VYSOKÉ UČENÍ TECHNICKÉ V BRNĚ
BRNO UNIVERSITY OF TECHNOLOGY

FAKULTA STAVEBNÍ
FACULTY OF CIVIL ENGINEERING

ÚSTAV TECHNICKÝCH ZAŘÍZENÍ BUDOV
INSTITUTE OF BUILDING SERVICES

BOUNDARY CONDITIONS FOR THE OPERATION OF THERMAL ENERGY DISTRIBUTION
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BAKALÁŘSKÁ PRÁCE
BACHELOR'S THESIS

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SUPERVISOR

BRNO 2018

VYSOKÉ UČENÍ TECHNICKÉ V BRNĚ
FAKULTA STAVEBNÍ

Studijní program	B3607 Stavební inženýrství
Typ studijního programu	Bakalářský studijní program s prezenční formou studia
Studijní obor	3608R001 Pozemní stavby
Pracoviště	Ústav technických zařízení budov

ZADÁNÍ BAKALÁŘSKÉ PRÁCE

Student	Skarleta Floreková
Název	Boundary conditions for the operation of thermal energy distribution
Vedoucí práce	doc. Ing. Jiří Hirš, CSc.
Datum zadání	30. 11. 2017
Datum odevzdání	25. 5. 2018

V Brně dne 30. 11. 2017

doc. Ing. Jiří Hirš, CSc.
Vedoucí ústavu

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Děkan Fakulty stavební VUT

PODKLADY A LITERATURA

Applicable laws, ordinances, regulations and standards related to the solving theme of bachelor thesis. Domestic, European and world literature, proceedings of scientific conferences and professional events in the field of HVAC. Sources on the Internet. Data from solved building.
Detailed information and further clarification of bachelor thesis provides supervisor during consultation.

ZÁSADY PRO VYPRACOVÁNÍ

A. Theoretical part - a literature review of a given topic, range 10 to 15 pages
B. Calculation part
B1. Diagnostic of external and internal boundary conditions of heat distribution in spa
B2. Analysis of boundary conditions of the pipelines for spa heat distribution
• proposals for measures to reduce energy consumption
• evaluation of the proposed measures
C. Project
• application of calculation methods to the part of pipe lines in the spa
• elaboration of solutions to increase of effectivity heat transfer
• description of created schemes and solutions
D. conclusion, list of sources, the list of abbreviations and symbols, list of annexes, attachments - drawings, diagrams

STRUKTURA BAKALÁŘSKÉ PRÁCE

VŠKP vypracujte a rozčleňte podle dále uvedené struktury:
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doc. Ing. Jiří Hirš, CSc.
Vedoucí bakalářské práce

ABSTRACT

Bachelor thesis ,,Boundary conditions for the operation of thermal energy distribution” is primarily focused on the analysis of the boundary conditions of balneotherapy operation at Slovak Health Spa Piešťany, a. s.. Due to its content, thesis is structurally divided to the analysis of internal and external boundary conditions.

In the part of experimental analysis of internal boundary conditions, the incrust was taken from distribution pipelines of natural healing water and subsequently subjected to chemical analysis and to differential thermal analysis. Partial conclusion of this part lists the recommended material list and procedures, leads to elimination of incrustation form on the surface of materials from natural healing water.

The second part is focused on the analysis of thermal fields in the subsoil at Slovak Health Spa Piešťany, a. s. and on usage possibilities of ground energy. For initial state, based on measured temperatures in the drills and project documentations, 2D thermal fields were created, by which it is possible to define zones with high and low potential usage of energy. Documents serve for the design way of energy use and for experimental verification of current state of thermal fields.

KEYWORDS

renewable source energy, natural healing water, incrustation, thermal field, ground heat potential, heat pump, horizontal ground collector

ABSTRAKT

Bakalárska práca ,,Boundary conditions for the operation of thermal energy distribution,, je primárne zameraná na analýzu okrajových podmienok prevádzky balneoterapie v Slovenských liečebných kúpeľoch Piešťany, a. s.. Vzhľadom k jej obsiahlosti sa práca štrukturálne delí na analýzu vonkajších a vnútorných okrajových podmienok.

V časti experimentálna analýza vnútorných okrajových podmienok bol odobratý inkrust nachádzajúcich v rozvodných potrubiach prírodne liečivej vody a následne podrobený chemickému rozboru a diferenčnej termickej analýze. Čiastkový záver tejto časti uvádza zoznam doporučených materiálov a postupov, vedúcich k eliminovaniu vzniku inkrustácie na povrchu materiálov z prírodne liečivej vody.

Druhá časť je zameraná na rozbor teplotných polí v zemine v Slovenských liečebných kúpeľoch Piešťany, a. s. a možnosťami využitia energie zeme. Pre východiskový stav, boli na základe nameraných teplôt vo vrtoch a projektových dokumentácií, vytvorené 2D teplotné polia, pomocou ktorých je možné definovať oblasti s vyšším a nižším potenciálom využitia energie. Podklady slúžia pre návrh spôsobu využitia energie a pre experimentálne overenie aktuálneho stavu teplotných polí.

KĽÚČOVÉ SLOVÁ

obnoviteľný zdroj energie, prírodne liečivá voda, inkrustácia, teplotné pole, potenciál tepla zeme, tepelné čerpadlo, plošný kolektor,

BIBLIOGRAFICKÁ CITACE VŠKP

Skarleta Floreková *Boundary conditions for the operation of thermal energy distribution.* Brno, 2018. 89s., 19s. příl. Bakalářská práce. Vysoké učení technické v Brně, Fakulta stavební, Ústav technických zařízení budov. Vedoucí práce doc. Ing. Jiří Hirš, CSc.

Declaration:

I declare that, bachelor thesis was written individually by myself and I stated all used information sources.

In Brno 25.5.2018

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Signature of author

Skarleta Floreková

Warning of author:

Stated data in bachelor thesis Boundary conditions for the operation of thermal energy distribution are the subject of company´s secret of its owner Slovak Health Spa Piešťany, a. s. and State Geological Institute of Dionýz Štúr, and were granted exclusively for elaboration of this bachelor thesis. Copying of this bachelor thesis and other manipulation with the stated data is allowed only with the written statement of author.

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Signature of author
Skarleta Floreková

Acknowledgments:

I would like to express my gratitude to my supervisor doc. Ing. Jiří Hirš, CSc., for his valuable comments and assistance in writing of bachelor thesis Boundary conditions for the operation of thermal energy distribution. Secondly I would like to express my gratitude to Ing. Michal Salaj from Alafa Laval Company, Ing. Lukáš Živner, Ph.D from NIBE Company and Ing. Lukáš Stojaspal from Alpha-InnoTec Company for their help with technical specification.

In Brno 25.5.2018

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Signature of author

Skarleta Floreková

CONTENT

1. INTRODUCTION

Europe had taken global leadership in energy and climate policy with long-term renewable targets and the European Union Emissions Trading System (EU ETS). The European Union has been joined by a diverse group of countries and regions that are pursuing effective energy and climate change policies in each of the key sectors of power, transport, buildings and industry. Use of renewable energy sources contributes to the fight against climate change by reducing greenhouse gasses emissions and leads to less pollution of the air.

The European Union Low carbon economy was enhanced to optimized production of greenhouse gases by its reduction for 80% below the 1990 levels by the year 2050. Milestones to achieve this reduction are 40 % emission cut by the year 2030 and 60% by the year 2040. All sector needs to contribute. The Low carbon transition is feasible and affordable.

Renewable energy sources development at Slovak republic would mean reduction in emissions CO_2 and thus mitigation of climate changes. Slovak republic, in comparison with other countries, has high potential of ground heat due to occurrence of thermal springs and natural healing waters. These waters are bound to the hydrological collectors located at depths 200 m – 5 000 m.

The Slovak Health Spa Piešťany has due to its position in valley between the Považský Inovec and Biele Karpaty mountain rich sources of natural healing water with average temperature 60 °C. This water has beneficial impact on human motion system treatment. The waste heat from these natural healing sources of energy is transferred to the subsoil.

Due to the fact that for medical reasons the natural healing water in Slovak Health Spa Piešťany is highly mineralized an incrust occurs during the operation of Balnotherapy at pipelines distribution and technological devices. Such incrust decrease the lifetime of individual materials and contaminate natural healing water.

The bachelor thesis “Boundary conditions for the operation of thermal energy distribution” aim on experimental analysis of thermal field of subsoil across the Spa Island at Slovak Health Spa Piešťany and the influences of incrustation caused by high mineralization of natural healing water. The main target is to design suggestions of systems able to collect waste heat from these sources and define materials resistant to the impacts of highly mineralized natural healing water at Slovak health Spa Piešťany.

2. THEORETICAL PART

Theoretical part is aimed on a literature review of given topic concerning law definitions, technological equipments characterization and literature review of thermal physics.

2.1. EUROPEAN ENERGY UNION

European Union´s energy policies aim to ensure that European citizens can access secure, affordable and sustainable energy supplies. The EU is working in number of areas to make this happen: [14]

- the Energy Union strategy is focused on boosting energy security, creating a fully integrated internal market, improving energy efficiency, decarbonising the economy (not least by using more renewable energy), and supporting research, innovation and competitiveness (Chart 2.1.);
- the Energy Security Strategy presents short and long-term measures to shore up the European Union´s security of energy supply;
- EU funding and other support is helping to build a modern, interconnected energy grid across Europe;
- safety across the European Union´s energy sectors, with strict rules on issues such as the disposal of nuclear waste and the operation of offshore oil and gas platforms.

As a part of its long-term energy strategy, the EU has set targets for 2020 and 2030. These cover emissions reduction, improved energy efficiency, and an increased share of renewable in the European Union´s energy mix. It has also created an Energy Roadmap for 2050, in order to achieve its goal of reducing greenhouse gas emissions by 80 – 95 %, when compared to 1990 level, by 2050. [14]

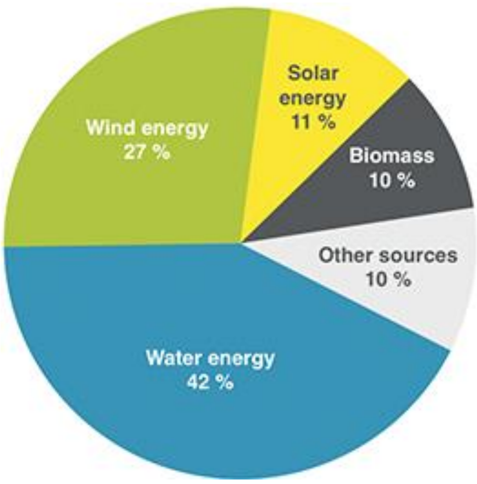


Chart 2.1. – The share of individual renewable energy sources within countries in the European Union

2.1.1. Targets 2020

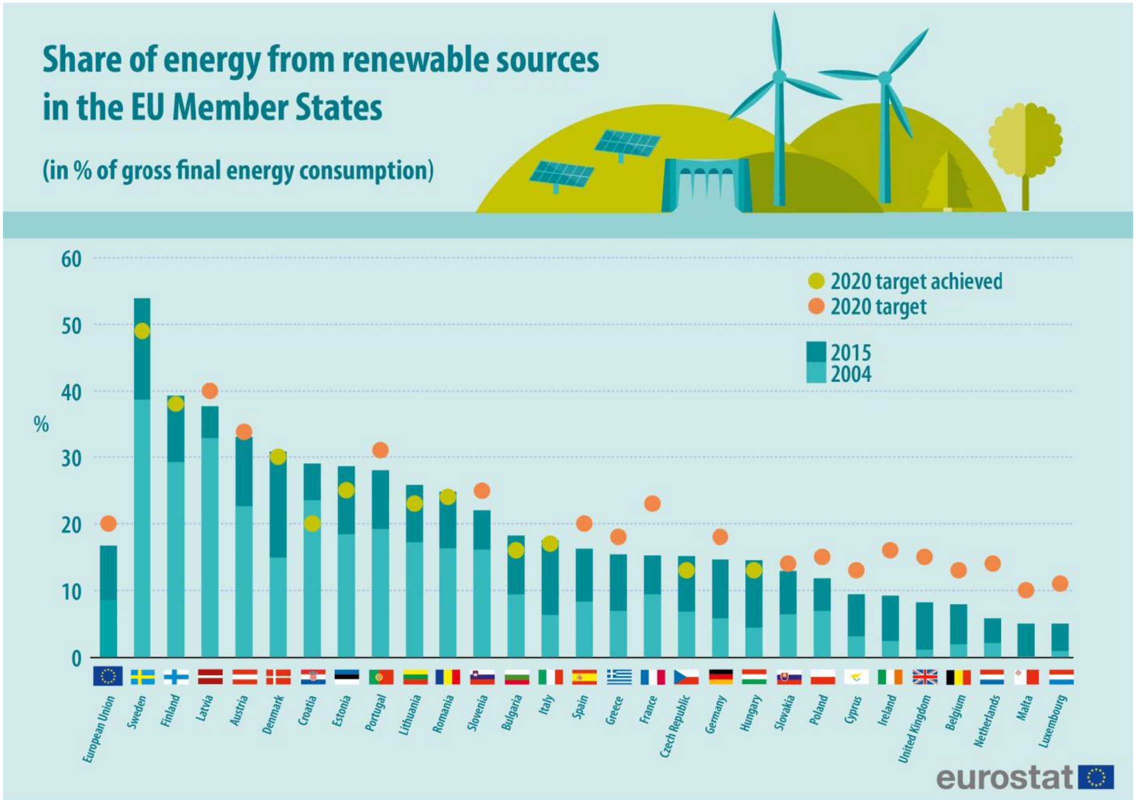
The 2020 package is a set of binding legislation to ensure the EU meets its climate and energy targets for the year 2020.

The package sets three key targets:

- 20 % out in greenhouse gas emissions (from 1990 levels);
- 20 % of EU energy from renewable sources (Picture 2.1.);
- 20 % improvement in energy efficiency. [14]

Achieving the goals of the 2020 package should also help to:

- increase the European Union´s energy security – reducing dependence on imported energy and contributing to achieving the European Energy Union;
- create job possibilities, advance green growth and make Europe more competitive. [14]



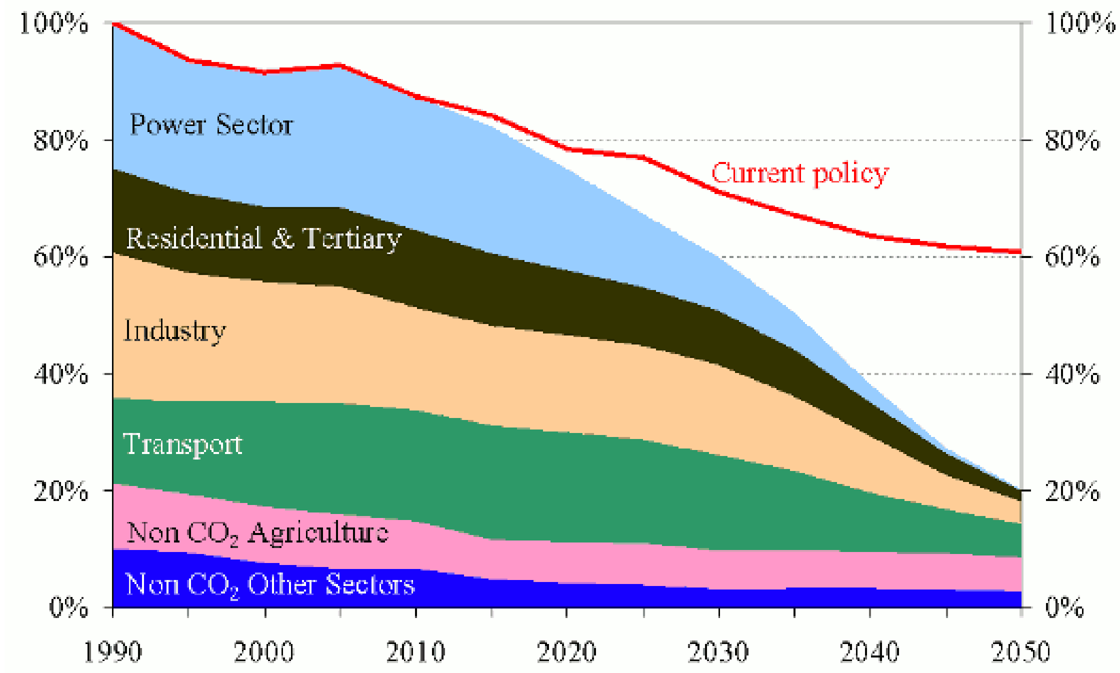
Picture 2.1. – The share of energy from renewable sources, 2004 and 2015 [14]

2.1.2. Targets 2050

The European Commission is looking at cost-efficient ways to make the European economy more climate-friendly and less energy-consuming. Its low-carbon economy roadmap suggests that: [14]

- by 2050, the EU should cut greenhouse gas emissions to 80 % below 1990 levels;
- milestones to achieve this are 40 % emissions cuts by 2030 and 60 % by 2040;
- all sectors need to contribute;
- the low-carbon transition is feasible and affordable.

The roadmap suggests that, by 2050, the EU should cut down its emissions to 80 % below 1990 levels through domestic reductions alone (Picture 2.2.). This is in line with the EU leaders' commitment to reducing emissions by 80 – 95 %by 2050 in the context of similar reductions to be taken by developed countries as a group. To reach this goal, the EU must make continued progress toward a low-carbon society. Clean technologies play an important role. [14]



Picture 2.2. – Possible 80 % cut in greenhouse gas emissions in the EU [14]

2.2. LEGISLATION OF RENEWABLE ENERGY SOURCES IN SLOVAKIA

The target which Slovakia is obligated to reach by 2020 is to produce 14 % of energy from renewable sources (currently about 8,7 %). The basic legal framework governed by the Act on Promotion of Renewable Energy and High-Efficiency Cogeneration No. 309/2009 Coll.. This is called feed in tariff law providing for certain support scheme. As of May 1 2010, with respect to requirements for the building of facilities producing energy, an amendment came into effect, which requires that the compliance of the investment certificate with the long-term energy policy is issued also for facilities producing electricity from solar sources with a capacity of 100 kW and more. [22]

According to the RES law, the following energy sources are eligible for support: hydro, solar, wind, geothermal, biomass, biogas and biomethane (Chart 2.2.).

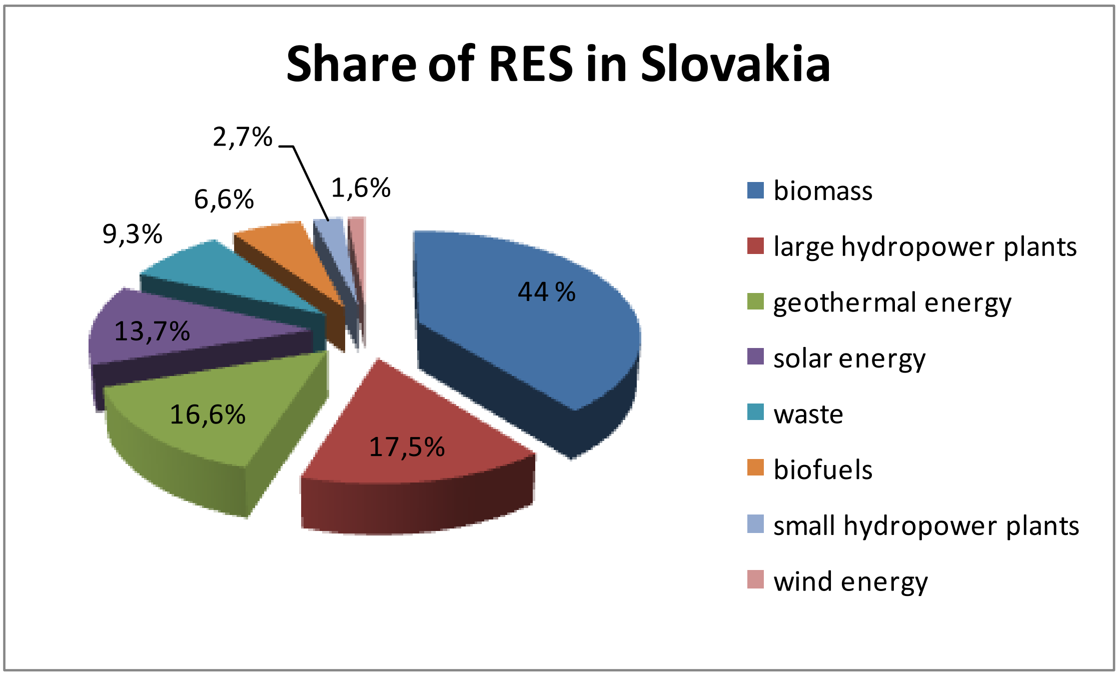
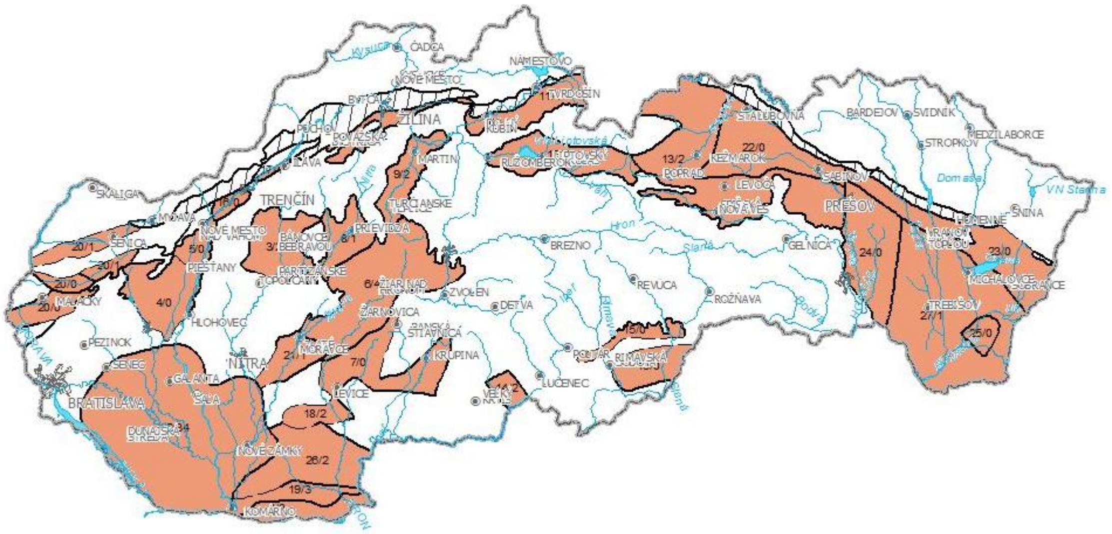


Chart 2.2. – The share renewable energy sources in Slovakia

2.3. LOCATION OF NATURAL HEALING SOURCES AT SLOVAK REPUBLIC

There are currently 17 spa complex in Slovak republic that use natural healing water for balneotherapy purposes. For clarifying, the map of Slovak republic with marked locations of natural healing sources and natural mineral waters is shown in the Picture 2.3..

This bachelor thesis is specifically focused on the SLKP, a. s., which is one of the most important spa complex in Slovak republic.



Picture 2.3. – Locations of natural healing sources and natural mineral waters [15]

2.4. MONITORING OF NATURAL HEALING AND MINERAL SOURCES

Monitoring of the natural healing sources is a part of monitoring of the life environment. The aim of this system is to collect data about mineral waters especially, their chemical, physical, microbiological and biological properties. [29]

Monitoring system of natural healing sources in Slovakia was established to ensure the protection of quality and quantity of NHS and their rationally using on the base of collect data from observations and measurements. [29]

2.5. DEFINITIONS AND PROPERTIES OF MINERAL WATERS AND NATURAL HEALING WATER

Mineral water according to the law 538/2005 Z.z. is underground water which is originally accumulated in a natural environment and pouring out of the ground by the one or more natural or artificial exit drills, which differs from other underground water by [35]:

- its origin,
- the content of trace elements,
- the content and character of total diluted solid particles exceeding 1000 mg.l^{-1} of carbon dioxide or at least 1 mg.l^{-1} of sulphur,
- minimum temperature 20 °C. [29]

Natural healing water according to the law 538/2005 Z.z. is mineral water which was due to its composition sufficient for healing procedures recognized by the State spa commission of the Ministry of Health of the Slovak republic. [29]

These types of water create incrustation, bio fouling and corrosion in the pipes and at the surface of technical devices.

Pipe deterioration has been investigated by various authors. Corrosion, incrustation and bio fouling are responsible for decrease and distortion of the pipe cross-section, increases in surface roughness and reduction of the quality of water. An increase in the hydraulic resistance of pipes (particularly steel or cast iron) is frequently attributed to incrustation of their walls by pipe corrosion or precipitation from water. [39]

2.5.1. Incrustation

Incrustation has composition of a slimy orange-brown deposit seem to be a major water quality problem in a water distribution networks. The type and amount of dissolved minerals and gases in the natural waters determines their tendency to deposit mineral as incrustation (Picture 2.4. and Picture 2.5.). The major forms of incrustation include [39]:

1. Incrustation from precipitation of calcium and magnesium carbonates or their sulphates.
2. Incrustation from precipitation of calcium and magnesium carbonates or their sulphates.
3. Scales caused by slime-producing iron bacteria or other slime-forming organisms.

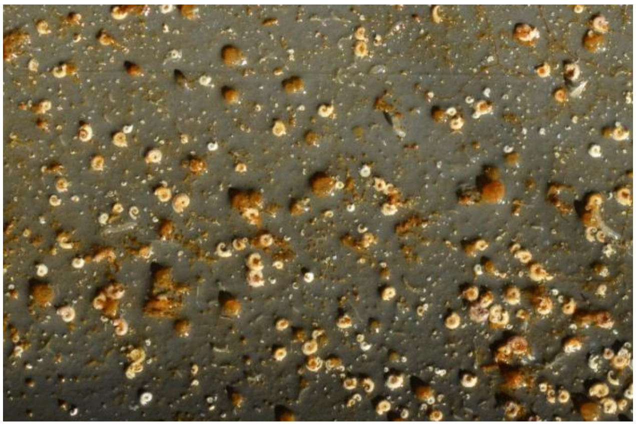
Incrustation of pipe inhibits water flow through the system, overworking pumps and increasing energy costs. Hydraulic losses result in increased pump load and reduced fire fighting capacity. Low pressure results from the rough or cracked pipe walls, and the corrosion internally on cast iron pipe affects water quality and flow. [39]

Picture 2.4. – The cast iron pipelines from the fabrication [24]

Picture 2.5. – Damaged cast iron pipeline after few years by incrust

2.5.2. Bio fouling

Bio fouling is the undesirable accumulation of microbiological deposits on a surface. This fact is shown in the Picture 2.6.. Biofilm accumulation is the result of physical, chemical and biological processes. Biofilms play a major part in the microbial characterization of water quality in distribution networks. It has been reported by various authors that aging ductile and cast iron pipes show extensive incrustation and bio fouling in water supply pipes, causing low and negative pressure. [39]



Picture 2.6. – Bio fouling inside of pipeline [35]

2.5.3. Corrosion

Corrosion may be defined as ,,the conversion of a metal to salt or oxide with a loss of desirable properties such as mechanical strength". Internal corrosion is the deterioration of the inside wall or wall lining of a pipe caused by reactions with water (Picture 2.7.). Internal corrosion plays an important role in the lifespan of the pipe and quality of water in the conveyance system. [39]

Picture 2.7. – Corrosion in pipeline [6]

2.5.4. Thermal analysis – TGA, DSC, DTA

In chapter 4 – PROJECT, we meet the term „thermal analysis” that was used to solve the problem of incrustation more closely. Therefore, it is necessary explain this term.

Thermal analysis is a group of techniques that study the properties of materials as they change with temperature. In practice thermal analysis gives properties like; enthalpy, thermal capacity, mass changes and the coefficient of heat expansion. Solid state chemistry uses thermal analysis for studying reactions in the solid state, thermal degradation reactions, phase transitions and phase diagrams. As an example I presented Chart 2.3. TGA-DTA [18]

Among the most commonly used thermal analyzes are: [18]

- thermogravimetric analysis (TGA): mass
- differential scanning calorimetry (DSC): heat difference
- differential thermal analysis (DTA): temperature difference

In DTA technique the heat flow to the sample and reference remain the same rather than the temperature. The material under study and an inert reference are made to undergo identical cycles. [18]

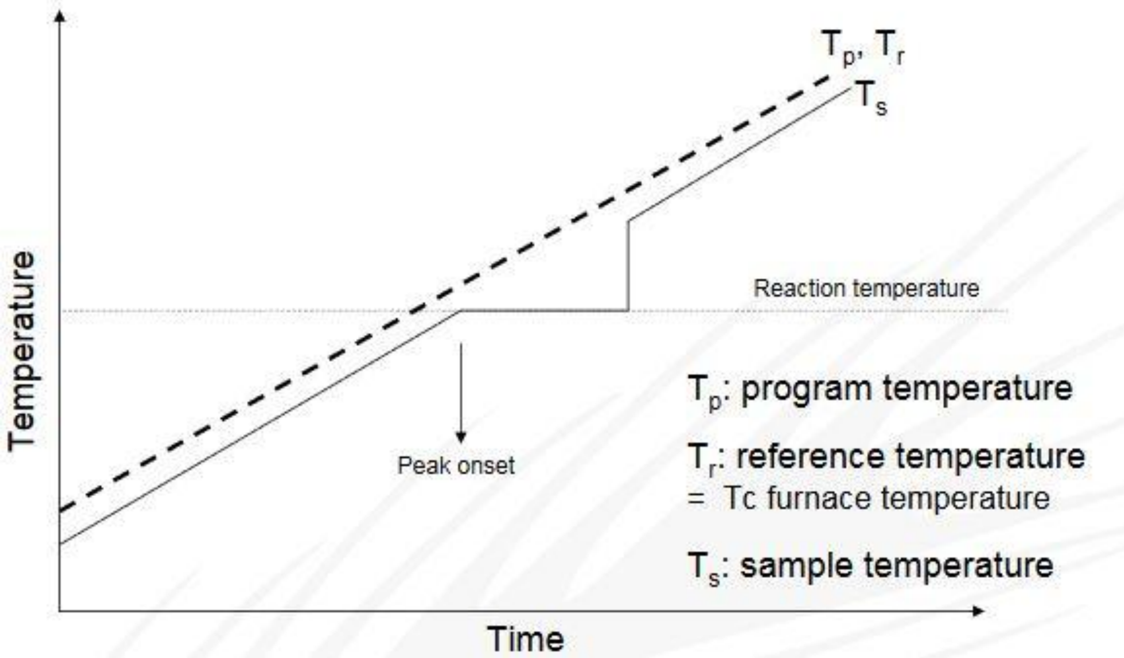


Chart 2.3. – Schematic chart showing the origin of the TGA-DTA signal [18]

2.6. THERMAL PHYSICS

Thermal physics is the combined study of thermodynamics, statistical mechanics and kinetic theory. This umbrella-subject is typically designed for physic students and functions to provide a general introduction to each of three core heat-related subjects. Starting with the basic of heat and temperature, thermal physics analyzes the first law of thermodynamics and second law of thermodynamics from the statistical perspective. [30]

2.6.1. Heat transfer

Heat is the process of heat transfer from high temperature reservoir to low temperature reservoir. In terms of the thermodynamic system, heat transfer is the movement of heat across the boundary of the system due to temperature difference between the system and the surroundings. The heat transfer can also take place within the system due to temperature difference at various points inside the system. The difference in temperature is considered to be „potential" that causes the flow of heat and the heat itself is called as a flux. There are three types of heat transfer as a conduction, convection and radiation, that are shown in the Picture 2.8.. [9]

Picture 2.8. – Three types of heat transfer [8]

2.6.1.1. <u>Conduction</u>

The heat transfer between two solid bodies is called as conduction. It depends on the difference in temperature of the hot and cold body. [9]

2.6.1.2. <u>Convection</u>

The heat transfer between the solid surface and the liquid as called as convection. Convection can arise spontaneously (or naturally, freely) through the creation of convection cells or can be forced by propelling the fluid across the object or by the object through the fluid. [9]

2.6.1.3. Radiation

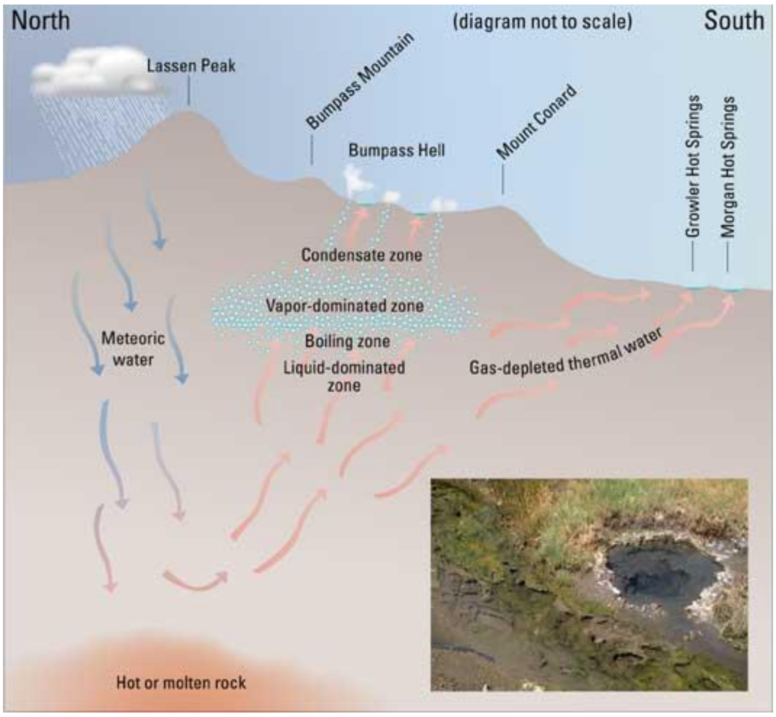
When two bodies are at the different temperatures and separated by the distance, the heat transfer between them is called as radiation heat transfer. The radiation heat transfer occurs due to the electromagnetic waves that exist in the atmosphere. One of the most important examples of radiation heat transfer is the heat of sun coming on the earth. [9]

2.7. THE HEAT OF THE GROUND TRANSMITTED BY GROUNDWATER

Difference of heat transfer by conduction and convection are generally known. Therefore, special attention must be paid to convection heat transfer in the earth´s crust by water medium. The importance of water for heat transfer in the deeper layers of the Earth, in the surface layer of the continental crust, generally in hydrosphere or in lithosphere is great, especially with respect and understanding of use this heat. [32]

Heat transfer by water is heat movement by convection. The movement is very fast and can be implemented even over long distance. Hot water in the ground could be of dual origin: [32]

Meteoric water is water coming from atmospheric precipitation. By methods of isotope geochemistry has been proven, that most groundwater is solely of meteoric origin. By gravity descends infiltrated precipitation water through the cracks and in pores of rocks into the depth. Several kilometres under surface the groundwater are heated up to 200 °C or higher. This fact is illustrated in the Picture 2.9. [32]



Picture 2.9. – Origin of hot meteoric water [40]

Juvenile water is „ new” water, whose sources are metamorphic and geochemical processes of rocks in deeper layers of Earth (Picture 2.10.). During this processes the water is released from the rocks and as hot overheated water or steam escapes to the surface of the Earth with gases. [32]

Picture 2.10. – Juvenile water (hot springs) in Umi jikogu – Japan [42]

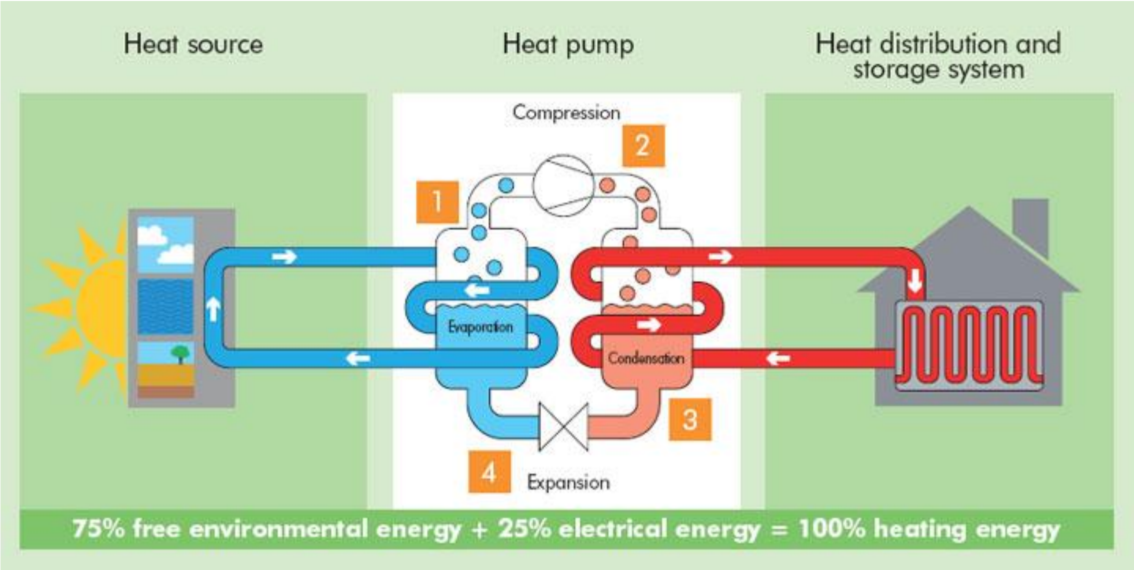
2.8. HEAT PUMP

Heat pump is device for transferring heat from a substance or space at one temperature to another substance or space at higher temperature. [28]

It consists of:

- a compressor,
- a condenser,
- a throttle or expansion valve,
- an evaporator,
- a working fluid – refrigerant.

The compressor delivers the vaporized refrigerant under high pressure and temperature to the condenser, located in the space to be heated. There, the cooler air condenses the refrigerant and becomes heated in the process. The liquid refrigerant then enters the throttle valve and expanding, comes out as a liquid-vapour mixture at lower temperature and pressure; it then enters the evaporator, where the liquid is evaporated by contact with a comparatively warmer space. The vapour then passes to the compressor, and the cycle is repeated. The Picture 2.11. below describes principle of the heat pump. [28]

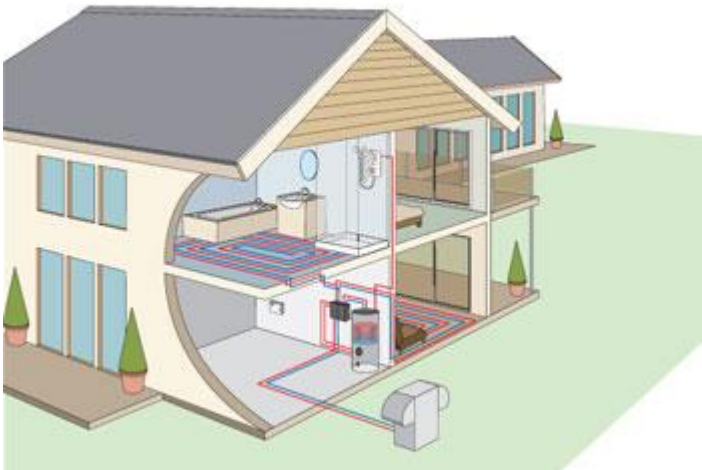


Picture 2.11. – Illustration of heat pump principle [34]

2.8.1. Heat pump air/water

Air-to-water heat pumps extract heat energy from the outside air in order to heat the home or business. An air-to-water heat pump has an outside heat exchanger unit that takes heat from the air. The air is pulled through the heat exchanger by a fan whenever the heat pump is on. The heat exchanger has a refrigerant running through it which is able to absorb heat at a low temperature. The heat pump air/water is shown in the Picture 2.12. [28]

This type of heat pump can heat building even when it is as low as -15 °C outside. This refrigerant is then compressed or pumped up to a higher temperature by the compressor. Then is passed to the water that circulates around through the radiators or under floor heating to heat the building or to hot water tank to heat shower and sink water. The temperature that the air-to-water heat pump gets from the air may only be at a low temperature but that heat can be pumped up to heat the water to 55 or 60 °C. [28]

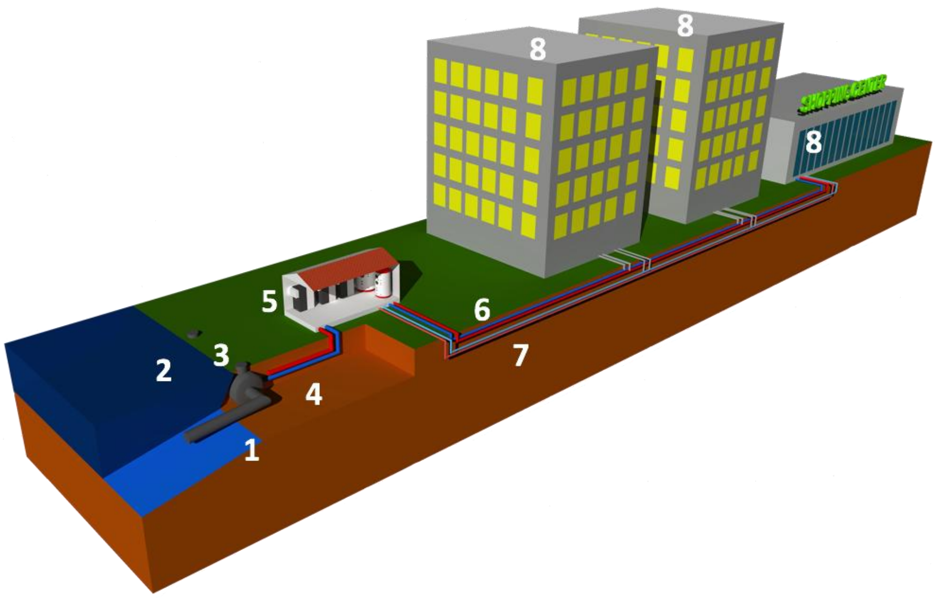


Picture 2.12. – Heat pump air/water [34]

2.8.2. Heat pump water/water

For this system, the natural source is surface, ground and underground water. From the source, mostly from the well and oceans (Picture 2.13.), the water is pumped and then passes through the exchanger of heat pump – evaporator, which removes the part of heat from heat pump and then returns it back to the ground by the second well. The distance between the boreholes should be at least 10 m. This water has a stable temperature around 10 °C, it is means that it is the warmest source. Coefficient of performance (COP) of this heat pump type is around 6 – 7.

1. Inlet for water
2. Outlet for water
3. Exchanger
4. Brine circuit to plant room
5. Plant room with ground source heat pumps
6. District heating pipes
7. District cooling pipes (option)
8. Buildings to be heated (and cooled)



Picture 2.13. – Heat pump water/water [19]

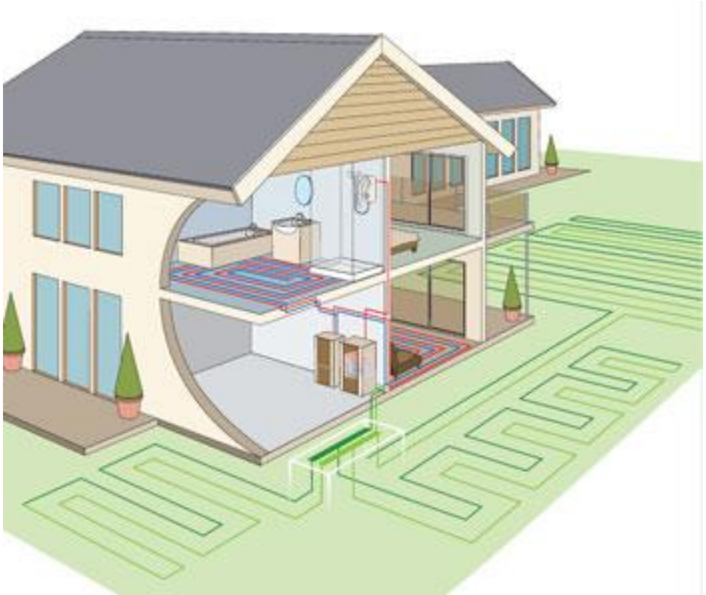
2.8.3. Heat pump ground/water

Ground source heat pumps (GSHP), sometimes referred to as GeoExchange, earth-coupled, ground-source heat pumps have been in use since the late 1940s.The use the constant temperature of the earth as the exchange medium instead of outside air temperature. Depending on latitude, ground temperature range from 7 °C to 21 °C. The GSHP take advantage of this by exchanging heat with the earth through the ground heat exchanger. Heat pumps ground-to-water mostly extracts low-potential heat from the surrounding subsoil. There are two types for the heat pump ground-to-water: [16]

- horizontal collectors
- vertical boreholes

2.8.3.1. <u>Horizontal collectors</u>

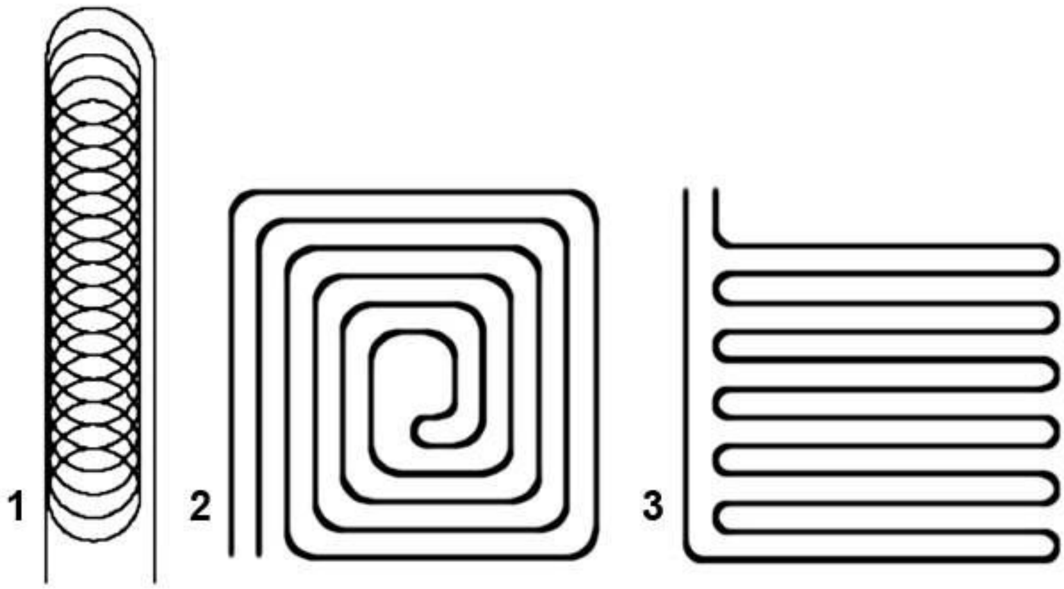
The ground collector is horizontally placed to the subsoil in depth from 1,2 m – 1,5 m (Picture 2.14.). The energy is obtained from the sun, which is accumulated in the top layers of the ground during the summer season. The thermal properties of the soil are decisive for the ground collector installation. Designers are guided by values listed in the Table 2.1.. This system is called as a closed-loop system and is considered maintenance-free. Most closed-loop ground heat pumps circulate an antifreeze solution through a closed-loop, usually made of plastic tubing – that is buried in the ground or submerged in water. A heat exchanger transfers heat between the refrigerant in the heat pump and the antifreeze solution in the closed loop.



Picture 2.14. – Horizontal ground collector [34]

The horizontal collector can be connected in way of slinky-loop, in spiral way and in meander way. This fact is described in the Picture 2.15.. [20]

1. Slinky-loop – is suitable for placement in flooded subsoil, where is high moisture concentration. Disadvantage of this type is great heat collection, relatively from small area and it causes local cooling of the subsoil.
2. Spiral – evenly extract of heat from area
3. Meander – ideally spread extract of heat. Advantage of this type is that from the heat pump flows a cooler liquid and after passing through the meander, the warmest liquid is collected to the heat pump.



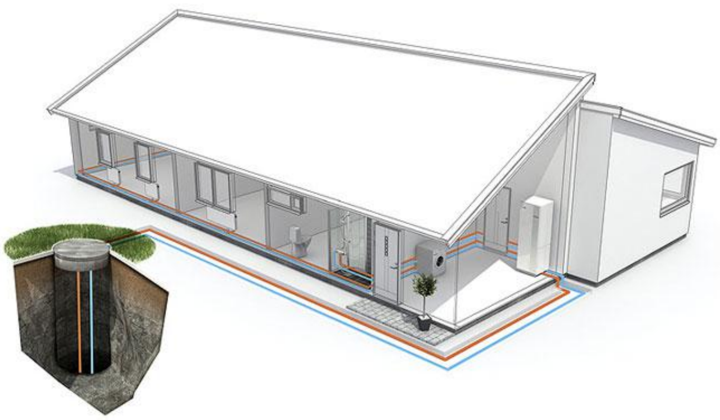
Picture 2.15. – Three types of horizontal collector connection [20]

Table 2.1. – Guidelines values to design the ground collector [33]

SUBSOIL	POSSIBLE HEAT COLLECTION	
	for 1 800 hours of operation	for 2 400 hours of operation
Dry frictional soil	10 W/m^2	8 W/m^2
Watered gravels and sand	20 - 30 W/m^2	16 - 24 W/m^2
Underground water, gravels and sand	40 W/m^2	32 W/m^2

2.8.3.2. Vertical boreholes

Vertical boreholes or probe are very popular especially at smaller plots as it requires a minimum of space. Therefore represent the best solution during the transition from heating by fossil fuels to heating by ground energy. (Picture 2.16.) As well as for the ground collector, antifreeze solution (refrigerant) is circulating in the closed-loop system.



Picture 2.16. – Vertical probe solution [33]

2.8.4. Coefficient of performance

The efficiency of refrigeration system and the heat pumps is denoted by its Coefficient of Performance (COP). The COP is determined by the ratio between energy usage of the compressor and the amount of useful cooling at the evaporator (for a refrigeration installation) or useful heat extracted from the condenser (for a heat pump). A high COP represents a high efficiency. [23]

The efficiency of the heat pump, COPh, depends on several factors. Especially the temperature difference between waste heat source and potential user is an important factor. The temperature difference between condensation and evaporation temperature mainly determines the efficiency, the smaller the difference, the higher the COPh. The Charts 2.4. bellow shows the influence of this temperature difference on the COPh value. The chart shows an increase in COPh with an increasing evaporation temperature. [23]

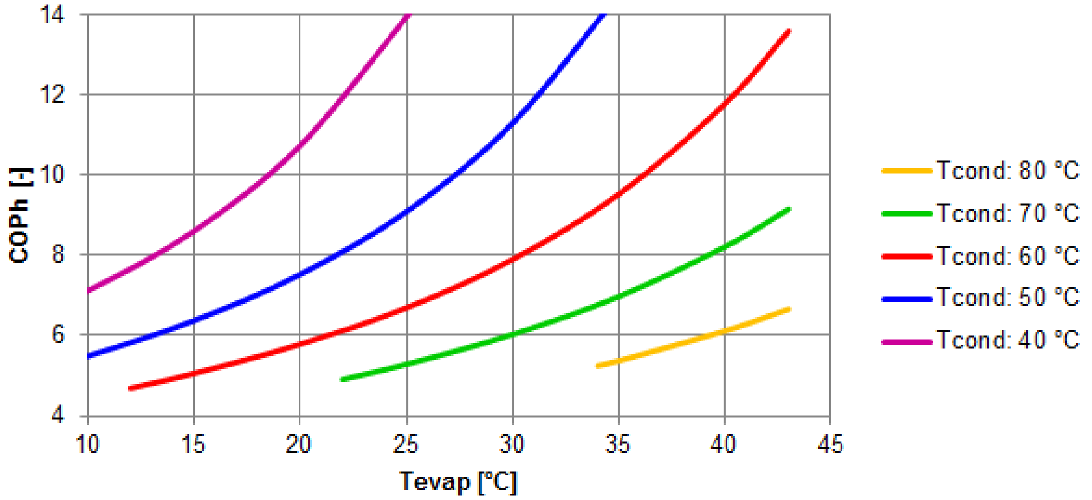


Chart 2.4. - Influence of the temperature difference on the COPh value [23]

2.8.5. Seasonal performance factor

The Seasonal Performance Factor (SPF) only applies to heat pumps. It is a measure of how efficiently the heat pump is operating. Put simply, the higher SPF value the more energy efficient system is. SPF is a measure of the operating performance of an electric heat pump heating system over a year. It is ratio of the heat delivered to the total electrical energy supplied over the year. [23]

2.8.6. Refrigerant

Is substance or mixture, usually fluid, used in heat pump and refrigeration cycle. In most cycles it undergoes phase transition from liquid to a gas and back again. Refrigerants are divided into three groups according to their chemical composition: HFCs, HCFCs and CFCs. [41]

HFCs = HydroFluoroCarbons are refrigerants that contain no chlorine and are not harmful to the ozone layer. HydroFluorCarbons are stron greenhouse gases and are regulated by the Kyoto Protocol – a 1997 international treaty to solve a global warming by curtailing emissions of greenhouse gases. However, their impact on the global warming is very large compared with traditional refrigerants. The most common HFCs refrigerants are shown in the Picture 2.17.. [41]

Picture 2.17. – HFCs refrigerants [1]

HCFCs = HydroChloroFluoroCarbons; the slow phase-out of CFCs shows it is a costly process. However, and more importantly, it also shows the problems and indecisiveness surrounding the availability of HCFCs, which were officially indicated as a temporary (until 2030) substitute for CFCs. [41]

The HCFCs contain less chlorine than CFCs, which means a lower ODP – Ozone Depleting Potential (factor indicating a substance´s relative ozone damaging power). Examples of HCFCs refrigerants is possible to see in the Picture 2.18.. [41]

Picture 2.18. – HCFCs refrigerants [1]

CFCs = ChloroFluoroCarbons are refrigerants that contain chlorine. They have been banned since the beginning of the 90´s because of their negative environmental impacts. Examples of CFCs are R11, R12 and R115. The conversion of equipment and systems using CFCs has no yet been completed. On the contrary, the illegal market for this type of refrigerants flourishes worldwide, and it is estimated that no more than 50 % of CFC system worldwide have been upgraded. The types of CFCs refrigerants is possible to see in the Picture 2.19.. [41]

Picture 2.19. – CFCs refrigerants [1]

3. CALCULATION PART

This chapter describes formulas that are used in project part of bachelor thesis for calculation and evaluation of data.

3.1. Diagnostic of external and internal boundary conditions of heat distribution in spa

For internal boundary conditions were developed chemical formulas to determine of incrust compositions that are obtained in the chapter 4. PROJECT.

Calorimetric equation

The calorimetric equation is describing heat transport through the law of motions. On its base is possible to determine specific heat capacity, amount of heat, which is necessary to add or remove, in order to obtain temperature change or to gain the total heat transport.

$$\boldsymbol{Q = m.c.(\Theta_2 - \Theta_1)} \tag{3.1}$$

$$\boldsymbol{Q_{handover} = Q_{obtianed}} \tag{3.2}$$

$$\boldsymbol{c_1.m_1.\Delta\Theta_1 = c_2.m_2.\Delta\Theta_2} \tag{3.3}$$

$$\boldsymbol{c_1.m_1.(\Theta_1 - \Theta) = c_2.m_2.(\Theta - \Theta_2)} \tag{3.4}$$

Where:

m	amount of NHW
c	thermal conductivity of water
Θ	temperature of NHW

3.2. Analysis of boundary conditions of the pipelines for spa heat distribution

For this case Picture 3.1., an estimate for soil theral resistance may be used. This estimate is sufficietly accurate (within 1%) for the ratios of burial depth to pipe radius indicated for Equations (1) and (2). Both the actual resistance and the approximate resitance is presented, along with the depth/radius criteria for each.

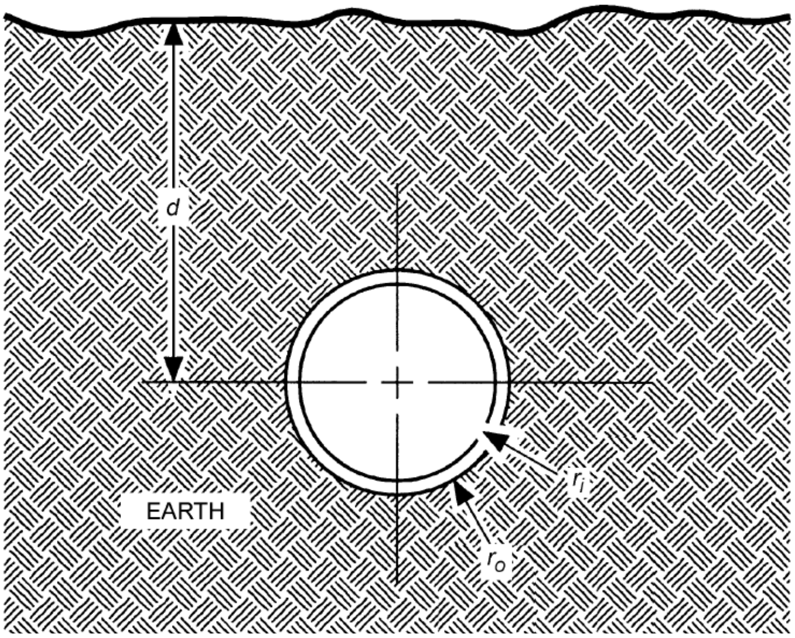
Thermal resistance of soil

$$\boldsymbol{R_s = \frac{\ln\left\{(d/r_0)+\left[(d/r_0)^2-1\right]^{1/2}\right\}}{2\pi k_s}} \qquad \text{for } d/r_0 > 2 \tag{3.5}$$

$$\boldsymbol{R_s} = \frac{\ln(2\boldsymbol{d}/\boldsymbol{r_0})}{2\pi\boldsymbol{k_s}} \qquad \text{for } d/r_0 > 4 \qquad (3.6)$$

Where:

R_s	thermal resistance od soil - (m.K)/W
k_s	thermal conductivity of soil - W/(m.K)
d	buried depth to centerline of pipe - m
r_0	outer radius of ipe or conduit - m



Picture 3.1. – Single uninsulated buried pipe [Source: ASHRAE]

The thermal resistance of the pipe is included if it is significant when compared to the soil resistance. The thermal resistance of the pipe or any concentric circular region given by:

Thermal resistance of pipe wall

$$\boldsymbol{R_p} = \frac{\ln(\boldsymbol{r_0}/\boldsymbol{r})}{2\pi\boldsymbol{k_p}} \qquad (3.7)$$

Where:

R_p	thermal resistance of pipe wall - (m.K)/W
k_p	thermal conductivity of pipe - W/(m.K)
r_i	inner radius of pipe - m

Rate of heat transfer

$$\boldsymbol{q = \frac{t_f - t_s}{R_t}} \tag{3.8}$$

R_t	total thermal resistance (i.e., R_s + R_p in this case of pure series heat flow) - (m.K)/W
t_f	fluid temperature - °C
t_s	average annual soil temperature - °C
q	heat loss or gain per unit length of system - W/m

The negative result indicates a heat gain rather than a loss. Note that the thermal resistance of the fluid/pipe interface has been neglected, which is a reasonable assumption because such resistances tend to be very small for flowing fluids.

Volume of fluid per length of pipe

$$\boldsymbol{V_l = \frac{\pi}{4} \times D_i^2} \tag{3.9}$$

Where:

D_i	inner diameter of pipe - m
V_l	volume of fluid - m^3

Mass of fluid per length of pipe

$$\boldsymbol{M_{tw} = V_l \times \rho_w} \tag{3.10}$$

Where:

V_l	volume of fluid - m^3
ρ_w	density of fluid - kg/m^3
M_{tw}	mass of fluid - kg

Temperature of fluid after time interval

$$\boldsymbol{T_f = -\frac{\tau \times q}{c_{pw} \times M_{tw}} - T_i} \tag{3.11}$$

Where:

τ	time interval - s
q	heat loss or gain per unit length of system - W/m
T_i	initial temperature of the water – °C
T_f	temperature of water at the end of time interval - °C
c_{pw}	specific heat of water – J/kg.K
M_{tw}	mass of fluid – kg

4. PROJECT

The subject of this chapter is application of calculation methods to the part of pipelines in the spa, elaboration of solutions to increase of effectivity heat transfer and description of created schemes and solutions.

4.1. LOCATION OF PIEŠŤANY

Piešťany is located in a picturesque setting by the River Váh in south-western Slovakia at an elevation of 162 m. It is situated 86 km north-east of Bratislava, the capital city of Slovakia (Picture 4.1.). The motorway D1 exit from Bratislava to Žilina with connections to Vienna and Brno also goes through the town. The Považský Inovec mountains form the eastern boundary of this part of the Váh valley.

Picture 4.1. – Location of town Piešťany [21]

4.2. SPA ISLAND PIEŠŤANY

For the purpose of this bachelor thesis elaboration due to its size of issues it will be aimed only on chosen part of Slovak Health Spa Piešťany. For overall evaluation is necessary to understand it as a complex system from ground energy of the earth´s crust through hydrogeology until the chemistry.

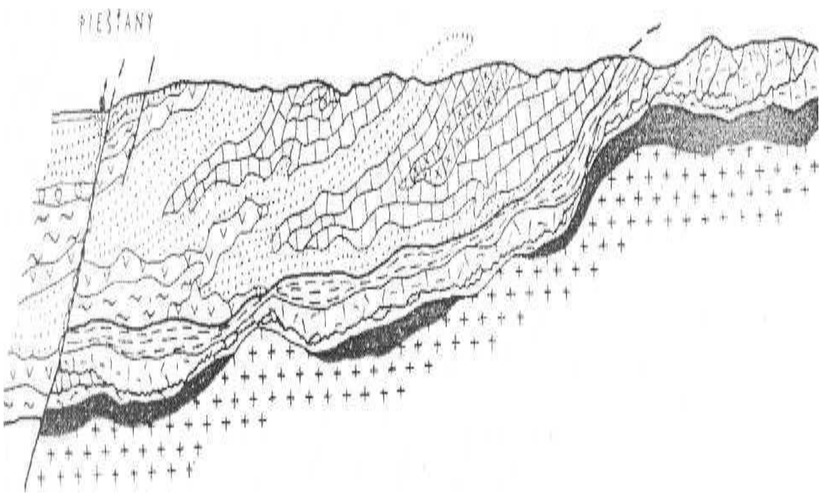
4.2.1. The spa heritage

The Spa Island of Piešťany is one of Europe's largest and most unique spa complexes (Picture 4.2.). Its curative waters comprise ten springs of natural healing water containing hydrogen sulphide and 1450 $mg.l^{-1}$ of mineral substances. These waters have permeated the limestone for many centuries and have been naturally heated by the Earth’s magma to temperatures of between 67 – 69 °C. [11]

Picture 4.2. – The photo of Piešťany Spa Island [Source: Archive of SLKP a.s.]

4.2.2. The oldest knowledge about natural healing waters in Piešťany

The first real scientific survey of natural healing waters in Piešťany was elaborated by professor Hynie with co-workers M. Dovolil and M. Wallenfels from Charles University in Prague. His first reports are dated since 1927 (Hynie, 1927) where he describes relationship between water temperature in thermal coupe in gravel river sediments and water level in Bypass river Váh. He led and carried out hydrogeological research of hot-spring area of natural healing waters in Piešťany. He collaborated with professor Maheľ (1950, 1952) and later with professor Augustin Rebro, who processed the old historic literature. Based on reports of prof. Hynie a and prof. Maheľ we can summarize the past age know-how. The system of springs in Piešťany and Koplotovce poure out on the left-hand side of the valley from tectonic plates under Považany which are boarded by Inovec (Picture 4.3.). [31]



Picture 4.3. – The schematic profile explaining the origin of NHW in Piešťany [3]

4.3. INTERNAL BOUNDARY CONDITIONS

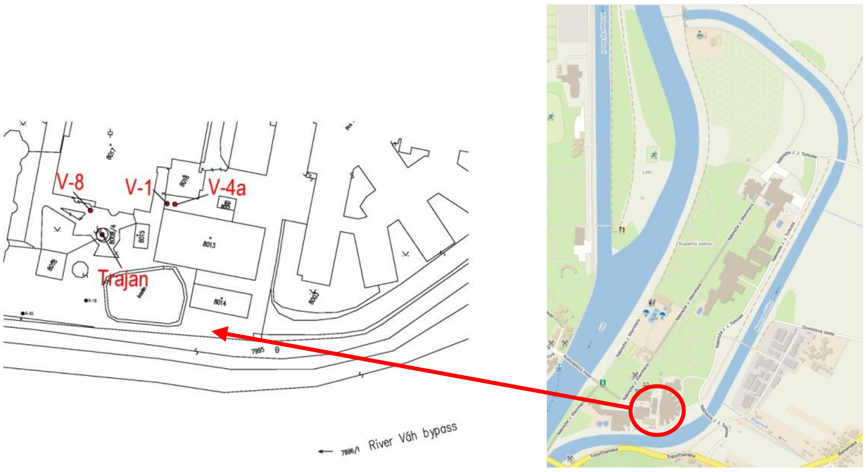
This chapter is focused on the internal boundary conditions of the SLKP, a. s. which concern division of drills and wells in spa, pipelines distribution and negative effect of natural healing water in devices for securing of healing procedures and subsequent analysis to eliminate of this effect.

4.3.1. Natural healing sources and natural mineral water in SLKP, a. s.

Recognition of natural healing water and recognition of natural mineral water is defined by Act No. 364/2004 Coll. – water law, in §§ 5 – 9. Mineral water can be recognized as natural healing water, when the healing effects are shown during at least 5 years in balneological practise and fulfil requirements given by generally mandatory regulation. The healing effects can be consider as proven even when this effects was verified by long-term balneological practise during use of waters with similar physical, chemical and physicochemical properties. As a natural mineral water can be recognized a water from the source, only, which one was monitored at least 3 years, during this season was shown stability of all its decisive indicators and there was no change of its nutritional properties and fulfil requirements given by generally mandatory regulation published by Ministry of Health. [5]

To allow the use of natural healing source and natural mineral source can be only in cases, when water from the source was recognized already and after published of decision about recognition of water is possible submit a request for permission to use the source. Natural healing sources should be use preferentially for healing effects and it can be used only within the scope of authorization. [5]

Based on this reality are using 3 drills V-1 (Picture 4.6.), V-4a (Picture 4.5.), V-8 and well Adam Trajan (Picture 4.7.), which are stated in Table 4.1. and situated on the map of Spa Island (Picture 4.4.).



Picture 4.4. – Situation of using drills and well at Spa Island [26]

Table 4.1. – Currently used drills and wells in spa [27]

Source of NHS water		Max. enabled collection of NHS water [l/s]	Temperature of NHS from long-term point of view [°C]	Depth [m]
Drills	V1	4,1	62,6 - 66,7	54,3
	V4a	8,0	64,4 - 66,5	54,0
	V8	6,2	62,2 - 67,0	55,0
Wells	Adam Trajan	13,5	60,8 - 62,5	16,0
Total		31,8		

Table 4.2. –The informations about drills and wells according geological works [27]

Drill	Ground [m /m]	Depth of drill [m]	Max. temperature [°C]	Collection from depth [m]	Q [l/s]	H_2S [mg/l]	Notes
V-1	159.84	55.20	67.5	55.20		11,00	Dressing 159,96 mn/m; 23,5 l/s
V-2		231.80	56.60	60.3	6,60		
V-3		125.00	59.4	26.00	16,00		
V-4a	159.84	54,00	68,00		24,00	8,90	Cavern 15 m; dressing 24 l/s
V-5		11,20	66.5	11,20	2,70		Drill V-5 and V-5a in Adam Trajan well 11m
V-5a		11,00	66.5	11.0	2,00		
V-6		57.8	67.1	24,00	10,00		
V-7	159.84	66.5	69.0	66.5	5,21	5,92	According to G-10, dressing 5.21 l/s
V-8	159.84	55,00	68.2	54.4	7,50	7,50	
V-9 teraz	159.84 159.65	81.7	69.6	81.7		8,60	Bearing temperature = 71.5 °C.
V-10	159.99						Situated near V-8, depth 16 m
V-11	160.87	70,00					
V-12	158.93	58,00					

The rest of drills V-2, V-3, V-6, V-7, V-9, V-10, V-11, V-12 are not used for balneotherapy due to negative influence to functioning and substantial drill shown above in the Table 4.2..

Picture 4.5. – Drill V-4a

Picture 4.6. – Drill V-1

Picture 4.7. – Drill V-8 and well Adam Trajan

4.3.2. Basic characteristics parameters of NHW

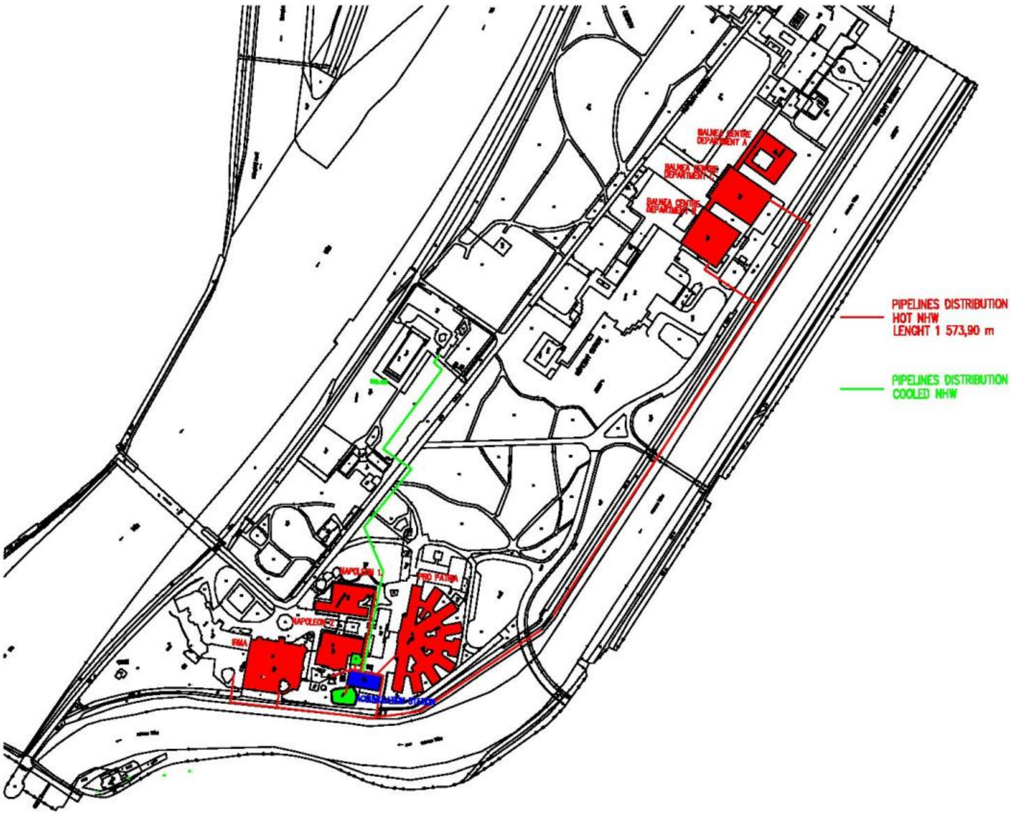
Among the basic parameters of natural healing source energy belong:

1. substantiality m_o [$l.s^{-1}$]
2. temperature at top of drill Θ_o [°C]
3. depth of source [m]

Inconsiderable parameters are the level of NHW mineralization, which value has essential influence for healing procedures, provided in balneological devices and ultimately for design of technical and technological devices related with usefulness of NHW.

4.3.3. Areal distribution of NHW

Pipelines tracing of NHW is stated in situation map of Spa Island in Picture 4.8.. Historical solution of balneotherapy located balneological devices near the source of NHW as Irma, Napoleon, Pro patria. Modern age concerning extension of spa complex SLKP a.s. as a construction of new balneotherapy – Balnea Centre, makes conditions for areal NHW distribution. The pipelines length of hot NHW is to Balnea Centre – 1 573,90 m.



Picture 4.8. – Pipelines tracing

4.3.3.1. <u>NHW pipelines current state</u>

NHW pipelines are made of cast iron DN 150 at over ground concrete pipeline collector. After personal exploration of pipelines we note, that part of pipelines is insulated by basalt wool and part is without insulation. The basics parameters of pipelines are stated in Table 4.3. [27]

Table 4.3. – Basic parameters of hot NHW pipelines [27]

BASIC PARAMETERS		VALUES
Dimension		DN 150
Pipeline material		cast iron
	• Density	7220 $kg.m^{-3}$
	• Thermal conductivity λ	198 $W.m^{-1}.K^{-1}$
	• Thermal diffusivity α	17,4 x 106 $m^{2}.s^{-1}$
	• Specific heat capacity c	500 $J.kg^{-1}.K^{-1}$
Thickness of thermal insulation		30 mm
	• Density	105 $kg.m^{-3}$
	• Thermal conductivity λ	0,038 $W.m^{-1}.K^{-1}$
	• Thermal diffusivity α	0,548 x 106 $m^{2}.s^{-1}$
	• Specific heat capacity c	600 $J.kg^{-1}.K^{-1}$
Fluid temperature in pipelines		65 °C
Surface temperature of pipelines	With insulation	57 °C
	Without insulation	61 °C
Air temperature at collector		21,2 °C
Outside air temperature		9,6 °C
Lenght of distribution		1 573,90 m

4.3.4. Qualitative analysis of NHW from chemical point of view

Natural healing water due to its mineralization used for healing procedures must be in a direct usage. From the source is the NHW distributed to individual balneological devices. This listed system has an unfavourable chemical and physical properties, because it causes serious technical problems during the transport, retain, storage, use of and directly impacts at service life of technological and energy devices.

Analysis of balenological systems operation, apparatuses and devices show, mineral and thermal water are aggressive for many metals and concrete building structures. During the transport of hydrogen sulphide water was found that steel pipes was withdrawn from service in 4-6 months, waters with NaCl in 1 year and carbonated waters in 2-3 years. [7]

Natural healing waters in Piešťany are sulphate-carbonate type with high mineralization until 1450 $mg.l^{-1}$ with pH 6,9. Hydrogen sulphide and its ionic bonds are unstable in water under oxidation conditions and then they can oxidized chemically and biochemically to sulphates. The rate of oxidation affects mainly pH and content of natural catalysts (Mn, Ca, Fe and other). The composition of the natural healing water is listed in the attachment as a protocol. [7]

The pumping of sulphate water from source by the immersion pump provides minimal degassing water. To larger losses of sulphide occurs when water is accumulated. It´s caused by air contact in the tanks. Except for contact with air, the thermal sulphurous water must be protected against corrosive materials, on the other hand sulphides of heavy metals are formed, which degrade and reduce sulphide content in water. Sulphide corrosive effects are among the strongest. [7]

4.3.5. Incrustation on building services and relevant components

A reason why the bachelor thesis is focused on this issue is tendency of incrustation form inside of pipelines considerably threatens the healing effects of water and reduce the pipe cross-section, thereby the hydraulic properties of system are changing. During the transport this kind of water with high content of iron due to contact air oxygen are formed ferric sediments inside of cast iron pipes. By reducing the free-gas concentration of carbon dioxide under its equilibrium, a carbonic accretions are being create – travertine creation, as we can see in the Picture 4.9..

These accretions are causing cooled thermal water blackening, when are applied to mirror pools.

Picture 4.9. – Clogging of cast iron pipe by carbonic accretions at SLKP, a. s.

White tint incrustation occur primary on the surface of building services and relevant components, such as valves and pipes, which reduce their life-time and increase the costs to service of technological processes (Picture 4.10. and Picture 4.11.).

Picture 4.10. – Incrust on the surface of the relevant component at SLKP, a. s.

Picture 4.11. – Incrust on the surface of the valve at SLKP, a. s.

4.3.6. Processing methods of incrustation

In order to create chemical assay and analysis, a sample of incrust was taken from supply pipe (Picture 4.13.) of natural healing water about temperature 67 °C of the ripening pools of natural healing mud in SLKP, a. s. (Picture 4.12.)

Picture 4.12. – Ripening pool [37]

Picture 4.13. – Incrust creation around the supply pipe

Incrust sample (Picture 4.14.) was subjected to chemical analysis for the presence of calcium, magnesium, sulphates, chlorides and iron, which is mentioned in Table 4.4. and thermal analysis also.

By chemical analysis was determined following compound:

- a sample dissolved in v H_2O

  Cl^-: $Cl^- + AgNO_3 \rightarrow AgCl + NO_3^-$

  SO_4^{2-}: $SO_4^{2-} + BaCl_2 \rightarrow BaSO_4 + 2\,Cl^-$

- a sample dissolved in diluted HCl

  Ca^{2+}: $Ca^{2+} + (COO)_2(NH_4)_2 \rightarrow (COO)_2Ca + 2\,NH_4^+$

  Mg^{2+}: $Mg^{2+} + 2NaOH \rightarrow Mg(OH)_2 + 2\,Na^+$

$$Mg(OH)_2 + titanium\ yellow \rightarrow red\ colored\ precipitate$$

Fe^{3+}: $Fe^{3+} + 3KSCN \rightarrow Fe(SCN)_3 + 3\,K^+$

red colored solution

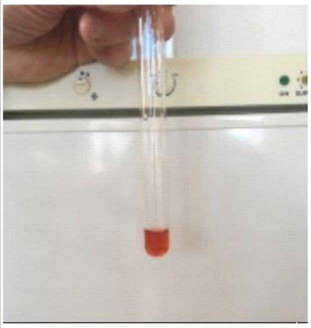
The residue after dissolution in HCl → silicic acid gel or indissoluble silicate

The indissoluble silicate is shown in the Picture 4.15..

Picture 4.14. – Incrust sample

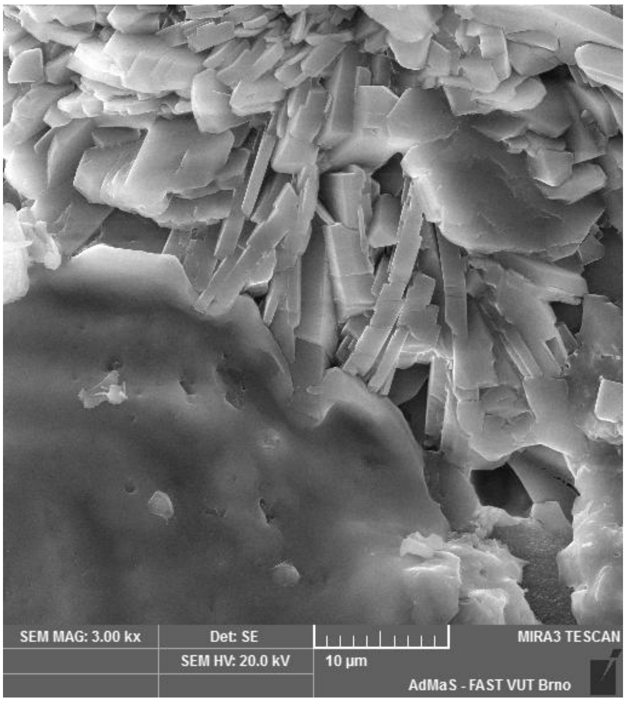
Picture 4.15. – Incrust sample on the left side, indissoluble silicate on the right side

Table 4.4. – Photographic processing of compounds presented in incrustation

Name of proof	Formula	Photographic record	Name of proof	Formula	Photographic record
Calcium	Ca^{2+}		Sulphates	SO_4^{2-}	
Magnesium	Mg^{2+}		Chlorides	Cl^{-}	
Iron	Fe^{3+}				

On the incrustation sample was used differential thermal analysis – DTA for identifying and quantitatively analyzing the chemical composition of substances by observing the thermal behaviour of a sample as it is heated.

The microscopic detail of incrust create in Faculty of Civil Engineering at research centre AdMaS is stated below as a Picture 4.16..



Picture 4.16. – Microscopic detail of incrust

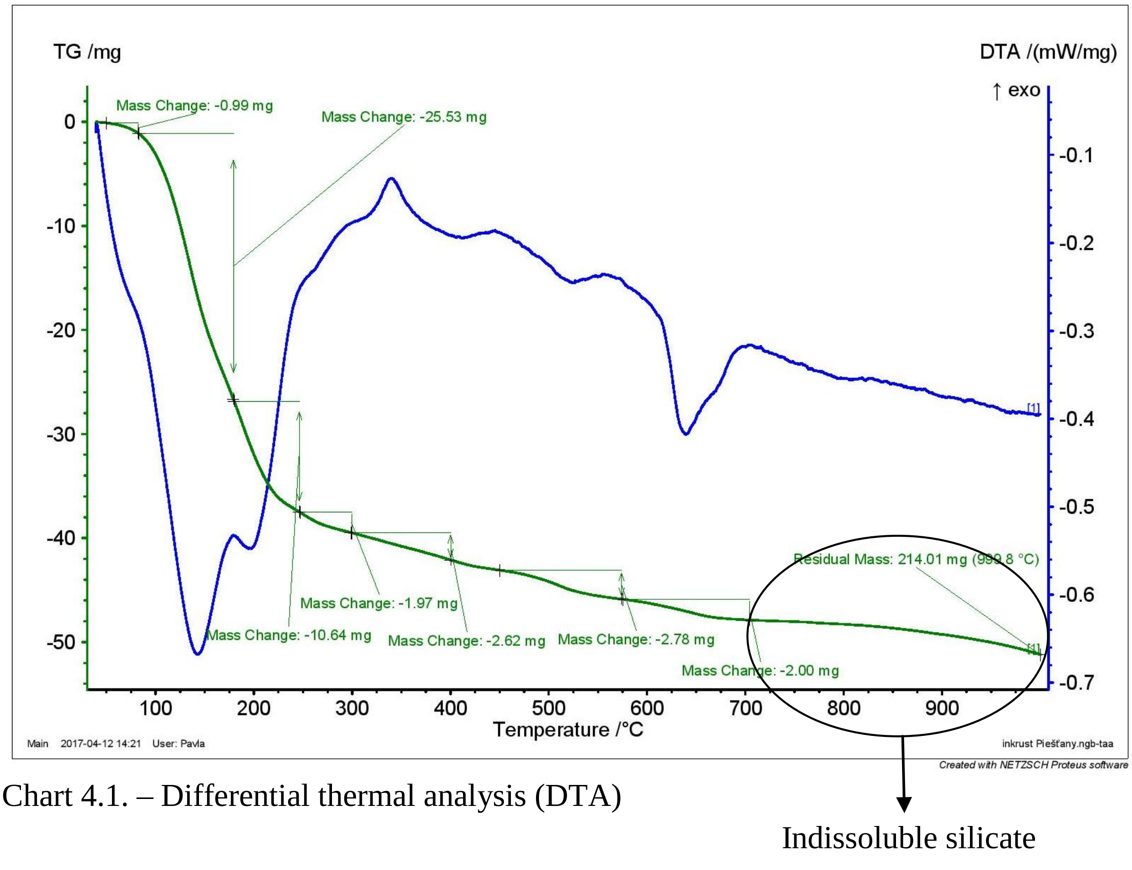


Chart 4.1. – Differential thermal analysis (DTA)

By these two experiments has been found, taken incrust content quite large amount of silicate, which was not possible dissolved by any acid, neither was not possible eliminate or completely remove upon heated at 1 000 °C. This fact is described by Chart 4.1.

4.3.7. Eliminating the problems of incrustation and water blackening

The blackening of water and incrustation in the pipes occurs under certain conditions, especially the pH shift to alkaline region. In water supply system are not maintained anaerobic – anoxic conditions, which lead to oxidation of unstable hydrogen sulphide and its ionic forms.

Chemical treatment of water is not considered and therefore based on of these facts I recommended measures to prevent incrustation and water blackening:

a) material replacement of cast-iron pipe for PPr (Picture 4.17.), titanium stainless steel (Picture 4.18.) or PTFE – polytetrafluorethylene – teflon (Picture 4.19.),
b) chemical stabilization of chemically unstable substances in water – pH stabilization by dosing of indifferent electrolytes. [7]

Picture 4.17. – PPr pipe [4]

Picture 4.18. – Titanium stainless steel pipe [13]

Picture 4.19. – PTFE pipe [12]

4.3.8. Partial conclusion

This part of bachelor thesis was focused on the issue of incrustation in pipelines distribution of natural healing water, technical and technological equipments serving for distribution and accumulation of natural healing water in SLKP, a. s., including naming of problems which seriously restrict their operation.

Internal boundary conditions also include the experimental and laboratory measurements with evaluations of obtained procedures.

Several parameters affect to formation of incrustation and water blackening. One of the most important is design right type of material for design proposal.

Mineral waters aggressively impacts on the metal pipe, it means, using of cast-iron pipe is unsuitable. As it is written in article *4.3.7. Eliminating the problems of incrustation and water blackening* , it is recommended to focused on pipes from PPr, titanium stainless steel also pipes with teflon layer – PTFE. These types of materials have a high chemical resistance, high temperature resistance from -200°C – 260°C and good sliding properties that prevent incrustation formation on the surface and mainly inside of pipes.

Another discovery was that eliminating incrustation creation is possible by dosing of indifferent electrolytes to stabilization of pH. Here is very important how it will affect to mineral composition of natural healing water, which is used to healing procedures in health spa only.

The intention of this part is familiarize the public with issue of origin and occurrence of incrust as a secondary undesirable product occurring in equipments for serving of healing procedures.

4.4. EXTERNAL BOUNDARY CONDITIONS

This chapter deals with ground energy, 2D thermal profiling of the earth´s subsoil in Spa Island Piešťany, possibilities of uses renewable source and environmental assessments.

4.4.1. History of NHW occurrence

The name Piešťany was first recorded in year 1113, in the Zobor Monastery document from Ungar king Koloman I. During later centuries, when the inhabitants learned about the influence of these waters, the settlement Teplice (derived from hot water) was established. Later the settlement merged with Piešťany. For first time the natural healing waters were recorded in the publication by Juraj Wrher in the the year 1549, called *De admirandis Hungarie aquis hypomnemation*. [25]

The memory of Piešťany NHW, spa and life around it is recorded by Adam Trajan in a celebrated poem in the year 1642. The work *Schediasma de thermos Posthenienisibus*, written by physicist Justus Ján Torkos from Bratislava (1754) states,
„I do not find any other reason why the springs of thermal water are still replaced, only that the riverbed of river Váh is also still replaced from one place to other. These waters are still flowing up from the depth, water from river press them and retain them in the permeable sand and gravel, until the thermal water will have greater pressure than water from river and than flow out on the bank of river as the spring," (Picture 4.20.). According to the origin, he mentioned, "We have no doubts that our natural healing waters have their origin in these mountains." In the second half of the 19th century the opinion that the thermal water has a volcaning origin prevailed. At the beginning of the 20th century, J. Knett (1920) decided that the occurrence of these waters belongs to the Považie fault, which provides natural healing waters not only to Piešťany but also to Belusske Slatiny, Trenčianske Teplice and Svätý Jur near Bratislava. [25]

Picture 4.20. – Natural swimming in natural springs along the river Váh [3]

Current views concerning the origin and classification of Slovak natural healing waters including Piešťany, are mentioned in the works of M. Maheľ (1952), O. Hynie (1963), G. Rebro (1966), O. Franko et. al. (1975), O. Franko and D. Bodis (1989).

Based on these facts a painting was created, which is attached below as a Picture 4.21.. The painting illustrates naturally-springing water to healing objects – Thermia Palace, Irma, Napoleon Spa and Pro Patria.

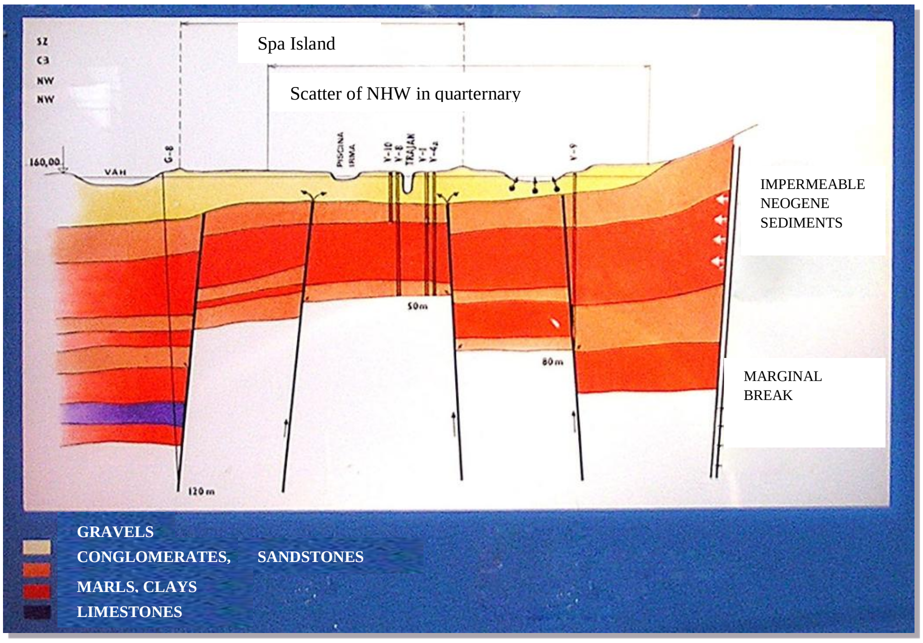
Picture 4.21. – Naturally-springing water to healing objects [Source: Archive of SLKP a.s.]

4.4.2. Geological and aquatic conditions

Interest area is created by quaternary sediments that are represented by river alluviums from river Váh, that are covered by 1 – 3 m layer of watery loam. The loam contains sandy admixture and smaller amount of pebble. In some place above this watered loam layer is made up ground layer. Sand-gravel alluviums from Váh of different thicknesses within the range 6 m – 12 m are placed under clay blanket. This thickness of sand-gravel sediments is dependent on non-flat surface that was broken by erosive gully. [38]

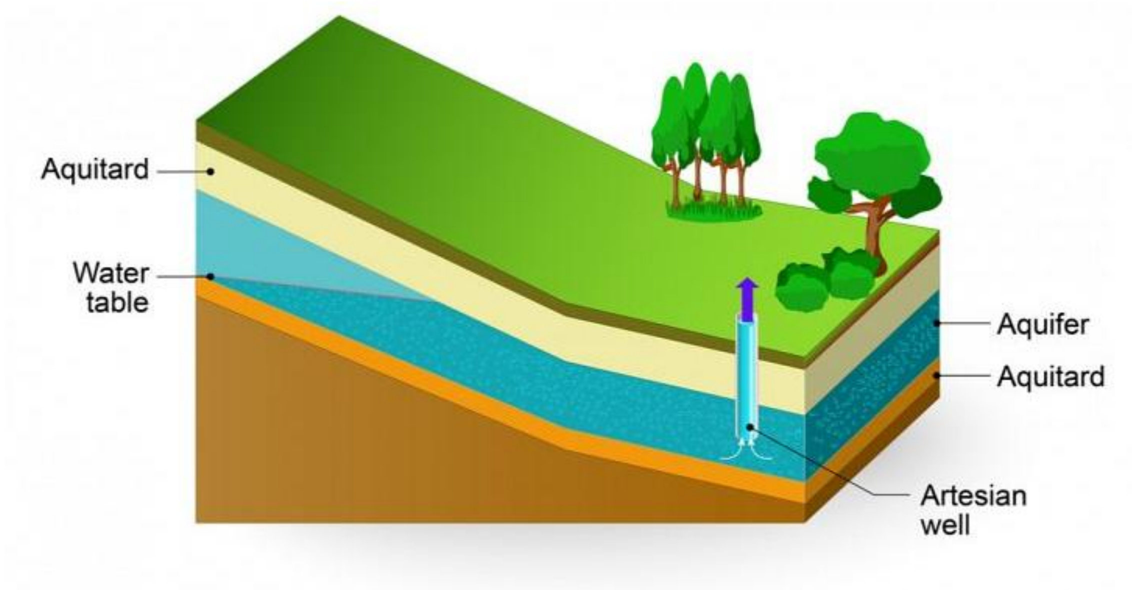
In the subsoil of quaternary sediments is placed a neogene, which is formed by fine-grained to medium-grained sediments at the surface. The water creates a groundwater stream with free level in sand-gravel alluviums. The water in the alluviums is in direct hydrogeological connections with water from Váh, it is mean, that fluctuation of water level in the river is immediately manifested by groundwater fluctuation. [38]

The subsoil of quaternary materials creates relatively impermeable neogene sandstone, which contain kaolinic sealant. Common groundwater is mixed with natural healing water that goes through the breaks, as it is possible to see in the Picture 4.22., from considerable depths from mesozoic carbonate rocks. [38]



Picture 4.22. – Scheme of spring area construction [Source: Archive of SLKP a.s.]

The neogene is composed from clay sediments, in which sands or sandstone layers are not enclosed. These enclosed layers of sands or sandstones contain an artesian aquifer (Picture 4.23.), which means that the artesian aquifer is a confined aquifer containing groundwater under positive pressure. This causes the water level in a well to rise to a point where hydrostatic equilibrium has been reached. [38]



Picture 4.23. – Profile representation of artesian aquifer [44]

4.4.3. Evaluation of drills A in the Spa Island

In the Spa Island Piešťany was on 24. 10. 1955 – 17. 03. 1956 installed 54 pieces of observation drills. Drills were built-in on the way of well with gravel backfill, which exceeds the perforation length on each side 0,20 m and is protected on both sides by coarse layer of sand 0,20 m, against the ingress of clay soil to observation drills. [43]

Observation in system A drills allow to find out approximate amount of springing water at different level of groundwater. It is possible to determine the height of groundwater depth and its temperature from the documents thus obtained. [43]

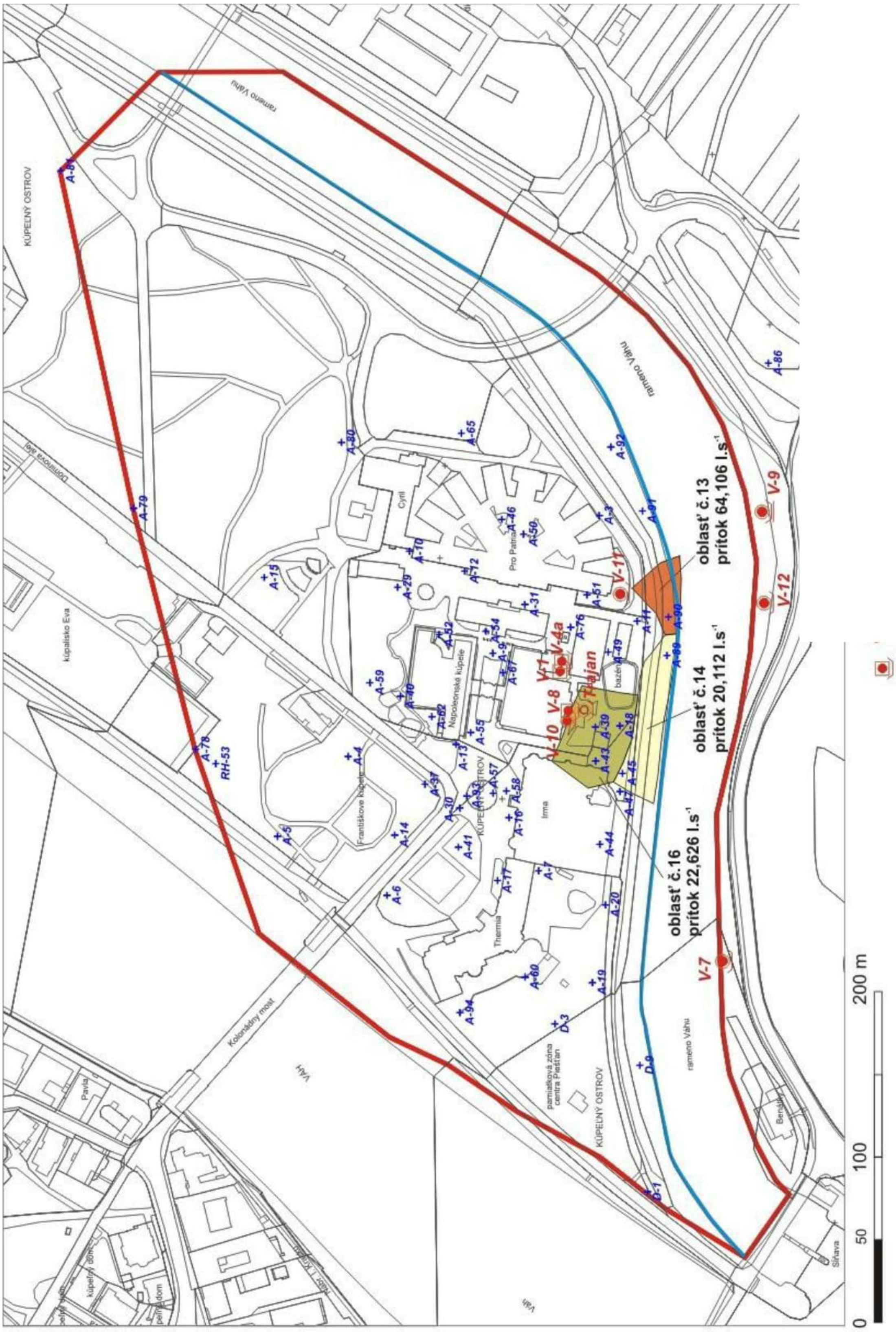
Groundwater level is affected by water level of river Váh, by rainfalls and pumping from individual wells. Based on correlation of water level in observation objects, it will be possible to determine the places of greatest permeability close to the most powerful seeps of natural healing water.

By finding and comparing the amount of natural healing water flowing in quarter-highs will be possible to find out rate of capture of natural healing water in the tertiary subsoil. [43]

In the situation of Spa Island in Piešťany are plotted all observation drills of system A – Picture 4.24..

Table 4.5., which is mentioned below, consist of the drill number, drill depth, temperature at the base and at the water level show that maximum temperature is 64,7 °C in depth 7,67m at the base of drill A-18. Data were measured on 27. 03. 1956 during the afternoon hours. Due to electric current failure the pumps were not in operation at the well Trajan from 27. 03. 1956 until 28. 03. 1956. These values are no to affected by any artificial intervention. [43]

According to the temperature measurement results by thermistor thermometer is possible to assume, that even in the south-eastern part of thermal area scattering was mainly in the horizon upper part and then the values temperature shift will be more pronounced. [43]



Picture 4.24. – Situation of Spa Island with marked all drills of system A [36]

Table 4.5. – Evaluation of drill system A [36]

4.4.4. Temperature measurements and outputs

In 1965, temperatures in the observation drills of system A were again measured. Based on measured values, the drawings were experimentally created of Spa Island, which are shown by temperature isolines.

Five types of drawings (profiles) were created:

- 1a
- 1b
- P-2a
- P-4
- P-4a

For each of them were measured temperatures in months 5th, 6th, 7th, 8th, 9th, 10th, 11th, 12th. For clarification I chose the profile „1a", which I am describing in chapter 4.4.6. Analysis of thermal profile No. 1a. The rest of profiles we can find as a attachment.

From obtained drawings – profiles from State Geological Institute of Dionýz Štúr I have created an interpolation tables depending on depth, length and temperature, which I subsequently transformed to the 2D thermal profiles.

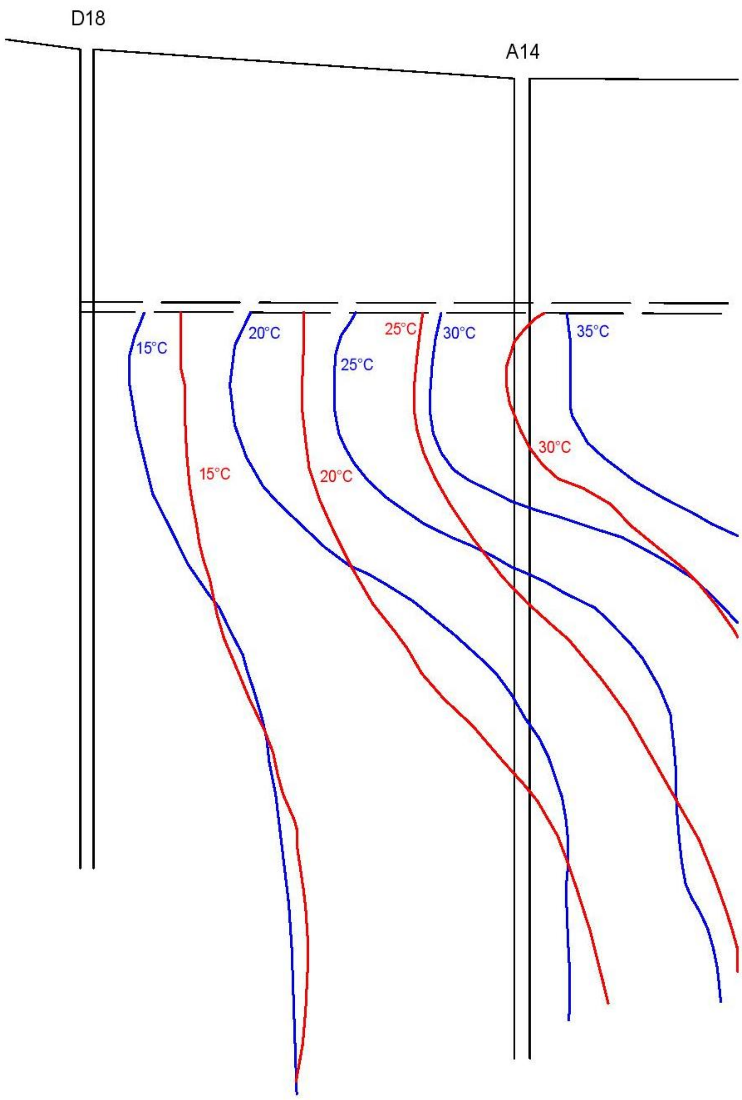
The drawings consist of the thermal isolines divided to 2 colours – blue one and red one. Each colour is characterized by different date of measurement. Next one what we can find in the drawings is water level of bypass river, drills of system A and D and named buildings. Example drawing is stated in attachment.

As the temperature of the subsoil is affected by climatic conditions I chose a summer season and winter season. Climatic conditions is listed in chapter 4.5..

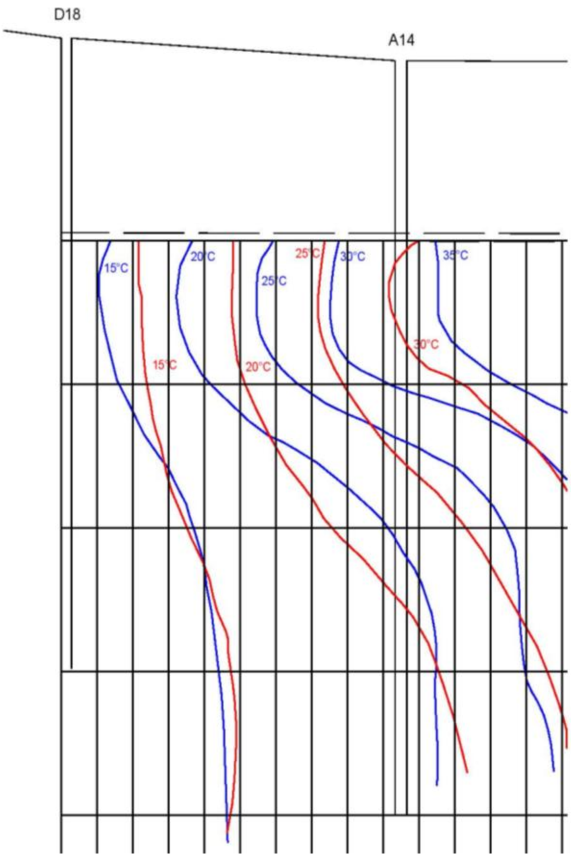
4.4.5. 2D modelling process

The temperature measurements in the Spa Island of drills A during the summer season were in July and August and during the winter season the temperature measurement were in November and December. Based on these data were created the drawings in State Geological Institute of Dionýz Štúr, which describes temperature of groundwater mixed with natural healing water.

The all profiles was redrawed in AutoCad , where grids was created with depths 2 m, 4 m, 6 m, 8 m and 10 m, and with different lengths. An interpolation table was done in Excel and then 2D thermal profile was subsequently developed. For illustration are inserted below part of drawing with grid (Picture 4.25.) and without grid (Picture 4.26.) and 2D thermal profile (Picture 4.27.).



Picture 4.25. – Part of redrawed drawing without grid



Picture 4.26. – Part of redrawed drawing with grid

LENGTH (m) — **basepoint D18**

95	90	85	80	75	70	65	60	55	50	45	40	35	30	25	20	15	10	5	29.11. 1965
30	30	30	25	20	20	20	15	15	15	15	15	15	15	15	15	15	15	15	**2**
35	30	30	30	25	25	20	20	15	15	15	15	15	15	15	15	15	15	15	**4**
35	35	30	30	25	25	25	20	20	15	15	15	15	15	15	15	15	15	15	**6**
35	35	30	30	30	25	25	20	20	20	15	15	15	15	15	15	15	15	15	**8**
35	35	30	30	30	25	25	20	20	20	15	15	15	15	15	15	15	15	15	**10**

DEPTH (m)

Picture 4.27. – Detail of 2D profile

4.4.6. Analysis of thermal profile No. 1a

The profile No. 1a consists of four main ground subsoil 2D thermal profiles. Two are processed for the summer and two for the winter. Temperature data for the profile creation in the summer were measured on 27. 07. 1965 (Chart 4.2. – the first profile) and on 24. 08. 1965 (Chart 4.2. – the second profile), for winter were measured on 29. 11. 1965 (Chart 4.3. – the first profile) and on 28. 12. 1965 (Chart 4.3. – the second profile). I chose the base point D18 – drill. The length of this profile is 500 m. The profiles are created in the following depths: 2 m, 4 m, 6 m, 8 m, and 10 m. The white area flank bypass river Váh. The profile border starts from drill D18 and ends about 120 meters behind the bypass river.

Because these two seasons the profiles are influenced by outside temperatures, rainfalls and in case of winter by snow also was necessary determine stable and unstable temperatures in the ground subsoil by temperature differential.

Maximal temperature: 55 °C
Minimal temperature: 15 °C

4.4.6.1. Summer season

Temperature difference between the months July and August is almost unchanged. The average temperatures during these two months are mentioned in the Chart 4.2. as a third profile. We can see in the two meters depth is temperature scattering of 55 °C already. Epicentre of the highest temperatures is collect in the length range from about 105 m – 255 m in depths from 2 m – 6 m and in depths from 8 m – 10 m is length range between 105 m – 270 m.

4.4.6.2. Winter season

The temperatures are radically influenced during the months November and December by climatic conditions in comparison with summer months, especially in depth of 2 m – 4 m. In this case is maximal temperature 50°C in two meters depth. However, the temperatures are increasing in 10 m depth from 50 °C to 55 °C and from 40 °C to 45 °C. This fact is shown in the Chart 4.3. in length range 130 m – 305 m .

4.4.6.3. Temperature differential

In case of profile 1a the temperature difference between the summer and the winter season is mostly 0 °C – 5 °C (Chart 4.4.) Such a small thermal differential is in depths 6 m – 10 m due to it is not influenced by external conditions like a rainfalls, snow in global by outside temperature. Maximal temperature difference is 20 °C in depth 2 m of 10 m length and in depth 4 m of length 5 m only.

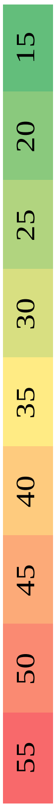


Chart 4.2. – Thermal fields of Spa Island No. 1a during the summer season and their average

Chart 4.3. – Thermal fields of Spa Island No. 1a during the winter season and their average

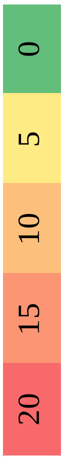


Chart 4.4. – Temperature differential of the summer and the winter season, No. 1a

4.4.7. Climatic characteristics

According to the Map of climate zones in Slovakia, interest area lies in warm climatic region in a district characterized as a warm, slightly dry, with slight winter. It belongs to the climatically-geographic type of lowland area mostly warm.

Piešťany lie in the well-ventilated north-south valley of Váh between the mountains Považský Inovec on the east and Malé Karpaty on the west, at altitude 162 meters and they are among the warmest places in Slovakia. The town has a typically lowland, slightly dry and slightly windy climate without extreme heat with slight winter. There is relatively little clouds, the sun is shining around 2080 hours annually. 75 days a year is town without sunrise. [36]

With average temperature in July 20 °C Piešťany is one of the warmest and the driest area of Slovakia. Average annual temperature is 9,2 °C. The winter with all-day frost takes from 11. December until 20. February. Average temperature in winter season is -2,2 °C. The temperature up to 0°C has 103 days in year, especially from December to March. 29,2 days is temperature below 0 °C. The coolest month is January. The temperature below -10 °C takes 1,3 day. The days with temperatures above 30 °C per year is 14,3; above 25 °C is 62,4 days mainly in July and August. The average temperature in summer season (June, July, August) is 19,7 °C. [36]

Below are mentioned two tables, which are describes average climatic conditions in years 1961 – 1990, 1997, 1998, 2008 and 2009 during the whole year. In the first table are listed average monthly air temperatures in °C - Table 4.6. and in the second table are listed average monthly rainfall in mm – Table 4.7..

It is possible to see that average annual temperature in years 1961 – 1990 is 9,2°C. The lowest average annual temperature is 8,8 °C in 1997. The highest average annual temperature is 10,8 °C in 2009. We could say that the temperature of the air is increasing in comparison with temperatures in 2016, which is 13,8 °C and in 2017, which is 14,7 °C.

In the second table that is listed below is possible to see that the most rainfall during the whole year was in 1998 which is 699 mm. The least rainfall in average per year was in 1997, which is 468 mm.

1961-1990-2009

Average monthly air temperature in °C

Year	Month												
	January	February	March	April	May	June	July	August	September	October	November	December	per year
1961-1990	-2,0	0,4	4,5	9,6	14,5	17,4	18,9	18,4	14,6	9,7	4,2	-0,1	9,2
1997	-3	1,3	3,8	6,5	15,1	18,5	18,2	19,7	14,2	6,9	6,8	-2,7	8,8
1998	1,5	3,7	3,4	11,8	14,9	19,3	20,3	20,2	14,7	10,5	4,8	1,9	10,6
2008	1,8	2,6	5,1	10,6	15,7	20,1	20,4	19,6	14,4	10,9	3,4	0,9	10,3
2009	-2,7	0,6	5	13,9	15,6	17,8	21,3	20,9	17,2	9,5	7,2	2,9	10,8

Table 4.6. – Average monthly air temperature in °C

1961-1990-2009

Average monthly rainfall in mm

Year	Month												
	January	February	March	April	May	June	July	August	September	October	November	December	per year
1961-1990	32	33	28	40	66	72	59	65	44	40	52	46	577
1997	13	30	12	31	48	52	199	9	25	18	19	12	468
1998	12	2	14	32	32	86	40	25	208	128	100	20	699
2008	21	25	43	29	44	52	103	56	52	27	37	25	514
2009	35	52	67	11	57	67	120	54	21	62	27	42	613

Table 4.7. – Average monthly rainfall in mm

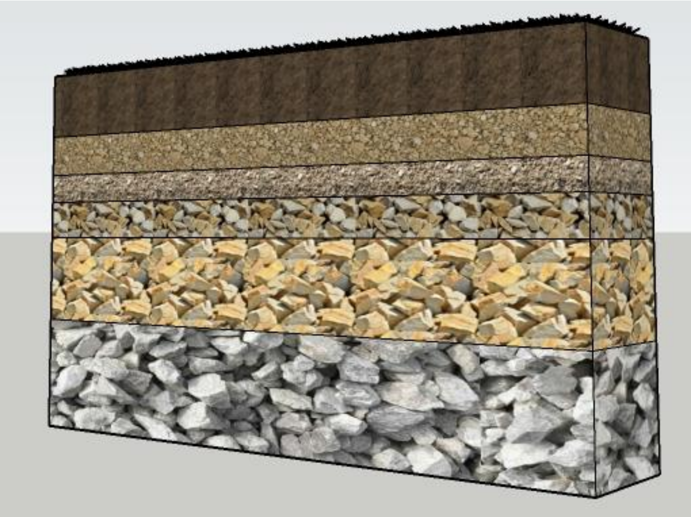
4.4.8. Soil composition

For calculations is necessary to know a soil composition. Each soil or rock has a different thermal conductivity λ. In isotropic homogeneous medium is for a given rock a constant, which characterizes the ability of the rocks to conduct heat.

The Spa Island is usually dominated by clay, gravel, loam, limestone, sand and sandstone. According the type of soil and depth was created a Table 4.8. and soil composition model in software SketchUp (Picture 4.28.).

Table 4.8. – Soil composition

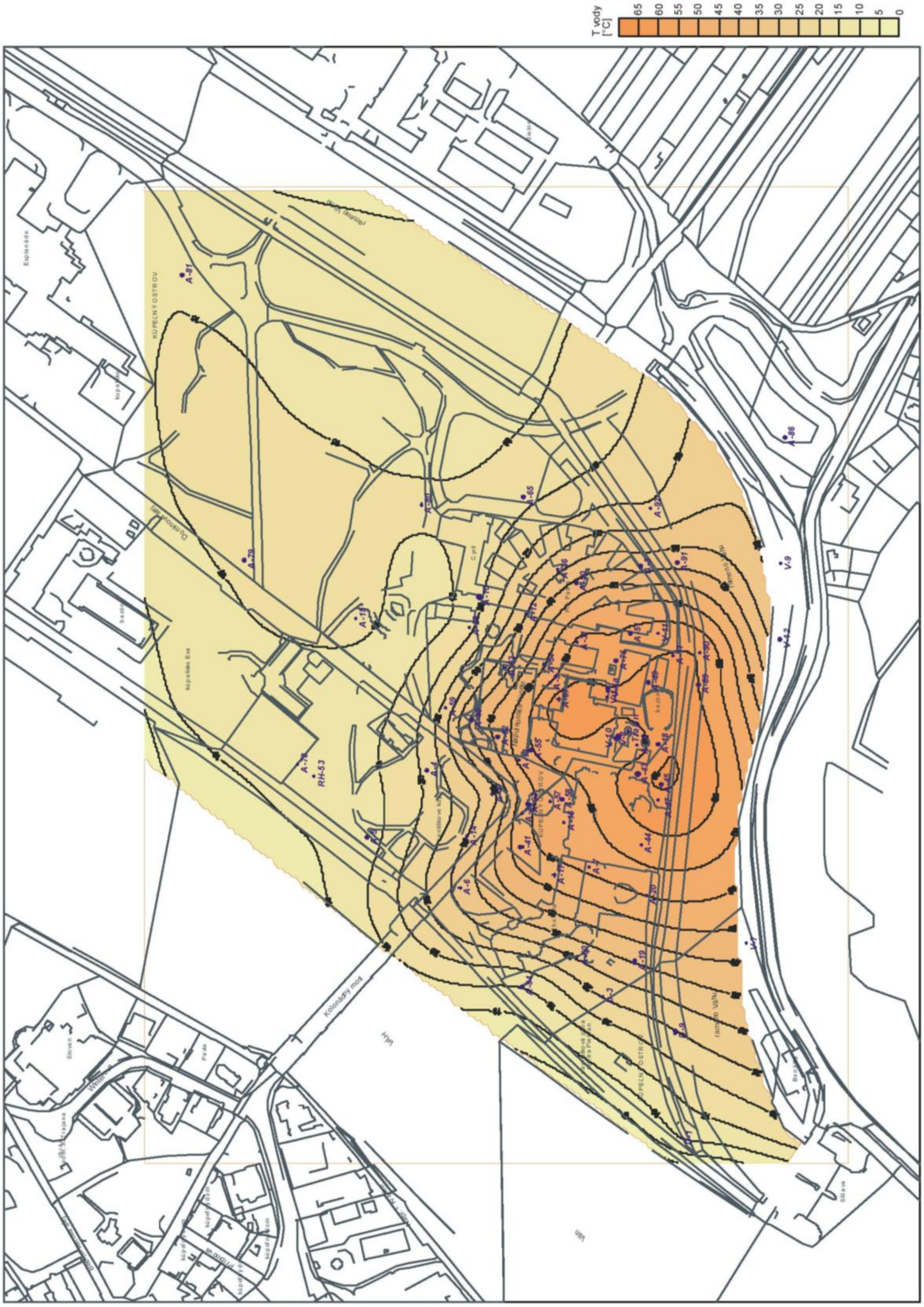
Depth	Soil composition
0,00-1,60	Loam
1,60-2,60	Coarse gravels with sand, thickly clayey
2,60-3,30	Coarse gravels with sand, weakly clayey
3,30-4,20	Coarse gravels up to Ø10 cm
4,20-6,30	Sandstone with putty of thermal salts
6,30-9,00	Coarse gravels up to Ø12 cm



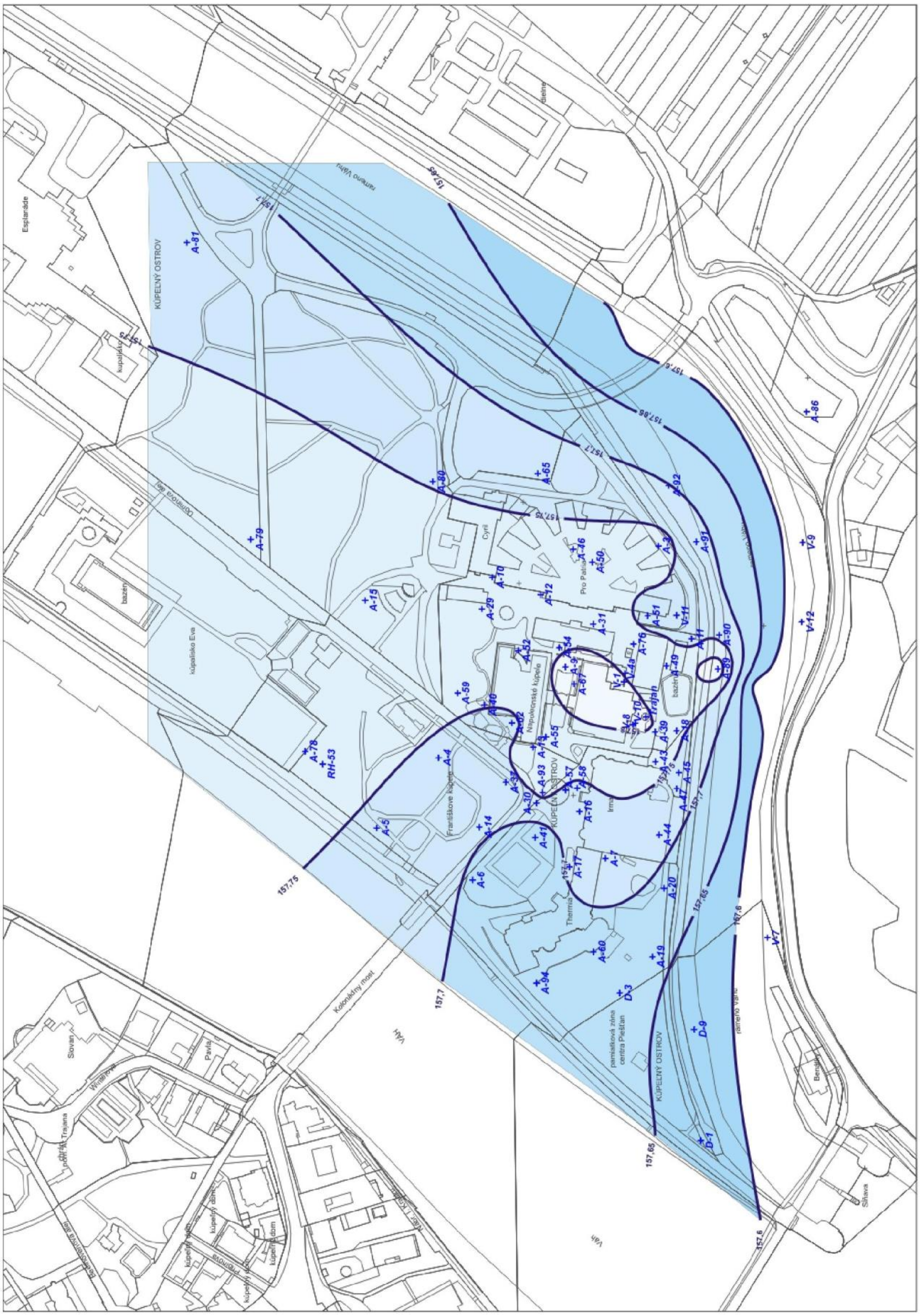
Picture 4.28. – SketchUp illustration of soil composition in the Spa Island

4.4.9. Complex evaluation of thermal potentials

The heat map of Spa Island, that is listed below as a Picture 4.29. show us the all temperatures in the island. The map was made up in 2009. The temperatures are shown again by isolines. These values are measured by thermistor thermometer at depths of first ground water strike (Picture 4.30.). These depths are in some locations 1,80 m; 1,90 m or more; generally around in 2 m. The epicentre of natural healing water springs of highest temperature 65 °C is concentrated near the healing objects and from this place is subsequently decreased up to temperature 5 °C.



Picture 4.29. – Heat map of Spa Island [36]



Picture 4.30. – Water level isolines at Spa Island [36]

4.4.10. Variants of potential use

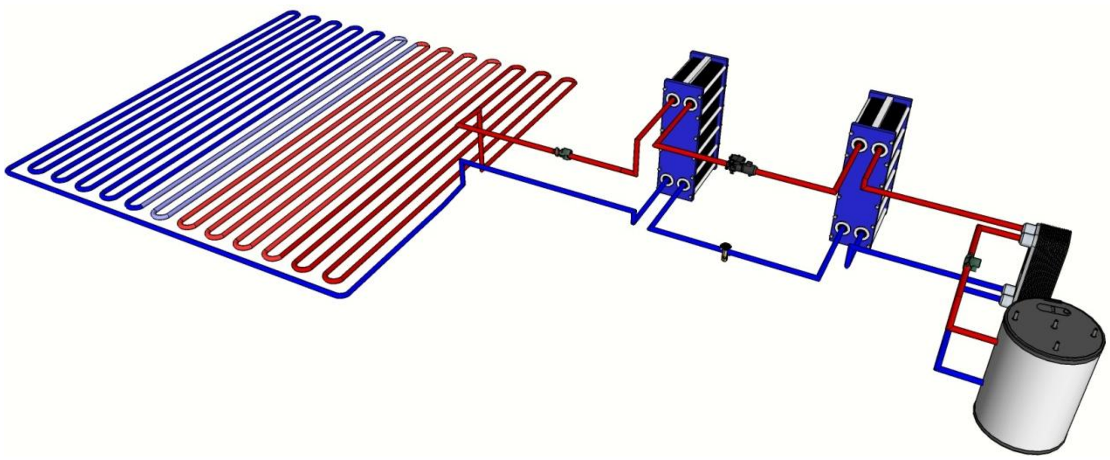
Based on the thermal profiles design of ground subsoil, the temperature differentials and based on the heat map is possible to determine low-potential places and high-potential places. At lower potential is considered temperature of 15 °C and at higher potential places is considered temperature up to 55 °C. It is necessary to know that considered temperatures at the lower potential and at the higher potential places are year-round stable. For comparison, the table with average annually temperature measurement during the years 1961 – 1990, 1997, 1998, 2008 and 2009 is shown in the attachment.

4.4.10.1. Lower potential use of energy

At lower potential is suitable to choose common variant use of energy as a heat pump ground/water. With the help of the companies alpha innotec and Alfa Laval the heat pump and the horizontal ground collector were designed. Technical specifications of heat pump is possible to see in the Picture 4.32., Picture 4.33. and in the Picture 4.34.. The drawing details of heat pump are listed in the attachment. To clarify of horizontal ground collector connection to the heat pump and to the heat boiler was developed connections scheme in software SketchUp (Picture 4.31.).

Horizontal ground collector:

Dimension	40 x 3,9	mm
Material	HDPE	-
Installed depth	2	m
Lenght	200	m
Apart	0,8	m
Total lenght	4 500	m
Refrigerant	R410A	-



Picture 4.31. – Connection scheme of horizontal ground collector to the heat pump and to the heat boiler developed in SketchUp

Technical specification of plate heat exchanger Alfa Laval

Model: ACH1000DQ-190AH-F (1*94AHR, 1*95AHB)

Navrhoval: **Michal Salaj, Alfa Laval Slovakia (email: michal.salaj@alfalaval.com)**
Návrh: Kondenzátor 800kW
Dátum: 14. 5. 2018

Médium		**R410A**	**Water**
Hmotnostný prietok	**kg/h**	**14790**	**138000**
Médium Konden./Výparník	**kg/h**	**14790**	**0.000**
Vstupná teplota	**°C**	**85.0**	**47.0**
Kondenzačná teplota	**°C**	**55.0**	
Výstupná teplota	**°C**		**52.0**
Pracovný tlak	**In/Out bara**	**34.3/34.3**	
Tlaková strata	**kPa**	**5.26**	**59.1**
Rýchlosť v pripojení	**In/Out m/s**	**3.48/2.73**	**5.82/5.83**
Výkon	**kW**	**800.0**	
Teplovýmenná plocha	m2	79.1	
Súč. prestupu tepla teoretický	W/(m2*K)	2391	
Súč. prestupu tepla skut.	W/(m2*K)	1958	
Súč. zanesenia * 10000	m2*K/W	0.0	
Rezerva	%	22	
LMTD	K	5.2	
Typ prúdena médií		Protiprúd	
Pripojenia		Viď výkres	
Počet dosiek		190	
Počet efektívnych dosiek		188	
Kanály		1*94AHR	1*95AHB
Počet priechodov		1	1
Materiál dosiek/spájka		Alloy 316 / Cu	
Veľkosť pripojení	mm	82.0	65.1
Rýchlosť prúdenia v hrdle	m/s	3.475	5.832
PED		PED	
Návrhový tlak pri -196.000000	Bar	45.0	16.0
Návrhový tlak pri 150.000000	Bar	45.0	16.0
Návrhová teplota	°C	-196.0/150.0	
Rozmery (Dĺžka, šírka, výška)	mm	577 x 487 x 864	
Hmotnosť čistá / pracovná	kg	298 / 396	

Táto špecifikácia je vypočítaná na základe údajov poskytnutých zákazníkom. Prevádzka výmenníka bude zodpovedať tejto špecifikácii len v prípade dodržania prevádzkových podmienok, pre ktoré bola táto špecifikácia vypracovaná.

Fyzikálne vlastnosti

	Teplá strana		**Studená strana**	
	R410A		**Water**	
	Kvapalina	**Para**	**Kvapalina**	**Para (vstup/výstup)**
Hustota	648.5/873.7	111.9/147.4	988.0/985.9	
Sp.Teplo	3.865/2.664	1.367/2.540	4.174/4.173	
Viskozita	0.0512/0.0809	0.0234/0.0180	0.575/0.528	
T.Vodivosť	0.0353/0.0693	0.0181/0.0154	0.639/0.644	
Bod varu		54.8/54.8		
Rosný bod		55.0/55.0		
Mol. hm.		72.59/72.59		
Kritický Pr		49.03/49.03		
Kritická teplota		71.4/71.4		
Latentné teplo		131.6/132.3		

Picture 4.32. – Design of condenser made by Alfa Laval Co.

Technical specification of plate heat exchanger Alfa Laval

Model: ACH1000DQ-182AH-F (1*91AHB, 1*90AHR)

Navrhoval: **Michal Salaj, Alfa Laval Slovakia (email: michal.salaj@alfalaval.com)**
Návrh: Výparník 572kW
Dátum: 14. 5. 2018

Médium		**35.0% Eth.glycol**	**R410A**
Hmotnostný prietok	**kg/h**	**56990**	**14620**
Vstupná teplota	**°C**	**15.0**	**4.9**
Výparná teplota	**°C**		**3.0**
Výstupná teplota	**°C**	**5.0**	**8.0**
Pracovný tlak	**In/Out bara**	**/**	**12.5/8.81**
Tlaková strata	**kPa**	**13.8**	**367**
Rýchlosť v pripojení	**In/Out m/s**	**2.25/2.25**	**29.2/12.3**
Výkon	**kW**	**572.0**	
Teplovýmenná plocha	m2	75.8	
Súč. prestupu tepla teoretický	W/(m2*K)	2064	
Súč. prestupu tepla skut.	W/(m2*K)	1923	
Súč. zanesenia * 10000	m2*K/W	0.0	
Rezerva	%	7	
LMTD	K	3.9	
Typ prúdena médií		Protiprúd	
Pripojenia		Viď výkres	
Počet dosiek		182	
Počet efektívnych dosiek		180	
Kanály		1*91AHB	1*90AHR
Počet priechodov		1	1
Materiál dosiek/spájka		Alloy 316 / Cu	
Veľkosť pripojení	mm	65.1	33.1
Rýchlosť prúdenia v hrdle	m/s	2.254	29.21
PED		PED	
Návrhový tlak pri -196.000000	Bar	16.0	45.0
Návrhový tlak pri 150.000000	Bar	16.0	45.0
Návrhová teplota	°C	-196.0/150.0	
Rozmery (Dĺžka, šírka, výška)	mm	558 x 487 x 864	
Hmotnosť čistá / pracovná	kg	287 / 386	

Táto špecifikácia je vypočítaná na základe údajov poskytnutých zákazníkom. Prevádzka výmenníka bude zodpovedať tejto špecifikácii len v prípade dodržania prevádzkových podmienok, pre ktoré bola táto špecifikácia vypracovaná.

Fyzikálne vlastnosti

	Teplá strana		**Studená strana**	
	Eth.glycol		**R410A**	
	Kvapalina	**Para**	**Kvapalina**	**Para (vstup/výstup)**
Hustota	1054/1057		1162/1143	33.92/31.08
Sp.Teplo	3.626/3.600		1.515/1.567	1.540/1.103
Viskozita	2.97/4.18		0.163/0.154	0.0120/0.0123
T.Vodivosť	0.469/0.467		0.114/0.111	0.0117/0.0119
Bod varu			/2.9	
Rosný bod			/3.0	
Mol. hm.			72.59/72.59	
Kritický Pr			49.03/49.03	
Kritická teplota			71.4/71.4	
Latentné teplo			221.5/216.4	

Picture 4.33. – Design of vaporizer made by Alfa Laval Co.

Technical specification of plate heat exchanger Alfa Laval

Model: M15-MFM 75PL ALLOY 316

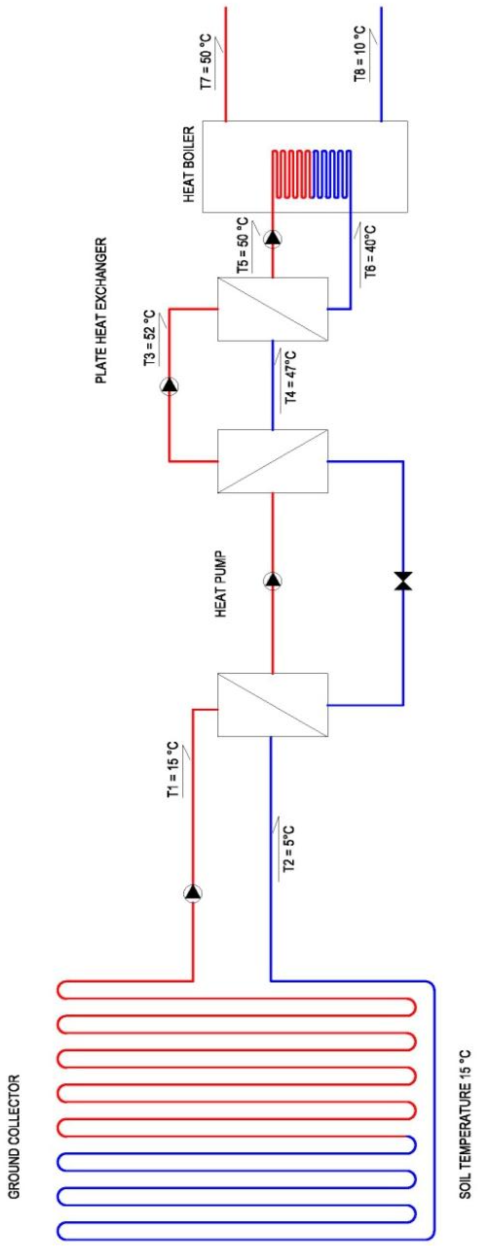
Navrhoval: **Michal Salaj, Alfa Laval Slovakia (email: michal.salaj@alfalaval.com)**
Návrh: Rozoberateľný DVT
Dátum: 14. 5. 2018

		Teplá strana	**Studená strana**
Tekutina		Water	Water
Hustota	kg/m3	987.0	988.9
Merná tepelná kapacita	kJ/(kg*K)	4.17	4.17
Viskozita vstup	cP	0.528	0.654
Viskozita výstup	cP	0.575	0.546
Objemový prietok	**m3/h**	**140.0**	**69.6**
Teplota vstupu	**°C**	**52.0**	**40.0**
Teplota výstupu	**°C**	**47.0**	**50.0**
Tlaková strata	**kPa**	**29.4**	**7.96**
Výkon	**kW**	**800.0**	
LMTD	K	4.0	
Súč. prest. tepla teoret.	W/(m2*K)	4447	
Súč. prest. tepla skut.	W/(m2*K)	4447	
Teplovýmenná plocha	m2	45.3	
Súč. zanesenia * 10000	m2*K/W	0.0	
Rezerva	%	0.0	
Typ prúdenia médií		Protiprúd	
Smer prúdenia		S1 -> S2	S4 <- S3
Počet dosiek		75	
Rezerva na rozšírenie		35	
Materiál dosiek/hrúbka		ALLOY 316 / 0.50 mm	
Materiál tesnenie		NBRB Clip-on	NBRB Clip-on
Velkosť pripojení	mm	150.0	150.0
Rýchlosť prúdenia v hrdle	m/s	2.200	1.099
Konštruk./Test. pretlak	bar	10.0/13.0	10.0/13.0
Konstrukční teplota	°C	90.0	90.0
Celková dĺžka x šírka x výška	mm	1450 x 610 x 1885	
Obsah tekutiny	dm3	92.5	92.5
Čistá hmotnosť, prázdná / pracovná	kg	962 / 1140	
Prepravná hmotnosť (SKID BASE LYING)	kg	1060	
Objem	m3	3.5	
dĺžka x šírka x výška	mm	2150 x 880 x 1850	

Táto špecifikácia je vypočítaná na základe údajov poskytnutých zákazníkom. Prevádzka výmenníka bude zodpovedať tejto špecifikácii len v prípade dodržania prevádzkových podmienok, pre ktoré bola táto špecifikácia vypracovaná.

Picture 4.34. – Design of plate heat exchanger made by Alfa Laval Co.

In software AutoCad was developed simplify connection scheme of horizontal ground collector to the heat pump and to the heat boiler with marked individuals temperatures (Scheme 4.1.)



Scheme 4.1. – Designed low-potential energy collection system

T1 – Inlet temperature to the vaporizer from the ground collector
T2 – Outlet temperature from the vaporizer back to the ground collector
T3 – Inlet temperature to the condenser from the vaporizer
T4 – Outlet temperature from the plate heat exchanger to the condenser
T5 – Inlet temperature from the plate heat exchanger to the heat boiler
T6 – Outlet temperature from the heat boiler back to the plate heat exchanger
T7 – Outlet temperature from the heat boiler for possibility of use in the shower
T8 – Inlet temperature to the heat boiler

The place with low-potential use of energy is located predominantly in the grassy part of Spa Island such as parks. This fact is illustrated in the Picture 4.35.

Picture 4.35. – Low-potential location at the Spa Island [26]

4.4.10.2. Higher potential use of energy

As in this case the year-round temperature 55 °C is considered the passive energy use is possible, respectively passive energy take-off from the ground. Instead of refrigerant, the service water will flow in the pipeline of temperature 10 °C. As this is a very specific case, a time of water heating in the pipeline was necessary to calculate to design the horizontal ground collector by company NIBE.

To calculation were used a mathematical-physical knowledge. The time was calculated with 1 m pipe length without flow from 10 °C to 50 °C. More enter data are contained in the Table 4.9. According to the Chart 4.5. can be seen that water in the pipe will be heat from 10 °C to 50 °C in 1:06 minutes.

Table 4.9. – Enter data to calculation of water heating in the pipeline

Fluid temperature	10	°C
Soil temperature	55	°C
Wanted fluid temperature	50	°C
d - Burial depth of pipe	2	m
r_0 - outer radius of pipe	0,02	m
r_i - inner radius of pipe	0,0163	m
Lenght of pipe	1	m
Volume of water	0,00083469	m^3
Mass of water	0,833437718	kg
d/r_0	100	-
Thermal conductivity of soil	3,69	W/m.K
Thermal resistance of soil	0,228523956	m.K/W
Thermal conductivity of pipe	0,51	W/m.K
Thermal resistance of pipe	0,063838972	m.K/W
Rate of heat transfer	-153,9182833	W/m

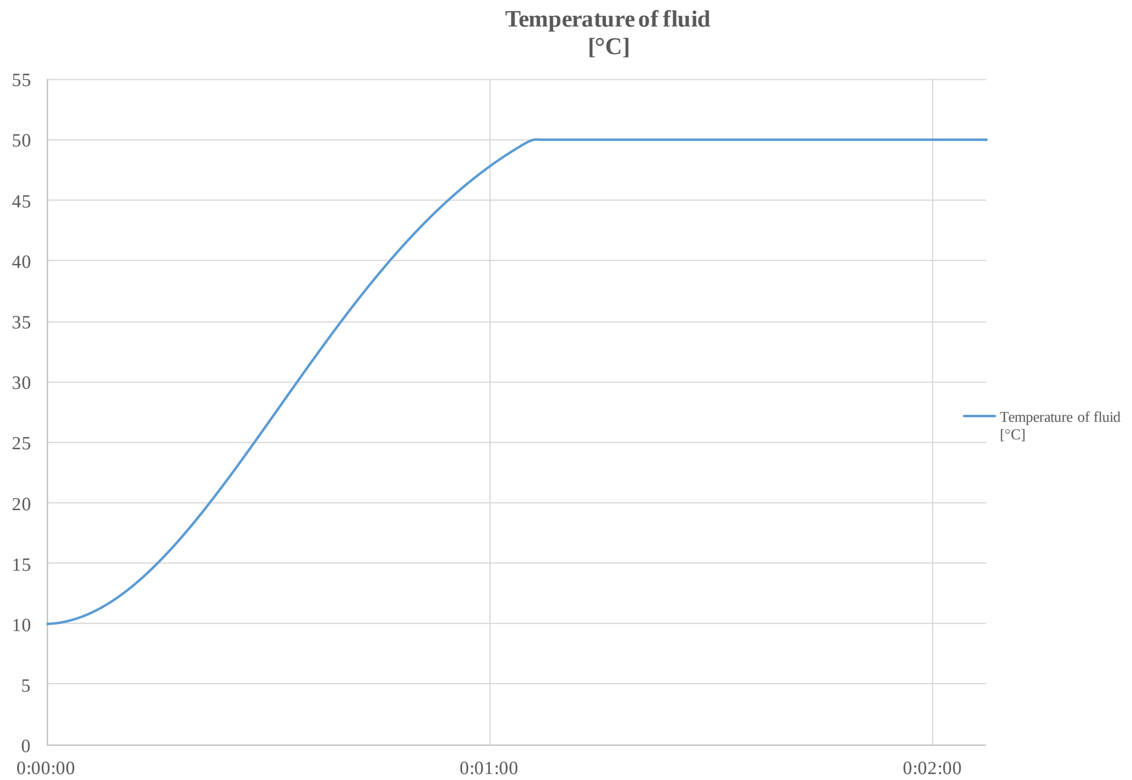


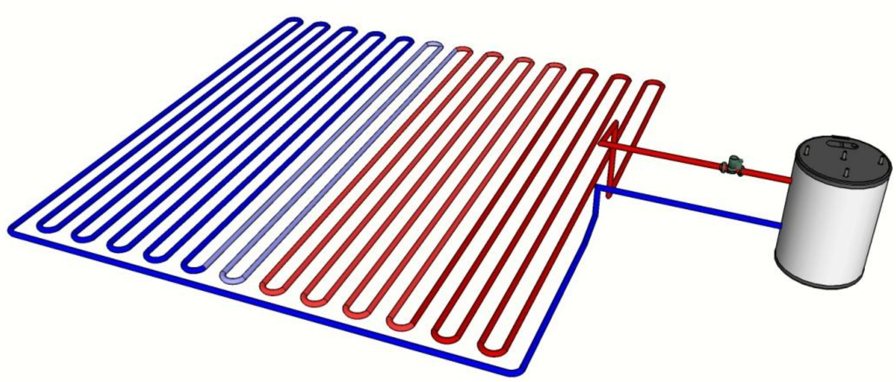
Chart 4.5. – Pipeline water heating overall time calculation

Horizontal ground collector:

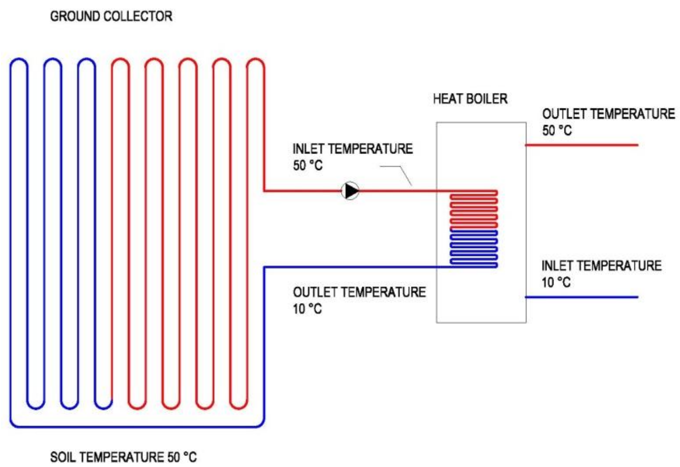
NIBE

Dimension	40 x 3,7	mm
Material	PE-RC	-
Installed depth	2	m
Lenght	150	m
Apart	0,8	m
Total lenght	250	m

For understand of directly connection of horizontal ground collector to the heat boiler was created scheme in the software SketchUp (Picture 4.36.) and in software AutoCad (Scheme 4.2.).



Picture 4.36. – Connection scheme of horizontal ground collector directly to the boiler developed in the software SketchUp



Scheme 4.2. – Designed high-potential energy collection system

In case of higher potential are temperatures 55 °C – 65 °C located below and around the healing objects and in the small of grassy parts. This fact is described by Picture 4.37..

Picture 4.37. – High-potential location at the Spa Island [26]

The heat must be still taken in the same amount, during the permanent circulation of water in the horizontal ground loop (collector), when inlet water is under the same temperature and when heat movement from rocks is large enough.

In the broken rock (crushed or cracked) is the higher thermal conductivity with the respect to this the cracks are filled with water and therefore have several times the higher thermal conductivity. Some authors reports the values by 1 row higher. The inlet water under the same temperature is then able to collect the higher temperature without a rapid cooling of the rocks. [32]

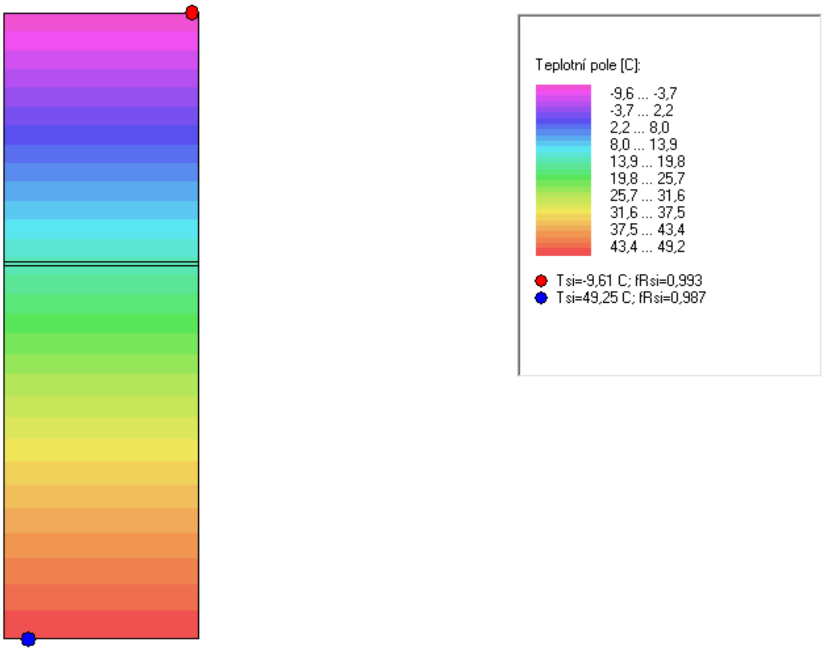
4.4.11. 2D numerical simulations

As a part of analyse there were elaborated 2D numerical simulations of subsoil thermal field in the software AREA 2010. Numerical model was developed with overall depth 5 m and ground collector pipeline with service water of temperature 10 °C without flow in depth 2 m, with boundary condition – 10 °C and 55 °C. The first simulation illustrated common loam (Picture 4.38.) and the second simulation illustrated the wet loam with sand (Picture 4.39.)

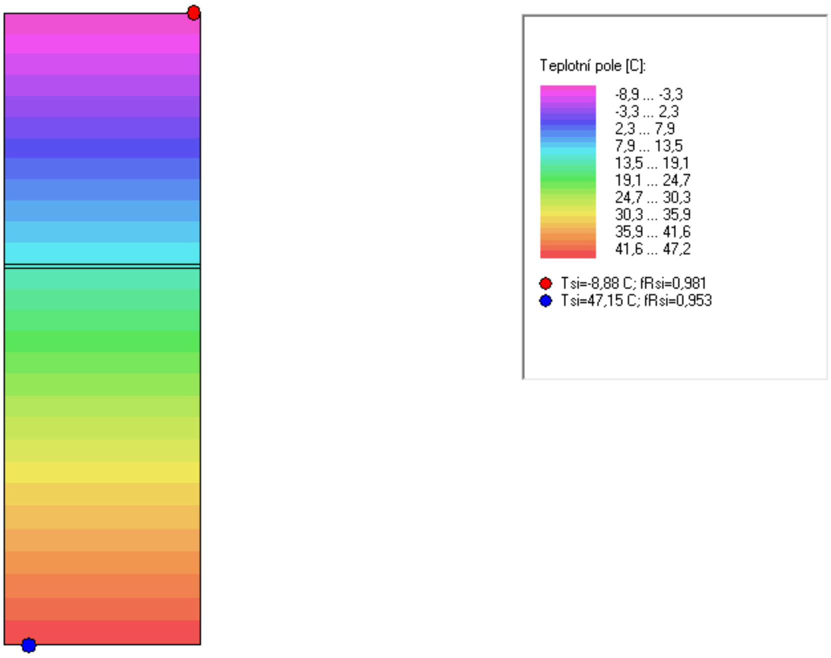
After analyses of these natural phenomena it was discovered that to be able to obtain accurate result is necessary to experimentally analyze given soil its physical and thermomechanical parameters, located at Spa Island Piešťany. Such a experimental analyses is not possible to provide in this bachelor thesis as it required long-term measurement and detailed analyses and can be elaborated as a future extension of this project.

For the future simulation is necessary to clarify soil physical and thermomechanical parameters listed below:

- coefficient of thermal conductivity,
- moisture factor of soil
- specific heat capacity,
- density,
- diffusion resistance factor.



Picture 4.38. – Numerical simulation illustrated common loam



Picture 4.39. – Numerical simulation illustrated wet loam with sand

4.4.12. Partial conclusion

The last part of bachelor thesis was focused on map out of possible potentials in the ground subsoil at the Spa Island in Piešťany and finding of possible solution for the use of low-temperature and high-temperature potential.

The experimental processes, analyzes and boundary conditions are contained in the work that led to the 2D modelling of thermal fields. Totally 20 thermal fields were created from five different profiles of Spa Island and for each of them were created two for summer season and two for winter season. Due to influence of ground subsoil by climatic conditions were created average temperatures for summer and winter from which the temperature differentials are processed. Based on these temperature differentials is possible to determine places without and with change. The highest temperature difference is 20 °C but in small sections only. In majority, the temperature difference is maximal in range from 0 °C to 5 °C. The maximum temperature is 65 °C, which is located predominantly below the healing objects and of small area in grassy part. In dependence on the created thermal fields is possible to state as a partial conclusion that the thermal field of temperature 15 °C can be marked as a low-temperature potential, while in case of 55 °C the thermal field can be marked as a high-temperature potential.

At low-temperature potential, the common variant was chosen as a heat pump ground-to-water, while at high-temperature potential, the uncommon variant was chosen as a passive energy collection.

The last part of this chapter refers to mathematical modelling concerning heat flux formulas based on ASHRAE text book and numerical simulations in software AREA 2010 of natural phenomena. After developing numerical and mathematical models it is possible to stated that such analyzes requires future experimental measurement and evaluations to obtain accurate data of composition and thermal properties of soil.

5. CONSLUSION

Bachelor thesis „Boundary conditions for the operation thermal energy distribution" is primarily focused on analysis of the boundary conditions of balneotherapy operation at Slovak Health Spa Piešťany, a. s.. Due to its size of issue, thesis is structurally divided to the analysis of internal and external boundary conditions.

The part with experimental analysis of internal boundary conditions was focused on the incrustation of natural healing water distribution pipelines, mainly determination and definition of the issues which caused serious problems during the operation of balneotherapy. The sample incrust was taken from distribution pipelines of natural healing water and subsequently subjected to chemical analysis and to differential thermal analysis. Based on these two experiments was discovered that taken incrust contents large amount of silicate, which was not possible to dissolved by any acid, neither was not possible to completely remove upon heated up to 1 000 °C. Natural healing water aggressively impacts on the metal pipeline, it means using of cast-iron pipe is unsuitable. After experimental research it is possible to determine materials resistant to incrustation such as PPr, titanium stainless steel or PTFE. These types of materials have a high chemical resistance, high temperature resistance from -200 °C up to 260 °C and good sliding properties that prevent formation of incrust. Elimination of incrust creation is also possible by dosing of indifferent electrolytes to stabilization of pH.

The second part is focused on the analysis of thermal fields in the subsoil at Slovak Health Spa Piešťany, a. s. and searching for possible solutions for the use of low-temperature and high-temperature potential. Totally 20 thermal fields in 2D were elaborated from five different profiles of Spa Island. Based on these thermal field profiles is possible to determine zones with low and high energy potential. After exploration the solution for low potential zone containing subsoil with overall temperature 15 °C was developed as a energy collection system consisting of heat pump and plate heat exchanger where on secondary side is obtained fluid temperature 50 °C with flow rate 69,6 m^3/h. Secondly, the solution for the high potential zone with subsoil temperature 55 °C was elaborated as a direct energy collection, consisting of horizontal ground collector and heat boiler.

The results discovered during the first stage of the experimental research efficiency decrease the operation cost of balneotherapy by determining materials with long-term durability against incrustation and the second stage, defined systems for collection the subsoil high energy potential at the Spa Island and in this way help European Union to fulfil low carbon economy targets.

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6.1. LIST OF PICTURES

6.2. LIST OF TABLES

6.3. LIST OF CHARTS

6.4. LIST OF SCHEMES

7. LIST OF ABBREVATIONS AND SYMBOLS

R_s	thermal resistance of soil	[(m.K)/W]
k_s	thermal conductivity of soil	[W/(m.K)]
d	buried depth to centerline of pipe	[m]
r_0	outer radius of ipe or conduit	[m]
R_p	thermal resistance of pipe wall	[(m.K)/W]
k_p	thermal conductivity of pipe	[W/(m.K)]
r_i	inner radius of pipe	[m]
R_t	total thermal resistance	[(m.K)/W]
t_f	fluid temperature	[°C]
t_s	average annual soil temperature	[°C]
q	heat loss or gain per unit length of system	[W/m]
D_i	inner diameter of pipe	[m]
V_l	volume of fluid	[m^3]
ρ_w	density of fluid	[kg/m^3]
M_{tw}	mass of fluid	[kg]
τ	time interval	[s]
q	heat loss or gain per unit length of system	[W/m]
T_i	initial temperature of the water	[°C]
T_f	temperature of water at the end of time interval	[°C]
c_{pw}	specific heat of water	[J/kg.K]

EU	European Union
NHW	Natural healing water
NHS	Natural healing source
SLKP	Slovak Health Spa Piešťany
GSHP	Ground source heat pump
2D	Two dimensional
No.	Number
AdMaS	Advanced Materials, Structures and Technologies

8. LIST OF ANNEXES