Market uptake of small modular renewable district heating and cooling grids for communities

Project No: 691679

Heating/cooling demand and technical concept for district heating/cooling in Visoko

Municipality of Visoko (Bosnia and Herzegovina)
District heating of central zone of Visoko

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Authors: Christian Doczekal, Güssing Energy Technologies, Austria
Linn Laurberg Jensen, PlanEnergi, Denmark
Jakob Worm, PlanEnergi, Denmark
Anes Kazagić, EPBiH, Bosnia and Herzegovina
Ajla Merzić, EPBiH, Bosnia and Herzegovina
Elma Redžić, EPBiH, Bosnia and Herzegovina
Dino Trešnjo, EPBiH, Bosnia and Herzegovina
Marin Petrović, Municipality of Visoko, Bosnia and Herzegovina

Editors: Christian Doczekal, Güssing Energy Technologies, Austria
Dominik Rutz, WIP Renewable Energies, Germany

Contact: Güssing Energy Technologies GmbH
Christian Doczekal
Email: c.doczekal@get.ac.at, Tel: +43 3322 42606 331
Wienerstraße 49
7540 Güssing, Austria
www.get.ac.at

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CoolHeating website: www.coolheating.eu

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1 Introduction

The heating and cooling demand in Europe accounts for around half of the EU's final energy consumption. Renewable energy policies often mainly focus on the electricity market, whereas policies for renewable heating and cooling are usually much weaker and less discussed in the overall energy debate. Therefore, it is important to support and promote renewable heating and cooling concepts, the core aim of the CoolHeating project.

The objective of the CoolHeating project, funded by the EU's Horizon2020 programme, is to support the implementation of "small modular renewable heating and cooling grids" for communities in South-Eastern Europe. This is achieved through knowledge transfer and mutual activities of partners in countries where renewable district heating and cooling examples exist (Austria, Denmark, Germany) and in countries which have less development (Croatia, Slovenia, Macedonia, Serbia, Bosnia-Herzegovina). Core activities, besides techno-economical assessments, include measures to stimulate the interest of communities and citizens to set-up renewable district heating systems as well as the capacity building on financing and business models. The outcome is the initiation of new small renewable district heating and cooling grids in five target communities up to the investment stage. These lighthouse projects will have a long-term impact on the development of "small modular renewable heating and cooling grids" at the national levels in the target countries.

For each of the CoolHeating target municipalities one or two potential projects are identified in which small modular renewable heating and cooling grids could be implemented. The current report describes the technical concept to meet the heat demand in the central zone of Visoko.

2 General description of the current situation and concept

District heating systems were well developed in towns and cities before the war in Bosnia and Herzegovina. During the war, many systems fell into disrepair and after the war could not recover customers due to a fall in the purchasing power of the population. The maintenance and investment in the remaining functioning district heating systems has been low, leading to obsolete technologies, as well as low efficiency and large heat losses on the network.

A district heating and cooling concept based on renewable energy sources would help to meet rising urban energy needs, to improve efficiency, to reduce emissions, and to improve the local air quality in the Municipality of Visoko. Air quality especially badly suffers during the heating season due to heavy use of coal for heating. Existing heating systems are mainly individual and currently dominated by coal as the cheapest energy source on the market. Therefore, they should be upgraded or new networks created, using solid biofuel and solar and geothermal energy technologies. Depending on local conditions, renewable-based DHC would bring a range of benefits, including increased energy security, improved health and reduced climate impact.

The concept shows the possibility of using solar thermal heat, a heat pump from the river, in combination with a seasonal storage, as well as a natural gas peak load boiler.

3 Key results of the survey for heating/cooling demand in the target community

By reviewing statistical data compiled through the survey (Puksec et al. 2016[1]), a great presence of wood as a fuel for the heating system has been noticed, especially in family houses with the heating system that includes individual hand-firing solid-fuel furnaces, but also in a great number of categories of collective housing buildings.

[1] Pukšec T. et al. (2016) Survey on the energy consumption and attitudes towards renewable heating and cooling in the CoolHeating target communities. – University of Zagreb FSB; CoolHeating Report available at www.coolheating.eu

More precisely, considering the numbers, the following graphs (Figure 1 and Figure 2) show the types of heating systems and energy sources used in private households in Visoko:

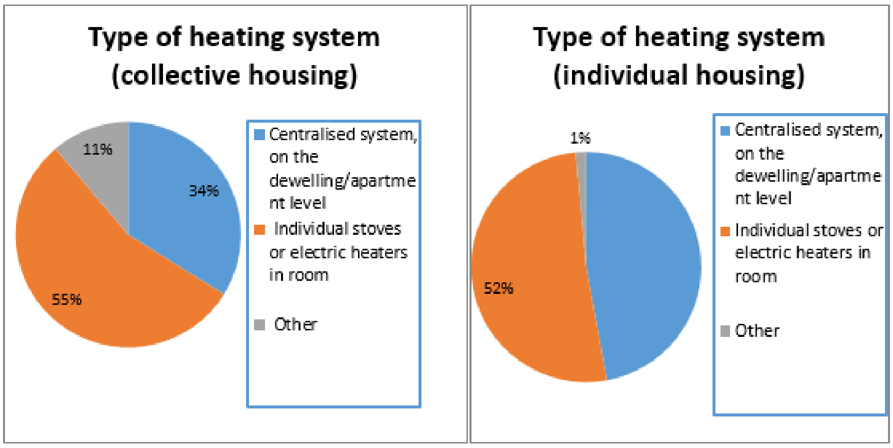


Figure 1: Type of heating systems used in households in Visoko (Puksec et al. 2016)

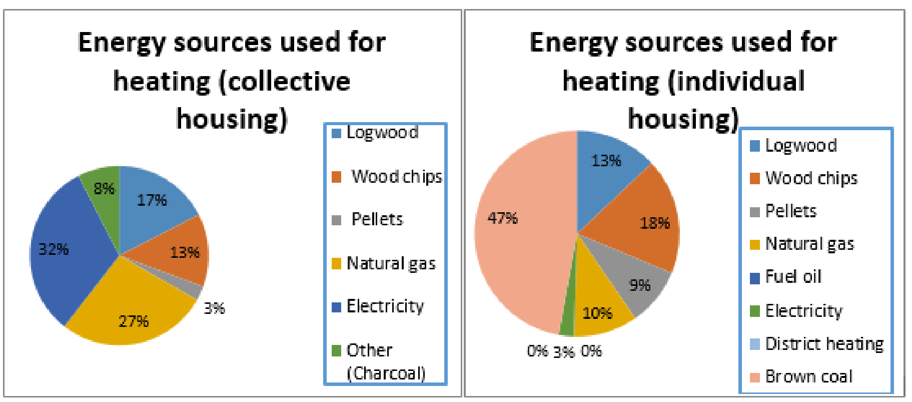


Figure 2: Energy sources used for heating of households in Visoko (Puksec et al. 2016)

4 Heating/cooling demand for the concept and initial situation

By reviewing statistical data compiled through the survey, a great presence of wood as a fuel for the heating system has been noticed, especially in family houses with the heating system that includes individual hand-firing solid-fuel furnaces, but also in a great number of categories of collective housing buildings.

The DHC system concept is planned to cover the central area of the town. The zone includes different types of buildings. The main focus is on public buildings which are in the jurisdiction of the Municipality, which represent the biggest consumers in the town. On the other side, there is private and collective housing outside of the jurisdiction of the Municipality, whose connection to the centralized heating system would contribute to the reduction of air pollution and more rational use of energy resources.

In order to determine the consumer affordability of the heating costs, it is necessary to review the main socio-economic parameters of the population and energy consumption of households in Visoko.

4.1 Map: Potential buildings to be connected to the DH grid

The buildings to be considered by the DH concept are shown in Figure 3 and marked by consecutive numbers (Google maps):

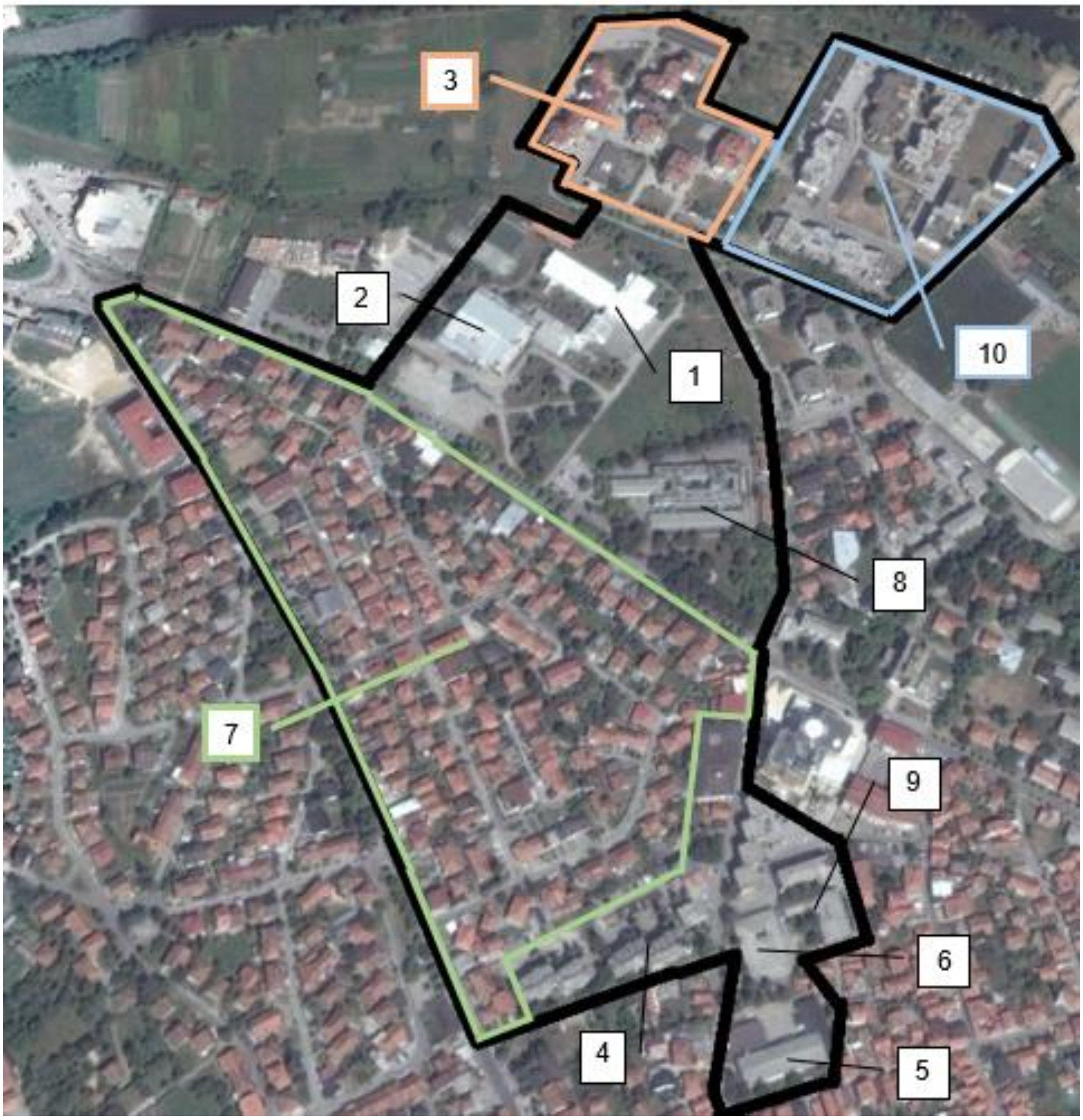


Figure 3: Project area: the north-eastern part of Visoko

Table 1 gives a short description including the data of the heated area, category of buildings, existing heating system and estimated operating time.

Amongst the buildings considered, the medical centre is the largest polluter on the municipality using coal as the primary energy source. The primary and music school usees fuel oil of questionable quality, irregularly supplied by relevant cantonal ministry. Therefore, it happens that the school sometimes runs out of fuel or has to keep sparing the fuel lowering the inner temperature with pupils often sitting in their jackets.

Individual and collective housings use mainly coal obtained on black market, then firewood, gas, electricity, or the combination thereof. Collective housing as well as 25% of individual houses have individual central heating in use.

Table 1: Data on objects covered by project area

consecutive number	name or type of building	category	heated m² of building	existing heating system	estimated operating time per day
1	Secondary school "Hazim Šabanović"	public	5,047	central heating by natural gas	5am - 8pm
2	Sports centre "Mladost"	public	3,350	central heating by natural gas	5am - 11pm
3	Collective housing facilities – LUKE 1	household	12,510	individual system	5am - 10pm
4	Collective housing facilities „Dahirovac"	household	12,000	individual system	5am - 10pm
5	Primary school „Safvet beg Bašagić" and Music school „Avdo Smajlović"	public	3,027	central heating by fuel oil	5am - 8pm
6	Crèche	public	1,065	central heating by natural gas	5am - 8pm
7	Individual housing facilities „Hadžijina voda"	household	37,585	individual system	5am - 10pm
8	Medical centre	public	4,895	central heating by coal	0am - 12pm
9	Social work centre	public	390	central heating by natural gas	5am - 8pm
10	Collective housing facilities - LUKE 2	household	12,000	individual system	5am - 10pm

Individual systems consider both systems where single stove in the apartment is used for heating (one or more rooms) and also individual central heating systems installed for the household. As far as operating mode is concerned, all public buildings, except the Medical centre, are heated in one operating (daily) mode, where the heating is turned off during the night. Medical centre and all private households have daily (high) mode and lowered heating regime during the night. Some photos of the buildings are shown in Figure 4 to Figure 8.


Figure 4: Secondary school "Hazim Šabanović"

Figure 5: Sports centre "Mladost"

Figure 6: Medical centre

Figure 7: Represents of collective housing buildings in Luke

Figure 8: Damage on most of buildings remained from war time

It is important to notice the lack of applied energy efficiency measures on considered buildings. Residential and non-residential buildings have extremely large glazed areas with high heat transfer coefficients – "U" value (single or double-glazing), walls with no insulation and large amounts of damage, oversized and unbalanced heating/cooling systems without regulation, etc. All this leads to high heat losses during heating season or gains during summertime.

4.2 Assessment of the heating/cooling demand

A number of strategic documents in Bosnia and Herzegovina, at the level of entities, canton and local communities, have dealt with energy consumption evaluations in buildings at the level of final energy and energy generating products (electric, heat, natural gas, oil and oil derivatives, coal and biomass) as well as possibilities for its reduction. Except for some buildings, evaluations have not been done based on reliable data on energy consumption in buildings which have been obtained by energy audits of residential buildings, but based on statistical data, energy balance and energy development plans. Therefore, a “top-down” approach has been used.

When assessing heat demand in Visoko, it was necessary to take into account the lack of standard energy audits for most of considered buildings. Energy audit is a complex task and requires the engagement of professionals from various fields including mechanical engineers, electrical engineers, civil engineers, architects, lighting engineers and electronics specialists.

Some audits have been carried out for few buildings and their results are summarized in Table 2, while for most of them no energy audits are available, so the data about their heat demand had to be assumed.

Table 2: General characteristics of the considered buildings

consecutive number	name or type of building	heated area of building [m²]	specific heat demand for space heating and hot water [kWh/m²/a]	demand for heating and hot water preparation in [kWh/a]
1	Secondary school “Hazim Šabanović”	5,047	242 *	1,222,163
2	Sports centre “Mladost”	3,350	347 *	1,162,738
3	Collective housing facilities – LUKE 1	12,510	180 **	2,251,800
4	Collective housing facilities „Dahirovac“	12,000	180 **	2,160,000
5	Primary school „Safvet beg Bašagić“ and Music school „Avdo Smajlović“	3,027	180 **	544,860
6	Crèche	1,065	180 **	191,700
7	Individual housing facilities „Hadžijina voda“	37,585	220 **	8,268,700
8	Medical centre	4,895	180 **	682,654
9	Social work centre	390	200 **	78,000
10	Collective housing facilities - LUKE 2	12,000	200 **	2,400,000

* - measured specific heat demand
** - assessed specific heat demand

The total annual heat consumption at 80% connection rate for private housing facilities and 100% connection rate for public buildings was calculated with 18.13 GWh (including heat losses within the grid).

The annual load line to supply the DH grid in Visoko is shown in Figure 9.

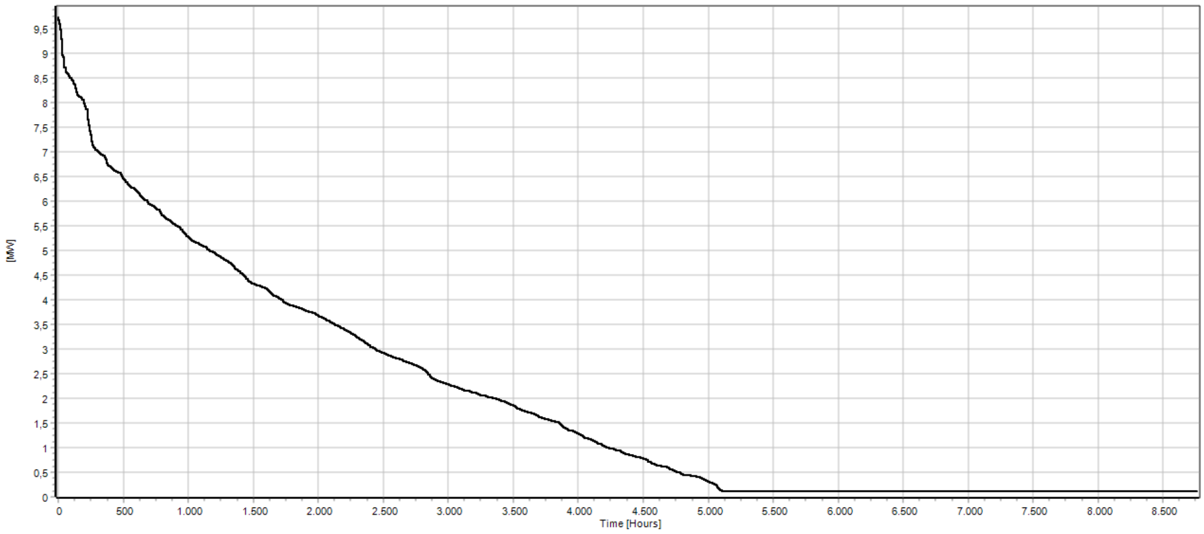


Figure 9: Annual load line for the planned district heating grid in Visoko at 80% connection rate for private houses and 100% connection rate for public buildings

5 Technical concepts for heat/cold generation

From the very beginning of the project, the aim was to create and find the best solution in accordance with the conditions in the municipality, taking into account similar examples of good practice in the region and in Europe.

The choice of the heat generation technology should be selected based on the geographic location of the site, available space for the installation of production units, availability and fuel prices.

The DH system is planned so that the heat production would be achieved with different production units: heat pumps (water-water), solar thermal collectors and existing peak load gas boilers which would start automatically if the heating output of the renewable energy sources in the DHC system is insufficient to cover the demand. All these units would be located in close proximity to the river in the northwest of the city, at the area of approx. 11,000 m², and the solar thermal collectors and heat pumps would be connected to a seasonal pit thermal storage. It will be no problem to expand the currently envisaged location, if the more concrete planning requires a larger surface area for these production units.

Considering the technologies separately, it's important to note the following:

- for the use of solar thermal collectors, it is important to note that the location of Visoko in the river valley has a large number of foggy days in winter time. Insolation data needs to be checked properly;
- no groundwater sites in the project area (previous researches conducted);
- proximity of a river;
- no possibility of using industrial waste heat;
- gas network exists in some parts of the project area;
- necessary to carefully analyse biomass market needs, biomass logistics supply, potential suppliers, price, quality and quantity.

No other requirements and obligations were included in the planning process, such as minimal efficiency, minimal grid density, emission limits etc, as there is lack of relevant legislation treating this topic.

Before any construction works, it is necessary to check, for each case, the height of the groundwater. Some geotechnical researches were carried out in places nearby and no shallow groundwater was found. It is anticipated that water from river Bosna would be partly induced through a newly built pool and used for heat extraction by the heat pumps. Taking into account the temperature of the river Bosna which is about 10°C and the temperature level of the whole system (80/60°C), it is expected that the coefficient of performance in this case due to $\Delta T=T_{cond}-T_{evap}=70$ K would be quite low (COP 2.5 to 3.7). For this reason, it is planned to supply the heat at a temperature of 70 °C, and in extremely cold winter days, the heating at 80 °C would be achieved by gas boilers, and so a COP between 2.8 and 4.0 for heat pumps could be achieved.

Long-term (seasonal) storage would mean storing heat for several months, including from summer to winter. Introducing a large-capacity thermal storage in the district heating system gives extremely good conditions for a very flexible production from combined production units. Heat storage could also contain an additional heat pump to raise the temperature from the seasonal storage to the DH grid.

It is also planned that photovoltaics would be installed on the roofs of public institutions, which would contribute to the justification and sustainability of such a project. Energy produced by photovoltaics would entirely be fed into the public grid at a price that is a bit higher than the regular price of electricity. At one stage in the development of the concept, a CHP plant on biomass was also considered, however, the circumstances concerning the electricity and thermal energy price ratios were unfavourable and therefore this scenario was given up. The planned locations of production units and the DH grid are shown in the Figure 10 below.

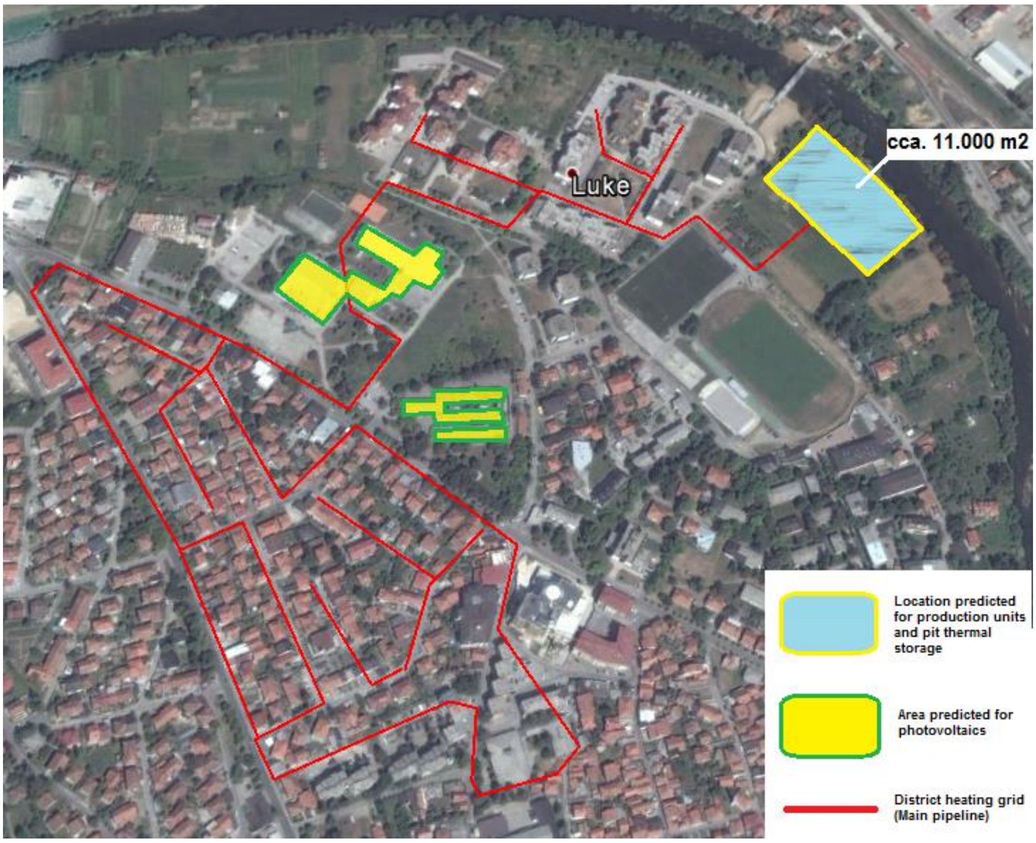


Figure 10: Map of potential locations for installation of production units, thermal storage, photovoltaics

5.1 District heating / cooling grid

This chapter provides an overview of the district heating network details. By precisely defining the location of the production plant, it was possible to draw a route from the main pipeline. The Figure 11 shows the main heating network with the trench length of approx. 4,000 meters with additional 1,500 meters length to the consumers (10 meters connection to each consumer on average). This leads to a total length of the DH grid of 5,500 m. There are approximately 150 private residential houses, 30 collective buildings and 6 public institutions within the project area.

An important parameter to assess the cost effectiveness of a DH system is the grid density which is defined as the ratio of the annual heat delivered (for consumers) to the total length of the DH piping and network. The calculated grid density for municipality of Visoko is 3,482 kWh per meter of pipeline and per year.

The annual heat losses for the DH grid in Visoko were calculated with 5.9% or 1,129 MWh/a, based on empirical data for real DH grids in Austria (calculation based on Malik (2012)[2]), for the grid density shown above.

About 17 GWh per year could be sold to the consumers, therefore **18,13 GWh/a in total** are needed to feed into the DH grid.

The material of the DH pipes could be steel or plastic, because of a flow temperature of lower than 90°C. Simultaneity of the load was calculated with 100%. The temperature level of the DH grid will be designed with 80°C flow and 60°C return flow.

Figure 11: Map of the main pipes from the DH grid

An indirect system with separate heat exchangers (substations) is suggested for public and large residential buildings. On the other side, direct system is suggested for individual households, with one heat exchanger for all private housing facilities and one heat exchanger per collective housing facility. Larger substations would require larger diameter pipes increasing the investment price for the pipeline, while single substation for each individual household would again increase investment costs, meaning high connection fee would have

[2] A. Malik et. al. (2012) Was ist ein gutes Heizwerk? - Landesenergieverein Steiermark and qm heizwerke Datenbank; https://www.klimaaktiv.at/dam/jcr:9f6e7fe5-48b0-4cb1-a9d6-8a57dc908713/Was_ist_ein_gutes%20Heizwerk.pdf

to be charged. The combination of indirect and direct system seems as the optimal compromise.

5.2 Heating / Cooling generation

The determination of the capacities of the production units, as well as optimization of the operating mode itself, was performed by the specialized software EnergyPRO (Figure 12). It is a modelling software used primarily in relation to district heating projects. It is used to carry out an integrated detailed technical and financial analysis of both existing and new energy projects. The software was used to plan the optimal production for the energy plant for a whole year. The period for the optimization was refined to the minutes scale with a detailed production plan. Inputs for the optimization are typically parameters such as content of stored energy at the beginning of the optimization period, expected energy demands within the period as well as expected fuel and electricity prices. The calculations are based on:

- inputs for all units separately,
- climate conditions,
- 80% connection rate for private and collective housing facilities and 100% for public buildings,
- prices of all energy sources,
- energy efficiency performance of the facilities,
- temperature level (80/60 °C),
- heat losses assumption in the grid of approx. 5.9%.

The operating time was also considered in EnergyPRO. It can be taken as realistic estimation that the building would have high and low load periods of heating, assuming that for private apartments high period would be 7 am to 9 pm, lowering temperature during the night (night setback), also with peaks in the morning. Same principle was assumed for public buildings with the difference of shorter daily high load period (7 am to 3 pm). Daily values of energy consumption with operating hours per day are available for the secondary school and the sports hall.

Temperature levels of 80/60°C are suggested as realistic for the operation of the system. Higher temperatures would be very difficult to achieve taking into account the use of heat pumps. Temperature difference 20 K is suggested, based on not adjusted hydraulic systems at the consumer side.

Figure 12 shows the calculated production units of Visoko with PV, heat pump, solar thermal collectors, seasonal thermal storage and gas peak load boiler.

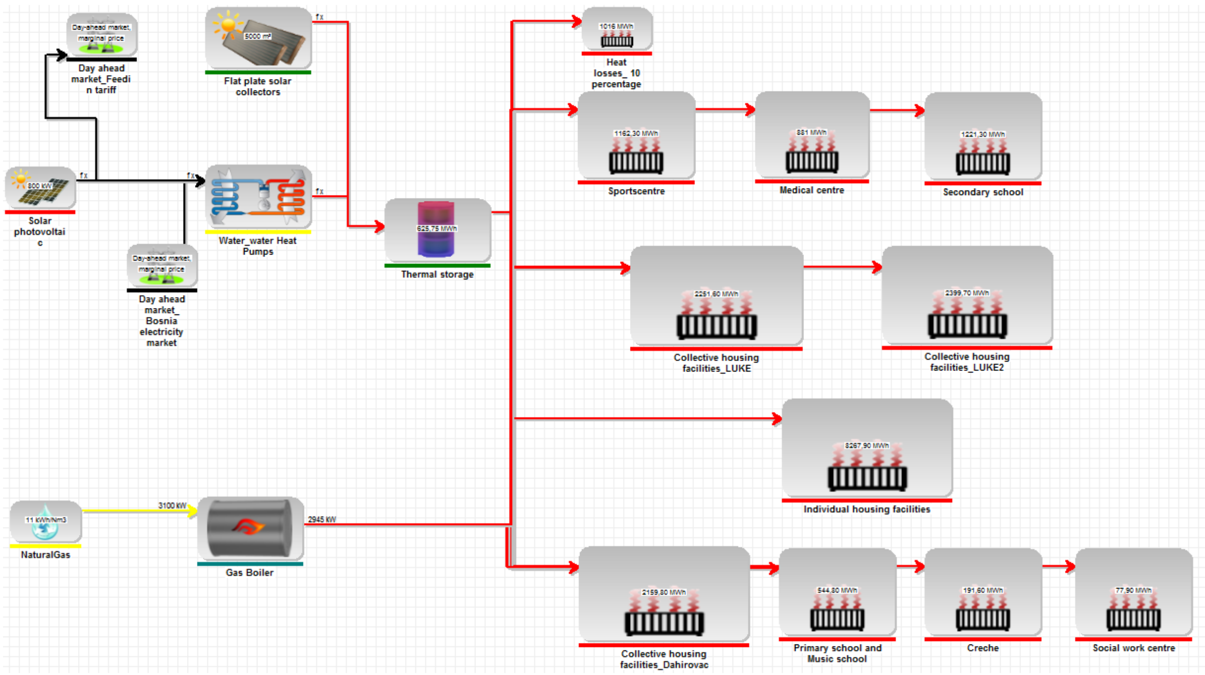


Figure 12: Site overview in EnergyPRO with the calculated heat production units in Visoko

The total installed power for all production units was found to be 9.4 MW_{th}, including the area of 5,000 m^2 of solar collectors. An overview of the obtained capacities of all production units for the most optimal variant in the techno-economic sense is as follows:

- Heat pumps 6.3 MW
- Gas boilers 3.1 MW
- PVs 800 kW
- Solar collectors 5,000 m^2
- Heat storage 13,500 m^3

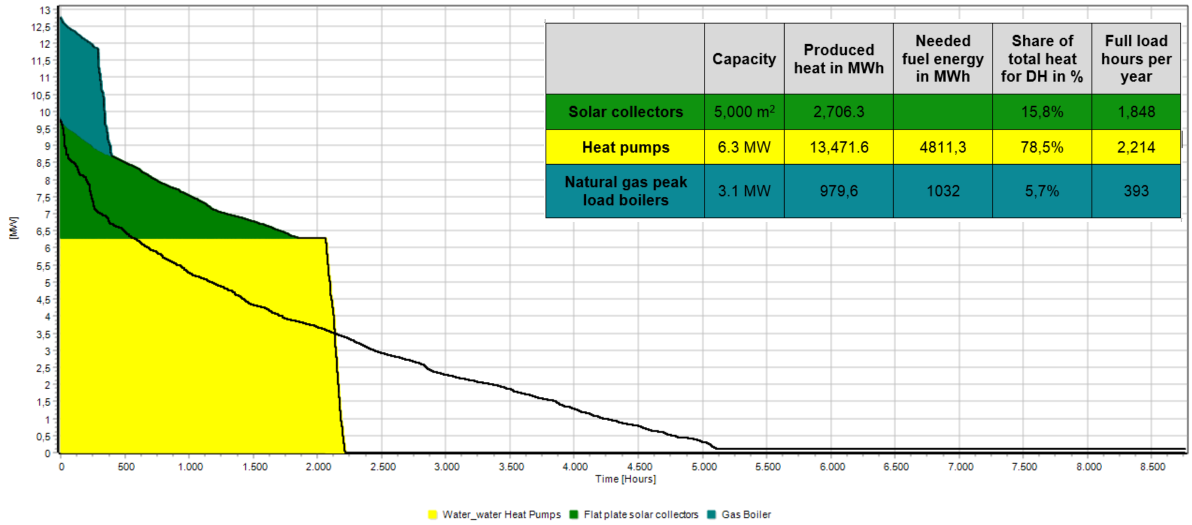
For a possible realization of the system, it could be considered to implement the heat pump directly to the DH grid, without storing the heat in the seasonal storage. With this operation mode the seasonal storage would have more capacity for the solar collectors.

Several existing natural gas boilers would be used only to cover the peak loads as mentioned earlier. Their total capacity is calculated with 3.1 MW. Historically it happened that back-up boilers were sized based on the entire system demand in case of possible disruption. However, considering that all buildings have some kind of alternative heating systems, it is suggested that back-up boilers are unnecessary. There is no legislation treating this criteria at the moment.

According to the analysis performed and taking into account all insolation data (Climate Forecast System Reanalysis – CFSR2) for the municipality of Visoko, about 1,256.6 MWh electricity would be produced by photovoltaics.

Figure 13 and Figure 14 give a more detailed view of the data by the separate heat production units. About 15.8% of the total heat demand for the DH grid could be generated with the solar thermal collectors, about 78.5% with the heat pump and only 5.7% with the gas peak load boilers. The storage capacity of the seasonal storage is shown in Figure 15.

The solar thermal collectors could produce about 2,706.3 MWh/a heat. The heat pump might need about 3,367.8 MWh/a (at COP 4.0) to 4,811.3 MWh/a (at COP 2.8) electricity to produce 13,471.6 MWh/a heat (6.3 MW nominal thermal capacity).



	Capacity	Produced heat in MWh	Needed fuel energy in MWh	Share of total heat for DH in %	Full load hours per year
Solar collectors	5,000 m²	2,706.3		15,8%	1,848
Heat pumps	6.3 MW	13,471.6	4811,3	78,5%	2,214
Natural gas peak load boilers	3.1 MW	979,6	1032	5,7%	393

Figure 13: Annual load line and calculation details for heat production units for DH grid in Visoko

Below is a review of several characteristic calculation results obtained in EnergyPRO:

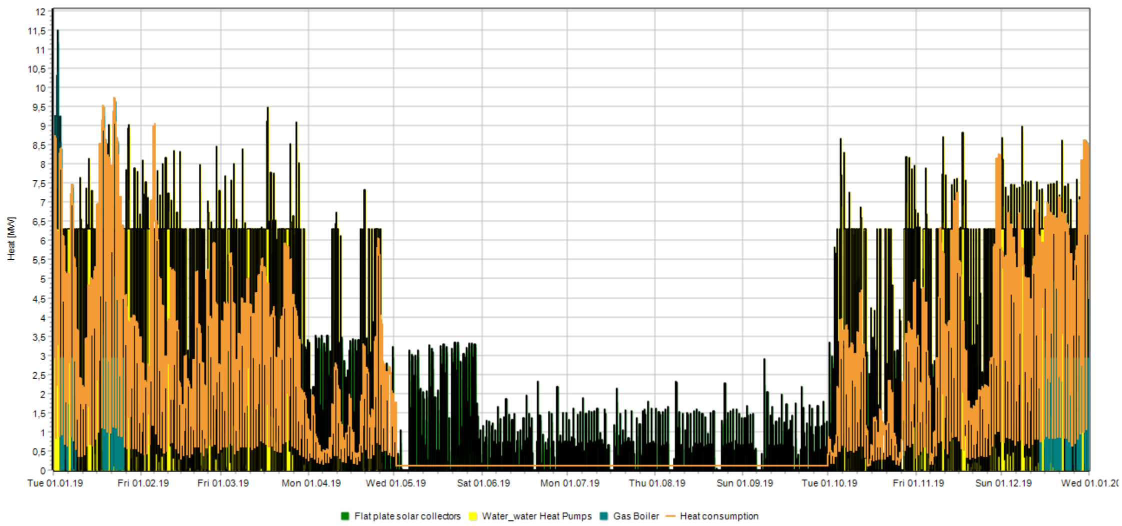


Figure 14: Load line of production of all units and annual heat demand

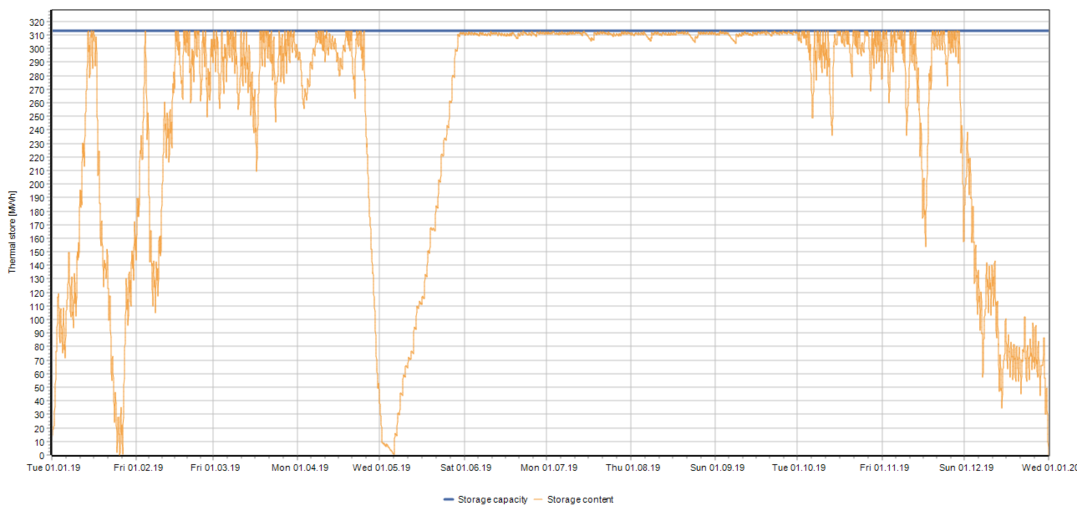


Figure 15: Storage capacity/content during a year

Being located in the region of moderate continental climate, located at an altitude of 450 m and surrounded by hills, it is anticipated that the cooling potential of the system would be insufficiently utilized during the summer months for any serious analysis to be undertaken. Furthermore, currently, people rarely use cooling in their premises due to the low purchasing power. Therefore, the consideration of cooling within the system would be too expensive.

On the other side, there might be considerable demand for domestic hot water (DHW) also in summertime. DHW is entirely getting prepared by electric boilers at present. People would switch to DH hot water preparation if it comes out cheaper.

6 Summary of the technical concept

The planned district heating (DH) system in Visoko would supply around 150 private houses, 30 collective housing facilities and 6 public buildings. About 4,000 of Visoko Municipality's 40,000 citizens would be covered by this DH system.

The DH production for the transmission system would come from following production units: solar collectors, heat pumps and gas boilers. In addition to the above mentioned technologies, thermal storage with capacity of 13,500 m^3 is also planned, which would ensure reliability and efficiency of mentioned technologies. One of the main problems in the energy supply especially in the case of the renewable technologies is the temporary gap between the availability of the resource and the demand. The storage would allow filling this gap, therefore it is a key factor for improvement of the renewable rate in such energy mix. Base heat production would be achieved through solar collectors (15.8%) and heat pumps (78.5%), which would be connected to storage, while the rest and peak loads would cover the gas boiler.

The DH grid was calculated with 5,500 m. A direct system is suggested for individual households, with one heat exchanger for all private housing facilities and one heat exchanger per collective housing facilities. The predicted heat consumption for the connection rate of 80% private housing facilities and 100% connection rate for public buildings is **18,13 GWh** including grid heat losses with about 5.9%. The temperature level of the DH grid will be designed with 80°C outgoing flow and 60°C return flow.

In conclusion, DH system on renewable energy sources would achieve a number of advantages: reduction of emissions currently being reflected in considerable pollution, increasing reliability and efficiency, helping to manage the supply and demand of heat, reducing labour and maintenance costs associated with individual systems, variety of renewables used, etc.

In the next step, economic calculations will be made for these scenarios in order to facilitate the selection of the best concept in order to develop an individual business model. In the final step, a feasibility check will be made to present the potential project with most feasible technologies and business options to decision makers and investors.

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