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ASPEKTY EXPERIMENTÁLNEHO RIEŠENIA PRI VYUŽÍVANÍ GEOTERMÁLNEJ ENERGIE V BALNEOTERAPII
ASPECTS OF AN EXPERIMENTAL SOLUTION WITH THE USE OF GEOTHERMAL ENERGY IN BALNEOTHERAPY

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AUTOR PRÁCE
AUTHOR
Ing. Denis Miček

VEDOUCÍ PRÁCE
SUPERVISOR
prof. Ing. JIŘÍ HIRŠ, CSc.

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Student	Ing. Denis Miček
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prof. Ing. Jiří Hirš, CSc.
Vedoucí ústavu

prof. Ing. Miroslav Bajer, CSc.
Děkan Fakulty stavební VUT

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prof. Ing. Jiří Hirš, CSc.
Vedoucí disertační práce

ABSTRAKT

Zem, náš domov je rozdielny od iných svetov. Tretia planéta od Slnka je jediné miesto v známom vesmíre, ktoré je potvrdené pre hostiteľský život. My, ľudia sme vždy smerovali k dosiahnutiu stanovených cieľov, inovácii našich technológií a spôsobu života. Skutočnosť, že sme si nikdy neboli vedomí, je, že tento závod do našej svetlej a modernej budúcnosti ničí náš domov. V súčasnosti globálna teplota sa od roku 1880 zvýšila o 1,9 °C, roztopilo sa 427 gigaton ľadových plátov a v našej atmosfére je 414 ppm častíc oxidu uhličitého. Keďže sa tento trend mení je na čase, aby sme uvažovali o ekologickom spôsobe bývania a tým je potrebné vypracovať roadmaps a akčné plány na zastavenie, prípadne zníženie už spôsobených škôd.

Európska únia začala pozorovať a poskytovať akčné plány na zníženie znečistenia a produkcie skleníkových plynov od roku 1990, ktorý bol stanovený ako referenčný rok pre porovnanie s pokrokom. Táto dohoda prinútila krajiny začať hodnotiť súčasné stavy svojho verejného a priemyselného sektora z hľadiska zmeny klímy a poskytovať klimatické plány na zníženie skleníkových plynov.

Najdôležitejšou súčasťou akčných plánov v oblasti klímy je zapojenie obnoviteľných zdrojov energie do všetkých verejných a priemyselných sektorov a tým aj začatie ekologického spôsobu života. Preto musí byť výskum a správne pochopenie týchto problémov hlavným zameraním technických univerzít a vedeckých sektorov.

Táto dizertačná práca je vyvrcholením 8 ročných štúdií a výskumov v oblasti obnoviteľných zdrojov energie, zameraných hlavne na geotermálnu energiu, ktorej produkcia v roku 2002 bola 0 GWh. Hlavným cieľom je experimentálne analyzovať navrhnuté riešenia, vypracované v rámci diplomovej a bakalárskej práce, v reálnom fungovaní oddelenia balneoterapie v Slovenských liečebných kúpeľoch Piešťany, Slovensko z energetického, ekonomického a environmentálneho hľadiska, založiť energetický management, vodné hospodárstvo a plne porozumieť spôsobu zapojenia geotermálnej energie ako obno

KLÍČOVÁ SLOVA

Obnoviteľný zdroj energie, výmenník tepla, prírodný liečivý zdroj, geotermálna energia, uhlíkový výmenník tepla, kúpele, nízkouhlíková ekonomika, 2030, 2050,

ABSTRACT

The Earth, our home planet is world unlike any other. The third planet from the sun is the only place in the known universe confirmed to host life. We, the humans always headed up to reach set up goals, innovate our technologies and way of living. The fact that, we had never been aware of is that this race to our bright and modern future is destroying our home. By this time, the global temperature arises by 1,9 ^{o}C since 1880, 427 gigatons of ice sheets were melted and there are 414 ppm of carbon dioxide particles in our atmosphere. As the trend is changing and we are above to think in green way of living, there is necessity to set up roadmaps and actions plans to stop, eventually decrease the damage which was already caused.

The European union started to measure and provide actions plans to decrease the pollution and production of greenhouse gases since the year 1990 – which was set up as reference year for comparison to progress. This arrangement forced the countries to start evaluating the current statuses of their public and industrial sectors in terms of climate changes and provide climate plans for reducing the greenhouse gases.

The most important part of climate action plans is to involve the renewable sources of energy into all public and industrial sectors and in this way start the green way of living. Therefore, the investigation and proper understanding of this problems must be the main focus of technical universities and scientific sectors.

This dissertation thesis is the summit of 8 years studies and investigation in field of renewable sources of energy, mainly focused on geothermal energy which production in year 2002 was 0 GWh. The main goal is to experimentally analyze designed solutions, elaborated within master and bachelor thesis in real operation of Balneotherapy departments at Slovak Health Spa Piestany, Slovakia from energy, economic and environmental point of view, to set up energy, aqua management and fully understand the way of involving geothermal energy as a renewable source of energy in industrial sectors of EU´s member countries in form of scientific investigation, recommendation and real operation results

KEYWORDS

Renewable source of energy, heat exchanger, natural healing source, geothermal energy, carbon heat exchanger, spa, low-carbon economy, 2030, 2050

BIBLIOGRAFICKÁ CITACE

Ing. Denis Miček *Aspekty experimentálneho riešenia pri využívaní geotermálnej energie v Balneoterapii.* Brno, 2022. 113 s., 2 s. příl. Disertační práce. Vysoké učení technické v Brně, Fakulta stavební, Ústav technických zařízení budov. Vedoucí práce prof. Ing. Jiří Hirš, CSc.

PROHLÁŠENÍ

Prohlašuji, že jsem disertační práci s názvem Aspekty experimentálneho riešenia pri využívaní geotermálnej energie v Balneoterapii zpracoval(a) samostatně a že jsem uvedl(a) všechny použité informační zdroje.

V Brně dne 24. 4. 2022

Ing. Denis Miček
autor práce

WARNING OF AUTHOR

Stated data in diploma thesis ASPECTS OF AN EXPERIMENTAL SOLUTION WITH THE USE OF GEOTHERMAL ENERGY IN BALNEOTHERAPY are the subject of company´s secret of its owner Slovak Heath Spa Piešťany a.s., and were granted exclusively for elaboration of this doctor thesis. Copying of this doctor thesis and other manipulation with the stated data is allowed only with the written statement of author.

In Brno 24.04.2022

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Ing. Denis Micek

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In Brno 24.04.2022

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Ing. Denis Micek

CONTENT

1. INTRODUCTION

“If you really think the environment is less important than economy try to hold your breath while you count your money”. Year 2020 show unity of world nations and large progress in decreasing amount of carbon dioxide released to the atmosphere, which has positive impact on global warming. As forecast for future looks now better, this fight for zero-emission community is not over yet and there is long way to achieve these goals. Therefore, revision of European Union primary goals in low-carbon economy was revised and new criteria set up. The main focus is now aimed on utilization “green” energy from renewable source of energy, which leads to supporting scientist from all over the world to take part in and investigate new technological procedures and inventions.

Based on a comprehensive impact assessment, the EU has set new target for 2030 of reducing net greenhouse gas emissions by at least 55% compared to the levels in 1990. The new EU 2030 is included in the law, where new target for 2040 was set up as well. [7]

Climate neutrality by 2050 means achieving net zero greenhouse gas emissions for EU countries, mainly by cutting emissions, investing in green technologies and protecting natural environment. [7]

Slovak republic actively participates in reaching of goals given by European Union from the year 1990, where greenhouse emissions were cut down 44,5% against the year 1990. Statistical progress also shows slowing down tendency from year 2014, which provides warning for reaching low-carbon economy goal for year 2030 and support new ideas for elimination of this negative impact.

Dissertation thesis “Aspects of an experimental solution with the use of geothermal energy in Balneotherapy” aim mainly on utilization of not fully understood source of renewable energy – natural healing sources, which can be found within all land area at Slovak republic. The main goal is to provide technological solution, applicable to real operation for processing natural healing water at spa Piestany, which is currently used only for medical purposes and in this way take part in fulfilling low-carbon economy idea of European Union.

Provided solution is based on experimental real time measurement of balneotherapy operation, which set up base model for utilization of proposed technological solution. The proposal made at Slovak Health Spa Piestany AS set up guideline for similar departments within Slovak Republic and enhanced them to invest into green technologies which will increase their profit and decrease amount of greenhouse gases released to the atmosphere.

2. EVALUATION OF THE STATE OF KNOWLEDGE IN THE FIELD

Chapter evaluation of the state of knowledge in the field is comprising solved problems into theoretical framework. Contains literature research, citations, opinions of individual authors which are related to the issues addressed in dissertation thesis aim. This chapter also contains detailed analysis with description of the determined current state, allowing to monitor and to integrate the assigned topic into a broader context. The results of the analytical part are the default platform for designing part. In partial conclusion there are stated the reasons for choosing typical methods for experimental solution and design of technological procedures for enhancing renewable source of energy.

2.1. European Union

The EU is fighting climate change through ambitious policies at home and close cooperation with international partners. It is already on track to meet its greenhouse gas emissions reduction target for 2020, and it has put forward a plan to further cut down emissions by at least 55% by 2030. By 2050, Europe aims to become the world's first climate neutral continent. Alongside reducing greenhouse gas emissions, the EU is also taking action to adapt the impacts of climate change. By 2050, Europe aims to be a climate-resilient society. [18]

Climate action is the heart of **the European Green Deal** – an ambitious package of measures ranging from ambitiously cutting green-house gas emissions, to investing in cutting-edge research and innovation, to preserving Europe' s natural environment. First climate action initiatives under the Green Deal include European Climate Law to enshrine the 2050 climate-neutrally objective into EU Law, European Climate Pact to engage citizens and all parts of society in the climate action, 2030 Climate Target Plan to the further reduction of net greenhouse gas emissions by at least 55% by 2030, New EU strategy on Climate adaptation to make Europe a climate resilient society by 2050, fully adapted to the unavoidable impacts of climate change. [18]

2.1.1. Targets and aim of European Union in renewable sources of energy

On 14th July 2021, the European Commission adopted a series of legislative proposals setting out how it intends to achieve climate neutrality in the EU by 2050, including the intermediate target of an at least 55% net reduction in greenhouse gas emissions by 2030. The package proposes to revise several pieces of EU climate legislation, including EU ETS, Effort Sharing Regulation, transport and land use legislation, setting out real terms the ways in which the Commission intends not reach EU climate targets under the European Green Deal. At international level, The EU will continue to lead international negotiations to increase the ambition of major emitters ahead of the United Nations climate change conference in Glasgow (COP26). The commissions are also keen to reduce its environmental impact as an institution and employer. It will present a comprehensive action plan in 2021 to reflect the objectives of the Green Deal across all its sites and become climate neutral by 2030. A feasibility and scoping study for the commissions to become climate neutral by 2030 has been carried out to inform the action plan. [18]

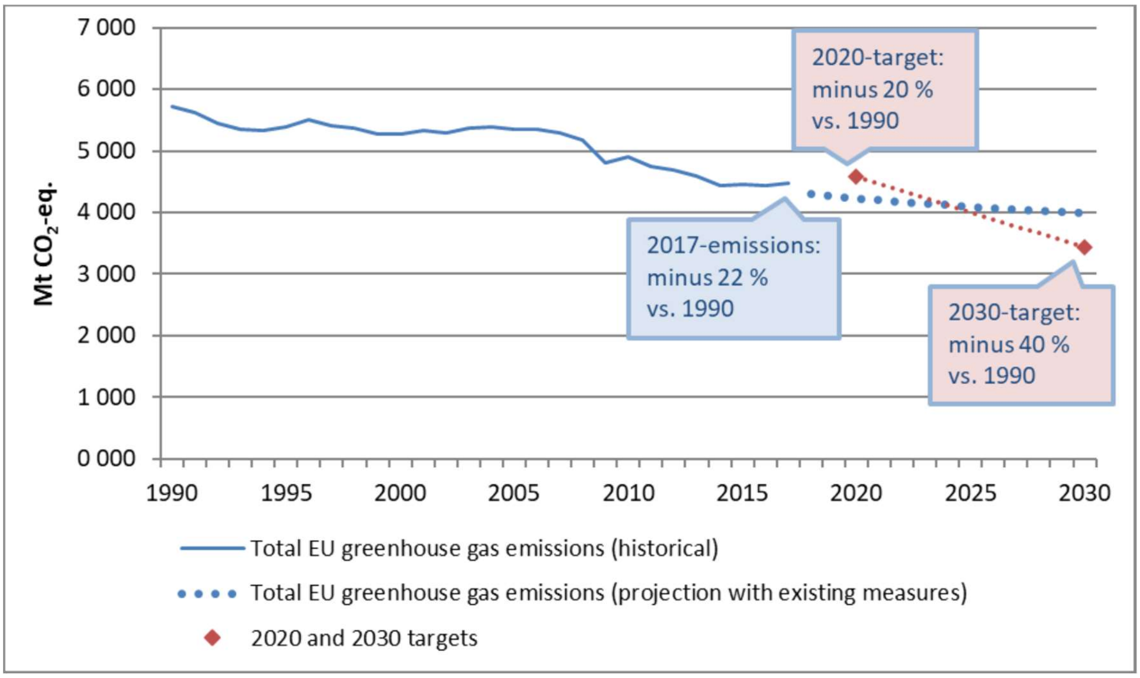


Chart 2.1. Total GHG emissions in the EU (historical emissions 1990-2017, forecast emissions 2018-2030 - in million tonnes of CO_2 equivalent) and the targets for reduction of GHG emissions. [10]

2.1.1.1. Guidelines for energy efficiency

- *Setting requirements for new and existing buildings*: The new buildings must comply with the minimum requirements. Before the construction starts, there must be a feasibility study that will consider the renewable resources, cogeneration systems, etc. The existing buildings must comply with the minimum requirements when undergoing major reconstruction, so its systems will satisfy the national, regional and European requirements. [4]

- *Energy management*: This measure provides support for assessment of potential energy savings in industrial plants through an implementation of energy audit. The audit scheme for the industry should include: A) Mandatory energy audits for companies with an annual energy consumption of more than prescribed in the rulebook on energy audits B) Voluntary scheme for other companies, especially for SMEs C) Introduction and implementation of ISO 50001 scheme for Energy Management in Industry. [4]

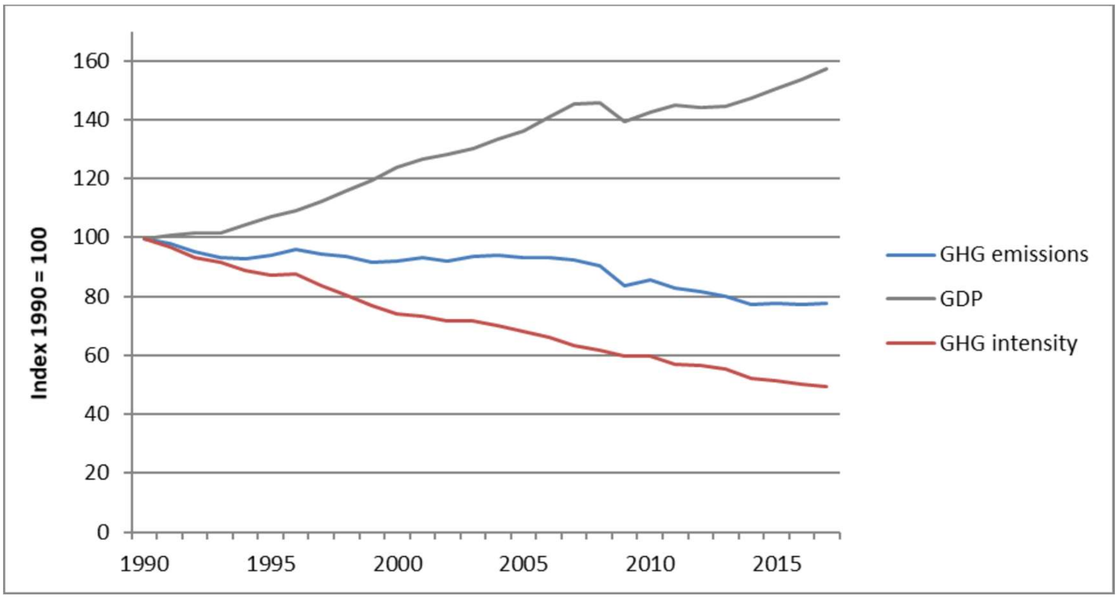


Chart 2.2. GHG emissions, actual GHG emissions in the EU [10]

2.1.1.2. Guidelines for sustainable exploration of renewable resources

- *Feed-in tariffs*: Feed in tariff is a policy mechanism designed to accelerate investment in renewable energy technologies. It achieves this by offering long-term contracts to renewable energy producers, typically based on the cost of generation of each technology. The goal of feed in tariffs is to offer cost-based compensation to renewable energy producers, providing the price certainty and long-term contract that help finance renewable energy investments. [4]

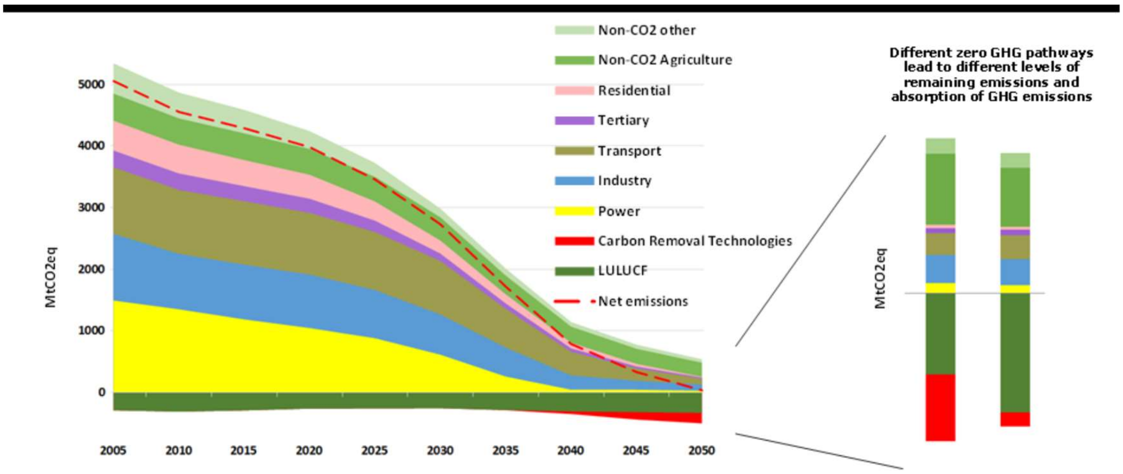


Chart 2.3. GHG emissions under the scenario of a global temperature increase [10]

- *Energy Audits with recommendations of RES measures*: Energy audits are almost everywhere mandatory in given time period. Good policy recommendation is for the Energy Audit Report to include justified and economical renewable energy sources measures for implementation on the building in question. The analysis of the possibilities in the report will be also educational and motivational for building owner. [4]

- *Compliance with legal obligations and contracts ("polluter pay")*: If the big polluters cannot be forced to stop the pollution, that the legal obligations and contract must ensure that they will pay for the pollution. The money will be used for environmental actions and project that will compensate for the pollution of polluters. [4]

2.1.2. Future in implementation of renewable sources of energy

In June 2018, the European Parliament and council reached an agreement on the revised Directive on Energy Efficiency, which sets an energy efficiency target to 32,5% for the EU by 2030, with clause for upward revision by 2023. It also extends the annual energy saving obligation beyond 2020 and the Renewable Energy directive, which sets a binding renewable energy target of 32% by 2030, including a 2023 review clause upward of the EU level target. It also improves the design and stability of support schemes for renewables pursues streamlining and reduction of administrative procedures; raises level of ambition for the transport and heating/cooling sectors; includes new sustainability criteria for the forest biomass, aimed at minimising the risk of using unsustainable feedstock for energy generation in the EU. In addition, in May 2018, the revised Directive on Energy Performance in Buildings was adopted. This includes measures that will accelerate the rate of building renovation towards more energy-efficient systems and improve the energy performance of new building, with the use of intelligent energy management systems. [2]

Sustainable exploitation of renewable resources means sustainable development of the renewable or moreover maximum use of the resources and RES without compromising the future generations. For each region, country, or city to have sustainable development into terms of using RES and resources, strategy for sustainable development should be developed, and strategy for transport, because transport sector is one of the biggest energy consumers. The EU state of art policy making in sense of a sustainable exploitation of renewable sources can be elaborated and analysed according through the important documents/directives of the EU. The elaboration is according to the Renewable Energy Road Map and the promotion of the use of energy from renewable sources and also the proposal for the Global Energy Efficiency and Renewable Energy Fund, relevant statistics are taken from the Eurostat data base of the European Commission. [4]

The road to a climate neutral economy would require join actions in seven strategic areas: (a) energy efficiency; (b) deployment of renewables; (c) clean, safe and connected mobility; (d) competitive industry and circular economy; (e) infrastructure and interconnections; (f) bio-economy and natural carbon sinks; (g) CCS to address remaining emissions. [10]

Chart 2.4. Overview of the Energy Efficiency Directive [4]

2.2. Nordic countries

Two years ahead of schedule, the nordic countries had all met their 2020 targets set in the EU Renewable Energy Directive, while less than half of member states were on track, concludes Renewable Energy in the Nordics – the report to be published by Nordic Energy Research in 2021. The Eu aimed to meet 20 percent of its energy needs with renewables before 2020. Nordic targets ranged from 30 to 72 percent. These achievements, though remarkable, are perhaps not surprising. [25]

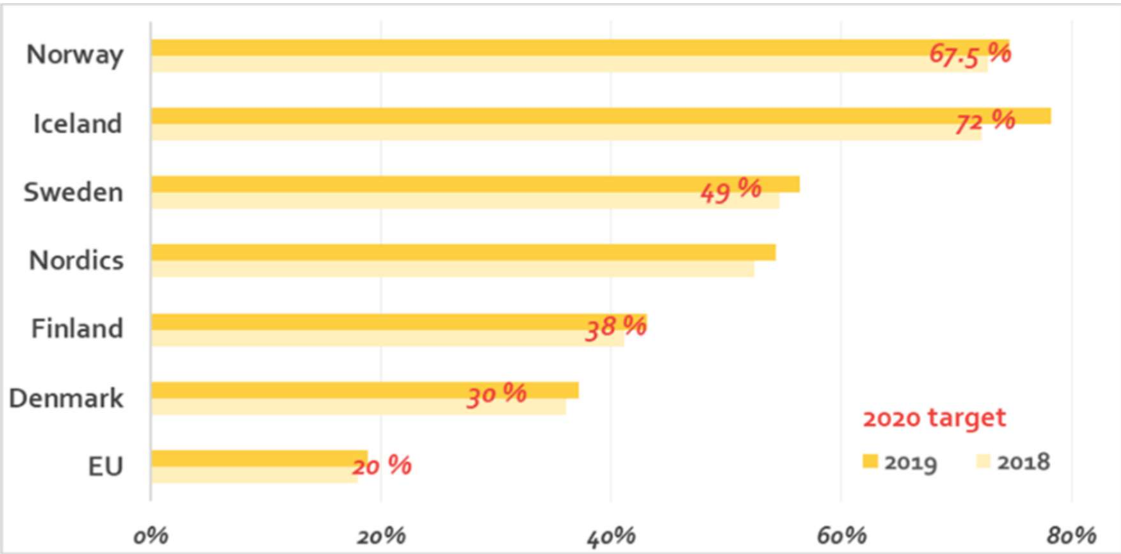


Chart 2.5. Renewable energy shares vs. 2020 targets (% of consumption) - 2018 / 2019. [16]

2.2.1. Current state of renewable sources of energy implementation

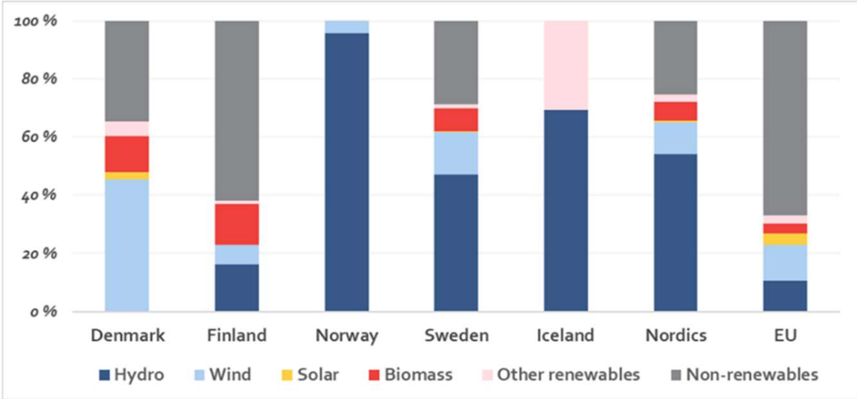


Chart 2.6. Renewables in Nordic and EU electricity mix 2019 (% of consumption). [25]

All nordic countries derive more than one third of their heat from renewables; Sweden, two thirds and Iceland more than three quarters. Per capita, the region consumes four times as much renewable energy for heat as the EU, Norway draws on its hydropower, while in the other countries, widespread district heat networks, often based on renewables, reduce the demand for electricity. In 2018 fossil fuels accounted for 40 % of total primary energy demand in the Nordic countries. Oil, which is primarily used in the transport sector, accounts for about two thirds of total fossil fuel consumption. Natural gas is mainly used in industries and for heating. [15]

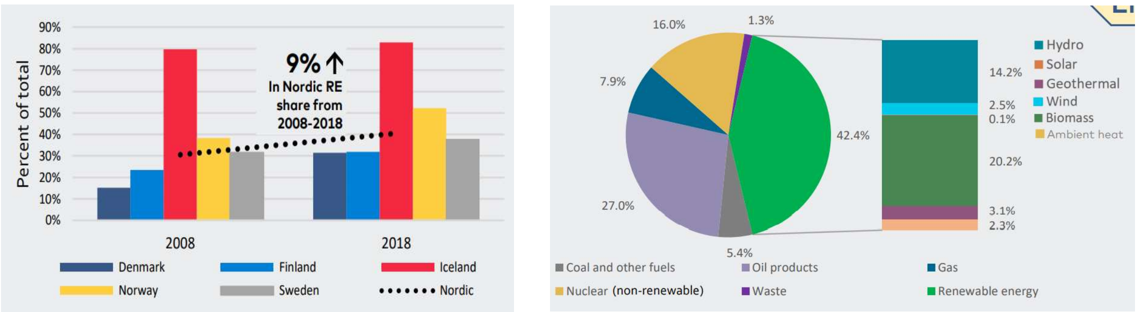


Chart 2.7. (Left) share of RE on total primary energy consumption (%) (Right) percentage of total primary energy demand by energy source (2018). [15]

All five nordic countries have seen significant increases in the utilization of renewable energy. Compared to the primary energy demand, the overall renewable shares at Nordic level have risen from 31% in 2008 to 40% in 2018. In 2018, the shares of RES on the primary energy supply settled only 15% in the EU27. Increasing use of bioenergy is the main reason behind the upwards trend. Norway and Iceland have the highest shares of renewable in their power systems. In some years, renewable energy generation has even exceeded demand in Norway, with subsequent exports resulting in RE shares above 100%. Denmark displays the highest share of variable renewable electricity (VRE) within power consumption, but in terms of total installed GW wind and solar capacity, Sweden has overtaken Denmark. By the year 2023 biggest Danish power plants decided to phase out coal fired power in production, following Finnish government requirement to ban using coal for electricity production by 1th May 2029. [15]

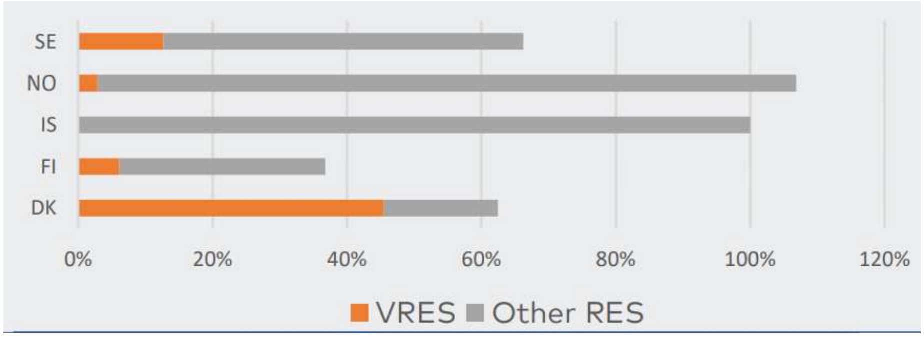


Chart 2.8. RE shares on gross electricity production, i.e. including network losses. [15]

2.2.2. Prognosis of renewable sources of energy usage

The five Nordic countries - Denmark, Finland, Iceland, Norway and Sweden – have some of the most ambitious energy and climate policies in the world. Despite this, achieving the Paris Climate Agreement' s vision of maintaining the global temperature rise "well below two degrees" will require radical change. Nordic Energy Technology Perspective 2016 (NETP) presents a detailed scenario-based analysis of how the Nordic countries can achieve a near carbon neutral system by 2050. The report is a Nordic edition of the International Energy Agency's (IEA) global Energy Technology Perspectives 2016 (ETP). This publication evaluates the progress being made towards Nordic Carbon Neutrality and compares progress with the Carbon Neutral Scenario (CNS) in NETP 2016. The NETP publication and publication deal with energy related CO_2 emissions, which account for just under two-thirds of total greenhouse gas (GHG) emissions in the Nordic region. [15]

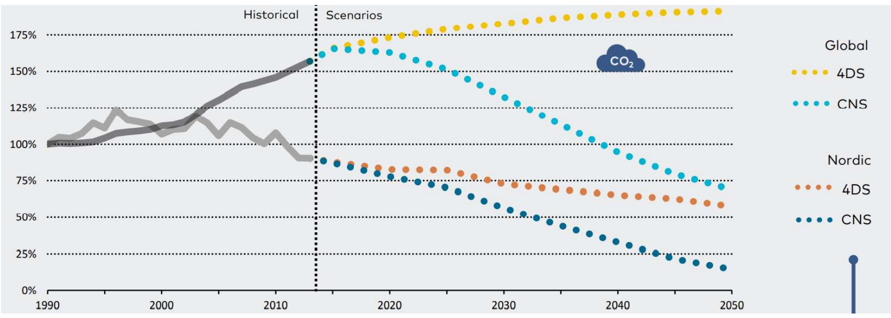


Chart 2.9. Reduction pathways for energy related CO_2 by scenario (indexed to 1990). [15]

The figure shows the CO_2 emissions in the NETP scenarios. NETP 2016 was published by Nordic Energy Research and the Nordic Council of Ministers in 2016 and is an integral part of the global analysis set out by IEA's ETP 2016. The Nordic 4 Degrees Scenario (4DS) reflects the Nordic contribution to the IEA global 4-Degree Scenario. The ETP 2 - Degrees Scenario (2DS) requires global energy-related CO_2 emissions to be cut by more than half by 2050 (compared with 2013) and to ensure that emissions continue to fall thereafter. The Nordic Carbon Neutral Scenario (CNS) is based on an 85% reduction in Nordic energy-related CO_2 emissions by 2050 (from 1990 levels) at lowest total cost. The CNS targets even greater emissions reductions within the Nordic region than the IEA´s global 2DS, while applying the same models and assumption. [15]

In October 2015, Nordic Council of Ministers decided to carry out a strategies review of Nordic cooperation on energy and how this could be developed over the next 5-10 years. The remit was to present several concrete proposals that would further enhance cooperation in areas in which significant positive outcomes have been achieved over the past two decades. The review found that competition from the larger players in the area of the green solutions is increasing rapidly. The Nordic countries must therefore act as one and avoid suboptimal national solutions. Among the 14 proposals formulated, the review recommended drawing up a vision for Nordic energy and energy research cooperation, creating a joint Nordic research and demonstration program and conducting Nordic peer review before deciding on and implementing national policies. [15]

2.3. Slovak republic in terms of renewable sources of energy

The main qualified goals of the NECP within Slovak republic until 2030 are to reduce greenhouse gas emissions for non-ETS sectors by 20% (the share was increased from the originally declared level of 12%). The use of RES for final energy consumption is set in 2030 at the amount of 19,2% with the fulfilment of the required target 145 RES in transport. Processed measures for the achievement of the national contribution of the Slovak republic in field of energy efficiency is shown by values lower (30,3%) than the European target 32,5%. Industry will be key to achieving the goals and buildings. The interconnection of electrical systems is already above 50% and will be the same in 2030, so the target of at least 15% will be met.[3]

Table 2.1. EU and SR goals – climate strategy 2030. [3]

EU and SR goals	EU 2030	SR 2030
Greenhouse gas emissions (as for 1990)	-40%	No targets set for each memeber
Emissions in the ETS sectors	-43%	
Greenhouse gas emissions in not-ETS sectors (as for 1990)	-30%	-20%
Share of renewable energy sources (RES) total	32%	19,20%
Share of RES in transport	14%	14%
Energy effciency	32,50%	30,30%
Electrical interconnection	15%	52%

2.3.1. Renewable sources of energy at Slovak republic

A technical exploitable potential of the individual renewable sources is shown in Table 2.2., where is also shown the energetic potential of the unused renewable sources, which could be used after the introduction of available technologies, breaking administration, and ecological barriers. Nowadays we can say that the most energetic potential has biomass (over 44%), then the geothermal energy (16,6%), the solar energy (13,7%), the waste management (9,3%), the biological fuels (6,6%) and the wind energy (1,6%). [22]

Table 2.2. Technical exploitable potential of individual renewable sources. [22]

Name of renewable source	Technical exploitable potential		Present using of source		Unused energetic potential	
	TJ/r	GWh/r	TJ/r	GWh/r	TJ/r	GWh/r
Geothermal energy	**22 680**	**6 300**	**1 224**	**240**	**24 456**	**5 960**
Wind energy	2 178	605	0	0	2 178	605
Solar energy	18 720	5 200	25	7	18 695	5 193
Small water power stations	3 722	1 034	727	202	2 995	832
Biomass	60 458	16 794	11 491	3 192	48 967	13 602
Waste management	12 726	3 535	4 504	1 251	8 222	2 284
Biological fuels	9 000	2 500	1 188	330	7 812	2 170
Sum of energy:	129 484	35 968	19 159	5 222	113 325	30 646
Water power stations	23 785	6 607	18 335	5 093	5 450	1 514
Sum of energy:	153 269	42 575	37 494	10 315	118 775	32 160

2.3.2. Natural healing source as renewable source of energy at SR

Currently the NHS energy is used at almost 40 locations and next 26 are considered to be new source of renewable energy. At the depth 1000 m under the therian level, should has the natural healing water temperature around θ = 40 °C, this fact influences the surface temperature. The water is getting into this depth primary by curtain from mountain ridges after rainfall. In Liptovský Mikuláš region reach the limestone mountains the depth around two kilometers and the water is naturally heated to the temperature θ = 60 – 70 °C. [23]

2.3.3. Potential of natural healing source of water at SR

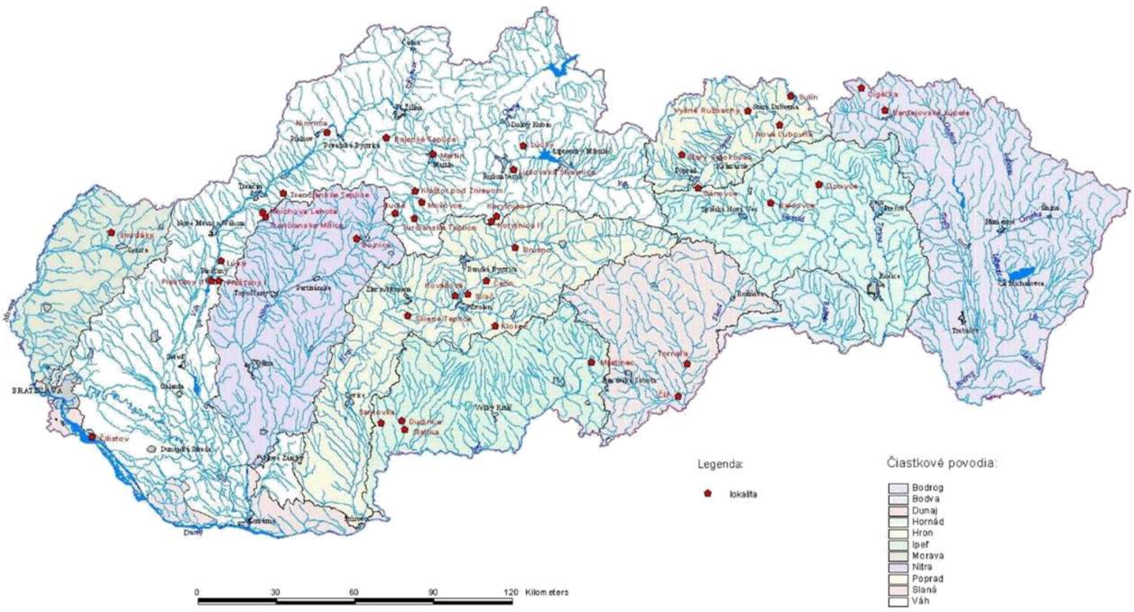
A spa area is declared as town territory or as the part of town territory, on which are located the natural healing water sources, the natural healing spa, the healing spa and other devices necessary for providing healing procedures. A Spa territory is comprehensive territory at the spa area, which size is defined in the statute of the spa area. At the spa area is applied protection of a spa regime. The regulation No. 446/2006 Z.z. issued by the Slovak government were assigned statutes of the spa area, which can be seen in Table 2.1. with the resolution number of the Slovak government. At the Slovak Republic only these places are allowed to provide healing procedures by using natural healing sources. [13]

2.3.4. Monitoring of renewable sources of energy

The monitoring system of the natural healing sources and the natural mineral water sources is independent part of environment monitoring system. The Monitoring system of the NHS and the natural mineral water sources is system, through which the regime monitoring of hydrogeological, chemical, physical, microbiological and biological parameters of natural healing sources, natural mineral water sources, observation wells, observation objects and meteoroidal parameters of given area to the extent specified in the permit to use natural healing source is providing. The user of source is obligated to ensure and provide the monitoring system of the natural healing source, or the natural mineral water source and the observation wells connected to the national monitoring system of Slovak Ministry of Health, according to the conditions of using sources, continuously send data to the database of the Slovak Ministry of Health and provide local information system. [14]

2.3.5. The aim of monitoring system

The aim of monitoring system is to ensure qualitative and quantitative parameters of the natural healing sources and the natural mineral water sources and their rational using on the base of relevant data from the observation of given qualitative and quantitative parameters, hydrological and climatic data of local sources - Picture 2.1. [13]



Picture 2.1. Map of natural healing sources in Slovakia. [13]

2.3.6. Mineral water

According to the law 538/2005 Z. z. mineral water 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: [12]

- its origin
- the content of trace elements
- the content and character of total diluted solid particles exceeding 1000 $mg.l^{-1}$ or by the content of dissolved gas particles exceeding 1000 $mg.l^{-1}$ of Carbon Dioxide, or at least 1 $mg.l^{-1}$ of Sulfur
- minimal temperature 20 °C [12]

2.3.7. Natural healing water

According to law 538/2005 Z. z. the natural healing water 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. [12]

2.3.8. Natural healing source of water

The natural healing source of water is source of the mineral water, from which was water recognized by the State Spa commission of the Ministry of Health of the Slovak republic as a natural healing water according to the law 538/2005 Z. z.. [15]

According to the conception of geological research and investigation at the territory of Slovak republic from the year 2011, Slovakia has a great energetic potential of the NHS. These renewable sources are split over the whole country and it using has economic and ecological benefits. [22]

- Sources with low temperature from 20 ºC to 100 ºC
- Sources with medium temperature from 100 ºC to 150 ºC
- Sources with high temperature more than 150 ºC

For the better understanding at Table 2.3. is shown the division of geothermal sources of the water according to individual authors and their categorization of the temperature of the geothermal sources. [22]

- With slight substantiality – less than 1,0 ls^{-1}
- With very low substantiality – from 1,0 ls^{-1} to 5,0 ls^{-1}
- With low substantiality – from 5,0 ls^{-1} to 10,0 ls^{-1}
- With medium substantiality – from 10,0 ls^{-1} to 25,0 ls^{-1}
- With large substantiality – from 25,0 ls^{-1} to 50,0 ls^{-1}
- With very large substantiality – more than 50,0 ls^{-1}

Table 2.3. Division of geothermal sources of water according to individual authors [17]

Author / Classification of source	Muffler Cataldi (1978)	Hochstein (1990)	Benderriter Corny (1990)	Mavrickij et. al. (1977)	Haenel et al. (1988)
low temperature	< 90 °C	< 125 °C	< 100 °C	< 70 °C	< 150 °C
medium temperature	90 - 150 °C	125 - 225 °C	100 - 200 °C	70 - 100 °C	-
high temperature	> 150 °C	> 225 °C	> 200 °C	> 100 °C	> 150 °C

2.3.9. Comparison to the developed countries

The Eu aimed to meet 20 percent of its energy needs with renewables before 2020. Nordic targets ranged from 30 to 72 percent. The main qualified goals of the NECP within Slovak republic until 2030 are to reduce greenhouse gas emissions for non-ETS sectors by 20% (the share was increased from the originally declared level of 12%). The use of RES for final energy consumption is set in 2030 at the amount of 19,2% with the fulfilment of the required target 145 RES in transport. [11]

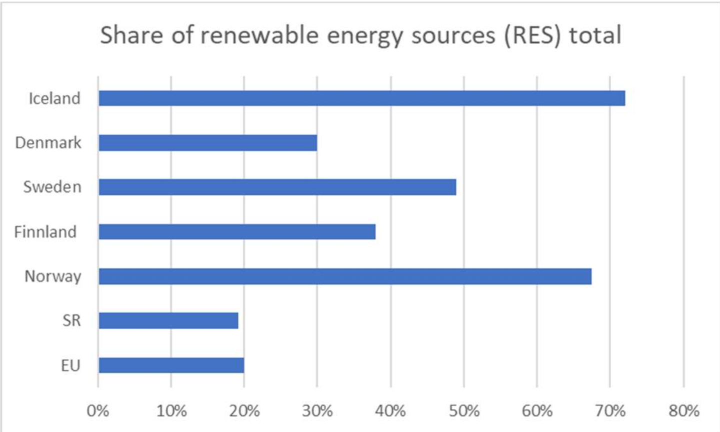


Chart 2.10. Share of renewable energy sources (RES) total. [11]

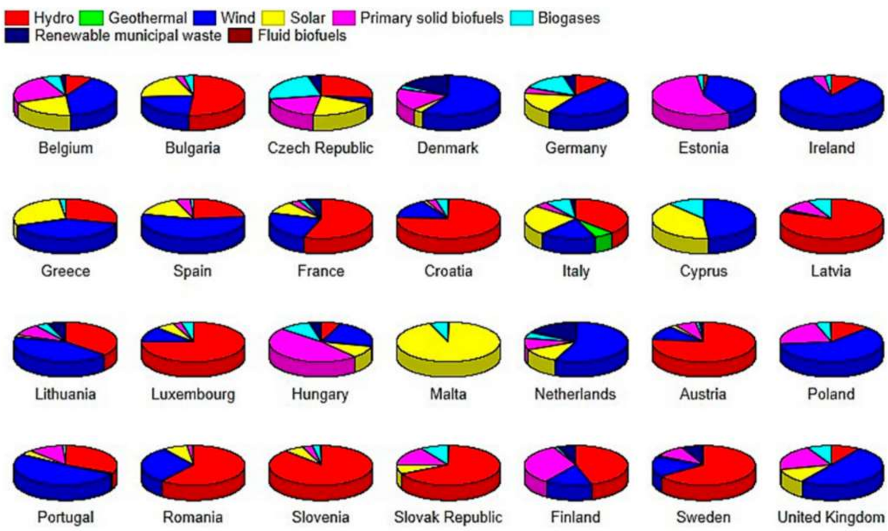


Chart 2.11. Structure of energy production from renewable source per GDP 2017. [8]

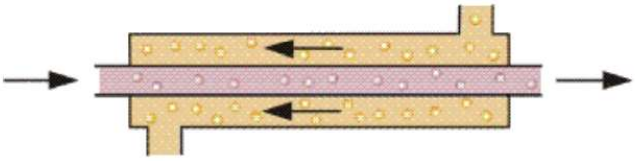
2.4. Technological devices for utilization NHS

Heat exchanger is a device used to transfer heat between two or more fluids. The fluids can be single or two phase and depending on the exchanger type, may be separated or in direct contact. Devices involving energy sources such as a nuclear fuel pins or a fired heater are not normally regarded as the heat exchanger although many of principles involved in their design are the same. [24]

In order to discuss the heat exchanger, it is necessary to provide some form of categorization. There are two approaches that are normally taken. The first considers the flow configuration within the heat exchanger, while the second is based on the classification of equipment type primarily by construction. Both are considered below: The classification of heat exchanger by four basic flow configurations: [24]

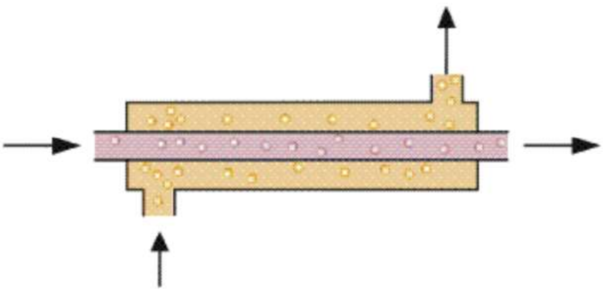
- Counter flow
- Concurrent flow
- Crossflow
- Hybrids such as Cross Counter flow and Multi Pass Flow

Picture 2.2. illustrates an idealized counterflow exchanger in which the two fluids flow parallel to each other but in opposite directions. This type of flow arrangement allows the largest change in temperature of both fluids and is therefore most efficient (where efficiency is the amount of actual heat transferred compared with the theoretical maximum amount of heat that can be transferred). [24]



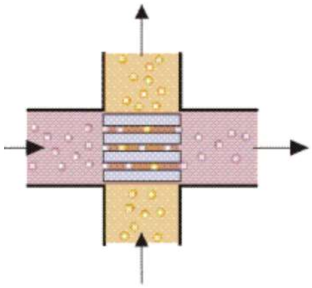
Picture 2.2. Counter current flow [24]

In cocurrent flow heat exchanger, the streams flow parallel to each other and in the same direction as shown in Picture 2.3. This is less efficient than counter current flow but does provide more uniform wall temperatures. [24]



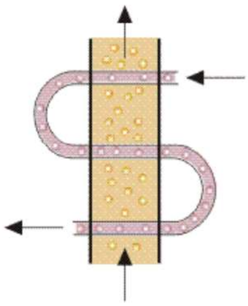
Picture 2.3. Cocurrent flow [24]

Crossflow heat exchanger are intermediate in efficiency between counter current flow and parallel flow exchangers. In these units, the streams flow at right angles to each other as shown on Picture 2.4.. [24]



Picture 2.4. Crossflow [24]

In industrial heat exchanger, hybrids of the above flow types are often found. Example of these are combined crossflow/counter flow heat exchangers and multi pass flow heat exchangers (Picture 2.5.). [24]



Picture 2.5. Cross/counter flow [24]

Classification of heat exchangers according to the construction is shown on Chart 2.12..

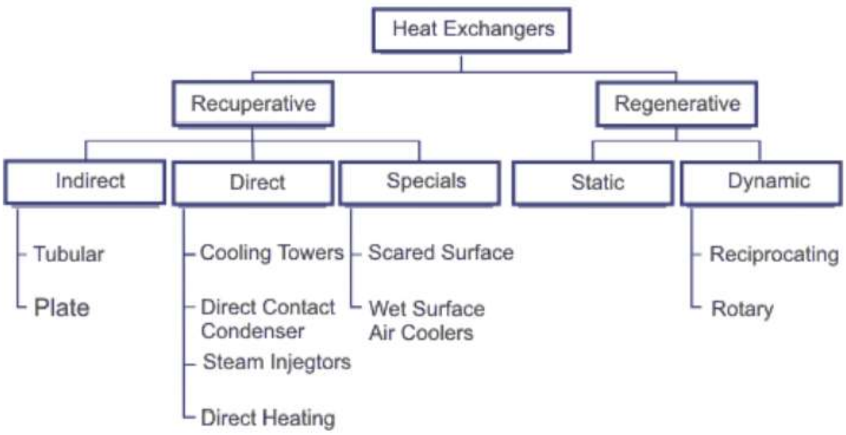
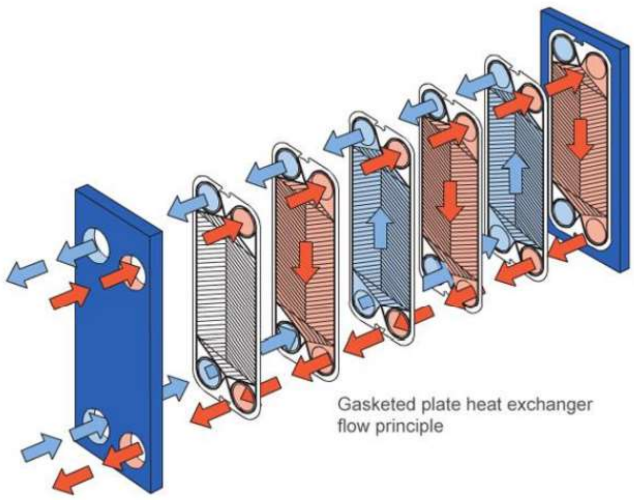


Chart 2.12. Classification according to construction [24]

2.4.1. Plate heat exchanger

The plate heat exchangers are constructed on the base of the building kit principles (Picture 2.6.). The surface of heat transfer area could be resized by adding or subtracting plates. Fluids are flowing through slots between the plates, which are profiled in the way to be the heat transfer maximal and simultaneously sediment occurs minimally. Sedimentation is occurring less in the plate heat exchangers in comparison with the tubular heat exchangers. The typical plate of heat exchanger is pressed, made of stainless steel and has four openings, for each chamber are two openings function and two openings are separated from flow chamber by sealing liner. The design way of sealing liner, shape of plates are subjects of systematic development. [5]



Picture 2.6. Scheme of plate heat exchanger [5]

Advantages: [5]

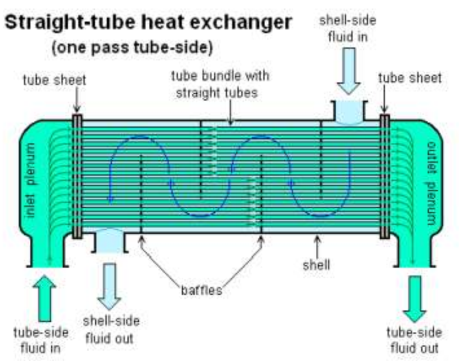
- Possibility to changer heat transfer area according to requirements
- Profiling of plates caused turbulent flow at small flow rates
- Short rest periods
- High possibility for cleaning
- Hygienic

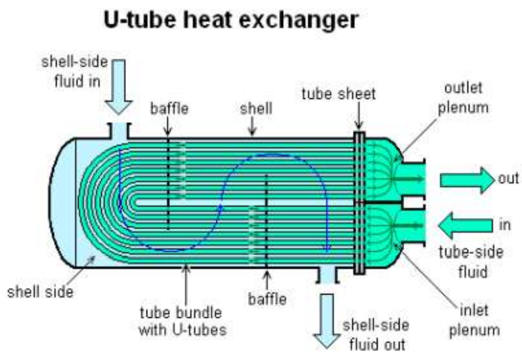
Disadvantages: [5]

- Limited scope of temperatures and pressures (given by material of sealing liner and stiffness of plates)
- Sealing liner (long sealing areas)

2.4.2. Shell and tube heat exchanger

It is the most common type of the heat exchanger in the oil refineries, other large chemical processes and is suited for higher-pressure applications. As its name implies, this type of heat exchanger consist of the shell (a large pressure vessel) with a bundle of the tubes inside it. One fluid runs through the tubes, and another fluid flows over the tubes (through the shell) to transfer heat between the two fluids. The set of the tubes is called a tube bundle, and may be composed of several types of the tubes, plain, longitudinally finned, etc. The tubes may be straight or bent in the shape of a "U", called U-tubes (Picture 2.7., Picture 2.8.). [5]





Picture 2.7. Straight-tube heat exchanger [27] Picture 2.8. U-tube heat exchanger [5]

The simple design of a shell and a tube heat exchanger makes it ideal cooling solution for a wide variety of the applications. One of the most common application is the cooling of the hydraulic fluid and the oil in engines, transmissions and hydraulic power packs. With the right choice of the material they can also be used to cool or heat other mediums, such as swimming pool water. [5]

Advantages: [5]

- Possibility to use wide range of materials – stainless steel, glass, plastic lath
- Good design of flow rate sections
- Can be used in wide range of temperature and pressures
- Possibility of mechanical cleaning
- Easy for production

Disadvantages: [5]

- Relatively high pressure lost, mainly at multi-flow exchangers
- Higher weight of shell and tube heat exchanger

2.4.3. Physical parameters measurement

I. Continuity equation:

Explains the law of conservation of mass for flowing liquid. The equation we can be described in the way that, liquid is during its flowing divided into separated particles, which are moving with the speed c. During the movement of particles at observed endless small time interval is particle made of same molecules and has to respect the law of fluid compressibility ρ = ρ (ρ, s). Particle of liquid could during the time change its volume (density). The equation of continuity can be explain in derivative or integral form.

Integral form:

$$\iiint_V \frac{\partial \rho}{\partial t} dV + \iint_S \rho(\vec{c}.d\vec{S}) = 0 \tag{2.1}$$

Derivative form:

$$\frac{\partial \rho}{\partial t} + div\ \rho\vec{c} = 0 \tag{2.2}$$

II. Equation of motion:

Equation of motion of flowing liquid are derived from Newton´s laws of motion. According to this law is time change of motion of moving liquid particle equals to a sum of all outer forces acting on particle. For description of time change we use the difference of liquid movement.

Integral form:

$$\iiint_V \frac{\partial \rho\vec{c}}{\partial t} dV + \iint_S \rho\vec{c}(\vec{c}.d\vec{S}) = \sum_i \vec{F}_i \tag{2.3}$$

Derivative form:

$$\frac{\partial \rho\vec{c}}{\partial t} + div\rho\vec{c}\,\vec{c} = \rho\sum_i \frac{\vec{F}_i}{m} = \rho\sum_i \vec{f}_i \tag{2.4}$$

III. Energy equation

Energy equation is specific form of axiom conversation of mass, while we consider heat, kinetic energy, geopotential energy and mechanical work.

Integral form:

$$\iiint_V \frac{\partial \rho e}{\partial t} dV + \iint_S \rho e\,(\vec{c}.d\vec{S}) = \dot{Q} - \dot{W} \tag{2.5}$$

Derivative from:

$$\frac{\partial \rho e}{\partial t} + div\, \rho e\vec{c} = \frac{\rho\,(\dot{Q} - \dot{W})}{m} \qquad (2.6)$$

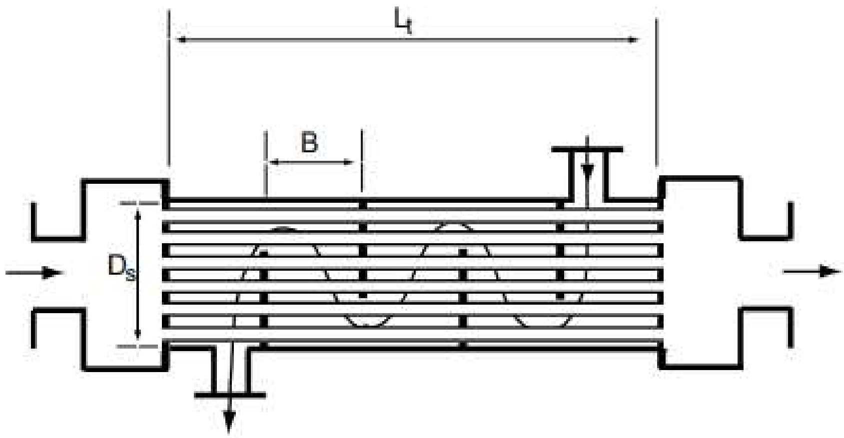
IV. Calorimetry equation:

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

$$Q = m.c.(\theta_2 - \theta_1)$$

$$Q_{handover} = Q_{obtained} \; \text{--->} \; c_1.m_1.\Delta\theta_1 = c_2.m_2.\Delta\theta_2 \qquad (2.7)$$

V. Dimensions of Shell-and-tube heat exchanger



Where:

- L tube length
- N_t number of tube
- N_p number of pass
- D_s shell inside diameter
- N_b number of baffle
- B baffle spacing

The baffle spacing is obtained:

$$B = \frac{L_t}{N_b + 1} \qquad (2.8)$$

Shell-Side Tube Layout

Figure 5.21 shows a cross section of both a square and triangular pitch layout. The tube pitch P_t and the clearance C_t between adjacent tubes are both defined. Equation (2.9) of the equivalent diameter is rewritten here for convenience.

$$D_e = \frac{4A_c}{P_{heated}} \tag{2.9}$$

From Figure 5.21, the equivalent diameter for the square pitch layout is:

$$D_e = \frac{4\left(P_t^2 - \pi d_o^{\,2}/4\right)}{\pi d_o} \tag{2.10}$$

From Figure 5.21, the equivalent diameter for the triangular pitch layout is:

$$D_e = \frac{4\left(\frac{\sqrt{3}P_t^2}{4} - \frac{\pi d_o^{\,2}}{8}\right)}{\pi d_o/2} \tag{2.11}$$

The cross flow area of the shell A_c is defined as:

$$A_c = \frac{D_s C_t B}{P_T} \tag{2.12}$$

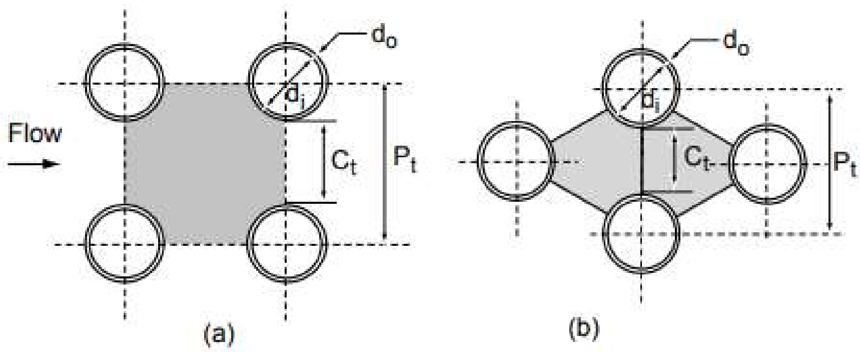


Figure 5.21 (a) Square-pitch layout, (b) triangular-pitch layout.

The diameter ratio d_r is defined by:

$$d_r = \frac{d_o}{d_i} \tag{2.13}$$

The tube pitch ratio P_r is defined by:

$$P_r = \frac{P_t}{d_o} \tag{2.14}$$

The tube clearance C_t is obtained from Figure 5.21.:

$$C_t = P_t - d_o \tag{2.15}$$

The number of tube N_t can be predicted in fair approximation with the shell inside diameter D_s.

$$N_t = (CTP)\frac{\pi D_s^2/4}{ShadeArea} \tag{2.16}$$

where CTP is the tube count constant that accounts for the incomplete coverage of the shell diameter by the tubes, due to necessary clearance between the shell and the outer tube circle and tube omissions due to tube pass lanes for multiple pass design [1] – CTP = 0,93 for one-pass exchanger, CTP = 0,9 for two-pass exchanger, CTP = 0,85 for three-pass exchanger.

$$ShadeArea = CL \cdot P_t^2 \tag{2.17}$$

where CL is the tube layout constant. CL = 1 for square-pitch layout, CL = sin(60°) = 0.866 for triangular-pitch layout.

Plugging Equation (2.17.) into (2.16.) gives:

$$N_t = \frac{\pi}{4}\left(\frac{CTP}{CL}\right)\frac{D_s^2}{P_t^2} = \frac{\pi}{4}\left(\frac{CTP}{CL}\right)\frac{D_s^2}{P_r^2 d_o^2} \tag{2.18}$$

Overall Heat Transfer Coefficient:

$$U_o = \frac{1/A_o}{\frac{1}{h_i A_i} + \frac{\ln\left(\frac{d_o}{d_i}\right)}{2\pi k L} + \frac{1}{h_o A_o}} \tag{2.19}$$

Tube side:

Reynolds number:

$$Re_D = \frac{\rho u_m d_i}{\mu} = \frac{\dot{m} d_i}{A_c \mu} \quad (2.20)$$

$$A_c = \frac{\pi d_i^2}{4} \frac{N_t}{N_p} \quad (2.21)$$

Laminar flow (Re < 2300):

$$Nu_D = \frac{h d_i}{k_f} = 1.86 \left(\frac{d_i \, Re \, Pr}{L} \right)^{\frac{1}{3}} \left(\frac{\mu}{\mu_s} \right)^{0.14} \quad (2.22)$$

$$\begin{aligned} &0.48 < Pr < 16{,}700 \\ &0.0044 < (\mu/\mu_s) < 9.75 \\ &\text{Use } Nu_D = 3.66 \text{ if } Nu_D < 3.66 \end{aligned} \quad (2.23)$$

Turbulent flow (Re > 2300):

$$Nu_D = \frac{h d_i}{k_f} = \frac{(f/2)(Re_D - 1000) Pr}{1 + 12.7 (f/2)^{1/2} (Pr^{2/3} - 1)} \quad (2.24)$$

$$\begin{aligned} &3000 < Re_D < 5 \times 10^6 \text{ [4]} \\ &0.5 \le Pr \le 2000 \end{aligned} \quad (2.25)$$

Friction factor:

$$f = (1.58 \ln(Re_D) - 3.28)^{-2} \quad (2.26)$$

Square pitch layout:

$$D_e = \frac{4(P_t^2 - \pi d_o^2/4)}{\pi d_o} \quad (2.27)$$

Triangular pitch layout:

$$D_e = \frac{4\left(\frac{\sqrt{3} P_t^2}{4} - \frac{\pi d_o^2}{8} \right)}{\pi d_o / 2} \quad (2.28)$$

Cross flow area:

$$A_c = \frac{D_s C_t B}{P_t} \tag{2.29}$$

Reynolds number:

$$\mathrm{Re}_D = \frac{\rho u_m D_e}{\mu} = \frac{\dot{m} D_e}{A_c \mu} \tag{2.30}$$

Nusselt number:

$$Nu = \frac{h_o D_e}{k_f} = 0.36\,\mathrm{Re}^{0.55}\,\mathrm{Pr}^{1/3}\left(\frac{\mu}{\mu_s}\right)^{0.14} \tag{2.31}$$

$$2000 < \mathrm{Re} < 1 \times 10^6 \tag{2.32}$$

ε-NTU Method

Heat transfer unit (NTU):

$$NTU = \frac{U_o A_o}{(\dot{m} c_p)_{\min}} \tag{2.33}$$

Capacity ratio:

$$C_r = \frac{(\dot{m} c_p)_{\min}}{(\dot{m} c_p)_{\max}} \tag{2.34}$$

Effectiveness One shell (2, 4,… passes):

$$\varepsilon = 2\left\{1 + C_r + \left(1 + C_r^{\,2}\right)^{1/2} \frac{1 + \exp\left[-NTU_1\left(1 + C_r^2\right)^{1/2}\right]}{1 - \exp\left[-NTU_1\left(1 + C_r^2\right)^{1/2}\right]}\right. \tag{2.35}$$

$$NTU_1 = NTU / N_p \tag{2.36}$$

Heat transfer unit (NTU):

$$NTU = -\left(1 + C_r^{\,2}\right)^{-1/2} \ln\left(\frac{E-1}{E+1}\right) \tag{2.37}$$

$$\text{where } E = \frac{2/\varepsilon - (1 + C_r)}{\left(1 + C_r^{\,2}\right)^{1/2}} \tag{2.38}$$

Effectiveness:

$$\varepsilon = \frac{q}{q_{\max}} = \frac{(\dot{m}_1 c_{p1})(T_{1i} - T_{1o})}{(\dot{m}c_p)_{\min}(T_{1i} - T_{2i})} = \frac{(\dot{m}_2 c_{p2})(T_{2o} - T_{2i})}{(\dot{m}c_p)_{\min}(T_{1i} - T_{2i})} \quad (2.39)$$

Heat transfer rate:

$$q = \varepsilon(\dot{m}c_p)_{\min}(T_{1i} - T_{2i}) \quad (2.40)$$

Tube Side Pressure Drop

Pressure drop:

$$\Delta P = 4\left(\frac{f \cdot L_t}{d_t} + 1\right) N_p \frac{1}{2}\rho \cdot \mathrm{v}^2 \quad (2.41)$$

Laminar flow:

$$f = 16/\mathrm{Re}_D \quad (2.42)$$

Turbulent flow:

$$f = (1.58\ln(\mathrm{Re}_D) - 3.28)^{-2} \quad (2.43)$$

Shell Side Pressure Drop:

$$\Delta P = f \frac{D_s}{D_e}(N_b + 1)\frac{1}{2}\rho \cdot \mathrm{v}^2 \quad (2.44)$$

$$f = \exp(0.576 - 0.19\ln(\mathrm{Re}_s)) \quad (2.45)$$

VI. Energy optimalization

VII. Economy analysis

The economy analysis assesses the short to medium -term determinants of price developments. The focus is on real activity and financial conditions in the economy the economic analysis takes account of the fact that price developments over those horizons are influenced by the interplay of supply and demand in the goods, service and factor markets. [18]

VIII. Annual savings

$$B = S\,.\,E - \Delta P\&\acute{U} \tag{2.46}$$

Where:

S saving of energy per year (kWh/r)
E price of energy ΔP&Ú -difference of cost of operation and maintains (+ or -) (Currency/year)
IX. Method of gross return – Payback

$$PB = \frac{I_0}{B}(roky) \tag{2.47}$$

Where:

I_o total initially investment (currency)
B annual savings (currency/year)

X. Net present value method

If the result is positive the investment is profited.

$$NPV = B.\frac{1-(1+r)^{-n}}{r} - I_0(-) \tag{2.48}$$

Where:

r real interest rate Io - total initially investment (currency)
B annual savings (currency/year)

XI. Coefficient of net present value

$$NPVQ = \frac{NPV}{I_0}(-) \tag{2.49}$$

Where:

I_o total initially investment (currency)
NPV net present value

XII. Net return method – Pay-OFF (PO)

- Annuity factor

$$f = D^{-1} = \frac{r}{1-(1+r)^{n}} \tag{2.50}$$

Where:

r - real interest rate

n - net return

2.5. Partial conclusion

Chapter Evaluation of knowledge in field of science provide complex analysation of current knowledge with aim on future goals of European Union to prevent global warming cause by green-house gases released to the atmosphere as well as basic formulas for designing of technological devices for utilization renewable source of energy.

Main focus is settled on EU low carbon economy which set out goals for milestones in years 2030 and 2050 with the target of green-house realised gases amounts for individual countries. To be able to reached given goals all scientific departments are enhanced to provide researches, which will help to fulfil ideology.

Dissertation thesis is following mindset of Nordic countries which currently were able by their politics and environmental mentality reach given goals by European Union.

Slovak republic has from world-wide point of view large deposits of natural healing water, which is currently used only for medical procedures. Ideology of dissertation thesis is to provided complex analyzation of one of natural water healing sources located on spa town Piestany, Slovakia and perform realization of technological renovation in terms to be able to collect renewable energy hidden in natural healing water.

Evaluation of knowledge in field is already on high level, which open possibilities to share ideas and combine technological inventions to obtain maximum possible efficiency in processing of natural healing source solved in following chapters.

3. DISSERTATION THESIS OBJECTIVES

Dissertation thesis Aspects of an experimental solution with the use of geothermal energy in Balneotherapy provides complex analysis and scientific research with 8 years focus in field of renewable sources of energy mainly natural healing sources of water, which can be primarily used for treatment procedures with focus on unique project at Slovak Health Spa a.s. Piestany and therefore main goals and objectives are stated below in Chapter 3.1..

3.1. Dissertation thesis goals

Main goals:

1) Goal: Complex analysis of current state at natural healing water treatment system at Slovak Health Spa a.s. Piestany
2) Goal: Design technological devices and equipment innovation in connection to EU Low-carbon economy and decreasing the amount of greenhouse gases to the atmosphere
   a) Goal: Realization of chosen solution at real spa complex based on elaborated analysis
   b) Goal: Recommendation for future sustainable development in using natural healing water sources as a renewable source of energy
3) Goal: Simulation and comparison between the design solution and real operation at chosen technological devices

4. EXPLANATION OF METHODOLOGY

Dissertation thesis contains two aspects for given problem solution – theoretical (designing solution) and experimental solution within designed solution implementation. The main content of work is describing new advance way for natural healing source of water utilization under conditions for primary use in medicine field. Current status experimental analysis is elaborated as a basic input for theoretical solution which is followed by experimental solution involving accumulation station partial reconstruction and implementation of designed solution.

4.1. Complex analysis of current state at natural healing water treatment system at Slovak Health Spa Piestany a.s.

This section will describe complex analysis of natural healing water processing as renewable source of energy at water treatment facility at Slovak Republic. The main focus will be on the unique example Slovak Health Spa Piestany, where it can be clearly seen the wasting of potential green energy – the main reason is that according to the law the natural healing water can be primarily used only for healing procedures. By implementation of proper technological research and devices this energy can be used efficiently and in this way be part of European Unions´ green future idea concerning decreasing the amount of greenhouse gases released to atmosphere.

The main goal is to fully understand all technological processes at Slovak Health Spa Piestany based on experimental measurement and scientific research. The output will be in form of charts and mathematic tables describing individual section of this complex. To be able to experimentally understand full spa complex, there is exclusion necessity for few physical parameters and processes.

4.1.1. Description of measuring devices

For the analyzation of given object, we have to use proper measuring devices. In following text are described the basic information about the devices used during the elaboration of this thesis.

- Temperature measuring:

The Temperature (sometimes called thermodynamic temperature) is a measure of the average kinetic energy of the particles in a system. Adding heat to a system causes its temperature to rise. While there is no maximum theoretically reachable temperature, there is a minimum temperature, known as absolute zero, at which all molecular motion stops. Temperature is commonly measured in the Kelvin or Celsius scales, (Fahrenheit scale in the USA). [30]

For measurement of temperature at solved object described in next chapter I used Data logger and thermography described below.

- Data logger Comet:

The logger is designed for measurement and record of temperature from four temperature probes connected via connectors. Measured values are displayed on the twoline LCD display and are stored in selectable time interval to internal nonvolatile memory. All logger control and setting are performed from PC. Minimum and maximum measured values can be displayed (display switches to actual measured values and min/max values automatically). Stored values can be transferred from logger memory to the PC by means of communication adapter. (Picture 4.1. and 4.2). [9]

Picture 4.1. Data logger S0141 Picture 4.2. - Downloading measured data [9]

Technical parameters:

- Measuring range: - 90 °C to 260 °C (RTD Pt1000/3850 ppm probes)
- Measuring range: - 50 °C to 150 °C (RTD Ni1000/6180 ppm probes)
- Resolution: 0,1 °C
- Logging interval to memory: 10 s to 24 h
- Dimensions: 93 x 64 x 29 mm

Accuracy of the inputs without probes:

- ± 0,2 °C from -50 °C to 100 °C
- ± 0,2 % from reading from 100 °C to 260 °C
- ± 0,4 % from reading from -50 °C to -90 °C

- Portable thermometer 1832 DEGREE:

The temperature measurement of the heat transfer medium in pipelines by the portable thermometer 1832 DEGREE (Picture 4.3. and 4.4.). [9]

Picture 4.3. Portable thermometer Picture 4.4. – Measurement of temperature [9]

Technical parameters:

- Measuring unit: Celsius (°C)
- Resolution: ± 0,01 °C
- Accuracy: ± 0,01 °C
- Dimensions: 300 x 80 x 15 mm

- Thermography Flir:

The temperature measurement of the collective natural healing water from source by thermography – Thermography camera Flir I7 (Picture 4.5.). [9]

Picture 4.5. Thermography camera Flir i7. [9]

- Flow rate measuring

The flow measurement is quantification of the bulk fluid movement. Flow can be measured in a variety of ways. Positive displacement flow meter accumulate a fixed volume of the fluid and then count the number of times the volume is filled to measure the flow. Other flow measurement methods rely on the forces produce by the following stream as it overcomes a known constriction, to indirectly calculate the flow. Flow may be measured by measuring the velocity of the fluid over a known area. [9]

Flow meter Krohne:

The flow rate measurement of the collected natural healing water by the portable ultrasonic flow meter UFM 610P Krohne (Picture 4.6.). [9]

Picture 4.6. Portable ultrasonic flow meter UFM 610P Krohne [9]

Technical parameters:

- Measuring unit: l/s; kg/h
- Resolution: 0,001 l/s
- Accuracy: ± 0,001 l/s

Flow meter Omega:

The flow rate measurement of the collected natural healing water by the portable ultrasonic flow meter FDT-21 Omega (Picture 4.7.). [9]

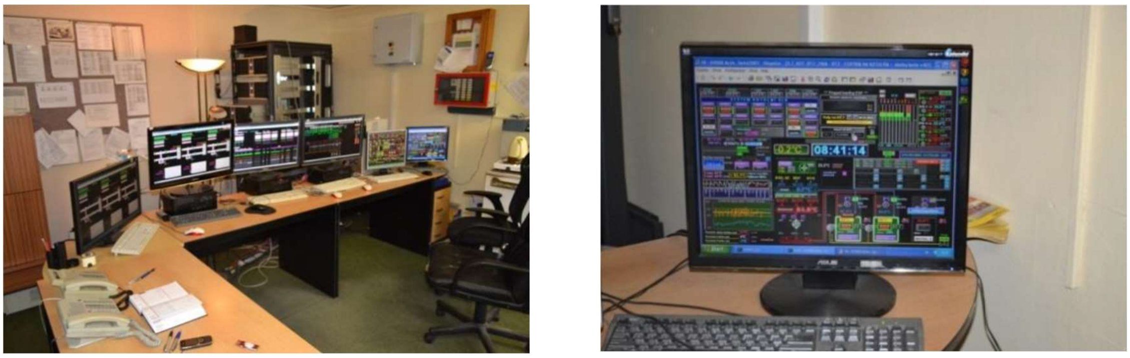
Technical parameters:

- Temperature range: 0 °C to 70 °C or 0 °C to 160 °C
- Velocity: ± 0,01 to 30 m/s
- Pipe size: DN 19 to DN 6000
- Accuracy: ± 1%

Picture 4.7. Left ultrasonic flow meter FDT-21, right flow meter case [9]

- Dispatching of measurement and regulation:

Working place of the MaR dispatching at the SLKP a.s. (Picture 4.8.) is equipted with six monitoring stations, where the software was developed by the IPSOFT Žilina company, the system Actis D 2000, version 7.01.010. [9]



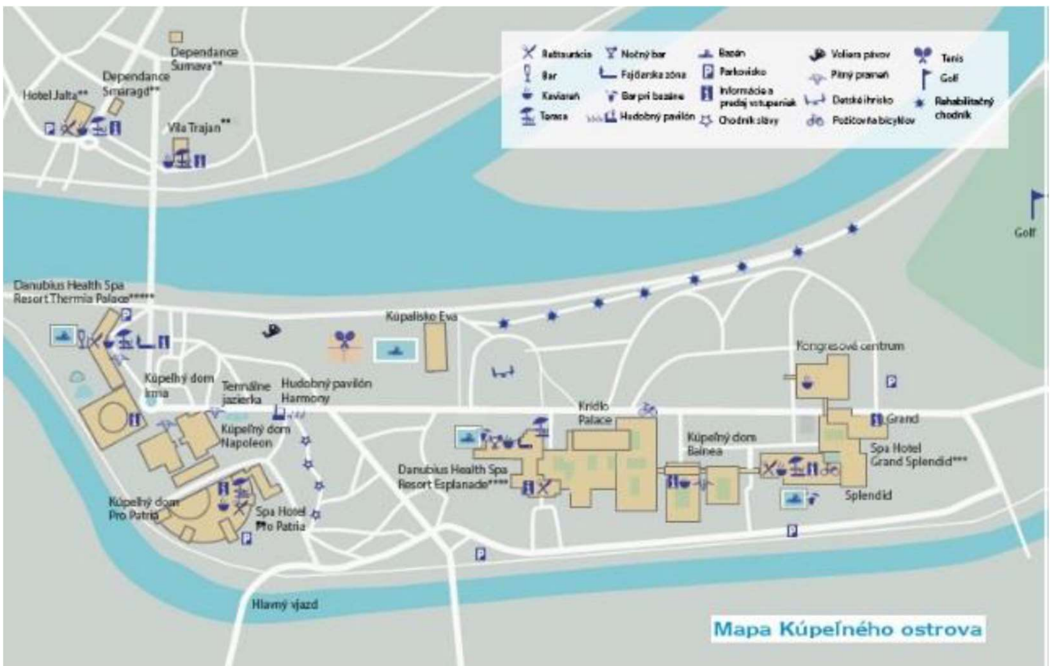
Picture 4.8. Dispatching MaR at SLKP a.s. [9]

4.1.2. Piešťany SLKP A.S. - location of solved area

For the purpose of elaborating this diploma thesis, was chosen a small spa town Piešťany, located at the west side of Slovakia, 80 km from the capital city Bratislava (Picture 4.9.). Because of its good position from the Vienna International Airport Schwechat – road distance 160 km and from Bratislava International Airport – road distance 80 km, is visiting yearly by thousands of visitors and people willing to be curate.

Picture 4.9. Location of spa town Piešťany

Piešťany are well known because of its Spa Island (Picture 1.1), which is situated on a river Váh at east side of town Piešťany. Thank to springs with the natural healing water the world famous spa was established here. Besides the spa resort, spa buildings and hotels people can as well enjoy a public swimming pool EVA and play golf on a golf curt located at the east side of the Spa island. The island is connect with the city center with pedestrian Colonnade Bridge (Picture 4.10.), and next three bridges were built as a transport connection to village Banka. [9]



Picture 4.10. Map of Spa Island [9]

4.1.3. Natural healing source of water – drills v1, v4a, v8 and well Adam trajan

The result of the complex geological structure of the natural healing sources of water and the hydrogeological factors is, that nowadays the Balneotherapy departments in the SLKP a.s. are supplied from drills V1, V4a (Picture 4.12.), V8 (Picture 4.13.) and supplement well Adam Trajan signed as drill V5, V5a (Picture 4.11.). [9]

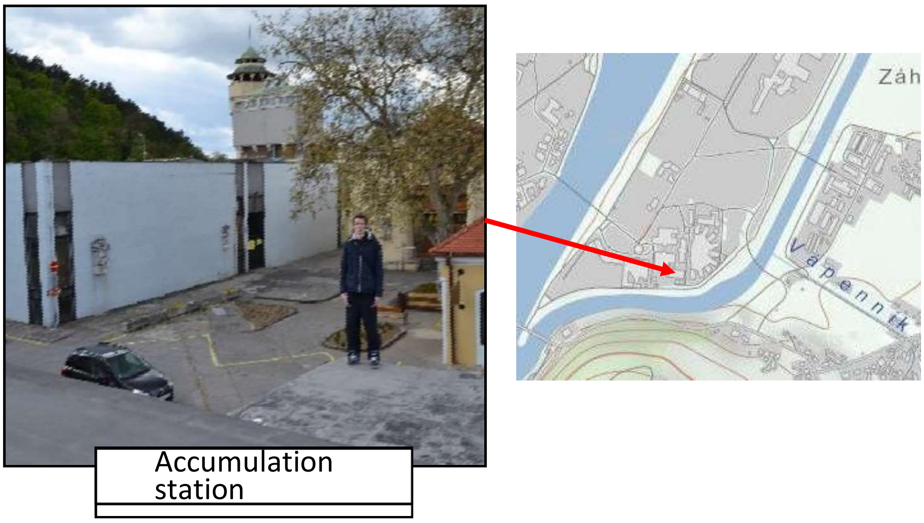
Picture 4.11. Well Adam Trajan V5 (Left picture view before reconstruction, right picture view after reconstruction) [9]

Picture 4.12. Left picture drill V-1, right picture drill V-4a [9]

Picture 4.13. Drill V8 [9]

4.1.4. Accumulation station – location

Accumulation station is situated at west side of the Spa Island (Picture 4.14.) and was constructed in the year 1985. The purpose of this building is to group technological devices for operation of the Balneotherapy departments and the hotel complexes. The location was designed near the natural healing sources of water, because of technical means of that age, which do not allow company to transport the natural healing water to far away from source. [9]



Picture 4.14. Location of accumulation station [9]

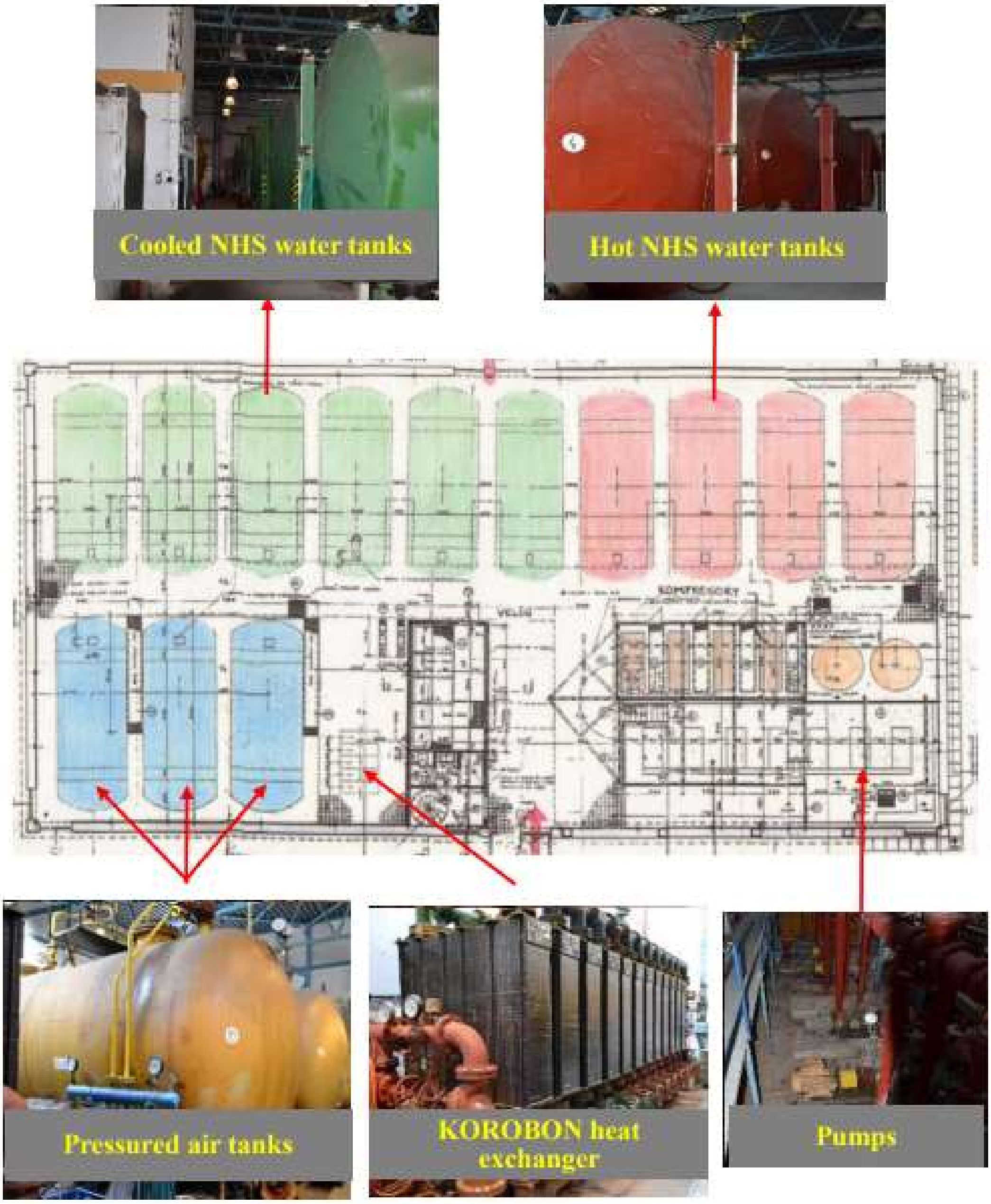
4.1.4.1. Accumulation station basic information

Since the natural water has temperature cca. 65 °C at source, is useless for the healing procedures at the Balneotherapy departments and it is necessary to mixed it with the cooled NHS water. Mixing of the NHS water with another water e.g. from common well is not possible due to its mineral composition which will discard healing proposition of this water and cause its coloring. For this reason it is necessary to cooled down the NHS water collected from the natural healing water source. [9]

From the source is the NHS water flow-through gravitationally collected at lower part of the accumulation station - Picture 4.15, where with the help of a pumps is pressed into the opened distribution system. [9]

At the accumulation station is collected the NHS water from the flow-through well and drills with the help of pumps pressed and distributed into individual departments. To secure required amount of the NHS in consideration of nonlinear requirement, there are situated horizontal tanks for the accumulation of at NHS at accumulation station. Nowadays Spa Piešťany owned 4pc. of an horizontal tanks for hot NHS and 6 pc. for cold NHS – Picture 4.15.. [9]

Accumulation station is grouping technological devices necessary for cooling down the NHS water and its distribution (Picture 4.15.). [9]



Picture 4.15. Accumulation station technological solution of accumulated NHS water [9]

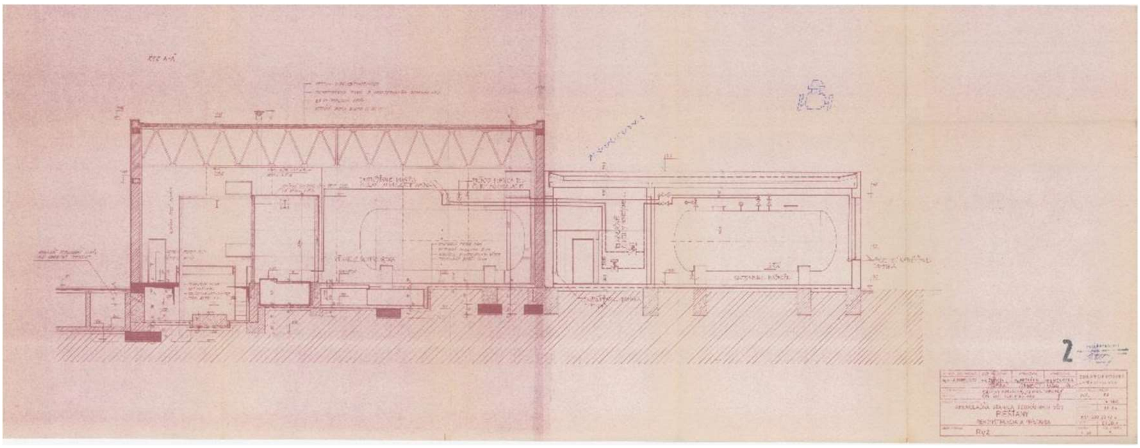
4.1.4.2. Accumulation station analysis

The accumulation station has the biggest impact as concerning energetic, environmental and ecological point of view. Analysis of this object is the most important part of this doctor thesis, because all the Balneotherapy departments are supplied and depended on this operation. Analysis is divided into two parts, first part is concerning analyzation of accumulation station as a whole object – disposition, space requirements, basic and detailed calculations, drawings, second part is concerning analyzation of the graphite heat exchanger Korobon – which provide the cooling down of the natural healing water from source. [9]

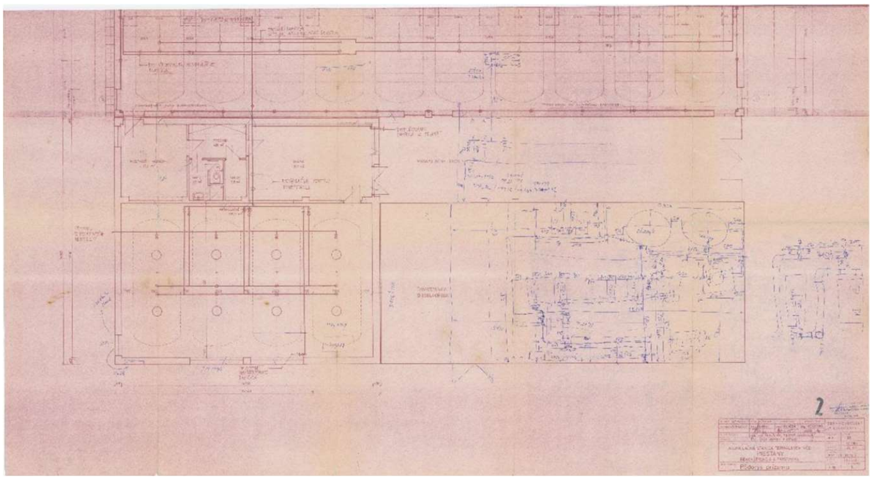
4.1.4.3. Analyzation of accumulation station

For the purpose of analyzation the Slovak Health Spa Piešťany a.s. provided original project documentation of the station (Picture 4.16. and Picture 4.17.). During the years of operation small improvement and reconstructions mainly at pipelines were made. For this reason it was necessary to map current state of the accumulation station, by individual measurement directly in the accumulation station concerning disposition, space requirements, types of armatures, dimensions which validate original project documentation. This project documentation, was redraw into electronical by using project design software Autocad and redesign to respond the reality. The output of first part of this analyzation is the project documentation of current state stated in attachment. [21]

Picture 4.16. Accumulation station section plan provided by SLKP a.s. [21]



Picture 4.17. Accumulation station floor plan provided by SLKP a.s. [21]



4.1.4.4. Accumulation station – design simplified schemes

For the purpose of analyzation, it was necessary to develop scheme of current pipelines involvement (Chart 4.1.).

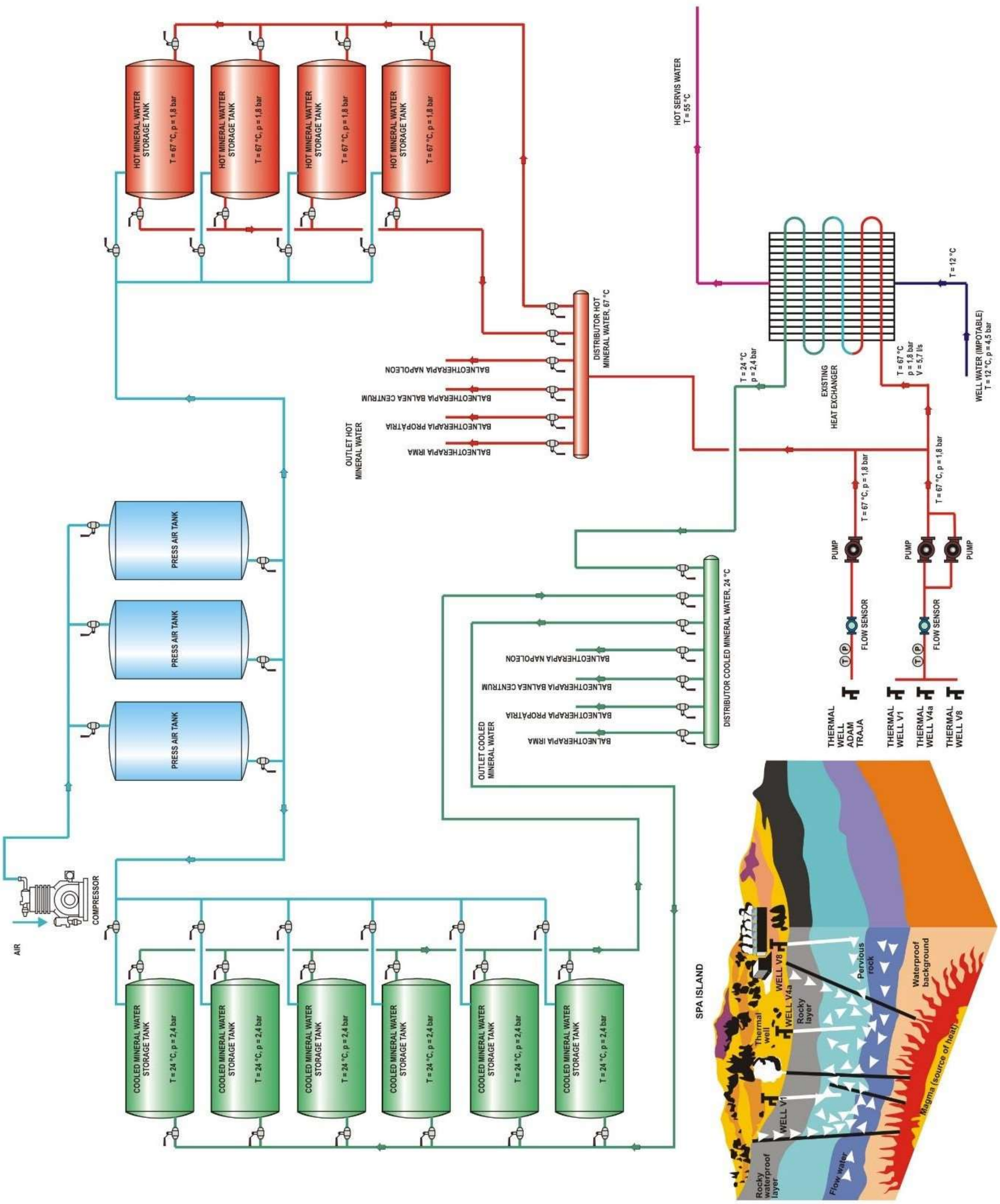
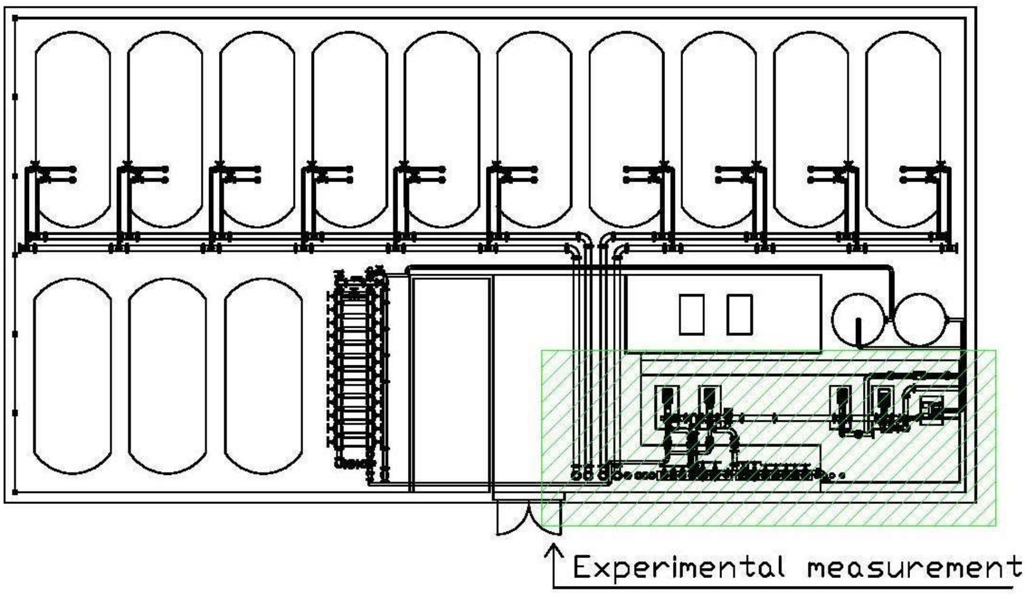


Chart 4.1. Scheme of current accumulation station state [9]

Chart 4.1. shows distribution of the natural healing water from drills V1,V4a,V8 and well Adam Trajan in bottom right corner at the accumulation station. The amount of water is on the base of the monitoring system of the Slovak Ministry of Health monitored and recorded. Average temperature of the natural healing water which is pumped into the water distribution system is 67 °C, which was obtained from long-term measurement. Part of the NHS water is flowing directly to the hot water distributor (marked with red color), from where is flowing into the Balneotherapy departments, second part is flowing into the block graphite heat exchanger Korobon, where is cooled down to temperature ccs. 24 °C and flowing to the cooled water distributor (marked with green color), from where is flowing to the Balneotherapy departments. Analysis of block graphite heat exchanger is evaluated in next section. The distributor of hot NHS water separate partially amount of NHS hot water for the hot NHS water storage tanks, where is stored at temperature cca. 67 °C and pressure 1,8 bar. The cold NHS distributor separate partially amount of the NHS cooled water for the cooled NHS water storage tanks, where is stored at temperature cca. 24 °C and pressure 2,4 bar. The pressure in the storage tanks is provided with the help of air collected from the compressor at the pressure air tanks (marked with blue color). In the case of high demand of water it is possible to use this stored water in the distribution system. [9]

4.1.4.5. Accumulation station - thermography evaluation

Thermography evaluation was provided with the help of thermo camera FLIR at the selected part of accumulation station – distributors of hot and cooled natural healing water (Picture 4.18.). [9]



Picture 4.18. Location of experimental thermography measurement [9]

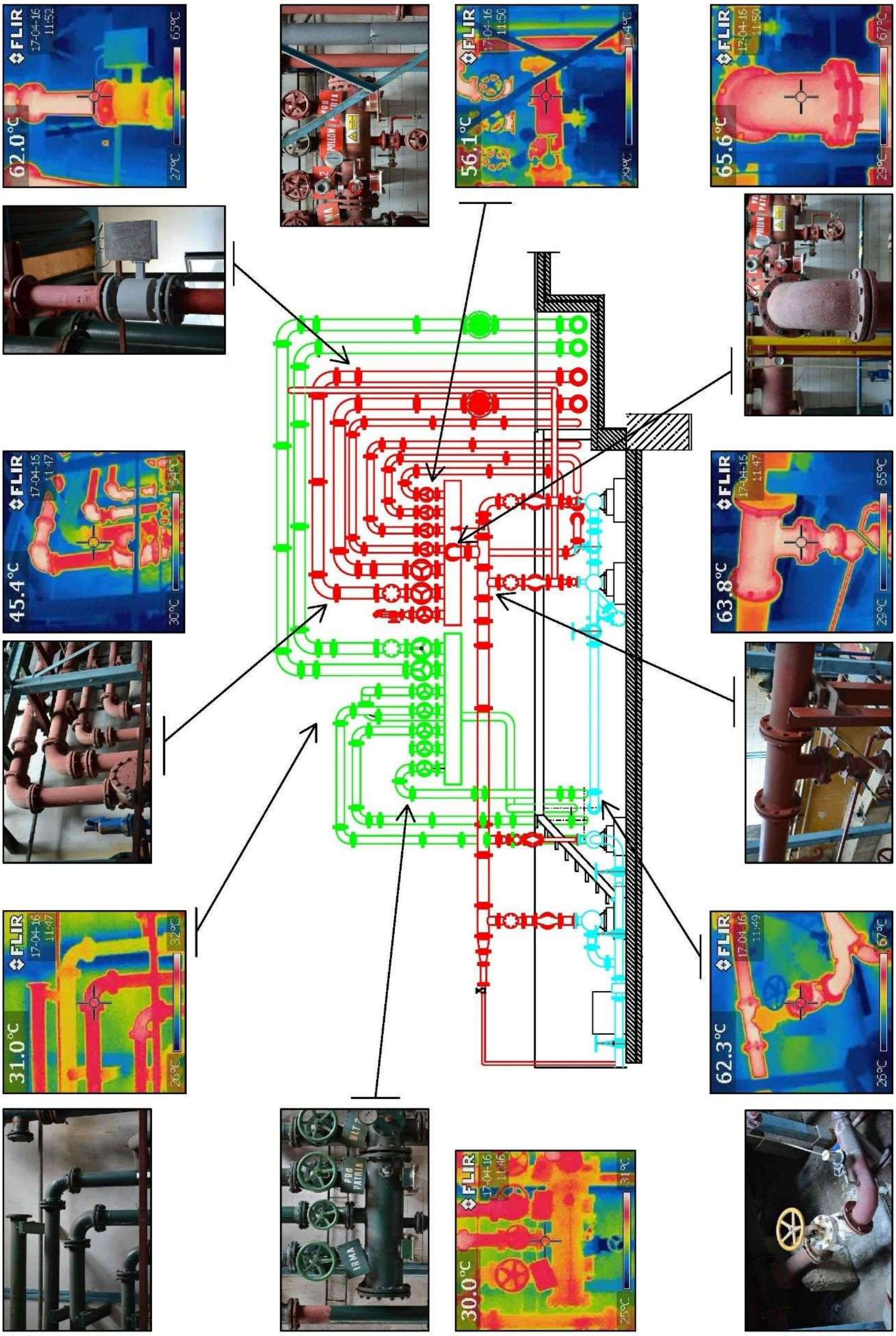
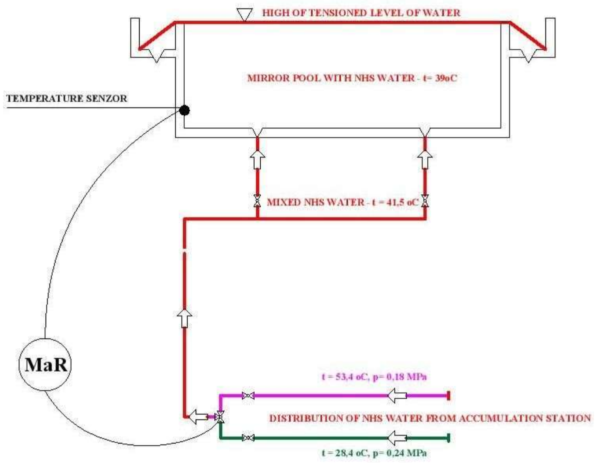


Chart 4.2. Experimental thermography measurement [9]

The experimental measurement (Chart 4.2.) was elaborated on 28.03.2017 during the operation of the Balneotherapy with thermography camera Flir – basic parameters stated in the Chapter 2. From thermography pictures it is possible to say, that at the time of measurement hot natural healing water distributed to the Balneotherapy departments was 62,0 – 65,6 °C and temperature of cooled natural healing water distributed to the Balneotherapy was 30 – 31 °C which depends on the temperature sensor at bottom of technological devices and its current using (Chart 3.8.). It is although possible to say that temperature of fluid distributed from accumulation station is higher than temperature at mixing armature due to distribution losses stated in previous section. [9]

Chart 3.8. mixing armature and temperature sensor at balneotherapy technological devices [9]



4.1.4.6. Distributors of NHS - Temperature measurement

Experimental measurement of NHS water distributor temperature was provided by Comet data logger – basic parameters are stated in previous chapter. Table 4.1. shows example of experimentally measured values, which were process into charts stated below. [9]

Table 4.1. Example of experimentally measured values at distributor of NHS water

Date and time	**Hot NHS water**	**Cooled NHS water**
	[°C]	**[°C]**
13.3.17 3:45	64,20	31,20
13.3.17 4:00	65,40	31,40
13.3.17 4:15	65,40	31,30

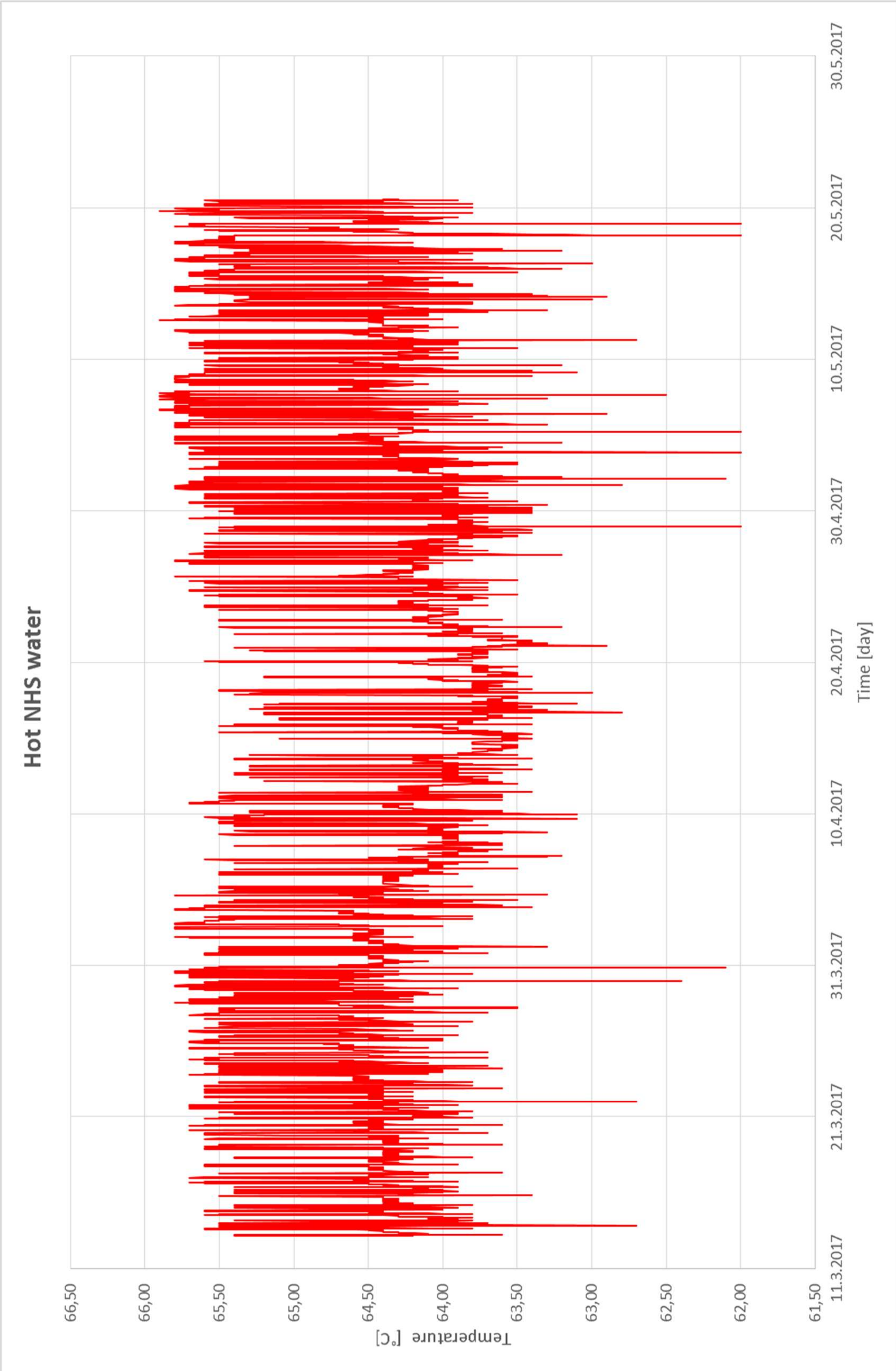


Chart 4.3. Experimental measurement of time and temperature dependence of hot NHS water from distributor

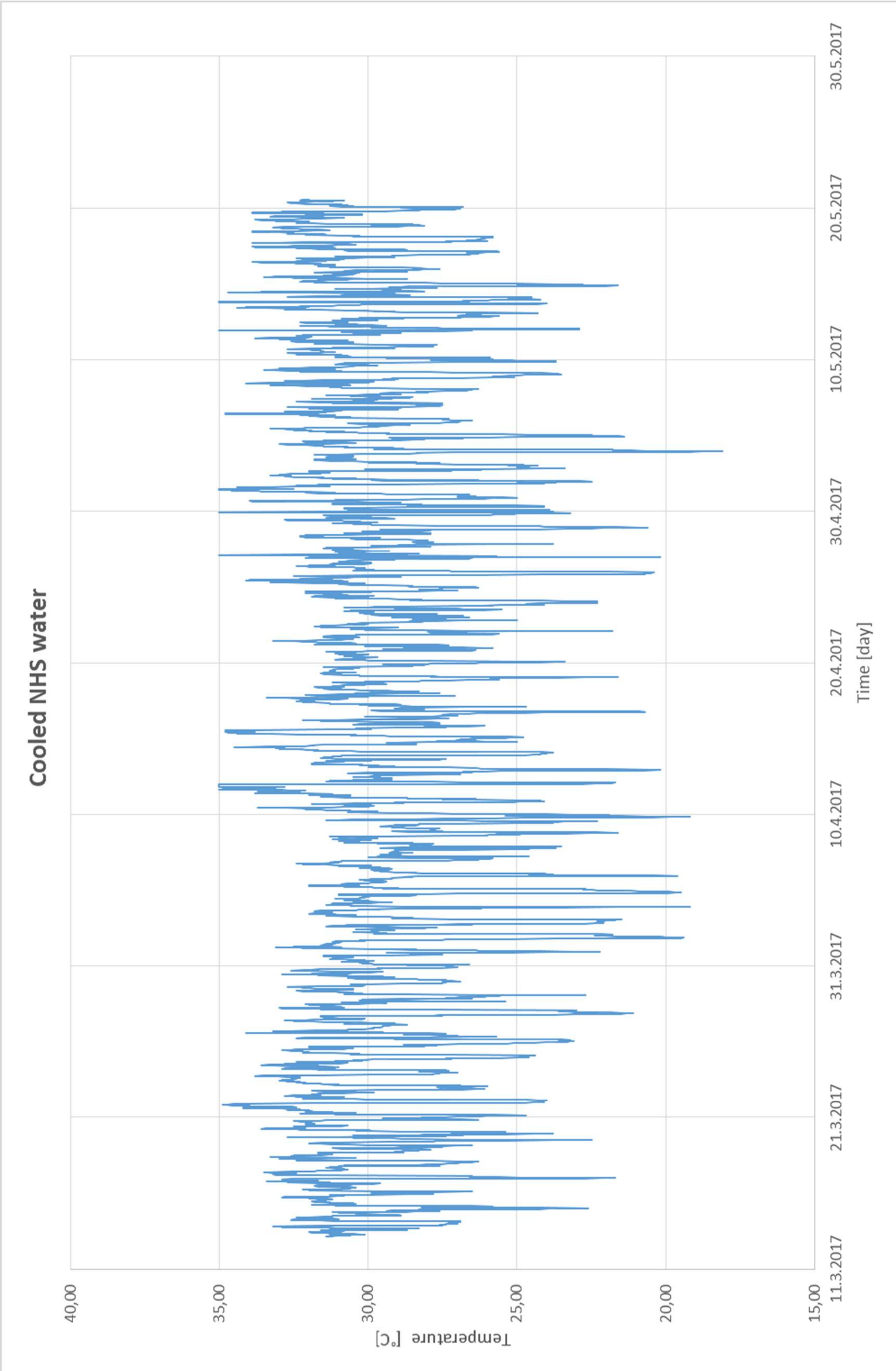


Chart 4.4. Experimental measurement of time on temperature dependence of cooled NHS water from distributor

After chart review, it is possible to say that, during the experimental measurement hot the NHS water distributed to the Balneotherapy departments is in range 63 – 65,7 °C (Chart 4.3.) and the cooled NHS water distributed to the Balneotherapy departments is in range 20,0 – 35,0 °C (Chart 4.4.). Obtained values will be input data for design of actions which will help to the SLKP to fulfill the European Union´s goals. [9]

4.1.5. Korobon – graphite heat exchanger

For ensuring the operation of the Balnotherapy in the SLKP a.s., the opened natural healing water system is complete with the distribution of cooled NHS water, which is prepared at the Korobon graphite block heat exchanger (see Chart 4.5.). The Korobon heat exchangers is special atypical heat exchanger situated at the accumulation station. It was constructed in 1965 in the Germany Democratic republic by company VEB ELEKTROCHEMISCHES KOMBINAT BITTERFIELD under the name KAMMER – WÄRMEUBERTRAGER– KOROBON 10302 (Picture 3.24.). [9]

Basic parameters:

- Number of units: 12
- Heat transfer surface area: 22 m^2 / unit
- Height: 1,63 m
- Length: 1,565 m
- Width: 0,440 m
- Power of one unit: 112 kW
- Power of heat exchanger: 1 344 kW

Picture 4.19. Korobon block graphite heat exchanger

4.1.5.1. Developing simplified schemes – korobon

Due to the fact that Korobon block graphite heat exchanger is the most important part of opened natural healing water system for further evaluation it is necessary to develop simplified schemes with the basic dimensions of the heat exchanger (Chart 4.5.). [9]

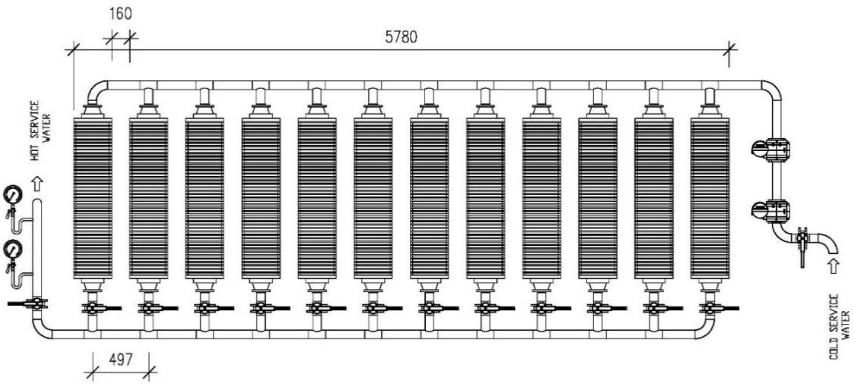


Chart 4.5. Korobon: side view [9]

4.1.5.2. Temperature and flow rate measurement – Korobon

The experimental measurement of the NHS water at the Korobon graphite block heat exchanger was provided by the Comet data logger from 20.11.2016 to 11.03.2017 and was hold on the pipelines of the hot natural healing water (red color in scheme), the cooled natural healing water (green color in scheme), the hot service water (yellow color in scheme) and the cold service water (blue color in the scheme) (Chart 4.6.). [9]

After an consultation and technical decision there were four temperature sensors placed, one on each pipelines (see Chart 4.6.). All sensors were insulated from outer influences with polystyrene th. = 40 mm, and the heat transfer area was increased with the help of aluminum foil in shape of U (Picture 4.20. and 4.21.). [9]

Picture 4.20. Left: Temperature sensor at cooled natural healing water (green pipeline), Right: Temperature sensor at cold service water (blue pipeline) [9]

Picture 4.21. Left: Temperature sensor at hot service water (yellow pipeline), Right: Temperature sensor at hot natural healing water (red pipeline) [9]

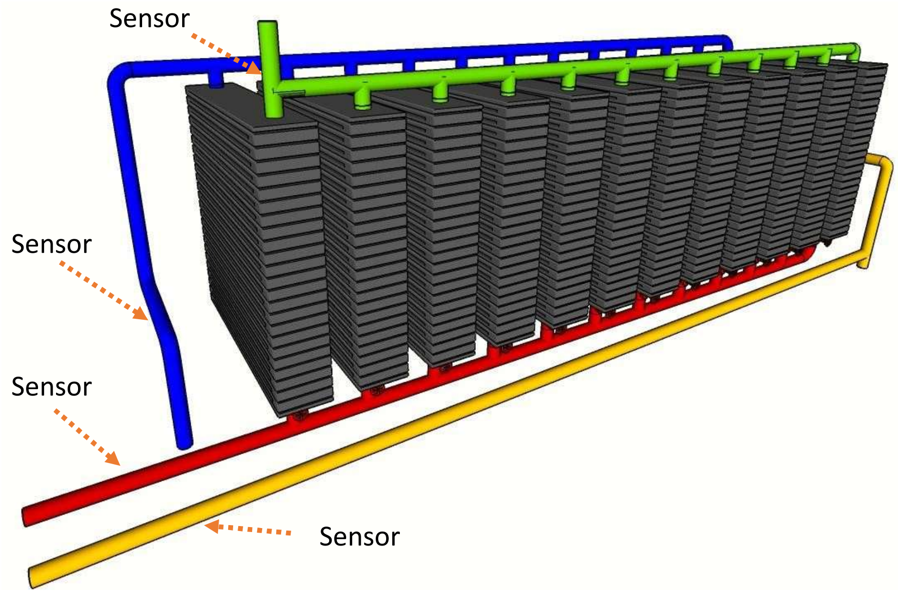


Chart 4.6. Position of senors at Korobon heat exchanger

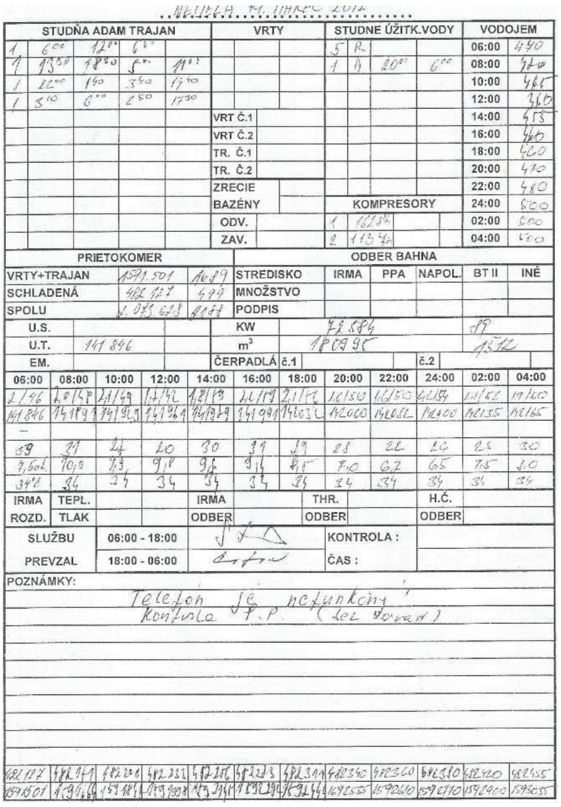
The temperature data obtained from data logger were recorded into a table and after wise analyzed with the help of graphic solution. Since measurement contains more than 100000 records table below is only for illustration purpose (Table 4.2.). [9]

Table 4.2. Korobon – recorded values from Comet data logger

TIME AND DATE	HOT THERMAL WATER	COOLED THERMAL WATER	COLD SERVICE WATER	HOT SERVICE WATER
	[°C]	[°C]	[°C]	[°C]
20.11.16 12:00	64,00	26,20	18,30	44,00
20.11.16 12:15	64,10	26,30	18,20	43,80
20.11.16 12:30	64,00	25,90	18,30	43,60
20.11.16 12:45	64,10	26,50	18,20	44,70

Measurement of the flow rate was elaborated in two variants. First variant was measured by the Ultrasonic Flow Meter Krohne – basic details are available in Chapter 2. Analyzation by this flow meter was unsuccessful, due to the sedimentation incrust with thickness more than 30 mm on the inner pipeline perimeter (Picture 4.22.) Second variant was elaborated on the base of the recorded data by specialized workers in the accumulation station. This data are archived for global archive of the Slovak Ministry of Health - Spa monitoring system (Picture 4.23.). [9]

Picture 4.22. Sedimentation incrust at inner pipeline perimeter [9]



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Picture 4.23. Flow rate data recorded by specialized workers at SLKP a.s. [9]

Data recordation is provided every two hours from the water-gauges situated at the hot natural healing water pipeline and cold service water pipeline. This data were processed into an excel table (Table 4.3.) and edited with the help of mathematical spline algorithm from the flow rate m^3/2hours to m^3/15min to be compatible with the temperature measurement – table has only informative purpose, due to the total amount of recorded data more than 10000 values. Mathematical spline algorithm was developed with the help of Microsoft Visual Basic. [9]

Table 4.3. Experimental flow rate measurement

TIME AND DATE	WATER-GAUGE		AMOUNT OF WATER		FLOW RATE - 15 min	
	SERVICE WATER	NHS WATER	SERVICE WATER	NHS WATER	SERVICE WATER	NHS WATER
	[m^3]	[m^3]	[m^3]	[m^3]	[m^3 /15min]	[m^3 /15min]
	93645,000	434277,000	0,000	0,000		
20.11.16 12:00	93708,000	434312,000	63,000	35,000	7,875	4,375
20.11.16 12:15	93712,915	434316,575	67,915	39,575	7,408	4,407
20.11.16 12:30	93717,790	434321,107	72,790	44,107	6,944	4,433
20.11.16 12:45	93722,586	434325,554	77,586	48,554	6,490	4,446
20.11.16 13:00	93727,263	434329,871	82,263	52,871	6,049	4,442
20.11.16 13:15	93731,783	434334,018	86,783	57,018	5,625	4,414
20.11.16 13:30	93736,105	434337,950	91,105	60,950	5,222	4,356

Validation of the mathematical spline algorithm was elaborated on the base of comparison of the area under the chart polylines. Chart 4.7. shows original obtained data from specialized workers at spa Piešťany (orange polyline) and data calculated with the help of algorithm (blue polyline). Area under the orange polyline (original data) is 2185,39 units and area under the blue polyline (calculated data) is 2204,64 units. From the analyzation of areas it is possible to stated, that ratio is 99,12 % which is less than 5 % error in transformation and from the technical point of view is satisfied. [9]

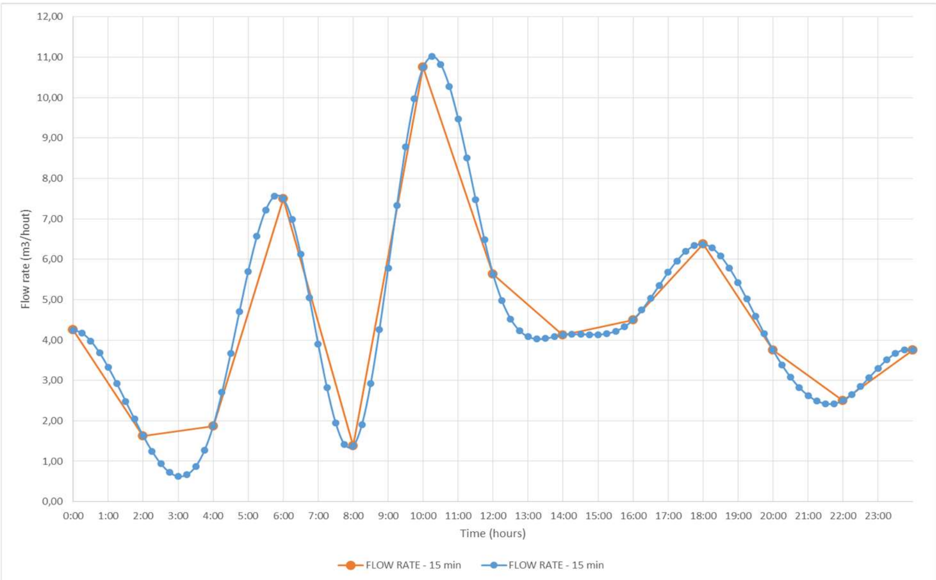


Chart 4.7. Edited flow rate by mathematical spline algorithm [9]

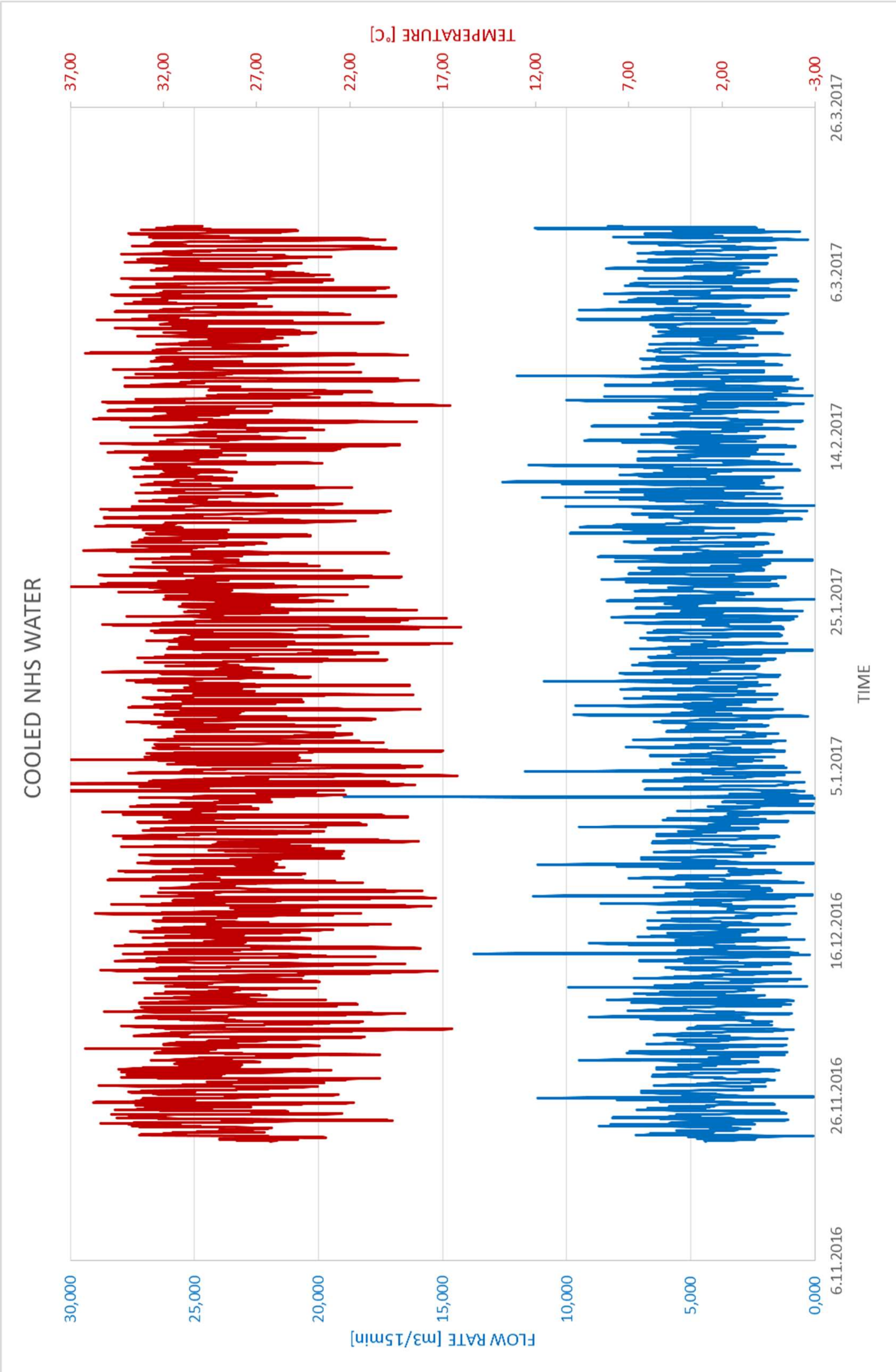


Chart 4.8. Senor 1: dependence of time on temperature and flow rate of cooled natural healing water (green pipeline)

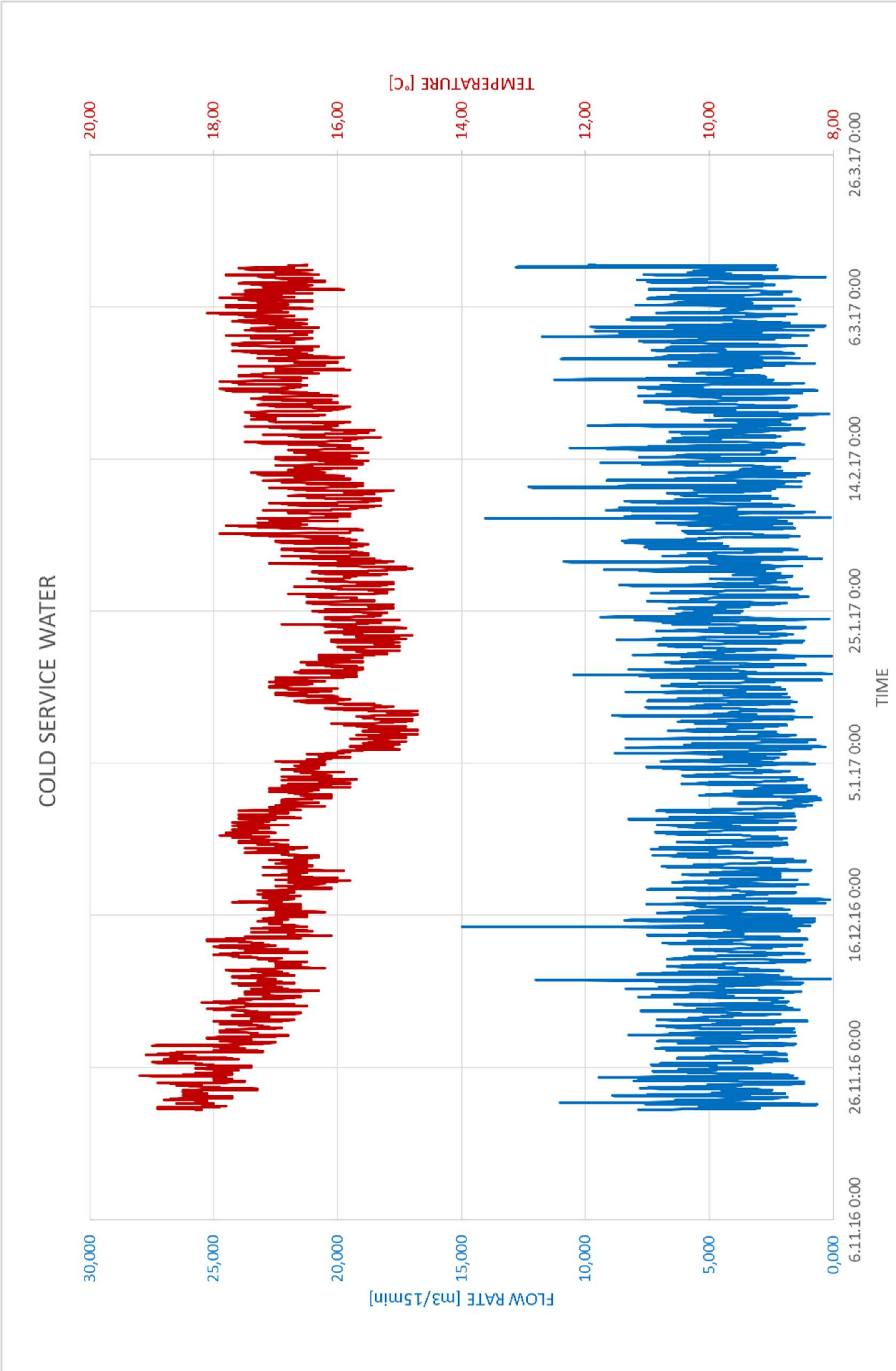


Chart 4.9. Sensor 2: dependence of time on temperature and flow rate of cold service water (blue pipeline)

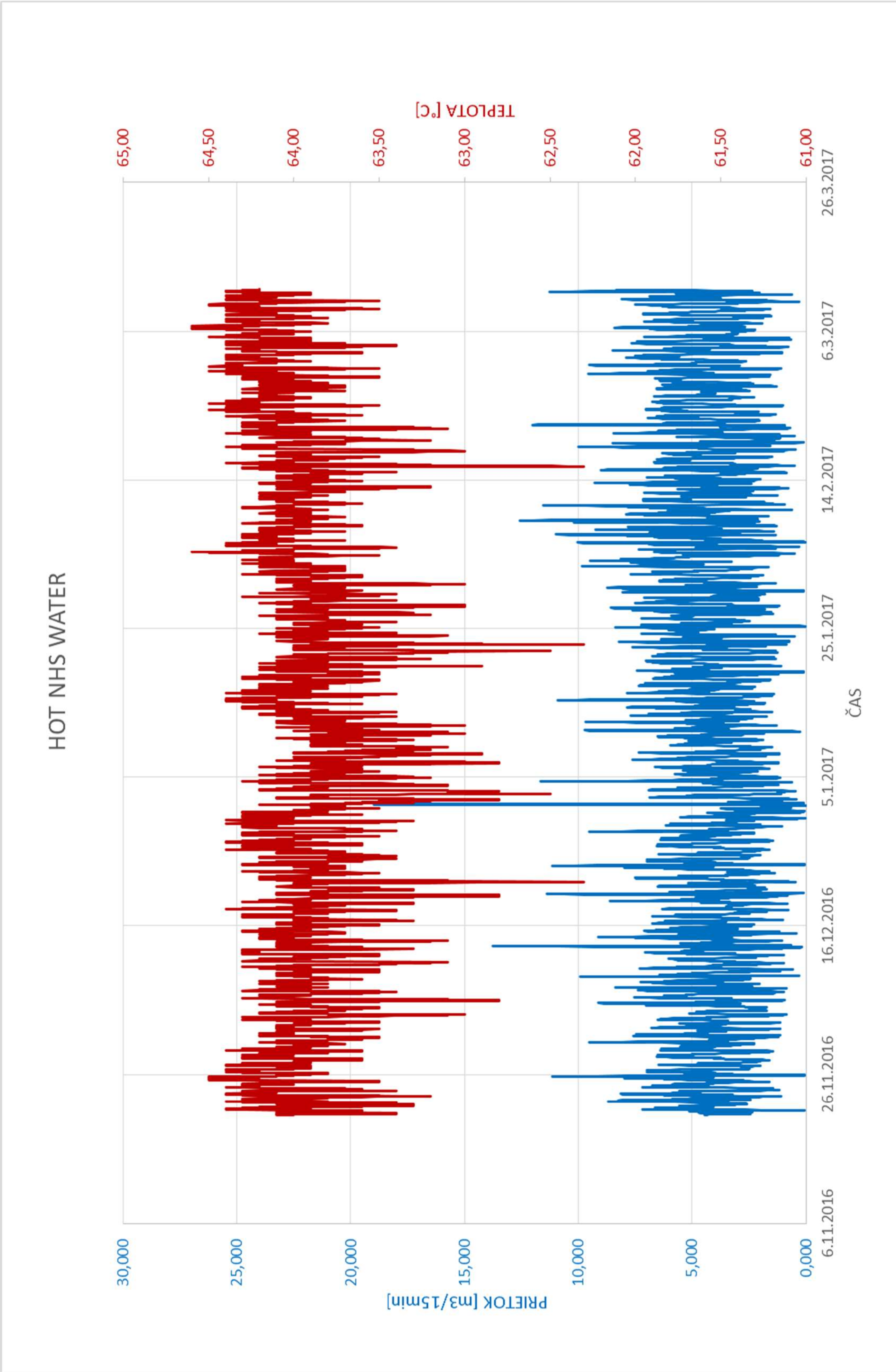


Chart 4.10. Sensor 3: dependence of time on temperature and flow rate of hot natural healing water (red pipeline)

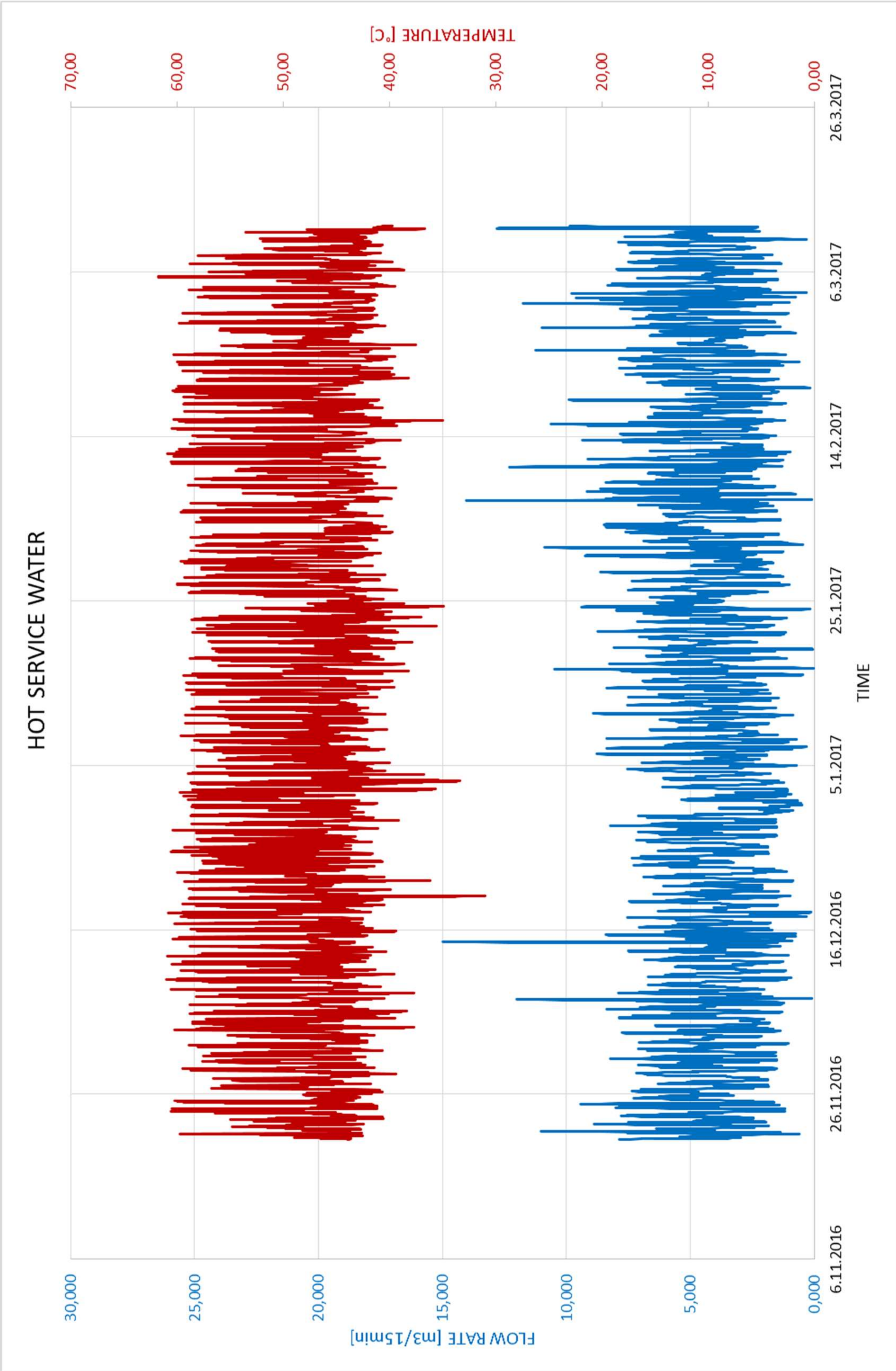


Chart 4.11. Sensor 4: dependence of time on temperature and flow rate of hot service water (yellow pipeline)

After revision of Charts 4.8. – 4.11. it is possible to state that, for the analyzation from the temperature point of view it is necessary to find the average temperature interval of the Korobon heat exchanger operation. For this purpose was developed charts, which shows the temperature values in dependence on the number of values. [9]

From Chart 4.12. – Temperature measurement of the hot natural healing water is clear that more than 99 % of operation time is the temperature interval (63,0 °C – 64,6°C), which will be input data for the experimental solution. The temperature interval (62,3 °C – 63,0 °C) is less than 1 % of operation time and could be considerate as an error in measurement caused by outer influences, such as manual control of sensor. [9]

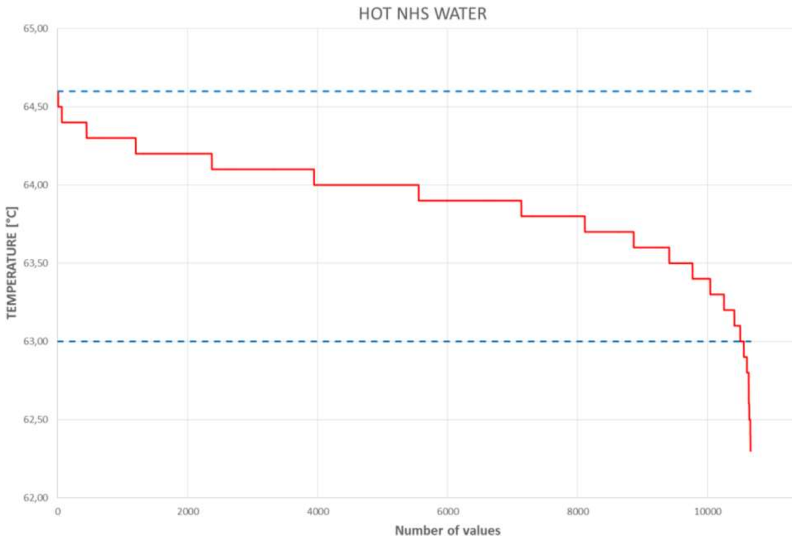


Chart 4.12. Dependence of temperature and number of values – hot NHS water

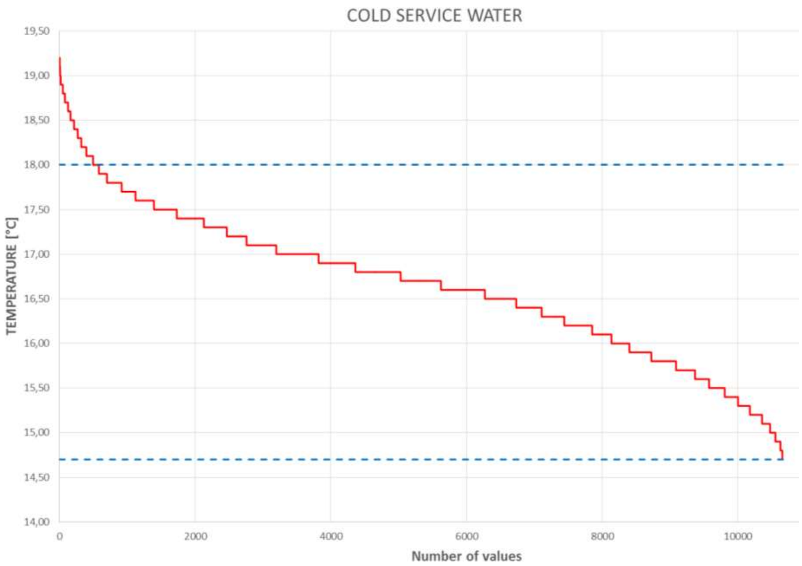


Chart 4.13. Dependence of temperature and number of values – cold service water

Analyzation of Chart 4.13. – Temperature measurement of the cold service water shows that more than 95 % of operation time is the temperature interval of cold service water (14,7 °C – 18,0 °C) and will be input data for the experimental solution. Temperature data from interval (18,0 °C – 19,3 °C) is less than 5 % of the operation time and could be considered as an error in measurement, caused by outer influences, such as manual control of sensors. [9]

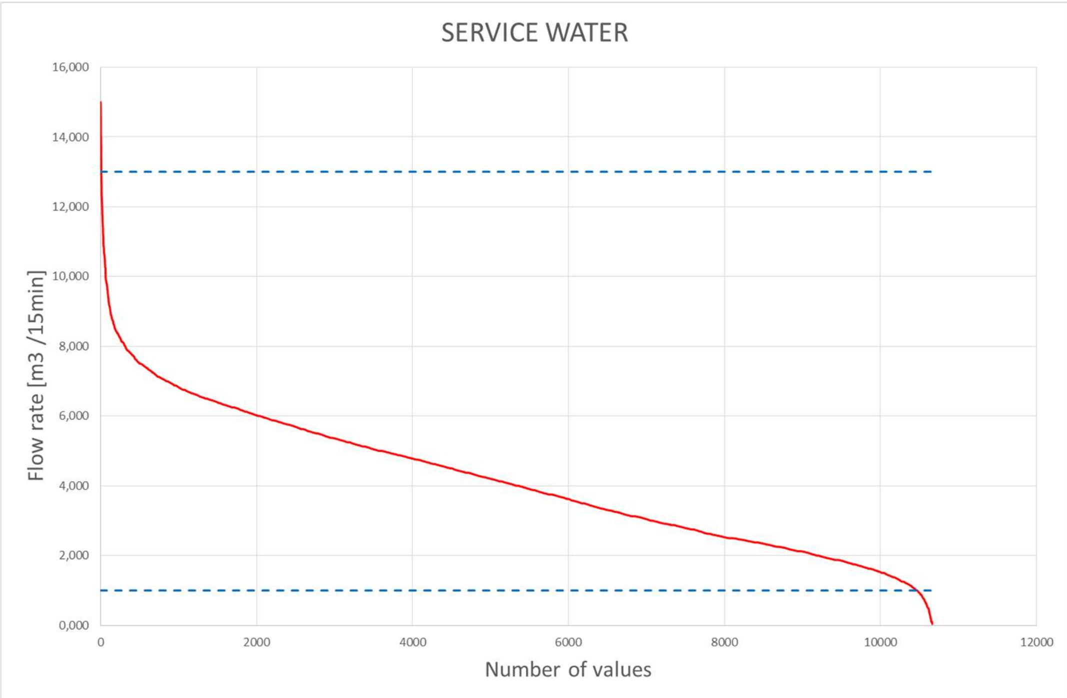


Chart 4.14. Service water flow rate measurement dependent on number of values

Chart 4.14. – shows dependence of the service water measured values and the number of data, analyzation of the flow rate was consulted with the project manager of SLKP a.s., and after technical revision it could be stated that the flow rate during the operation of the Balneotherapy is in interval (1 m^3/15 min – 13 m^3/15 min), which is 95,2 % of the operation time. Values outside interval are impossible to obtain and could be considered as an error in measurement, caused by human factor. This error is 4,8 % of operation time, which is from technical point of view acceptable.

Chart 4.15. – shows dependence of the hot natural healing water measured values and the number of data, analyzation of the flow rate was consulted with the project manager of SLKP a.s., and after technical revision it could be stated that the flow rate during the operation of Balneotherapy is in interval (1 m^3/15 min – 13 m^3/15 min), which is 96,85 % of operation time. Values outside interval are impossible to obtain and could be considered as an error in measurement, caused by human factor. This error is 3,14 % of operation time, which is from technical point of view acceptable.

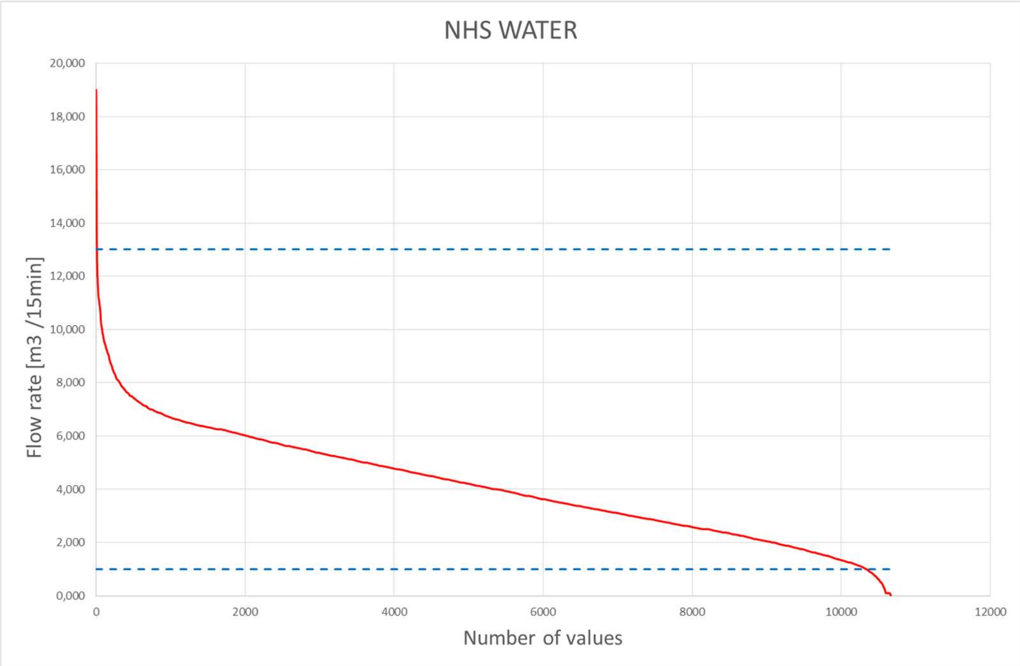


Chart 4.15. NHS water flow rate measurement dependent on number of values

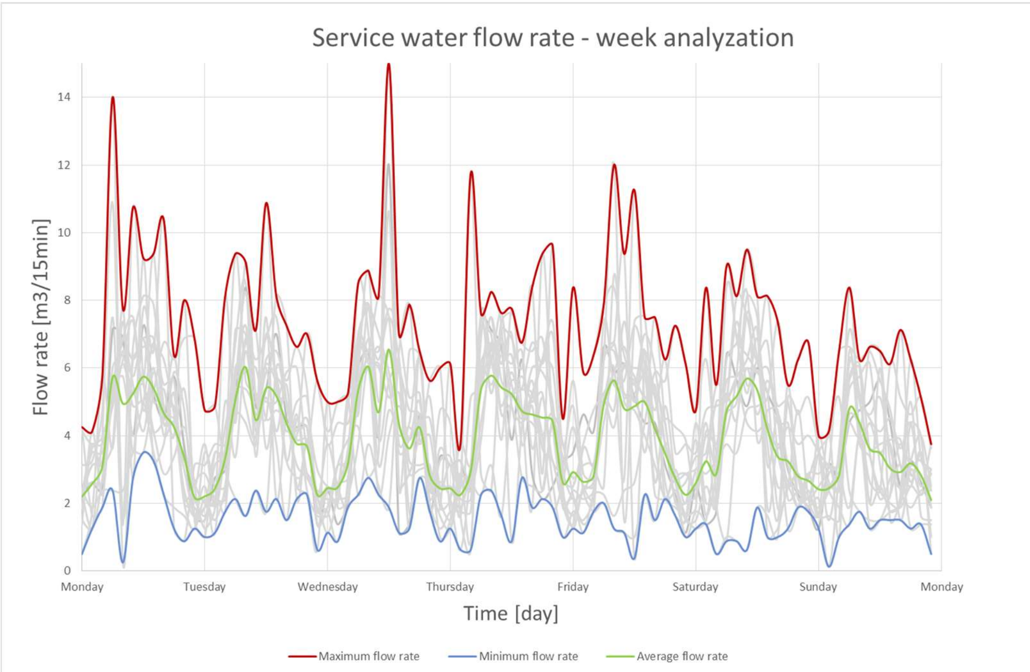


Chart 4.16. Service water flow rate week analyzation

A service water week analyzation (Chart 4.16.) shows the maximum (red line), the average (green line) and the minimum flow rates (blue line) during the measurement at the certain time. From week analyzation it is possible to state that service water system is working with daily periodicity, where the maximum flow rates are reaching during the operation of Balneotherapy and lowest during the night – out of BT operation. [9]

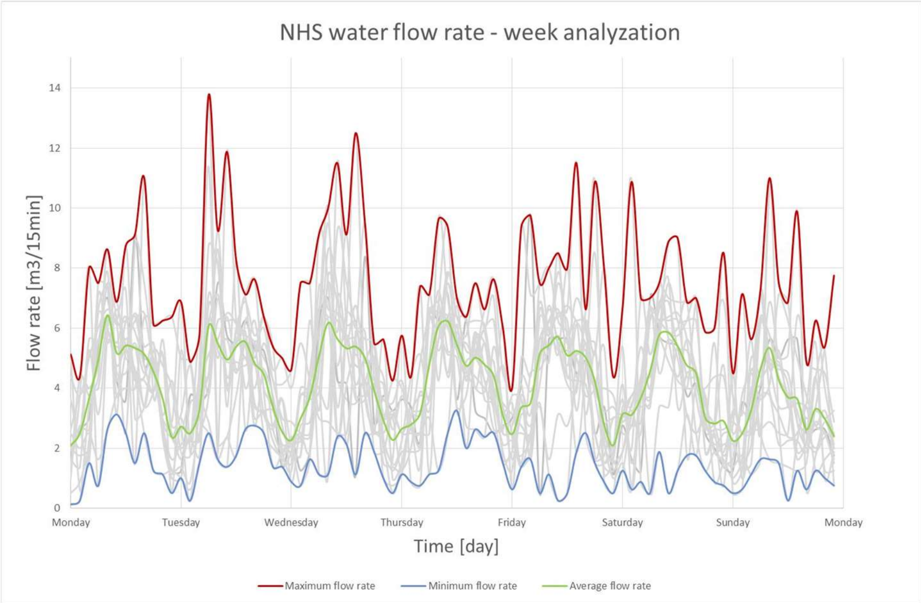
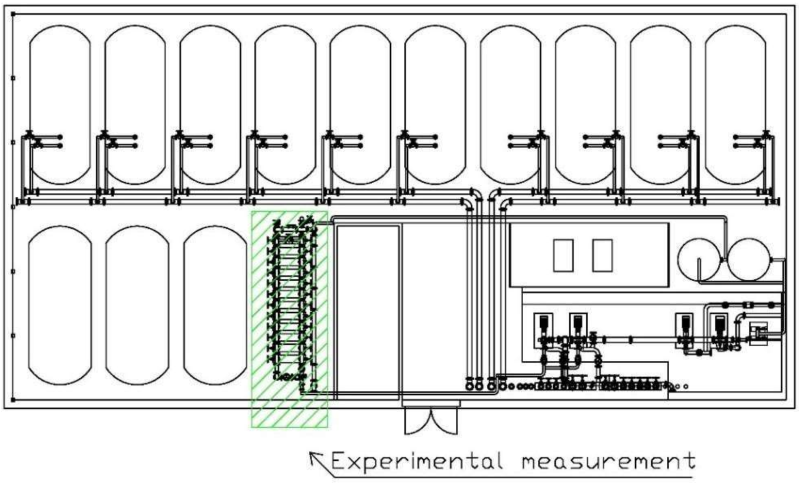


Chart 4.17. Hot natural healing water flow rate week analyzation

The hot natural healing water flow rate week analyzation (Chart 4.17.) shows the maximum (red line), the average (green line) and the minimum flow rates (blue line) during the measurement at the certain time. From week analyzation it is possible to state that service water system is working with daily periodicity, where the maximum flow rates are reaching during the day – operation of Balneotherapy and lowest during the night out of Balneotherapy operation. [9]

4.1.5.3. Korobon – thermography analyzation

The thermography analyzation was provided with by thermo camera FLIR (parameters are stated in previous chapter), at the selected part of the Korobon heat exchanger (Picture 4.24.). [9]



Picture 4.24. Experimental measurement location in accumulation station

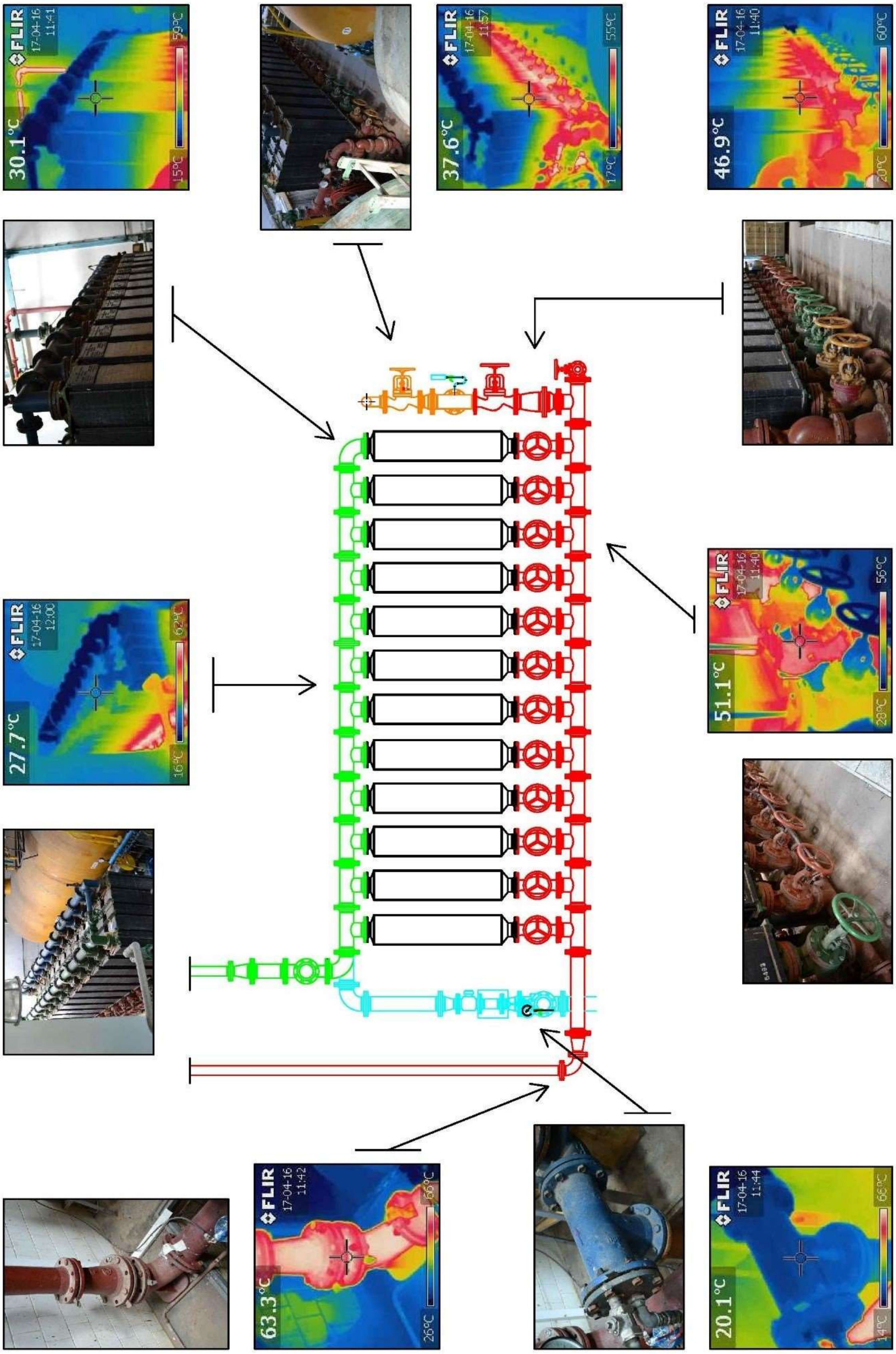


Chart 4.18. Korobon heat exchanger thermography analyzation [9]

4.1.6. Analyzation of natural healing sources of water

Analyzation of the natural healing sources at the Slovak Health Spa a.s. Piešťany has geological character, which describes the existing natural healing water system. This section is including in this diploma thesis as it is considered to be initial data for the elaboration complex analysis of the Balneotherapy. The analyzation provide information about the temperature and the flow rate of individual natural healing water source, which is affected by the level of recipient and its flow rate regulation (Table 4.4. and Table 4.5.). [9]

Table 4.4. Information about well and drills at Spa Island. [9]

Source of NHS water		Max. enabled collection of NHS water	Temperature of NHS from long-term point of view	Depth
		[l/s]	[°C]	[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 4.5. Temperatures and dimensions of drills according to geological works [9]

Drill	Ground	Depth of drill	Max. temperature	Collection from depth	Q	H_2S	Notes
	[m /m]	[m]	[°C]	[m]	[l/s]	[mg/l]	
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					

Analyzation of the natural healing sources of water shows that currently the Slovak Health Spa a.s. Piešťany is for operation of the Balneotherapy using drills V1, V4a, V8 and well Adam Trajan, whose temperature and flow rate as well as amount of H2S will be initial data for a design elaboration to make improvement in the opened natural healing water source system. [9]

4.1.7. Balneotherapy department

Healing treatments at the Slovak Health Spa Piešťany a.s. are currently provided at four Balneotherapy departments, situated on the Spa island (Picture 4.25.).

Picture 4.25. Map of Balneotherapy departments

Table 4.6. Balance sheet of natural healing sources of water - Balneotherapy Irma

Natural healing source of water collection places	Time	Pool surfac e area	Pool volume	Temperature of mixed NHS water	Temperature of cooled NHS water	Temperature of hot NHS water	Amount of mixed NHS water		Amount of hot NHS water		Amount of cooled NHS water	
	[hours]	[m^2]	[m^3]	[°C]	[°C]	[°C]	[l*s^{-1}]	[m^3*deň$^{-1}$]	[l*s^{-1}]	[m^3*deň$^{-1}$]	[l*s^{-1}]	[m^3*deň$^{-1}$]
Mirror pool man - water filling	2,25	28,70	34,45	40,89	23,00	65,80	0,45	39,11	0,19	16,34	0,26	22,77
Mirror pool man - water adding	13,00			41,33	23,00	65,80	0,45	39,24	0,19	16,81	0,26	22,43
Mirror pool woman - water filling	2,00	28,70	34,45	40,32	23,00	65,80	0,51	44,10	0,21	17,85	0,30	26,25
Mirror pool woman - water adding	13,00			40,80	23,00	65,80	0,45	39,24	0,19	16,32	0,27	22,92
Bathtubs treatment department - 120 procedures/day	1,70											
6 x bathtubs			1,56	37,00	23,00	65,80	0,36	31,20	0,12	10,21	0,24	20,99
Water treatment department 100 procedures/day	1,70											
5 x bathtubs			1,4	37,00	23,00	65,80	0,32	28,00	0,11	9,16	0,22	18,84
Mud kitchen	24,00					65,80			0,07	6,48		
Mud pool	12,00	169,04	177,49			65,80			0,08	7,00		
TOTAL IRMA									**1,16**	**100,16**	**1,55**	**134,21**
BALANCE OF WASTE NATURAL HEALING SOURCE WATER AT COOLING SEDIMENTARY TANK												
Amount of waste natural healing source water - during the operation of balneotherapy										151,16		[m3*deň-1]
Amount of waste natural healing source water - during the out of the time operation of balneotherapy										83,21		[m3*deň-1]
Total for balneotherapy										**234,37**		[m3*deň-1]
Total for balneotherapy										**2,71**		[l*s-1]
BALANCE OF HOT NATURAL HEALING SOURCE WATER DURING THE OPERATION OF BALNEOTHERAPY												
Amount of collection NHS water out of the operation of Balneotherapy									**34,19**	[m^3*deň$^{-1}$]	**0,40**	[l*s^{-1}]
Amount of collection NHS water during the operation of Balneotherapy									**65,97**	[m^3*deň$^{-1}$]	**0,76**	[l*s^{-1}]
BALANCE OF COOLED NATURAL HEALING SOURCE WATER DURING THE OPERATION OF BALNEOTHERAPY												
Amount of collection NHS water out of the operation of Balneotherapy									**49,02**	[m^3*deň$^{-1}$]	**0,57**	[l*s^{-1}]
Amount of collection NHS water during the operation of Balneotherapy									**85,19**	[m^3*deň$^{-1}$]	**0,99**	[l*s^{-1}]

Table 4.6. shows in upper part the collection places list of the natural healing source of water, the time of its operation, basic technical properties, average daily temperature of the hot, cooled and mixed natural healing water including its daily average collection based on the expert decision from long-term analyzation. For energy evaluation the most important values are: [9]

- Temperature of NHS water at object: 65,8 °C
- Amount of hot NHS water at object: 1,16 l/s = 100,16 m^3/day
- Amount of cooled NHS water at object: 1,56 l/s = 134,21 m^3/day

Middle part of table shows the balance of the waste NHS water at the cooling sedimentary tank with the division into a balance at operation time and a balance out of operation time. For energy evaluation determined the amount of NHS water is 2,71 l/s = 234,37 m^3/day, based on expectation this amount of the NHS water collected in the Balneotherapy Irma is equal to the amount of water poured into sedimentary cooling tank. Average temperature was measured by the portable thermometer = to 38,2 °C. [22]

Table 4.7. Balance sheet of NHS - Balneotherapy Napoleón

Natural healing source of water collection places	Time	Pool surface area	Volume of the pool or healing devices	Temperature of mixed NHS water	Temperature of cooled NHS water	Temperature of hot NHS water	Amount of mixed NHS water		Amount of hot NHS water		Amount of cooled NHS water	
	[hours]	[m²]	[m³]	[°C]	[°C]	[°C]	[l*s⁻¹]	[m³*deň⁻¹]	[l*s⁻¹]	[m³*deň⁻¹]	[l*s⁻¹]	[m³*deň⁻¹]
Mirror pool man - water filling	1,5	27,185	32,6	41,20	23,10	67,40	0,68	58,60	0,28	23,94	0,40	34,66
Mirror pool man - water adding	10,5			45,10	23,10	67,40	0,09	7,98	0,05	3,96	0,05	4,02
Mirror pool woman - water filling	1,5	27,185	32,6	41,20	23,10	67,40	0,68	58,60	0,28	23,94	0,40	34,66
Mirror pool woman - water adding	10,5			45,10	23,10	67,40	0,09	7,98	0,05	3,96	0,05	4,02
Mirror pool + salt cave - water filling	1,5	29,283	35,13	41,20	23,10	67,40	0,71	61,30	0,29	25,05	0,42	36,25
Mirror pool + salt cave - water adding	6,5			45,10	23,10	67,40	0,10	8,25	0,05	4,10	0,05	4,15
RT hot tube + sauna	4	1,22	1,37		23,10	67,40			0,03	2,74		
Water treatment 120 proc./day	1,5											
15 x bathtubs			2,7	37,00	23,10	67,40	0,25	21,60	0,08	6,78	0,17	14,82
Mud pool	12	31,882	38,26			67,40			0,55	47,52		
TOTAL NAPOLEON									1,64	141,99	1,53	132,58

BALANCE OF WASTE NATURAL HEALING SOURCE WATER AT COOLING SEDIMENTARY TANK NAPOLEON				
Amount of waste natural healing source water - during the operation of balneotherapy		74,47	[m3*deň-1]	
Amount of waste natural healing source water - during the out of the time operation of balneotherapy		200,10	[m3*deň-1]	
Total for balneotherapy		274,57	[m3*deň-1]	
Total for balneotherapy		3,18	[l*s-1]	
BALANCE OF HOT NATURAL HEALING SOURCE WATER DURING THE OPERATION OF BALNEOTHERAPY				
Amount of collection NHS water during the operation of Balneotherapy	79,71	[m³*deň⁻¹]	0,92	[l*s⁻¹]
Amount of collection NHS water out of the operation of Balneotherapy	62,28	[m³*deň⁻¹]	0,72	[l*s⁻¹]
BALANCE OF COOLED NATURAL HEALING SOURCE WATER DURING THE OPERATION OF BALNEOTHERAPY				
Amount of collection NHS water out of the operation of Balneotherapy	120,39	[m³*deň⁻¹]	1,39	[l*s⁻¹]
Amount of collection NHS water during the operation of Balneotherapy	12,19	[m³*deň⁻¹]	0,14	[l*s⁻¹]

Table 4.7. shows in upper part the collection places list of the natural healing source of water, time of its operation, basic technical properties, average daily temperature of the hot, cooled and mixed natural healing water including its daily average collection based on the expert decision from long-term analyzation. For energy evaluation the most important values are: [9]

- Temperature of NHS water at object: 67,4 °C
- Amount of hot NHS water at object: 1,64 l/s = 141,99 m^3/day
- Amount of cooled NHS water at object: 1,53 l/s = 132,58 m^3/day

Middle part of table shows a balance of the waste NHS water at the cooling sedimentary tank with the division into a balance at operation time and a balance out of operation time. For energy evaluation determined the amount of NHS water is 3,18 l/s = 274,57 m^3/day, based on the expectation that the amount of the NHS water collected in the Balneotherapy Napoleón is equal to the amount of water poured into the sedimentary cooling tank. [9]

Bottom part of table shows a balance of collective hot and cooled NHS water at the Balneotherapy, divided into two parts: during and out of operation time. [9]

- Amount of collection hot NHS water out of the operation: 0,72 l/s
- Amount of collection hot NHS water during the operation: 0,92 l/s
- Amount of collection cooled NHS water during the operation: 0,14 l/s
- Amount of collection cooled NHS water out of the operation: 1,39 l/s

Table 4.8. Balance sheet of NHS Balneotherapy Pro Patria

Natural healing source of water collection places	Time	Pool surface area	Volume of the pool or healing devices	Temperature of mixed NHS water	Temperature of cooled NHS water	Temperature of hot NHS water	Amount of mixed NHS water		Amount of hot NHS water		Amount of cooled NHS water	
	[hours]	[m^2]	[m^3]	[°C]	[°C]	[°C]	[l*s^{-1}]	[m^3*deň$^{-1}$]	[l*s^{-1}]	[m^3*deň$^{-1}$]	[l*s^{-1}]	[m^3*deň$^{-1}$]
Mirror pool man - water filling	1,5	20,75	16,08	40,50	23,10	67,10	0,27	23,40	0,11	9,25	0,16	14,15
Mirror pool man - water adding	8			49,50	23,10	67,10	0,07	5,74	0,04	3,44	0,03	2,30
Mirror pool woman - water filling	1,5	20,75	16,08	40,50	23,10	67,10	0,27	23,40	0,11	9,25	0,16	14,15
Mirror pool woman - water adding	8			49,50	23,10	67,10	0,07	5,74	0,04	3,44	0,03	2,30
Mud kitchen	24					67,10			0,08	7,02		
Showers man - 8x	1,2			37,00	23,10	67,10	0,07	6,41	0,02	2,02	0,05	4,39
Showers woman - 8x	1,2			37,00	23,10	67,10	0,07	6,41	0,02	2,02	0,05	4,39
Water treatment 52 proc./day	5,2											
4 x bathtubs LAGUNA PUBBLE			1,04	36,52	23,10	67,10	0,16	13,52	0,05	4,12	0,11	9,40
Bathtubes treatment 28 proc./day	2,6											
2 x bathtubs OCEÁN FORTE			0,56	36,52	23,10	67,10	0,03	3,02	0,01	0,92	0,02	2,10
Mud pool	24			43,80	23,10	67,10	1,01	86,90	0,47	40,88	0,53	46,02
TOTAL PRO PATRIA									**0,95**	**82,39**	**1,15**	**99,17**

BALANCE OF WASTE NATURAL HEALING SOURCE WATER AT COOLING SEDIMENTARY TANK PRO PATRIA				
Amount of waste natural healing source water - during the operation of balneotherapy		134,76		[m3*deň-1]
Amount of waste natural healing source water - during the out of the time operation of balneotherapy		46,80		[m3*deň-1]
Total for balneotherapy		**181,56**		[m3*deň-1]
Total for balneotherapy		**2,10**		[l*s-1]
BALANCE OF HOT NATURAL HEALING SOURCE WATER DURING THE OPERATION OF BALNEOTHERAPY				
Amount of collection NHS water out of the operation of Balneotherapy	**18,51**	[m^3*deň$^{-1}$]	**0,21**	[l*s^{-1}]
Amount of collection NHS water during the operation of Balneotherapy	**63,89**	[m^3*deň$^{-1}$]	**0,74**	[l*s^{-1}]
BALANCE OF COOLED NATURAL HEALING SOURCE WATER DURING THE OPERATION OF BALNEOTHERAPY				
Amount of collection NHS water out of the operation of Balneotherapy	**28,29**	[m^3*deň$^{-1}$]	**0,33**	[l*s^{-1}]
Amount of collection NHS water during the operation of Balneotherapy	**70,87**	[m^3*deň$^{-1}$]	**0,82**	[l*s^{-1}]

Table 4.8. shows in the upper part collection places list of the natural healing source of water, time of its operation, basic technical properties, average daily temperature of the hot, cooled and mixed natural healing water including its daily average collection based on the expert decision from long-term analyzation. For energy evaluation the most important values are: [9]

- Temperature of NHS water at object: 67,1 °C
- Amount of hot NHS water at object: 0,95 l/s = 82,3 m^3/day
- Amount of cooled NHS water at object: 1,15 l/s = 99,17 m^3/day

Middle part of table shows a balance of the waste NHS water at the cooling sedimentary tank with the division into a balance at operation time and a balance out of operation time. For energy evaluation determined the amount of NHS water is 2,10 l/s = 181,56 m^3/day, based on expectation that the amount of the NHS water collected in the Balneotherapy is equal to the amount of water poured into cooling tank. [9]

Bottom part of table shows a balance of collective hot and cooled NHS water at the Balneotherapy, divided into two parts: during and out of operation time.

- Amount of collection hot NHS water out of the operation: 0,21 l/s
- Amount of collection hot NHS water during the operation: 0,74 l/s
- Amount of collection cooled NHS water during the operation: 0,33 l/s
- Amount of collection cooled NHS water out of the operation: 0,82 l/s

Table 4.9. Balance sheet of NHS - Balneotherapy Balnea Centrum

Natural healing source of water collection places	Time	Volume of the pool or healing devices	Temperature of mixed NHS water	Temperature of cooled NHS water	Temperature of hot NHS water	Amount of mixed NHS water		Amount of hot NHS water		Amount of cooled NHS water	
	[hours]	[m^3]	[°C]	[°C]	[°C]	[l*s^{-1}]	[m^3*deň$^{-1}$]	[l*s^{-1}]	[m^3*deň$^{-1}$]	[l*s^{-1}]	[m^3*deň$^{-1}$]
Mirror pool man - water filling	11,49	80,9	40,50	22,10	54,50	1,47	126,90	0,83	72,07	0,63	54,83
Mirror pool man - water adding	9,11		48,90	22,10	51,30	0,87	75,40	0,80	69,20	0,07	6,20
Mirror pool woman - water filling	11,49	80,9	40,50	22,10	54,50	1,47	126,90	0,83	72,07	0,63	54,83
Mirror pool woman - water adding	9,11		48,90	22,10	51,30	0,87	75,40	0,80	69,20	0,07	6,20
Mud kitchen	24				54,50			0,08	6,92		
Tractions man - water filling	10	19,41	37,21	22,10	54,50	0,30	25,90	0,14	12,08	0,16	13,82
Tractions man - water adding	10,5		37,21	22,10	50,89	0,06	5,30	0,03	2,78	0,03	2,52
Tractions woman - water filling	10	19,41	37,21	22,10	54,50	0,30	25,90	0,14	12,08	0,16	13,82
Tractions woman - water adding	10,5		37,21	22,10	50,89	0,06	5,30	0,03	2,78	0,03	2,52
Water treatment 285 proc./day	2,25										
23 x bathtubs LAGUNA PUBBLE		5,98	36,52	22,10	54,50	0,86	74,10	0,38	32,98	0,48	41,12
Bathtubs treatment 315 proc./day	2,25										
10 x bathtubs OCEÁN FORTE		2,8	36,52	22,10	54,50	0,38	33,04	0,17	14,70	0,21	18,34
16 x bathtubs VOD 56		5,92	36,52	22,10	54,50	0,87	74,86	0,39	33,32	0,48	41,54
Drinking fountain of NHS water	24				52,80			0,08	6,91		
TOTAL BALNEA CENTRUM								**4,71**	**407,09**	**2,96**	**255,74**

BALANCE OF WASTE NATURAL HEALING SOURCE WATER AT COOLING SEDIMENTARY TANK BALNEA CENTRUM		
Amount of waste natural healing source water - during the operation of balneotherapy	357,23	[m3*deň-1]
Amount of waste natural healing source water - during the out of the time operation of balneotherapy	305,60	[m3*deň-1]
Total Balnea Centrum	**662,83**	[m3*deň-1]
Total Balnea Centrum	**7,67**	[l*s-1]

BALANCE OF HOT NATURAL HEALING SOURCE WATER DURING THE OPERATION OF BALNEOTHERAPY				
Amount of collection NHS water out of the operation of Balneotherapy	**168,29**	[m^3*deň$^{-1}$]	**1,95**	[l*s^{-1}]
Amount of collection NHS water during the operation of Balneotherapy	**238,80**	[m^3*deň$^{-1}$]	**2,76**	[l*s^{-1}]

BALANCE OF COOLED NATURAL HEALING SOURCE WATER DURING THE OPERATION OF BALNEOTHERAPY				
Amount of collection NHS water out of the operation of Balneotherapy	**137,31**	[m^3*deň$^{-1}$]	**1,59**	[l*s^{-1}]
Amount of collection NHS water during the operation of Balneotherapy	**118,43**	[m^3*deň$^{-1}$]	**1,37**	[l*s^{-1}]

Table 4.9. shows in the upper part collection places list of the natural healing source of water, time of its operation, basic technical properties, average daily temperature of hot, cooled and mixed natural healing water including its daily average collection based on the expert decision from long-term analyzation. For energy evaluation the most important values are: [9]

- Temperature of NHS water at object: 54,5 °C
- Amount of hot NHS water at object: 4,71 l/s = 407,09 m^3/day
- Amount of cooled NHS water at object: 2,96 l/s = 255,74 m^3/day

Middle part of table shows a balance of the waste NHS water at the cooling sedimentary tank with the division into a balance at operation time and a balance out of operation time. For energy evaluation determined the amount of NHS water is 7,67 l/s = 662,83 m3/day, based on expectation that amount of the NHS water collected in the Balneotherapy is equal to the amount of water poured into cooling tank. [9]

- Amount of collection hot NHS water out of the operation: 1,95 l/s
- Amount of collection hot NHS water during the operation : 2,76 l/s
- Amount of collection cooled NHS water during the operation: 1,59 l/s
- Amount of collection cooled NHS water out of the operation: 1,37 l/s

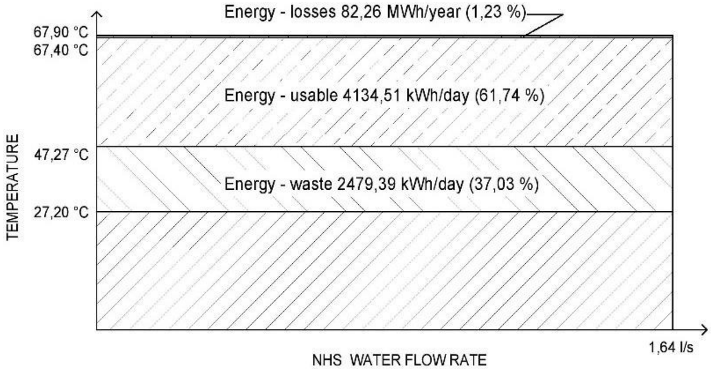


Chart 4.19. Energetic balance of Balneotherapy Napoleón

Chart 4.19. shows an energetic balance of the Balneotherapy Napoleón, where first part refers to an energetic losses at the distributive natural healing water – 1,23 % from the theoretical energetic usage, second part refers to the consumption of an energy during the operation of Balneotherapy – 61,74 %, third part refers to a energy, which is lost at the sedimentary cooling tank – 37,03 %. [9]

Table 4.10. Total energy balance of Balneotherapy Pro Patria

Theoretical energy losses	244,14	[kWh/day]
Theoretical energy usable	3 050,64	[kWh/day]
Theoretical energy waste	1 541,60	[kWh/day]
Theoretical energy	4 836,39	[kWh/day]
Theoretical efficiency energy losses	5,05	[%]
Theoretical efficiency energy usable	63,08	[%]
Theoretical efficiency energy waste	31,88	[%]

Table 4.10. shows current using ratio of the energy heat losses at the Balneotherapy Pro Patria based on average values, which were obtained by the experimental measurement and consultation with the Slovak Health Spa a.s. Piešťany.

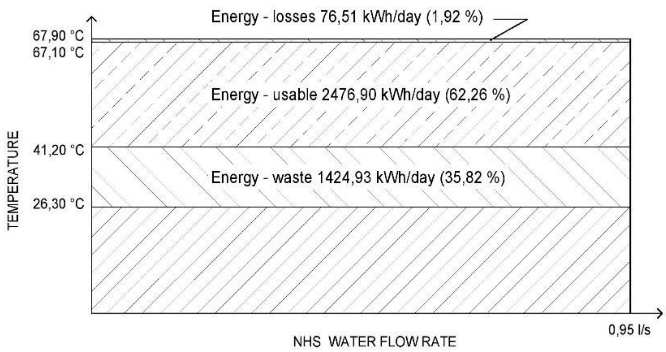


Chart 4.20. Energetic balance of Balneotherapy Pro Patria

Chart 4.20. shows an energetic balance of Balneotherapy Pro Patria, where first part refers to the energetic losses at the distributive natural healing water – 1,92 % from theoretical energetic usage, second part refers to the consumption of an energy during the operation of Balneotherapy – 62,26 %, third part refers to an energy, which is lost at the sedimentary cooling tank – 35,82 %. [9]

Table 4.11. Total energy balance of Balneotherapy Balnea Centrum

Theoretical energy losses	6 331,68	[kWh/day]
Theoretical energy usable	6 969,57	[kWh/day]
Theoretical energy waste	6 591,56	[kWh/day]
Theoretical energy	19 892,81	[kWh/day]
Theoretical efficiency energy losses	**31,83**	[%]
Theoretical efficiency energy usable	**35,04**	[%]
Theoretical efficiency energy waste	**33,14**	[%]

Table 4.11. shows current using ratio of the energy heat losses at the Balneotherapy Balnea Centrum based on average values, which were obtained by the experimental measurement and consultation with the Slovak Health Spa a.s. Piešťany.

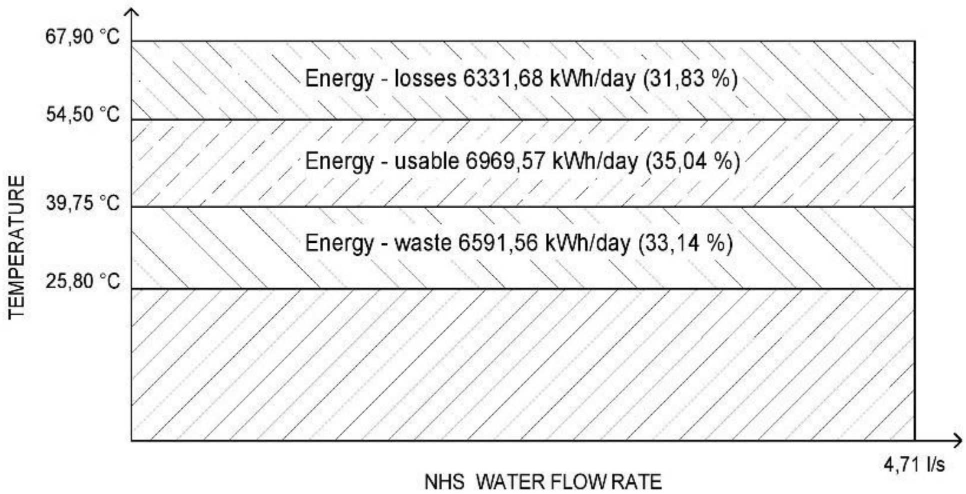


Chart 4.21. Energetic balance of Balneotherapy Balnea Centrum

Chart 4.21. shows an energetic balance of the Balneotherapy Balnea Centrum, where first part refers to an energetic losses at the distributive natural healing water – 31,83 % from theoretical an energetic usage, second part refers to a consumption of energy during the operation of Balneotherapy – 35,04 %, third part refers to an energy, which is lost at the sedimentary cooling tank – 33,14 %. [9]

4.1.8. Slovak Health Spa Piešťany a.s. – energy overall evaluation

Operation of the Balneotherapy in the SLKP a.s is complicated accumulation and distribution system. For this purpose, was elaborated the current state overall analyzation. Table 4.12. concerns all partial analyzation stated before and provide results of measurements. Based on the measured data and analyzation it is possible to say that for operation of the Balneotherapy and other collection places, is necessary to accumulate 731,64 m^3/day of the hot NHS water and 621,69 m^3/day of the cooled NHS water.

Table 4.12. Overall analyzation of SLKP a.s.

NHS water collection places		Temperature of NHS water at entry of objects	Amount of hot NHS water at entry of objects				% ratio of hot NHS water	Temperature of cooled NHS water at entry of objects	Amount of cooled NHS water at entry of objects				% ratio of cooled NHS water
		[°C]	[l*s^{-1}]	[m^3*deň$^{-1}$]	[l*s^{-1}]	[m^3*deň$^{-1}$]	[%]	[°C]	[l*s^{-1}]	[m^3*deň$^{-1}$]	[l*s^{-1}]	[m^3*deň$^{-1}$]	[%]
BALNEOTHERAPY IRMA	During the oeration	65,80	1,16	100,16	0,40	34,19	8,04	23,00	1,55	134,21	0,57	49,02	27,43
	Out of the operation				0,76	65,97					0,99	85,19	
BALNEOTHERAPY NAPOLEÓN	During the oeration	67,40	1,64	141,99	0,72	62,28	11,39	23,10	1,53	132,58	0,14	12,19	27,10
	Out of the operation				0,92	79,71					1,39	120,39	
BALNEOTHERAPY PRO PATRIA	During the oeration	67,10	0,95	82,39	0,74	63,89	6,61	23,10	1,15	99,17	0,82	70,87	20,27
	Out of the operation				0,21	18,51					0,33	28,29	
BALNEOTHERAPY BALNEA CENTRUM	During the oeration	54,50	4,71	407,09	2,76	238,80	23,45	22,10	2,96	255,74	1,37	118,43	52,27
	Out of the operation				1,95	168,29					1,59	137,31	
Total amount of NHS water at Balneotherapy during the operation					4,62	399,16					2,90	250,51	
Total amount of NHS water at Balneotherapy out of the operation					3,85	332,48					4,29	371,18	
Total for Balneotherapy			8,47	731,64			42,15			621,69			127,07
Other collection places	Drinking fountains 4 ks	45,60	0,20	17,28			29,67						-27,07
	Ripening mud pools	65,20	5,23	452,01									
	Accumulation tanks		0,29	25,00					-1,53	-132,43			
	Swimming pool EVA		0,15	12,80									
	Outer swimming pool Thermia Palace		0,09	7,85									
Total for Balneotherapy and other collection places			5,96	1 246,58			71,81						
Korobon heat exchanger			5,66	489,26			28,19		5,66	489,26			100,00
Total for accumulation station		67,90	20,09	1 735,84			100,00						

Current accumulation system – the Korobon heat exchanger is able to accumulate 489,26 m^3/day of the cooled NHS water, which is less than total amount of the cooled NHS water daily used in operation of the Balneotherapy. This water amount difference is currently solved by the accumulation of cooled and hot NHS water in the accumulation tanks from where is transporting to the Balneotherapy in case of higher water amount demand. [9]

4.1.9. Evaluation of technical solution - the proposed state

Reconstruction is based on the project documentation "Modernizing and enhancing the performance of the accumulation station technology with the waste heat utilization " projected by doc. Ing. Marian Mikulík, PhD. November 2016 in which the main objectives are to enhance the performance insufficiency (failure to achieve the necessary fluid parameters), maximize the energy potential of hot water with a temperature of approx. 55 °C such as waste heat obtained from cooling the natural healing water in the accumulation station and thus reduce the costs of primary energy sources, providing and heating of hot water, hot relaxation pools and energy cost savings at Balneotherapy departments. Reconstruction is divided into two stages. First stage takes into account the cooled natural healing water capacity enhancement by technology devices optimization at existing accumulation station. [9]

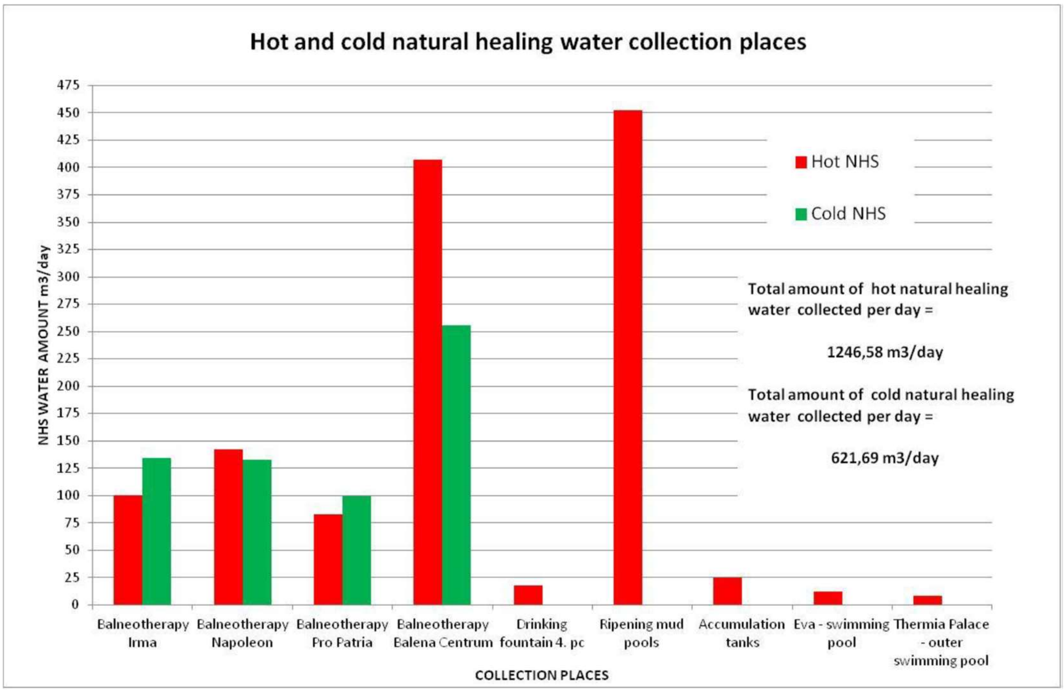


Chart 4.22. The consumption amount of hot and cooled natural healing water

The project first stage includes the completion of the existing system of accumulation stations with two parallel-connected titanium plate heat exchangers from Alfa-Laval A4QLP certificate AHRI 400, each with a rated output of 1000 kW and reconstruction of existing natural healing water pipelines distribution. [9]

The project second stage involves the application of energy management in the form of:

- Inclusion the sensory measurement of temperature and flow rate of hot natural healing water (NHS)

- NHS water level measurement at accumulation tanks
- The pressure measurement of the compressed air at the accumulation containers
- Measuring the amount, flow rate, temperature, water level and conductivity of NHS drills and well
- Measurement of the flow rate and the water quantity amount processing to the SLKP a.s. objects
- Fault states at accumulation station (maximum levels in accumulation tanks, engine room flooding and loss of electric energy)
- Power control, start/stop, operating and fault frequency well converters, well pumps
- Operation of 16 collection places at SLKP a.s. by water management and measuring and regulating throttle assemblies
- AQUA DISPATCHING:
    - ♦ Monitoring of actual temperatures at NHS water distributor by RIKZ
    - ♦ Monitoring of current flow rate, water level and conductivity NHS water distributor by RIKZ

4.1.10. Proposed solution – assessment

Based on the results of experimental analysis and processed project is the involvement of titanium plate type heat exchangers A4QLP with certificate AHRI 400 unsuitable solution due to mineral sedimentation that, if the solution will be implemented, have to be removed by chemical substances. A suitable solution is proposal SGL Group, which built the existing graphite block heat exchanger Korobon.

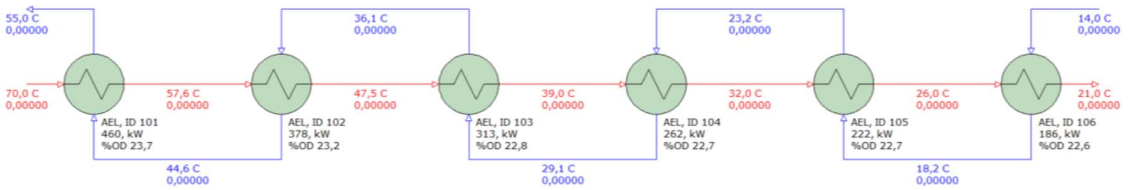
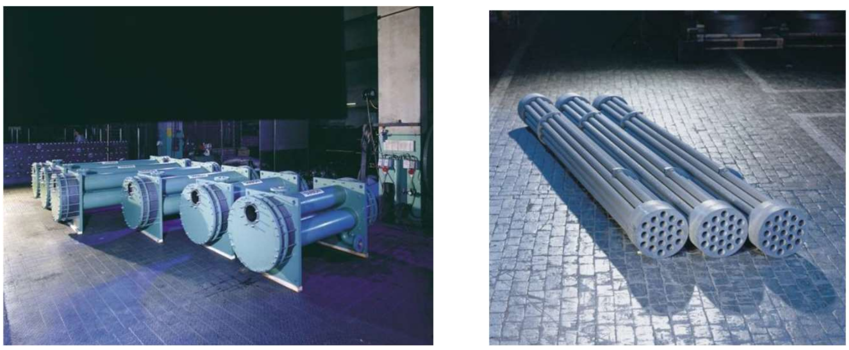


Chart 4.23. Schematic representation of the natural healing water cooling processes



Picture 4.26 DIABON Shell and Tube Heat Exchanger

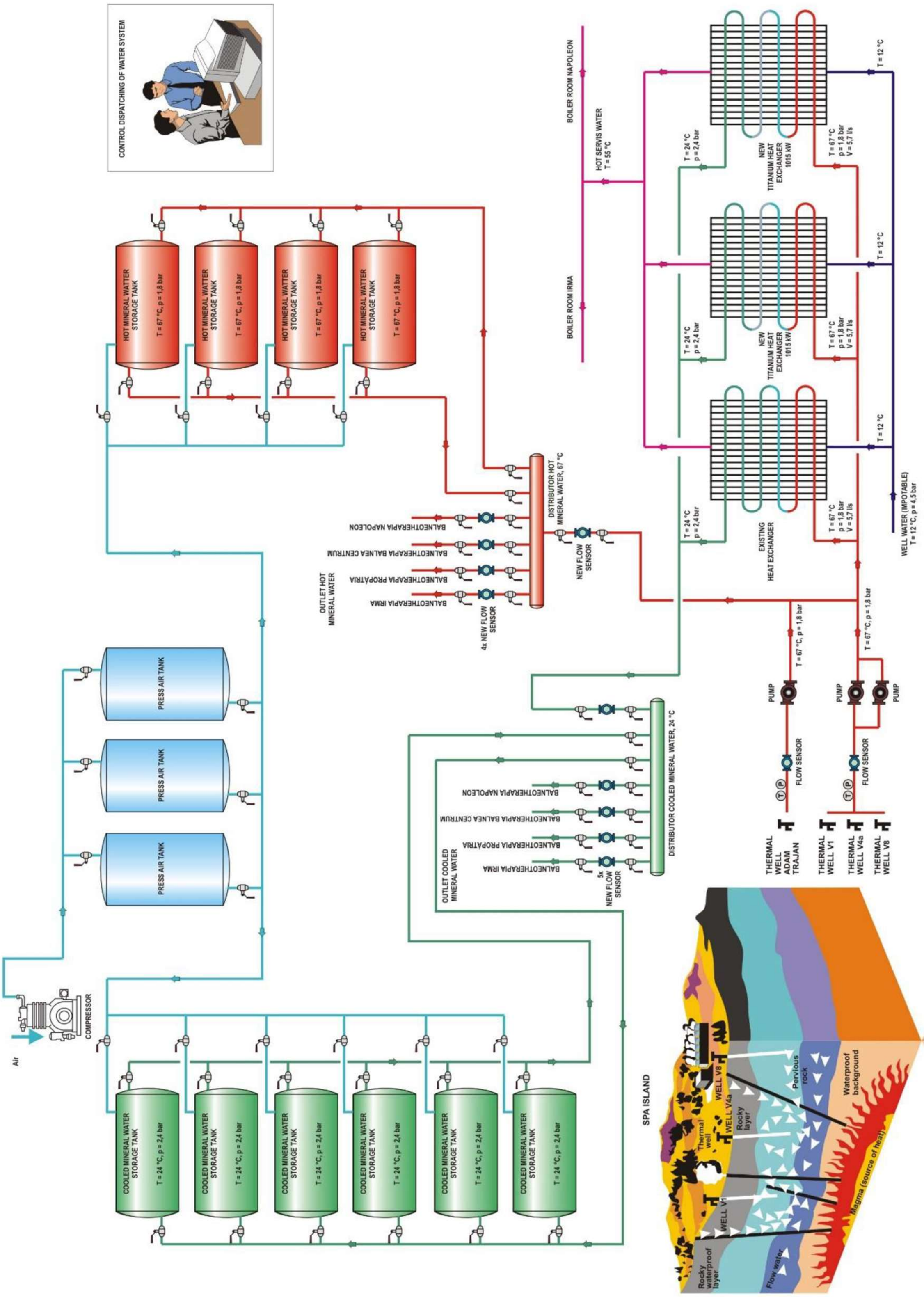


Chart 4.24. Scheme of accumulation station – designed solution [9]

4.1.11. Experimental solution – Design for reconstruction of accumulation station

Based on long term experimental analysis, reconstruction of accumulation station was executed in two stages during the full operation of Spa Piestany AS to ensure smooth operation of Balneotherapy and other collection places. First stage Based on experimentally calculated and simulated model, final decision based on multicriterial analysis was to compare four products based on several assumptions. To each variant cooperation with heat exchanger company was established to obtain best possible result for reconstruction of accumulation station:

Variant input:

- Variant A – plate heat exchanger (Stainless steel)
- Variant B – plate heat exchanger (Titanium steel)
- Variant C – plate heat exchanger (Carbon steel)
- Variant D – graphite tube heat exchanger (Carbon steel)

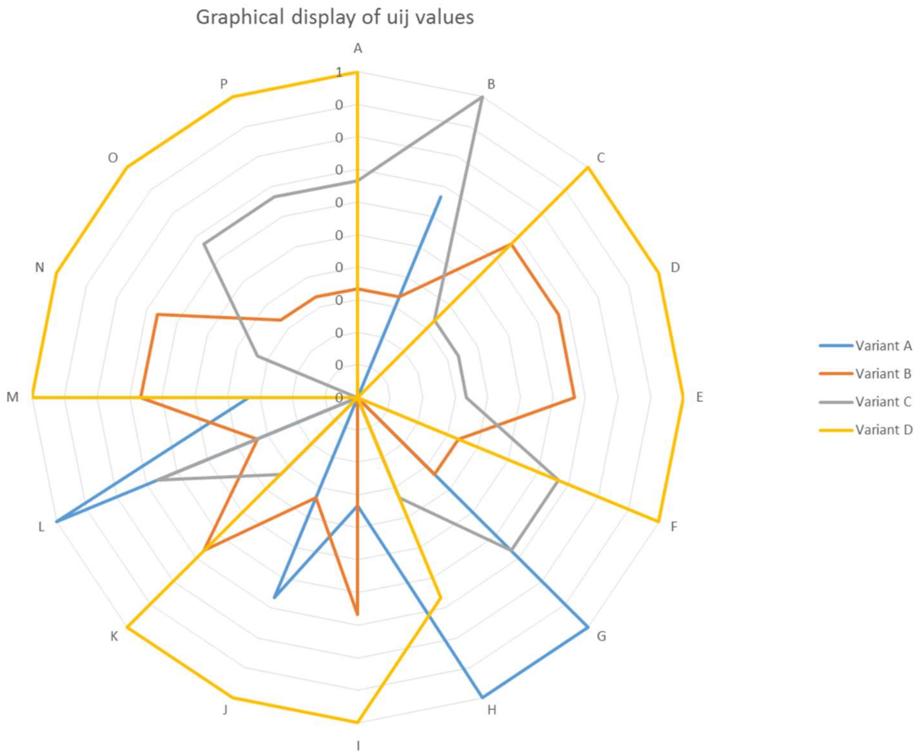


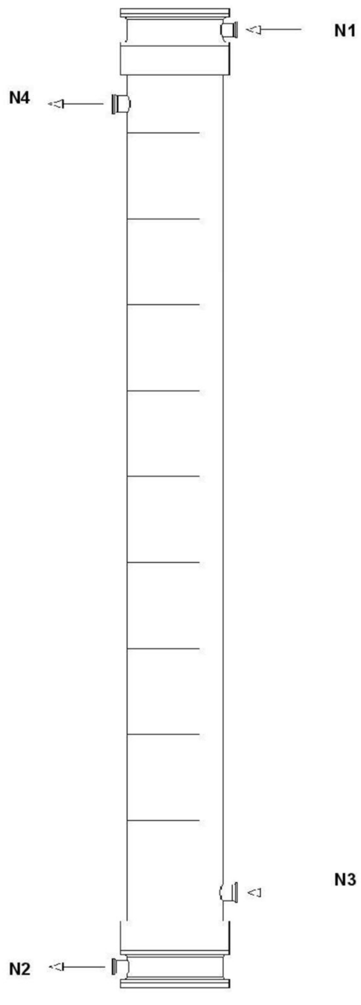
Chart 4.25 Graphical displaying partial variants usefulness values uij

Where criteria A. Material (chosen because each material has different durability in NHS water), B. Estimated price (total costs for purchasing), C. Experience in operation (SLKP a.s. experience in operation of heat exchanger from long-term point of view), D. Possibility of cleaning, E. Ability and ease of future expansion, F. Width, G. Length, H. Height, I. Heat transfer area, J. Maximum design temperature, K. Minimum design temperature, L. Maximum working pressure, M. Maximum flow rate, N. Minimum flow rate, O. Calcium sedimentation (Aggressive water in SLKP a.s. and its sedimentation at given material according to boundary conditions), P. Sulfur sedimentation (Aggressive water in SLKP a.s. and its sedimentation at given material according to boundary conditions).

Based on experimental analysis and long-term knowledge multi-criteria analysis showed as a optimal solution Variant D – Graphite tube heat exchanger from company SGL group.

sgl carbon

Shell and Tube Heatexchanger	Offer number:	14213168
RS77-1-61.60.1	Date:	27.11.2018
	Data sheet:	3168.2 Rev01



Principle Sketch

Design data		Tube side	Shell side
Operating Pressure	bar g	3	3
Operating Temperature	°C	70 / 21	14 / 55
Design Pressure	bar g	-1 / 6	-1 / 6
Design Temperature	°C	-10 / 100	-10 / 80

Design Code	AD 2000
Flange Connection	ISO DIN PN16

Nozzle	Description	DN
N1	Thermal Water IN	80
N2	Thermal Water OUT	80
N3	Service Water IN	100
N4	Service Water OUT	100

DIMENSIONS AND WEIGHT			
Volumes	~	155 / 450	dm3
Diameter	~	418	mm
Total Length	~	7000	mm
Weight (empty)	~	1100	kg
Weight (water filled)	~	1705	kg

Material	
Shell	rubberlined P265GH
Tube bundle	DIABON Graphite with Carboguard Wrapping
Headers	rubberlined P265GH

PAINTING
Samdblasting: Sa 2 ½ (EN ISO 12944-4)
Primer: Base coat with 1-component epoxy zinc primer (80 µm)
Each dry film thickness: 40 µm

REMARK
All sizes and weights are based for one RS77-1-61.60.1 without piping and support.

Datum:	27.11.2018
Erstellt:	Ch. Leuschner

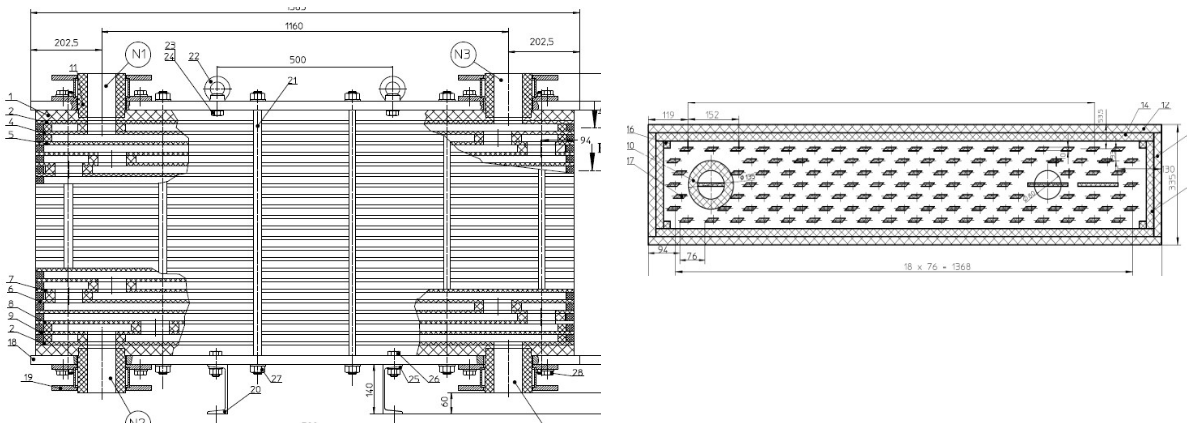
Picture 4.27. Graphite tube heat exchanger

4.1.12. Experimental solution – Simulation of Korobon heat exchanger and graphite heat exchanger

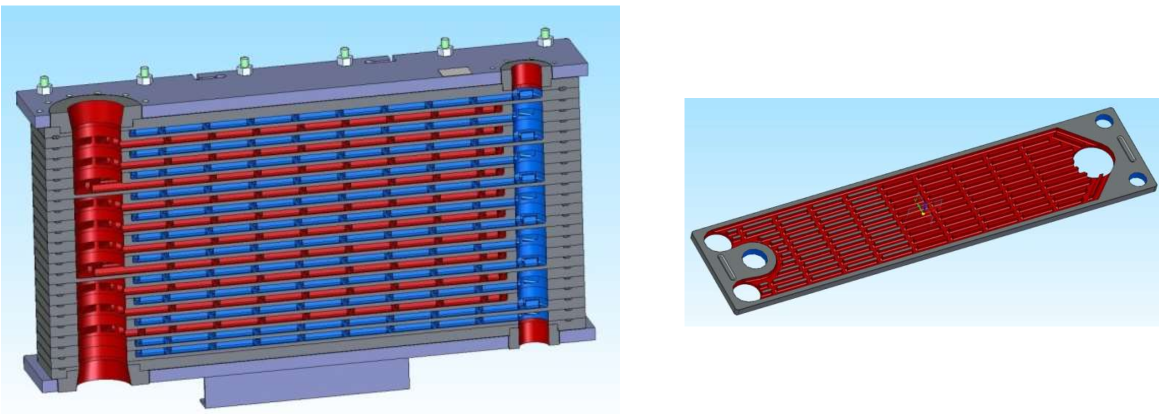
For efficiency maximalization in utilization of renewable energy from natural healing source of water, in cooperation with SGL group company where developed several simulations describing heat transfer within current technological solution – Korobon graphite heat exchanger and proposal solution with graphite tube heat exchanger and its variant GHX graphite heat exchanger.

Simulation was based on real time measurement provided at Slovak Health Spa accumulation station which were continuously held for more than year. This data provide strong base for description of current status and determined future behavior of designed system.

Due to SGL group company and Slovak Health Spa Piestany a.s. regulations and protection of products it is not possible to publish detailed simulations or results or in any way reveal obtained results Picture 4.28. and 4.29..



Picture 4.28. Scheme of proposal solution with GHX heat exchanger



Picture 4.29. Computer analyzation basic model

4.1.13. Experimental solution – reconstruction of accumulation station

Statistical determination shows efficient growth in popularity of spa treatments at SLKP as Piestany which are becoming world known for its cure for rheumatological diseases. Based on previous experimental analysis and research, Slovak Health Spa Piestany a.s. decided to make investigation into revitalization of accumulation station on "spa island" as this technological device is heart of spa. The decision was made mainly due to research at Brno University of Technology – Faculty of civil engineering, where the experimental research was on going for more than seven years. Reconstruction of accumulation station consist of several patrial reconstructions – which were planned in order not to affect full operation of Balneotherapy.

There were four main operations:

- Transport and assembling new graphite heat exchanger – This was crucial part as the graphite heat exchanger were designed and manufactured in Germany and transported in six pieces to Slovak Health Spa Piestany. These parts cannot be disassembled so new gateway to accumulation station had to be created
- Increasing pump efficiency at accumulation station - This was second step in order to the obtain efficient flow rate for assembling new heat exchanger, where 4 new pumps were necessary to assemble
- Revitalization of current pipeline system - As experimental analysis show that there is nominal sedimentation due to old age of pipe and effect of sulfuric composition of natural healing water.
- Automatization of accumulation station (planned 2023) in order to obtain maximal effectiveness in procession of natural healing, new Aqua management was elaborated with possibility of distance parameters analyzation and fully automatic correction in real time.

4.1.13.1. Transport and assembling of graphite heat exchanger

Project documentation for reconstruction and revitalization of accumulation station was finished in winter 2019 on which was placed order for manufacturing 6 pieces of graphite heat exchanger from SGL Group company. Delivery was done according to the plan in July 2020. Due to Corona pandemic progress in revitalization and reconstruction of accumulation station was stopped and begin again in summer 2021. Pandemic has negative effect on travelling and hospitality, but in same way the demand for hot natural healing water was lower to minimum, which allowed Slovak health spa to faster proceed with reconstruction. All part for new graphite heat exchanger was fully delivered in September 2020. Overall status for production is shown in official report from SGL Group company in Table 4.13..

Table 4.13. Production and delivery plan

Report date:
13.01.2020

MANUFACTURING PROGRESS REPORT
SUPPLIER : SGL Carbon GmbH
MONTH : 2020/01
Order number: 374/09/19/SLKP

Purchase order

CIP Delivery 30.04.20

Original plan, readiness percentage
Current forecast, readiness percentage
Actual situation, readiness percentage

		2019			2020								
Situation at End of Calendar month		10	11	12	1	2	3	4	5	6	7	8	9
Situation at End of Delivery months		1	2	3	4	5	6	7	8	9	10	11	12
		Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
		Engineering			Production								
6x THX - Engineering & Manufacturing, Original plan		5	10	20	25	30	50	80	100	100	100	100	100
6x THX - Engineering & Manufacturing, Current forecast		0	10	20	25	30	50	80	100	100	100	100	100
6x THX - Engineering & Manufacturing, Actual		5	8	20	22	22	22	22	22	22	22	22	22
Weighted value %	100,0												
Weighted value %	0,0												
Total weighted value, %	100,0												
Summary Engineering & Manufacturing, Original plan		**5**	**10**	**20**	**25**	**30**	**50**	**80**	**100**	**100**	**100**	**100**	**100**
Summary Engineering & Manufacturing, Current forecast		**0**	**10**	**20**	**25**	**30**	**50**	**80**	**100**	**100**	**100**	**100**	**100**
Summary Engineering & Manufacturing, Actual		**5**	**8**	**20**	**22**	**22**	**22**	**22**	**22**	**22**	**22**	**22**	**22**
Shipping, Planned		**0**	**0**	**0**	**0**	**0**	**0**	**0**	**100**	**100**	**100**	**100**	**100**
Shipping, Forecast		**0**	**0**	**0**	**0**	**0**	**0**	**0**	**100**	**100**	**100**	**100**	**100**
Shipping, Actual													

Due the fact, that graphite heat exchanger was exported and transported in six parts which cannot be disassembled and to prevent any damage on sensitive part, preparation for transport had to be done in advance. Original building was constructed in 1940, where all oversized technological devices were placed in before roof was closed. This operation included revitalization of accumulation station with new architectonic design, which for future allows Slovak Health Spa Piestany effectively in transport and out transport all technological devices in case of future extension. The architectural proposal was to create new gate way 8m x 5m based on size evaluation of technological devices placed inside building and creating new foundations from reinforcement concrete to meet criteria for weight limits. After all preparation operations were fully completed, follows actual in transport of new technological devices and assembling on right location within building. Mounting and assembling of new heat exchanger was under full control of SGL Group as a main subcontractor. Transport and assembling of graphite heat exchanger is shown in Picture 4.29. and Picture 4.30..

Picture 4.29. In transport of new graphite heat exchanger and proposal architectonic design

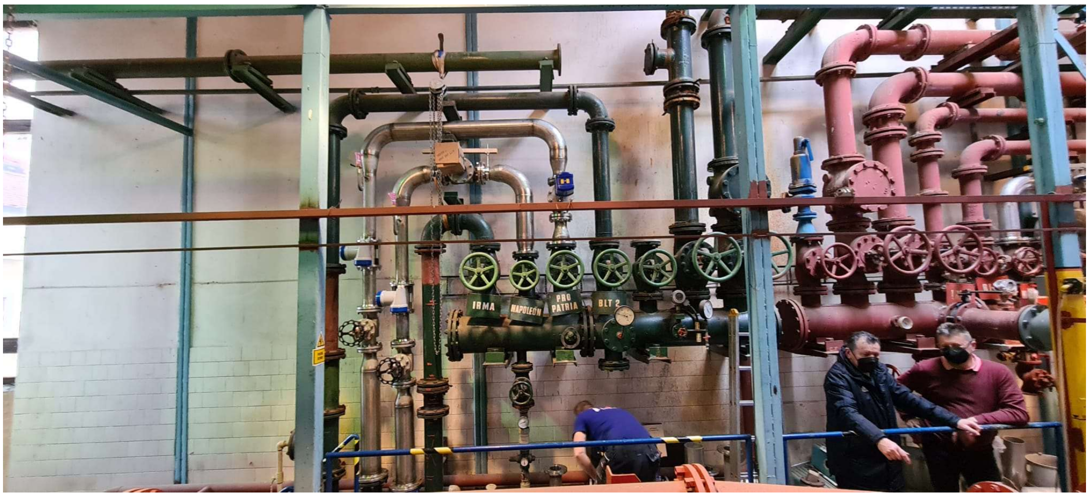
Picture 4.30. Assembling of new graphite heat exchanger

4.1.13.2. Increasing pump efficiency at accumulation station

Due to the fact, that all technological devices in accumulation station supporting processing of natural healing water were outdated, Slovak Health Spa AS Piestany decided based on recommendation of Brno University of Technology – faculty of Civil Engineering in elaborated report “The assessment of the changes effectiveness at accumulation station technology for natural healing water source sustainable development with the impact on thermal economy at Slovak Health Spa Piešťany” to make investment to obtain efficient processing of natural healing water. This investment consists of revitalization of pumping system with 5 new water pumps, which substitute old ones. All pumps had to meet criteria to work in condition with contact with mineral water with high amount of sulphur. Partial revitalization is shown in Picture 4.31..

Picture 4.31. Partial revitalization of pumping system

4.1.13.3. Revitalization of current pipeline system



Picture 4.32. Revitalization of distribution system for natural healing water

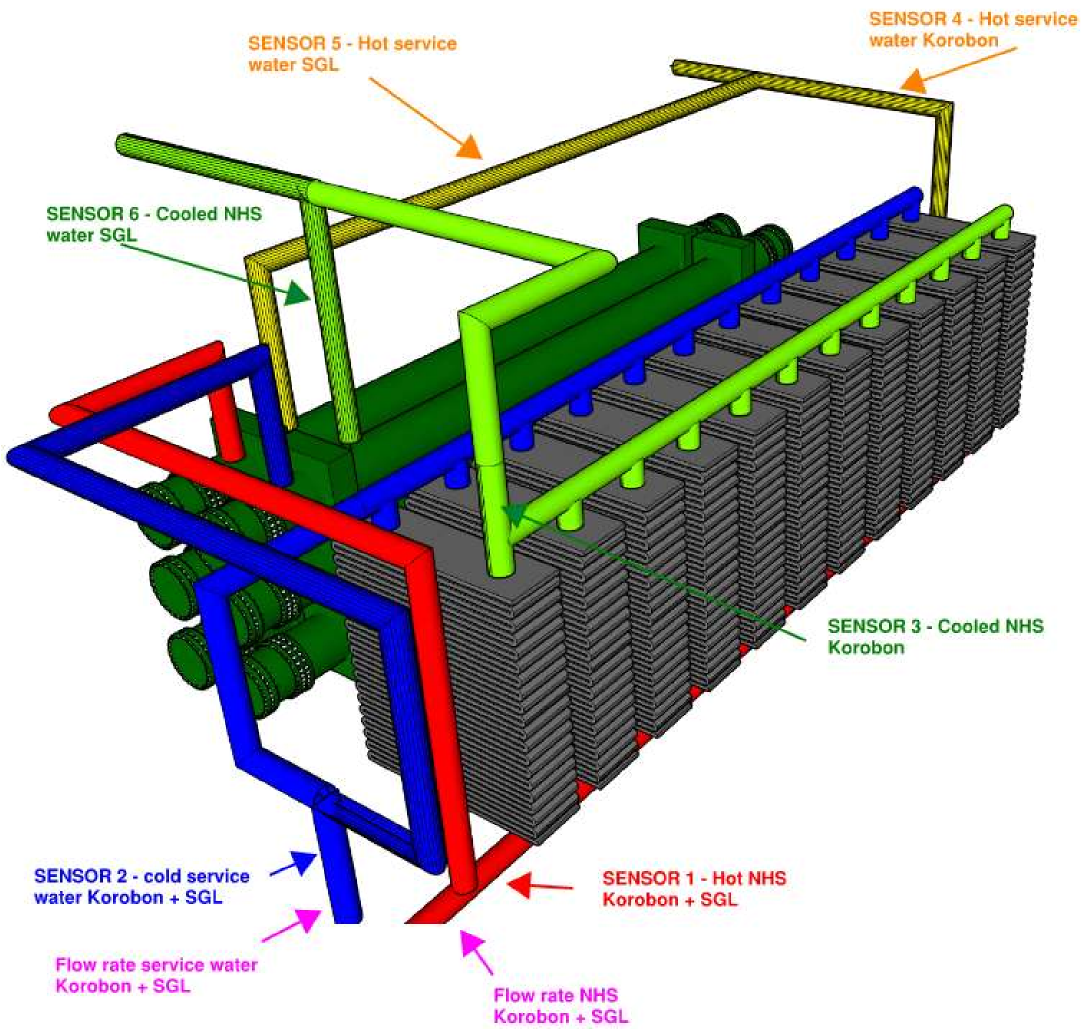
Experimental analysis of flow rate was not possible to be executed with ultrasonic flow meter, due to high mineral sedimentation inside the pipeline system – detailed analyzation is described in previous chapter. Based on project documentation finished in winter 2019 – all water distribution system within accumulation station were renewed. Due to the full operation of Balnotherapy during the revitalization of pipelines network construction meet tight time schedule for finishing all works. This part of reconstruction was mainly elaborated during the nights, when the Balneotherapy was closed which results in extra economy costs due to overtime of workers. Main importance was to primary reconstruct distribution network to biggest Balneotherapy – Pro patria and Napoleon which provide 60% of all treatments at Spa Island. – Picture 4.32..

4.1.13.4. Experimental measurement and analysis

Experimental measurement and analysis were elaborated with the help of Brno University of Technology – Faculty of Civil engineering. Due the fact, that automatization of accumulation station is planned in 2023 to obtain maximal effectiveness in procession of natural healing, this analysis was main input for Aqua management to be elaborated with possibility of distance parameters analyzation and fully automatic correction in real time.

Picture 4.33. Position of sensors – real view

For detailed analyzation, measurement was done on 7 places at both Korobon graphite heat exchanger and SGL graphite heat exchanger. Seven temperature sensors and two flow rate meters were placed on main natural healing water distribution pipelines to obtain precise results – shown on Picture 4.33. Long term measurement is ongoing from May 2021 until now to fully analyse impact on operation of Balneotherapy.



Picture 4.34. Scheme of sensors and flow rate meters position at SGL and Korobon graphite heat exchanger

Table 4.14. Overview for data input from sensors and flow meters

	Flow rate		KOROBON				SGL RS77			
Date	Flor rate service water	Flow rate NHW	Hot NHW	Cold NHW	Cold service water	Hot service water	Hot NHW	Cold NHW	Cold service water	Hot service water
01.05.21 0:00	1,862	2,995	63,49	33,02	13,09	37,83	63,49	22,91	13,09	52,85
01.05.21 0:15	2,879	6,297	63,84	27,84	19,08	50,54	63,84	23,86	19,08	56,44
01.05.21 0:30	5,121	4,959	62,43	26,99	16,58	49,17	62,43	23,14	16,58	56,29
01.05.21 0:45	2,006	7,513	62,42	28,04	16,68	48,08	62,42	28,39	16,68	55,60
01.05.21 1:00	3,280	5,879	65,27	24,53	17,71	45,33	65,27	19,81	17,71	54,94
01.05.21 1:15	3,583	0,970	64,61	32,09	15,58	41,88	64,61	20,82	15,58	53,12
01.05.21 1:30	0,502	3,080	65,02	29,90	15,93	51,42	65,02	23,85	15,93	55,23
01.05.21 1:45	0,223	5,265	64,54	33,34	17,34	54,24	64,54	23,57	17,34	55,16
01.05.21 2:00	5,060	1,636	64,28	19,26	17,27	46,76	64,28	20,84	17,27	55,73
01.05.21 2:15	2,084	3,737	64,09	29,30	14,48	52,31	64,09	20,24	14,48	54,50
01.05.21 2:30	8,122	3,119	64,43	22,57	15,25	46,01	64,43	21,61	15,25	54,11
01.05.21 2:45	4,811	4,801	63,82	28,93	16,10	49,12	63,82	23,34	16,10	55,00
01.05.21 3:00	2,226	6,302	64,13	24,29	16,81	47,61	64,13	22,20	16,81	52,79
01.05.21 3:15	5,922	5,395	64,93	26,62	15,30	45,82	64,93	24,51	15,30	54,62
01.05.21 3:30	3,489	4,362	62,26	24,08	17,55	46,37	62,26	23,90	17,55	53,24
01.05.21 3:45	6,999	7,122	63,90	28,58	17,43	44,85	63,90	22,96	17,43	55,41
01.05.21 4:00	6,893	3,621	63,95	33,44	16,83	40,15	63,95	24,30	16,83	52,78
01.05.21 4:15	4,276	3,398	63,36	30,52	15,51	43,23	63,36	23,66	15,51	57,07
01.05.21 4:30	5,689	1,921	62,78	25,91	18,33	42,41	62,78	21,98	18,33	53,94
01.05.21 4:45	5,371	0,382	64,23	30,25	15,24	45,50	64,23	19,29	15,24	56,41
01.05.21 5:00	3,227	4,523	62,85	30,38	15,51	44,26	62,85	24,63	15,51	56,86
01.05.21 5:15	7,816	15,020	65,48	30,91	17,02	53,31	65,48	23,32	17,02	52,21
01.05.21 5:30	1,516	6,274	65,08	24,87	15,70	43,94	65,08	27,66	15,70	55,30
01.05.21 5:45	1,817	4,333	63,74	23,73	17,68	40,97	63,74	22,00	17,68	54,36
01.05.21 6:00	4,505	3,453	62,68	36,56	17,81	49,81	62,68	23,51	17,81	55,67
01.05.21 6:15	6,602	6,049	63,21	28,25	15,41	53,47	63,21	22,18	15,41	55,76

For the purpose of dissertation thesis was out of long-term experimental measurement within trial period collected data for reference week with full operation of Balneotherapy based on occupancy of Slovak Health Spa Piestany AS. Table 1.14. show overview for data input from temperature sensors and flow meters where due to simplification data is shown in Chart 4.26 to 4.31. where individual analyzation of temperature sensors and flow rates was elaborated for Hot/Cooled natural healing water and Warm/Cold service water.

From Table 4.14. summary of collected data from experimental analysis are shown in Chart 1.1. – Hot natural healing water Korobon + SGL graphite heat exchanger, Chart 4.26. - Cold Natural healing water SGL graphite heat exchanger, Chart 4.27. – Cold service water Korobon + SGL graphite heat exchanger, Chart 4.28. – Hot service water SGL graphite heat exchanger and Chart 4.29. – Hot service water Korobon heat exchanger.

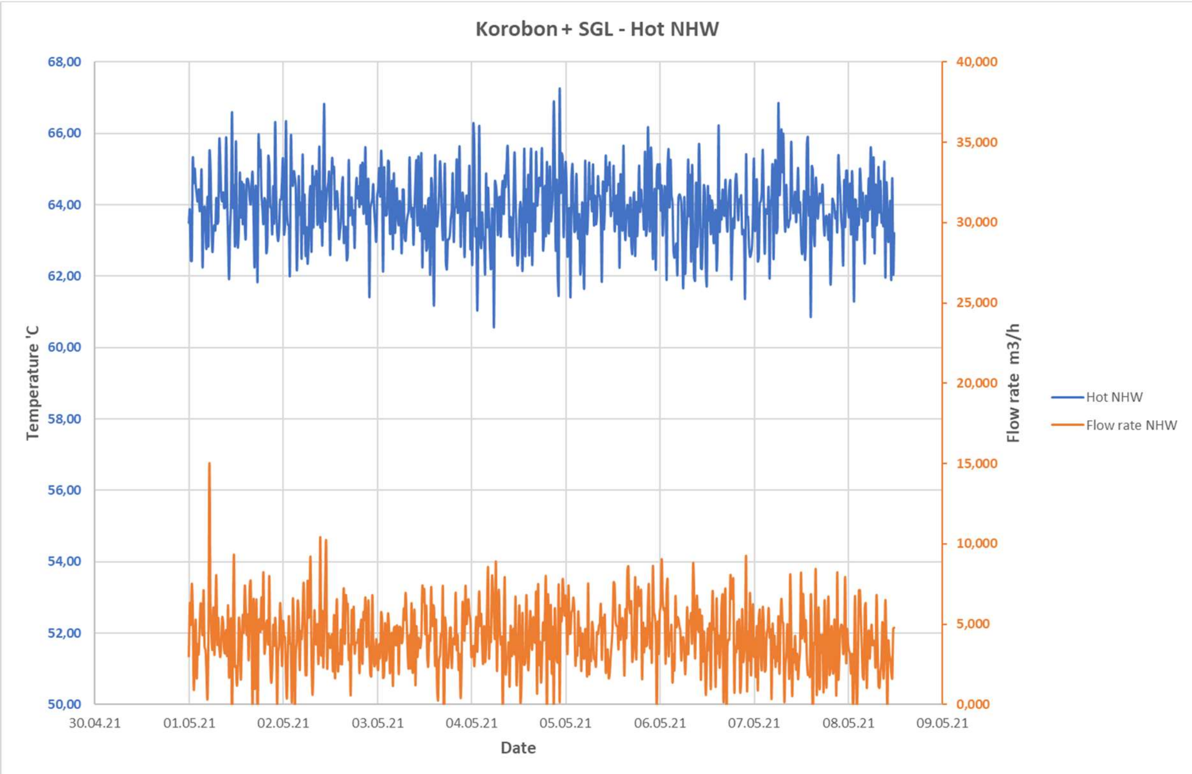


Chart 4.26. Hot natural healing water Korbon + SGL graphite heat exchanger cooperation

Analysis provided in Chart 4.26. Hot natural healing water Korbon + SGL graphite heat exchanger cooperation show that average temperature of hot natural healing water from source is in interval (63,0 ºC – 64,5 ºC), which correspond to average measured temperature at inlet to accumulation station. Temperatures measured above 64,5 ºC and under 63,0 ºC can be considered as mistake in measurement due to outside factors and retracted from analysis. Flow rate of hot natural healing water is within interval (3 m^3/15min to 6 m^3/15min). Values above and under interval can be considered as mistake in measurement and retracted from measurement analysis.

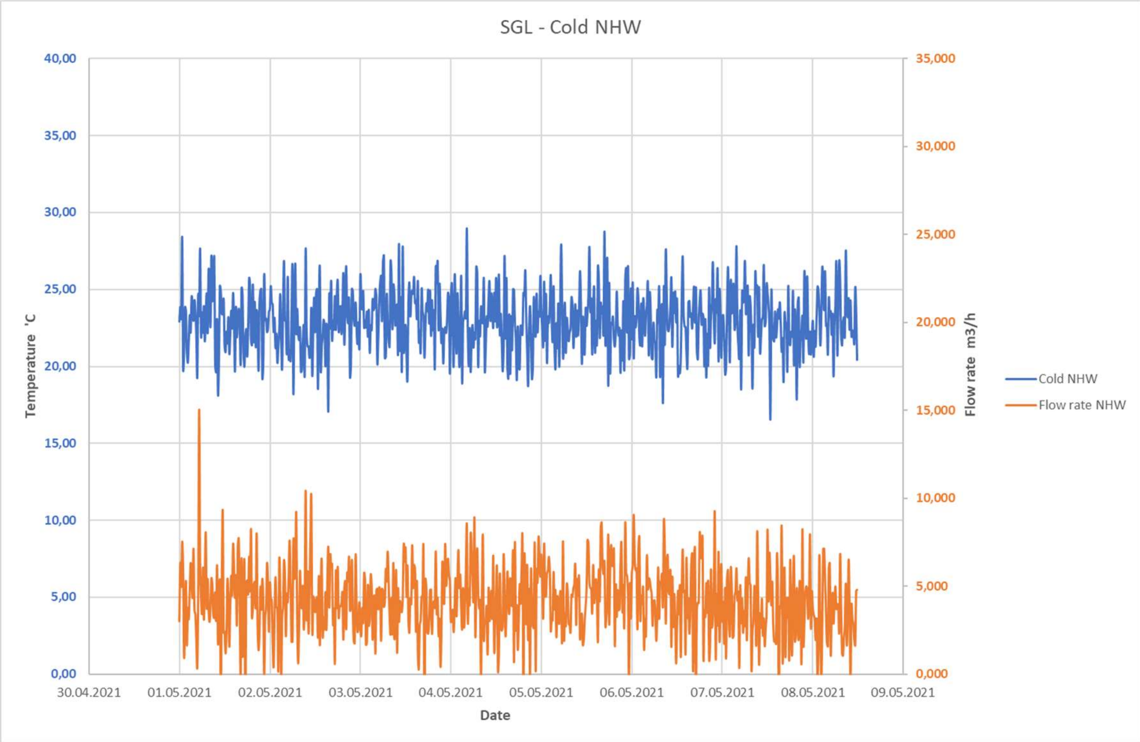


Chart 4.27. Cold natural healing water SGL graphite heat exchanger

Analysis provided in Chart 4.27. Cold natural healing water SGL graphite heat exchanger show that average temperature of cooled natural healing water from source is in interval (21,0 ºC – 22,0 ºC), which correspond to prediction from SGL group and experimental simulations elaborated at Brno University of Technology – Faculty of Civil engineering. Temperatures measured above and under interval can be considered as mistake in measurement due to outside factors and retracted from analysis. Flow rate of hot natural healing water is within interval (3 m^3/15min to 6 m^3/15min). Values above and under interval can be considered as mistake in measurement and retracted from measurement analysis.

Analysis provided in Chart 4.28. Cold service water Korobon + SGL graphite heat exchanger cooperation show that average temperature of cooled service water from source is in interval (16,0 ºC – 18,0 ºC), which correspond to average measured temperature at inlet to accumulation station. Temperatures measured above and under interval can be considered as mistake in measurement due to outside factors and retracted from analysis. Flow rate of hot natural healing water is within interval (2 m^3/15min to 5 m3/15min). Values above and under interval can be considered as mistake in measurement and retracted from measurement analysis.

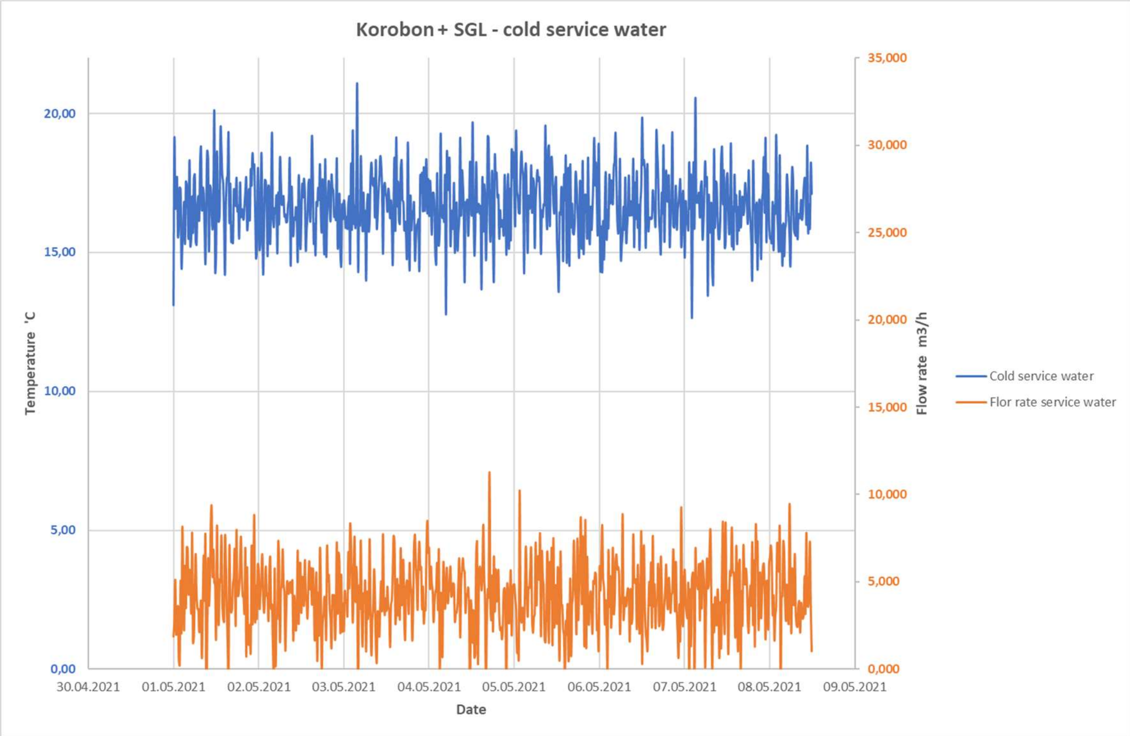


Chart 4.28. Cold service water Korobon + SGL graphite heat exchanger cooperation

Analysis provided in Chart 4.29. Hot service water SGL graphite heat exchanger show that average temperature of hot service water from source is in interval (52,0 ºC – 53,0 ºC), which correspond to prediction from SGL group and experimental simulations elaborated at Brno University of Technology – Faculty of Civil engineering. Temperatures measured above and under interval can be considered as mistake in measurement due to outside factors and retracted from analysis. Flow rate of hot natural healing water is within interval (3 m^3/15min to 6 m^3/15min). Values above and under interval can be considered as mistake in measurement and retracted from measurement analysis. This water is currently used for swimming pool EVA and swimming pools located within Spa Island at Slovak Health Spa Piestany a.s. – as solution for hot service water is not part of this dissertation thesis, development of possibilities for its usage will be task for future experimental research.

Analysis provided in Chart 4.30. Hot service water Korobon graphite heat exchanger show that average temperature of hot service water from source is in interval (42,0 'C – 47,0'C), which correspond to prediction from SGL group and experimental simulations elaborated at Brno University of Technology – Faculty of Civil engineering. Temperatures measured above and under interval can be considered as mistake in measurement due to outside factors and retracted from analysis. Flow rate of hot natural healing water is within interval (3 m^3/15min to 6 m^3/15min). Values above and under interval can be considered as mistake in measurement and retracted from measurement analysis. This water is currently used for swimming pool EVA and swimming pools located within Spa Island at Slovak Health Spa Piestany – as solution for hot service water is not part of this dissertation thesis, development of possibilities for its usage will be task for future experimental research. Comparing to existing measurement at SGL graphite heat exchanger, it is possible to state signific increase in efficiency of processing service water.

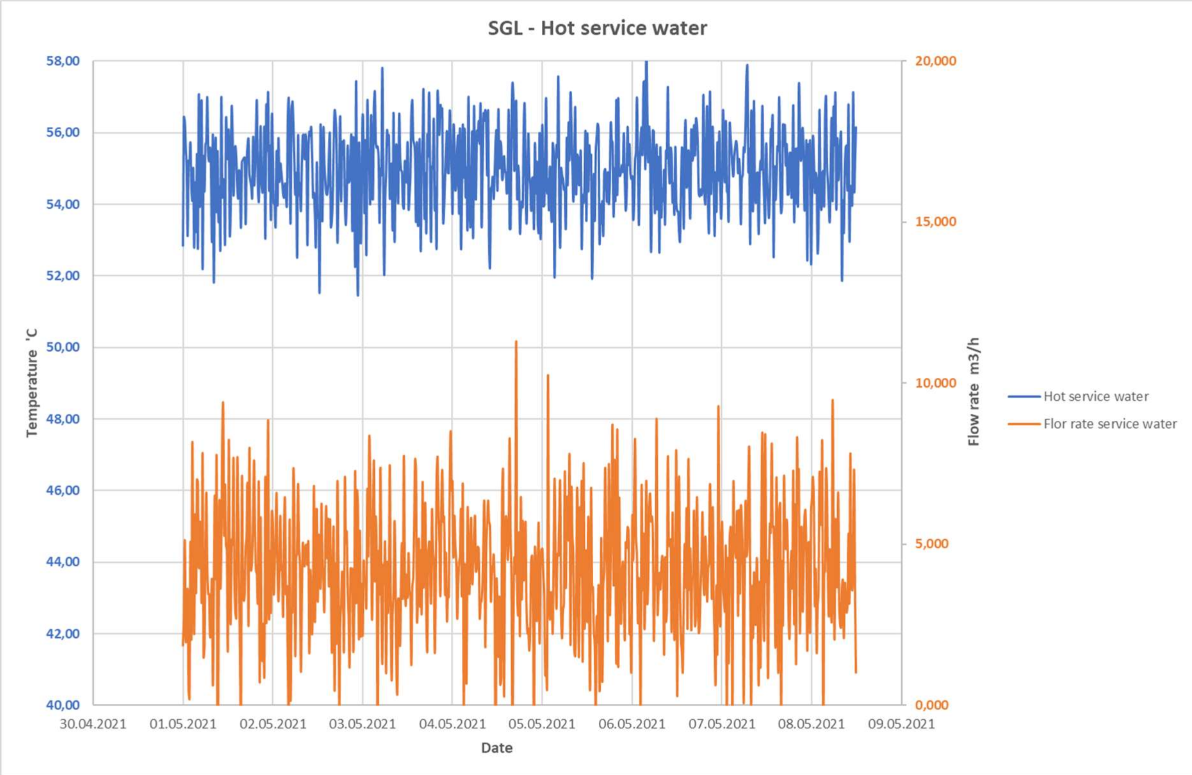


Chart 4.29. Hot service water SGL graphite heat exchanger

After revision of Charts 4.26. – 4.29. it is possible to state that, for the analyzation from the temperature point of view it is necessary to find the average temperature interval of the Korobon heat exchanger operation. For this purpose was developed charts., which shows the temperature values in dependence on the number of values.

Chart 4.31. - Hot service water – dependence of temperature and number of values shows comparison between efficiency of SGL graphite heat exchanger and Korobon graphite heat exchanger where we can stated that temperature significantly increase within proposal solution, which allows future development and extension of Slovak Health Spa Piestany.

Chart 4.32. - Cold natural healing water dependence of temperature and number of values shows comparison between efficiency of SGL graphite heat exchanger and Korobon graphite heat exchanger where we can stated that temperature significantly decrease within proposal solution, which allows future development and extension of Slovak Health Spa Piestany.

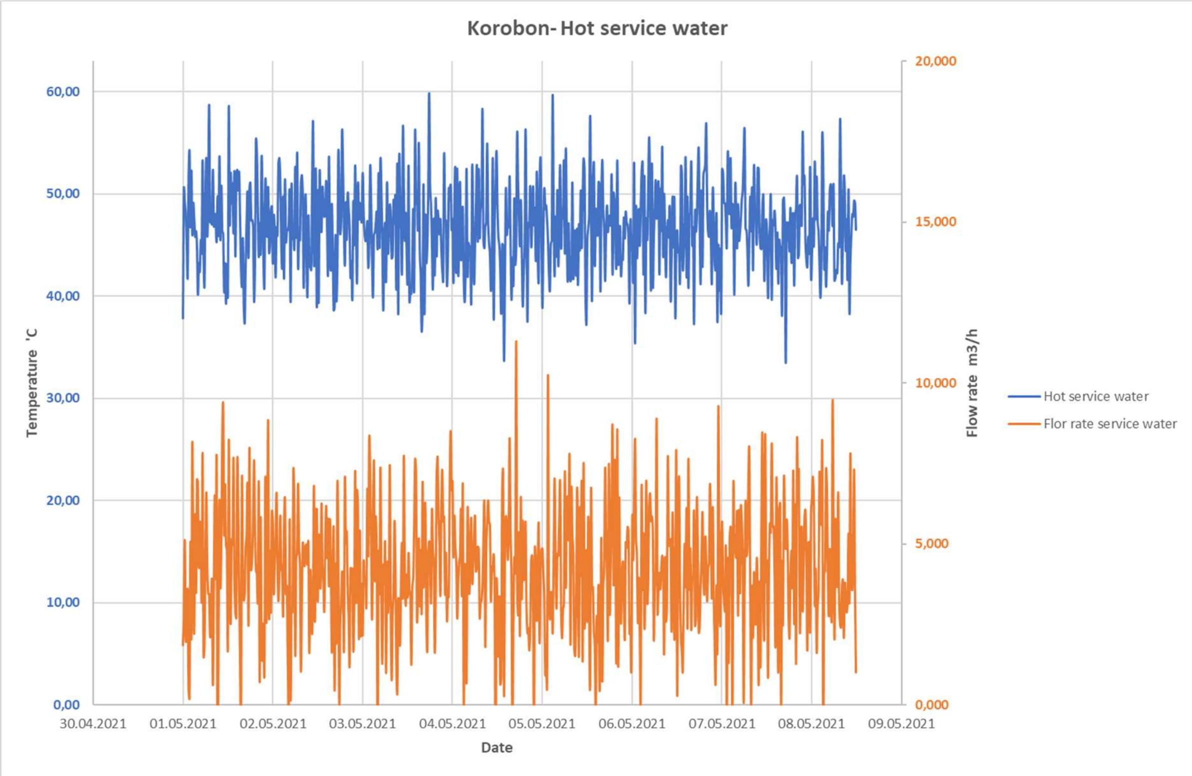


Chart 4.30. Hot service water Korobon graphite heat exchanger

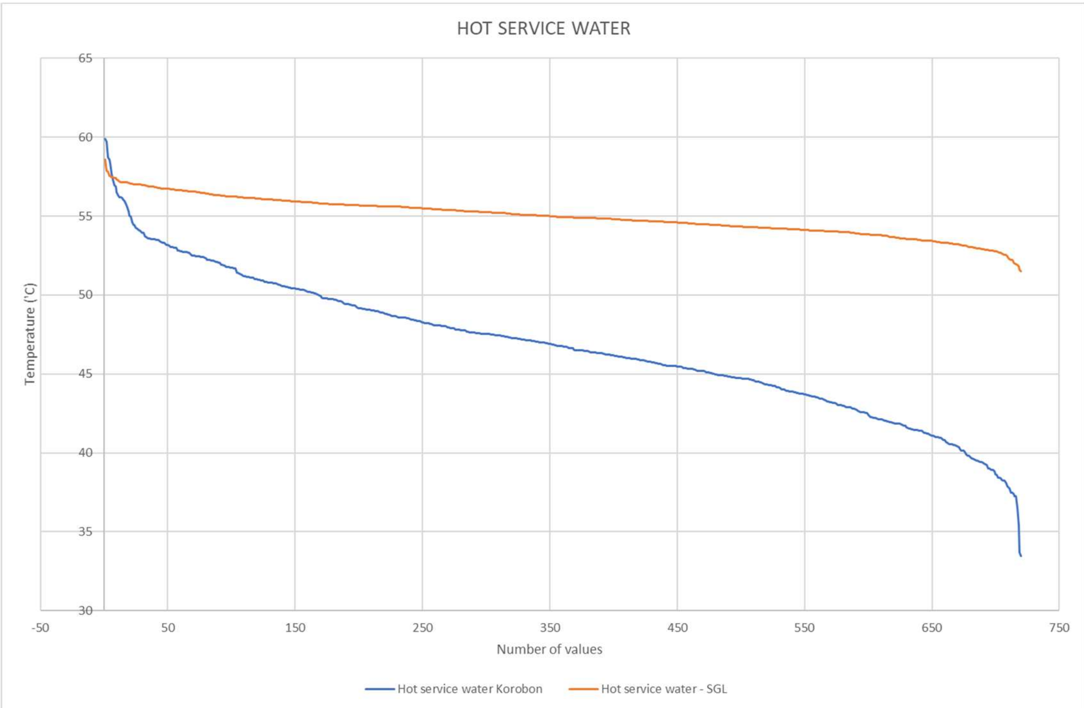


Chart 4.31. Hot service water – dependence of temperature and number of values

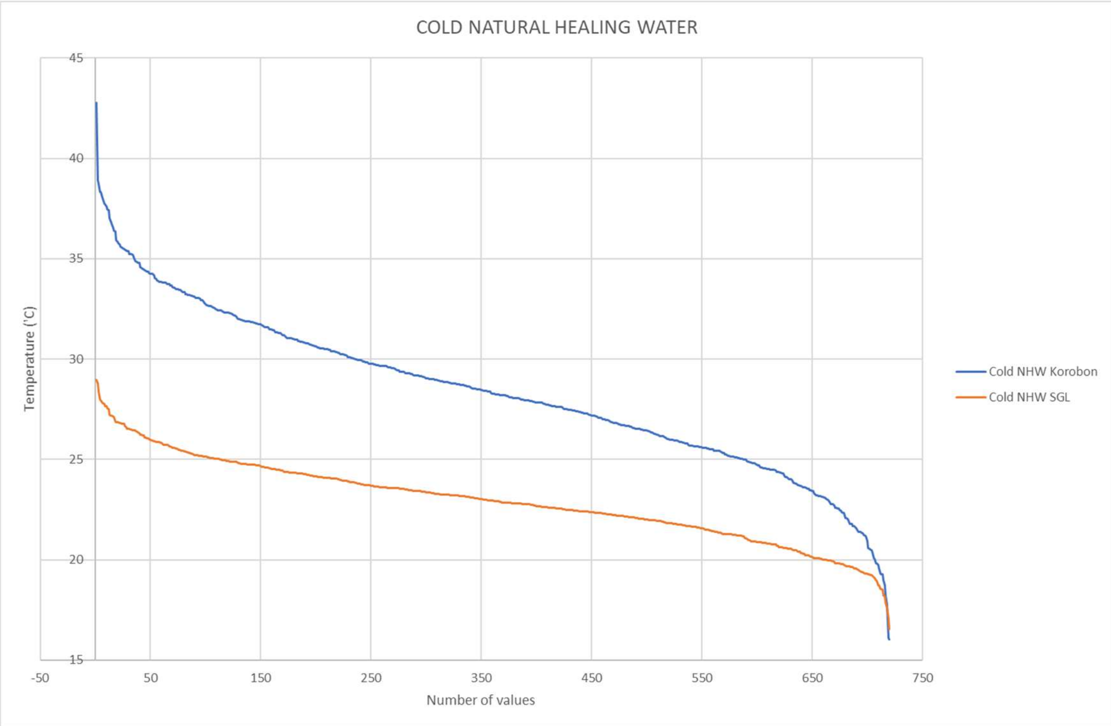


Chart 4.32. Cold natural healing water dependence of temperature and number of values

4.1.14. Energy, economic and environmental evaluation of experimental solution

The energy point of view is the base solution of describing any NHS water system and its using. For the overall evaluation it is necessary to evaluate partially the NHS water system at collection places – the Balneotherapy departments and secondly evaluate the whole system using data obtained from experimental solution. Evaluation is based on comparison efficiency of the current NHS water system and the new experimentally designed NHS water system.

4.1.14.1. Energy evaluation

The Variant D - SGL graphite heat exchanger allowed the Slovak Health Spa Piešťany a.s. not only to cover deficit of the cooled NHS water, but to generate its surplus, which will be used for the current Balneotherapy extension. Ability to cool down the hot NHS water to the temperature 21 °C, caused by these new technological devices will result in consumption of the cooled NHS water decrease and consumption of the hot NHS water increase. Table 4.15. shows the total amount of NHS cooled and hot water calculation from overall opened geothermal system point of view.

The parallel connection of the existing Korobon graphite block heat exchanger and the designed Diabon graphite heat exchanger, in consideration of the fact that new designed heat exchanger will work on 100 %, cover existing deficit 132,43 m^3 /day and create surplus 529,07 m^3 /day, which will be used in future extension of the Balneotherapy departments.

Table 4.15. Overall analyzation of SLKP a.s. with new technological device

NHS water collection places		Temperature of NHS water at entry of objects	Amount of hot NHS water at entry of objects				% ratio of hot NHS water	Temperature of cooled NHS water at entry of objects	Amount of cooled NHS water at entry of objects				% ratio of cooled NHS water
		[°C]	[l*s⁻¹]	[m³*deň⁻1]	[l*s⁻¹]	[m³*deň⁻¹]	[%]	[°C]	[l*s⁻¹]	[m³*deň⁻¹]	[l*s⁻¹]	[m³*deň⁻¹]	[%]
BALNEOTHERAPY IRMA	During the oeration	65,80	1,23	106,15	0,42	36,38	8,52	21,00	1,48	128,22	0,54	46,83	11,39
	Out of the operation				0,81	69,78					0,94	81,38	
BALNEOTHERAPY NAPOLEÓN	During the oeration	67,40	1,71	147,99	0,73	62,83	11,87	21,00	1,46	126,58	0,13	11,64	11,24
	Out of the operation				0,99	85,16					1,33	114,94	
BALNEOTHERAPY PRO PATRIA	During the oeration	67,10	1,01	86,91	0,78	67,11	6,97	21,00	1,10	94,65	0,78	67,65	8,41
	Out of the operation				0,23	19,80					0,31	27,00	
BALNEOTHERAPY BALNEA CENTRUM	During the oeration	54,50	4,81	415,55	2,81	242,75	17,52	21,00	2,86	247,28	1,32	114,48	21,96
	Out of the operation				2,00	172,80					1,54	132,80	
Total amount of NHS water at Balneotherapy during the operation					4,73	409,08					2,78	240,59	
Total amount of NHS water at Balneotherapy out of the operation					4,02	347,53					4,12	356,13	
Total for Balneotherapy			8,75	**756,61**			**31,89**			**596,72**			**53,00**
Other collection places	Drinking fountains 4 ks	45,60	0,20	17,28			20,65						47,00
	Ripening mud pools	65,20	4,94	427,04									
	Accumulation tanks		0,29	25,00					6,12	529,07			
	Swimming pool EVA		0,15	12,80									
	Outer swimming pool Thermia Palace		0,09	7,85									
Total for Balneotherapy and other collection places			**5,67**	**1 246,58**			**52,55**						
Korobon + Diabon heat exchanger			**13,03**	**1 125,79**			**47,45**		**13,03**	**1 125,79**			**100,00**
Total for accumulation station		**67,90**	**27,46**	**2 372,37**			**100,00**						

4.1.14.2. Energetic balance of system with new heat exchanger

The energetic balance of the new Diabon block graphite heat exchanger, which will be parallel connected to the existing Korobon heat exchanger is described below.

Primary side of new heat exchanger:

- Inlet temperature: T1 = 67 °C
- Outlet temperature: T2 = 21 °C
- Average temperature: T12 = 44 °C
- Density of water: $\rho = 998\ kg/m^3$
- Flow rate: $Vgv_2 = 13{,}03\ l/s = 46{,}92\ m^3/h$
- Mass flow: $Mgv_2 = 46{,}92 \times 998 = 46826{,}16\ kg/h = 13{,}01\ kg/s$

From calorimetric equation it is possible to obtain heat power:

$$Q_1 = M_{gv2} \times c \times (T_1 - T_2) = 13{,}01 \times 4180 \times (67-21) = 2\ 501\ 562\ W = 2{,}5\ MW$$

Where:

c - specific heat capacity ($J.kg^{-1}.k^{-1}$)

This heat power must be transfer to secondary side.

Secondary side of new heat exchanger:

- Inlet temperature: T_1 = 14 °C
- Outlet temperature: T_2 = 58 °C
- Average temperature: T_{12} = 36 °C
- Density of water: ρ = 998 kg/m^3

From calorimetric equation it is possible to obtain mas flow rate at secondary side:

$$M_{sv} = \frac{Q_1}{c \times (T_1 - T_2)} = \frac{2501562}{4180 \times (58 - 14)} = 13{,}601 \frac{kg}{s} \times 3600 = 48964 \frac{kg}{h}$$

Where:

c - specific heat capacity (J.kg^{-1}.k^{-1})

Hot service water flow rate:

$$V_{sv} = \frac{M_{sv}}{\rho} = \frac{48964}{998} = 49{,}06\ m^3/h$$

4.1.14.3. Outputs from energetic balance of system with new heat exchanger

- At 100 % utilization of the new Diabon heat exchanger will be possible from the opened NHS water system obtain 46,92 m^3/h which is equal to 1126,32 m^3/day of the cooled NHS water with the temperature 21 °C for healing procedures.
- At the same time it is possible to obtain at 100 % utilization of the new Diabon heat exchanger 49,06 m^3/h which is equal to 1177,32 m^3/day of the hot service water with the temperature 58 °C.
- Due to the fact that hot service water will be used during the operation and out of the operation of the Balneotherapy, mainly for a pools heating at wellness centrum, an outer pooled heating, a water heating for showers at the Balneotherapy or equivalent showers at the accommodation units, it is possible to calculate with utilization of whole capacity obtained from the cooling down of hot NHS water.

4.1.15. Theoretical savings from waste heat in slkp a.s.

The theoretical savings of gas is calculated from assumed utilization of the waste heat, which will be obtained from 1126,08 m^3/day of the NHS water from temperature 67 °C to temperature 21 °C.

- Assumed amount of cooled NHS water: V_o = 1126,08 m^3
- Density of water: ρ = 998 kg/m^3
- Specific heat capacity of water: c = 4180 $J.kg^{-1}.K^{-1}$
- Coefficient of energy losses at system: z = 0,9

Daily transferred heat for cooling NHS water:

$$Q_{o,d} = 10^{-3} \times \frac{z \times \rho \times c \times V_o \times (T_2 - T_1)}{3600}$$

$$Q_{o,d} = 10^{-3} \times \frac{0{,}9 \times 998 \times 4180 \times 1126{,}08 \times (67 - 21)}{3600}$$

$$Q_{o,d} = 54\,022{,}404\ kWh$$

By cooling down 1126,08 m^3 of hot NHS water will SLKP a.s. daily generate cca. 1177,44 m^3 with the temperature 58 °C. If this hot service water will be used for energy purpose of SLKP a.s., than it is possible to obtain:

$$Q_T = Q_{O,d} \times d = 54022{,}404 \times 365 = 19\,718\,177\ kWh$$

The amount of energy obtained by cooling down assumed amount of the hot NHS water is 19718177 kWh = 70985,437 GJ. It is necessary to take into account heat losses at distribution and in heat exchanger – 15 %, it is possible to calculate with the generated heat from hot NHS water 60337,621 GJ/year.

4.1.16. Economic and ecologic evaluation

The economic evaluation is based on compartment of the heat boiler room Balnea Centre with performance 9,98 MWh and the designed opened NHS water system – Table 4.16. and Table 4.17.

Table 4.16. Economic evaluation of the heat boiler room in Balnea Centre

The heat boiler room Balnea Centre - performance 9,98 MWh		
Measured amount of consumed gas in July 2015	m^3	40 918
Average amount of consumed gas per one day	m^3	1 320
Costs of gas in July 2015	€	19 780
Price for m^3	€/m^3	0,4834
Calorific value of gas in July 2015	kWh / m^3	9,685
Measured amount of energy in gas July 2015	kWh	396 291
Measured amount of energy per one day	kWh	12 784
Measured amount of consumed gas per year 2015	m^3	1 614 815

Table 4.17. Total savings per one day

Amount of green house gases	The heat boiler Balnea Centre	Korobon	Diabon	Korobon + Diabon
	kg/day	kg/day	kg/day	kg/day
TZL	0,10031515	0,00640270	0,00727227	0,01367497
SO2 / SOx	0,01203772	0,00076832	0,00087267	0,00164098
CO	1,95614453	0,12485264	0,14180917	0,26666181
TOC	0,78998157	0,05042127	0,05726910	0,10769036
Amount of used NHS water per one day	kWh	**25293,61**	**28728,79**	**54022,40**
Amount of saved gas	m3	2612	2966	5578
Total savings per one day	€	1262	1434	2696

Calculation of payback time:

- Theoretical savings per one day: 1434 €
- Theoretical savings per one year: 523410 €
- Total investments: 1250 000 €

$$Ts = IN \;/\; CF = 1250000 \;/\; 523410 = 2{,}38\ year = 2\ years\ 140\ days$$

Where:

IN - investments, one-off costs to realize savings
CF - annual cash flow

5. MEETING DISSERTATION THESIS GOALS

Dissertation thesis Aspects of an experimental solution with the use of geothermal energy in balneotherapy provides complex analysis and scientific research with eight years focus in field of renewable sources of energy mainly natural healing sources of water, which can be primarily used for treatment procedures with focus on unique project at Slovak Health Spa a.s. Piestany. The investment project assessment is based on the experimental analysis of the accumulation station current state at SLKP a.s. which proves the importance and traceability to the operations at Balneotherapy departments and other collection places and therefore it is possible that all main goals and objectives were met:

Main goals:

- Goal: Complex analysis of current state at natural healing water treatment system at Slovak Health Spa Piestany a.s.
    - ♦ Result: Dissertation thesis Aspects of an experimental solution with the use of geothermal energy in balneotherapy provide complete experimental and research analysis, where the deficit of cooled natural healing water was discovered which result to impossibility for future development of Slovak Health Spa as well as importance for backup technological system for processing natural healing water in case of failure of current Korobon graphite heat exchanger.
- Goal: Design technological devices and equipment innovation in connection to EU Low-carbon economy and decreasing the amount of greenhouse gases to the atmosphere
    - ♦ Result: Projection of technological design started 2017 based on various report elaborated at Brno University of Technology – faculty of civil engineering and was finished in winter 2019. Concept of new technological devices enhance efficient processing of natural healing water which result in over producing cooled NHW, which allows Slovak Health Spa future expansion as well as security in form of backup within processing of NHS in case of sudden failure of current system
- Goal: Realization of chosen solution at real spa complex based on elaborated analysis
    - ♦ Result: Realization of reconstruction and revitalization of accumulation station begun in spring 2020, where new technological devices were connected and implemented to current system for processing NHS and will be fully completed in 2023
- Goal: Recommendation for future sustainable development in using natural healing water sources as a renewable source of energy
    - ♦ Result: The experimental analysis has demonstrated performance insufficiency 132.43 m3/day of cooled natural healing water

- ♦ Result: As part of the revitalization process it is necessary that, the material of technological devices has to resist heavy mineral sedimentation, while in terms of experience is the best material graphite compound - current Korobon, where the evidence is trouble-free operation
- ♦ Result: Titanium plate heat exchangers should not be involved in the technological system because mineral sedimentation can only be removed with a chemical substance, with the risk of contamination of natural healing water.
- ♦ Result: As part of streamlining operations and distribution of natural healing water, it is necessary to design an energy management control center with Aqua dispatching, which will effectively control technological processes and thereby decreasing the economic burden of operation resulting as a reduction in staff needed for the operation - the current state of measurement and control comes from the mid-20th century.
- ♦ Result: At the second stage, it is necessary based on mineral sedimentation experimental analysis provide current pipeline distribution revitalization in the way of replacement the distribution pipelines for the material durable against mineral sedimentation. This replacement is related to the original natural healing water distribution pipelines in the range of approx. 3.4 km.

- Goal: Simulation and comparison between the design solution and real operation at chosen technological devices
    - ♦ Result: During the diploma thesis we elaborated simulation of proposal solution where expected value of cooled natural healing water temperature was 21 ºC. After reconstruction and revitalization of accumulation station it is possible to state that current outflowing temperature of cooled natural healing water is in interval 21 ºC to 22 ºC. Main advantage of new implemented system is stability in outflowing temperature and flow rate which allows Slovak Health Spa to project proper Aqua management in terms of real time correction of temperature and flow rate based on actual values. The experimental analysis has demonstrated performance insufficiency 132.43 m^3/day of cooled natural healing water which was fully covered in real operation after assembling new technological system.

6. CONCLUSION

"We are in danger of destroying ourselves by our greed and stupidity. We cannot remain looking inwards at ourselves on a small and increasingly polluted and overcrowded planet." by Stephen Hawking. Question of life environment and global warming cause by rising amounts of green-house gases in atmosphere is now reaching its critical levels. Therefore, it is primary task for many scientists to elaborate solution for arising global problem.

Dissertation thesis Aspects of an experimental solution with the use of geothermal energy in balneotherapy provides complex analysis and scientific research with eight years focus in field of renewable sources of energy mainly natural healing sources of water, which can be primarily used for treatment procedures with focus on unique project at Slovak Health Spa Piestany providing unique overview and implementation of new technological procedures to revitalize current systems for processing natural healing water.

The main goal of dissertation thesis is complex analysis of current technological system with an attention on cooled natural healing water deficit in connection with increasing amounts of carbon dioxide production caused by traditional way of energy utilization. Reconstruction and technological revitalization are considered as high priority. For this purpose, three main goals were established and answered during the elaboration concerning technological devices for processing natural healing water design, realization of designed solution and comparison between predicted behavior of system and real operation after reconstruction

The overall result is in the form of real time experimental measurement comparison to experimentally simulated and predicted behavior of designed system for utilization energy from natural healing source of water. Firstly, it was proven that traditional way of utilization energy from natural healing water is inefficient and unsustainable. Secondly, by implementation of new technological system will increase amount of the gas saved by heating up water demand for Balneotherapy departments and in this way fulfill the European Union Low Carbon economy.

Within the elaboration of dissertation thesis was discovered huge potential hidden in natural healing source of water and recommendation for future way of designing new technological devices for fulfilling European Low-Carbon economy and meeting climate goals set up for year 2030 and 2050.

7. LITERATURE REVIEW

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8. LIST OF ABBREVIATIONS AND SYMBOLS

BT	Balneotherapy
CCS	CLIMIT: Fond for CO_2-håndtering
CNS	Carbon Neutral Scenario
EPA	Environmental Protection Agency's
ETP	Energy Technology Perspectives
ETS	Emission trading system
EU	European Union
GDP	gross domestic product
GHG	greenhouse gas
IEA	International Energy Agency's
NECP	National energy and climate plans
NETP	Nordic Energy Technology Perspective
NHS	natural healing source
NHW	natural healing water
PC	portable computer
RE	renewable energy
RES	renewable energy source
SLKP as.	Slovak Health Spa Piestany as
SMEs	European Labour Authority, Directorate-General for Employment, Social Affairs and Inclusion
SR	Slovak Republic
Th.	Thickness
VRE	variable renewable electricity

9. LIST OF SOURCES

9.1. List of pictures

9.2. List of charts

9.3. List of tables

10. LIST OF ANNEXES

Annex 1.1. 6 RS77 – Simulation 70 ºC

Annex 1.2. 6 RS77 – Simulation 60 ºC