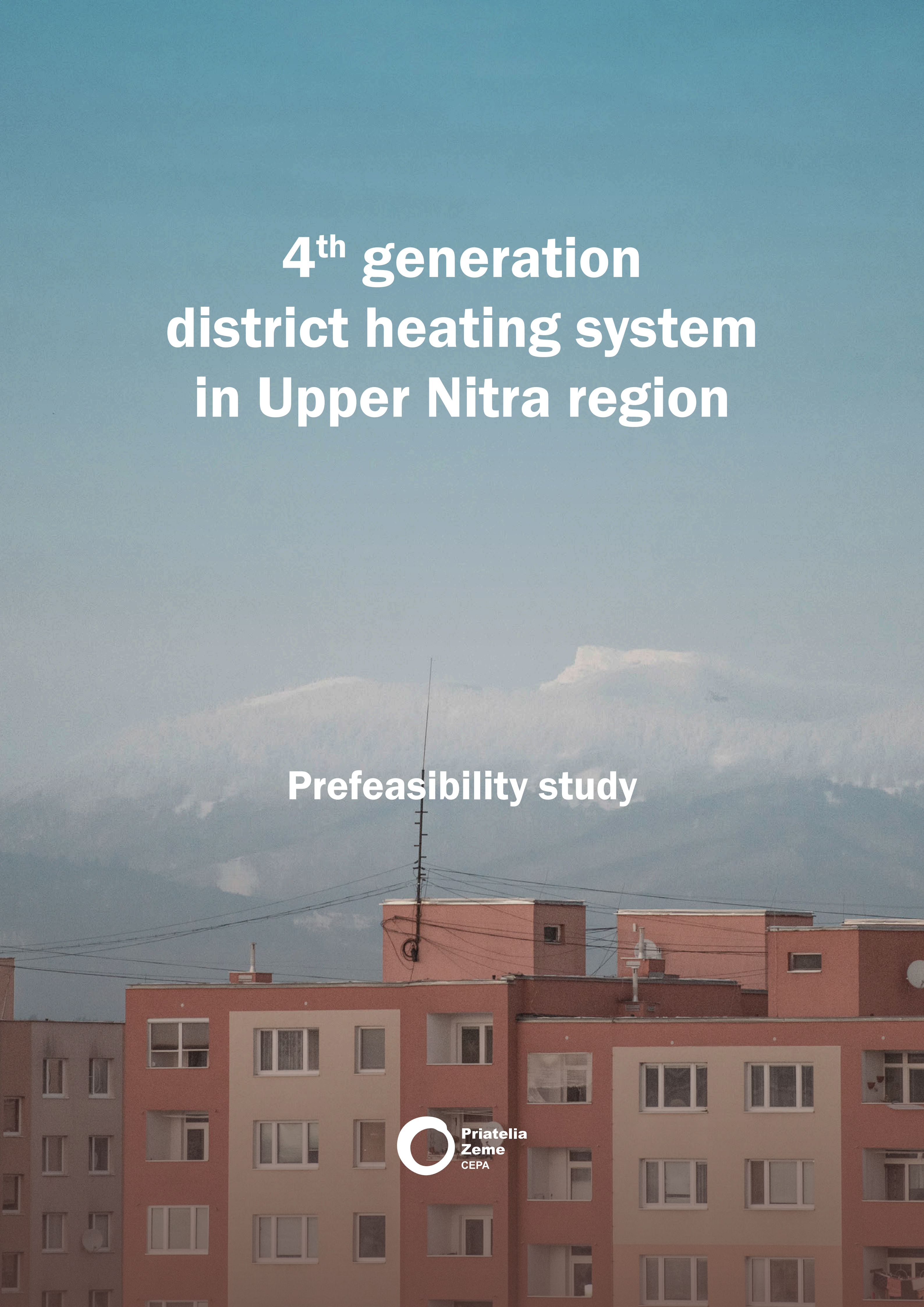
4th generation district heating system in Upper Nitra region

Prefeasibility study



Priatelia Zeme CEPA

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Executive summary

The goal of this study was to design a concept of the 4th generation district heating system for the Upper Nitra region using only renewable energy sources and seasonal heat accumulation. This concept should help to design the 2nd phase of the district heating system solution following the 1st phase which should be in operation in 2023 at the latest. The reason for elaborating of the 2nd phase concept is that the 1st phase solution cannot be considered as a long-term solution since it uses fossil fuel and is based on non-optimized heat consumption[1].

The described concept of the 4th generation district heating system in this study is not a proposal for a heating solution, as it is based on many assumptions (chapter 3), which must be examined to design a specific solution.

The concept of the 2nd phase heating distribution system for a town of Prievidza is divided into two parts – northern and southern one, mainly due to the technical feasibility of a seasonal heat storage. In addition to this technology, there are also other heat sources, specifically heat pumps (HP) and additionally biomass boilers. Every part had two scenarios. Percentual coverage of specific heat source for the specific scenario was following:

- Scenario A_1 (northern part of Prievidza):
    - Solar system and pit thermal storage – 65 %,
    - Biomass boiler – 35 %.
- Scenario A_2 (northern part of Prievidza):
    - Solar system and pit thermal storage with discharging through HP – 75 %,
    - Biomass boiler – 25 %.
- Scenario B_1 (southern part of Prievidza):
    - Solar system and borehole storage with discharging through HP – 35 %,
    - Mine and geothermal water with usage of HP – 52 %,
    - Biomass boiler – 13 %.
- Scenario B_2 (southern part of Prievidza):
    - Solar system and borehole storage with discharging through HP – 37 %,
    - Mine and geothermal water with usage of HP – 63 %.

If the concept of the 2nd phase district heating system was extended to a solution, the production heat cost[2] without any financial aids would be from 55.8 to 58.2 eur/MWh[3]. If we considered that an appropriate non-repayable financial contribution for whole technology[4] was used, the production heat cost could be lowered to 32 eur/MWh[5]. If we also took into account necessary investments into infrastructure, other supporting technologies and a reasonable profit all by estimation, the distribution heat cost of such system would be from

[1] By application of deep renovation of buildings and thorough reconstruction of piping system

[2] Meaning the production heat cost without a reasonable profit. The reasonable profit up to a certain limit is allowed by Slovak legislation.

[3] Considering all economic assumptions described in the study.

[4] With 40 % co-financing of the technology.

[5] Without considering additional investments (e.g. reconstruction of piping system etc.).

42.5 do 56.1 eur/MWh[6]. Current total heat cost in Prievidza is about 102.1 eur/MWh[7], while for the 1st phase solution the heat cost should not be higher than 55.8 eur/MWh[8]. In summary, it can be concluded that the proposed 2nd phase concept using only renewables could operate with much lower distribution heat cost compared to a current obsolete district heating system and with comparable or lower heat cost compared to the proposed 1st phase solution (depending on the chosen scenario of the 2nd phase system).

In town of Nováky, the concept of the 2nd phase of the district heating system was based on the elimination of biomass usage which should be a dominant heat source in the solution of the 1st phase. The proposed concept of optimization (the 2nd phase) is based on the use of HP using mine water which thermal efficiency would be improved by solar thermal preheating of the water. While dimensioning solar collectors, solar surplus heat was taken into account and its storage into mining space was estimated. The heat cost of such a designed system without any financial aids was calculated at a value of about 74.4 eur/MWh[9]. If we considered that a non-repayable financial contribution for whole technology[10] was used, the distribution heat cost could be decreased to 59,5 eur/MWh[11]. The heat cost is higher compared to 2nd phase solutions in Prievidza mainly due to smaller dimensions of the project which causes higher specific investment and operational costs. Despite of these aspects the heat cost of the proposed concept of the 2nd phase system for Nováky would be still much lower compared to the current heat cost (93,8 eur/MWh[12]). In addition, the heating concept of the 2nd phase was designed solely on renewables and without any usage of wooden chips, unlike the 1st phase.

The study does not contain a concept of a district heating system for a village of Zemianske Kostoľany since after an initial economic analysis of the current grid it showed that it is uneconomic to operate a DH system in there (chapter 4.2). Although there is still a possibility that some of the buildings there could create an efficient microgrid system based on 5th generation of district heating. This investigation, however, was not a part of this study.

At the end of the study, outputs from the analysis of CO_2 emissions[13] and their potential reduction are shown (Tab. 39). These results would be achieved if the proposed concepts were examined, the assumptions were correct and the concept was transformed into a project and implemented. An application of the 2nd phase scenario with the lowest carbon footprint would result in almost 57-times lowered the amount of annual CO_2 emitted to the

[6] Meaning the distribution heat cost with a reasonable profit (additional costs for distribution and reasonable profit was estimated).

[7] The heat cost is from September 2020 and it is taken from a document called *Transformácia elektrárne Nováky, Nový centrálny zdroj tepla: Riešenie problematiky zásobovania teplom v regióne Hornej Nitry, 2020.*

[8] The price was guaranteed as a heat cost value for the 1st phase heating solution by PTH company and it is possible to find it in a document called *Prezentácia zámeru rekonštrukcie zdroja tepla pre SCZT Prievidza v technickom riešení KVET na zdrojovej báze OZE a ZPN v areáli bane Cigeľ a v meste Prievidza vrátane mesta Nováky a obce Zemianske Kostoľany. Bratislava: Ministerstvo hospodárstva SR, 2020.*

[9] Meaning the production heat cost without a reasonable profit. The reasonable profit up to a certain limit is allowed by Slovak legislation.

[10] With 40 % co-financing of the whole technology.

[11] Without considering additional investments (e.g. reconstruction of piping system etc.).

[12] The heat cost is from September 2020 and it is taken from a document called *Transformácia elektrárne Nováky, Nový centrálny zdroj tepla: Riešenie problematiky zásobovania teplom v regióne Hornej Nitry, 2020.*

[13] Calculation was made based on values of CO_2 emissions for specific heat sources from Decree 364/2012.

atmosphere for the system in Prievidza and more than 20-times reduction in Nováky compared to the current heating solution supplying heat from Nováky Power Plant.

From the point of view of international obligations of the Slovak Republic within the energy sector about the need for adaptation and mitigation of climate change and overall development in the heating sector, it is very important to make a transition to higher generation district heating systems. Concepts offered in this study after an appropriate completion could serve as demonstration pilot projects which would show that such systems can be implemented in Slovakia as well.

1 Introduction

The task of this preliminary study was to design a concept for a heating system in Prievidza, Nováky, and Zemianske Kostoľany, which would be based on the 4th generation of district heating system. Projects of this type require long-term planning based on optimizing heat consumption and a local examination of potential sustainable heat sources based on renewables or on the possibility of building seasonal heat accumulators. The study offers an initial proposal, which should serve as a basis, which will be further expanded as time progresses.

2 Instructions for readers

This chapter contains sections where instructions for readers are described. It is assumed that readers have at least some knowledge of district heating systems.

2.1 Structure of the study

The following table shows sections of the study with their content (Tab. 1).

Tab. 1: Described content of every section of the study

Sections	Explanation of the content
Assumptions of the concept	Explanation of the individual assumptions used in the concept. Assumptions have their reference directly in specific parts of the study.
Evaluation of the suitability of an area for DH project	Analysis of the suitability of implementation/reconstruction of DH system for particular municipalities.
Heat demand	Analysis of the potential of building heat demand reduction and heat losses reduction in the heat distribution system. Determining assumed values of the future heat demand for the target period in which the solution of the 2nd phase will be proposed.
Basic characteristics of the concept	Description and explanation of basic technical features of the solution.
DHS concept in Prievidza	Technical description of Prievidza DHS design.
DHS concept in Nováky	Technical description of Nováky DHS design.
Economy of the solution	Analysis of capital, operating, and total annual costs of designed DH systems and their production heat costs.
CO_2 reduction	Analysis of reduction of CO_2 emissions of designed systems compared to the current system and the 1st phase system.
Final evaluation	Evaluation of technical and economic aspects from the perspective of authors and analysis of distribution heat costs after inclusion of estimated additional investments and a reasonable profit margin.

2.2 Instructions

The study is written in a logical sequence. The Assumptions chapter (chapter 3) should be read in advance and it is necessary to go back and reread individual assumptions according to the relevant references when reading the next text of the study.

2.3 Abbreviations

In the table below (Tab. 2) common abbreviations used in the study are summarized.

Tab. 2: Used abbreviations

Abbreviation	Explanation
DH	District heating
DHS	District heating system
NPP	Nováky Power Plant
SE	Slovenské elektrárne a.s. (company)
PTH	Prievidzské tepelné hospodárstvo a.s. (company)
HBP	Hornonitrianske bane Prievidza a.s. (company)
HSP NPP PD	Heat supply pipeline from Nováky Power Plant leading to Prievidza
DHW	Domestic hot water
RES	Renewable source of energy, renewable energy sources
SPF	Seasonal performance factor of heat pump
HP	Heat pump, heat pumps
NFC	non-repayable financial contribution
MW	Mine water
SH	Space heating
TPB	Thermal protection of a building

2.4 Phrases

In the table below (Tab. 3) common phrases used in the study are summarized.

Tab. 3: Used phrases

Phrase	Explanation
1st phase of the heating solution	A solution which heat generators are designed by a company PTH (for Prievidza) and by companies PTH and KOOR s.r.o. (for Nováky and Zemianske Kostoľany) and they will be in operation since 2023. Further information about this solution can be found in chapter 3.1.1.
2nd phase solution	A concept that is designed in this study and should theoretically be in operation in the future.
Target period	A period during which the 2nd phase concept should be (hypothetically) in operation. This period is estimated around 2034[14] and it is based on a technical lifespan of biomass boilers from the 1st phase solution.
Renewables	Renewable energy sources

[14] From document from PTH company - *Prezentácia zámeru rekonštrukcie zdroja tepla pre SCZT Prievidza v technickom riešení KVET na zdrojovej báze OZE a ZPN v areáli bane Cigeľ a v meste Prievidza vrátane mesta Nováky a obce Zemianske Kostoľany. Bratislava: Ministerstvo hospodárstva SR, 2020.*

3 Assumptions of the 2nd phase concept

Assumptions of the proposed concept are described in the following chapter. Every assumption is marked by a chapter number and it is referred to its location in a text of the study. Some of assumptions are described directly in the text later and they are not a part of following sections.

3.1 General assumptions

Basic assumptions are explained below.

3.1.1 Assumption of implementation of 1st phase of DHS

The study assumes that the **technical solution of the 1st phase of DHS** of the region, respectively towns of Prievidza and Nováky and the municipality of Zemianske Kostoľany **will be designed as it is described in official documents**[15,16,17]. A brief summarization of used heat sources in the 1st phase solution is shown in a table below (Tab. 4).

Tab. 4: Designed heat sources in the 1st phase solution for Prievidza, Nováky and Zemianske Kostoľany

Municipality	Heat sources
Prievidza	Gas boilers (2 x 15 MW + 1 x 5 MW) Biomass boilers (2 x 3 MW) HP for mine water (4 x 1,025 MW) Cogeneration unit (1,15 MW) Thermo-solar system for preheating of mine water for HP (2,5 MW)
Nováky	Biomass boilers (2 x 3 MW) HP for mine water (2 x 1,85 MW)
Zemianske Kostoľany	Gas boiler (1 MW)

Source[18,19,20]

[15] NOVÝ ZDROJ TEPLA PRE SYSTÉM CENTRÁLNEHO ZÁSOBOVANIA TEPLOM MESTA PRIEVIDZA: Zámer činnosti podľa zákona č. 24/2006 Z.z. o posudzovaní vplyvov na životné prostredie a o zmene a doplnení niektorých zákonov v znení neskorších predpisov. Banská Bystrica: Prievidzské tepelné hospodárstvo, 2021.

[16] *Záväzné stanovisko o súlade výstavby tepelných zariadení s Koncepciou rozvoja mesta Nováky v tepelnej energetike v zmysle § 13 ods. 2 zákona o tepelnej energetike.*

[17] *Záväzné stanovisko obce o súlade výstavby tepelných zariadení pre nový tepelný zdroj SCZT Zemianske Kostoľany.*

[18] NOVÝ ZDROJ TEPLA PRE SYSTÉM CENTRÁLNEHO ZÁSOBOVANIA TEPLOM MESTA PRIEVIDZA: Zámer činnosti podľa zákona č. 24/2006 Z.z. o posudzovaní vplyvov na životné prostredie a o zmene a doplnení niektorých zákonov v znení neskorších predpisov. Banská Bystrica: Prievidzské tepelné hospodárstvo, 2021.

[19] *Záväzné stanovisko o súlade výstavby tepelných zariadení s Koncepciou rozvoja mesta Nováky v tepelnej energetike v zmysle § 13 ods. 2 zákona o tepelnej energetike.*

[20] *Záväzné stanovisko obce o súlade výstavby tepelných zariadení pre nový tepelný zdroj SCZT Zemianske Kostoľany.*

3.1.2 Assumption of transition from 1st and 2nd phase of DHS

The study assumes that **the solution of the 1st phase of DHS will be temporary**[21] and after specific time the solution will be optimized, respectively it will **transit to the 2nd phase**. Estimated time of transition from the 1st to the 2nd phase of the solution is around 2034 when the expiration of biomass boilers technical lifespan is assumed[22].

3.2 Heat demand assumptions for building sector

Assumptions regarding the heat demand of buildings for heating and preparation of DHW are described in following chapters.

3.2.1 Assumption of reduced building heat demand for heating

The preliminary study deals with the design of the heating concept which should be put into operation in the 2nd phase, after the end of the operational period of the 1st phase of the region's DHS (specifically for municipalities Prievidza, Nováky and Zemianske Kostoľany). A possible start of the operation of the 2nd phase is estimated around 2034[23]. Before this year there is **an assumption that heat demand for heating will be reduced** (not heat demand for DHW preparation[24]) thanks to a complex building renovation of apartment and non-apartment buildings connected to DHS. The level of renovation is estimated in scenarios in chapter analyzing heat demand (chapter 3.2).

3.2.2 Assumption of heat demand for domestic hot water preparation

DHW preparation is related mainly to behavior of users of buildings (age distribution of users in a building, their habits, etc.). Some buildings in the region have older pipes and older DHW substations and by their renovations it would be possible to reduce the heat demand. However, there was a lack of data needed to be able to calculate potential reduction of the heat demand of such renovations. Because of that, **the current heat consumption of DHW was taken into account** in the target period when the 2nd phase could be implemented.

3.2.3 Assumption of a necessary reconstruction of heating elements in some buildings

The preliminary study proposes DHS that works with reduced water temperature in the system. In the case of implementation of such a system, **it will be necessary to consider replacement, modification[25] or expansion of radiators or other heaters** in order to achieve thermal comfort of users **of some buildings**. **This aspect**, due to the preliminary nature of the study and due to the need to perform a complex survey of radiators of buildings

[21] Because of the use of gas boilers.

[22] Transition from the 1st to 2nd phase can occur in a different period. Time of transition also depends on other factors than technical, e.g. political decisions etc.

[23] Year based on lifespan of biomass boilers which are about to be used in the 1st phase system (from a document from PTH company - *Prezentácia zámeru rekonštrukcie zdroja tepla pre SCZT Prievidza v technickom riešení KVET na zdrojovej báze OZE a ZPN v areáli bane Cigeľ a v meste Prievidza vrátane mesta Nováky a obce Zemianske Kostoľany. Bratislava: Ministerstvo hospodárstva SR, 2020)*

[24] Explained in another assumption.

[25] If possible, it is necessary to provide underfloor or wall heating. If not, classic radiators should be replaced by low-temperature ones.

or extensive measurements, **is not analyzed** in the study and should be performed in the future if 2nd phase solution was about to be implemented.

3.2.4 Assumed pre-heating of heating water in non-refurbished buildings

In some scenarios it is assumed that not all buildings connected to DHS will be renovated to the required level when time of implementation of 2nd phase solution comes. For those cases, it is possible that to achieve thermal comfort at a lower temperature of heating water, (chapter 6.2) the enlarging of heating elements or their change could not be sufficient (previous assumption – chapter 3.2.3). In such cases there is **an assumption that non-refurbished buildings will have installed their decentralized pre-heating systems** which will assure thermal comfort even in colder days (HP for return space heating water or direct electric heating)[26]. If these users refuse the installation of decentralized pre-heating device, for the benefit of all stakeholders it is recommended to allow these users to disconnect from DHS. Due to the preliminary character and scope of this study, no more detailed analysis of this issue has been made.

3.2.5 Assumed reduced heat demand of apartment buildings in Prievidza

Assumed reduced heat demand for space heating of apartment buildings in Prievidza was determined to a level of 36,7 % to 46,5 % **based on** outcomes of **a study made by Friends of the Earth - CEPA**[27]. This assumption was analyzed more in chapter 5.1 where scenarios with more conservative values of heat demand reduction for apartment buildings have been set.

3.2.6 Assumed reduced heat demand of non-apartment buildings in Prievidza

Due to the unavailability of data of heat consumption of **office buildings, schools and school facilities and other non-apartment buildings**[28] which are connected to the current DHS, **reduced heat demand for space heating** of such buildings was assumed from data of heat demand of schools and school facilities analyzed **in the study from Friends of the Earth - CEPA**[29] where an estimated future heat demand of non-apartment buildings was set to a level of 65,3 % to 70,9 % of the current consumption. This assumption was analyzed more in a chapter 5.1 where scenarios with more conservative values of heat demand reduction for non-apartment buildings have been set.

[26] Economic burden of decentralized heating could motivate inhabitants of non-renovated buildings to decide to completely refurbish their buildings.

[27] VILGA, Filip. *Potenciál úspor tepla na vykurovanie budov pripojených do sústavy centrálneho zásobovania teplom v meste Prievidza.* Dostupné tiež z: https://zivotpouhli.sk/novinky/item/331-potencial-uspor-tepla-na-vykurovanie-budov-pripojenych-do-sustavy-centralneho-zasobovania-teplom-v-meste-prievidza

[28] For the purpose of the study all these buildings are called non-apartment buildings

[29] VILGA, Filip. *Potenciál úspor tepla na vykurovanie budov pripojených do sústavy centrálneho zásobovania teplom v meste Prievidza.* Dostupné tiež z: https://zivotpouhli.sk/novinky/item/331-potencial-uspor-tepla-na-vykurovanie-budov-pripojenych-do-sustavy-centralneho-zasobovania-teplom-v-meste-prievidza

3.2.7 Assumed reduced heat demand of apartment and non-apartment buildings in Nováky

Assumed reduced heat demand of buildings connected to DHS **in Nováky was based on a study prepared for Friends of the Earth - CEPA[30].** For design purposes of the 2nd phase concept, the achievable **heat demand reduction of those buildings was set to 35 %.** More information about this issue is possible to find in chapter 5.4.

3.2.8 Assumption of the termination of heat supply from Fortischem factory

For the target period when the 2nd phase DHS for Nováky could be implemented, there is **no longer considered of the heat supply from Fortischem factory**. Based on this assumption the preliminary concept of DHS was dimensioned for all buildings in Nováky (with assumed reduced heat demand – chapter 3.2.7) which are connected to the current NPP DHS and also to the current Fortischem DHS.

3.3 Assumptions of heat losses in a distribution system

Assumptions regarding heat losses and the technical state of the current DH network are described in the following chapters.

3.3.1 Assumptions of heat losses reduction in the piping system

The analysis of heat losses in the DH network **was based on a study made by Friends of the Earth - CEPA[31]**, in which the quantification of the potential for reduction of heat losses for towns of Prievidza and Nováky and the municipality of Zemianske Kostoľany was performed.

3.3.2 Assumption of the suitability of the current piping system and related facilities from a technical perspective

There was an assumption that **the current DH piping system**, respectively the piping system in the target period when the 2nd phase concept was about to be implemented, **would be technically and hydraulically ready for the transition to 4th generation of DHS** and for all the other changes which would come with it (reduced heat demand, lowered network temperature of water etc.). There was also an assumption that all other technical facilities regarding the DH network (substations, control and metering technology etc.) would be optimized to a level that the transition to higher generation of DHS required.

3.4 Assumptions for dimensioning of heat generators

Assumptions important for dimensioning of heat source technologies are described in the chapters below.

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[30] GOLEJ, Július a Miroslav PÁNIK. *Odhad potenciálu úspor energie na vykurovanie a prípravu teplej vody budov zapojených do centrálneho zásobovania teplom z Elektrárne Nováky*. 2020.

[31] VILGA, Filip. *Potenciál zníženia tepelných strát v distribučnom systéme centrálneho zásobovania teplom v regióne Hornej Nitry*. 2021.

3.4.1 Assumption of available lands for DH facilities

Due to the complexity of determining the current land conditions and the preliminary nature of this study, **it was assumed that lands suitable for construction of the 2nd phase technologies** (mainly for solar collectors and seasonal heat storage) **would be secured** in the target period, therefore there is no assessment of the land suitability for a specific heat source investigated in the study.

3.4.2 Assumed absorber area of solar collectors

For purposes of the study and for designs where solar energy was used, **absorber solar area was set to a value of 2,26 m²/collector.**

3.4.3 Assumption of the use of geothermal well Púšť for DH purposes

For the study, it was assumed that **the geothermal well Púšť would be used for the purposes of DHS for Prievidza** and not for the planned recreational purpose[32].

3.4.4 Assumption of suitable conditions for the construction of heat storage accumulators

There was an assumption that **all types of heat accumulators** used in designs in the study **would have suitable conditions** for the time of their construction **to be built up** (e.g.: suitable type of soil for borehole heat storages, suitable groundwater level for pit heat storages, or suitable technical structure of mining spaces for heat accumulation etc.).

[32] VYUŽITIE GEOTERMÁLNYCH VÔD V LOKALITE PÚŠŤ: Zámer činnosti podľa zákona č. 24/2006 Z.z. v znení neskorších predpisov. Banská Bystrica: ENVIGEO, 2018.

3.5 Economic assumptions

Assumptions regarding the economy of designed projects are explained below.

3.5.1 Assumption of building renovation financing

Investment and operating costs associated with the considered renovation of buildings are not included in the heat cost. These costs are assumed to be covered either directly by building users or in the form of co-financing through various financial contributions from dedicated institutions.

3.5.2 Assumption of DH distribution system financing

Assumption 3.3.2 needs some funds to become a reality. The DH network is owned by PTH. Due to the complexity of quantifying the necessary funds for a comprehensive renovation of the piping system (lack of provided data about pipelines), **the impact of investments in the piping reconstruction in heat pricing was not considered**. **In the last chapter** (chapter 11) **estimated investments for the reconstruction of the distribution system** and other regarded facilities **were taken into account for distribution heat cost** (Tab. 40 and Tab. 41).

3.5.3 Assumption of current energy prices

Due to the preliminary nature of the study, it is very difficult to determine the price of energy entering processes since many commodities are dependent on market developments. For this reason, **it was assumed with current energy and fuel prices**.

4 Evaluation of the suitability of an area for DH project

In the 1st phase solution of DHS[33] the current system will be divided into three parts (Prievidza, Nováky, Zemianske Kostoľany). For every part, where new district heating systems are about to be implemented, it is necessary to evaluate the suitability of the particular area for implementation of a new DHS. The division of the current form of the DH network and implementation of new heat sources in the 1st phase solution should be considered as a big intervention in the state of DHS, therefore it is necessary to analyze the suitability of an individual DH network, at least for the smallest municipality (Zemianske Kostoľany). The comparison with other projects that demonstrate a good practice of various types of DHS abroad[34] shows that Prievidza and Nováky have the potential to implement a new DHS and therefore basic indicators for assessing the suitability of construction or reconstruction of the DHS for these towns were not analyzed in more detail.

4.1 Methodics to assess the suitability of a DHS

A basic indicator for an assessment of the suitability of an area for building a DHS is so-called **heat demand density**. This indicator can be calculated by this formula[35]:

$$Heat\ demand\ density\ [kWh/m^2 \cdot a] = \frac{Annual\ heat\ consumption\ (SH + DHW)\ [kWh/a]}{Property\ area\ of\ the\ zone\ [m^2]}$$

The calculated value of the heat demand density is then evaluated according to the table below (Tab. 5).

Tab. 5: Recommended heat demand density

Suitability for building DHS	Heat demand density
Not eligible	< 50 kWh/(a.m^2)
Partly eligible	Between 50 and 70 kWh/(a.m^2)
Eligible	> 70 kWh/(a.m^2)

Source[36]

After analysis of the suitability of an area for building DHS it is necessary to evaluate economic aspects of the project. For this analysis so-called **linear heat demand density** is used which should indicate if a planned project is operationally efficient. The indicator is calculated as it is shown in the formula below[37]:

[33] Explained in the chapter 3.1.1

[34] Comparison was based on available information about users connected to the system, current operation of heating devices and other data.

[35] NUSSBAUMER, Thomas, Stefan THALMANN, Andres JENNI a Joachim KÖDEL. *Handbook on Planning of District Heating Networks*. 2020. ISBN 3-908705-39-8.

[36] NUSSBAUMER, Thomas, Stefan THALMANN, Andres JENNI a Joachim KÖDEL. *Handbook on Planning of District Heating Networks*. 2020. ISBN 3-908705-39-8.

[37] NUSSBAUMER, Thomas, Stefan THALMANN, Andres JENNI a Joachim KÖDEL. *Handbook on Planning of District Heating Networks*. 2020. ISBN 3-908705-39-8.

$$Line\ heat\ demand\ density\ \ [MWh/m \cdot a] = \frac{Annual\ heat\ consumption\ (SH + DHW)\ [MWh/a]}{Total\ length\ of\ the\ pipeline\ route\ [m]}$$

Tab. 6: Recommended linear heat densities of the heat distribution to meet the target value of the specific investment costs

Extension Level		Suitable line heat demand density [MWh/(a.m)]
Initial extension stage	Unfavorable conditions	> 1,4
	Favorable conditions	> 0,7
Final capacity stage	Unfavorable conditions	> 2,0
	Favorable conditions	> 1,2

Source[38]

For most of projects the unfavorable conditions limit should be considered. Unfavorable conditions are aspects that would burden the project in some way from the investment point of view. These include the necessary additional investments for the reconstruction of DH network, the lack of suitable heat sources in the vicinity etc. If the project or the reconstruction of the current DHS has favorable conditions (e.g.: available potential heat source thereabouts), it is allowed to evaluate the indicator according to limit values for favorable conditions[39].

If there are some uncertainties in determining some of the explained indicators, a balance sheet and a budgeted plan income statement should be created (full cost accounting)[40].

4.2 Evaluation of the suitability of DHS for Zemianske Kostoľany

Zemianske Kostoľany is a municipality with 1777 inhabitants[41]. Buildings that are currently connected to the DHS can be seen in the picture below (Figure 1). Annual heat consumption for space heating and DHW preparation is estimated at 2141 MWh[42]. The length of a current heat pipeline from NPP to Zemianske Kostoľany is around 3150 metres[43]. After implementation of the 1st phase solution the main heat pipeline leading from Mine Nováky to Zemianske Kostoľany should be long about 2500 metres[44].

[38] NUSSBAUMER, Thomas, Stefan THALMANN, Andres JENNI a Joachim KÖDEL. *Handbook on Planning of District Heating Networks*. 2020. ISBN 3-908705-39-8.

[39] NUSSBAUMER, Thomas, Stefan THALMANN, Andres JENNI a Joachim KÖDEL. *Handbook on Planning of District Heating Networks*. 2020. ISBN 3-908705-39-8.

[40] NUSSBAUMER, Thomas, Stefan THALMANN, Andres JENNI a Joachim KÖDEL. *Handbook on Planning of District Heating Networks*. 2020. ISBN 3-908705-39-8.

[41] From a municipality website: https://www.zemianskekostolany.sk/obyvatelia.html

[42] GOLEJ, Július a Miroslav PÁNIK. *Odhad potenciálu úspor energie na vykurovanie a prípravu teplej vody budov zapojených do centrálneho zásobovania teplom z Elektrárne Nováky*. 2020.

[43] Value from an energy audit - Správa z účelového energetického auditu pre projekt výstavby sústavy tepelných zariadení alebo jej časti v prevádzke Elektrárne Nováky, odštepný závod: Slovenské elektrárne, a.s. 2020.

[44] KOOR, s.r.o., *ŠTÚDIA REALIZOVATEĽNOSTI Tepelný zdroj pre Nováky a Zemianske Kostoľany*, 2020.

Figure 1: Connected buildings to the current DHS

Source[45]

In Zemianske Kostoľany there is 78 buildings connected to the DHS (70 buildings are from a private sector and 8 buildings should be public ones)[46]. There was an assumption that all these buildings would stay connected to the DHS in the future even after the 2nd system would be implemented. Property land of these buildings was calculated to a value around 17746 m^2 via the online tool ZGBIS[47].

Evaluation of this zone towards the suitability of a new DHS implementation was made according to previous chapter 4.1. First, the heat demand density indicator was calculated:

$$Heat\ demand\ density_{ZK} = \frac{2141000\ kWh/a}{17746\ m^2} = 120{,}6\ kWh/m^2 \cdot a$$

If we compare this value with the limit value from Tab. 5, we can state that from the heat demand density perspective Zemianske Kostoľany is suitable for heat supply by DHS.

Since the heat demand density for Zemianske Kostoľany has been met, the economic indicator (line heat demand density) can be calculated:

$$Line\ heat\ demand\ density_{ZK} = \frac{2141\ MWh/a}{2500\ m} = 0{,}9\ MWh/m \cdot a$$

[45] GOLEJ, Július a Miroslav PÁNIK. *Odhad potenciálu úspor energie na vykurovanie a prípravu teplej vody budov zapojených do centrálneho zásobovania teplom z Elektrárne Nováky*. 2020.

[46] GOLEJ, Július a Miroslav PÁNIK. *Odhad potenciálu úspor energie na vykurovanie a prípravu teplej vody budov zapojených do centrálneho zásobovania teplom z Elektrárne Nováky*. 2020.

[47] https://zbgis.skgeodesy.sk/mkzbgis/sk/kataster?pos=48.800000,19.530000,8

For Zemianske Kostoľany it is necessary to compare calculated line heat demand density value with limits for the final capacity stage and unfavorable conditions (Tab. 6) due to following reasons:

- There is very low or no potential to connect new users to the grid (it is a small municipality and many inhabitants have their own heating systems, therefore the final capacity stage from Tab. 6 was chosen),
- Unsatisfactory condition of the current heat pipelines (necessary reconstruction since the age of distribution network is more than 40 years),
- Seasonal use of DHS (DHW is prepared by individual decentralized heaters during summer[48]),
- Most of connected buildings are houses (there are no apartment buildings connected to the DHS),
- Potential cheap heat source (e.g. mine water) is not in the vicinity of the municipality.

If we compare the resulting value of the linear heat demand density indicator for buildings connected to the DHS with the limit value of 2.0 MWh/a.m (Tab. 6), we can claim, that the resulting value is much lower.

From the statements and calculations performed above, it is possible to assume that it is not economically appropriate to maintain the heat supply from DHS in Zemianske Kostoľany. For purposes of this study, we have therefore no longer considered Zemianske Kostoľany as a zone suitable for the design of the 2nd phase concept. However, it is possible to consider that the area could be suitable for building of the so-called energy communities, where selected neighboring buildings would form a functional decentralized system based on the 5th generation of DH. Unfortunately, due to the scope of this document, this issue was not investigated in the study.

[48] Stated in the preliminary study of the 1st phase solution for Zemianske Kostoľany in the document - KOOR, s.r.o., *ŠTÚDIA REALIZOVATEĽNOSTI Tepelný zdroj pre Nováky a Zemianske Kostoľany*, 2020.

5 Heat demand

Determining the heat demand of buildings in areas with considered heat supply is crucial when dimensioning heat sources. Assumptions related to this issue are summarized in chapters 3.2 and 3.3 with references to specific assumptions in the following subchapters.

5.1 Heat demand for space heating and domestic hot water in Prievidza

After the 1st phase of the coal region's transformation (assumption 3.2.1), there were considered two scenarios of reducing the heat demand for DH in Prievidza based on the systematic renovation of buildings.

Scenarios were created based on a study from Friends of the Earth - CEPA[49]. As an “at least limit” for the necessary renovation of buildings was selected the category TPB 5[50], which means that a building that was built or renovated at TPB level 5 and higher (e.g. since 2013), was understood as the building for which no renovation was required until the target period[51]. Buildings belonging to TPB level 4 and below were a part of different renovation scenarios (explained below).

Tab. 7: Classification of existing buildings in TPB levels according to the build or major renovation period

TPB category	Built or major renovation period	Construction system
TPB1a	until 1984	Burnt Clay Brick, other masonry
TPB1b	until 1984	Concrete Brick, Precast Blocks and Panels
TPB2	1984–1992	Concrete Brick, Engineering Bricks
TPB3	1993–1996	Various materials and compositions
TPB4	1997–2012 (built) 2003–2012 (major renovation)	Various materials and compositions
TPB5	2013-2015	Various materials and compositions
TPB6	2016 to the present (required)	Various materials and compositions
TPB7	from 2020 (recommended)	Various materials and compositions

Source: Friends of the Earth – CEPA based on methodics [52]

The target TPB levels for the renovation of buildings in mentioned scenarios were TPB 6 (legislatively required level) and TPB 7 (legislatively recommended)[53].

[49] VILGA, Filip. *Potenciál úspor tepla na vykurovanie budov pripojených do sústavy centrálneho zásobovania teplom v meste Prievidza.* Dostupné tiež z: https://zivotpouhli.sk/novinky/item/331-potencial-uspor-tepla-na-vykurovanie-budov-pripojenych-do-sustavy-centralneho-zasobovania-teplom-v-meste-prievidza

[50] TPB 5 (thermal protection of a building) is a level of a thermal-technical part of a building with an expected period of construction or significant renovation of the building since 2013 until 2015. Further information can be found in a document - Metodika na stanovenie potreby energie v sektore budov, available online here https://cepa.priateliazeme.sk/images/publikacie/EVS_vystupy/Metodika_budovy_web.pdf

[51] The assumption that no major renovation will be required for buildings at the TPB 5 level or higher was based on the creation of the most feasible heat demand scenarios for the proposed Prievidza heating solutions. By no means is this the opinion of authors of this study on the issue of building renovation.

[52] BENDŽALOVÁ, Jana a Daniela MUŠKÁTOVÁ. Metodika na stanovenie potreby energie a potenciálu energetických úspor v sektore budov: Metodický postup pre tvorbu regionálnych nízkouhlíkových stratégií. 2020. Dostupné z: https://energoportal.org/images/dokumenty/Vystupy_EVS/Metodika_budovy_web.pdf

[53] According to STN 730540-2

Scenarios for the total heat demand reduction were as follows:

Scenario A (applies to buildings in the urban districts Kopanice, Zápotôčky, and Necpaly):

- Main assumption - all buildings will meet the minimum level TPB 5 in the target period[54].
- Renovation is no longer foreseen for existing buildings that already meet level TPB 5 or higher.
- All existing buildings that belong to level TPB 4 or below will be renovated, partly to level TPB 6 (50% of renovated buildings)[55] and partly to level TPB 7 (50% of renovated buildings).

Scenario B_1 (a pessimistic view of the buildings renovation in urban areas Píly a Staré mesto[56]):

- Main assumption – not all buildings will meet the minimum level TPB 5 in the target period (see third bullet below).
- Renovation is no longer foreseen for existing buildings that already meet level TPB 5 or higher.
- Existing buildings that belong to level TPB 4 or below will not all be renovated but only half of them. Expected levels of these renovated buildings are TPB 6 (50% of renovated buildings) and TPB 7 (50% of renovated buildings)[57].

Scenario B_2 (an optimistic view of the buildings renovation in urban areas Píly a Staré mesto):

- Main assumption - all buildings will meet the minimum level TPB 5 in the target period.
- Renovation is no longer foreseen for existing buildings that already meet level TPB 5 or higher.
- All existing buildings that belong to level TPB 4 or below will be renovated, half of them to level TPB 6 and the remaining half to level TPB 7.

5.2 Heat losses in the district heating network in Prievidza

In the target period, not only the reduction of space heating is considered (chapter 5.1), but also the reduction of heat losses in the heat distribution piping system. The scenarios described below were created based on the Friends of the Earth - CEPA study document[58].

[54] The target period is the intended period of implementation of the proposed thermal solution.

[55] "50 % of renovated buildings" means 50 % of the heat demand for space heating of defined buildings.

[56] Under the label „Staré mesto" are for simplification included urban districts Staré mesto, Stred, Dlhá ulica and Mládež.

[57] In short, scenario B assumes that 50% of currently non-renovated buildings will remain without renovation, 25% of buildings will be renovated to TPB 6 and 25% to TPB 7.

[58] VILGA, Filip. *Potenciál zníženia tepelných strát v distribučnom systéme centrálneho zásobovania teplom v regióne Hornej Nitry*. 2021.

Percentage reductions of heat losses in pipes and their values were assigned to the scenarios from the previous chapter (Chapter 5.1) and together they indicated the total heat demand of a particular scenario based of which heat sources were dimensioned (chapter 6).

Scenarios for reductions of heat losses in the DH network were as follows.

Scenario A and **scenario B_1:**

- For these scenarios, it was assumed that up to 75% of the current heat distribution systems, which are currently insulated on site with conventional insulation, will be revitalized to pre-insulated pipes[59].
- Such a reconstruction will mean a reduction of heat losses of the current piping system to **10.2 %**.

Scenario B_2:

- For this scenario, it was assumed that all heat pipelines insulated on site by conventional insulation will be revitalized to pre-insulated pipes.
- Such a reconstruction will mean a reduction of heat losses of the current piping system to **7 %**.

5.3 Total heat demand in Prievidza

Heat sources of proposed heating solutions (chapter 6) were dimensioned based on scenarios of total heat demand, which consisted of heat demand for space heating and DHW (chapter 5.1) and heat losses of the district heating piping system (chapter 5.2).

The proposal of the system did not consider the consumption of the technological heat, which is not included in the 1st phase of the regional DHS either. This is because industrial enterprises currently connected to the DH have stated that they would stop the consumption of technological heat from the DHS after 2023.

The total heat demand of particular scenarios can be seen in the following table (Tab. 8).

Tab. 8: Total heat demand of particular scenarios

Scenario	Urban districts	Total heat demand [MWh/a]
A	Kopanice, Zápotôčky a Necpaly	41 067
B_1	Píly a Staré mesto	35 268
B_2	Píly a Staré mesto	24 400

Source: Own calculation based on data from studies [60,61]

[59] By a classic insulation is meant an insulation on old steel pipes, which is mostly made of a mineral mat and its top cover consists of an aluminum layer.

[60] VILGA, Filip. *Potenciál úspor tepla na vykurovanie budov pripojených do sústavy centrálneho zásobovania teplom v meste Prievidza.* Dostupné tiež z: https://zivotpouhli.sk/novinky/item/331-potencial-uspor-tepla-na-vykurovanie-budov-pripojenych-do-sustavy-centralneho-zasobovania-teplom-v-meste-prievidza

[61] VILGA, Filip. *Potenciál zníženia tepelných strát v distribučnom systéme centrálneho zásobovania teplom v regióne Hornej Nitry*. 2021.

5.4 Heat demand for space heating, DHW preparation and coverage of heat losses in the DHS in Nováky

The heat from DHS in Nováky is currently distributed from two suppliers - NPP heat through the heat supplier, the company Benet s.r.o. (branches 2, 4, and 5) and heat from the chemical plant of Fortischem a.s. (own branch). These facts can be seen in the following figure (Figure 2). From the heating season in 2023 (the end of operation NPP), a new heating solution in Nováky should start operating. The proposed solution of the 1st heating phase of Nováky by PTH and KOOR s.r.o. is explained in chapter 8.1.

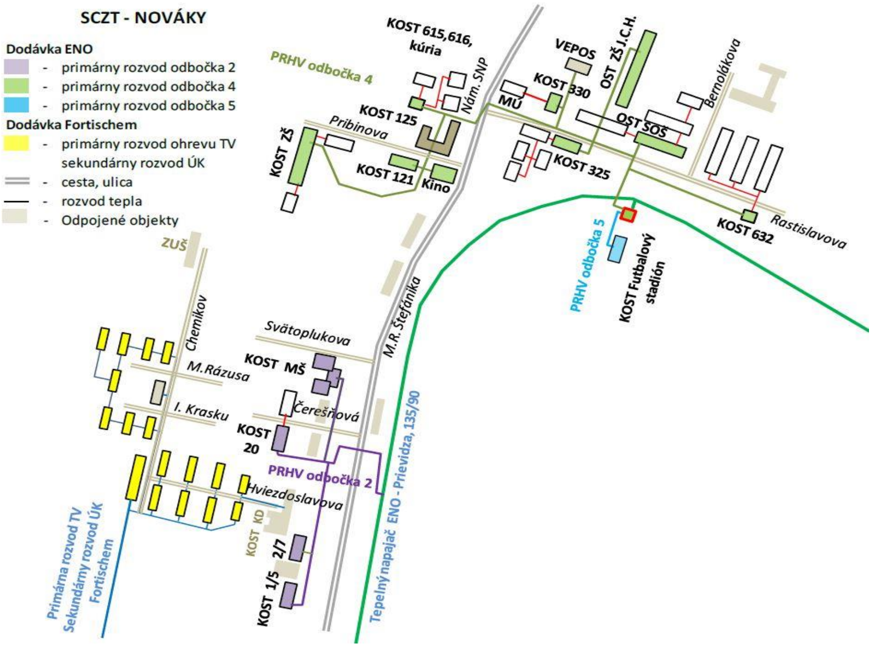
Reference values of heat demand for SH and DHW of currently connected buildings to individual branches of DHS were determined based on the study[62] and can be seen in the table below (Tab. 9).

Tab. 9: Current total heat demand of buildings sorted by branches

Branch	Current total heat demand of the buildings [MWh/a]
Branches 4 and 5	4 000
Branch 2	750
Branch Fortischem	2 000
Total	6 750

Source: Friends of the Earth – CEPA based on the study[63]

Figure 2: Heat distribution in Nováky



Source: Koncepcia rozvoja mesta Nováky v oblasti tepelnej energetiky[64]

[62] VILGA, Filip. *Potenciál zníženia tepelných strát v distribučnom systéme centrálneho zásobovania teplom v regióne Hornej Nitry*. 2021.
[63] VILGA, Filip. *Potenciál zníženia tepelných strát v distribučnom systéme centrálneho zásobovania teplom v regióne Hornej Nitry*. 2021.
[64] NOVACO s.r.o., *Aktualizácia koncepcie rozvoja mesta Nováky v oblasti tepelnej energetiky*, 2021.

Values in the table (Tab. 9) indicate the current heat demand of the buildings connected to the defined DHS. For the design of the 2nd phase heating concept, it is necessary to determine the future total heat demand for these buildings, as a major renovation of the buildings is crucial for the implementation of the 4th generation DHS solution. Based on this fact, it was necessary to determine potential savings for the total heat demand of buildings connected to the DHS in the town of Nováky. Based on the analysis of a study created for Friends of the Earth - CEPA[65], the potential for savings in the total heat demand of buildings was estimated to 35%[66]. The reduced total heat demand of objects connected to individual branches can be seen in the table (Tab.10)

Tab. 10: Estimated reduced total heat demand of the buildings sorted by branches

Branch	Reduced total heat demand of the buildings [MWh/a]
Branches 4 and 5	2 600
Branch 2	487,5
Branch Fortischem	1 300
Total heat demand	**4 387,5**

Source: Own analysis

It is still necessary to add heat losses of the distribution piping system to the values of the table above (Tab. 10). These values were determined according to the analysis from the study[67] and according to the assumptions summarized in chapter 3.3. The total heat demand for space heating, DHW, and the coverage of heat losses of heat distribution of DHS is determined in the table below (Tab. 11). Data from this table will be used for the design of heat sources.

Tab. 11: Estimated total heat demand for the design of heat sources in the 2nd phase concept of DHS in Nováky

Branch	Estimated heat loss of distribution system [%]	Total heat demand [MWh/a]
Branches 4 and 5	7	2 782
Branch 2	5,6	514,8
Branch Fortischem	3,7	1 348,1
Total heat demand	**-**	**4 644,9**

Source: Own analysis

[65] GOLEJ, Július a Miroslav PÁNIK. *Odhad potenciálu úspor energie na vykurovanie a prípravu teplej vody budov zapojených do centrálneho zásobovania teplom z Elektrárne Nováky.*

[66] In the case of real planned implementation of the proposed solution, it is necessary to make a more detailed thermal-technical analysis of buildings in Nováky connected to DHS and determine a more accurate potential for savings in heat demand for SH and DHW.

[67] VILGA, Filip. *Potenciál zníženia tepelných strát v distribučnom systéme centrálneho zásobovania teplom v regióne Hornej Nitry.* 2021.

6 Basic characteristics of the concept

Basic characteristics of the DH concept based on the 4th generation are described in the following chapters. These parameters are valid for both municipalities – Prievidza and Nováky.

6.1 Basic characteristics of the designed DHS

DH concept for Prievidza and Nováky is based on the 4th generation that generally considers with several RES working synergically thanks to implemented immediate and seasonal heat accumulation, minimized heat demand, reduced heat loss in pipelines and advanced smart control and metering technologies. The basic sign of 4th generation DHS is a lowered temperature of network water (from 30 to 70 °C) thanks to which more RES and different kinds of waste heat (datacentres, industries, etc.) can be included since there is no need for a source with such high temperature heat. An investigation of which temperature level is suitable for designed systems is described in the following chapter 6.2.

6.2 Temperature level of supply network water

Temperature level of the primary supply water is a very important parameter of DHS. In 4th generation DHS a lowered temperature of the water is considered. For proposed systems supply water temperatures **from 55 °C** (summer months) **to 70 °C** (cold winter days) were chosen. Simplified relation between supply water temperature and outside temperature can be seen in the picture below (Figure 3). Designed primary supply temperature of water in the system influences many factors, mainly:

- Character of heat consumption,
- Method of DHW preparation.

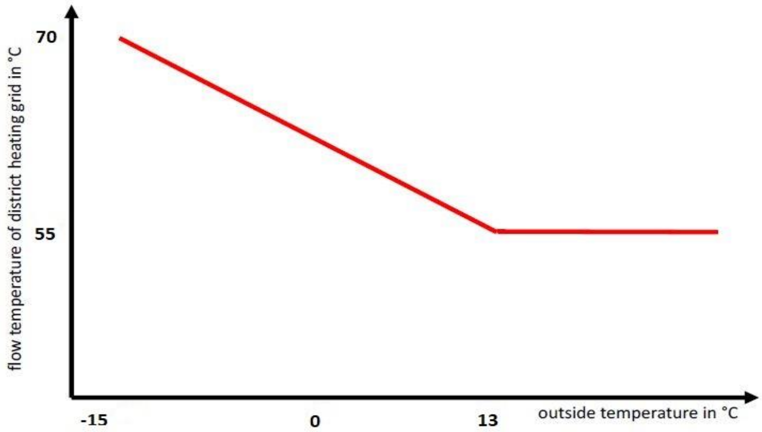
The character of the heat supply or consumption for Prievidza and Nováky will be defined just by the heat for SH and DHW preparation. There is no requirement for the process heat, not even in the proposed 1st phase solution. Due to this reason, a major factor influencing a choice of primary water supply temperature in the network will be a form of heat transfer in the network (direct or indirect) and a type of thermal protection of connected buildings. For the concept, there is an assumption that the heat transfer will be indirect, which means through heat exchangers in DH substations and therefore a minimum mean temperature difference[68] of their heat exchangers has to be taken into account. In the concept, we considered that a complex renovation of some buildings would happen according to scenarios described in chapter 5.1. Before the implementation of such a system with the lowered primary supply temperature of network water, detailed measurements and analysis of the sufficiency of current radiators in individual buildings will be needed (chapter 3.2.3). For buildings, which in the target period would not be renovated to required parameters

[68] From a technical point of view, we took into account that heat exchanger stations would have correctly dimensioned plate heat exchangers and the mean logarithmic temperature difference of a plate heat exchanger would then be 5 °C (maximum 10 °C).

(scenario B_1), the assumption 3.2.4 had to be taken into account. Based on all these statements and assumptions, it is possible to consider that a maximum primary water supply temperature of 70 °C, which would mean a secondary supply water temperature (heating water temperature) between 60 to 65 °C at a considered mean temperature difference of heat exchangers. This temperature range should be enough to ensure thermal comfort of users (for users in unrenovated buildings, a higher temperature of secondary supply water will be needed – explained in the assumption 3.2.4).

Another important factor, which influences a water supply temperature in DHS is a way of DHW preparation (due to an issue of Legionella bacteria). In the concept, we do not plan to propose small DHW accumulators in buildings since it is well-known that in the stagnant water of higher volumes the reproduction of Legionella is faster[69]. Taking into account this fact, only flow heating of DHW through installed heat exchangers is considered. It was assumed that user buildings in the target period would have prepared DHW systems in a way that only a minimum volume of water would be between heat exchangers and water taps[70]. The detailed technical analysis of such systems has not been further investigated due to the scope and preliminary character of this study. Based on all assumptions and facts described above, a value of 55 °C for the primary supply water temperature has been chosen in designed DH networks. This minimum temperature of supply water in the DH system will ensure that the DHW temperature will be in the range from 45 to 50 °C[71].

Figure 3: Supply temperature as a function of the outside temperature



Source: Own processing based on a document[72]

[69] LUND, Henrik et al. *4th Generation District Heating (4GDH) Integrating smart thermal grids into future sustainable energy systems*. 2014.

[70] Some companies already install small plate heat exchangers directly in apartments, which reduces the volume of DHW in the system and the risk of an incidence of Legionella bacteria as well.

[71] Considered mean logarithmic difference of a plate heat exchanger from 5 to 10 ° C.

[72] RUTZ, Dominik, Christian DOCZEKAL, Richard ZWEILER, Morten HOFMEISTER a Linn LAURBERG JENSEN. *Small Modular Renewable Heating and Cooling Grids: A Handbook*. 2017. ISBN 978-3-936338-40-9.

7 Proposed concept of DH system in Prievidza

Specific technical parameters of technologies used in the design of the 2nd phase solution for Prievidza are described in the following chapters.

7.1 Choice of heat sources

Heat generators have been chosen in a way to be compatible with the 4th generation of DHS definition. In a case, when a technical explanation of a calculation of a specific heat source has been too complicated, further information has been described in appendixes of this study (references were in the text). A software Sunstore 4 Feasibility Evaluation Tool[73] was used for calculation.

7.2 Division of DHS

To design heat generators, the total heat demand was necessary to know. It has been calculated in chapter 5.3 and it was calculated as a sum of the considered building heat demand and heat distribution losses. The total heat demand has been divided into three scenarios based on an assumption of a different building renovation speed in different settlements (look the chapter 3.2). While designing technologies for the DHS in Prievidza to cover this heat demand, it was found, that the optimum solution would be a division of the DHS into two subsystems[74]:

- Northern DHS – settlements Kopanice, Zápotôčky a Necpaly,
- Southern DHS – settlements Píly and Staré mesto.

The division can be seen in the picture (Figure 27) in Appendix 1.

7.3 Northern DHS in Prievidza

The northern part of the designed system was marked as the scenario A (look the chapter 5.3). This part of the town had no geothermal source of energy, available mine water or another source of low or high potential heat in the vicinity. Based on this predisposition, the most suitable basic heat source seemed to be the use of solar collectors in combination with a seasonal heat storage technology, which would partially cover peak loads during a winter season. To cover rest of peak load, a biomass boiler had to be designed. The placement of sources was according to the assumption 3.4.1. Due to limitations described in following chapters, two scenarios for the northern part of Prievidza have been designed.

[73] The software was modified for the purpose of this study by authors of the study.

[74] In the case of maintaining one DHS for Prievidza, a designed seasonal heat accumulator would be built on gigantic dimensions.

7.3.1 Scenario A_1 – solar collectors, seasonal heat storage and biomass boiler

Scenario A_1 was based on a combination of solar collectors with a seasonal heat accumulation. The seasonal heat storage was dimensioned as big as current technological possibilities allow. A chosen type of accumulator was a pit thermal energy storage which belongs to the most economic ones in volumes between 60 to 200 thousand cubic metres[75]. Technical limitation was determined according to the volume of the pit heat storage in Vojens[76]. According to the size of the designed pit storage, a solar collector area was calculated. A type of discharging of the accumulator was direct in the scenario A_1 which meant that there was no HP to cool down the accumulated water. Technical parameters of the solar collector technology combined with the seasonal pit thermal energy accumulator can be seen in the table below (Tab. 12).

Tab. 12: Technical specification of solar collectors and the pit thermal storage for the scenario A_1 (northern DHS)

Parameter	Value
Efficiency of solar collectors	40 %
Efficiency of the accumulator	70 %
Type of the seasonal accumulator	pit storage
Global horizontal solar radiation[77]	1 197 kWh/a.m^2
Ratio of a seasonal storage volume to a solar collector area	2,4 m^3/m^2
Calculated solar collector gain	38,1 GWh/a
Calculated net solar gain	26,7 GWh/a
Needed solar collector area	79 600 m^2
Number of solar collectors	35 221 pcs
Needed volume of seasonal storage technology	191 000 m^3

Source: Calculated outputs and own chosen inputs based on research and analysis

Discharging of the designed accumulator should cover peak loads until the beginning of December by estimation[78]. Since that time a biomass boiler will have to be in operation along with the accumulator (Figure 5). Characteristics of the biomass boiler can be seen in the table below (Tab. 13). Regarding the thermal protection of buildings (buildings in a level of

[75] KALLESØE, A.J. a T. VANGKILDE-PEDERSEN. Underground Thermal Energy Storage (UTES): state-of-the-art, example cases and lessons learned. HEATSTORE project report, 2019, 130 s.

[76] The volume of the largest built pit reservoir in the world in the Danish town of Vojens was chosen as the limit of feasibility. Information about this project is available online here: https://stateofgreen.com/en/partners/ramboll/solutions/world-largest-thermal-pit-storage-in-vojens/

[77] The global horizontal radiation for the Upper Nitra Basin was determined from the Global Solar Atlas application and represents a value of solar radiation incident per year to 1 m^2 in this area.

[78] Depends on other factors, such as weather etc.

TPB 5 or higher), full load hours were determined to 2000 h/a[79]. Maximum boiler capacity was then calculated and its value was 7,2 MW[80].

Tab. 13: Technical specification of a biomass boiler for the scenario A_1 (northern DHS)

Parameter	Value
Boiler efficiency	85 %
Maximum boiler capacity	7,2 MW
Estimated full load hours of the boiler	2 000 h/a
Needed energy in biomass	16,9 GWh/a
Calculated net biomass boiler gain	14,4 GWh/a

Source: Calculated outputs and own chosen inputs based on research and analysis

Expected annual coverage of chosen heat sources for the scenario A_1 was then as follows:

- Solar system and pit thermal energy storage – 65 %,
- Biomass boiler – 35 %.

Chosen heat sources had to cover the annual heat consumption of 41.1 GWh/year in total (Tab. 8). Total thermal capacity of all heat generators was 20,5 MW[81]. Estimated heat source coverage during a year can be seen in the picture below (Figure 5). For a more detailed determination of annual heat source use, mainly seasonal heat accumulator, it is necessary to perform a more complex mathematical analysis which was not possible in this study due to its preliminary character. The solution scheme is in the picture below (Figure 4).

Figure 4: Scheme of the thermal solution for scenario A_1

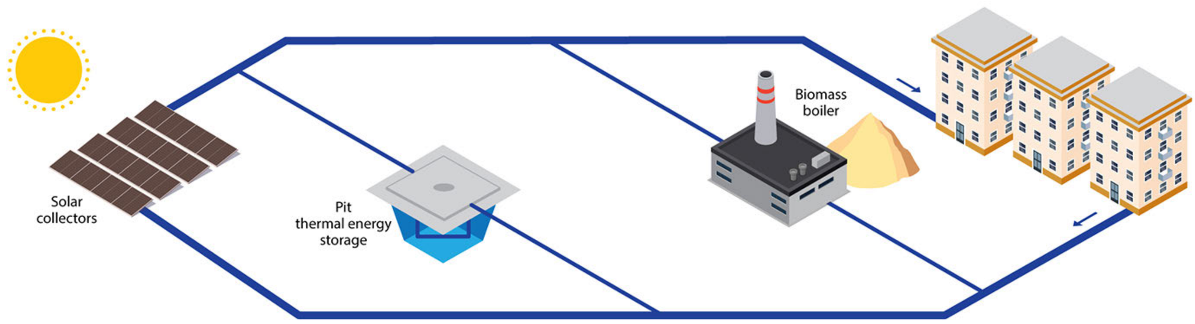


Illustration: R. Watzka

Possible annual exploitation of solar energy through the seasonal accumulator can be estimated from the picture below (Figure 5). Accumulated heat in the pit storage should be able to cover all heat demand during October and November (orange color). From December until the beginning of April, the biomass boiler would need to be in operation. There is also direct use of solar collectors (yellow color) throughout the year and during summer months

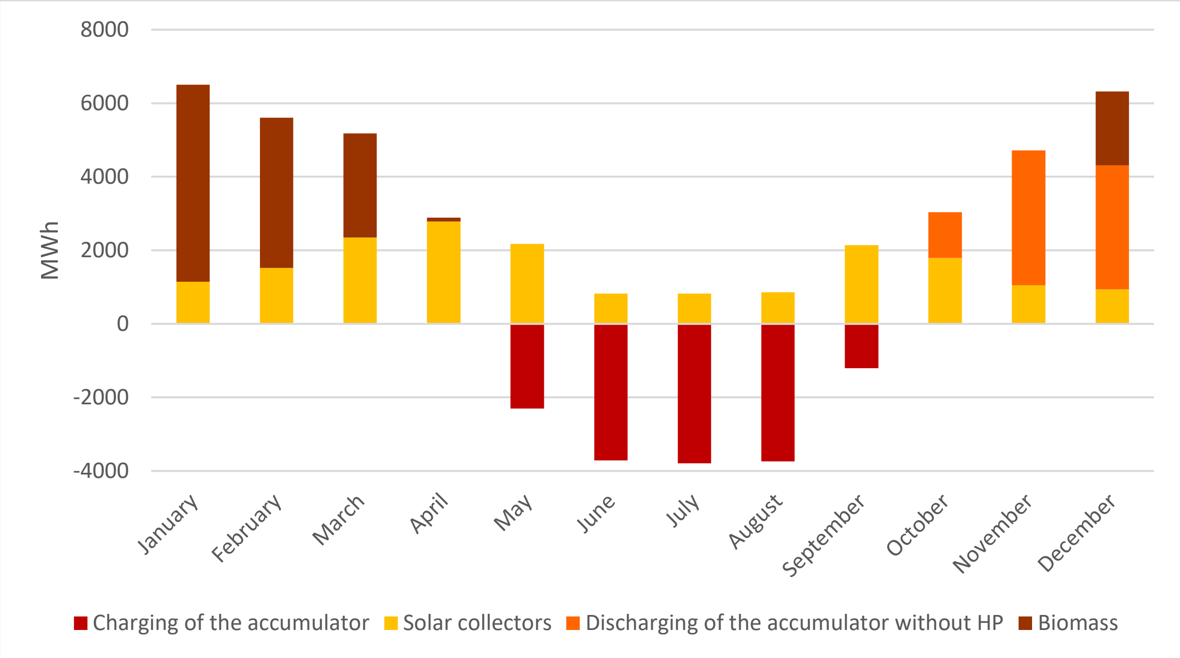
[79] Estimated value based on analysis in Appendix 3 of this study according to a document *Handbook on Planning of District Heating Networks, 2020.*

[80] For optimization of heat load peaks it is possible to divide the capacity into more pieces of biomass boilers.

[81] It is not an installed thermal power which is higher since the system is more complex due to the combination of the solar system with the accumulation.

they are the only heat source supplying heat to the DHS since there is just a need for DHW. There is also an assumption that the storage will provide a short-term accumulation of heat from day to night. From May until September, heat charging of the designed seasonal accumulator should happen since there is a heat surplus.

Figure 5: Estimated heat source coverage during a year for scenario A_1



Source: Based on own analysis.

7.3.2 Scenario A_2 – solar collectors, seasonal heat storage with HP and biomass boiler

Scenario A_2 was based on a solar system in combination with seasonal heat storage with HP for its discharging. The added HP secured better exploitation of the accumulated thermal energy of the pit storage which caused a smaller needed volume of this technology[82]. According to the size of the designed pit storage, a solar collector area was calculated. Parameters of the combination solar collectors, pit thermal energy storage and HP can be seen in the table below (Tab.14)

Tab. 14: Technical specification of solar collectors and the pit thermal storage with HP for the scenario A_2 (northern DHS)

Parameter	Value
Efficiency of solar collectors	40 %
Efficiency of the accumulator	70 %
Type of the seasonal accumulator	pit storage
Global horizontal solar radiation [83]	1 197 kWh/a.m^2

[82] More information about this issue can be found in Appendix 2.

[83] The global horizontal radiation for the Upper Nitra Basin was determined from the Global Solar Atlas application and represents a value of solar radiation

Ratio of a seasonal storage volume to a solar collector area	1,8 m^3/m^2
Calculated solar collector gain	29,3 GWh/a
Calculated net solar gain	20,5 GWh/a
Needed solar collector area	61 300 m^2
Number of solar collectors	27 124 pcs
Needed volume of seasonal storage technology	110 300 m^3
SPF of HP	3,4
Needed capacity of HP	5,1 MW
Estimated full load hours of the HP	1 600 h/a
Annual electricity consumption of HP	3,0 GWh/a
Calculated net HP gain	10,3 GWh/a

Source: Calculated outputs and own chosen inputs based on research and analysis

Discharging of the accumulator through the HP should cause a longer heat supply compared to a version without HP but for the coldest days, there still be a need for a biomass boiler. Parameters of such boiler are in the table below (Tab.15).

Regarding the thermal protection of buildings (buildings in a level of TPB 5 or higher), full load hours of the biomass boiler were determined to 2000 h/a according to which a maximum boiler capacity was chosen (5,1 MW).

Tab. 15: Technical specification of a biomass boiler for the scenario A_2 (northern DHS)

Parameter	Value
Boiler efficiency	85 %
Maximum boiler capacity	5,1 MW
Estimated full load hours of the boiler	2 000 h/a
Needed energy in biomass	12,1 GWh/a
Calculated net biomass boiler gain	10,3 GWh/a

Source: Calculated outputs and own chosen inputs based on research and analysis

Expected annual coverage of chosen heat sources for the scenario A_2 was then as follows:

- Solar system, pit thermal energy storage with HP – 75 %,
- Biomass boiler – 25 %.

incident per year to 1 m^2 in this area.

Scenario A_2 was designed as a counter-proposal to the scenario A_1 to eliminate the use of biomass as much as possible. However, due to the unavailability of other sources of low or high-potential heat in the vicinity and for the safest and most economic heat supply, it is not recommended to reduce the annual heat production of the biomass boiler more than designed 25%[84]. An estimated diagram of the annual use of heat sources (Figure 7) shows that the discharge of the seasonal heat storage by the HP can cover the heating period until January. Until then it is necessary to use the biomass boiler as well[85].

In total, heat sources had to cover the same amount of heat demand as in scenario A_1 and it was 41,1 GWh/a (Tab. 8). Total thermal capacity of all heat generators was also the same – 20,5 MW[86]. Estimated heat source coverage during a year can be seen in the picture below (Figure 7). The solution scheme is in the following picture (Figure 6).

Figure 6: Scheme of the thermal solution for scenario A_2

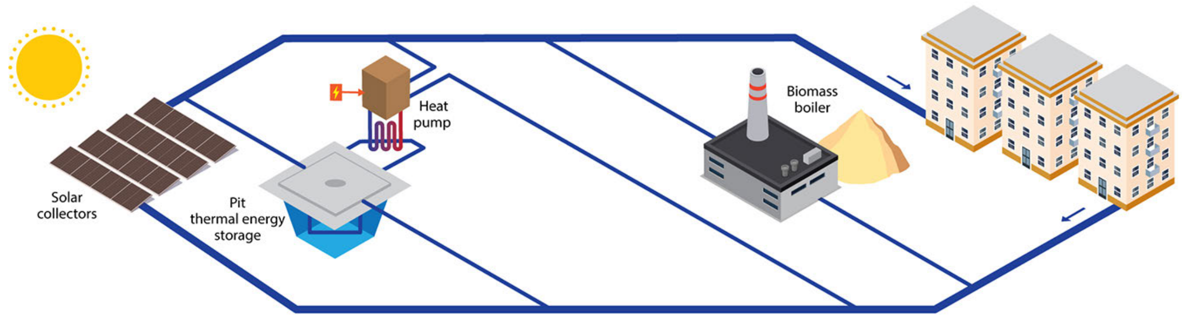
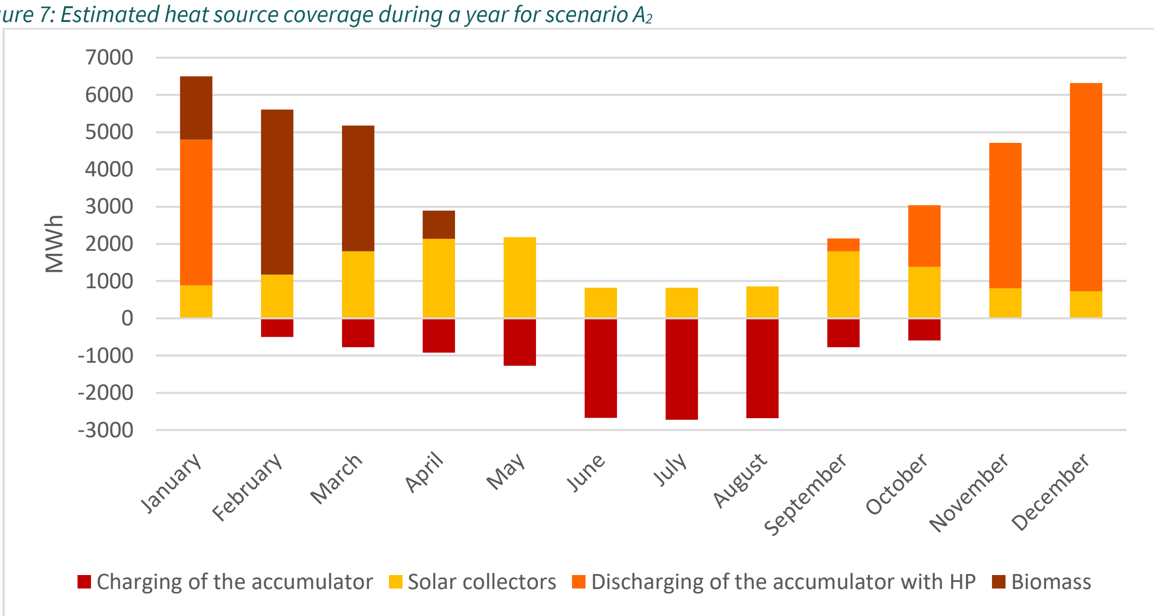


Illustration: R. Watzka

Figure 7: Estimated heat source coverage during a year for scenario A_2



Source: Based on own analysis.

[84] It is necessary to use only biomass, the use of which is sustainable.

[85] To more accurately determine the annual use of individual resources, especially the seasonal accumulator, it would be necessary to perform more complex mathematical modelling, which could not be done within the scope of this study.

[86] It is not an installed thermal power which is higher since the system is more complex due to the combination of the solar system with the accumulation.

The influence of the HP on the increase of heat storage capacity is significant. The inclusion of accumulation with discharging through the HP caused a reduction of the required solar collector area as well as the required volume of the accumulator, although, the annual coverage of the seasonal storage technology is greater (Figure 7). Cooling down the seasonal storage to lower temperatures also affected its charging as it is possible to accumulate heat even at a lower temperature level and thus store more heat. These were significant advantages of this solution compared to the storage technology without HP. On the other hand, if you use an accumulator with the HP, there are higher operating costs (electricity for the HP). However, if the thermal solution is limited by the need for huge thermal energy storage that deviates from the current technical standards, then it is appropriate to consider how this dimension could be reduced, e.g. by the inclusion of a HP.

7.4 Southern DHS in Prievidza

The southern part is divided into two scenarios according to the heat demand – scenarios B_1[87] and B_2[88] (look the chapter 5.3). Mine water in a village Cígel and a geothermal well Púšť were considered as possible heat sources since there are located in the vicinity of settlements Píly and Staré mesto. The use of mine water in Cígel for DH purposes is planned even for the 1st phase solution by company PTH[89]. Geothermal water of the well Púšť (Š1-NB IV) should be used as a heat source for a recreational centre[90], however, according to the latest available data of the Slovak Hydrometeorological Institute (2019), this geothermal well has not been used yet[91] and therefore we consider it as a potential heat source (assumption 3.4.3). The temperature of the geothermal water at a wellhead is 51 °C and the mine water temperature is around 12 °C therefore their use in terms of DH supply is possible only with a HP.

As a basic heat source that should operate as often as possible were chosen solar collectors with seasonal heat storage with discharging through a HP. The solar system in this configuration should supply heat to the DHS at least until the end of a year. A considered seasonal heat accumulator was a borehole type due to a calculated volume of the accumulated substance. The HP system using mine and geothermal water should be used throughout the year to expect for periods when the solar system can cover all heat load demand (summer months). For winter time (the highest peak loads) a biomass boiler was designed but only for scenario B_1 which works with higher heat demand compared to the scenario B_2.

[87] Pessimistic analysis of the renovation wave of buildings in the urban district of Píly and Staré mesto and the expected renovation of 75 % of current heat pipelines.

[88] Optimistic analysis of the renovation wave of buildings in the urban district of Píly and Staré mesto and the expected renovation of all heat pipelines.

[89] Horúcovod Baňa Cigeľ - Prievidza: Zámer činnosti podľa zákona č. 24/2006 Z.z o posudzovaní vplyvov na životné prostredie v znení neskorších predpisov. Banská Bystrica: ENVIGEO, 2021.

[90] Hydrogeologický vrt Š1-NB IV s geotermálnou vodou - lokalita Púšť pri Prievidzi: Súhmná technická správa. Banská Bystrica: ENVIGEO, 2018.

[91] Využiteľné množstvá sú uvedené podľa rozhodnutí č.19/2010, č.162/2017 a údajov Vodohospodárskej bilancie množstva podzemnej vody za rok 2019 (SHMÚ).

7.4.1 Scenario B_1 – solar collectors, seasonal heat storage with HP, mine and geothermal water and biomass boiler

Scenario B_1 is based on an assumption that not all buildings connected to DHS will meet a level TPB 5 (look the chapter 5.1) and the reconstruction of the current heat network will be just partial (look the chapter 5.2).

The dimensioning of heat generators has been based on the availability of mine and geothermal water. The mine water was dimensioned to the full usable range with cooling down through HP to 5 °C[92]. The geothermal water was set to a more economical way, the cooling down via HP was to 15 °C[93]. Due to the character of buildings of the scenario B_1, full load hours of these HP were set to 2400 hours a year[94].

Parameters of HP for mine and geothermal water are shown in tables below (Tab. 16 and Tab. 17).

Tab. 16: Technical parameters of the HP for mine water for the scenario B_1 (southern DHS)

Parameters	Value
SPF	3,4
Capacity of the HP	4,1 MW
Estimated full load hours of the HP	2 400 h/a
Electricity consumption	2,9 GWh/a
Generated heat	9,8 GWh/a

Source: Calculated outputs and own chosen inputs based on research and analysis

Tab. 17: Technical parameters of the HP for geothermal water from the well for the scenario B_1 (southern DHS)

Parameters	Value
SPF	4
Capacity of the HP	3,6 MW
Estimated full load hours of the HP	2 400 h/a
Electricity consumption	2,2 GWh/a
Generated heat	8,6 GWh/a

Source: Calculated outputs and own chosen inputs based on research and analysis

Since there was an assumption that not all buildings would meet in the target period a level of TPB 5 or higher, a biomass boiler had to be designed in the scenario B_1 to ensure a sufficient supply temperature of network water in the coldest days. A capacity of this boiler was 1,5 MW. Technical parameters of the boiler can be seen below (Tab. 18).

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[92] Considered SPF of 3,4.

[93] More economic operation will result in a higher SPF – considered SPF of 4,0.

[94] Estimation made according to an analysis in Appendix 3 based on a document *Handbook on Planning of District Heating Networks, 2020.*

Tab. 18: Technical specification of a biomass boiler for the scenario B_1 (southern DHS)

Parameters	Value
Boiler efficiency	85 %
Maximum boiler capacity	1,9 MW
Estimated full load hours of the boiler	2 400 h/a
Needed energy in biomass	5,4 GWh/a
Calculated net biomass boiler gain	4,6 GWh/a

Source: Calculated outputs and own chosen inputs based on research and analysis

The combination of solar collectors and seasonal heat storage with a HP was designed to cover a base load with partial coverage of peak loads. Due to the estimated heat demand and heat load demand and the resulting amount of needed accumulated substance, a borehole heat storage seemed to be the most suitable heat accumulating technology. Technical parameters of these technologies are below (Tab. 19).

Tab. 19: Technical specification of solar collectors and the borehole storage with HP for the scenario B_1 (southern DHS)

Parameters	Value
Efficiency of solar collectors	40 %
Efficiency of the accumulator	70 %
Type of the seasonal accumulator	borehole storage
Global horizontal solar radiation[95]	1 197 kWh/a.m^2
Ratio of a seasonal storage volume to a solar collector area	1,0 m^3/m^2
Calculated solar collector gain	15,1 GWh/a
Calculated net solar gain	10,6 GWh/a
Needed solar collector area	31 600 m^2
Number of solar collectors	13 982 pcs
Needed volume of seasonal storage technology	31 600 m^3
Physical storage volume borehole	126 400 m^3
SPF of HP	3,4
Needed capacity of HP	0,7 MW

[95] The global horizontal radiation for the Upper Nitra Basin was determined from the Global Solar Atlas application and represents a value of solar radiation incident per year to 1 m^2 in this area.

Parameters	Value
Estimated full load hours of the HP	2400 h/a
Annual electricity consumption of HP	0,5 GWh/a
Calculated net HP gain	1,8 GWh/a

Source: Calculated outputs and own chosen inputs based on research and analysis

Expected annual coverage of chosen heat sources for the scenario B_1 was then as follows:

- Solar system, borehole thermal energy storage with HP – 35 %,
- HP for mine water and geothermal water – 52 %,
- Biomass boiler – 13 %.

In total, the heat sources of the scenario B_1 had to cover the heat demand of 35,3 GWh/a (Tab. 8). Total thermal capacity of all heat generators was 14,5 MW[96].

Schematically, the heating solution can be seen in the picture below (Figure 8).

Figure 8: Scheme of the thermal solution for scenario B_1

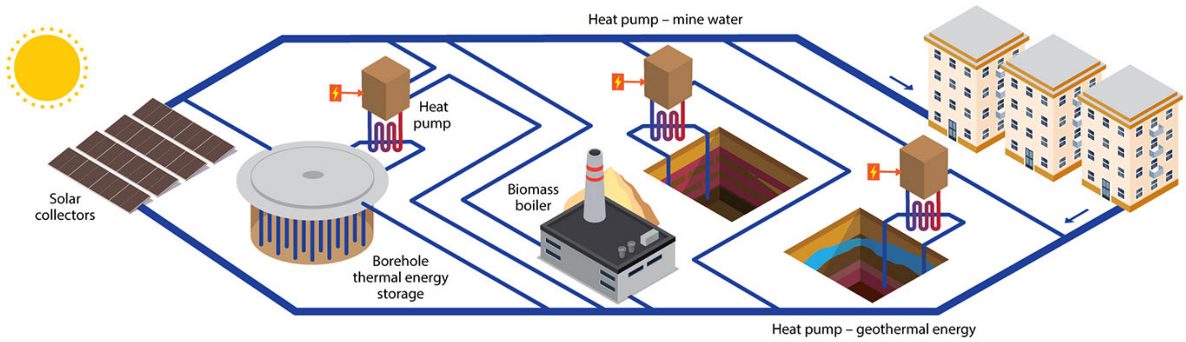


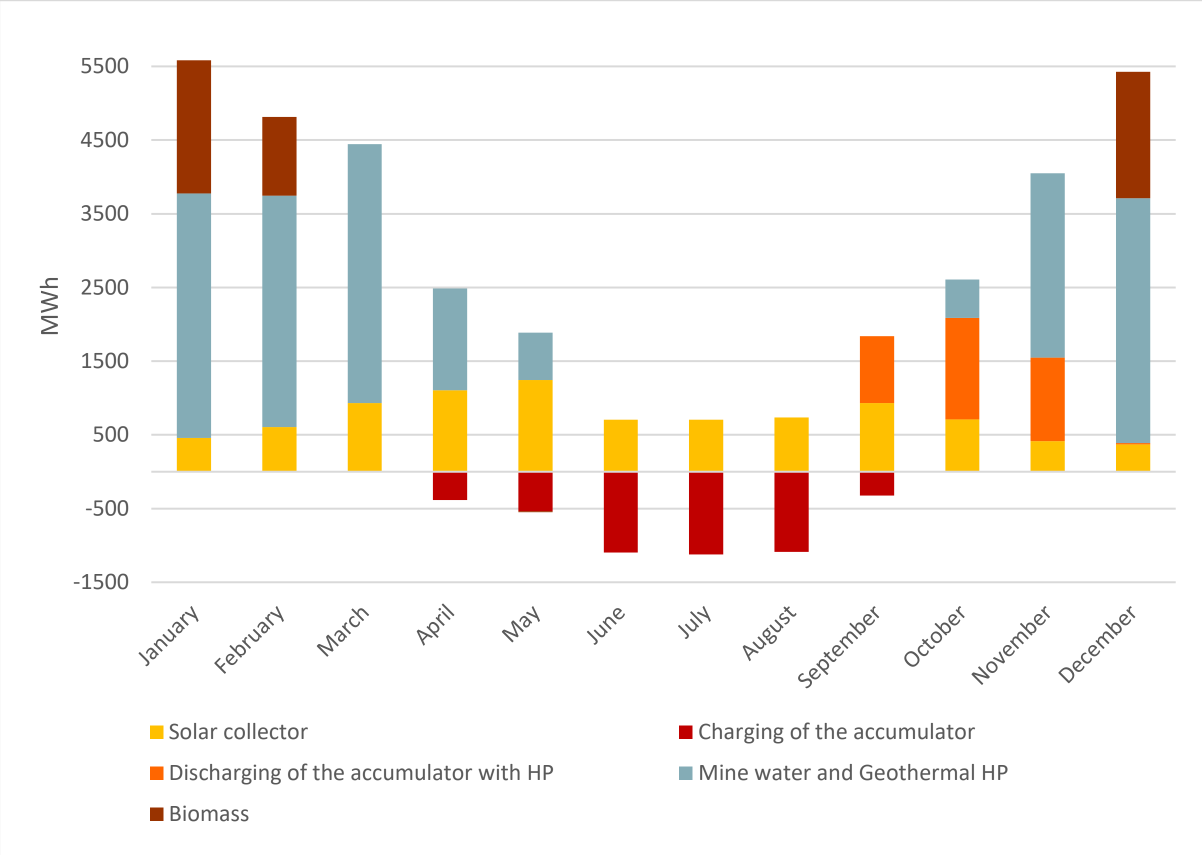
Illustration: R. Watzka

The estimated annual heat demand coverage of the particular heat sources can be seen in the diagram (Figure 9).

Longer charging period of the seasonal accumulator (from April to September) is caused by the HP which helps to increase its storage capacity. The inclusion of other available heat sources in the vicinity (mine and geothermal water) means a reduction of the capacity of the solar system. The relatively lower amount of storage substance is reflected in the shorter discharging time of the accumulator. In the coldest months (December, January, February) a biomass boiler should help to cover peak loads.

[96] It is not an installed thermal power which is higher since the system is more complex due to the combination of the solar system with the accumulation.

Figure 9: Estimated heat source coverage during a year for scenario B_1



Source: Based on own analysis.

7.4.2 Scenario B_2 – solar collectors, seasonal heat storage with HP, mine and geothermal water

In this scenario, there was an assumption that all buildings would meet at least TPB 5 in the target period (look the chapter 5.1) and all heat pipelines would be reconstructed (see chapter 5.2) which was reflected in much lower heat demand. Due to this lowered heat demand, a biomass boiler for this scenario B_2 was not considered.

Similarly, as the scenario B_1, the B_2 scenario also comes out from the availability of mine and geothermal water, however, due to the optimistic approach towards the renovation of buildings and the distribution network, full load hours of these heat sources were set to 2000 hours a year.[97]

Technical parameters of HP for mine and geothermal water for the scenario B_2 are stated in the tables below (Tab.20 and Tab.21).

[97] Estimation made according to an analysis in Appendix 3 based on a document *Handbook on Planning of District Heating Networks, 2020.*

Tab. 20: Technical parameters of the HP for mine water for the scenario B_2 (southern DHS)

Parameters	Value
SPF	3,4
Capacity of the HP	4,1 MW
Estimated full load hours of the HP	2 000 h/a
Electricity consumption	2,4 GWh/a
Generated heat	8,3 GWh/a

Source: Calculated outputs and own chosen inputs based on research and analysis

Tab. 21: Technical parameters of the HP for geothermal water from the well for the scenario B_2 (southern DHS)

Parameters	Value
SPF	4
Capacity of the HP	3,6
Estimated full load hours of the HP	2 000 h/a
Electricity consumption	1,8 GWh/a
Generated heat	7,2 GWh/a

Source: Calculated outputs and own chosen inputs based on research and analysis

The borehole heat storage in the scenario B_2 had smaller dimensions compared to the scenario B_1 despite the fact, that in the scenario B_2 no biomass boiler was considered and HP for mine and geothermal were dimensioned smaller. The main reason for the lower needed capacity of heat generators was lowered heat demand due to renovations of buildings and pipelines. Parameters of a combination of solar collectors and the borehole heat storage system with the HP can be seen in the table below (Tab. 22).

Tab. 22: Technical specification of solar collectors and the borehole storage with HP for the scenario B_2 (southern DHS)

Parameters	Value
Efficiency of solar collectors	40 %
Efficiency of the accumulator	70 %
Type of the seasonal accumulator	borehole storage
Global horizontal solar radiation[98]	1 197 kWh/a.m^2
Ratio of a seasonal storage volume to a solar collector area	1,0 m^3/m^2
Calculated solar collector gain	11,1 GWh/a
Calculated net solar gain	7,8 GWh/a

[98] The global horizontal radiation for the Upper Nitra Basin was determined from the Global Solar Atlas application and represents a value of solar radiation incident per year to 1 m^2 in this area.

Needed solar collector area	23 200 m^2
Number of solar collectors	10 265 pcs
Needed volume of seasonal storage technology	23 200 m^3
Physical storage volume borehole	92 800 m^3
SPF of HP	3,4
Needed capacity of HP	0,6 MW
Estimated full load hours of the HP	2000 h/a
Annual electricity consumption of HP	0,4 GWh/a
Calculated net HP gain	1,2 GWh/a

Source: Calculated outputs and own chosen inputs based on research and analysis

Expected annual coverage of chosen heat sources for the scenario B_2 was then as follows:

- Solar system, borehole thermal energy storage with HP – 37 %,
- HP for mine water and geothermal water – 63 %.

The scenario B_2 was designed as a counter-proposal to the scenario B_1 to emphasize the importance of a major renovation of buildings to lower their energy performance thanks to which it is possible to create a DHS which operation produces neither greenhouse gases[99]nor particulate matter.

In total, the heat sources of the scenario B_2 had to cover the heat demand of 24,4 GWh/a (Tab. 8). Total thermal capacity of all heat generators was 12 MW.

The scenario B_2 shows a way how to cover the heat demand without any combustion of fossil fuels and biomass. The seasonal heat accumulator has an increased storage capacity the beginning of its charging period is already in April. The discharge process with cooling down through HP lasts until November. In December it is necessary to use almost exclusively HP for mine and geothermal water. When considering the following scenario B_2, it is important to examine possibilities of own electricity production to cover the consumption of HP.

[99] Assuming that electricity for HP, circulating pumps and other measuring and controlling devices of DHS is from RES.

Figure 10: Scheme of the thermal solution for scenario B_2

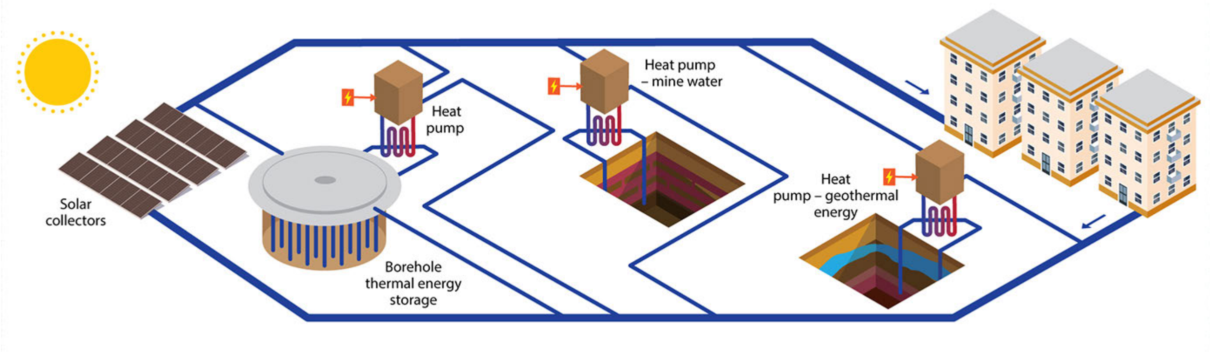
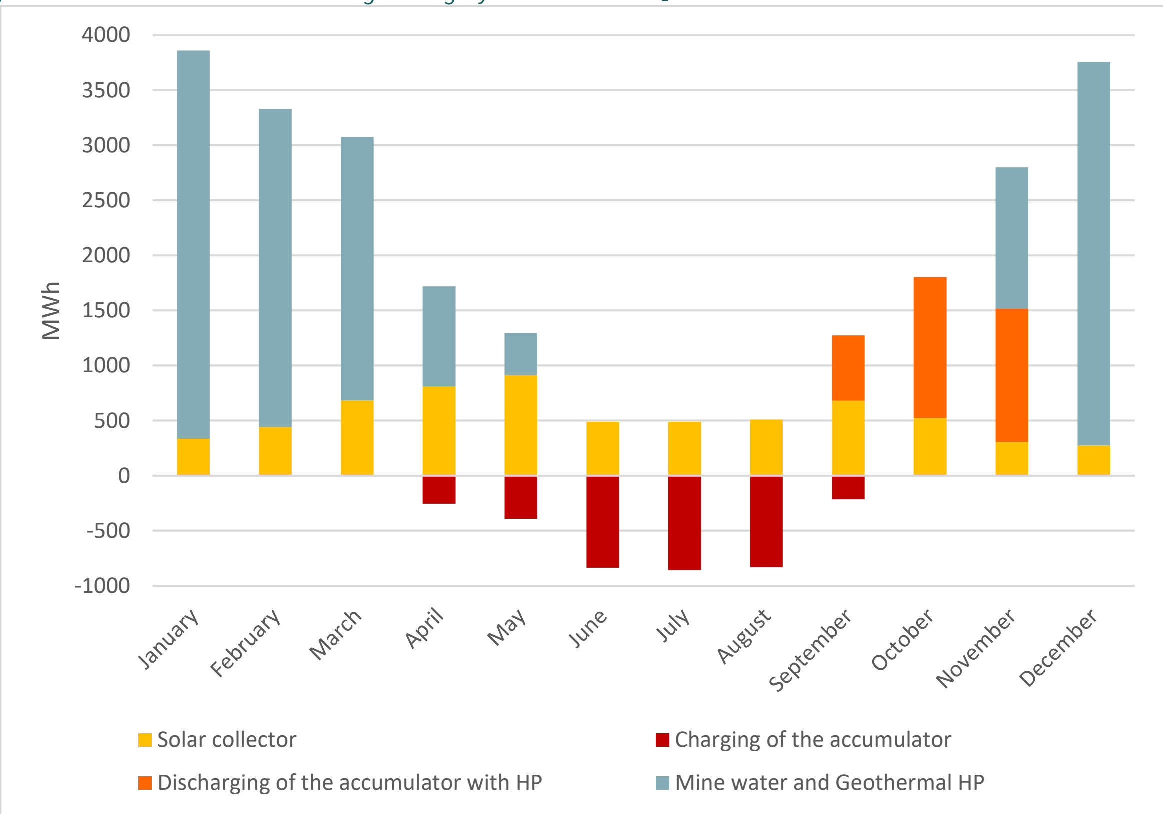


Illustration: R. Watzka

The estimated annual heat demand coverage of the particular heat sources can be seen in the diagram below (Figure 11).

Figure 11: Estimated heat source coverage during a year for scenario B_2



Source: Based on own analysis.

8 Proposed concept of DH system in Nováky

The following chapters discuss the concept of the 2nd phase DH system for Nováky, which is based on an analysis of the proposed heat solution of the 1st phase.

8.1 Analysis of the 1st phase of the heating solution in Nováky

Heating solution in Nováky after the shutdown of the NPP operation in 2023 will be managed by the company KOOR s.r.o. in cooperation with the PTH. According to the latest, available information about the 1st phase should the heat remain distributed from two suppliers. Branch to which heat is supplied from the Fortischem a.s. and branches that will be supplied from a new heat source that will replace the heat supply from the NPP.

The Fortischem branch should be slightly enlarged to supply heat to other buildings that were previously supplied from the NPP via branch 2. The second part of the town connected to the DHS (branches 4 and 5) will be supplied with heat produced in biomass boilers and heat pumps located in the Nováky mine complex.

The original proposal[100] to replace the heat source from the NPP consisted of a combination of a gas boiler located directly in the city (1.7 MW) and a wood chip boiler built on the site of the Nováky mine (3 MW), to which three HP would be added (3 x 1 MW).

The newer proposal[101] consists only of renewables, namely two wood chip boilers (2 x 3 MW) and two mine water HP (2 x 1.85 MW). Both technologies should be located in the mine site.

Comparing the installed capacities of heat generators of the original and the new proposal, it is obvious that the gas boiler was replaced by another biomass boiler, while the total installed capacity of the heat generators increased from 4.7 MW to 6 MW.

Not only an increase of the installed capacity of boilers but also an increase of the capacity of HP are included in the new proposal (the previous design of heat pumps was 3 MW, the new design is 3.7 MW). The reasons for the increase in total installed capacity are likely to come from the following considerations:

- Ensuring that the heat demand of the enlarged Fortischem branch (included branch 2) would be covered in case that the heat supply from the chemical plant Fortischem was terminated,
- Preferred heat production from biomass boilers in the winter due to more economic operation compared to heat pumps and possible coverage of peak load only with biomass boilers.

[100] KOOR, s.r.o., *ŠTÚDIA REALIZOVATEĽNOSTI Tepelný zdroj pre Nováky a Zemianske Kostoľany*.

[101] *Záväzné stanovisko o súlade výstavby zariadení s Koncepciou rozvoja mesta Nováky v tepelnej energetike v zmysle § 13 ods. 2 zákona o tepelnej energetike. Nováky*: Mesto Nováky, 2021.

8.2 Concept of the 2nd phase of the heating solution in Nováky

The proposed DHS in Nováky for the 2nd phase is similar to the proposed 2nd phase DHS in Prievidza based on the concept of the 4th generation of heat supply. Assumptions considered on the side of the heat demand of buildings are described in chapters 3.2.1, 3.2.2, 3.2.3, 3.2.4, 3.2.7, and 3.2.8, assumptions taken into account for covering heat losses of heat distribution are described in chapter 3.3. Assumptions given in chapters 3.4.1, 3.4.2 were used to calculate the parameters of heat sources, and assumptions from chapter 3.4.4 were used for seasonal accumulation.

Parameters of heat accumulation in mine water are difficult to estimate because they are individual for each mine and their values are usually not generalized. Due to this reason, conservative values were used for the proposed solution according to the source[102]. However, within the pre-investigation part of the project (feasibility study) real conditions screening of the thermal energy storage in mine water Nováky is required.

Based on the mentioned assumptions stated in the previous chapter 8.1, we suggest the following proposal of the 2nd phase of the heating solution in Nováky:

- Summer:
  - dimensioning of the thermal solar system, which will cover the heat demand of DHS in the summer period and will produce surplus heat for seasonal storage,
  - accumulation of surplus heat from the thermal solar system during the summer in mine water to increase the efficiency of the heat supply in the heating period.
- Heating season:
  - the use of low-potential heat of the mine water with HP as the source for base load in DHS, which with its capacity can cover even the peak load in the coldest period,
  - economic use of the HP with use of the source mine water down to 10 °C,
  - to increase the efficiency of the HP, use the thermal solar system in the heating period to preheat the mine water,
  - in case of sufficient preheating of the mine water[103] for the HP, use the thermal solar system also for direct preheating of the return water in the DHS.

Technical parameters of the proposed thermal solar system with the accumulation of surplus heat in mine water are given in the following table (Tab.23).

[102] RUTZ, Dominik, Christian DOCZEKAL, Richard ZWEILER, Morten HOFMEISTER a Linn LAURBERG JENSEN. Small Modular Renewable Heating and Cooling Grids: A Handbook. Munich, Germany: WIP Renewable Energies, 2017. ISBN 978-3-936338-40-9.

[103] Preheated mine water will reach a temperature of at least 30 °C

Tab. 23: Technical specification of solar collectors and the mine water thermal storage for the proposal of the 2nd phase of the heating solution in Nováky

Parameter	Value
Efficiency of solar collectors	40 %
Global horizontal solar radiation [104]	1197 kWh/rok.m^2
Type of the seasonal accumulator	Mine water
Efficiency of the accumulator [105] [106]	50 %
Estimated accumulation capacity of mine water[107] [108]	30 kWh/m^3
Calculated solar collector gain	1,87 GWh/a
Calculated solar collector gain for direct preheating of DHS return water	0,85 GWh/a
Calculated solar collector gain for preheating of mine water for heat pumps in heating season	0,67 GWh/a
Calculated solar collector gain for accumulation in mine water	0,39 GWh/a
Usage of accumulated heat	0,20 GWh/a
Needed solar collector area	3 909 m^2
Number of solar collectors	1 709 pcs

Source: Calculated outputs and own chosen inputs based on research and analysis

The technical parameters for HP result from availability and temperature of mine water and are listed in more detail in the following table (Tab. 24).

Tab. 24: Technical specification of HP for the proposal of the 2nd phase of the heating solution in Nováky

Parameter	Value
SPF of HP [109]	3,4
Needed capacity of HP	3,7 MW
Annual electricity consumption of HP	1,1 GWh/a
Calculated net HP gain	3,8 GWh/a

Source: Calculated outputs and own chosen inputs based on research and analysis

[104] The global horizontal radiation for the Upper Nitra Basin was determined from the Global Solar Atlas application and represents a value of solar radiation incident per year to 1 m^2 in this area.

[105] The efficiency of heat accumulation in mine water was chosen according to a typical efficiency of aquifer storage technologies (ATES)

[106] RUTZ, Dominik, Christian DOCZEKAL, Richard ZWEILER, Morten HOFMEISTER a Linn LAURBERG JENSEN. Small Modular Renewable Heating and Cooling Grids: A Handbook. Munich, Germany: WIP Renewable Energies, 2017. ISBN 978-3-936338-40-9.

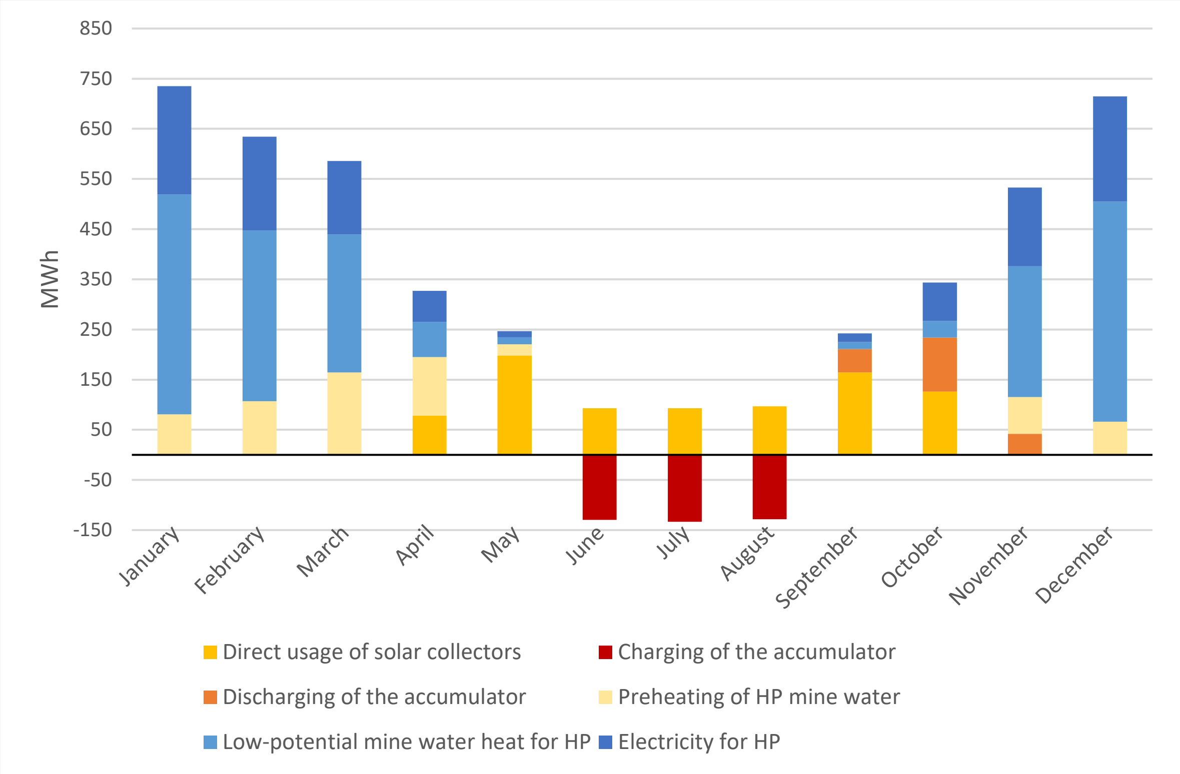
[107] Akumulačná kapacita bola volená podľa akumulačnej capacity zásobníkov tepla vo zvodnenej vrstve (ATES).

[108] RUTZ, Dominik, Christian DOCZEKAL, Richard ZWEILER, Morten HOFMEISTER a Linn LAURBERG JENSEN. Small Modular Renewable Heating and Cooling Grids: A Handbook. Munich, Germany: WIP Renewable Energies, 2017. ISBN 978-3-936338-40-9.

[109] Seasonal performance factor of HP is considered for the temperature drop of mine water from 18 °C to 10 °C.

As can be seen in the following figure (Figure 12), with the increasing availability of solar energy during the year, electricity consumption by HP decreases, thus a more economical operation of the DHS happens. In the warmer months of the heating period (April, May, and September, October), the thermal solar system has the function of preheating the mine water and even direct preheating the return water in the DHS. During the summer period, the thermal solar system can cover the total heat supply and the obtained surplus heat energy is accumulated in the mine water. The stored heat in the mine water is used during the autumn what contributes to more economical operation in DHS.

Figure 12: Estimated heat source coverage during a year for the 2nd phase of the heating solution in Nováky



Source: Based on own analysis.

The annual coverage of heat consumption by the heat produced by particular sources would then be:

- mine water through HP (82%[110]),
- the direct use of solar collectors (18%).

[110] Including preheating of mine water and use of seasonal heat accumulation.

9 Economy of proposed DH system concepts

The economy of designed DH systems was evaluated in the following chapters. A base tool for determining a production heat cost of a particular DHS was Sunstore 4 software[111]. A method used for calculation of project economy was based on levelized cost of heat (LCoH).

9.1 Estimated prices of input energy and fuels

Prices of electricity and wood chips were set based on an assumption (chapter 3.5.3) to following values:

- Wood chips – 20 eur/MWh[112],
- Electricity (also for HP) – 135 eur/MWh[113].

9.2 Estimated investment conditions

Loan interest rates are constantly changing and it is therefore quite difficult to determine which interest rate could be expected when applying for a loan in the future. For this reason, a conservative average value of current interest rates was taken into account. A reference payback period was set for 15 years which is supposed to be a minimum lifespan of a technology used in solutions.

Investment conditions then were:

- Interest rate – 3 %[114]
- Reference period – 15 years.

When estimating the investment value of some technologies (such as solar collectors or seasonal heat storage) purchase of land had to be taken into account. There was an assumption that lands for this purpose would be available in the future (chapter 3.4.1). The estimated specific price for the land was determined to 10 eur/m^2.

9.3 Estimated investment and operating costs for DHS in Prievidza

Particular prices for devices and their components were set for values that were based on various criteria and our market research with a conservative approach. There were also considered operating costs of each technology. In the following chapters, the investment and operating costs of every technology of every designed DHS in Prievidza are analyzed.

[111] The software was modified for the purpose of this study by authors of the study.

[112] Calculated from weight units and a common moisture content.

[113] The price of electricity was set for wholesale consumption after a discussion with a local electricity supplier and according to an own market survey executed in August 2021. A low tariff has the dominancy in the electricity supply.

[114] Based on data from National bank of Slovakia. Online available here: https://www.nbs.sk/sk/statisticke-udaje/financne-trhy/urokove-sadzby/priemerne-urokove-miery-z-uverov-bank

There was an assumption that prices of the equipment in the target period would be around the same as it is nowadays.

9.3.1 Prievidza – northern DHS, scenario A_1

Heat sources of the scenario A_1 were as follows:

- Solar collectors with seasonal pit storage without HP,
- Biomass boiler.

In a table below (Tab. 25), estimated costs for the solution can be seen.

Tab. 25: Considered investment and operating costs for technologies of the scenario A_1

Technology	Typical parameter of the technology	Specific investment price [eur/unit]	Investment [eur]	Operating costs [eur/a]	Total annual costs[115] [eur/a]
Solar collectors	Collector area 79 600 m^2	170 eur/m^2	13,5 mil.	20,6 thousand	1 154 thousand
Seasonal heat storage	Storage volume 191 000 m^3	22,2 eur/m^3	4,2 mil.	-	356 thousand
Biomass boiler	Boiler capacity 7,2 MW	479 thousand/MW	3,5 mil.	546 thousand (fuel costs included)	834 thousand
In total	-	-	**21,1 mil.**	**566,6 thousand**	**2 344 thousand**

Source: Based on an own analysis using Sunstore 4 calculation tool.

[115] The sum of the annual operating costs and the annual costs for covering a loan at a given time.

9.3.2 Prievidza – northern DHS, scenario A_2

Heat sources of the scenario A_2 were as follows:

- Solar collectors with seasonal pit storage with discharging through HP,
- Biomass boiler.

In a table below (Tab. 26), estimated costs for the solution can be seen.

Tab. 26: Considered investment and operating costs for technologies of the scenario A_2

Technology	Typical parameter of the technology	Specific investment price [eur/unit]	Investment [eur]	Operating costs [eur/a]	Total annual costs[116] [eur/a]
Solar collectors	Collector area 61 300 m^2	170 eur/m^2	10,4 mil.	15, 8 thousand	889 thousand
Seasonal heat storage	Storage volume 110 300 m^3	25,8 eur/m^3	2,8 mil.	-	239 thousand
HP for discharging of accumulator	Capacity of HP 5,1 MW	263,5 thousand /MW	1,4 mil.	409 thousand (electricity costs included)	522 thousand
Biomass boiler	Boiler capacity 5,1 MW	539 thousand/MW	2,8 mil.	410 thousand (fuel costs included)	642 thousand
In total	-	-	**17,4 mil.**	**834,8 thousand**	**2 292 thousand**

Source: Based on an own analysis using Sunstore 4 calculation tool.

[116] The sum of the annual operating costs and the annual costs for covering a loan at a given time.

9.3.3 Prievidza – southern DHS, scenario B_1

Heat sources of the scenario B_1 were as follows:

- Solar collectors with seasonal borehole storage with discharging through HP,
- Mine water and geothermal water from the well – both with the use of HP,
- Biomass boiler.

The production geothermal well is not overflowing which causes increased costs for pumping work[117] and a need to use special submersible pumps.

In a table below (Tab. 27), estimated costs for the solution can be seen.

Tab. 27: Considered investment and operating costs for technologies of the scenario B_1

Technology	Typical parameter of the technology	Specific investment price [eur/unit]	Investment [eur]	Operating costs [eur/a]	Total annual costs[118] [eur/a]
Solar collectors	Collector area 31 600 m^2	206,3 eur/m^2	6,5 mil.	8,2 thousand	555 thousand
Seasonal heat storage	Storage volume 31 600 m^3	80,5 eur/m^3	2,5 mil.	-	213 thousand
HP for discharging of accumulator	Capacity of HP 0,7 MW	263,5 thousand /MW	0,2 mil.	70 thousand (electricity costs included)	86 thousand
HP for mine water	Capacity of HP 4,1 MW	263,5 thousand /MW	1,1 mil.	362 thousand (electricity costs included)	453 thousand
HP for geothermal water	Capacity of HP 3,6 MW	263,5 thousand /MW	0,9 mil.	313 thousand (electricity costs included)	391 thousand
Submersible pump	Electricity input 0,075 MW	495 thousand /MW	0,04 mil.	8,6 thousand	11 thousand
Biomass boiler	Boiler capacity 1,9 MW	629 thousand/MW	1,2 mil.	243 thousand (fuel costs included)	344 thousand
In total	**-**	**-**	**12,4 mil.**	**1005 thousand**	**2 053 thousand**

Source: Based on an own analysis using Sunstore 4 calculation tool.

[117] According to the project plan called Využitie geotermálnych vôd v lokalite Púšť which was made according to Act no. 24/2006 Coll. as amended from November 2018, geothermal water will be pumped by a pump with an output of 75 kW

[118] The sum of the annual operating costs and the annual costs for covering a loan at a given time.

9.3.4 Prievidza - southern DHS, scenario B_2

Heat sources of the scenario B_2 were as follows:

- Solar collectors with seasonal borehole storage with discharging through HP,
- Mine water and geothermal water from the well – both with the use of HP.

In the scenario B_2, lower heat demand of connected buildings was assumed (all buildings would be renovated at least to level of TPB 5), thanks to which there was not considered with a necessity of a biomass boiler. The production geothermal well is not overflowing in this solution either which causes increased costs for pumping work[119] and a need to use special submersible pumps.

In the table below (Tab. 28), estimated costs for the solution can be seen.

Tab. 28: Considered investment and operating costs for technologies of the scenario B_2

Technology	Typical parameter of the technology	Specific investment price [eur/unit]	Investment [eur]	Operating costs [eur/a]	Total annual costs[120] [eur/a]
Solar collectors	Collector area 23 200 m^2	217,0 eur/m^2	5 mil.	6 thousand	428 thousand
Seasonal heat storage	Storage volume 23 200 m^3	93 eur/m^3	2,2 mil.	-	181 thousand
HP for discharging of accumulator	Capacity of HP 0,6 MW	263,5 thousand /MW	0,2 mil.	48 thousand (electricity costs included)	61 thousand
HP for mine water	Capacity of HP 4,1 MW	263,5 thousand /MW	1,1 mil.	300 thousand (electricity costs included)	396 thousand
HP for geothermal water	Capacity of HP 3,6 MW	263,5 thousand /MW	0,9 mil.	270 thousand (electricity costs included)	346 thousand
Submersible pump	Electricity input 0,075 MW	495 thousand/MW	0,04 mil.	7,2 thousand	9,6 thousand
In total	-	-	**9,4 mil.**	**631 thousand**	**1422 thousand**

Source: Based on an own analysis using Sunstore 4 calculation tool.

[119] According to the project plan called Využitie geotermálnych vôd v lokalite Púšť which was made according to Act no. 24/2006 Coll. as amended from November 2018, geothermal water will be pumped by a pump with an output of 75 kW

[120] The sum of the annual operating costs and the annual costs for covering a loan at a given time.

9.4 Production heat cost of DHS concepts in Prievidza

An analysis of a potential production heat cost for particular scenarios of DHS concept in Prievidza was based on assumed capital and operating costs from the previous chapter 9.3.

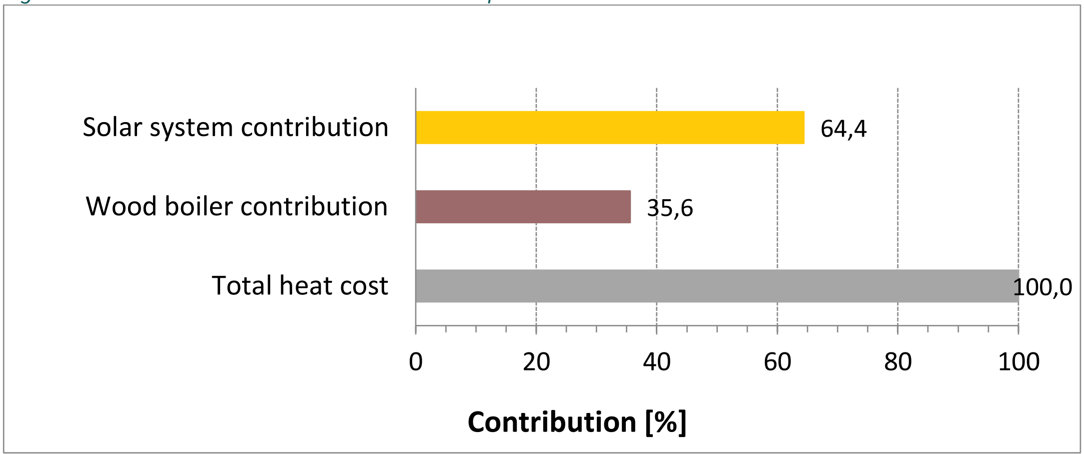
Software Sunstore 4 has been used for the production heat cost calculation. The cost was calculated without reasonable profit[121]. The influence of the NFC[122] was analyzed in three different scenarios while co-financing was always 40 %:

- NFP_1 in the amount of 60 % would be provided for the investment for all major technologies except for biomass boiler and seasonal heat storage.
- NFP_2 in the amount of 60 % would be provided for the investment for all major technologies except for the biomass boiler.
- NFP_3 in the amount of 60 % would be provided for the investment for all technology[123].

9.4.1 Prievidza – northern DHS, scenarios A_1 and A_2

An influence of particular heat sources on the production heat cost is shown in the following graphs (Figure 13 and Figure 14).

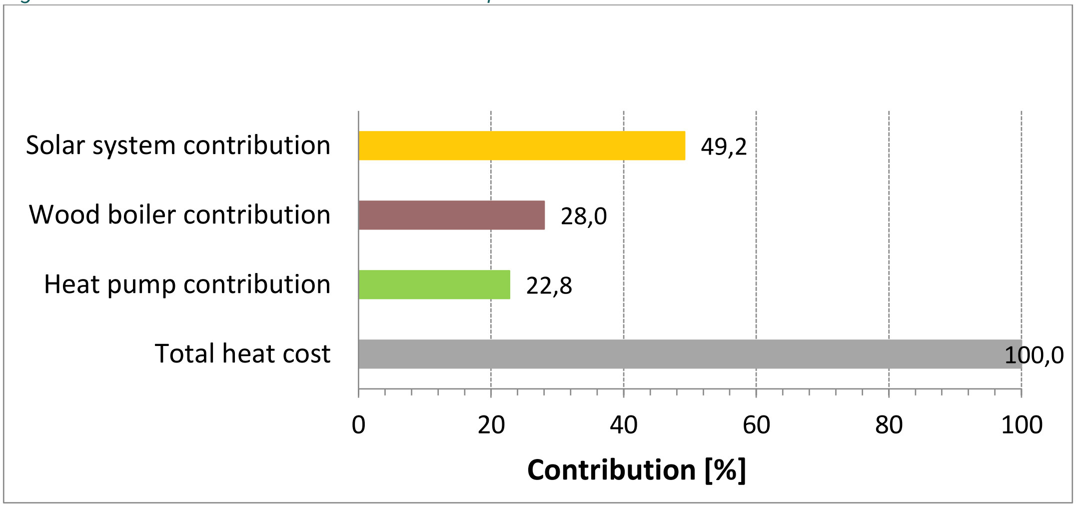
Figure 13: Contribution of each heat source to the production heat cost for the scenario A_1



Source: Own analysis using Sunstore 4

[121] Chapter 11 contains an estimation of the distribution heat cost which a reasonable profit is included in.
[122] Non-repayable financial contribution
[123] All RES technology with seasonal thermal energy storage included.

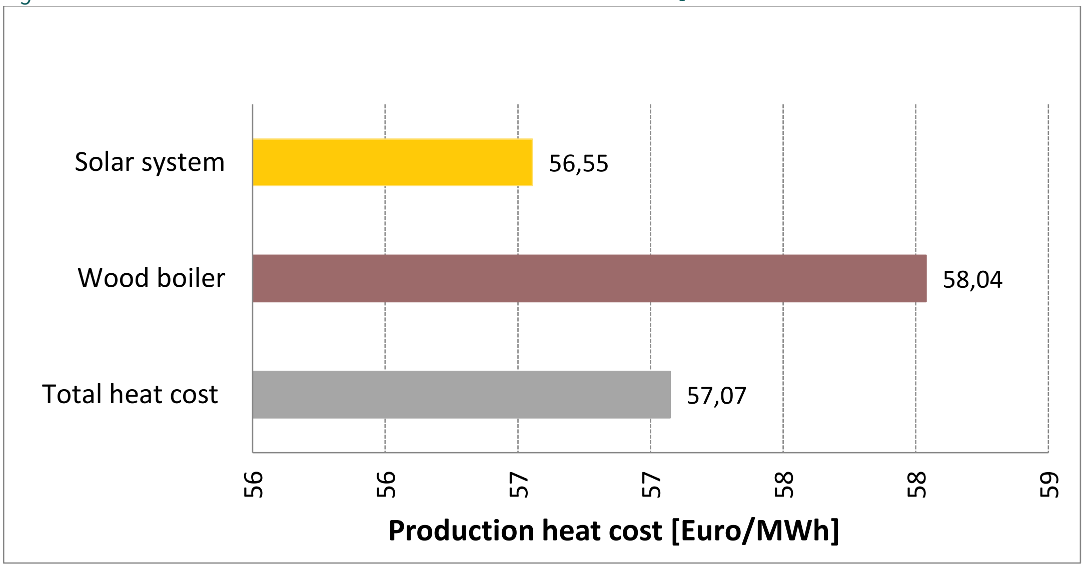
Figure 14: Contribution of each heat source to the production heat cost for the scenario A_2



Source: Own analysis using Sunstore 4

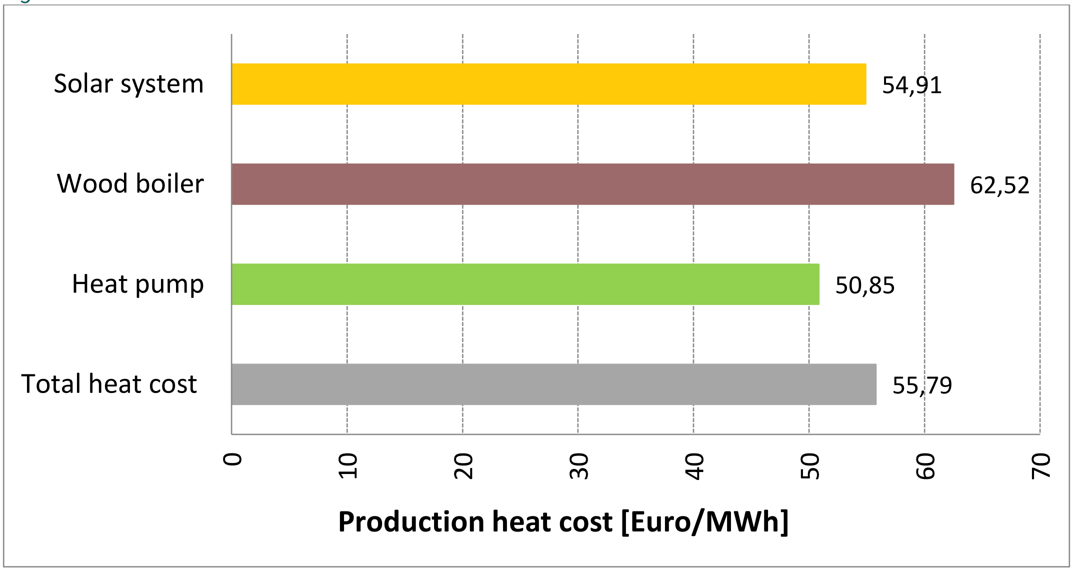
The partial costs of heat produced from a particular heat source can then be seen in the charts below (Figure 15 and Figure 16).

Figure 15: Production heat cost of each heat source for the scenario A_1



Source: Own analysis using Sunstore 4

Figure 16: Production heat cost of each heat source for scenario A_2



Source: Own analysis using Sunstore 4

In the following tables and figures, the influence of NFC on the co-financing investment (Tab. 29), total annual costs (Tab. 30), and the production heat cost itself (Tab.31, Figure 17 and Figure 18) are summarized.

Tab. 29: Influence of NFC on the investment co-financing for scenarios A_1 and A_2

Scenarios	Co-financing [mil. eur]			
	Without NFC	NFC 1[124]	NFC 2[125]	NFC 3[126]
A_1	21,2	13,6	11,0	8,9
A_2	17,4	10,7	9,0	7,2

Source: Own analysis using Sunstore 4

Tab. 30: Influence of NFC on total annual costs for scenarios A_1 and A_2

Scenario	Operating costs[127] [mil. eur]	Total annual costs [mil. eur]			
		Without NFC	NFC 1	NFC 2	NFC 3
A_1	0,566	2,34	1,70	1,49	1,31
A_2	0,835	2,29	1,73	1,59	1,44

Source: Own analysis using Sunstore 4

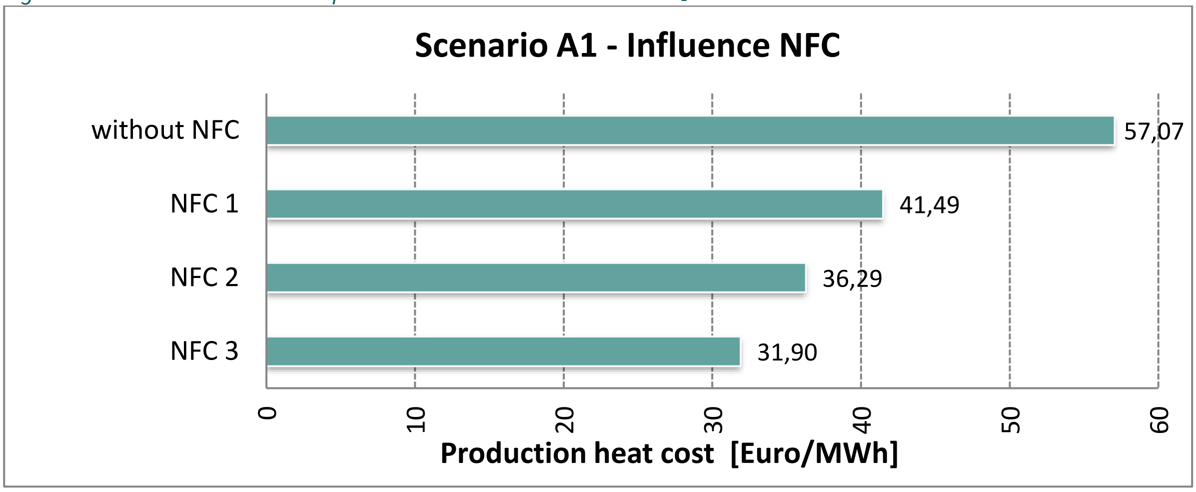
[124] Scenario, where NFC (60 %) will be provided for the investment for all major technologies expect for the biomass boiler and the seasonal heat storage.
[125] Scenario, where NFC (60 %) will be provided for the investment for all major technologies expect for the biomass boiler.
[126] Scenario, where 60 % NFC will be provided for the investment for all technology.
[127] Independent of NFC

Tab. 31: Influence of NFC on the production heat cost for scenarios A_1 and A_2

Scenario	Production heat cost [eur]			
	Without NFC	NFC 1	NFC 2	NFC 3
A_1	57,1	41,5	36,3	31,9
A_2	55,8	42,1	38,6	35,1

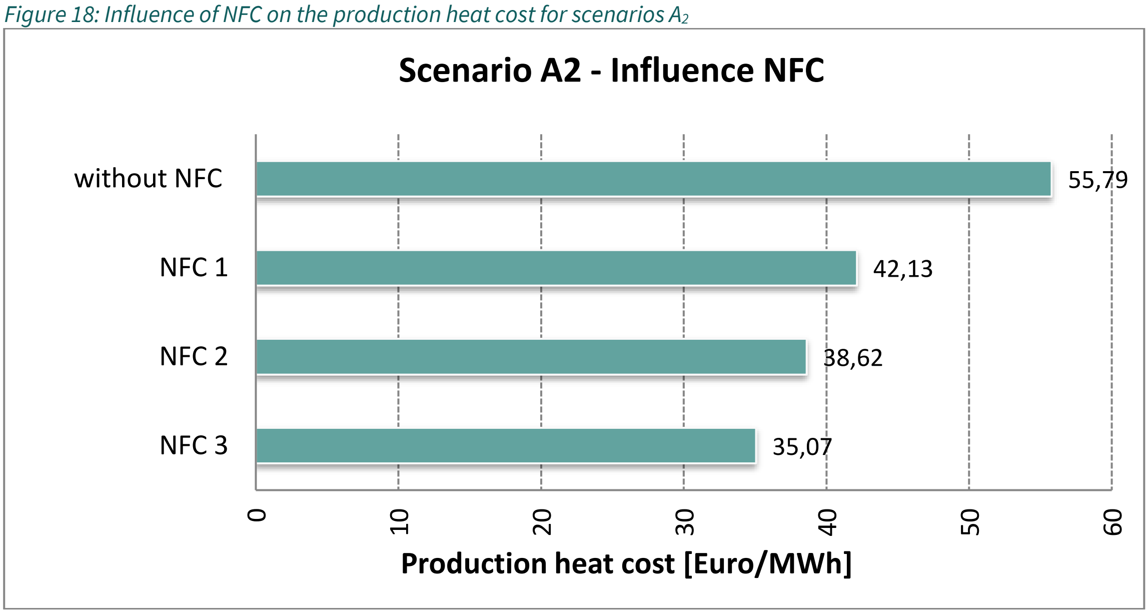
Source: Own analysis using Sunstore 4

Figure 17: Influence of NFC on the production heat cost for scenarios A_1



Source: Own analysis using Sunstore 4

Figure 18: Influence of NFC on the production heat cost for scenarios A_2

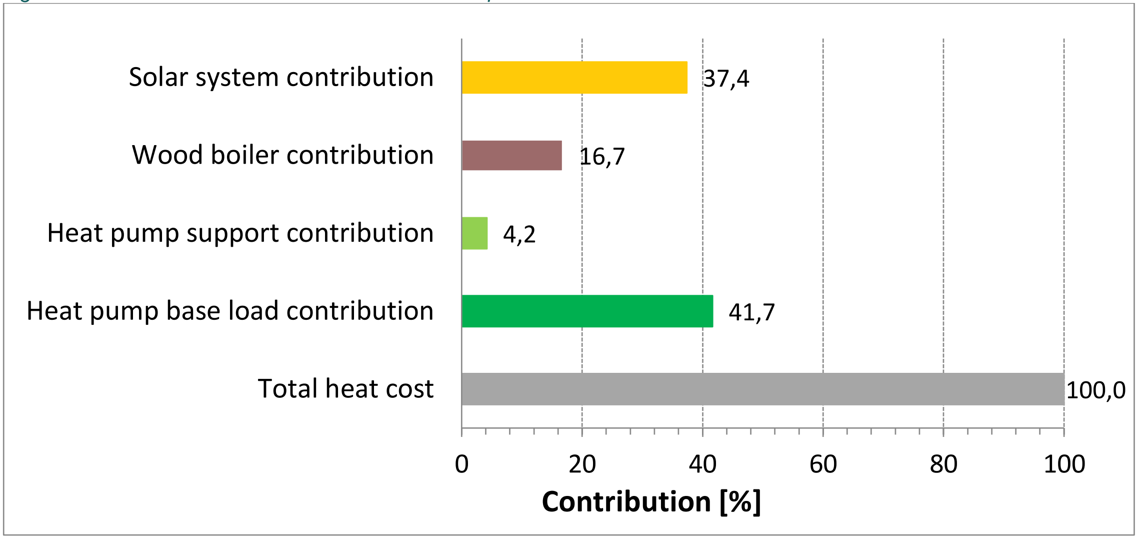


Source: Own analysis using Sunstore 4

9.4.2 Prievidza – southern DHS, scenarios B_1 and B_2

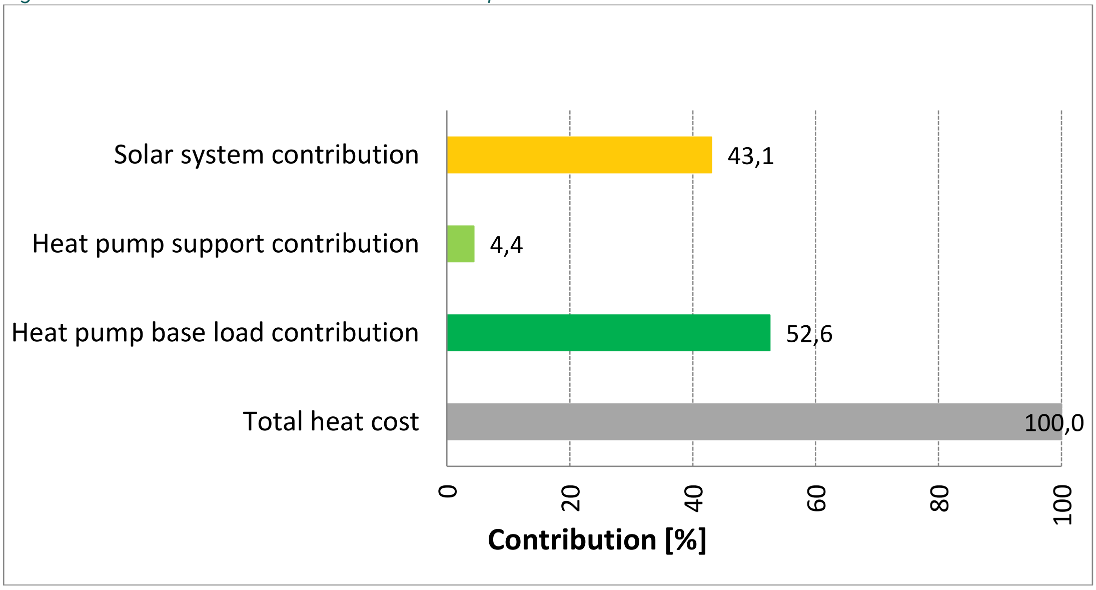
An influence of particular heat sources on production heat cost is shown in the following graphs (Figure 19 and Figure 20). Partial costs of heat produced from a particular heat source can then be seen in the charts below (Figure 21 and Figure 22).

Figure 19: Contribution of each heat source to the production heat cost for the scenario B_1



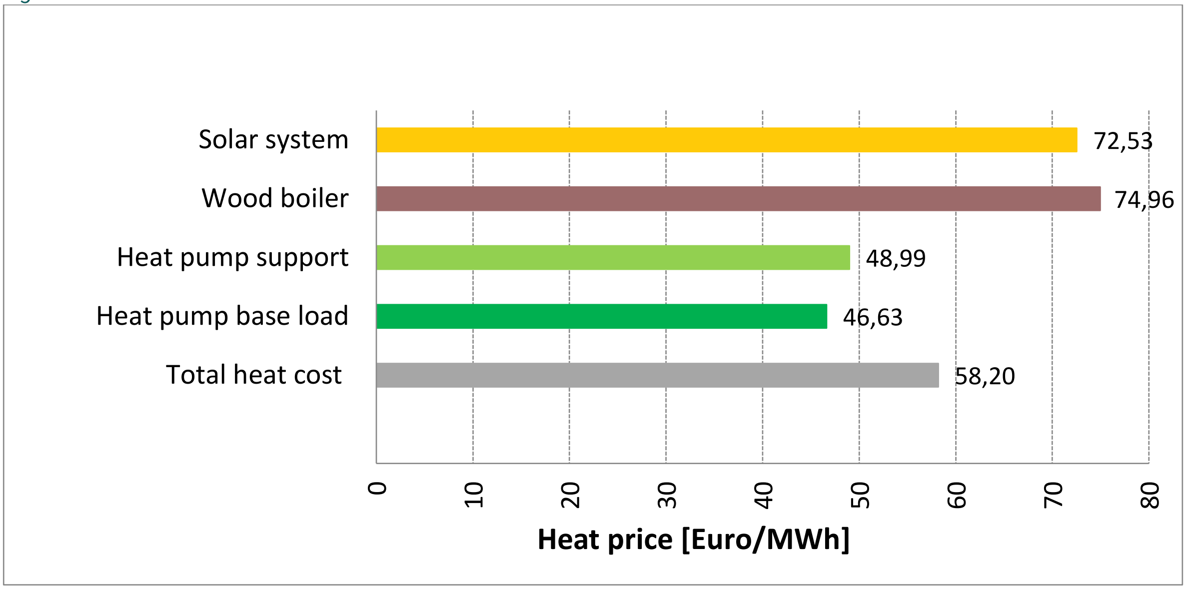
Source: Own analysis using Sunstore 4

Figure 20: Contribution of each heat source to the production heat cost for the scenario B_2



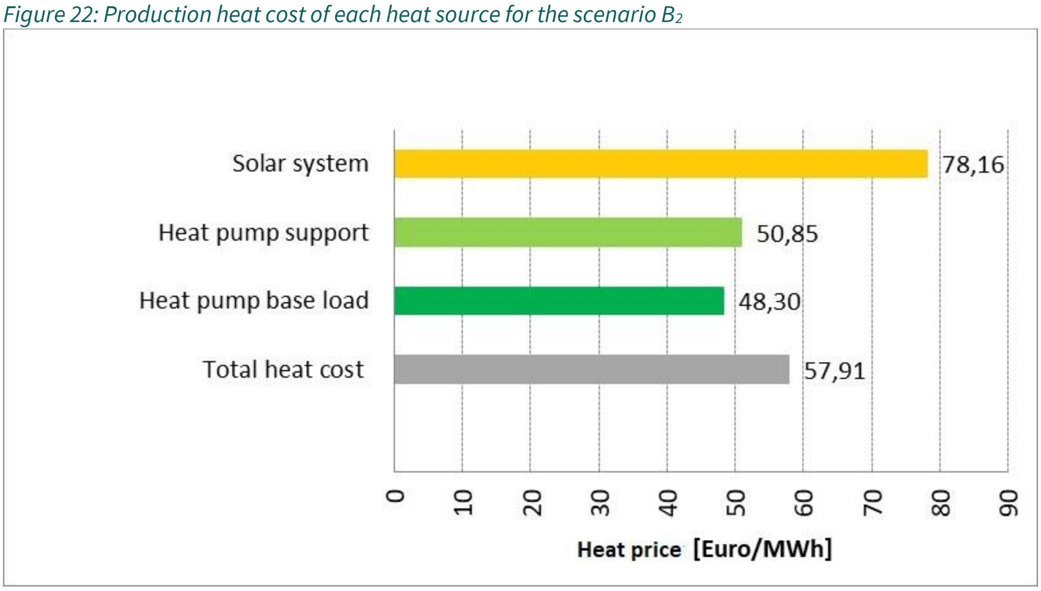
Source: Own analysis using Sunstore 4

Figure 21: Production heat cost of each heat source for the scenario B_1



Source: Own analysis using Sunstore 4

Figure 22: Production heat cost of each heat source for the scenario B_2



Source: Own analysis using Sunstore 4

In the following tables and figures, the influence of NFC on the co-financing investment (Tab.32), total annual costs (Tab. 33), and the production heat cost itself (Tab. 34, Figure 23 and Figure 24) are summarized.

Tab. 32: Influence of NFC on the investment co-financing for scenarios B_1 and B_2

Scenario	Co-financing [mil. eur]			
	without NFC	NFC 1	NFC 2	NFC 3
B_1	12,47	7,4	5,8	5,1
B_2	9,4	5,2	3,9	3,9

Source: Own analysis using Sunstore 4

Tab. 33: Influence of NFC on total annual costs for scenarios B_1 and B_2

Scenario	Operating costs[128] [mil. eur]	Total annual costs [mil. eur]			
		Without NFC	NFC 1	NFC 2	NFC 3
B_1	1,005	2,05	1,62	1,49	1,43
B_2	0,624	1,41	1,07	0,96	0,96

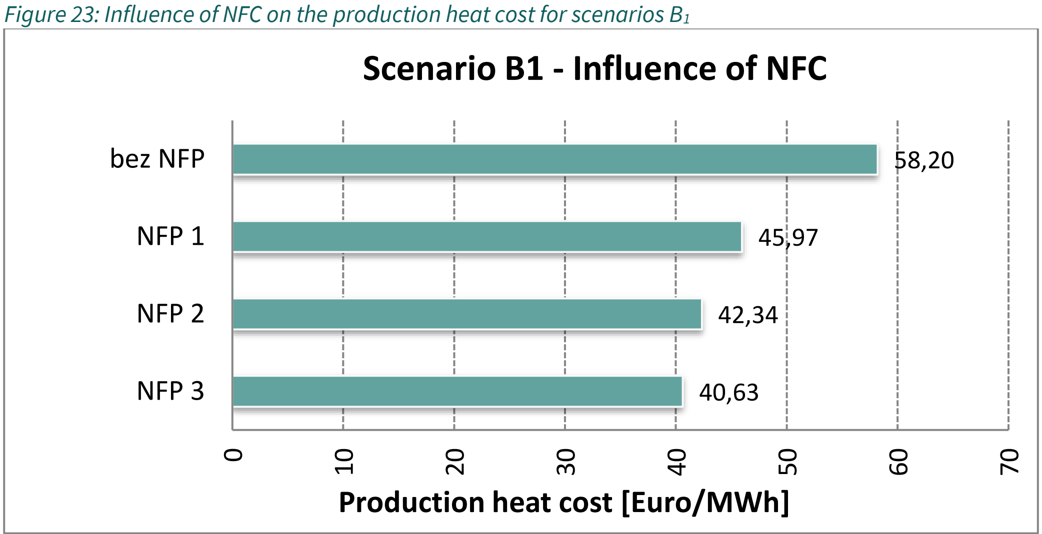
Source: Own analysis using Sunstore 4

Tab. 34: Influence of NFC on the production heat cost for scenarios B_1 and B_2

Scenario	Production heat cost [eur]			
	Without NFC	NFC 1	NFC 2	NFC 3
B_1	58,2	46,0	42,3	40,6
B_2	57,9	43,7	39,2	39,2

Source: Own analysis using Sunstore 4

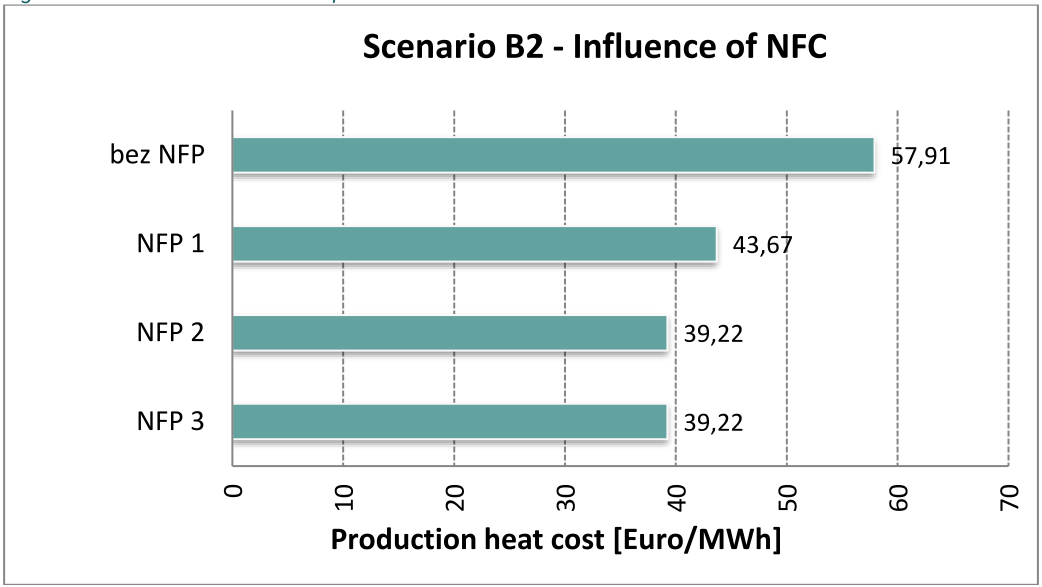
Figure 23: Influence of NFC on the production heat cost for scenarios B_1



Source: Own analysis using Sunstore 4

[128] Independent of NFC

Figure 24: Influence of NFC on the production heat cost for scenarios B_2



Source: Own analysis using Sunstore 4

9.5 Estimated investment and operating costs for DHS in Nováky

Quantification of investment costs for Nováky DHS was based on estimated prices of technology and components, which were determined based on own survey with a conservative approach[129]. The specific price of the investment also depends on the size of the characteristic parameter of the device, and for a smaller technology, a higher specific price of the investment is then needed and vice versa. It was also assumed that technology prices in the target period would be in similar price ranges. Operating costs for the proposed solution were based on the prices listed in chapter 9.1.

The proposal of the 2nd phase of the heating concept in Nováky consisted of the following heat sources:

- Thermal solar system,
- Mine water HP[130].

Tab. 35: Considered investment and operating costs for technologies of the 2nd phase of the heating concept in Nováky

Technology	Typical parameter of the technology	Specific investment price [eur/unit]	Investment [eur]	Operating costs [eur/a]	Total annual costs[131] [eur/a]
Solar collectors	Collector area 3 909 m^2	278 eur/m^2	1,1 mil.	1 thousand	92 thousand

[129] The cheapest solution on the market was not necessarily considered, but the price-quality ratio was taken into account.
[130] Mine water, which is heated by a solar system and it is used as a seasonal heat accumulation.
[131] The sum of the annual operating costs and the annual costs for covering a loan at a given time.

Mine water HP	Capacity of HP 3,7 MW	263,5 thousand/MW	0,97 mil.	147 thousand (electricity costs included)	229 thousand
Submersible pump	Electricity input 0,15 MW	495 thousand/MW	0,08 mil.	19 thousand (electricity costs included)	25 thousand
In total	-	-	**2,15 mil.**	**167 thousand**	**346 thousand**

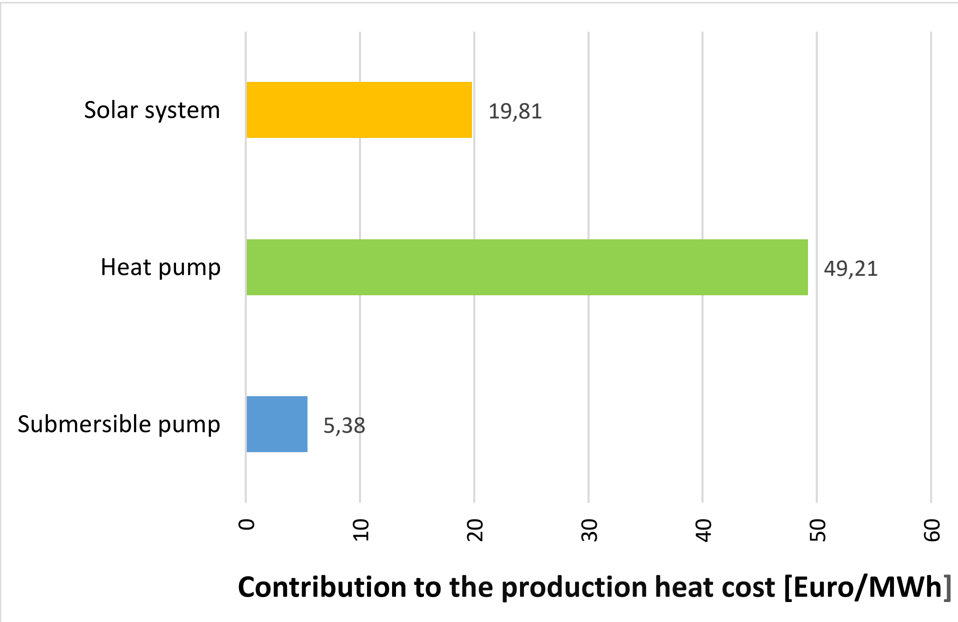
Source: Based on an own analysis using Sunstore 4 calculation tool.

9.6 Production heat cost of DHS concept in Nováky

An analysis of the potential production heat cost for the 2nd phase heat concept in Nováky is based on the assumed investment and operating costs listed in the previous chapter (chapter 9.5). The production heat cost was computed with the Sunstore 4 calculation program without considering a reasonable profit. The cost of heat was analyzed according to the percentage share of a particular heat source in the production heat cost. Individual technologies producing heat expressed the cost contribution per unit of energy.

The percentage contribution of individual heat sources to the production heat cost can be seen in the following graph (Figure 25).

Figure 25: Contribution to the production heat cost by individual heat sources for the 2nd phase of the heating solution in Nováky



Source: Based on an own analysis using Sunstore 4 calculation tool

The impact of NFCs on capital costs was analyzed in only one scenario, where NFC will be provided for an investment of 60 % for all major technologies[132]. The remaining 40 % is the estimated co-financing of capital costs. The amount of provided NFC affects both the total annual costs and the cost of heat itself, which can be seen in the following tables (Tab.36, Tab.37 and Tab.38).

Tab. 36: Impact of a non-repayable financial contribution (NFC) on the co-financing of an investment for the 2nd phase heating concept in Nováky

Scenario	Co-financing [mil. eur]	
	without NFC	NFC
Nováky	2,1	0,8

Source: Based on an own analysis using Sunstore 4 calculation tool

Tab. 37: Impact of a non-repayable financial contribution (NFC) on the total annual costs for the 2nd phase heating concept in Nováky

Scenario	Operational cost[133] [mil. eur]	Total annual costs [mil. eur]	
		without NFC	NFC
Nováky	0,167	0,35	0,24

Source: Based on an own analysis using Sunstore 4 calculation tool

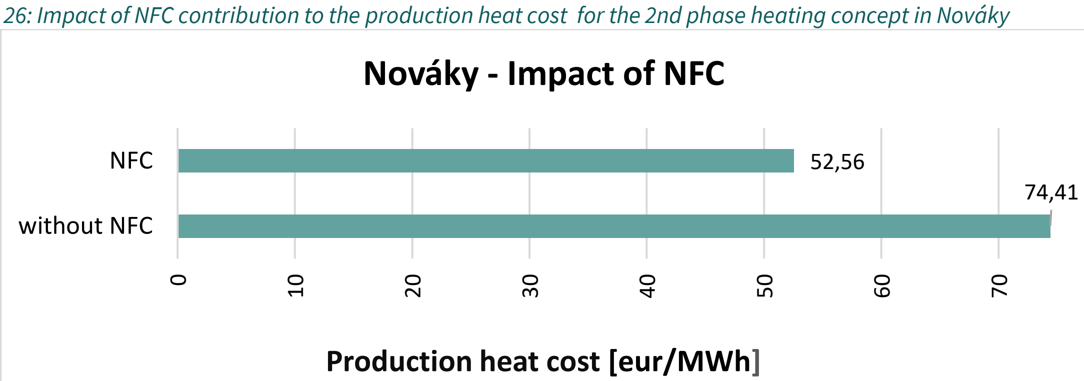
Tab. 38: Impact of a non-repayable financial contribution (NFC) on the production heat cost for the 2nd phase heating concept in Nováky

Scenario	Production heat cost [eur]	
	without NFC	NFC
Nováky	74,4	52,6

Source: Based on an own analysis using Sunstore 4 calculation tool

The effect of NFC contribution to the production heat cost is also visible in the following graph (Figure 26).

Figure 26: Impact of NFC contribution to the production heat cost for the 2nd phase heating concept in Nováky



Source: Based on an own analysis using Sunstore 4 calculation tool

[132] NFC provided for solar collectors and HP
[133] Independent of NFC

10 Reduction of CO_2 emissions

The proposal of the 2nd phase concepts in Prievidza and Nováky will also cause a significant reduction of greenhouse gas emissions produced during operation in comparison with the current heat source in the NPP. A comparison of produced CO_2 emissions of the current heating source from the NPP, the 1st phase heating solutions from the PTH, and the 2nd phase heating concepts based on the principle of the 4th generation DHS can be seen in the table below (Tab. 39). Conversion factors to CO_2 emissions have been taken from the current decree[134,135], which takes into account only carbon dioxide emissions produced during the operation of heat generators and not the equivalent CO_2 emissions of all greenhouse gases during the entire life cycle of technology.

Tab. 39: Balance of CO2 emissions produced by current and future heat sources

Municipality	Produced CO_2 [t/a]		
	Current heating source (NPP)	Heating solutions from PTH (since 2023)	4G heating solution
Prievidza (scenario A_1)	64 285,7	17 913,2	378,2
Prievidza (scenario A_2)			774,5
Prievidza (scenario B_1)			1035
Prievidza (scenario B_2)			753,7
Nováky	3687,4	533	181

Source: Based on an own analysis

[134] National Decree 364/2012 Coll., Available online: https://www.slov-lex.sk/pravne-predpisy/SK/ZZ/2012/364/20200310

[135] In Decree 364/2012 Coll. are values of the CO_2 emission factors related only to the amount of CO_2 greenhouse gases produced.

11 Final technical and economic evaluation

The production heat costs of the designed heating concepts based on the 4th generation DHS were analyzed without reasonable profit and under conditions set by assumptions in chapter 3. It was based mainly on amounts of the investment for technologies and operating costs. However, the large capital and operating costs of DHS are also necessary investments in the equipment, which are used for distribution, controlling, metering, costs for revisions of devices, staff salaries, and a reasonable profit as a part of distribution heat cost. The impact of these aspects was analyzed by estimation in the following chapters.

11.1 Evaluation of the DHS concept for Prievidza

In the proposed solutions of the 2nd phase of DHS in Prievidza was thermal network divided into two parts - northern and southern. The main reasons for this division were as follows:

- size of seasonal heat storage accumulator [136],
- different categories of thermal protection of buildings in the northern and southern part [137],
- shortening heat distribution network[138].

Two scenarios were created for each part with different proposed parameters (difference in heat demands and use of heat sources). The table below (Tab. 40) summarizes in the columns on the left the production heat cost of particular scenarios without NFC, but also with the considered NFC (40% co-financing). The considered production costs of heat were without a reasonable profit and did not include the capital costs for ancillary equipment, or the necessary reconstructions (e.g. costs for the reconstruction of heat distribution) of these facilities. These costs are difficult to determine without an in-depth audit of the current heat supply technology, which would demonstrate which parts of the current system are suitable for use in the higher generation of DHS. Nevertheless, models for informative comparison were developed (two columns on the right in (Tab. 40). These models show distribution heat cost after increasing the estimated investment for ancillary equipment and a reasonable profit [139].

[136] In case of maintaining current form of the heating network (without division) the seasonal heat storage would be with a vast dimensions.

[137] The northern part consist of urban areas whose buildings are of the panel type and potential of major revonation is technically easier to implement in comparison to the southern part, which buildings are with more complex architecture. Renovation of these buildings will be more technically difficult and financially demanding.

[138] Heat losses of the thermal network cause not only losses in heat transfer but also decrease the temperature of supply water. By shortening the length of a piping system remain a higher water temperature at the border of customers. In the case of reconstruction of a piping system, the cylindrical surface of the pipeline will also be reduced, which will also decrease heat losses.

[139] Investments for additional technologies for each part of the proposed DHS in Prievidza were estimated at 10 mil. eur for the specified payback period of the project (the largest item would be the reconstruction of heat distribution - about 20 km of new distribution for each part).

Tab. 40: Comparison of the production and distribution heat cost after considering additional investment costs and a reasonable profit for heating concepts in Prievidza

Scenario	Heat cost [eur/MWh]			
	Production heat cost Base technology[140]		Distribution heat cost Base technology, ancillary equipment, and reasonable profit	
	without NFC	NFC	without NFC	NFC
Northern part – A_1	57,1	31,9	82,1	42,5
Northern part – A_2	55,8	35,1	80,8	45,8
Southern part – B_1	58,2	40,6	86,9	53,1
Southern part – B_2	57,9	39,2	97,8	56,1

Source: Based on an own analysis using Sunstore 4 calculation tool.

It is obvious from the table (Tab.40) that even in the case of increasing the heat cost by estimated additional investments for ancillary equipment, it is possible to create a modern RES-based heating system, that distribution heat cost is competitive with the heat cost of current DHS operating in Slovakia.

11.2 Evaluation of the DHS concept for Nováky

The proposed 2nd phase of DHS in Nováky was designed to point out the feasibility of a thermal network that uses a characteristic local feature in the form of available mine water. In the proposed solution the higher operating costs due to higher electricity consumption by heat pumps are taken into account. These higher operating costs were offset by the design of a thermal solar system. The primary goal of solar collectors is to reduce the economic burden of the solution by increasing the efficiency of HP, which should be achieved by preheating the mine water. The second use of the thermal solar system is to supply surplus heat into underground mine water for seasonal accumulation what also increases the efficiency of HP.

The heat costs (production and distribution) in Nováky compared to the heat costs in Prievidza are higher for two main reasons. The first is lower parameters of technology, which causes higher specific costs, and the other is more financially demanding operation. The heat costs of the 2nd phase heating concept in Nováky can be seen in the table below (Tab. 41), where two columns on the left show the production heat costs without NFC and with NFC (40% co-financing) without a reasonable profit. The two columns on the right show the distribution heat heat costs without NFC and with NFC, a reasonable profit and the capital costs for ancillary equipment, or the necessary reconstructions.

[140] Heat sources and expensive technology (eg submersible pump for geothermal water from Púšť well)

Tab. 41: Comparison of the production and distribution heat cost after considering additional investment costs and a reasonable profit for the 2nd phase of the heating solution in Nováky

Scenario	Heat cost [eur/MWh]			
	Production heat cost Base technology [141]		Distribution heat cost Base technology, ancillary equipment and reasonable profit	
	without NFC	NFC	without NFC	NFC
Nováky	74,4	52,6	88,4	59,5

Source: Based on an own analysis using Sunstore 4 calculation tool.

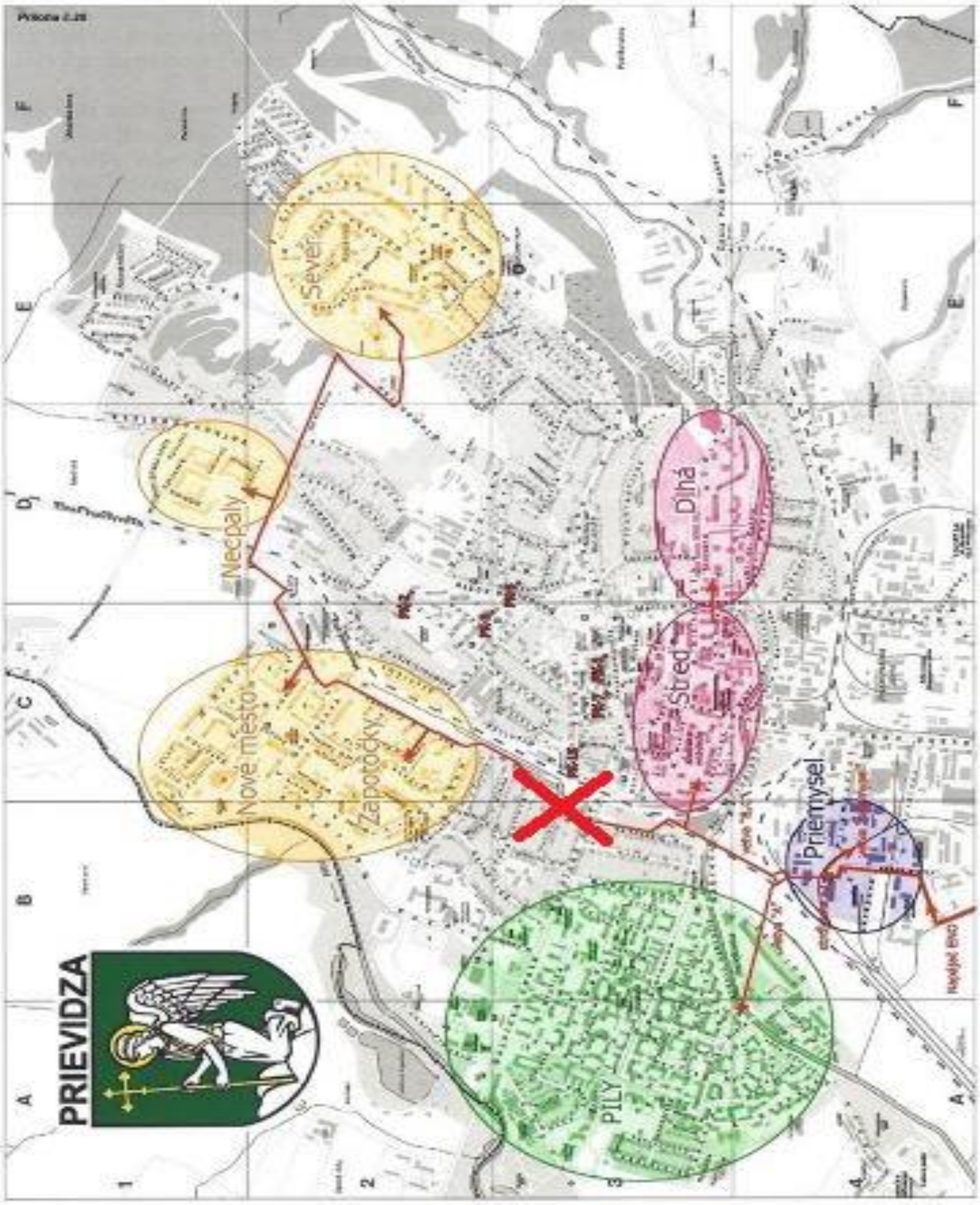
11.3 Evaluation of the DHS concept for Zemianske Kostoľany

Economic and technical indicators calculated in chapter 4.2 have shown that currently connected buildings to the DHS in the municipality of Zemianske Kostoľany are not suitable for the DHS operation (mainly from the economic point of view). However, the location of some buildings suggests that for some of the objects it would be possible to consider a creation of so-called energy communities where selected neighboring buildings would form a functional small decentralized system based on the 5th generation of DH. Due to the scope and preliminary character of this paper, this concept was not analyzed more in the study.

[141] Heat sources and expensive technology (eg submersible pump for mine water)

Annex 1 – Division of DH system in Prievidza

Figure 27: Northern and southern part of designed DHS for Prievidza (red X symbolizes the division of the network)[142]



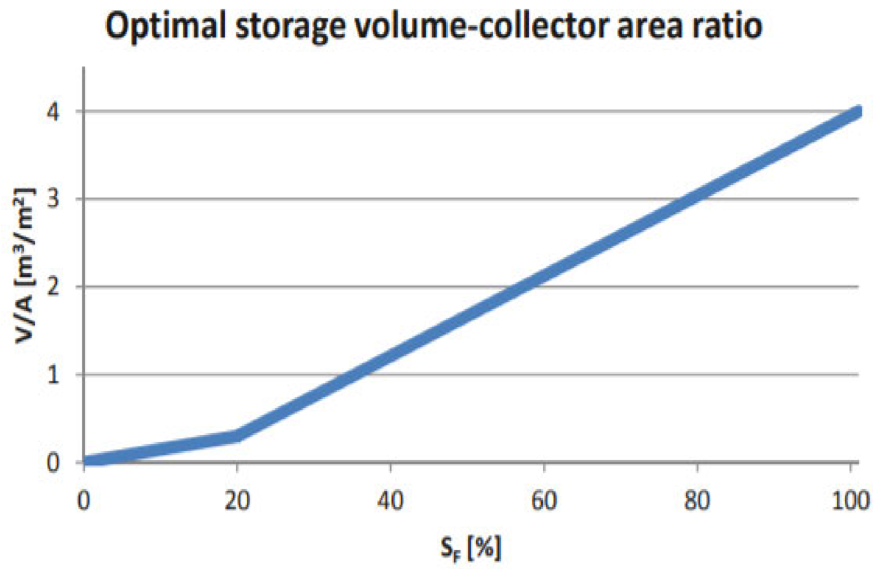
Source: website of a town of Prievidza

[142] Industrial zone (in the picture called “Priemysel”) will not be connected to the DHS. Northern DHS consists of yellow circles and southern one consists of green and pink circles.

Annex 2 – Dimensioning of seasonal heat storage accumulator

Seasonal heat storage is always designed in combination with solar collector system, while it is a rule that the bigger solar collector area, the bigger seasonal accumulation technology, but it is not a direct proportion. When we make a prefeasibility study of a heat storage technology, it is enough to use a simplified function defined by of a ratio of a volume of heat accumulator to a solar collector area (Figure 28).

Figure 28: Choice of a optimal volume of heat storage technology according to solar collector area



Source: HEATSTORE project report[143]

While dimensioning a heat storage technology, it is necessary to choose whether the accumulator is about to be discharged directly or indirectly (through HP).

Direct connection of a heat storage technology to the DH network (Figure 29) is cheaper[144] (both capital and operational costs) compared to the indirect connection but the solution without HP does not exploit a full potential of the accumulator.

[143] KALLESØE, A.J. a T. VANGKILDE-PEDERSEN. Underground Thermal Energy Storage (UTES): state-of-the-art, example cases and lessons learned. HEATSTORE project report, 2019, 130 s.

[144] Depends also on a price of electricity and efficiency of HP.

Figure 29: Direct connection of a thermal energy storage technology to the DH grid

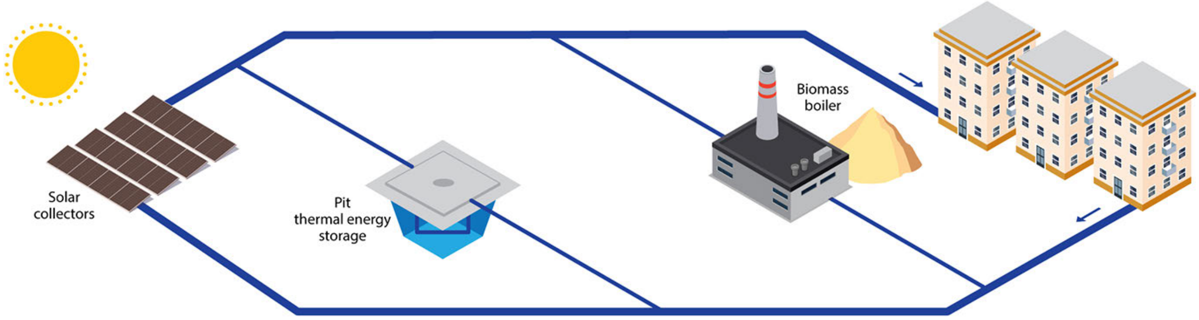


Illustration: R. Watzka

Connection of a thermal energy storage to the DH grid through HP (Figure 30) helps to achieve optimum exploitation of an accumulation potential of a specific accumulator (accumulated water is more cooled down thanks to HP). HP heats up return network water to required supply temperature. These types of HP are designed to cover peak loads and their capacity is dimensioned according to expected needed heat load demand.

Figure 30: Indirect connection of a thermal energy storage technology to the DH grid

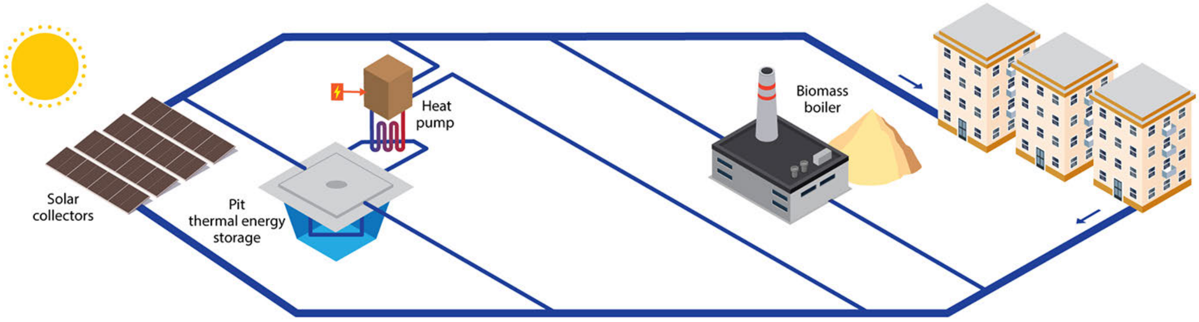


Illustration: R. Watzka

In order to the operation of thermal storage with HP was as economic as possible, it is recommended to use HP, which allow often on and off regimes (optimum use of off-peak tariffs of electricity).

HP, which heat up the DH return water, often use CO_2 as a refrigerant. HPs have to have such capacity and SPF to be able to ensure required temperature of supply water.

In the study, there were used two technologies of seasonal heat storage, namely Pit Thermal Energy Storage (PTES) and Borehole Thermal Energy Storage (BTES). BTES uses underground soil or rock to store thermal energy by circulating a fluid in plastic u-tube pipes installed in a large number of closely spaced boreholes. The advantage BTES over water heat storage systems[145] is its modularity with the possibility of supplementing boreholes and expanding its accumulation capacity as needed. The modularity of the BTES allows its use in dimensions that are not suitable for water heat storage system. On the other hand, flowing groundwater can cause problems with operation of the BTES related with constant heat

[145] The PTES also belongs to water heat storage systems

transfer, so the geological and hydrogeological assessment is necessary during the preparation phase. A suitable underground environment increases the storage capacity of this system, but in principle BTES reaches a lower value of heat capacity than water heat storage systems. BTES does not allow maintenance or repair, but still has a relatively long service life up to 50 years.[146]

Lessons from previous projects show that PTES has a suitable technical and economic application in larger dimensions with a volume of 60,000 cubic meters or more and it places higher demands on built-up area, which makes its construction near densely populated areas unsuitable. The pit is constructed with a geometry of a beveled cone or a pyramid turned upside down. Water with an accumulation temperature range between 50 and 90 °C is used in particular as the accumulator. The accumulation itself uses the principle of stratification, where the warmer medium is kept in the upper parts and colder (denser) water remains at the bottom of the tank, thus ensuring higher efficiency of the system. A problem with the implementation can be a high level of groundwater, which could seep into the pit and therefore is usually placed to a depth of a maximum of 15 meters. The technology also does not allow maintenance, which results in a relatively short service life of 20 years.[147]

[146] KALLESØE, A.J. a T. VANGKILDE-PEDERSEN. Underground Thermal Energy Storage (UTES): state-of-the-art, example cases and lessons learned. HEATSTORE project report, 2019, 130 s. + prílohy.

[147] KALLESØE, A.J. a T. VANGKILDE-PEDERSEN. Underground Thermal Energy Storage (UTES): state-of-the-art, example cases and lessons learned. HEATSTORE project report, 2019, 130 s. + prílohy.

Annex 3 – Operating hours of heat generation technologies

Determining operating hours, especially full operating hours[148], is key when designing a heat production system. The number of full operating hours depends mainly on these factors[149]:

- annual outside temperature characteristic curve,
- room temperature and its change over time (depends on building standard and TPB category) [150],
- air temperature defining the beginning/end of the heating season,
- other factors not affected by the weather.

In general, the full operating hours are estimated so it is important to have a secure heat supply at maximum heat load with sufficient reserve.

To design the heat sources in this study, the operating hours were selected as follows (Tab. 42).

Tab. 42: Estimated full operating hours of proposed thermal solutions

Heating system area	Scenario	TPB category	Number of full operating hours [hours/a]
Prievidza (northern part)	A_1	TPB 5 or higher	2000
Prievidza (northern part)	A_2	TPB 5 or higher	2000
Prievidza (southern part)	B_1	Buildings of all categories, about half of them at level TPB 5 or higher	2400
Prievidza (southern part)	B_2	TPB 5 or higher	2000
Nováky	-	TPB 5 or higher	2000

Source: Own analysis

[148] Full operating hours mean operating hours when the maximum heat load demand for space heating and domestic hot water is expected.

[149] Heat generators must be designed for the maximum heat load demand and must securely cover heat demand during peak loads.

[150] According to the valid national decree 152/2005 Coll. it is an outside temperature of 13 ° C. The whole text is as follows: The heating period begins when the average daily outside air temperature falls below 13 ° C for two consecutive days and the weather forecast is not expected to increase above 13 °C the following day. The average daily outside air temperature is calculated from four values measured at 7 AM, 2 PM and 9 PM (2-times). The decree allows the heat supplier and customers to agree on another outdoor temperature, when it starts heating.

Annex 4 – SPF of heat pumps

Seasonal performance factor (SPF) represents the ratio of heat output per year to electricity used. The SPF is a more accurate and comprehensive indicator for evaluating the efficiency of the operation of the heat pump as a coefficient of performance (COP), which refers only the moment (one point) on the actual operating characteristics of the heat pump. The SPF value therefore significantly depends on the climatic conditions, the operating conditions of a heat pump, but also on the method of its installation. [151]

Indicative SPF values for different primary heat sources and various types of heating systems are given below. These values are based on publicly available information from heat pump manufacturers and were prepared by the Slovak Innovation and Energy Agency.

Tab. 43: Indicative values of SPF depending on the type of primary heat source and the required output temperature

Zdroj tepla	**Typ vykurovacej sústavy**	**Optimistický odhad SPF**
Vzduch z okolia klimatická oblasť II (teplota od -15 °C do +15 °C)	Vykurovanie radiátormi teplota 50 °C (W50)	2,5
Vzduch z okolia klimatická oblasť II (teplota -15 °C do +15 °C)	Vykurovanie podlahové alebo stenové teplota 35 °C (W35)	3,3
Zemný zásobník teplota kolektora 0 °C (B0)	Vykurovanie radiátormi teplota 50 °C (W50)	2,9
Zemný zásobník teplota kolektora 0 °C (B0)	Vykurovanie podlahové alebo stenové teplota 35 °C (W35)	4,0
Podzemná voda Teplota vody 10 °C (W10)	Vykurovanie radiátormi teplota 50 °C (W50)	3,6
Podzemná voda Teplota vody 10 °C (W10)	Vykurovanie podlahové alebo stenové teplota 35 °C (W35)	5,5

Source: Slovak Innovation and Energy Agency [152]

In the study, a conservative SPF value of 3.4 was chosen according to Slovak Decree no. 364/2012 Coll. (Appendix 2 of the Decree) for water-to-water heat pumps for radiator heating. Considered conditions were for maximum use of source water down to 5 ° C. The above table (Tab. 43) also shows a similar value for the groundwater heat source[153], which means 3.6. When considering a more economical use of the heat pump with use of the source water down to 15 ° C, a higher efficiency with SPF value 4 was estimated. The expert estimate was based on an actual project[154] in the DH system in Sereď, where heat pumps are installed to use waste heat from a geothermal well.

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[151] Ako vybrať tepelné čerpadlo [online]. Bratislava: Slovenská inovačná a energetická agentúra, c2020 [cit. 2021-9-13]. Dostupné z: www.siea.sk/bezplatne-poradenstvo/publikacie-a-prezentacie/ako-vybrat-tepelne-cerpadlo/

[152] Ako vybrať tepelné čerpadlo [online]. Bratislava: Slovenská inovačná a energetická agentúra, c2020 [cit. 2021-9-13]. Dostupné z: www.siea.sk/bezplatne-poradenstvo/publikacie-a-prezentacie/ako-vybrat-tepelne-cerpadlo/

[153] If the temperature of the source groundwater is 10 ° C, then when used in a heat pump, it can be expected to cool it by 4 ° C to the final temperature level of 6 ° C.

[154] Veľké tepelné čerpadlá. Šamorín: Slovenský zväz pre chladiacu a klimatizačnú techniku, 2019. ISBN 978-80-89376-12-4. Zborník z konferencie Papiernička 2019.