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 Karposh

Municipality of Karposh (Macedonia)
Renewable district heating in Zajcev rid - Karposh

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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 Zajcev rid, Karposh.

2 General description of the current situation and concept

The surroundings of the area Zajcev Rid in the Municipality of Karposh, its location in the North-Western side of the city and the good connection to the city center has initiated the idea for implementation of an efficient and highly sustainable residential neighborhood. The question of how do deal with the heating of this new neighborhood stands out as an important one, and its importance steadily increases as a result of the disturbingly high air-pollution in Skopje and Karposh.

There are a few possible outcomes when choosing a heating system such as connecting to the existing DH grid, choosing individual heating solutions, utilizing a natural gas distribution system or implementing a small DHC grid. The area enclosed with this new neighborhood is currently not covered by the major DH system in Skopje or by a natural gas distribution system. On that account, this technical concept aims to lay down the foundations for a small, modular, renewable DHC system for the neighborhood.

The system for heat generation could contain a groundwater electric heat pump, a flat plate solar collector, a peak oil boiler and a thermal storage unit. The groundwater heat pump could be used to cover the majority of the heat demand.

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

The key results of the survey (Puksec et al. 2016[1]) shows that 56% of the buildings in the municipality of Karposh are households, 44% apartment buildings, about 39% have outer wall insulation and 30% have insulation on the rooftop. 13% of the buildings have a central

[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

heating system and 40% have a district heating system. 37% have individual stoves or electrical heaters in the rooms.

About 44% are heating with electricity, 28% with district heating and 25% logwood. 89% of the households are producing their domestic hot water with electricity. 69% of the households have cooling needs.

4 Heating/cooling demand for the concept and initial situation

In the process of planning of the development of the Municipality of Karposh, the local authorities have acknowledged the high density of buildings in the municipality. As a result of this, the increased housing demand could be met by exploiting the peripheral areas of the municipality. This should, nevertheless, be conducted in a strategically sound manner taking into account all relevant factors from a physical planning point of view, some of which exceed the scope of this document.

One of the important factors that should be mentioned, deals with the issue of local air pollution, putting an additional burden on local authorities to provide short term as well as long term solutions to the problem. That is why the implementation of a small scale renewable district heating system has been discussed as a possible solution for covering the heating demand.

Another important element is the support gained from the mayor of Karposh and the representatives from the Council in the phase of the discussions and meeting, undoubtedly showing the level of consent regarding this issue.

The neighbourhood Zajcev Rid is currently in the planning phase, therefore, there are no existing buildings in the area. However, a Detailed Urbanistic Plan (DUP) has been developed for Zajcev Rid. Five classes of land use have been listed in the DUP:

- **Residential** (land use category A/ Cyrillic “А”)
- **Commercial** (land use category B/ Cyrillic “Б”)
- **Public institutions** (land use category V Cyrillic “В”)
- **Production, distribution and service** (land use category G/ Cyrillic “Г”)
- **Parks and recreation** (land use category D/ Cyrillic “Д”)

The residential category can be further split into a category of residential houses with yards (A1) and residential collective houses (A2). Commercial institutions include small and large commercial buildings, large catering and accommodation buildings, hotels etc. Public institutions include buildings of educational, health, cultural and religious facilities. Although a policlinic is planned for this settlement, it will not be taken into account in the analysis because of its specific heat consumption regimes. The parks and recreation category takes into account all green areas intended to serve as parks, as well as sport and recreational facilities.

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

The planned concept in the Detailed Urbanistic Plan depends on the envisaged high quality infrastructure. The road network along with the electrical, water supply and telecommunication infrastructure are planned for every building. A plan for the atmospheric sewage system has also been developed. The Detailed Urbanistic Plan also envisages the implementation of a natural gas distribution system, but this option has a low likelihood of occurrence if one considers the development of the natural gas system in Skopje. All of the different carriers are laid in reinforced concrete channels or protective tubes with large enough diameters that allow interventions.

A screenshot of the detailed urbanistic plan for this area is shown in Figure 1.

Figure 1: Detailed Urbanistic Plan of Zajcev Rid, Municipality of Karposh

The concept of the heating system envisaged for this area covers the heat demand of the residential and commercial buildings, as well as the buildings of public institutions (categories A, B and V). The land parcels for the residential and commercial sector will most likely be sold to private investors and there are no architectural plans for the public institutions, so only a general estimation of the area of the buildings can be made.

Based on observations of the detailed urbanistic plan, the estimated floor areas for each of the first three categories is:

- **Residential:** $A_{total, res}$ = 225,370 m^2
- **Commercial:** $A_{total, com}$ = 533,035 m^2
- **Public institutions:** $A_{total, pub}$ = 63,665 m^2

The total area of all floors of residential, commercial and public buildings is equal to:

$A_{total} = A_{total, res} + A_{total, com} + A_{total, pub}$ = 822,070 m^2 = 0.822 km^2.

The total area covered by the Zajcev Rid settlement is equal to A_{sett} = 2.2 km^2 as estimated by a free online tool[2] (Figure 2). If the protected area of the Skupi Archeological zone and other land which is already covered are subtracted according to Figure 1, a total settlement area available for new buildings is equal to $A_{sett,b}$ = 1.37 km^2 (Figure 3).

Therefore, the coefficient of land utilization is equal to:

$K = A_{total} / A_{sett,b}$ = 0.822/1.37 = 0.6.

2 https://www.daftlogic.com/projects-google-maps-area-calculator-tool.htm

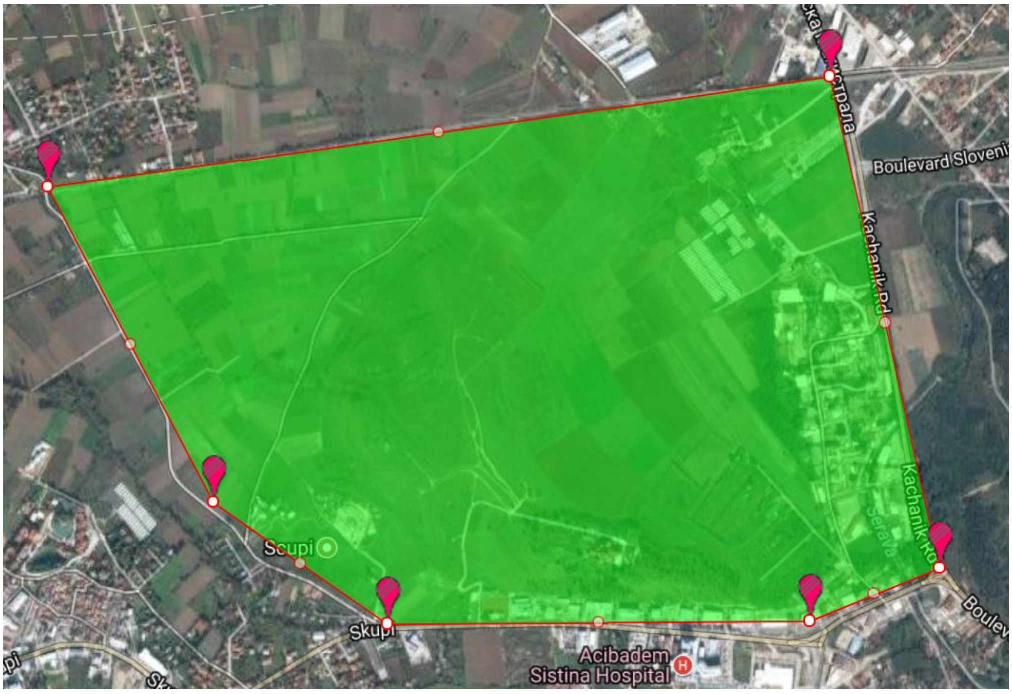

Figure 2: Total area of the settlement Zajcev Rid

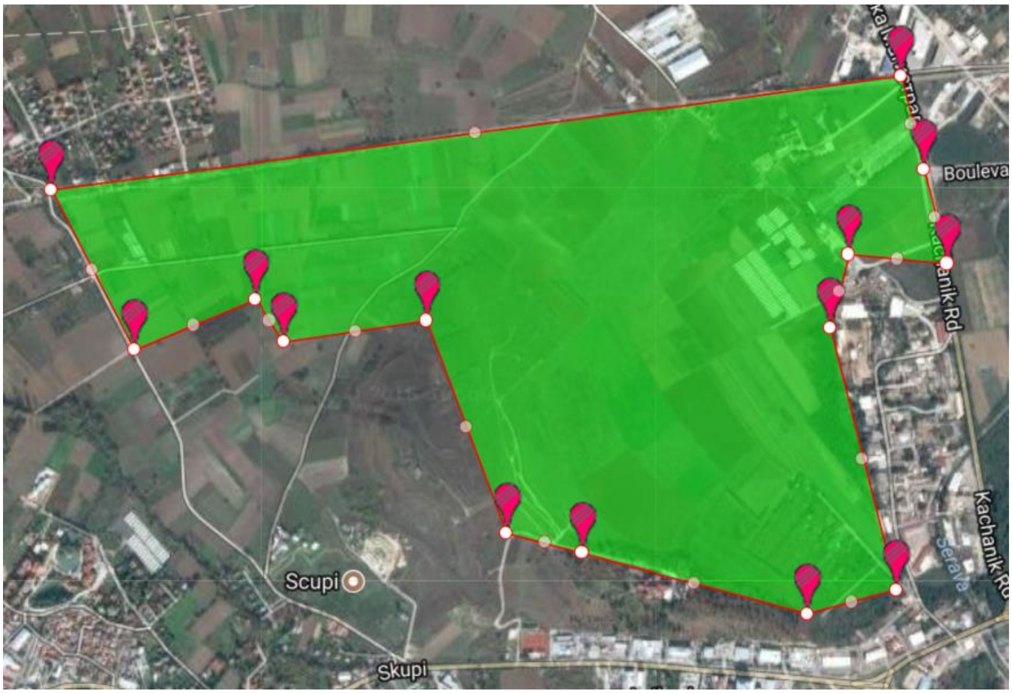

Figure 3: Available area of the settlement Zajcev Rid

4.2 Assessment of heating/cooling demand

The heating/cooling demand has been estimated by a combination of statistical analysis of buildings that have undergone an energy auditing process and consultation of national Rulebooks. A total of 598 buildings built in the period from February 2012 until November 2017 have been taken into account in his study. They are considered a good representative sample of energy consumption in new buildings. The results are shown in Table 1.

Table 1: Statistical overview of energy consumption of buildings

	A^+ class	A class	B class		C class			
	0-20 KWh/m²a	20-30 KWh/m²a	30-40 KWh/m²a	40-50 KWh/m²a	50-60 KWh/m²a	60-70 KWh/m²a	70-80 KWh/m²a	80-100 KWh/m²a
No.	ø	9	73	118	176	124	86	11
%	ø	1.51 %	12,. %	19.89 %	29.73 %	20.73 %	14.38 %	1.84 %

According to this analysis as well as past experience, the following assumptions about the energy consumption of the buildings in Zajcev Rid have been made:

- **Residential:** $E_{specific,\ res}$ = 60 kWh/m²/a;
- **Commercial:** $E_{specific,\ com}$ = 80 kWh/m²/a;
- **Public institutions:** $E_{specific,\ pub}$ = 70 kWh/m²/a;

Moreover, it is assumed that 70% of the total area of each category is heated, hence, the heated area of each category is equal to:

- **Residential:** $A_{heated,\ res}$ = 157,759 m²
- **Commercial:** $A_{heated,\ com}$ = 373,124 m²
- **Public institutions:** $A_{heated,pub}$ = 44,565 m²

By multiplying the specific energy consumption by category with the corresponding heated area of each category we obtain:

- **Residential:** E_{res} = 9,465,540 kWh/a;
- **Commercial:** E_{com} = 29,849,920 kWh/a:
- **Public institutions:** E_{pub} = 3,119,550 kWh/a;

The total annual energy supplied by the system is estimated to be equal to

$E_{total} = E_{res} + E_{com} + E_{pub}$ = 9,465,540 + 29,849,920 + 3,119,550 kWh/a

E_{total} = 42,435 MWh/a

Furthermore, it is good to know how this annual heat consumption will be distributed during the heating season. That is why it is necessary to obtain the temperatures in the region. Ideally, the daily temperatures would be known for a given period of time. However, the temperature data used for the analysis provides monthly averages. Although these data are sufficient for this stage of the project development, three meteorological databases were considered in order to eliminate as much uncertainty as possible: Meteonorm and NASA Satellite databases (taken from PVSYST V6.67 software) and the online available data from the World Meteorological Organisation (WMO)[3].

[3] http://worldweather.wmo.int/en/city.html?cityId=199

Figure 4 shows the average monthly temperatures in Skopje, where the settlement Zajcev Rid is located. It can be seen that the monthly temperature values of the different data sources differ, but nevertheless follow the same trend.

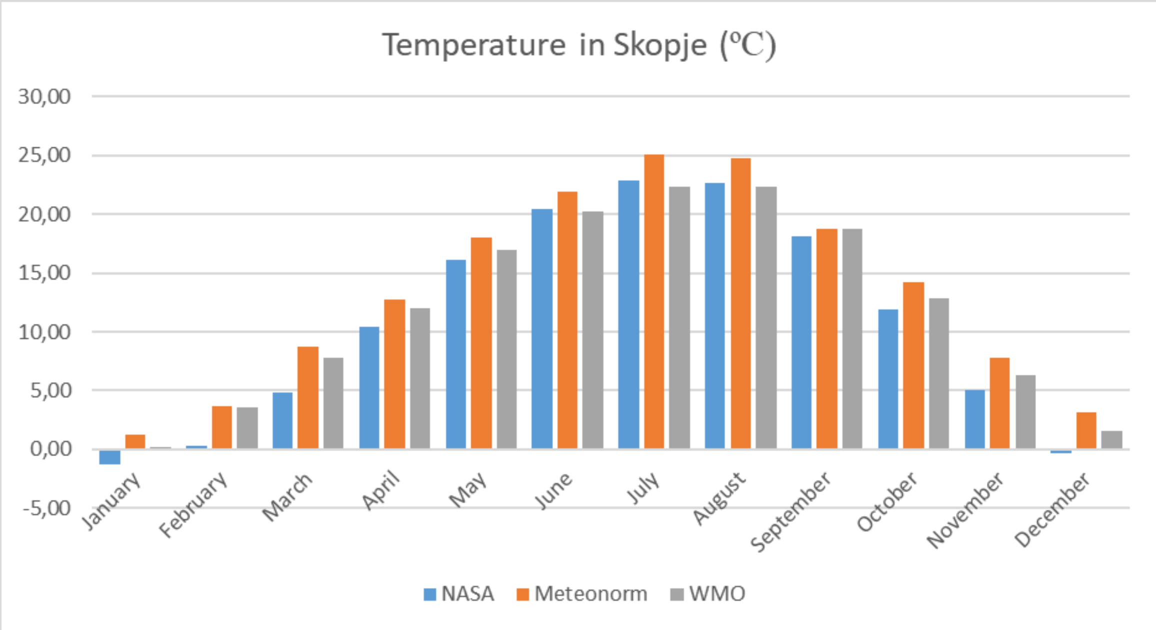

Figure 4: Average monthly temperatures in Skopje

The heating season lasts for about 165 days and is distributed from October to March. Only 15 days of October are heated. If the estimated heat demand is divided proportionally to the number of days of each month included in the heating season and to the temperature difference from 21ºC room temperature, the monthly heat demand shown in Figure 5 is calculated.

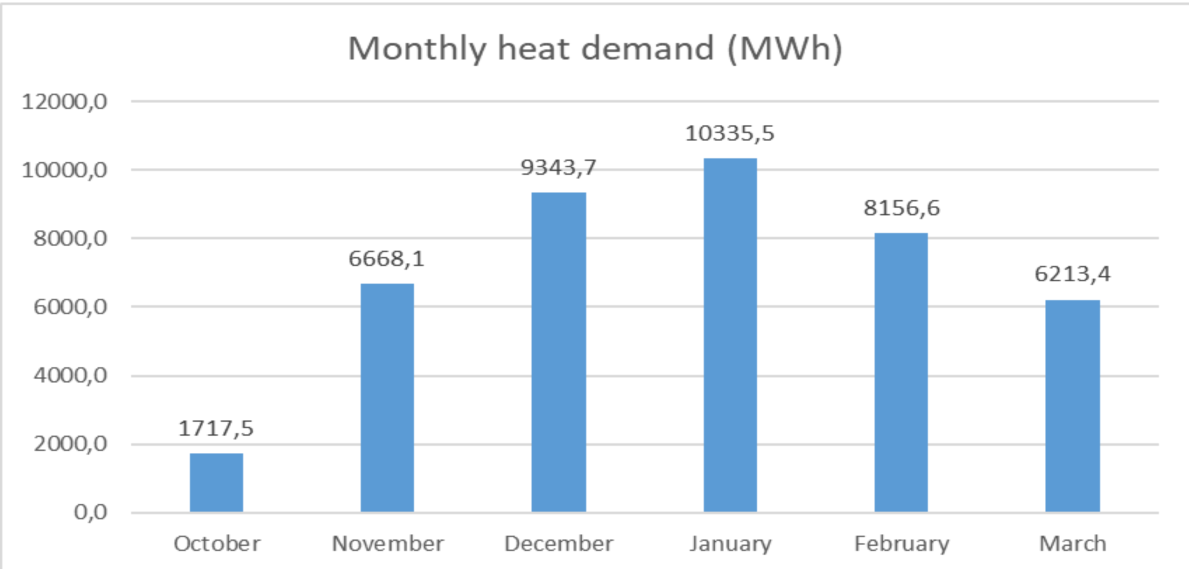

Figure 5: Distribution of heat demand by months

Based on the experience, the commercial buildings and public institutions use the heating system for 12 hours/day while the residential sector uses it for 16 h/day. Finally, the total peak power consumption is calculated to be around 20.235 MW. Provided per category, the corresponding values are given below:

- **Residential:** P_{res} = 3.59 MW
- **Commercial:** P_{com} = 15.08 MW
- **Public institutions:** P_{pub} = 1.58 MW

The assumed values involve a certain reserve margin of up to 10%. The load duration curve shown on Figure 6 has been obtained from the EnergyPRO software used to evaluate the technical concept. The result shows a peak load of about 23 MW. There is no heat demand in summer time.

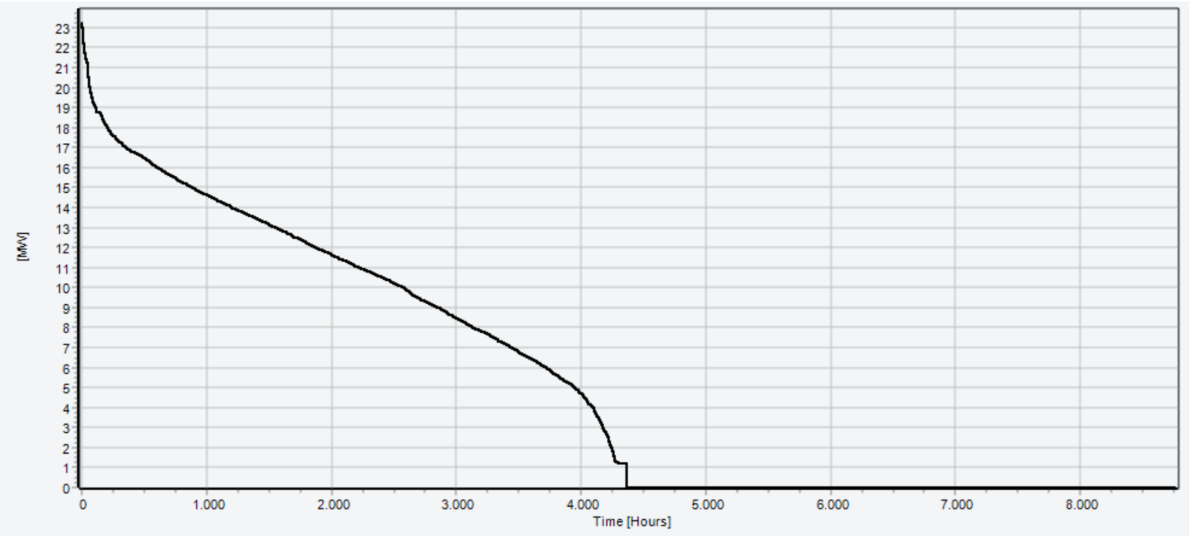

Figure 6: Generated load duration curve

5 Technical concepts for heat/cold generation

The concept for the DHC system in Zajcev Rid, Karposh, has been developed after a comprehensive assessment of the local resources and opportunities. The Municipality of Karposh is situated on underground water basins with temperatures of around 12°C, while having a daily global horizontal solar irradiation of approximately 3.4 kWh/m^2. Hence, the implementation of a water-water heat pump system for heating/cooling alongside ground mounted solar thermal panels with seasonal storage would be a good way of using the available local resources. On the other hand, the Municipality of Karposh does not have local biomass, so there would be a need of securing a biomass supply chain if biomass boilers were to be introduced. This is one of the main reasons why the use of biomass boilers was avoided.

The emission limits in the Republic of Macedonia are determined by the Rulebook for allowed values of emissions and types of polluting substances from exhaust gases and vapors emitted by stationary sources[4].

The following opportunities and obstacles were acknowledged for the planned system.

[4] Rulebook for allowed values of emissions and types of polluting substances from exhaust gases and vapors emitted by stationary sources, Ministry of Environment and Physical Planning, Official Gazette of R.M. no. 141, 25.10.2010 (http://www.novometal.mk/regulations/135.pdf)

Perspective:

- large heating demand;
- modularity of DHC system as new houses are built;
- availability of technical groundwater for heat pumps;
- "greenfield approach" – all infrastructure is designed systematically, at the beginning of the project;
- all new houses will be connected to the DH system;
- good opportunity for setting a lighthouse example of an energy efficient neighborhood, supplied by renewable energy sources.

Obstacles:

- the building process has not yet commenced;
- no residents to sign a letter of commitment.

This last issue can be resolved if the Municipality commits to supporting this project and creating an enabling environment for its development. The are no standards or recommendations in the Republic of Macedonia for DH systems that regulate the minimal efficiency of a DH system or the minimal grid density.
The system analyzed in this document should only cover the heat demand and not the demand for domestic hot water (DHW). It has been supposed that DWH will be produced by standard electric boilers, because this is standard in Macedonia. The heating system is also considered to have direct connections with the consumers (without a heat exchanger). As stated above, the neighborhood is in the planning phase and no concrete solution for the buildings/houses that are going to be built exists. Therefore, any statement of the type of technology used for heating in each individual household (fan coils, radiators, ground heating etc.) would likely resemble a speculation and not a backed argument. It is fairly difficult to state which technology the households will choose. This would largely depend on the development process of the neighborhood itself, but also depends on the implementation of the system.

5.1 District heating / cooling grid

The area enclosed in the neighborhood has a trapezoid shape, as shown on Figure 7. The dimensions of the trapezoid can be approximated as follows:

- Length of Northern base: 2 km
- Length of West leg: 1.5 km
- Length of Southern base: 1.5 km
- Length of Eastern leg: 1 km

According to the Zajcev Rid DUP developed in 2008, a natural gas distribution system was envisaged for the area. However, the implementation of a natural gas distribution network has not been successful so far, and it seems that its future developments will leave the Zajcev Rid settlement uncovered.

The project design of the natural gas system, on the other hand, contains valuable information which can be used in the initial development stage of the DHC network. In order to display the DH network on the map the following was determined:

- the road infrastructure will be developed according to the Detailed Urbanistic Plan from 2008
- the layout of parcels of categories A, B, V, G, D will be developed according to the Detailed Urbanistic Plan

- the right-of-way for the electrical and water supply distribution systems will have the right-of-way given in the Detailed Urbanistic Plan

It is therefore safe to assume that pipes of the DH system will have the same right-of-way as the natural gas distribution system elaborated in the Detailed Urbanistic Plan, hence, they will have a similar total length, but will not have an equal diameter.

Figure 7: Dimensions of Zajcev Rid settlement (source: https://www.google.com/maps/@42.019591,21.3974893,2331m/data=!3m1!1e3)

The general layout of the DH pipes in Zajcev Rid is visually displayed in Figure 8.

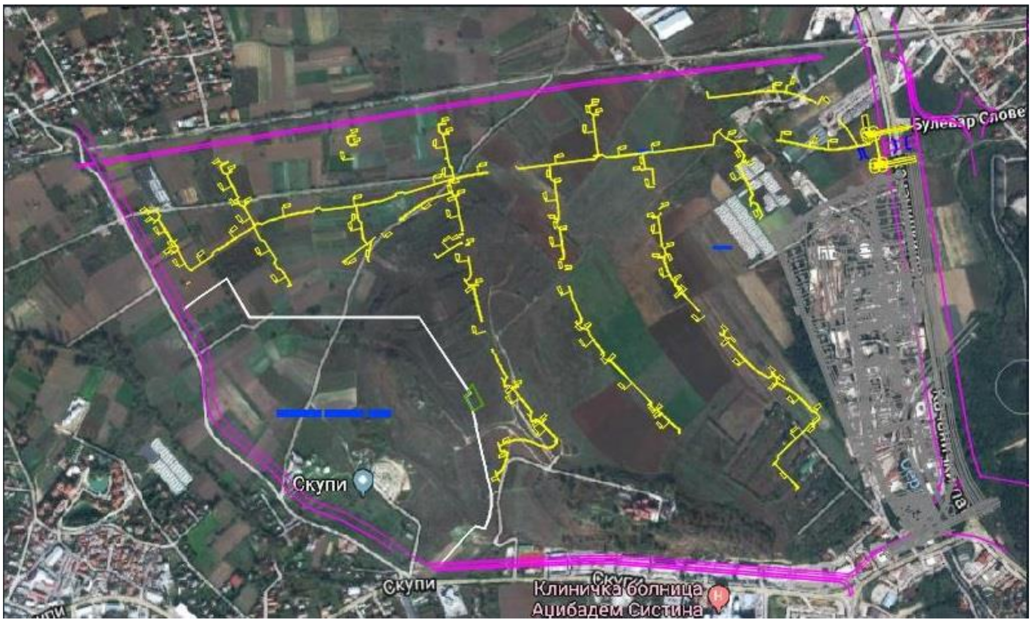

Figure 8: Layout of DH pipes in Zajcev Rid

The display has been obtained by overlapping the map of Zajcev Rid with the actual Detailed Urbanistic Plan. The surrounding purple lines, which give the outside contour of the settlement, are a CAD representation of the surrounding roads and are used as a marker for overlapping the map and the DH network. Furthermore, another marker that should be taken into account is the location of the two compressor stations, one at each side of Slovenia Boulevard.

The district heating grid could be around 9,500 m (9.5 km pipeline) including house connections, according to the Detailed Urbanistic Plan. The grid density can be calculated with the following equation:

Grid density = E_{total}/L_{pipes} = 42,435,010 (kWh/a) / 9,500 (m) = 4,466.8 kWh/m/a.

This pipe length takes into account the pipes reaching inside each residential block. The grid density is higher than the proposed rule-of-thumb values in Germany, Austria (higher than 900 kWh/m/a) and Denmark.

In the analysis, it is assumed that the forward temperature of the DH system is between 60 and 70 °C and the return temperature is 35 to 40 °C.

The annual heat losses of the grid were calculated with 11.3%, or 5,400 MWh/a. The material of the grid could be pre-insulated plastic or steel pipes.

In total there could **47,835 MWh/a heat** feed into the DH grid.

5.2 Heating / Cooling generation

The system for heat generation could contain a groundwater electric heat pump, flat plate solar collectors, a peak oil boiler and a seasonal thermal storage unit. The groundwater heat pump could be used to cover the majority of the heat demand, on the basis that Karposh has lots of groundwater basins and local experience with the technology. Nevertheless, considering the scale of the project, a more detailed analysis should be conducted in order to confirm the specific locations in the neighborhood as well as the amount of groundwater in the area. Additionally, experience in Karposh has shown that the wells for groundwater should not be further located than 150 to 180 meters from the heat pump station. The maximum electric power of the heat pumps could be 3.75 MW and a predicted COP of 4.0, the maximum heat power generation is 15 MW. As a result, the heat pumps have an annual heat production of around 42,660 MWh. The electrical consumption for the heat pump is about 10,687 MWh/a. The scheme of the heating and cooling production units is shown in Figure 9.

Additionally, 5,000 m² of flat plate solar collectors, positioned at an angle of 35° with respect to the horizontal surface (tilt) and efficiency of 82%, were considered in the analysis. The flat plate solar collectors could produce around 5,383 MWh of heat each year, thus supplying around 11% of the total heat demand. In order to be able to balance the supply of heat from the solar collectors and the demand of the consumers, a thermal storage system has been included in the design. The volume of the storage system should be around 55,000 m³. Although the storage system would support the higher utilization of the solar thermal collectors, it would also introduce around 384 MWh of internal heat losses. In order to increase the reliability of the system and to secure the desired comfort of the consumers during the periods of peak consumption, this technical concept includes an oil boiler. This boiler would produce heat during the periods of maximum consumption and should generate heat of around 154 MWh/a. The fuel oil consumption could be about 171 MWh/a (at 90% annual efficiency).

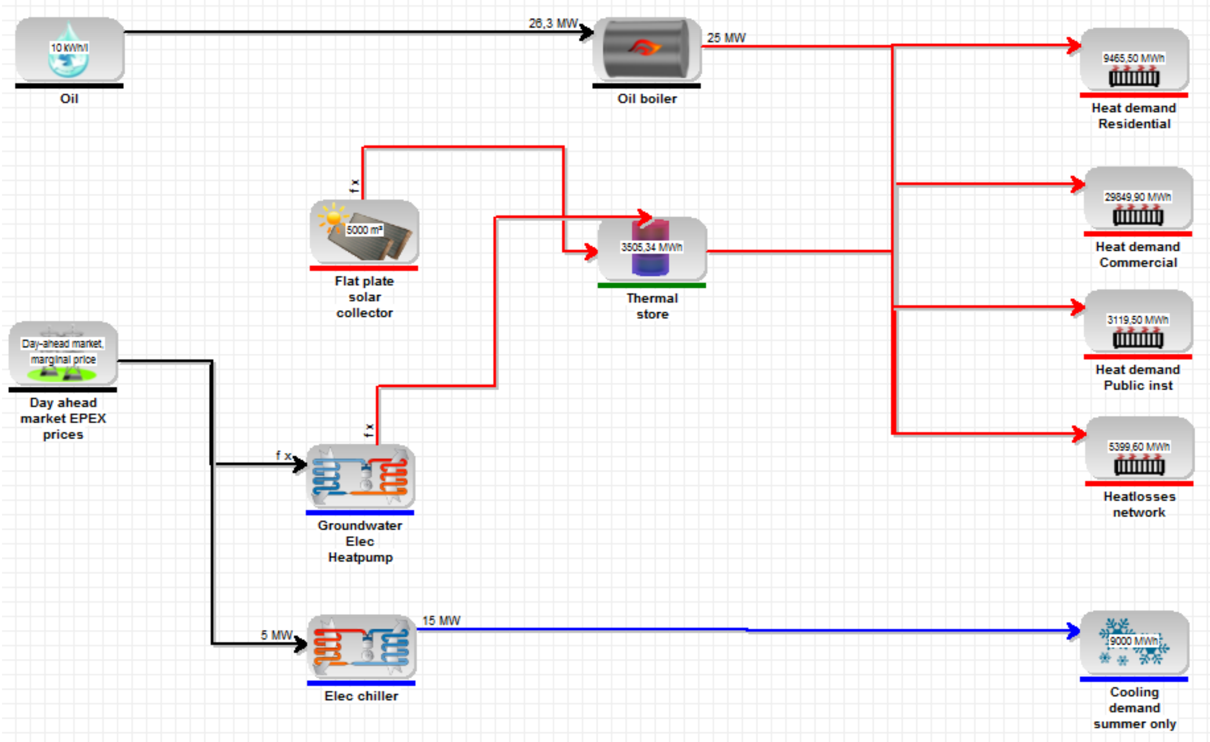

Figure 9: Scheme of heating and cooling production units and consumers, calculated in energyPRO

According to the projected heat demand for Zajcev rid, the energy needed to heat the buildings could be estimated at around 42,435 MWh/a. However, additional heat losses in the distribution grid and the heat storage system equal to about 12% of the generated heat have been taken into account. The heat balance of the district heating system has been provided in Table 2.

Table 2: Heat balance of the district heating system

Technology	Flat plate collector	Groundwater heat pump	Oil boiler
Heat (MWh/year)	5,383	42,660	154
Share (%)	11.2	88.5	0.3

The heat pump station of the district heating system is shown in Figure 10. It is also assumed that the solar thermal collectors are positioned near the heat pump station. These assumptions, of course, may change and vary if a concrete implementation of the project takes place. Nevertheless, the solar thermal collectors have been depicted in order to provide a sense for the space they would occupy. The oil boiler could also be located near the possible heat pump location.

The course of the seasonal storage within one year is shown in Figure 12.

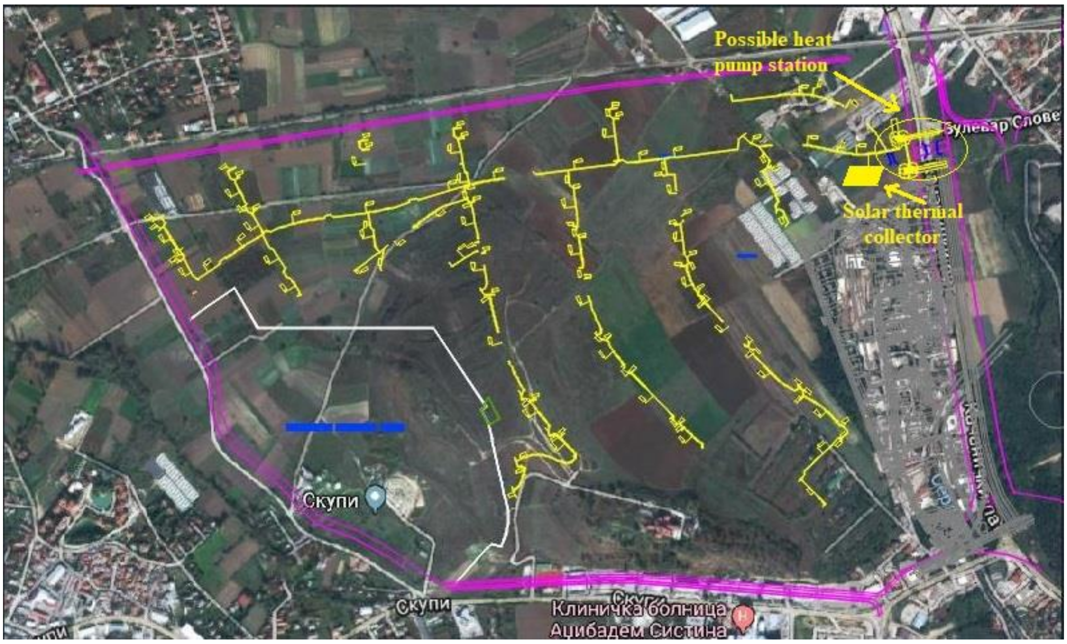

Figure 10: District heating system

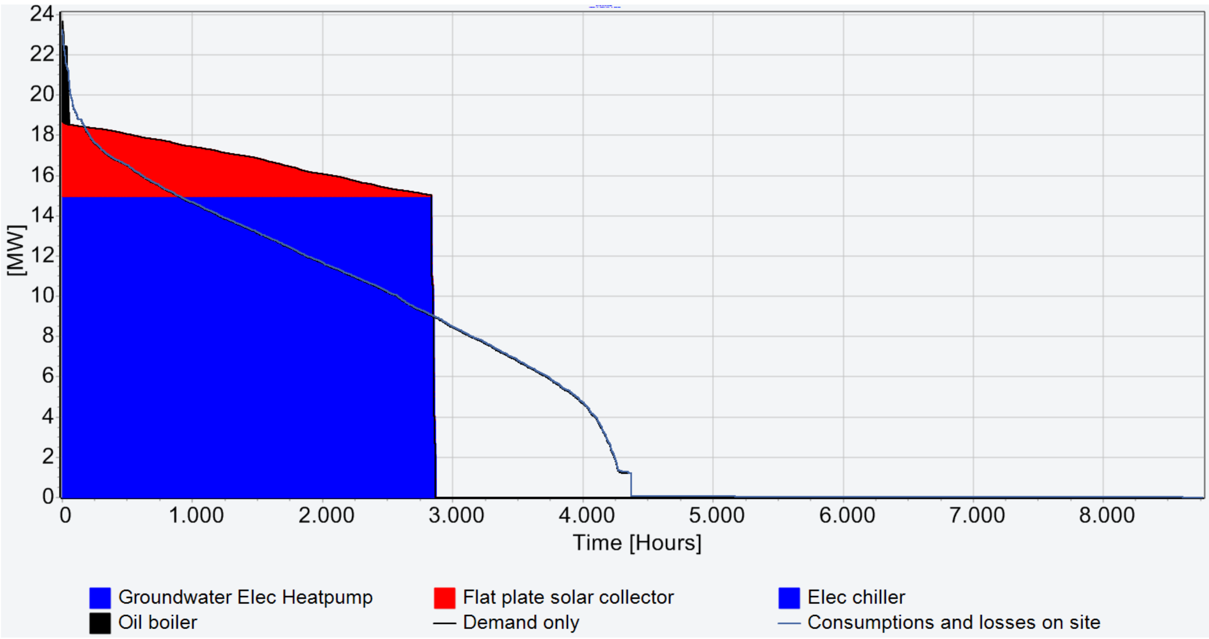

Figure 11: Annual load line for heat production units, calculated with energyPRO

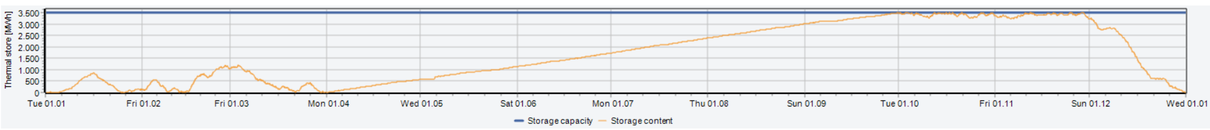

Figure 12: Storage capacity in MWh in the course of one year, calculated with energyPRO

After the heating season the grid could be used to supply the customers with cooling. Depending on the share of consumers who could be interested in cooling with the DHC grid, the following calculation was based on an annual cooling consumption of 9,000 MWh/a.

The cold water could be generated with electric chillers with about 5 MW electrical input and about 15 MW load for cooling. The electrical consumption for the chillers is about 2,999

MWh/a. The chillers could be located at the main heating plant. It should also be checked if the heat pump could be used for cooling in summer, as well as if it would be possible to put the waste heat of the chillers into the seasonal storage. This would be an additional benefit for the heating season and economy of the project.

It needs to be considered that the temperature difference at the heating grid could be about 20 K and the one for the cooling time about 8 K. This means a higher flow in summer time of about 2.5 times, causing higher pressure drops for the pumps. As a consequence, the cooling consumption is limited and only a fixed number of consumers could use this system. This needs to be assessed in detail in further steps. The annual load line is shown in Figure 13 and Figure 14.

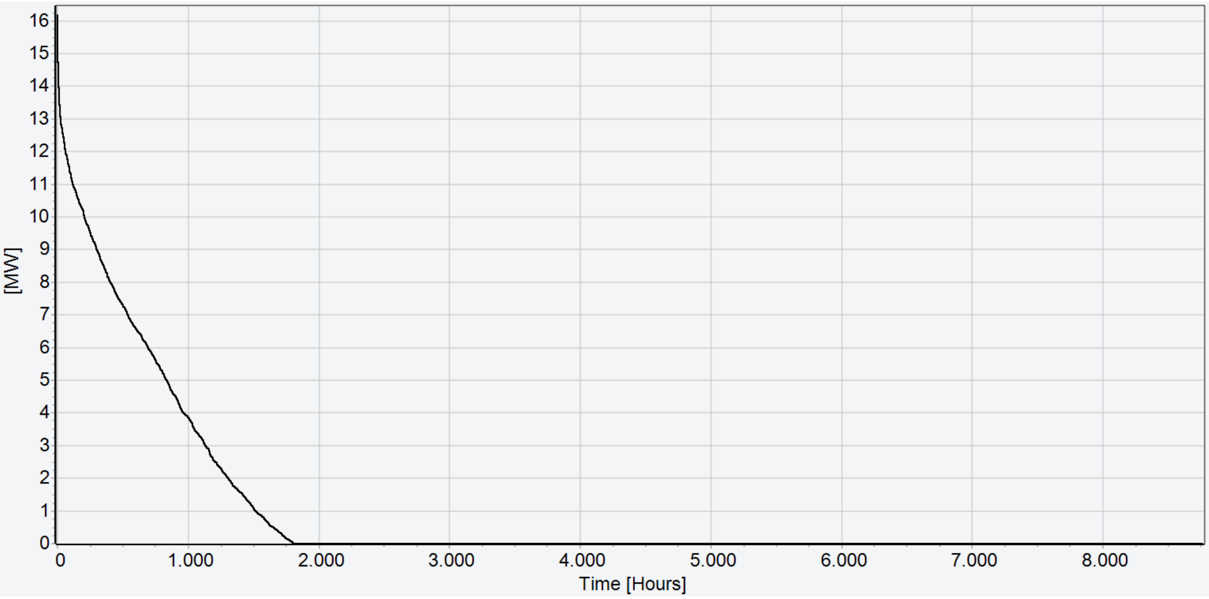

Figure 13: Annual load line for cooling, calculated with energyPRO

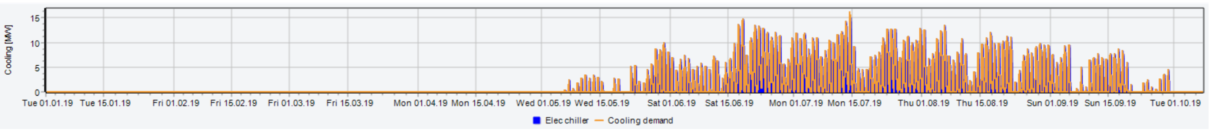

Figure 14: Cooling demand between 1st May and 30th September, calculated with energyPRO

There is no heat consumption in summer time, that is why the solar irradiation needs to be stored unit start of the heating season in October. That is why the seasonal storage is quite large with 55,000 m³. This size could lead to expensive investment costs and to an uneconomic operation of the system.

If the solution with solar thermal collectors and the seasonal storage might be not feasible, then a concept with a groundwater heat pump and a peak load boiler should be calculated.

6 Summary of the technical concept

The neighborhood “Zajcev rid” should be a new to build area for public, residential and commercial buildings.

The system for heat generation could contain a groundwater electric heat pump (about 15 MW_{th}), 5,000 m² flat plate solar collectors, a peak oil boiler (26 MW) and a seasonal thermal storage unit (55,000 m³). The groundwater heat pump could be used to cover about 88.5 % of the heat demand. The solar irradiation needs to be stored until October, because there is no heat consumption in summer time. That is why the seasonal storage could be uneconomic.

In total **47,835 MWh/a heat** could be fed into the DH grid.

Using the DH gird for cooling in summer could also be in option here. The DHC grid could be fed with an electric chiller with about 15 MW_{th} to produce 9,000 MWh/a cooling.

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.