Adoption of energy conservation measures in a heating system: a case study of the Baikal natural territory

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Abstract
The paper covers the main challenges of heating systems of the Baikal natural territory and considers the most effective measures for energy conservation in settlements and tourist zones of the territory in accordance with the adopted laws of the Russian Federation on energy conservation, heat supply, and protection of Lake Baikal. For the most effective implementation of these measures, it is proposed that they be ranked as per the priority map put forward in this study.

The case study illustrates the adoption of energy conservation measures and their environmental and economic effect for heat supplying companies and heat consumers in the village of Listvyanka located in the coastal area of Lake Baikal.

1. Introduction
In order to reduce the negative impact on the ecosystem of Lake Baikal, regulatory documents impose the restriction and even prohibition of certain types of economic activities [1]. The most stringent environmental requirements are defined for the Central Ecological Zone of the Baikal natural territory (the CEZ of the BNT). To ensure their implementation, there is an ongoing thorough examination of the current environmental conditions with efficient measures to minimize the pollution of the environment being under development [2].

We propose considering a set of energy conservation measures in the heating system that will contribute to the reduction of heat consumption, reduction of fuel consumption and, as a consequence, reduction of human-induced impact on the environment. In the case of the CEZ, an introduction of energy conservation measures under the conditions of environmental constraints [1] and its special social and economic status can become one of the dominant directions in resolving environmental and social and economic issues of the territory.

2. The challenges faced by the heating system from the point of view of energy conservation
The CEZ of the BNT is home to a number of small settlements with populations of up to 5,000 people, alongside with three larger towns: Baikalsk, Slyudyanka, and Severobaikalsk. The above towns are provided with district heating systems, while the rest of the settlements have either small local systems or individual heating facilities.

The issues related to the heating system within the boundaries of the CEZ of the BNT include the following:

1. Non-uniform heat supply to consumers (shortages faced by some of the consumers coexisting with excess supplies to others).
2. High level of heat network wear. Heat losses in heat networks reach 20-34%.
3) Lack of means to control the flow and parameters of the heat transfer media both at the input points into the local heat consumption systems of the facilities and in the networks themselves.
4. Designs adopted by the overwhelming majority of customers lack heat distribution units or other devices for the transformation of heat transfer medium parameters.
5. Lower temperature charts for qualitative heating control in some of the districts.
6. "Draining" the district heating system water at the consumers based in remote locations.
7. Wear and tear of heat source equipment and pumping stations.
8. Depreciation of buildings of the housing stock and budget-funded organizations (over 30%) with the largest share of dilapidated and dangerous buildings accounted for by rural settlements.

3. The choice of energy conservation measures
In line with the previously developed methods [3, 4], we propose a map of priorities of measures for heat supplying companies and heat consumers in the settlements located within the boundaries of the CEZ of the BNT (see Figure 1).

The most significant of the measures are placed on the right side of Figure 1. These include modernization of heat networks with the appropriate replacement of worn-out sections of the heating main, hydraulic control, and adjustment of heat networks with the installation of throttling devices (washers, nozzles of heat distribution units), as well as various types of insulation of buildings.

They are followed by the measures placed on the left in Figure 1, which are less urgent and more expensive. These include the installation of automated customized heat supply stations (CHSS) and balancing valves on the risers of the heating system. An equally important measure is the training of heat power engineering professionals for the above settlements, as their qualification directly affects the success of energy conservation measures, as well as the level of operation of newly installed equipment, and ultimately is the factor that the possible conservation of energy resources depends on.

4. Calculation of the environmental and economic effect of energy conservation measures in boiler houses in the village of Listvyanka
Heat supply to the village of Listvyanka has four heat sources: two electric boiler houses ("Baikal", "Ist-lend") and two fossil fuel-fired boiler houses ("Ugolnaya", "Mazutnaya"). For the purposes including that of the assessment of the environmental effect, let us consider the adoption of energy
conservation measures in residential buildings that are connected to the boiler houses fired by fossil fuels (Table 1). Heat supply scheme is dependent/open. The method of controlling heat supply from the heat source is qualitative; design heat carrier temperature is 95/70 °C.

Table 1. Data on boiler houses in the village of Listvyanka.

| Name of the boiler house | Power, Gcal/h | Heat load, Gcal/h | Tariff*, RUB/Gcal | Fuel type | flow t/year | specific flow rate, kgee/Gcal |
|--------------------------|---------------|------------------|-----------------|-----------|-------------|-----------------------------|
| Mazutnaya (Fuel oil-fired) | 7.53          | 2.04             | 2399.5          | M-100 fuel oil | 811         | 179                         |
| Ugolnaya (Coal-fired)    | 2.01          | 0.79             | 2399.5          | Borodinsky coal | 1424       | 260                         |

*residential heat energy tariff effective from July 1, 2019 onwards

9 residential buildings and 5 non-residential buildings are connected to the "Mazutnaya" boiler house, 4 residential buildings and 5 non-residential buildings are connected to the "Ugolnaya" boiler house. The total heat consumption of the buildings under consideration is 3,443 Gcal/year in the system served by the "Mazutnaya" boiler house, and 979 Gcal/year in the system served by the "Ugolnaya" boiler house.

Table 2 shows the characteristics of residential buildings where energy conservation measures are supposed to be adopted, in the given case it is the installation of balancing valves on the risers of the heating system and the installation of automated CHSSs instead of the existing ones that are based on heat distribution units.

Table 2. Residential buildings characteristics, heat load and annual heat consumption.

| House number, street | Year of construction | Material          | Number of stories | Area, sq. m. | Volume, cub. m. | Heat load, Gcal/h | Heat consumption, Gcal/year |
|----------------------|----------------------|-------------------|-------------------|--------------|-----------------|-------------------|-----------------------------|
| "Mazutnaya" (fuel oil-fired) boiler house |                       |                   |                   |              |                 |                   |                             |
| 1 Oktyabrskaya       | 1965                 | bricks            | 3                 | 732.6        | 4329            | 0.12              | 400                         |
| 2 Oktyabrskaya       | 1960                 | bricks            | 3                 | 1111         | 4754            | 0.136             | 456                         |
| 3 Oktyabrskaya       | 1960                 | bricks            | 3                 | 1106.5       | 4468            | 0.133             | 445                         |
| 4 Oktyabrskaya       | 1970                 | concrete panels   | 3                 | 1850.5       | 8041            | 0.218             | 727                         |
| 5 Oktyabrskaya       | 1982                 | concrete panels   | 3                 | 1878.1       | 6715            | 0.19              | 634                         |
| 6 Oktyabrskaya       | 1988                 | concrete panels   | 3                 | 2492.1       | 8658            | 0.234             | 781                         |
| "Ugolnaya" (coal-fired) boiler house |                       |                   |                   |              |                 |                   |                             |
| 13 Gudin             | 1976                 | concrete panels   | 3                 | 1769         | 15921           | 0.119             | 398                         |
| 31a Gudin            | 1986                 | concrete panels   | 3                 | 2088.5       | 18796.5         | 0.173             | 581                         |

Total consumption of the heat delivered from the "Mazutnaya" boiler house is 5,382 Gcal/year, while that from the "Ugolnaya" boiler house amounts to 2,300 Gcal/year.

Installation of automated CHSSs allows ensuring hydraulic autonomy of the heating system and heat consumption systems of buildings. This provides many advantages, such as
- improvement of comfortable living conditions;
- enhancement of the hot water quality;
- improvement of the reliability of heat supply;
- the adequacy of heat supply with respect to its consumption;
- the possibility of heat sources working together to make them perform in a cost-efficient way;
- reduction of heat losses and, accordingly, reduction of the costs it incurs.

Balancing valves allow distributing the flows of the heat carrier across the riser pipes as needed and provide the required indoor temperature in the apartments, excluding its existing imbalances in rooms located in the corners and in the middle of a building.

As per the methodological recommendations on calculating the effects of the implementation of energy conservation and energy efficiency enhancement measures, heat energy conservation due to these two measures amounts to the following: from the installation of balancing valves - 7%, from the installation of an automated CHSS - 15%.

Table 3 shows the data on capital expenditures, gains, and the payback period of recommended energy conservation measures.

| Measure | Capital expenditures, thous. rub. | Gains | Payback period |
|---------|---------------------------------|-------|---------------|
|         | Capital expenditures, Gcal/ year | Gains |               |
| "Mazutnaya" (fuel oil-fired) boiler house | | | |
| Balancing valves | 1350 | 7 | 580 | 240 | 2.3 |
| Automated CHSS | 4540 | 15 | 1240 | 520 | 3.7 |
| When used jointly | 5890 | 22 | 1820 | 760 | 3.2 |
| "Ugolnaya" (coal-fired) boiler house | | | |
| Balancing valves | 450 | 7 | 165 | 68 | 2.7 |
| Automated CHSS | 1516 | 15 | 352 | 147 | 4.3 |
| When used jointly | 1966 | 22 | 517 | 215 | 3.8 |
| TOTAL | 7856 | 22 | 2337 | 975 | 3.4 |

The installation of balancing valves in the heating system and automated CHSSs in residential buildings can reduce heat consumption by 22% [5].

The adoption of energy conservation measures will reduce fuel consumption: by 10% in the fuel oil-fired boiler house and by 3% in the coal-fired boiler house. Such a reduction will allow, on the one hand, saving on fuel costs and, on the other hand, reducing emissions of pollutants into the atmosphere without introducing special environmental protection measures.

To carry out environmental assessments, emissions calculations were carried out using the technique for determination of pollutant emissions from fuel combustion in the boilers with a capacity below 20 Gcal per hour [6, 7].

Calculations have shown that it is generally possible to reduce the emissions of two boiler houses by at least 5.5 tons per year, with the coal-fired boiler house contributing more due to reducing particulate matter emissions, Table 4. In the fuel oil-fired boiler house, it is the sulfur dioxide emissions that are mainly reduced (by about 2 tons per year).

It is worth noting that the gaseous emissions of the fuel oil-fired boiler house, given that it is located at an elevated position, can spread over long distances and precipitate as acid sludge on the surface of the earth and water bodies.

The emissions from the coal-fired boiler house and those of predominantly particulate matter are generally spread over close distances and are discharged directly into the surface layer where human activities are carried out.

Using the technique of calculation of the normative quantity of production and consumption waste generation [8] and the existing recommendations for estimating the quantity of ash and slag waste (ASW) in the power industry [9, 10] the calculation of the ash and slag mass from a coal-fired boiler house was carried out. Thus, the estimated amount of the ash and slag waste is 191 tons per year, and in case of a reduction of fuel consumption as a result of energy conservation measures the ash and slag mass at the same boiler house will decrease by 6 tons and will amount to 185 tons per year.
Table 4. Environmental effect of energy conservation measures implemented in boiler houses in the village of Listvyanka.

| Boiler house         | Fuel consumption, toe/year | Emission, t/year   | difference |
|----------------------|----------------------------|-------------------|------------|
|                      | before | after   | particulate matter | before | after   | sulfur oxides | before | after   | nitrogen oxides | before | after   | total | before | after   | difference |
| Mazutnaya (Fuel oil-fired) | 811   | 729.9   | 0.5 | 0.5 | 19.0 | 17.1 | 2.3 | 2.0 | 21.8 | 19.6 | 2.2 |
| Ugolnaya (Coal-fired)   | 1424  | 1381.3  | 98.3 | 95.3 | 11.4 | 11.1 | 0.2 | 0.2 | 109.9 | 106.6 | 3.3 |

In general, the greatest environmental effect from the introduction of energy conservation measures can be obtained at the coal-fired boiler house, as both the emission into the atmosphere and the volume of ash and slag waste are reduced.

Admittedly, this reduction in emissions and waste is not overly significant (by 4-5%) but the reduction in the flow of pollutants into all components of the environment improves not only the environmental conditions within the coastal areas of the unique site that Lake Baikal is but also contributes to the improvement in both health and living standards of the population.

5. Conclusion
Adoption of energy conservation measures is necessary for making all kinds of decisions on planning the type of energy supply to the settlements in the Baikal natural territory, because planning of large and small heating systems is inextricably connected with the design of the configuration and parameters of heat networks as well as the choice of equipment of heat inputs, hot water supply systems and heating systems of the consumer.

As was demonstrated by calculations, the adoption of energy conservation measures if done in a comprehensive way is economically viable and environmentally sound, in spite of significant capital expenditures.

Thus, efficient, target-oriented implementation of energy conservation measures in the settlements in the Baikal natural territory, on the one hand, contributes to the conservation of energy resources thus reducing their cost for the population, and, on the other hand, cuts down the human-induced impact of energy facilities on the environment.

Acknowledgments
The research was carried out under State Assignments III.17.4.3 (AAAA-A17-117030310437-4) and XI.174.2.2 (reg. No. AAAA-A17-117030310435-0) of the programs for basic research of the Siberian Branch of the Russian Academy of Sciences.

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