Forecasting changes in the parameters of the failure flow in heat networks at different temperature graphs

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Abstract. The paper considers the transition from the existing temperature graph to a temperature graph with reduced coolant parameters in the city's district heating system and the results of calculating the predictive values of the failure flow parameter in heat networks.

1 Introduction

The stages of development of heat supply systems can be divided into four generations. Generations differ in the parameters of the coolant, sources of thermal energy, control systems, use of non-traditional and renewable energy sources [1]. To date, most countries have heat supply systems of the 2nd 3rd generation. A number of European countries have moved to the 4th generation, and development strategies are being adopted for the transition of their heat supply systems to the fifth. An example is the city of Copenhagen, the capital of the Kingdom of Denmark, in which the heat supply system operates in combination with cooling stations, waste incineration plants, thermal power plants and peak boilers [2].

Heat supply systems of older generations differ from the previous ones in low coolant temperatures, which leads to an increase in the energy efficiency of systems through the use of non-traditional heat sources and a reduction in losses during its transportation.

In the Russian Federation (RF), one of the factors affecting the magnitude of heat losses in networks is the physical deterioration of pipelines (corrosive wear of pipeline metal) [3-5], which results in an increase in the number of accidents associated with the loss of thermal energy with the coolant (leaks in emergency sections, drains coolant during emergency restoration work) [6].

The main reason for the high wear and tear of heating networks is the insufficient volume of pipelines [7]. Thus, the replacement of heating networks in 2020 amounted to 3.371 thousand km in Russia as a whole, which is 6.7% of the required volume of replacement of networks [8].

Over the past 5 years, the situation with the transfer has not fundamentally changed: on average, 3.3 thousand km of heating networks are transferred to the Russian Federation per year, and this volume is insufficient, because. there is a steady increase in the length of pipelines in need of replacement and, as a result, an increase in the number of accidents and the magnitude of heat losses (Fig. 1) [9].

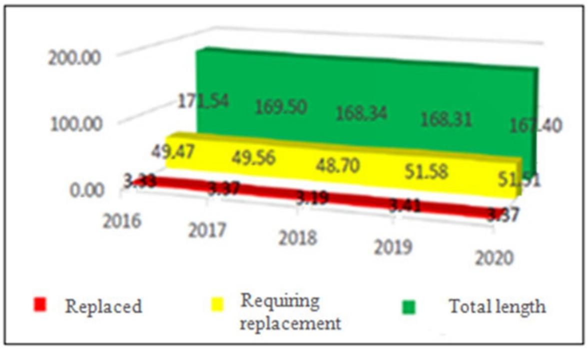

Fig. 1. The ratio of the total length of heating networks with the length of networks in need of replacement and replaced in the Russian Federation in 2016-2020, thousand km.

In the near future, the replacement of all dilapidated pipelines cannot be carried out for objective reasons [10]. A decrease in the temperature of the coolant will lead to a decrease in losses through insulation and a decrease in failure flows due to the fact that heating networks will switch to a more gentle operation mode.

The article deals with the reliability of the heat supply system of a settlement with a population of 65,000 people when it is transferred to a lower temperature schedule.

The design temperature of the outside air for the design of heating systems is assumed to be minus 33 °C. The duration of the heating period is 209 days.

2 State of the research question

2.1 Structure and characteristics of heat networks

The total length of heating networks is 242.3 km in one-pipe terms, including 55.3 km of main lines, 142.4 km of quarterly networks, and 44.6 km of hot water supply networks after heating points. The material characteristic of heat networks is 43.944 m^2. The

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length is dominated by pipelines with diameters of 50, 100 and 150 mm.

The output from the heat source is carried out according to the scheme with a common collector by means of a branch to two heating mains. Return network water is returned to the boiler shop according to a similar scheme. Consumers are connected to the centralized heating system through their own heating points and heating units, and hot water supply is being prepared in central heating points. A four-pipe heating network has been laid from the central heating point to consumers [11-12].

The regulation of the supply from the source of thermal energy is carried out by a qualitative method. The heat carrier parameters set during the design of the heating network corresponded to the values of 150/70°C at the calculated outdoor air temperature. Heating networks operate according to a temperature graph of 150/70 °C with a cutoff at 130 °C and a lower threshold of 70 °C, to ensure the load on the needs of hot water supply [13].

2.2 Wear of the walls of pipelines of heating networks

The corrosion rate was determined using data from the analysis of corrosion indicators installed annually on the inner surface of pipelines [14]. The measurement results are shown in the Table 1.

Table 1. Rate of internal corrosion, mm/year.

Installation location	2019	2020	2021
TM-1, TK-119 (supply)	0.0743	0.0747	0.0607
TM-1, TK-119 (return)	0.0758	0.0783	0.0667
TM-2, TK-2405 (supply)	0.0748	0.0705	0.0611
TM-2, TK-2405 (return)	0.0791	0.0694	0.0625
TM-5, TK-530 (supply)	0.0700	0.0671	0.0591
TM-5, TK-530 (return)	0.0743	0.0690	0.0626
TM-8, TK-822 (supply)	0.0746	0.0684	0.0618
TM-8, TK-822 (return)	0.0723	0.0798	0.0637
TM-12, TK-12004 (supply)	0.0786	0.0753	0.0643
TM-12, TK-12004 (return)	0.0757	0.0767	0.0581

To assess the residual resource of sections of the heat network, the results of the presented measurements are extended to all types of heat pipelines of heat networks.

The measurement results were processed in accordance with GOST R 8.736 2011 [15]. The verification of the hypothesis that the measurement results belong to the normal distribution was carried out with a significance level of 5%.

There are no actual data on external corrosion, so the corrosion rate was taken depending on the type of gasket in the range from 0.01 to 0.03 mm/year.

2.3 Damage (failures) in sections of heating networks

Data on failures of each group of pipeline diameters are given in the Table 2.

Table 2. Failures in the heating networks of the city for 2015-2021

Diameter of the section of the heating network, mm	Average service life, years	Length (in one-pipe terms), m	Number of failures in 7 years	Failure rate, 1/year	Reduced failure rate, 1/km/year
700	39.8	1 778	0	0.0	0.00
600	27.7	3 897	6	0.9	0.22
500	26.2	10 760	19	2.7	0.25
400	23.6	12 397	11	1.6	0.13
350	43.9	7 215	6	0.9	0.12
300	37.3	8 872	9	1.3	0.14
250	33.3	8 963	27	3.9	0.43
200	30.7	12 303	25	3.6	0.29
150	33.0	33 770	55	7.9	0.23
100	34.5	42 233	88	12.6	0.30
80	29.0	12 548	26	3.7	0.30
70	32.8	13 267	22	3.1	0.24
50	36.7	17 057	32	4.6	0.27
Total		**185 060**	**326**	**46.6**	**0.25**

For 7 years of observations during the operation period, 326 failures were registered. Most of the failures were recorded on heat pipes with diameters of 250 mm or less [16].

The weighted average service life of heat pipelines, the reduced failure rate (the reduced damage rate) of the heating network of the central heating systems of the city was calculated using the methodology and formulas given in [17]. The failure rate for each group of sections of heat networks is shown in Fig. 2. The failure rate for all diameters exceeds the frequency of stable failures equal to 0.05 1/year/km, which characterizes the city's heat supply system as medium reliable, in which the effect of aging (degradation) is manifested.

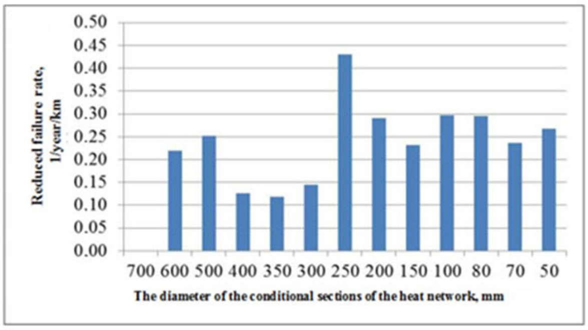

Fig. 2. Reduced failure rate of sections of the heat network of district heating systems.

3 Technical solution for the reconstruction of the heat supply system

The transition from a dependent to an independent connection scheme for all consumers in the city's centralized heat supply system remains unattainable in terms of the amount of required investments, sources and the timing of their return.

It is proposed to replace the existing dependent circuit for connecting consumer heating systems using elevator installations with a dependent circuit using corrective pumps [18]. The correction pump is installed parallel to the mixing line of the elevator and allows you to change the overall mixing ratio for the heat carrier supplied for heating from the heating network. The scheme for connecting the heating system at the subscriber input with a correction pump is shown in Fig. 3.

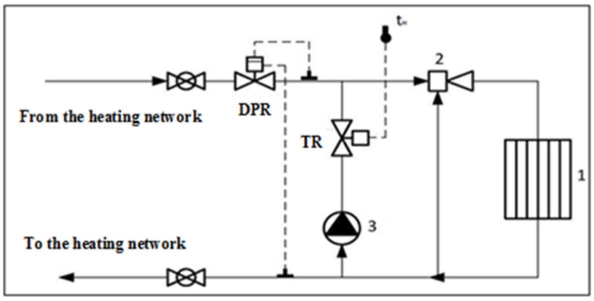

Fig. 3. Scheme of connection of the heating system with a corrective pump: 1 – heating system; 2 – elevator; 3 – corrective pump; DPR – differential pressure regulator; TR – temperature regulator.

The calculation of temperature graphs is made taking into account the implementation of a dependent scheme for connecting consumers using a corrective pump for a model heat supply system with a heat load of the heating system equal to 1 Gcal/h. It is assumed that the central regulation of heat supply to heating networks is carried out in accordance with the graph for heating heat load.

For completeness of the comparison conditions, in addition to the initial and reduced temperature graphs, a graph of 150/70 °C was also considered with the installation of corrective pumps:

- temperature graph 150/70 °C under initial conditions for connecting heating systems;
- temperature graph 150/70 °C with correction pump;
- temperature graph 130/70 °C with correction pump;
- temperature graph 110/70 °C with correction pump;
- temperature graph 95/70 °C with correction pump;

The conditions adopted in the calculation of indicators are given in the Table 3.

To compare regime indicators, calculations of temperature graphs, graphs of water flow from the heating network and through corrective pumps were carried out, and the dependence of heat supply on the outside air temperature was determined.

Table 3. Calculation conditions for various temperature graphs.

Temperature graph, °C	Estimated water consumption, t/h	Elevator mixing ratio
150/70 original	12.5	2.2
150/70	12.5	2.2
130/70	16.7	1.4
110/70	25.0	0.6
95/70	40.0	0.0

With a decrease in temperature graphs, the average annual average temperature in the supply and return pipelines decreases.

The average values of coolant flow rates increase with a decrease in the temperature graph, but this increase is significantly less than with a direct decrease in the temperature graph without the use of corrective pumps. Heat supply to consumers is the same for all temperature graphs. This is due to the operation of corrective pumps and the corresponding scheme of their automation.

4 Processing of data on failures in thermal networks

Data on failures in heat networks are presented only for the last seven years (from 2015 to 2021) and are not complete. The sample of data on failures in thermal networks refers to the samples "truncated on the left" and "censored on the right". The truncation on the left is formed due to the loss of data on failures of heat networks from the beginning of the service life until the start of observations. Censoring on the right is formed by taking into account sections of heating networks, the monitoring of which has been terminated without registering a failure.

To process data of this kind in models of lifetimes with the Weibull-Gnedenko distribution, the method of proportional intensities of Cox was used [19-20].

Evaluation of the impact of the transition to lower temperature graphs on the failure rate, the cost of emergency and major repairs is possible only in a comparable form. A comparable form is achieved by the estimated function of forecasting the number of failures per year for the entire complex of heating networks.

When switching to lower temperature graphs, heating networks need to be re-routed with an increase in their diameter in order to ensure standard pressure drops at subscriber inputs. Accounting for these shifts leads to an increase in the material characteristics of heat networks while maintaining its length unchanged and slightly affects the frequency of failures in them.

Data on the transfer of heat networks are given in the Table 4.

Table 4. The length of the transfers (km) of heating networks, to ensure the normative hydraulic regime of subscribers during the transition to a lower temperature graph.

Nominal diameter, mm	Temperature graph, °C				
	150/70	130/70	115/70	110/70	95/70
1000	0	0.00	0.00	0.00	0.50
800	0	0.00	0.00	0.00	0.01
700	0	0.00	0.00	0.00	2.49
600	0	0.00	1.34	1.88	2.28
500	0	0.00	0.26	0.36	1.85
450	0	0.00	0.00	0.00	0.94
400	0	0.00	0.26	0.26	0.39
350	0	0.00	0.00	0.09	0.56
300	0	0.00	0.01	0.10	0.81
250	0	0.02	0.12	0.59	2.48
200	0	0.40	1.75	1.94	5.26
150	0	0.27	0.86	1.31	4.68
125	0	0.58	2.03	2.25	3.76
100	0	0.32	0.92	0.87	3.17
80	0	0.14	0.33	0.62	1.52
70	0	0.27	0.56	0.58	1.53
40	0	0.00	0.00	0.00	0.00
50	0	0.00	0.23	0.23	0.07
Total, km	**0**	**2.01**	**8.68**	**11.07**	**32.30**

They characterize the length of the heating network transfers over existing sections with an increase in diameter.

For emergency repairs, it is assumed that all elements of the heat pipeline that have lost density during operation and hydraulic tests are replaced with new elements. It is assumed that the element is a section of the heat pipe with a length of 10 meters. For major repairs, it is assumed that the replacement of heating networks is carried out during the period of hydraulic tests.

Figure 4 shows the results of calculations of the predicted values of the failure rate parameter in the city's district heating networks for various temperature graphs.

An estimate of the costs of eliminating emerging failures was made based on the calculated values of the failure flow in heat networks (Fig. 4) at various calculated temperatures of the coolant in the supply heat pipeline of heat networks (temperature graphs) for all gradations of diameters of the heat pipelines of the existing heat network and data on the cost of eliminating these failures. The values of these costs for each temperature graph are taken into account in the financial and economic model.

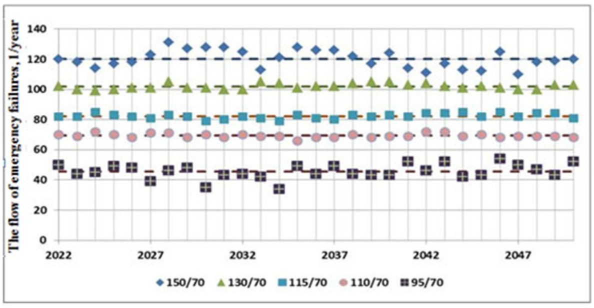

Fig. 4. Forecast values of failure flow parameters in city heat networks at different temperature graphs.

On Fig. 5. predicted values of heating network relocations are presented for various temperature graphs.

Based on the calculated values of the flow of overhauls in heat networks at various calculated temperatures of the coolant in the supply heat pipeline of heat networks (temperature graphs) for all gradations of diameters of heat pipelines of the existing heat network and the data of the approved values of the aggregated norms for the prices of construction of heat networks, an estimate was made of the costs of overhauls.

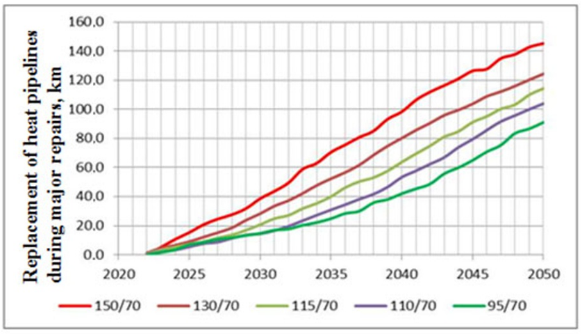

Fig. 5. Forecast values of heating network relocations as a cumulative total for various temperature graphs.

5 Conclusion

Based on the results of the work carried out, it was determined that the current temperature graph for the release of heat from the heat source is not optimal. EBITDA is taken as the target optimization function. To determine the value of EBITDA at different temperature graphs, a tariff-balance model was used, which makes it possible to predict the structure of heat supply costs, taking into account changes in the fuel and energy balance, operating and capital costs.

When determining the long-term price consequences and bringing capital investments in the implementation of projects to the prices of the corresponding years, macroeconomic parameters established by the Ministry of Economic Development of Russia were used:

- forecast of the social and economic development of the Russian Federation for 2022 and for the planned period of 2023 and 2024. (published November 9, 2021);

- forecast of socio-economic development of the Russian Federation for the period up to 2036 (published by the Ministry of Economic Development of the Russian Federation on November 28, 2018).

Assumptions adopted for the formation of the return on capital expenditures: capital expenditures are carried out at the expense of debt resources, return in annuity payments within 10 years, WACC = 12.5%.

It has been established that the maximum cost reduction is possible with the transition to a temperature graph of 130/70. When switching to lower temperature graphs, a significant increase in capital investments will be required, which increases the payback period and the burden on the end user in the form of an increase in payment tariffs.

Ultimately, when switching to the optimal temperature graphs for heat supply from a heat source, in the long term (a payback period of 10 years was considered), the purchase tariff will decrease below the level of 2022, which will make it possible to invest additional funds in the development of the city's heat supply system, replacing the heat exchanger equipment at the central heating point for the needs of hot water supply, as well as the use of more modern methods of control and automation.

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