Study of factors affecting reliability and efficiency of heat supply system

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Abstract. Reliable and uninterrupted supply of heat to consumers is the most important task of the heating system. Due to the connection to the heat network of a large number of dissimilar consumers, the heat supply system operates year-round. Damage to heat networks can lead to disconnection of consumers, disruption of internal engineering systems, and reduction of their operation parameters, which can be dangerous, especially during the heating period at low outdoor temperatures. To ensure the reliability and efficiency of the heat supply system, it is necessary to fulfill all the requirements of the technical operation rules, conduct timely rounds and inspections and identify damage to the heating network at an early stage. It is also necessary to identify factors affecting the reliability and, consequently, the efficiency of the heating system, identifying "risk zones" by the magnitude of damage, based on the results of the calculation. As well as the development of measures to identify and prevent failures in the heating system.

1. Introduction
The district heating system consists of [1, 2]:

- heat source;
- trunk and distribution heat networks;
- heat energy consumers.

Consumers are engineering systems located in buildings, namely the heating, ventilation and hot water supply systems. Each of the components of the system is a complex engineering design.

One of the main requirements for modern heating systems is their reliability. As system performance increases, reliability decreases, while reliability requirements increase.

The reliability of the system, in quantitative terms, is characterized by an indicator of reliability. The following indicators of reliability of the heat supply system can be distinguished:

- durability;
- maintainability;
- persistence;
reliability of work.

Reliability characterizes the property of the system to work without failures for a certain period of time. To study the reliability indicator, the following indicators are used:

- probability of failure-free operation (FBG). If the FBG tends to zero in a given period of time, the system under study can be considered to work smoothly.
- time between failures period of time during which the system worked until the first failure.

Durability is the ability of a system to operate for a long time while ensuring proper maintenance and repair.

The durability of heat supply systems is characterized by the service life of pipelines, heat mechanical equipment and equipment of heating units. If the system is recoverable, the service life is the sum of the duration of the operation and the duration of the restoration. Physical or moral deterioration of the system may be accompanied by the termination of the operation of the system that has not reached its limit state.

Maintainability is the system's ability to detect and troubleshoot. Within the framework of maintainability, such indicators as recovery probability and recovery time are distinguished.

Persistence – this property is to maintain reliability and durability.

The failure of the heating system may be complete: in this case, the system completely stops its operation. A complete failure may be caused by the failure of system components.

Failure of the heating system may be partial, when the consumer receives less thermal energy in the right quantity. This may be due to the malfunction of the equipment of an individual substation. The lack of thermal energy may be due to:

- with a decrease in temperature in the system of heating, ventilation and hot water supply below 60°C;
- reduction of coolant flow below the calculated value;
- reduction of pressure in the system below acceptable values.

Thus, the reliability of the heat supply system is understood as the ability to provide the consumer with a coolant with a given flow rate, pressure and temperature.

2. The method of analytical determination of indicators of reliability of the heating system

Energy efficiency of heating networks is determined in accordance with recommendations [1–4] as follows:

\[ \eta = \frac{\sum Q_r}{Q_v} \]  

\( \sum Q_r \) – the amount of thermal energy received by consumers, W; \( Q_v \) – the amount of thermal energy transmitted from the heat source, W.

And it depends on many factors, including the loss of thermal energy due to heat transfer through insulated piping structures of heat networks, heat energy consumption during transportation of the coolant and other factors specified in [1].

In addition, the amount of thermal energy transferred from the heat source depends on the efficiency of the heat source, the magnitude of its thermal energy losses and the possibility of its reduction [5, 6].

The ratio of the number of failed elements of the system to the number of serviceable for a given period of time is called the failure rate and is determined by the formula [7–20]:

\[ \frac{Q_r}{Q_v} \]
\[ \lambda = \frac{\Delta n}{n \Delta t} \]  

(2)

\[ n \] – number of serviceable elements; \( \Delta n \) – number of failed elements; \( \Delta t \) – time interval.

Figure 1 shows the time dependence of the failure rate. There are three periods:

- the first period – running-in: during this period, failures of system elements that had hidden defects are likely. The period has an initially high failure rate, which decreases over time.
- the second period is the period of normal work. Here the failure rate is constant.
- the third period is aging: the failure rate is constantly increasing until the system fails.

![Figure 1. Failure rate.](image)

The probability of trouble-free operation of the heating system can be determined in accordance with the exponential law [7–20]:

\[ p(t) = \exp(-\lambda t) \]  

(3)

For this law, the time between failures is determined by the formula [7–20]:

\[ T_0 = \frac{1}{\lambda} \]  

(4)

The maintainability of the heating system is determined by the probability of recovery at a given time interval and the intensity of restoration.

The recovery period in accordance with the exponential law can be determined by the expression [7-20]:

\[ T_R = \frac{1}{\mu} \]  

(5)

The probability of recovery at a given time interval is determined by equality:

\[ p(\tau) = 1 - \exp(-\mu \tau) \]  

(6)

Heating systems relate to the repaired system: the failure of equipment or piping system output portion for repair, and then re-introduced into service. failure sequence (conclusions repair) is called a flow failure and is characterized by a parameter \( \omega \) [7–20].

Inefficient operation of the heating system, due to a decrease in its reliability, and therefore, the task of introducing system reliability standards.

3. Analysis of results of the performed investigations

Studies were conducted for the existing outdoor heat network, consisting of 32 sites. Statistical data on failures of elements of the heat supply system are absent, therefore the failure rates of network
sections are determined by the results of analytical calculations at the initial failure rate of heat pipelines $\lambda_{\text{init}} = 5.7 \times 10^{-6}$ 1/(km·h).

The failure rate of the heating network elements is shown in the figure 2.

![Figure 2](image)

**Figure 2.** The failure rate of elements of the heating system.

From Figure 2 it can be seen that sections 1, 3, 12, 14, 15, 21, 22, 23, 24, 26, 32 have large values of failure rates. This is explained by the fact that the life of these areas is long enough, about 20–30 years. Thus, the operating conditions of these areas and equipment, as well as the technical condition of these elements should be analyzed and, in accordance with the results of the analysis, develop a plan for the replacement of the relevant sections of the heating network. [21–26]
The highest values of the failure rate (figure 3) of the elements 1, 2, 5, 6, 12, 13, 26 are due to the length of the sections.

The decrease in the probability of reliable heat supply below the standard value was obtained at the sections of the heating network with a lifetime of 20–30 years, as well as with a lifetime of 10–15 years. Thus, elements with a lifetime of 10–15 years were also in the «risk group».

If we conditionally divide the elements into 3 groups depending on the service life (up to 10 years, from 10 to 15, and from 15 years), the percentage of damage to the heating network can be represented as a diagram in Figure 4.

![Diagram showing failure rate of network elements depending on the life.](image)

**Figure 4.** The failure rate of network elements depending on the life.

In connection with the need to improve the reliability of heating networks, it is imperative to make calculations for reliability after a certain period of operation. The optimum value of the operational life is recommended to take 15 years, since it is elements with such a period of work and higher that significantly reduce the likelihood of reliable heat supply to consumers.

4. Conclusion

In case of failure of any element in the heating system, the heat supply to the corresponding consumer is stopped. If the heating system is redundant, then the consumer, in this case, will receive a reduced amount of thermal energy. The intensity of failures of elements of the heat network increases depending on the duration of the life of the heat network. Also, the probability of trouble-free operation of the heating system depends on the probability of failure-free operation of each element affecting the heating system. From the conducted research it can be concluded that it is necessary to study the factors affecting the reliability and efficiency of the heating system as a whole, as well as for each of its elements. The results of the research should be used in the preparation of operational documentation, namely in the development of the «Test program and instrumental measurements carried out on thermal power plants (heat network)», the schedule of shurfovok, SPR, bypasses and inspections of the heat network.

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