Determination of the Number of Heat Generators of an Independent Heat Supply Source When Planning the Development of the Urban Environment

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Abstract: The article concentrates on the selection of the number of boilers in boiler houses of independent heat supply sources. The analysis of the current standards to justify the selection of the number of boilers is carried out. For settlements, presented in the latest revision of climatological data, the values of the heat consumption reduction coefficient for heating needs in the cold month mode were obtained, the possible range of its change was established. Using the example of a low power boiler house, a significant influence of the climatic data of the cold month on the number of heat generators is shown. Based on the established range of variation of the heat consumption reduction coefficient, the ratio of heat consumption for heating and hot water supply for multi-apartment residential buildings with independent heat supply sources, the range of the possible number of boilers was established. The ranges of the heat consumption reduction coefficient for heating needs have been found, which make it possible to nearly determine the corresponding number of required heat generators.

1 INTRODUCTION

The heat supply system is part of the engineering infrastructure of cities. The sustainable development of city development is closely related to the development of the heat supply system. When planning general plans of cities, it is necessarily to take into account the development of generating capacities and the system of transporting heat energy. The federal law on heat supply in the Russian Federation obliged each settlement to develop and approve heat supply schemes, that determine the development of the entire system as a whole, and also update them annually. Often the planning horizon of the city general plan and the heat supply scheme coincide, i.e. their development is synchronous. In addition, the heat supply scheme during development is linked to the water supply and gas supply schemes. The approach to sustainable development of territories and engineering infrastructure should be complex (Kitaev, 2010; Semenov, 2010)

With the strategy of the sustainable development of the heat supply system, it is necessary to determine the possibility of connecting the promising city development to the existing systems. The centralized system does not always have the necessary capacity reserves, and in some cases, the construction of long underground networks with generation sources is not economically feasible. In recent decades, there has been an increase in the number of introduction of independent heat supply sources in the housing and utility services. In urban infrastructure, integrated heat supply sources are widely used, represented by built-in, attached and roof boiler houses (Semenov, 2011; Khavanov, 2005; Minin, 2016). Independent heat supply is widely used to provide energy to high-rise buildings in close city development, where it is impossible to use underground centralized heating pipelines (Gapeeva, 2018). The main advantage of such systems is the ability to accurately regulate the load of heat consumption systems, and the disadvantages are noise and vibration impacts. Beyond the scope of the article, we will drop the

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subject of the need for a decentralized approach to heat supply, its disadvantages and advantages over the priority direction of the development of centralized heat supply in the Russian Federation. In recent years, along with centralized, independent heat supply has been widely developing, this is a reality of our time (Kitaev, 2010; Melnikov,2015).

Determining the number of boilers, installed in boiler houses, is an important stage in the design of a heat supply system (Martynenko, 2018; Semenov, 2015). The reliability of heat supply, operating costs, and the cost of heat generation depend on the correct selection. The selection of the number of boilers is a multivariate task, that often requires creative approach. The number of installed boilers in the boiler house is influenced by many factors, such as the consumer reliability category, climatic data of the design area, the value of the design heat currents for heating, ventilation, hot water supply and technology, the value of the boiler house's needs, the minimum value of the heat load of the heat generator itself (Zbaraz, 2019; Panferov, 2020; Fang, 2015). Modern standards in the field of heat supply recommend, when determining the design capacity, to take into account additionally the own needs of boiler houses and waste of the heat energy during the transportation of the heat carrier (in heating networks). The correct value of the boiler house's own needs can be fulfilled only after the end of the calculation and selection of all equipment and pipelines, but even in this case, some data, for example, on the number of boiler start-ups, will have to be taken approximately. In addition, in boiler houses of centralized sources, the values of their own needs can reach 12-15% of the output, especially in the case of using fuel oil and coal dust. A similar situation is with waste of the heat energy in networks, the actual values of which can reach 15-20%. With a decrease in the capacity of the boiler house, own needs and waste in the networks decrease, especially when using gaseous fuel. In integrated heat supply sources, their own needs are minimal, and there are no networks.

Domestic and foreign authors pay great attention to the issues of influence of the number of installed boilers, modes of their load during the year on the efficiency of the boiler house, and the heat supply system as a whole. Measures are proposed to improve the efficiency of existing heat supply sources (Kitaev, 2020; Chicherin, 2019; Terhan and Comakli, 2017).

2 RESEARCH METHODOLOGY

Modern design standards contain recommendations for the selection of the required number of boilers. Let's consider them in more detail. In the current SP 124.13330.2012 (Heating networks), it is recommended in case of emergencies in the centralized heating system during the entire repair-recovery period to provide: supply of 100% of the required heat to consumers of the first category (unless other modes are provided for by the contract); heat supply for heating and ventilation to housing and utility and industrial consumers of the second and third categories in the amount (depending on the design temperature of the outside air from 78 to 91%); consumer-specified emergency mode of steam and process hot water consumption; consumer-specified emergency heat mode of operation of non-disconnectable ventilation systems; average daily heat consumption for the heating period for hot water supply (if it is impossible to turn it off).

SP.89.13330.2016 (Boiler-house plants) recommends to select the number and capacity of boilers, installed in the boiler house, providing: the design capacity of the boiler house; stable operation of boilers at the minimum permissible load during the warm season. In case of failure of the boiler with maximum output in the boiler houses of the first category, the remaining boilers must provide heat energy to consumers of the first category in an amount determined by: the minimum permissible loads (regardless of the outside air temperature) - for technological heat consumption and ventilation systems; mode of the coldest month - for heating and hot water supply. In case of failure of one boiler, regardless of the category of the boiler house, the amount of heat, supplied to consumers of the second and third categories, should be provided in certain amounts (as in the SP Heating networks). It should be noted, that these requirements do not apply to independent heat supply sources, integrated into buildings.

SP 373.1325800.2018 (Independent heat supply sources) recommends, in the event of failure of the boiler with maximum output, to provide heat with remaining in operation for the following purposes: technological heat supply of the ventilation system - in an amount, determined by the minimum permissible loads (regardless of the outside air temperature); heating, ventilation and hot water supply - in the amount, determined by the mode of the coldest month.

From the above recommendations, it can be concluded, that in the absence of a ventilation load (usually multi-apartment residential buildings), the requirements for independent heat supply sources and other boiler houses of the first category are the same in terms of reliability.

3 RESULTS

Putting aside the heat load for the ventilation system, it is usually absent for a residential building, then independent source need, in case of failure, to provide a load of heating and hot water supply in the cold month mode.

In this case, when determining the power value of the boiler house when the largest boiler fails, it will be necessary to evaluate the heat consumption reduction coefficient for heating needs by the well-known formula

$$K = \frac{t_i - t_{хм}}{t_i - t_0} .$$

To evaluate the coefficient K, the data of SP 131.13330.2018 (Construction climatology) were analyzed for the presented settlements (467 settlements). For the majority of the territory of the Russian Federation (except for two settlements), the coldest month is January. Table 1 presents climatic data and the value of the coefficient K for a sample of 51 settlements, that are regional capitals.

Table 1: Values of the heat consumption reduction coefficient.

Settlement	*K*	Settlement	*K*	Settlement	*K*
Krasnoyarsk	0.618	Maykop	0.517	Yakutsk	0.817
Sevastopol	0.514	Blagoveshchensk	0.790	Yekaterinburg	0.634
St. Petersburg	0.586	Arkhangelsk	0.620	Vladikavkaz	0.674
Magadan	0.748	Astrakhan	0.585	Smolensk	0.593
Yoshkar-Ola	0.590	Ufa	0.624	Stavropol	0.581
Saransk	0.592	Ulan-Ude	0.787	Kazan	0.604
Moscow	0.600	Vladimir	0.616	Tomsk	0.633
Murmansk	0.594	Vologda	0.594	Kyzyl	0.728
Naryan-Mar	0.633	Makhachkala	0.561	Tyumen	0.643
Nizhny Novgorod	0.585	Chita	0.791	Ulyanovsk	0.559
Novosibirsk	0.649	Irkutsk	0.714	Khabarovsk	0.815
Orenburg	0.618	Nalchik	0.578	Abakan	0.665
Perm	0.604	Kaliningrad	0.546	Chelyabinsk	0.660
Vladivostok	0.765	Sochi	0.600	Grozny	0.577
Pskov	0.552	Cherkessk	0.581	Cheboksary	0.620
Saratov	0.621	Vorkuta	0.649	Anadyr	0.686
Rostov-on-Don	0.589	Petropavlovsk-Kamchatsky	0.692	Yuzhno-Sakhalinsk	0.790

Fig. 1. shows the values of the coefficient K for all settlements

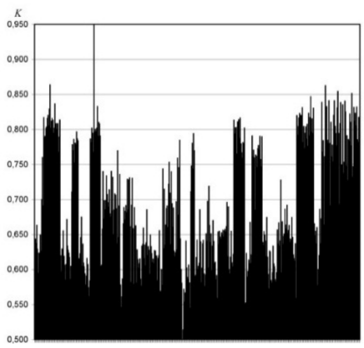

Figure 1: Values of the coefficient K.

From these calculations, it follows, that the minimum value of the coefficient K = 0.5 is observed for Klepnino (Rep. Of Crimea), and the maximum for the rural settlement of Kalakan is K = 0.949. The maximum value is an exception and is observed only for one settlement, moreover, with a small population and consisting of individual residential development. Putting aside the value of 0.949, then the following will be K = 0.863 for Zavitinsk, Amur Region.

It follows from the calculations, that the load of heating and ventilation systems in the coldest month mode can range from 0.5 to 0.863 of the design one.

Consider an example of determining the number of heat generators with the following initial data: maximum heating load Q_o^{max} = 3.4 MW; average load of hot water supply during the heating period $Q_{гвс}^{з}$ = 0.96 MW, in non-heating period $Q_{гвс}^{л}$ = 0.768 MW; own needs of the boiler house are 1%. Taking into account the initial data, the design capacity of the boiler house in the heating period will be $Q_p^з$ = 4.4 MW.

Table 2 shows the results of calculating the number of boilers, that meet the requirements for ensuring the load of heating and hot water supply in the event of the failure of the largest boiler, for various values of the coefficient K. Boilers of the KVa type with a unit capacity of N1 1, 1.25, 1.6, 2, 2.5 MW were considered. In table N1 is the result of dividing $Q_p^з$ by the number of boilers. The last column shows the load values in the summer period Δ,%. The minimum value for the type of boiler under consideration is 40%.

Table 2: Number of boilers.

Coefficient *K*	N_1, MW	N_1, MW	Number of boilers *n*, pcs	Δ,%
0.5	1.468	1.6	3	48
0.6	1.468	1.6	3	48
0.7	1.101	1.25	4	61.4
0.8	1.101	1.25	4	61.4
0.863	0.881	1	5	76.8

As can be seen from Table 2, climatic data have a significant impact on the number of boilers. In the example considered, the number of boilers is from three to five. The minimum number of boilers, that meet the requirement of standards, is three.

The heat load of the hot water supply system does not depend on the outside temperature, therefore, for the coldest month mode, the heat supply is determined by the formula

$$Q_{хм} = Q_o^{\max} K + Q_{гвс}^з = (0,5 \div 0,863) Q_o^{\max} + Q_{гвс}^з \quad . \qquad (1)$$

4 DISCUSSION OF RESULTS

Consider the range of ratios of the maximum heat consumption for hot water supply and heating 0.2≤ $Q_{гвс}^{\max} / Q_o^{\max}$ ≤1, used in a number of standards (SP 41-101-95 "Designing heat points", STO NP "RT" 70264433-5-1-2009 "Recommendations on the design of heat points, located in buildings"). This range of load ratios is predominant for residential buildings (Zbaraz, 2019; Panferov, 2020; On the analysis, 2017). Taking into account the ratio between the maximum and average heat consumption for hot water supply 2.4, given in SP 373.1325800.2018 "Independent heat supply sources", we obtain the range 0.083≤ $Q_{гвс}^{ср} / Q_o^{\max}$ ≤0.417. Therefore, the value of the average consumption for hot water supply is in the range of 0.083 $Q_o^{\max}$ ≤ $Q_{гвс}^{ср}$ ≤0.417 $Q_o^{\max}$. Substituting the minimum and maximum values of the ranges into expression (1), we get:

$$Q_{хм} = 0,5 Q_o^{\max} + 0,083 Q_o^{\max} = 0,583 Q_o^{\max};$$

$$Q_{хм} = 0,863 Q_o^{\max} + 0,4167 Q_o^{\max} = 1,28 Q_o^{\max}$$

As a result, without taking into account own needs, we obtain the possible range of heat load for the cold month

$$0.583 Q_o^{\max} \le Q_{хм} \le 1.28 Q_o^{\max} . \qquad (2)$$

The algorithm for selecting the number of boilers is shown in Figure 2 and contains the following stages.

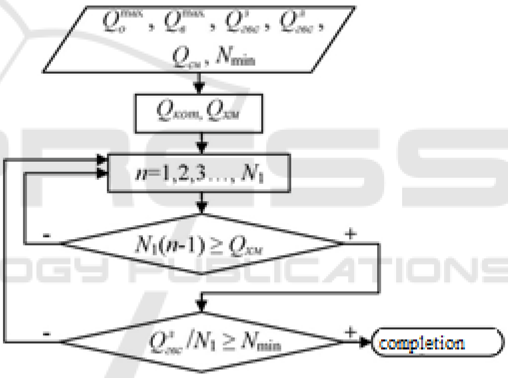

Figure 2: Block scheme of determining the number of boilers.

1. Based on the known load of the heating period, the maximum and minimum value of the load of the hot water supply and the boiler house is determined. In accordance with the accepted restraints, the design capacity of the boiler house can be in the range of

$$1.083 Q_o^{\max} \le Q_{ком} \le 1.4167 Q_o^{\max} . \qquad (3)$$

2. The unit capacity (of one boiler) of the boiler N1, installed in the boiler house, is determined by dividing the design capacity by the number of boilers n. In the initial approximation, the minimum allowable is taken, equal to two.

3. According to the catalog of boilers, we select a boiler with a capacity of Ncat equal or greater than the design N1. We install identical boilers of equal capacity, as people try to do in practice.

4. In order to fulfill the condition of providing the calculated load of heating and hot water supply in case of failure of the boiler with maximum output in the cold month mode, we evaluate the value of the load Qхм.

5. Check the fulfillment of the inequation N1 (n-1) ≥ Qхм. If it is valid, then proceed to checking the fulfillment of the requirement for the minimum boiler load during the heating period (see cl. 6). If the inequation is not valid, then go to step 2 and set more boilers (n + 1), repeat the calculation until the inequation is valid.

6. We check the fulfillment of the requirement to provide the minimum boiler load in the non-heating period $N_{\min}$, when only the hot water supply system is operating: $Q^{л}_{гвс}$ / N1≥ $N_{\min}$. If the inequation is valid, then we print the number of boilers, if not, then we increase the number of boilers (Cl. 2).

We use the algorithm considered to find the maximum and minimum number of boilers, installed in an integrated heat supply source.

Let's introduce additional restraints. We assume, that according to the catalog of boiler designs, it will be possible to select a boiler with a capacity Ncat equal to the design N1. We assume, that it is possible to select a boiler with an acceptable percentage of load for the summer period. This will be facilitated by the minimum value of boilers in the boiler houses of the housing and utilities services, equal to two, and the fact, that with an increase in the number of boilers, the percentage of the minimum load in the summer period of one boiler increases.

The requirement to provide the design load for the cold month, when the boiler with maximum output fails (with the same capacity of the boilers) is determined by the inequation

$$Q_{ком}\frac{(n-1)}{n} \ge Q_{хм} \quad (4)$$

The minimum number of boilers is determined by the expression

$$n = \left(1 - \frac{Q_{хм}}{Q_{ком}}\right)^{-1} \quad (5)$$

Taking into account expressions (2), (3), we evaluate the values of the minimum and maximum number of boilers, rounded to integers: nmin = 1.699≈2; nmax = 10.36≈11.

Using expressions (1), (2), (5), taking into account the inequation $0.083\, Q_o^{\max} \le Q^{ср}_{гвс} \le 0.417\, Q_o^{\max}$, the values of the ranges of the coefficient K for the corresponding number of boilers, presented in Table 3, were evaluated.

Table 3: Ranges of the heat consumption reduction coefficient for heating needs for the corresponding number of boilers.

n	2	3,4,5,6	7	8	9	10	11
K_{min}	0.5	0.5	0.511	0.531	0.546	0.558	0.568
K_{max}	0.63	0.861	0.863	0.863	0.863	0.863	0.863

From table 2 it follows, that two boilers cannot be installed in the range 0.63 < K < 0.863, 3-6 boilers at 0.861 < K, 7 boilers at 0.5 < K < 0.511, 8 boilers at 0.5 < K < 0.531, etc. The determining factor is the ratio of heat loads for heating and hot water supply.

5 CONCLUSIONS

The analysis of the standard literature allowed to establish the requirements for providing minimum consumer loads, affecting the determination of the number of heat generators. On the basis of modern climatic data, it has been established established, that the value of the heat consumption reduction coefficient for heating needs in the cold month mode can have a value from 0.5 to 0.863. Taking into account the data on the ratio of heat consumption for hot water supply and heating, it was established, that the number of boilers can be in the range from 2 to 11. The ranges of the heat consumption reduction coefficient for heating needs are evaluated for the corresponding number of boilers. The conclusions obtained are also valid for boiler houses of centralized heat supply systems of the first category of reliability in the presence of heating and hot water supply loads. The results obtained can be used in planning the development of independent heat supply sources for urban infrastructure.

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