (vrt), označenie vrtu
artificial discharge (well), well designation

Výdatnosť vývěrov v l.s^{-1}
Discharge in l.s^{-1}

menej ako 3 *less than 3*	3 - 10 *3 - 10*	10 - 25 *10 - 25*	25 - 50 *25 - 50*	viac ako 50 *more than 50*

Teplota vody v °C
Water temperature in °C

menej ako 20 *less than 20*	20 - 30 *20 - 30*	30 - 40 *30 - 40*	40 - 70 *40 - 70*	viac ako 70 *more than 70*

Obsah plynov
Gas content

CO_2 (viac ako 250 mg/l) *(more than 250 mg/l)*
H_2S (viac ako 1 mg/l) *(more than 1 mg/l)*

Chemické zloženie vôd (CH)
Water chemistry (CH)

Ca, Mg
Na
SO_4
HCO_3
Cl

Údaje z geotermálnych zariadení
Data from geothermal installations

Q (l/s) | CM - celková mineralizácia *T. D. S.*
T (°C) | CH - chemické zloženie vôd *water chemistry*

Údaje z geotermických, geologických a hydrogeologických vrtov
Data from geothermic, geologic and hydrogeologic wells

CM
CH

SYMBOLY CHRONOSTRATIGRAFICKÝCH A TEKTONICKÝCH JEDNOTIEK
SYMBOLS OF CHRONOSTRATIGRAFIC AND TECTONIC UNITS

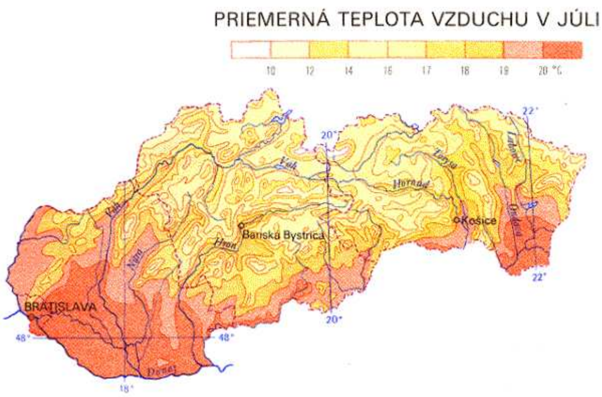
Q	kvartér *Quaternary*	sn	senón *Senonian*
pl	pliocén *Pliocene*	T_1	spodný trias *Lower Triassic*
r	ruman *Rumanian*	MZ	mezozoikum *Mesozoic*
d	dák *Dacian*	MZa	mezozoikum (východoalpské jednotky) *Mesozoic (Eastern Alpine units)*
pt	pont *Pontian*	MZb	mezozoikum (bradlové pásmo) *Mesozoic (Klippen Belt)*
pa	panón *Pannonian*	MZm	mezozoikum (manínsky príkrov) *Mesozoic (Manín nappe)*
pa_{2-3}	stredný a vrchný panón *Middle and Upper Pannonian*	MZch	mezozoikum (chočský a vyššie príkrovy) *Mesozoic (Choč and higher nappes)*
pa_1	spodný panón *Lower Pannonian*	MZk	mezozoikum (križňanský príkrov) *Mesozoic (Križna nappe)*
sm	sarmat *Sarmatian*	$MZ_{ot(v)}$	mezozoikum (obal; t - tatrikum, v - veporikum) *Mesozoic (envelope; t - Tatricum, v - Veporicum)*
b	báden *Badenian*	MZs	mezozoikum (silicikum) *Mesozoic (Silicicum)*
m_{2-3}	stredný a vrchný miocén *Middle and Upper Miocene*	MZms	mezozoikum (maďarské stredohorie) *Mesozoic (Central Hungarian Mts.)*
k	karpat *Carpathian*	PZms	paleozoikum (maďarské stredohorie) *Paleozoic (Central Hungarian Mts.)*
ot	otnang *Otnangian*	PZg	paleozoikum (gemerikum) *Paleozoic (Gemericum)*
eg	egenburg *Egenburgian*	PZ-MZi	paleozoikum - mezozoikum (iňačovsko - kričevská jednotka) *Paleozoic - Mesozoic (Iňačovo - Kričevo unit)*
er	eger *Egerian*	PZ-MZz	paleozoikum - mezozoikum (zemplinikum) *Paleozoic - Mesozoic (Zemplinicum)*
ok	kišcel *Ciscelian*	P	perm *Permian*
m_1	spodný miocén *Lower Miocene*	C	karbón *Carboniferous*
PG	paleogén *Paleogene*	PZ	paleozoikum *Paleozoic*
K	krieda *Cretaceous*	PTt(v)	proterozoikum (t - tatrikum, v - veporikum) *Proterozoic (t - Tatricum, v - Veporicum)*

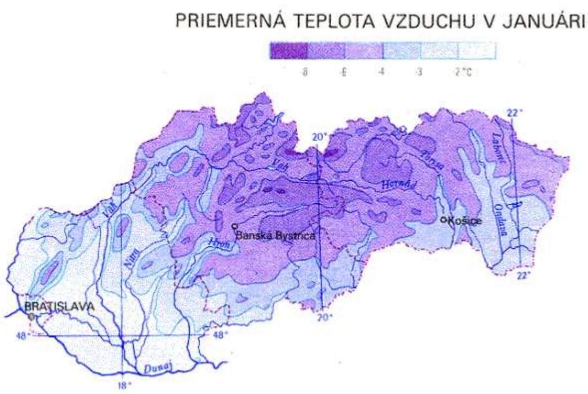
III - 0

Appendix 3: Classification of geothermal resources according to the temperature

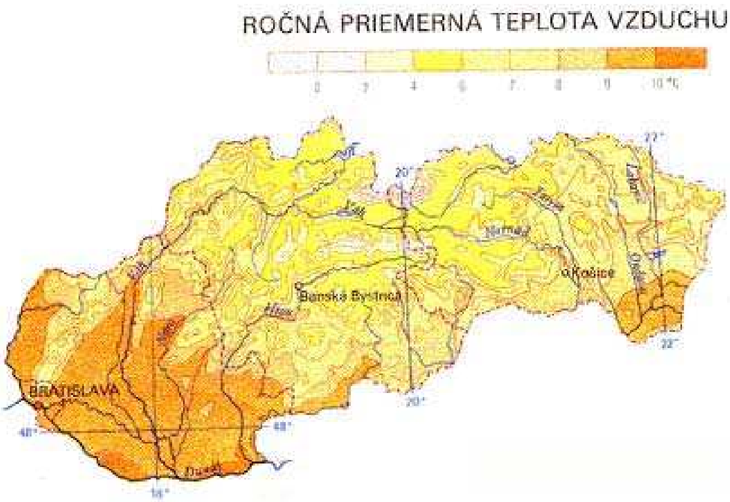
Temperature type	Defined geothermal water structure of area	Numbers of GT areas	Depth of GT collectors (m)
High temperature > 150 ℃	Beša – Čičarovce structure,	5	3000 – 4000
	Žiar basin (NW part of Central neovolcanics)		5000 – 6000
	Košice basin		2500 – 3000
	Vienna basin		6000
	Central depression of the Danube basin		3000 – 4000
Medium temperature 100 – 150 ℃	Beša – Čičarovce structure	16	2500 – 3000
	Central depression of the Danube basin		3000 – 4000
	Košice basin		2500 – 3000
	Humenský Ridge, Levoča basin (N and E parts)		3500 – 4500
	Turiec basin		4000 – 5000
	Bánovce basin		3500 – 5000
	Žiar basin (Ilava and Ternčín basins)		5000
	Liptov basin		2500 – 5000
	Trnava and Piešťany bay		4000 – 5000
	Vienna basin		4000 – 6000
	Komarno marginal block		3000 – 4000
Low temperature < 100℃	Komarno high block	26	100 – 5000
	Central depression of Danube basin		1000 – 3000
	Bánovce basin,		1000 – 3500
	Trnava bay		1000 – 4000
	Piešťany bay		1000 – 4000
	Central Slovakian neovolcanics (NW part)		1000 – 3000
	Central Slovakian neovolcanics (SE part)		1000 – 3000
	Upper Nitra basin		1500 – 3000
	Turiec basin		1500 – 4000
	Žilina basin		1000 – 5000
	Skorušiná depression		1000 – 2500
	Liptov basin		1000 – 4000
	Levoča basin (N and E parts)		1500 – 4000
	Horné Strháre – Trenčín graben,		600
	Rimava basin		150 – 4000
	Trenčín Basin		1000 – 5000
	Ilava Basin		1000 – 5000
	Levice block,		1000 – 2000
	Komarno marginal black,		1000 – 3000
	Vienna Basin,		2000 – 4000
	Komjatice depression		2000 – 3000
	Levoča Basin (N and E parts)		1500 – 4000
	Humensky Rigde		1000 – 3500
	Beša – Čičarovce		1000 – 2500

Appendix 4: Climatic maps of Slovakia



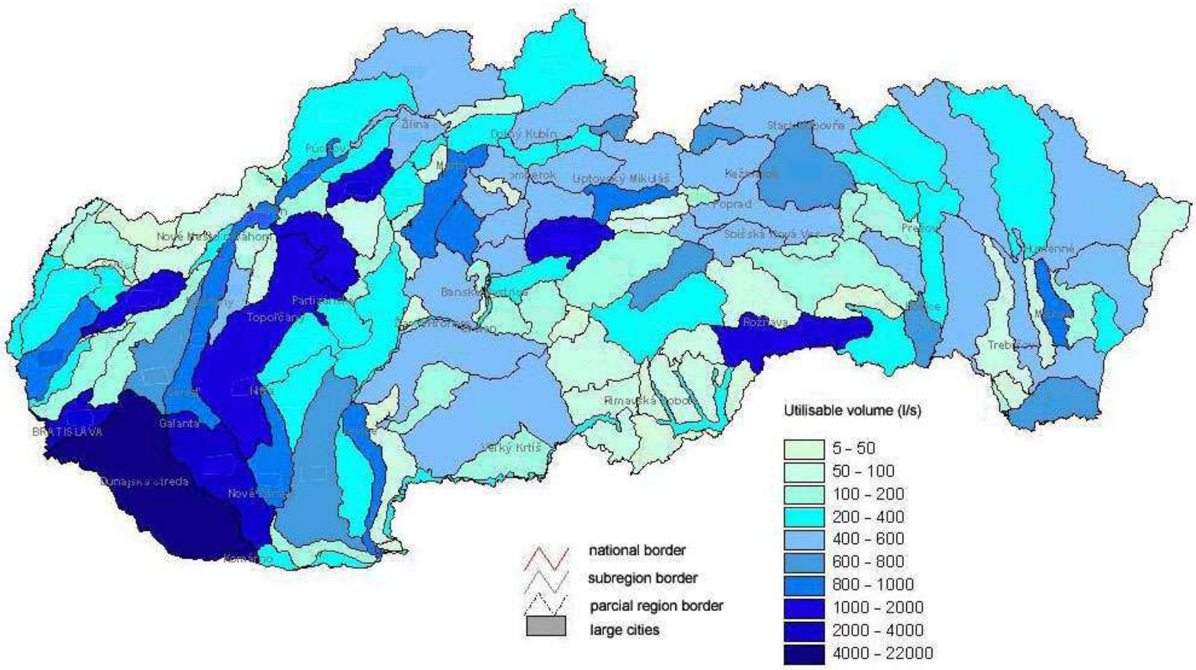


Average annual temperature in the hottest and coldest months (source: www.shmu.sk)



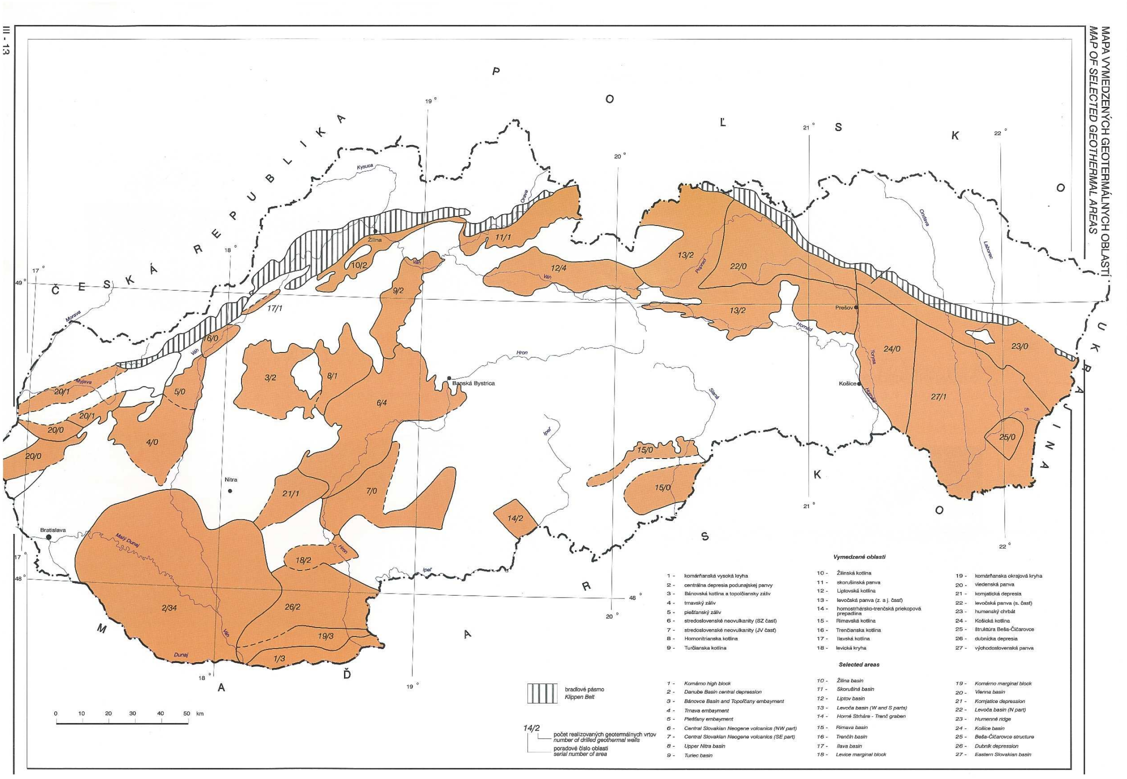
Average annual temperature of air (source: www.shmu.sk)

Appendix 5: Utilizable groundwater volumes in hydrogeological regions of Slovakia

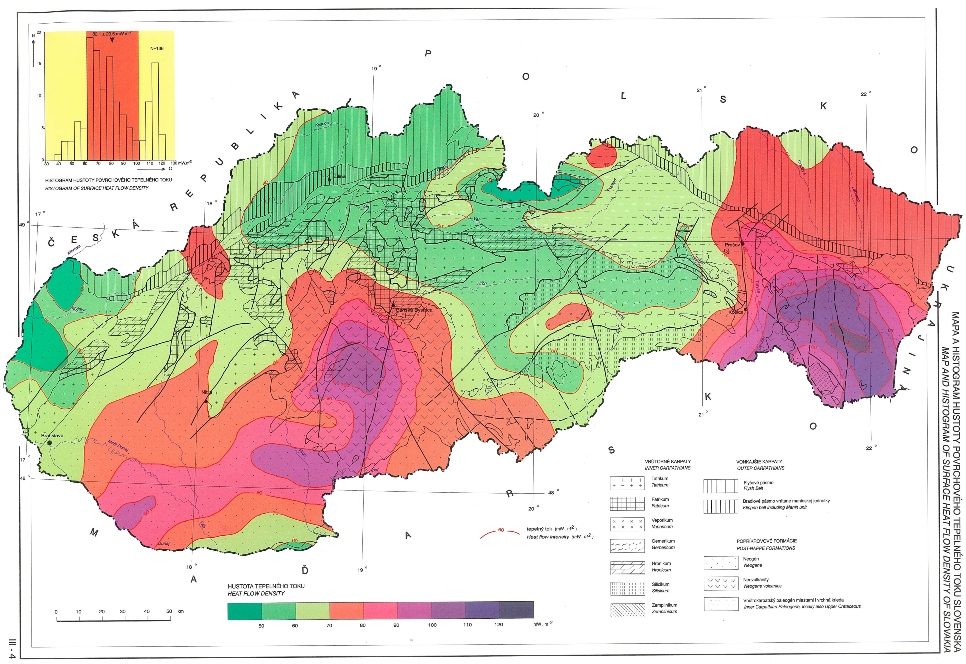


(source: www.vuvh.sk)

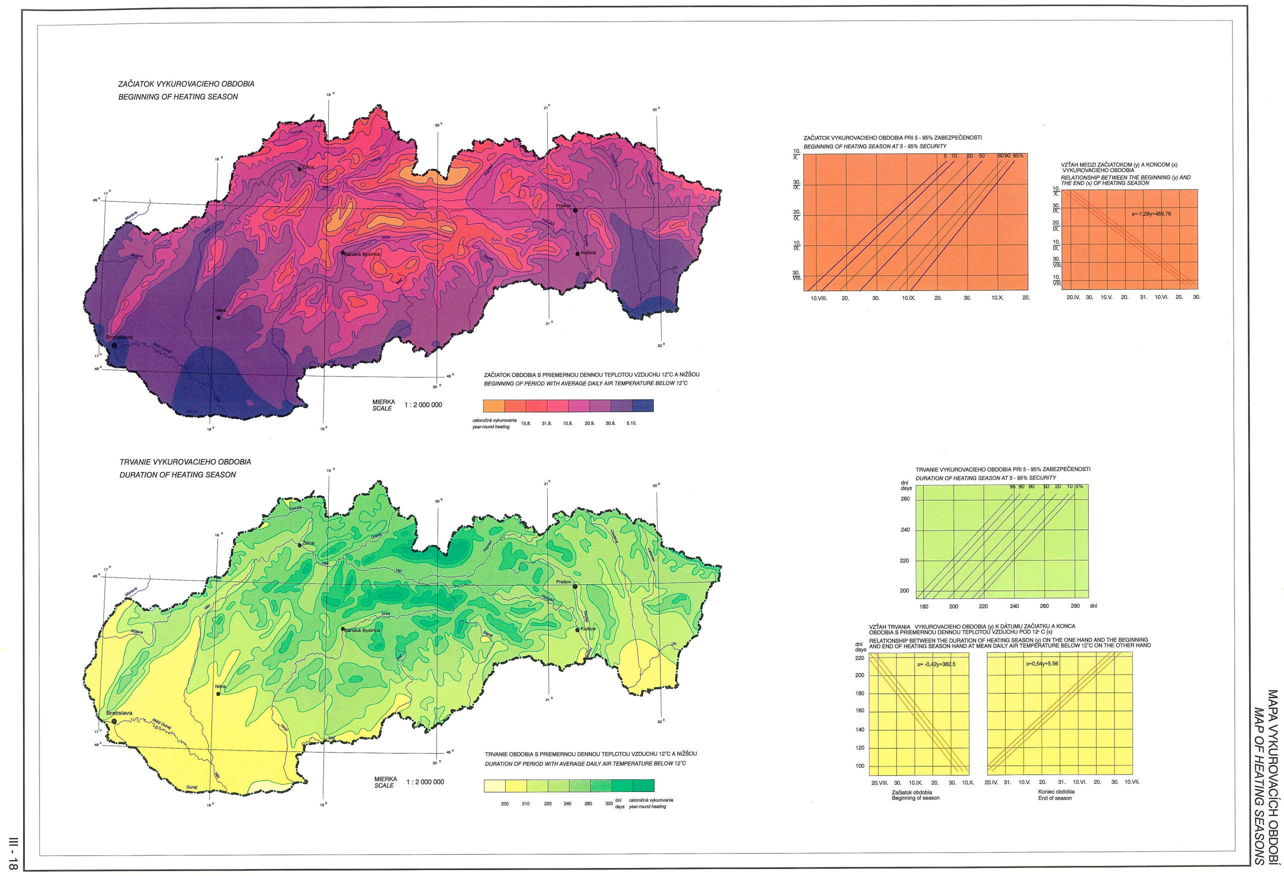
Appendix 6: Perspective localities and structures in Slovakia



Appendix 7: Map and histogram of surface heat flow density in Slovakia



Appendix 8: Map of heating seasons in Slovakia



Appendix 9: Review of distributors and manufacturers of heat pumps in Czech Republic

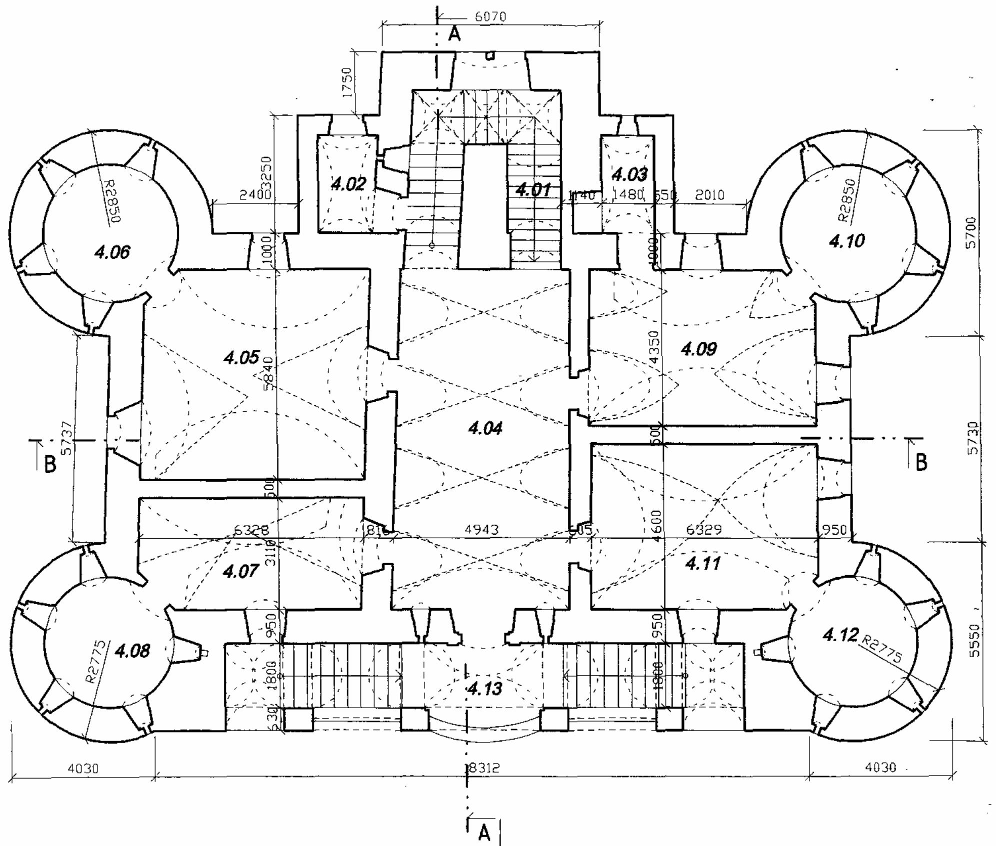
Brand Name	Manufacturer/ Supplier	Contact coordinates	Types of HP			
			Ground (water) /water	air /water	air /air	Ground (water) /air
AC Heating	AC Heating	kontakt Nepomucká 246/114, Plzeň, tel.: +420 775 211 408, e-mail: info@ac-heating.cz, www.ac-heating.cz		✔		
ACOND	ACOND	kontakt www.acond.cz		✔	✔	
AEG	ATEG TEPELNÁ TECHNIKA, s.r.o.	kontakt Květnového vítězství 2/83, Praha 4, tel.: +420 225 340 224, e-mail: info@ateg.cz, www.ateg.cz	✔	✔		
Airmaster	MASTER THERM CZ, s.r.o.	kontakt Elišky Krásnohorské 11/133, Praha 1, tel.: +420 222 326 588, e-mail: info@mastertherm.cz, www.mastertherm.cz	✔		✔	✔
Alpha-InnoTec	Tepelná čerpadla AIT, s.r.o.	kontakt nám. Republiky 15, Brno, tel.: +420 545 214 003, e-mail: info@alpha-innotec.cz, www.aplha-innotec.cz	✔	✔		
BUDERUS	Bosch Termotechnika s.r.o. , obchodní divize Buderus	kontakt Průmyslová 372/1, Praha 10, tel.: +420 272 191 111, e-mail: info@buderus.cz, www.buderus.cz	✔	✔		
CARRIER	SERVIS CARRIER Plzeň, s.r.o.	K cihelnám 100, Plzeň, tel.: +420 377 457 408, e-mail: carrierpm@carrierpm.cz, www.carrierpm.cz	✔	✔		
CIAT	CIATIK TRADE s.r.o.	kontakt Průběžna 41, Praha 10, tel.: +420 274 822 611, e-mail: info@ciat.cz, www.ciat.cz	✔	✔	✔	✔
ACOND	CLIMATEC Group a.s.	kontakt Štěrboholská 1434/102a, Praha 10, tel.“ +420 382 521 202, e-mail: info@climatec.cz, www.climatec.cz	✔	✔	✔	
Climate Master	MASTER THERM CZ, s.r.o.	kontakt Elišky Krásnohorské 11/133, Praha 1, tel.: +420 222 326 588, e-mail: info@mastertherm.cz, www.mastertherm.cz	✔		✔	✔
DANFOSS	DANFOSS, s. r. o.	kontakt V Parku 2316/12, Praha 4, tel.: +420 283 014 111, e-mail: danfoss.cz@danfoss.com, www.cz.danfoss.com	✔	✔		
DIMPLEX	TERMO KOMFORT, s.r.o.	kontakt nám. Republiky 1, Brno, tel.: +420 545 241 893, e-mail: info@termokomfort.cz, www.termokomfort.cz	✔	✔	✔	

EKOTERM	TIFR GROUP, s.r.o.	Škroupova 918/24, 430 01 Chomutov, tel.: +420 474 624 072	✔	✔	✔	✔
EMMETI	IVAR CS s.r.o.	kontakt Podhořany 9, Nelahozeves, tel.: 800 173 965, e-mail: info@ivarcs.cz, www.ivarcs.cz		✔		
ETT	ETL-EKOTHERM, s.r.o.	kontakt Sekaninova 48, Praha 2 tel.: +420 224 936 307, e-mail: etl@etl.cz, www.etl.cz	✔	✔		
FRIGERA	FRIGERA, a.s.	Zengrova 110, Kolín, tel.: +420 321 754 234, e-mail: customer@frigera.cz, www.frigera.cz	✔			
GeoWatt, AirWatt	JESY spol. s r.o.	kontakt Na Cvičírně 188, Liteň, tel.: +420 311 684 298, e-mail: jesy@jesy.cz, www.jesy.cz	✔	✔		
G-MAR	G - MAR PLUS, s.r.o.	Majakovského 29, Karlovy Vary, tel.: +420 353 447 211, e-mail: g-mar@g-mar.cz, www.g-mar.cz	✔	✔		
Goodman	Atanasovský Antonín	kontakt č. 587, Kozlovice, tel.: +420 558 697 697, e-mail: info@topimecerpadlem.cz, www.tepelnecerpadlo.info		✔		
Géothermie Confort	Géothermie Confort	kontakt Rue du Parc des Sports, F – 56 540 Le Croisty, Francúzsko, e-mail: export@geothermie-confort.com, www.geothermie-confort.com				
IVAR HEAT PUMPS	IVAR CS s.r.o.	kontakt Podhořany 9, Nelahozeves, tel.: +420 800 173 965, e-mail: info@ivarcs.cz, www.ivarcs.cz	✔	✔		
IVT	TEPELNÁ ČERPADLA IVT s.r.o.	kontakt Čs. exilu 2062/8, Praha 4, tel.: +420 800 488 488, e-mail: ivt@ivtcentrum.cz, www.cerpadla-ivt.cz	✔	✔		
Kostečka	Kostečka Group spol. s r.o.	kontakt Borského 1, Praha 5, tel.: +420 380 309 211, e-mail: info@kostecka.net, www.kostecka.net	✔	✔		
MACH	TC MACH, s.r.o.	kontakt U mostu 590, Moravský Krumlov, tel.: +420 737 260 793, e-mail: tcmach@tcmach.cz, www.tcmach.cz	✔	✔	✔	✔
MARKUS	TERMO KOMFORT, s.r.o.	kontakt nám. Republiky 1, Brno, tel.: +420 545 241 893, e-mail: info@termokomfort.cz, www.termokomfort.cz	✔	✔		✔
Multi Clima	MASTER THERM CZ, s.r.o.	kontakt Elišky Krásnohorské 11/133, Praha 1, tel.: +420 222 326 588, e-mail: info@mastertherm.cz, www.mastertherm.cz	✔		✔	✔
Mytos	MYTOS, s.r.o.	ul. Smiřických 2, 250 44 Škvorec, tel.: +420 241 484 124, e-mail: mytrade@iol.cz, www.mytos.cz	✔			
NIBE	Družstevní závody Dražice s.r.o - Divize tepelných čerpadel NIBE	kontakt Dražice 69, Benátky nad Jizerou, tel.: +420 326 373 801, e-mail: nibe@nibe.cz, www.nibe.cz	✔	✔		

OCHSNER	UNIVENTA Praha s.r.o.	kontakt Budova Mikrotechny, Pod Vinicí 23, Praha 4, tel.: +420 225 273 663**,** e-mail: info@univenta.cz, www.univenta.cz	✔	✔	✔	✔
PZP	PZP KOMPLET a.s.	kontakt Semechnice 132, Dobruška, tel.: +420 494 664 203, e-mail: info@pzp.cz, www.pzp.cz	✔	✔	✔	
Regulus CTC	REGULUS, spol. s r.o.	kontakt Do Koutů 1897/3, Praha 4, tel.: +420 241 762 726, e-mail: obchod@regulus.cz, www.regulus.cz	✔	✔		
Revel	REVEL, s.r.o.	kontakt Evropská 127, Příbram – Dubno, tel.: +420 318 620 904, e-mail: info@revel-pex.com, www.revel-pex.com		✔		
RIP	R.I.P. Děčín, spol. s r.o.	Březová 372/83, Děčín, tel.: +420 412 517 635, e-mail: info@rip.cz, www.rip.cz	✔	✔	✔	
Siemens	SIEMENS	kontakt nám. Republiky 15, Brno, tel.: +420 545 214 003, e-mail: info@alphatec.cz, www.siemens-tepelnacerpadla.cz	✔	✔		✔
HIESSMANN	NETsystems a.s. - SOLARsystems alternatívne zdroje	kontakt Hodžova 27, Nitra, tel.: +421 903 725304, e-mail: rdemo@netsys.sk, www.solarsystems.sk	✔	✔	✔	
STIEBEL ELTRON	STIEBEL ELTRON, s. r. o.	kontakt K Hájům 946, Praha 5, tel.: +420 251 116 111, e-mail: info@stiebel-eltron.cz, www.stiebel-eltron.cz	✔	✔	✔	
TEMPSTAR	MASTER THERM CZ, s.r.o.	kontakt Elišky Krásnohorské 11/133, Praha 1, tel.: +420 222 326 588, e-mail: info@mastertherm.cz, www.mastertherm.cz		✔	✔	✔
THERMIA	CLIMATEC Group a.s.	kontakt Štěrboholská 1434/102a, Praha 10, tel.“ +420 382 521 202, e-mail: info@climatec.cz, www.climatec.cz	✔	✔	✔	
TIFR	TIFR GROUP, s.r.o.	Škroupova 918/24, 430 01 Chomutov, tel.: +420 474 624 072	✔	✔	✔	✔
VIESSMANN	VIESSMANN, spol.s r.o.	kontakt Chrášťany 189, Rudná u Prahy, tel.: +420 257 090 900, e-mail: viessmann@viessmann.cz, www.viessmann.cz	✔	✔	✔	✔
WATERKOTTE	HENNLICH INDUSTRIETECHNIK, s. r. o. odštěpný závod G-TERM	kontakt Českolipská 9, Litoměřice, tel.: +420 416 711 250, e-mail: g-term@hennlich.cz, www.g-term.cz	✔			

Appendix 10: Dolná Mičiná manor house – current situation

Appendix 11: Floor projection of the Manor house

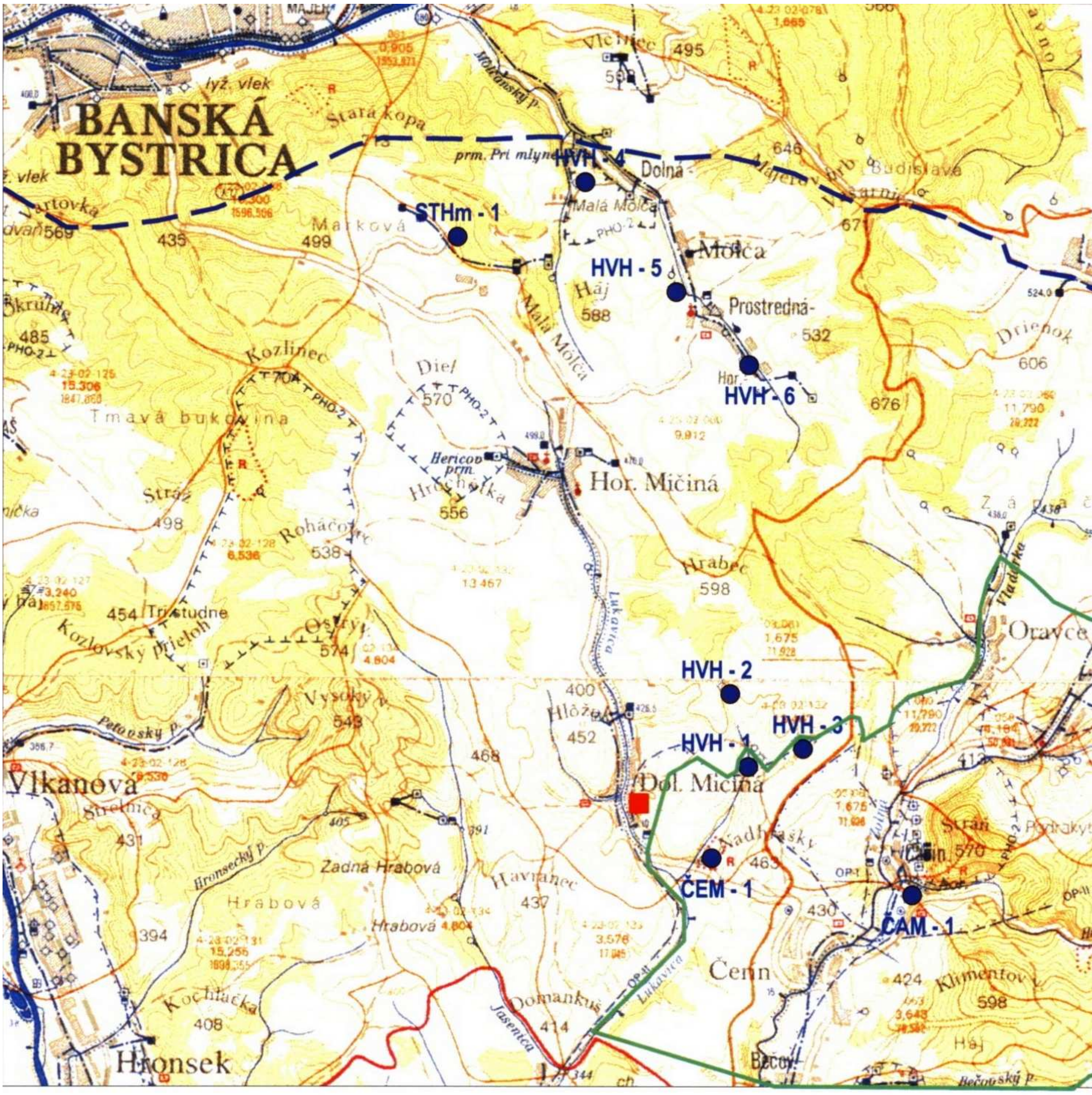


LEGENDA MIESTNOSTÍ

OZNAČENIE MIESTNOSTI	NÁZOV MIESTNOSTI	PLOCHA (m2)
4.01	SCHODISKO	15.29
4.02	MIESTNOSŤ	5.21
4.03	MIESTNOSŤ	5.79
4.04	MIESTNOSŤ	47.22
4.05	MIESTNOSŤ	36.36
4.06	MIESTNOSŤ	11.34
4.07	MIESTNOSŤ	19.02
4.08	MIESTNOSŤ	10.43
4.09	MIESTNOSŤ	27.07
4.10	MIESTNOSŤ	11.34
4.11	MIESTNOSŤ	28.67
4.12	MIESTNOSŤ	10.46
4.13	SCHODISKO	30.25
	SPOLU	258.45 m2
	ZASTAVANÁ PLOCHA:	395.32 m2

STAVBA: KAŠTIEĽ DOLNÁ MIČINÁ
SKUTKOVÝ STAV
OBSAH: PRÍZEMIE

Appendix 12: Situation of surveyed locality Dolná Mičiná (1 : 50 000)



Legend to the hydrogeological map:

- ■ Manor House
- ● Hydrogeological borehole
- Protected zone II. stage - locality Čerín - Čačín
- Protected zone III.stage - Sliač – Kováčová – Čerín - Čačín localities