Geothermal District Heating of Vilyuchinsk City (Kamchatka)

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ABSTRACT

Considerable part of the territory of Russia is located in the cold climate zone with long-lasting winter season characterized by low air temperatures, snow and strong winds so the problems of reliable heat supply of population, industrial and agricultural enterprises are most urgent.

The Project of geothermal heat supply of Vilyuchinsk city (Kamchatka) using resources of Upper-Paratunsky geothermal field permits supplying cheap and environmentally friendly heat energy for the consumers and displacing up to 37 t of mazut annually being combusted in the boilers now.

The geothermal heat supply system envisages both direct use of thermal water and application of geothermal heat pumps. For increasing efficiency of use of geothermal heat, the project envisages reduction of the temperature schedule of the heat supply system from 95/70 ^oC to 75/40 ^oC.

The article includes the description of geothermal resources of the Center of Kamchatka, circuit diagram of heat supply, annual diagrams of heat load coverage and results of economic calculations.

1. INTRODUCTION

More than 45% of all the consumed energy resources are expended today for heat supply of population, industrial and agricultural enterprises in Russia. More than 71% of all the heat is produced in district heating (DH) systems and about 29% - by decentralized sources. The power plants distribute more than 34% of all the heat and boiler-houses – about 50%. According to the data of the energy strategy of Russia, 1,3-times growth of heat consumption in the country is planned till 2020, and the share of decentralized heat supply would increase from 28,6% in 2000 to 33% in 2020.

At the same time considerable part of fossil energy resources expended for heat supply can be replaced by environmentally friendly and cheaper heat of the Earth.

Together with high-potential resources of Kamchatka and Kuril islands permitting producing electricity immediately from geothermal steam, reserves of thermal-energy water that can be used for heat supply of human settlements as well as in industry and agriculture, are available practically on the whole territory of Russia. The region of the Northern Caucasus should be specially marked out being extremely rich in thermal water with temperature reaching 125-130 ^oC.

In Kamchatka region, in particular in Vilyuchinsk city and human settlements of Elizovo district, the power supply is traditionally focused on expensive imported fuel (mazut, coal and diesel fuel). At the same time, Elizovo district on the territory of which the largest in Russia Paratunsky and Upper-Paratunsky geothermal fields of thermal water as well as Bolshe-Banny and Mutnovsky geothermal fields of steam-water fluid, are located, has unique geothermal resources sufficient for complete energy supply of Vilyuchinsk with heat and electricity. The special urgency of the problem is caused by severe climatic conditions and big duration of heating period at Kamchatka – about 260 days a year with minimal outdoor air temperature up to minus 25 ^oC.

The existing heat supply system of Vilyuchinsk city is based on combustion of expensive imported fossil fuel – mazut.

SC "GEOENCOM", on the order of SC "RusHydro", developed the Feasibility Study of the Project of geothermal heat supply of Vilyuchinsk city at Kamchatka.

With the purpose of transferring the heat supply of Vilyuchinsk city to local geothermal resources, it is supposed to create an environmentally friendly geothermal heat supply system using thermal water of Upper-Paratunsky geothermal field.

2. GEOTHERMAL RESOURCES OF THE CENTER OF KAMCHATKA AND UPPER-PARATUNSKY GEOTHERMAL FIELD

At Fig. 1 the prognostic hydrothermal map of the Center of Kamchatka is presented; it shows that the geothermal fields and thermal anomalies are located close to the cities Petropavlovsk-Kamchatsky, Elizovo and Vilyuchinsk, and use of their resources permits providing cheap and environmentally friendly heat for population and enterprises.

Paratunsky geothermal field of thermal water is located in the basin of middle-stream of Paratunka river near Paratunka and Termalny settlements 30,0 km to the South-South-West from Elizovo city.

Nine km to the South of it, Upper-Paratunsky geothermal field is situated, that is located in the basin of upstream of Paratunka river. In the West Karymshinsky hydro-geothermal anomaly (Termalny settlement – Karymshina river), in the South – South-Paratunsky hydro-geothermal anomaly (Tunrin stream – Left Topolyovaya river and Paratunka settlement – estuary of Bystraya river) side with it.

The geothermal fields were explored in 1960-1970s. At Paratunsky geothermal field, about 100 prospecting-exploration wells were drilled with total shaft sinking of 68745,0 m, 22 wells were put into operation; at Upper-Paratunsky geothermal field, 46 wells were drilled with total shaft sinking of 55428,0 m, including 24 production wells.

Depth of occurrence of ground thermal-energy water of the geothermal field is from several dozen meters to 2500 m, wellhead water temperature is from 40,0 °C to 96,0 °C.

Useful water storage of Paratunsky geothermal field is 23300 m^3/day and that of Upper-Paratunsky geothermal field – 21600,0 m^3/day.

Table 1: Characteristics of wells of Upper-Paratunsky geothermal field being of most interest for operation

No	Well	Wellhead water temperature, □C	Flow rate, l/s	State of well at present
1	88	87,5	9,4	Production
2	GK-37	95,6	7,1	Suspended
3	E-2	87,0	83,0	Production
4	E-1	85,0	65,0	Production
5	GK-22	77,5	12,4	Production
6	GK-44	78,0	13,8	Observation
7	GK-43	77,5	24,5	Suspended
8	GK42	75,1	11,7	Suspended
9	GK-29	78,0	30,5	Suspended
10	GK-30	84,0	30,1	Suspended
11	E-5	87,0	67,0	Observation
12	GK-36	79,0	16,6	Production
Average value		83,8	371,1	

Among these two geothermal fields only Paratunsky geothermal field is practically developed at present, thermal water is used mostly for heat supply of greenhouses of municipal enterprise “Termalnoye”, private greenhouses of residents of Paratunka and Termalny settlements, for heat supply of dwelling and public buildings, and a small amount of extracted water goes for balneology. Upper-Paratunsky geothermal field is practically not used today.

The lowest water temperature (from 50,0 to 60,0 °C) is noted at the Eastern and South-Eastern outskirt of geothermal field and the highest – near Goryachaya knoll – up to 88,0 °C. The highest piezometric water levels – from 106,7 to 119,1 m over ground surface – are also noted here.

Average weighted wellhead temperature around the geothermal field in general is 79,5 °C

For heat supply project 12 wells were selected, their characteristics (water temperature and flow rate for excess wellhead pressure of 0,15 MPa) are presented in table 1.

Calculation of total well flow rate and average weighted temperature show that in case of a use of above-mentioned wells with total flow rate of 371,1 l/s, the average temperature will be 83,8 □C.

General scheme of use of resources of Upper-Paratunsky geothermal field for heat supply of Vilyuchinsk city is presented at Fig. 2.

Thermal water from each well operating in well-spring regime is collected to collection tank via separate pipelines. For remote wells, local collection tanks are envisaged; the water from them is collected using pumps into main accumulating water reserve tanks with volume of 2x1000,0 m^3. Water degassing is executed in collection tanks. From the tanks the water with temperature of 83,8 ºC is pumped into header hot-water system with diameter of 500 mm and length of 35,6 km made of basalt-plastic tubes. Factory-built high-performance polyurethane foam insulation permits the supplying of the fluid from geothermal field to the city with minimal heat losses and providing the thermal water temperature of 80°C at least at the heat supply system inlet.

For provision of water transportation along the pipeline, intermediate pumping station near Termalny settlement is envisaged.

3. PROJECT OF GEOTHERMAL HEAT SUPPLY

The concept of the Project of geothermal heat supply of Vilyuchinsk city envisages stage-by-stage transition to use of geothermal resources for heating and hot water supply of the consumers. The Project I stage envisages satisfying of contemporary needs of Vilyuchinsk being about 39,0 Gcal/h, due to geothermal resources. This includes the heating load of 31,5 Gcal/h and hot water supply load of 7,3 Gcal/h.

The problem of transfer of the existing heat supply system to the use of geothermal water is that the existing system is rated for operation with heating system schedule of 95/70°C. This means that for outdoor air temperature below minus 20°C the water temperature in delivery pipeline must be 95°C and in return pipeline - 70°C.

The most efficient and simple solution for heat supply is the direct use of geothermal heat but the geothermal fluid temperature (80°C) is insufficient for heating of heating-system water up to the temperature of 95°C required during the maximum load so it is necessary to heat the heating-system water additionally in the boilers.

Such a situation is caused by the fact that temperature schedule 95/70 °C is standard for traditional heat supply systems based upon combustion of fossil fuel and justified from the technical point of view in case the heat production is executed in steam or hot-water boilers. The average temperature of indoor heaters being high enough permits making these heaters sufficiently compact and efficient. Rated temperature drop in heaters is 25°C. The heat of return heating-system water is not lost under temperature of 70°C and returned to the boiler so it is practically not important for such a system what temperature schedule is used. At the same time the water temperature in the heaters is certainly of importance, and the higher it is, the more compact these heaters may be.

For geothermal heat supply of Vilyuchinsk city the existing temperature schedule (95/70^{o}C) proves to be inefficient as, on one hand, thermal water with temperature of 80^{o}C can't heat the heating-system water up to 95^{o}C and its additional heating is necessary, and on the other hand, high temperature of return heating-system water (70^{o}C) does not give a chance to take enough heat from the thermal water for heat supply needs as the temperature of waste thermal water must be higher than the temperature in return header pipeline of the heating system. Some optimization and increase of heat removal are possible due to heating with thermal water of make-up cold water with temperature about 5^{o}C used for compensation of leakages in heating system as well as for hot water supply of the consumers.

During the periods of high heating load, with temperature schedule of 95/70^{o}C, minor heat amount would be withdrawn from the thermal water taking into account that its inlet temperature is about 80^{o}C, and most part of heat would be discharged with thermal water. The thermal water temperature at the discharge is determined by water temperature in return header pipeline of heating system and amount of necessary make-up water.

It follows from the above-stated that it is expedient to reduce the temperature schedule for geothermal water, for example from 95/70 ^{o}C to 75/50 ^{o}C or 75/40 ^{o}C, for fuller use of heat potential of thermal water.

Reduction of water temperature in heating-system leads to a decrease of heaters' temperature. For provision of comfortable conditions in the premises with lower average temperature of heaters, increase of heat exchange surface would be necessary.

The calculation shows that during transfer of heating-system to reduced temperature schedule 75/40 ^{o}C, increase of the heaters' surface by 75-80% would be necessary. This is a serious problem as it requires considerable capital costs for improvement of the heating system.

On the other hand, transfer of heat supply system to reduced temperature schedule permits excluding the peak additional heating of heating-system water in boiler-houses completely or partially and thus reducing the consumption of fossil fuel.

The project envisages transferring the heat supply system of Vilyuchinsk city to reduced (75/40^{o}C) temperature schedule, and this would permit satisfying by 99,9% the contemporary needs of the district in heating and hot water supply being about 39 Gcal/h, due to direct use of the thermal water heat. Minor shortage of heat with outdoor air temperature below minus 17,6^{o}C is covered by additional heating of heating-system water in electric boilers. Taking into account that the period of temperatures below 17,6^{o}C is just 84 hours according to climatology data, expenses for electricity for electric heating would be small.

The thermal circuit diagram of geothermal heat supply and parameters of fluids with outdoor air temperature of minus 20 ^{o}C are presented at Fig. 3.

Thermal water with temperature of 80^{o}C at least comes from Upper-Paratunsky geothermal field to Vilyuchinsk city by header pipeline and serially passes the heat exchangers HE-1-1 and HE-1-2 where it heats the network-system and make-up water correspondingly. The make-up water with temperature of 5^{o}C comes into heat exchanger HE-1-2 from the city water supply system, is heated up to the heating-system water temperature - 40^{o}C - in return heating-system pipeline and mixed with heating-system water.

The existing heat supply system of Vilyuchinsk city is open i.e. the water distribution for hot water supply takes place directly from the heating-system so the make-up water flow rate is determined by the hot water consumption by population and inevitable leakages from pipelines.

The Project II stage envisages increase of capacity of geothermal heat supply system up to 75,0 Gcal/h for heat supply of new consumers. Waste thermal water after first stage heat exchangers heats the make-up water in second stage heat exchanger and then it goes to evaporators of heat pumps which transfer its residual heat to heating-system water heating it up to 70 ^{o}C. With outdoor air temperatures below minus 16,2 ^{o}C, the heating-system water is additionally heated up to necessary temperature in peak electric boilers.

One heat pump is conditionally shown at the diagram. Efficiency of the heat pumps' operation is expressed in conversion factor being the ratio of produced heat power and power spent for heat pumps' drive. For increase of conversion factor, it is necessary that difference of temperatures in evaporator and condenser of heat pump should be small. With this purpose, 3 heat pumps are integrated into the system, and their evaporators and condensers are included serially for thermal and heating-system water.

Use of heat pumps permits using the heat of thermal water wasted after I stage heat exchangers HE-1-1 and HE-1-2 (its temperature may reach 40^{o}C) and heating the heating-system water. Temperature of waste thermal water after heat pumps is 10-12 ^{o}C. Total heat capacity of heat pumps is 28 Gcal/h with average conversion factor equal to 4,0.

4. HEAT LOAD COVERAGE DIAGRAMS

For determination of total annual heat production, load distribution during the year depending on outdoor air temperature, determination of shares of heat production by various sources, the diagrams of heat load duration during the year were composed (Fig. 4 – Fig. 6). These dependences were composed for climatic conditions of Vilyuchinsk city with temperature schedule of heating system of 75/40^{o}C.

At Fig. 4 the annual diagram of heat load of I stage geothermal heat supply system is presented.

It can be seen from the heat load diagram that with reduced temperature schedule of 75/40^{o}C the direct geothermal heat supply covers 99,88% of contemporary heating and hot water supply needs of Vilyuchinsk city, and just 0,1% of annual heat production will be provided by electric hot water boilers.

At Fig. 5 the annual diagram of heat load of II stage geothermal heat supply system is presented.

At Fig. 6 the annual diagram of heat load duration of geothermal heat supply system of Vilyuchinsk city is presented with total rated capacity of 75,0 Gcal/h. It can be seen from the diagram that with total annual heat production of 321651 Gcal considerable part of heat needs – 278220 Gcal (86,5%) - is satisfied by direct geothermal heat supply, about 13% of needs are covered by geothermal resources using heat pumps (42883 Gcal) and just minor part of peak load during the cold period with outdoor air temperatures below minus 16,2^{o}C during 122 hours of the heating period is provided with heating of heating-system water in electric boilers.

It should be noted that heat supply due to direct use of geothermal heat provides the rated load of hot water supply around the year, and heating loads - during considerable period of time – 2128 hours (more than one third of heating period). Geothermal heat supply with heat pumps covers the heating load during remaining 4088 hours of heating period.

Shares of heat production using thermal water, heat pump units and peak boilers for heat load of heat supply system of 39,0 Gcal/h and 75,0 Gcal/h (I and II stages correspondingly) are presented at Fig. 7 and Fig. 8.

As can be seen from Fig. 8, direct use of geothermal heat covers 86,5% of annual production, 13,33% of annual production are provided by geothermal heat pumps and 0,17% - by peak boilers.

5. CONCLUSION

Implementation of the Project of geothermal heat supply of Vilyuchinsk city permits the solving of the complex of various tasks including commercial, social and environmental ones.

The Project cost including I and II stages of construction is 60 mln USD.

Geothermal heat supply system permits producing more than 320 thousand Gcal of heat annually and providing heat and hot water for the consumers completely.

Transfer of heat supply system of Vilyuchinsk city to the use of geothermal resources (I stage geothermal heat supply system with capacity of 39 Gcal/h) permits reducing annual consumption of fossil fuel by 19,2 thousand tons.

Implementation of the Project II stage permitting bringing the capacity of geothermal heat supply system up to 75 Gcal/h provides the annual mazut saving up to 36,9 thousand tons.

Exclusion of fossil fuel use would permit reducing annual emission of contaminants into the atmosphere by 1150 tons.

Due to exclusion of use of expensive fossil fuel, the cost price of production of 1 Gcal of heat would decrease 2,86 times, and this would permit reducing the heat power tariffs considerably.

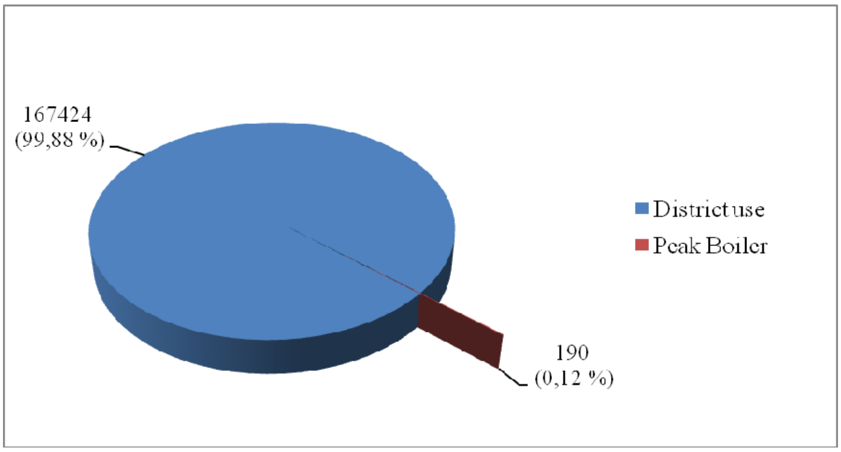

Fig. 7. Shares of heat production by various sources of geothermal heat supply system with Q_{max}= 38,85 Gcal/h (I stage geothermal heat supply system).

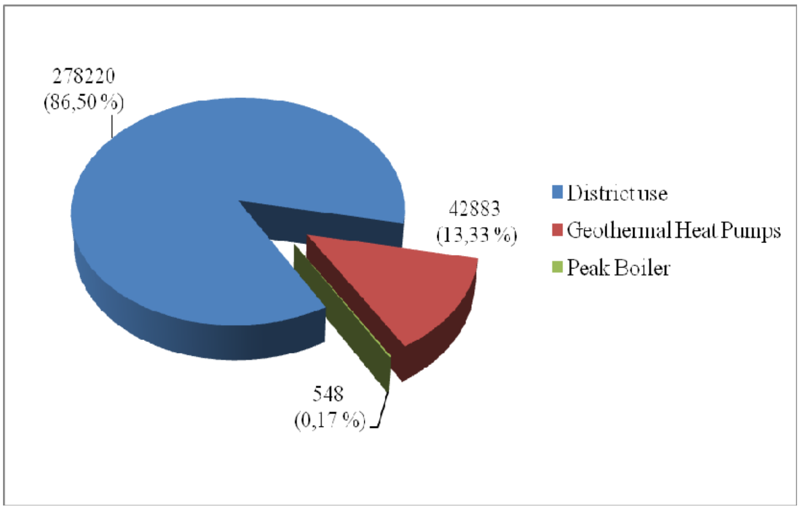

Fig. 8. Shares of heat production by various sources of geothermal heat supply system with heat pumps and peak electric boilers with Q_{max}= 75,00 Gcal/y (I and II stages)

Implementation of the Project of geothermal heat supply would also permit creating the conditions for construction of greenhouse complexes, swimming-pools with thermal water, balneal clinics, fish-farming etc.

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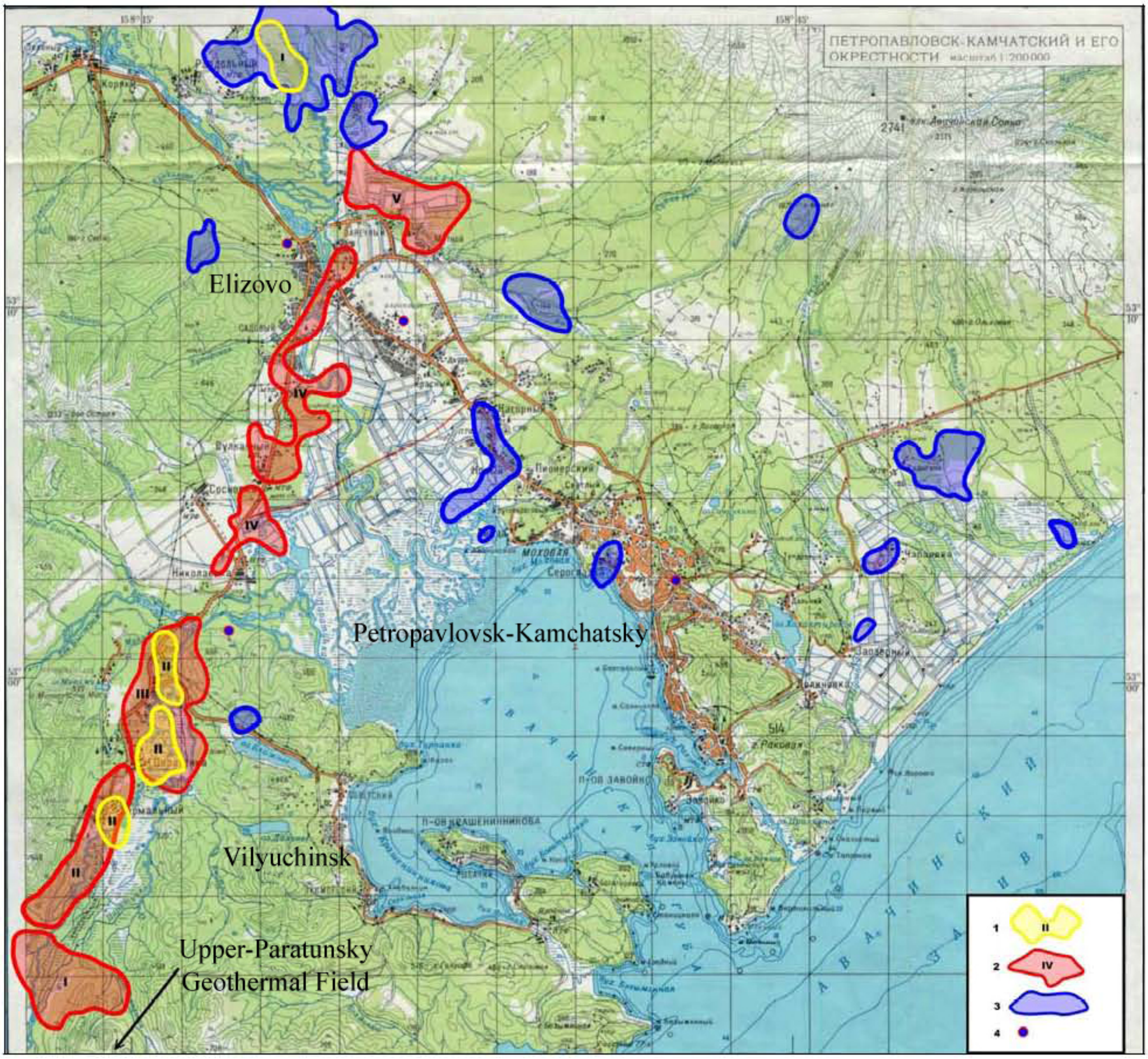

Fig. 1. Prognostic hydrothermal map of the Center of Kamchatka.

1) Explored geothermal fields: I – Ketkinsky, II – Paratunsky; 2) hydro-geothermal anomalies: I – Tunrin stream – Left Topolyovaya river, II – Paratunka settlement – estuary of Bystraya river, III – Termalny settlement – Karymshina river, IV – Tikhaya river – Mirnaya river, V – 1st Mutnaya river – 2nd Mutnaya river; 3) other hydro-geothermal anomalies; 4) exploration wells for thermal water.

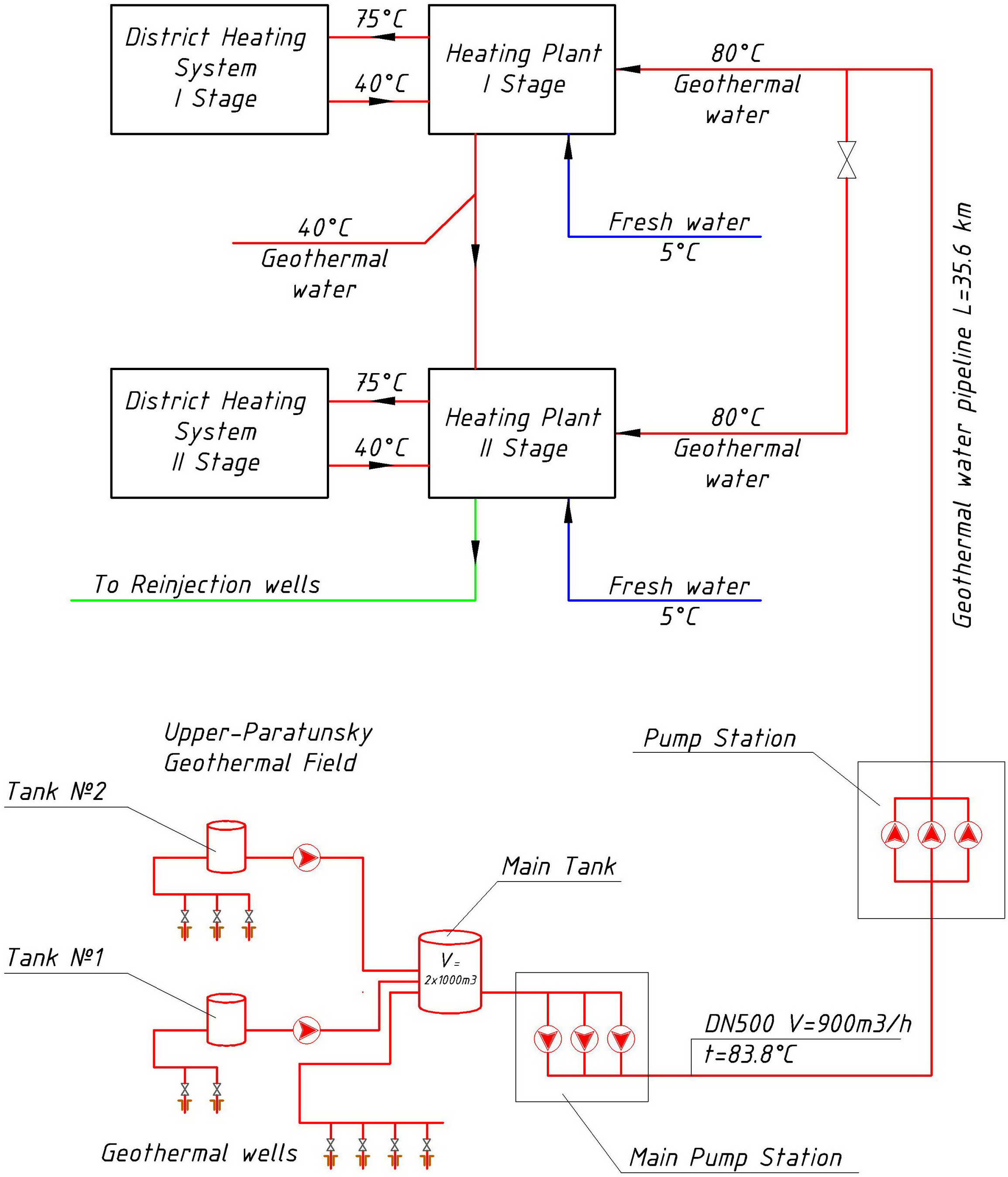

Fig.2. General circuit diagram of geothermal heat supply system of Vilyuchinsk city

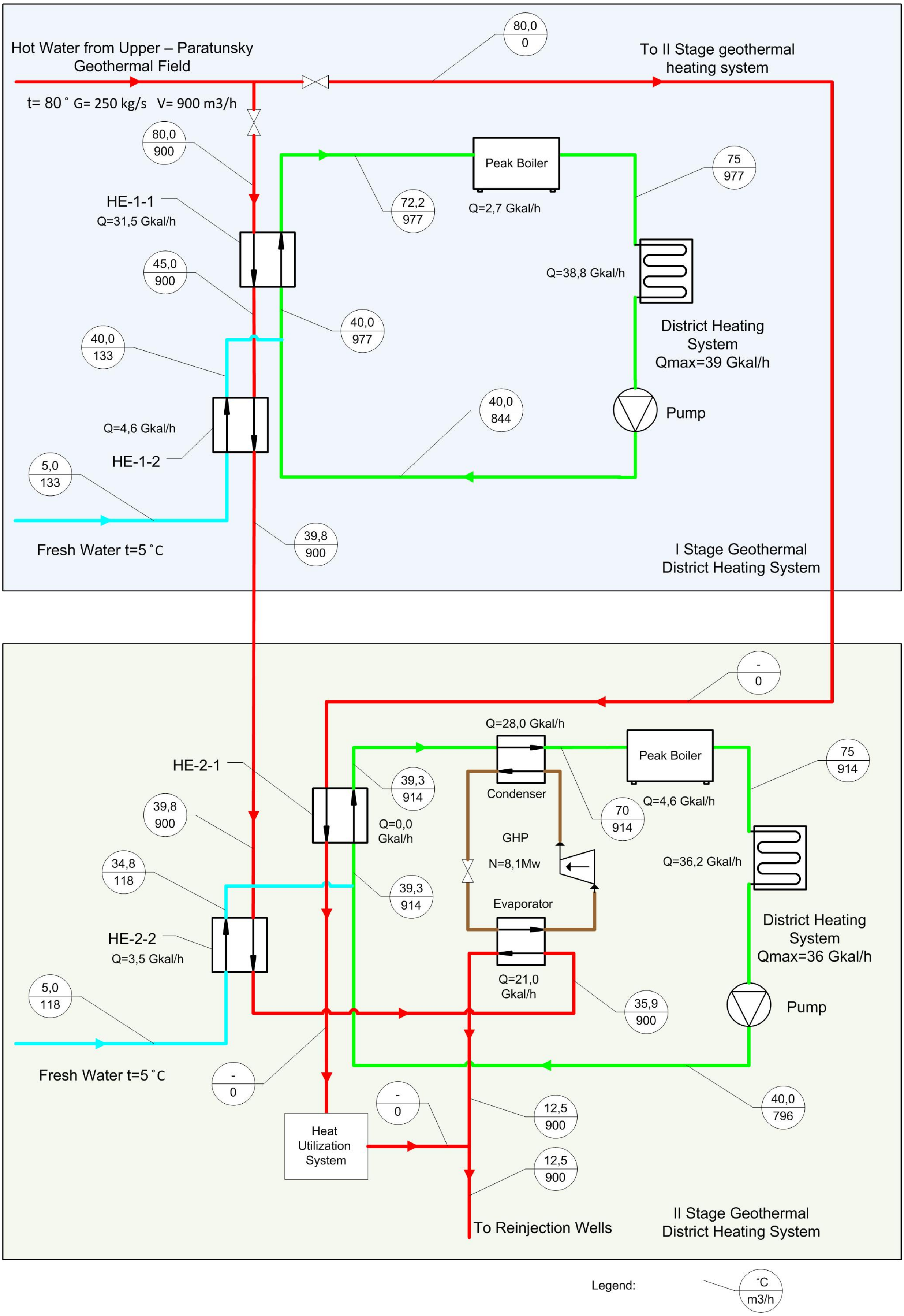

Fig. 3. Thermal circuit diagram of geothermal heat supply system and parameters of fluids with outdoor air temperature of minus 20°C

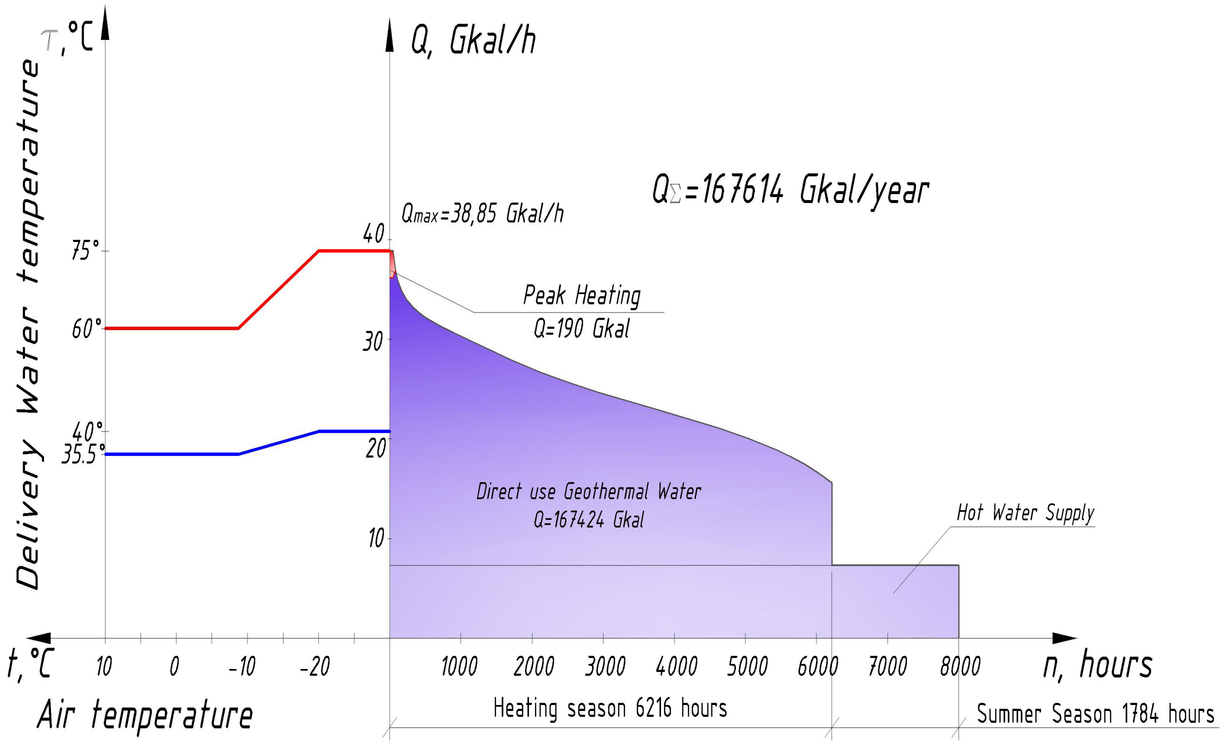

Fig. 4. Annual diagram of heat load duration of geothermal heat supply system of Vilyuchinsk city with capacity of 39,0 Gcal/h. (I stage)

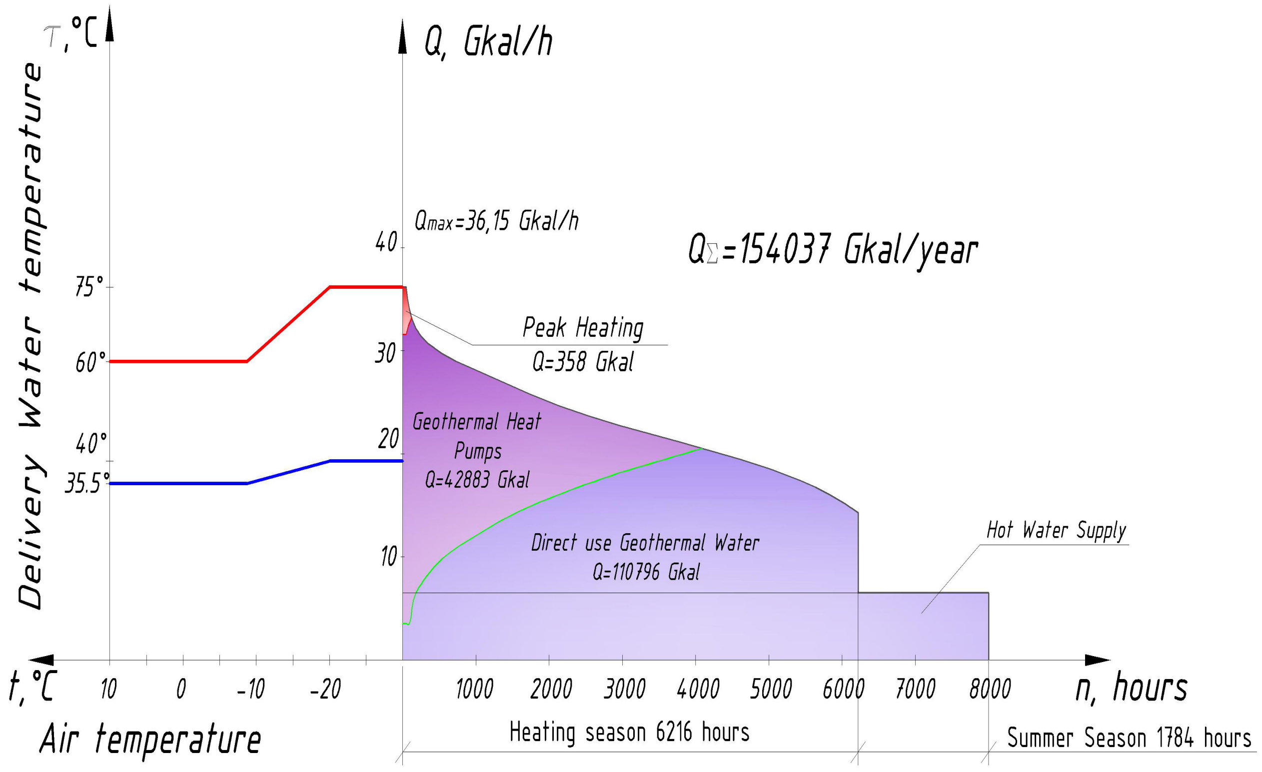

Fig. 5. Annual diagram of heat load duration of II stage geothermal heat supply system of Vilyuchinsk city with capacity of 36,15 Gcal/h

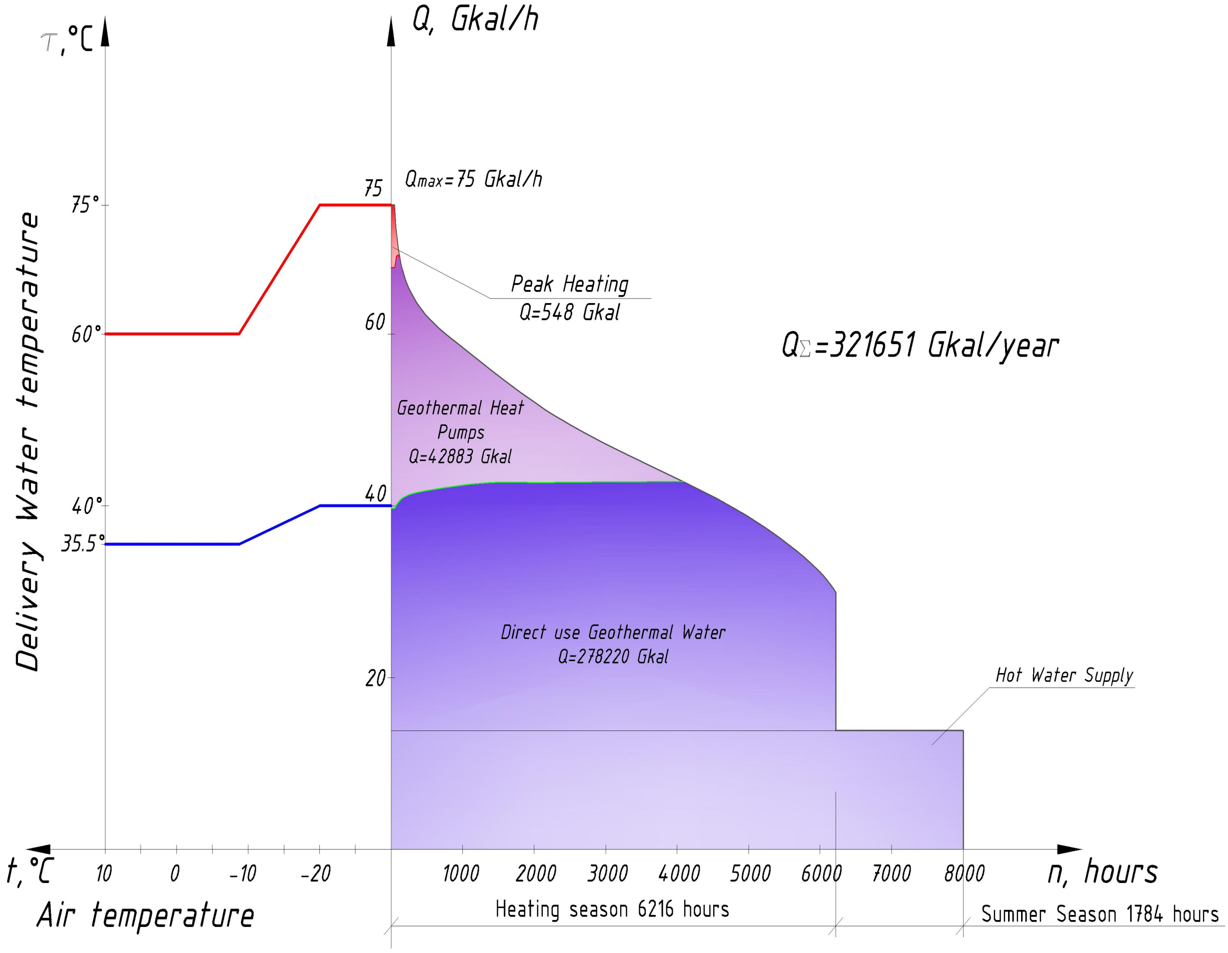

Fig. 6. Annual diagram of load of geothermal heat supply system of Vilyuchinsk city with total rated capacity of 75,0 Gcal/h