Improving the economic efficiency of heat sources and heating systems

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Abstract. Russia produces more than 41,000 million Gcal of heat energy annually, of which only 36% is produced in a combined way. The centralized heat supply system also has the potential of increasing efficiency up to 50%. To improve the efficiency of heat energy generation, the article proposed 5 ways to reconstruct enterprises supplying heat to the population and industrial enterprises.

1. Introduction
The current electricity market model functions on the basis of a package of federal laws on the electricity market rules, approved by the Russian Government. There is a wholesale and retail electricity (capacity) market. Thermal energy is supplied to consumers through the pipeline system from a source of thermal energy. The process of heat supply to consumers is governed by the Decisions of the Government of the Russian Federation on the rules for the organization of heat supply in the Russian Federation.

Heat production is based on two methods: separate generation and combined generation of heat and electric energy. Separate generation of heat energy is based on the production of heat at boilers and the generation of electrical energy from the electrical network. Combined production at CHPs allows saving up to 20% of fuel for energy supply purposes compared with a separate generation of heat and electrical energy.

The economic efficiency of the CHP, as is known, is largely determined by the amount of thermal energy supplied, while the competitiveness of thermal power plants increases in the winter months and decreases in the summer. While reducing the heating load, the heat capacities of these power plants operate in the mode of technological load minimum determined by the conditions of uninterrupted supply of heat to consumers (social load) and maintaining the system reliability of the power systems (if there are external power flow restrictions on the electrical networks). Accordingly, the production of additional electricity at CHP in the summer period is carried out in a less efficient - condensation mode.

According to the report of the Energy Development Fund for heat supply in the Russian Federation, 36% is produced in a combined way using the effect of heat, the rest thermal energy is generated at boiler houses [1]. The production of a significant amount of thermal energy in a separate way allows us to consider options for reducing the cost of fuel by heat sources. The authors, in this paper, have tried to summarize all the currently available technologies for optimizing fuel use in the generation of thermal energy in order to popularize the combined generation as one of the ways to improve the energy efficiency of a particular enterprise, the region and the Russian Federation as a whole.
2. Results of research
The operation of power equipment in modern conditions is characterized by a lack of investment in basic equipment and wear, operation in off-design modes, “boiler house” and, as a consequence, a decrease in the efficiency of CHP-based systems, multiple entities and manageability complications, tariff balance imbalances, lack of accounting and so on. Under these conditions, the heating system has sharply reduced its efficiency and reliability.

2.1. Industry problems
The main problems of the industry can be divided into several large groups:
1. Systemic problems: the imbalance of the regulatory framework and the lack of implementation of a comprehensive policy for the development of life support systems (including heat supply); imbalance in the electricity and heat supply market; cross-subsidization, distorting the real price of heat and electricity (power); the opacity of the sphere due to the lack of open information; lack of a unified research policy; lack of incentives in heat supply organizations to address the needs of end users; lack of qualified personnel in the energy sector.
2. Low level of energy efficiency in the operation of heating networks: a high percentage of wear; large heat loss; decrease in reliability of heat networks, increase in the number of accidents; the hydraulic modes of the networks are not adjusted, which increases the cost of heat for heating and electricity for pumping coolant.
3. Low energy efficiency in heat production: wear of generating facilities; irrational use of fuel due to “boiler house”; non-efficient technologies for the production of thermal energy are being introduced and used; low automation and insufficient measurements.
4. Problems of tariff-balance regulation, in terms of maintenance costs and beneficial supply to consumers, as well as inconsistency and non-transparency of regulatory procedures, lead to chronic underfunding of infrastructure facilities.
5. Suboptimal behaviour of heat consumers: high heat losses due to the unsatisfactory state of housing and communal services; irrational consumption of thermal energy in buildings; chronic defaults for consumed heat energy and overstating the connected capacity of consumers.

It is actual that in recent years active steps have been taken to improve the entire heat supply system in Russia. One of the key elements is the development of territorial development plans, including heat supply schemes for cities and settlements. As part of the development of a heat supply scheme, the municipality determines a single heat supply organization (ETO), which becomes a tariff holder for final consumers and concludes contracts for the sale and purchase of heat energy with heat sources and a transport contract with heat networks. The organization that has received the status of ETO is faced with the choice of the way to optimize the heat supply scheme and the volumes of the heat energy being acquired and transported to meet the needs of consumers.

Given the long-term nature of the problems of the industry and the chronic underfunding of heat networks and heat sources, their current state does not correspond to the current level. The current state of the heat source, thermal power plant (TPP) or boiler house with outdated boilers is characterized by a load of no more than 30-40% of the installed heat capacity. The operation of such a heat source leads to high operating costs, fuel consumption, high accident rate and, ultimately, high cost of thermal energy.

When choosing options for the reconstruction of heat sources, first of all, current and forecast volumes of consumption of heat and electric energy [2-3], availability of raw materials and scenario conditions taking into account the forecast of macroeconomic indicators for the planning period should be taken into account. Environmental restrictions and peculiarities of state regulation of the industry should be taken into account. The decision on the method of reconstruction of existing sources of heat energy is determined by the owner, which is reflected in the heat supply scheme of a settlement during its development or updating and may be included in investment programs [4].
2.2. Optimization of heat sources.

In Russia and the world, various methods are used to reduce the cost of fuel for the production of thermal energy and increase economic efficiency. Consider the main ones:

- modernization of steam boilers with installation of steam and gas units (CCGT);
- superstructure of water boilers with gas turbines (GTU);
- reconstruction of CHP with the exception of peak water boilers and their replacement by peak boiler plants operating on selected steam turbines;
- construction of gas piston installations for heating boilers.

Let us consider in more detail the options for the reconstruction of heat sources and circuit solutions used by the developers of heat supply schemes:

1. Reconstruction of steam boilers with the transfer of their work in the PSU mode.

The use of combined-cycle operating mode for the production of electric and thermal energy is the most efficient way to modernize existing boiler houses, provided that the connected load is more than 20 Gcal / h. It is advisable to use this method on heat sources that have equipment with an exhausted working life or when modernizing steam turbine CHP plants operating on low-efficiency gas. The most advantageous use of CCGT is the construction of separate units in a room that has lightweight structures and is located on the territory of an existing heat source using its communications and heat networks [3]. To cover the peak heat loads of the coldest period, use the fuel afterburner system in the waste heat boiler (one or two stages) [5].

The CCGT units, due to the use of the binary cycle, have high efficiency indicators: Efficiency reaches 50-60%, depending on the power, circuit layout and efficiency of the equipment used.

Steam-and-gas plants, as a rule, include:

- booster compressor station (if necessary);
- gas turbine engine with generator (GTE) / gas turbine (GT) (one or two);
- waste heat boiler (KU), which uses gas turbine exhaust gas heat to produce steam;
- steam cogeneration turbine with a generator;
- dry or wet cooling tower.

The experience of reconstruction of the Omsk CHP-3 with the installation of PGU-90 allowed to reduce fuel consumption for electricity generation from 365 g / kW h to 205-210 g / kW h, and for the supply of thermal energy from 165-170 kg / Gcal to 105-120 kg / Gcal [8].
The use of CCGT to produce thermal and electrical energy reduces the cost of energy produced on expensive natural gas and ensures a break-even sale of electricity on the market with competing coal and gas stations with outdated PSU.

2. Superstructure of water boilers with gas turbine units (GTU). Considering that the majority of heating boilers in the European part of Russia operate on natural gas, it is advisable to use the effect of combined energy production to reconstruct them in the mode of gas turbine CHP where gases after the GTU are dumped into a steam or hot water boiler.

When choosing the capacity of a gas turbine unit, it is necessary to take into account the volumes of summer heat consumption from the heat source to the hot water supply. The amount of heat received from the heat and power plant must be at least the amount of heat released during the summer period, which will ensure the operation of the CCGT with maximum efficiency throughout the year.

Boiler units using gas from gas turbines can be performed according to the following scheme: as a waste heat boiler or as a boiler with fuel afterburner (additional burners for burning gaseous fuel), which provide greater heat output and manoeuvrability of the unit. The efficiency of the installation without the afterburning of the fuel will be 44-46%, and with the afterburning of the fuel exceed 37-38%.

If the heat supply schedule during the year released by this heat source changes significantly, then the greater effect of the reconstruction will be achieved at industrial boilers, where there is a constant consumer of steam energy according to the GTU-boiler scheme with a burner.

Experience in developing GTU-CHP for new construction shows that these power plants have specific fuel consumption for the generation of heat and electricity close to combined-cycle CHP, but are more advantageous in terms of capital expenditures. These installations are simpler in the design and operation of equipment. When developing this reconstruction scheme, it is necessary to take into account the minimum power consumption of heat, which will provide the maximum effect at the combined generation of warm energy, at the installation consisting of a gas turbine and a waste-heat boiler for heating network water.

The use of exhaust gases from gas turbines is possible to heat the network water in gas preheaters. In cases of reducing heat consumption, the exhaust gases of gas turbines are discharged into the atmosphere and the units operate in the mode of generation of electrical energy.
Fuel consumption at the GTU – CHP for electricity generation reaches 336.0 g / kW h, for heat supply 150-160.0 kg / Gcal [9]. The efficiency of use of these facilities allows the consumer to provide thermal energy and replace the purchase of electricity from the market with its own generation. In more detail, the possibility of superstructuring heating boilers according to the scheme of PGU and GTU can be found in the works of JSC «Russian Research and Planning Institute of Power Engineering», by authors A.G. Tumanovsky, P.A. Berezents, etc. [4, 5].

3. Reconstruction of CHP with replacement of peak water boilers with peak boilers for heating network water.

According to the standard projects of operating heat and power plants, the provision of peak heat supply loads in the winter period provides for the installation of peak water heating boilers of the type PTVM or KGVM. Peak boilers, usually operating on fuel oil, are put into operation during the period when the outside air temperature drops below -20 °С to warm the supply water above 110-115 °С. Recently, petrochemical plants increase the efficiency of oil refining, which significantly reduced the production of fuel oil and increased its cost. The cost of heat obtained from burning mazut exceeds the cost of heat obtained from burning coal.

Peak boilers have significant wear, because when they are put into operation during a limited period of winter maximum and a long period of conservation, accelerated corrosion of the heating surfaces of the units and a decrease in their reliability occur. To control the equipment of peak boilers during the conservation period, it is necessary to ensure the presence of operating and maintenance personnel. According to the schedule of the frequency of capital and current repairs, repairs to the boilers are carried out every 4-5 years, and the boiler operating time per year is no more than 500-800 hours. The cost of heat produced from peak boilers reaches 3000 -5000 rubbles / Gcal. Receiving additional heat in the peak mode from boiler plants allows to increase the coefficient of heat supply when using heat taken from turbines.

The use of peak boilers using unregulated steam of medium and high-pressure steam turbines as a source of heat for heating network water can significantly reduce fuel consumption for the generation of thermal energy. The efficiency of using such steam is increased due to the generation of electrical energy in the flow part of the steam turbine of high and medium pressure cylinders. Parameters of heating steam of peak boilers must ensure heating of the network water to the temperature required by the schedule of network water for a given locality.

Such solutions for the reconstruction of CHP are possible in the presence of an excess of steam industrial selections of turbines. Obtaining thermal energy by a combined method due to steam from turbine selections allows, in the period of low outdoor temperatures, to additionally produce thermal energy only slightly reducing the generation of electrical energy.

4. Construction of gas piston installations (GPU) at heating boilers.

The purchase of electric energy, as a rule, is made in the wholesale market or the retail market where its price is constantly changing. In some periods, the cost of electricity increases by 15-20%. To reduce the cost of the purchase of electric energy it is possible to install gas piston units (GPU) with an efficiency of 40-43%.

Gas reciprocating installations have high manoeuvrability (starting time of 3-5 minutes), are compact and can be used for 7000-8000 hours per year. Installation of installations is carried out in separate rooms and the cost of 1 kW of power can be $ 500-800, which is half the cost of the construction of a CCGT. Depending on the configuration, prices for gas piston installations can reach $ 2000 / kW. Modern gas piston units reach a power of 10 MW. To maintain the installation does not require a large number of staffs. The disadvantage of these power plants is high oil consumption, frequent maintenance (up to 32 per year) and unstable operation in isolated systems during loading [7].

Comparing the gas turbine and hcp in the current urban environment, the following advantages of hcp in the power range up to 10–12 MW can be noted:

- No need for back-up diesel fuel, since starting from 2125 kW of full power and 1000 kW of partial diesel, BMZ diesel generators can be used, which can operate not only on gas, but also on fuel oil, which is a backup fuel for boiler houses. In boiler houses supplying consumers only 2 categories (determined by agreement with regional authorized authorities) do not provide reserve fuel, therefore
serial GPUs based on the internal combustion engine of gaseous fuel with emergency diesel fuel reserve can be used.

No need to build a booster compressor for fuel gas, since all gas compressor units are capable of operating on medium pressure gas, and a significant part on low pressure gas.

5. Preservation of the existing boilers and the chimney with the superstructure of the GPU, since the GPUs have several times lower gas consumption than the gas turbine units of the same capacity and are able to overcome the aerodynamic drag of the boilers installed in the boiler houses.

6. Due to the lower gas consumption of the GPU, the problems of noise suppression are less acute.

7. When using gaseous fuel in a GPU, there are wide possibilities for reducing emissions of nitrogen oxides. If necessary, they can be eliminated altogether, which is impossible even in a conventional boiler house, by operating the hcp on a rich mixture, followed by post-combustion of the combustion products in the boiler.

8. In Russia there are 14 engine-building factories, each of which produces several engine sizes with a range of power changes, which makes it possible to select the optimal serial engine in each specific case. The use of mini-CHP on the basis of piston engines of gaseous fuel with a unit capacity of 30 kW to 12 MW is not only widespread by enterprises, but also by hospitals and educational institutions abroad.

The main difficulties in carrying out the modernization of heat sources may be: the constraints of the existing sites on which the facilities are located, the need to issue increasing power, increasing the limits of natural gas and the volume of reserve (emergency) fuel.

2.3. Optimization of heating systems.

Improving the efficiency of the heating network alone is not less capital-intensive, as they were often created in the 1960-80s on the basis of the forecasts for the growth of energy consumption of the USSR State Plan, which are not relevant today. After the collapse of the USSR, the XIII five-year plan for the period 1991-95 was not implemented. The construction of settlements and the connection of heat sources to the centralized heat supply system were often conducted situationally and without proper analysis of the consequences.

As a result, a lot of jumpers appeared, duplicating the lines of heat networks and the deregulated heat source and heat networks. In order to remedy this situation, an electronic model is used within the framework of the heat supply circuits that are being created with reference to the heat sinks, heating networks, and subscriber loads.

- improving the efficiency of the heating network by setting up heating systems with optimization of the thermal-hydraulic regimes of the heating network;
- improvement of the structure of heat supply systems of populated areas with conservation of heating boilers and provision of heat supply from adjacent CHP network.

1. Optimization of operating modes of thermal networks.

Optimization of operating modes of heating networks refers to organizational and technical measures that do not require significant financial costs for implementation, but leading to significant economic results.

All production and economic divisions of the enterprise of thermal networks should be involved in the work on the management and adjustment of operating modes of heating networks. The main task is to determine the optimal heat-hydraulic regime and measures for their organization. Production and technical services analyse the actual modes, carry out the developed measures and the adjustment of the automatic control system, as well as quickly control the modes, control the consumption of thermal energy by consumers.

Development of regimes (during heating and inter-heating periods) should be carried out annually, taking into account the analysis of the actual modes of operation of the heating network in previous periods, specification of characteristics according to the volume of overhaul, reconstruction and technical re-equipment of thermal networks, actual and expected changes in heat loads of subscribers. Using this information, thermal-hydraulic calculations are carried out with the compilation of a list of commissioning measures, including the calculation of throttle devices for each substation, measures to change the operating modes of the heat pipelines and transfer pumping stations.
The main task of regulating heat supply in heat supply systems is to maintain a comfortable temperature and air humidity in heated premises at varying external climatic conditions throughout the heating period and a constant temperature of water entering the hot water system at variable flow during the day [9, 10]. The fulfillment of this condition is one of the criteria for evaluating the effectiveness of the system.

2. Improving the system of heating of residential areas.

Existing heating systems of residential areas of settlements, as a rule, are provided with heat during the whole year from a particular heat source. Taking into account the difference in heat tariffs within one settlement from different sources, an enterprise performing the role of a unified heat supply organization should optimize the cost of purchasing heat from different sources. To this end, a single heat supply organization can use various sources of production and options for transferring thermal energy covering the needs of consumers for thermal energy. Consider some of them:

3. Preservation of the heat and power boiler house during the heating season (in summer) with hot water supply from adjacent CHP networks. Schemes of heat supply of settlements, as a rule, are developed with the condition that the consumer receives heat from the boiler house, which has a large tariff throughout the year, which is not always beneficial to the consumer. To reduce the tariff load on the consumer and increase the share of the combined energy production, it is advisable to consider the regimes in which in the spring-summer period there is a change in the boundaries of heat supply from the CHP. The economic efficiency of the CHP, as is known, is largely determined by the amount of thermal energy supplied. While reducing the heating load, the heat capacities of these power plants operate in the mode of technological load minimum determined by the conditions of uninterrupted supply of heat to consumers (social load) and maintaining the system reliability of the power systems (if there are external power flow restrictions on the electrical networks).

4. Improving the mode of operation of various heat sources in the heating period. To use the effect of the difference in heat energy tariffs from different heat sources, it is necessary to consider the modes of joint operation of CHP and boiler houses with the same temperature schedule of heat networks. Considering that the period of peak loads in the winter period lasts less than a month, it is advisable to provide a mode with heat release from the CHP to all consumers not only in the spring and summer, but also the winter periods (when the outside air temperature does not fall below -100 °C) negative ambient temperatures for heating network water additionally connect the heating boiler, previously operating in this neighbourhood. The effect of obtaining thermal energy in a combined way allows during the heating period and the summer period to save on fuel costs for heating network water. For example, this method is widely used in Moscow.

3. Conclusion

In the past five years, the Russian Government has been discussing new approaches to territorial planning and the target model of the heat market, which will attract the necessary investments to upgrade the industry. The heat supply system is a combination of heat source objects and heat networks of different nature. After the development of heat supply schemes for settlements, it becomes feasible to develop additional hierarchical mathematical models that would take into account the cumulative properties of these objects. The development of such models will allow to model the change in current costs of providing energy for the purpose of minimizing the total cost of ownership (control) of such systems. The implementation of the proposed options for the reconstruction of heat sources and heat networks saves fuel costs for heat supply of enterprises, localities and generation of electric energy, reduces emissions of pollutants into the atmosphere and, most importantly, in the long run, reduces consumer costs.

4. Reference

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