Estimation of the effective heating systems radius as a method of the reliability improving and energy efficiency

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Abstract. When conducting an energy survey of heat supply enterprise operating several boilers located not far from each other, it is advisable to assess the degree of heat supply efficiency from individual boiler, the possibility of energy consumption reducing in the whole enterprise by switching consumers to a more efficient source, to close in effective boilers. It is necessary to consider the temporal dynamics of perspective load connection, conditions in the market changes. To solve this problem the radius calculation of the effective heat supply from the thermal energy source can be used. The disadvantage of existing methods is the high complexity, the need to collect large amounts of source data and conduct a significant amount of computational efforts. When conducting an energy survey of heat supply enterprise operating a large number of thermal energy sources, rapid assessment of the magnitude of the effective heating radius requires. Taking into account the specifics of conduct and objectives of the energy survey method of calculation of effective heating systems radius, to use while conducting the energy audit should be based on data available heat supply organization in open access, minimize efforts, but the result should be to match the results obtained by other methods. To determine the efficiency radius of Kazan heat supply system were determined share of cost for generation and transmission of thermal energy, capital investment to connect new consumers. The result were compared with the values obtained with the previously known methods. The suggested Express-method allows to determine the effective radius of the centralized heat supply from heat sources, in conducting energy audits with the effort minimum and the required accuracy.

Introduction

When conducting an energy survey of heat supply enterprise operating several boilers located not far from each other, it is advisable to assess the heat supply efficiency degree from individual boiler, the possibility of energy consumption reducing in the whole enterprise by switching consumers to a more efficient source, to close in effective boilers. It is necessary to consider the perspective load connection temporal dynamics, conditions in the market changes. To solve this problem the radius calculation of the effective heat supply from the thermal energy source can be used.

Studies to determine the limit radius district heating were started in 1931 [1]. In 1934 during development of the Moscow district heating General Plan for the first time an attempt to calculate the "economic" and "limit" of the district heating radius was implemented [2].

In 1938 analytical expressions of the optimal and limiting economic radius of heat transportation were developed by E.Ya. Sokolov [3]. According to this technique, the optimal and limiting radius of the thermal network must be determined by the formulas [3]:

$$R_{опт} = \left(\frac{140}{s}\right)^{0.4} \cdot \varphi^{0.4} \left(1 + B^{0.1}\right) \left(\Delta \tau / \Pi\right)^{0.15},$$
Рпред = [(p - C) / 1.2K]^{2.5},
 s - the unit cost of the heat network material characteristic, rubles / m^2;
 φ - correction factor, depending on the constant part for the CHP plant construction costs;
 B - average number of subscribers per 1 km^2;
 Δτ - calculated temperature heat carrier drop in the heat network, °C;
 Π - the heat region density of the, Gcal / h · km^2;
 p - the difference in the heat cost produced at the CHP and in individual boiler rooms, rubles / Gcal;
 C - a variable part of the specific operating costs for heat transport, rubles / Gcal;
 K - the constant part of the specific operating costs for heat transport at a 1 km radius of the heat network, rubles / Gcal · km.

2010 is the key to reviving of effective heat supply zones. The scientists interests were supplemented by the published Federal Law «On Heat Supply» [4]. This law regulates the definition: «The radius of effective heat supply is the maximum distance from the heat-consuming installation to the nearest heat energy source in the heat supply system, beyond which the connection (technological connection) of the heat-consuming installation to this heat-supply system is impractical due to the increase in total costs in the heat supply system».

In the same year, V.N. Papushkin presented scientific work [5], which served as a benchmark for determining of effective heat supply radius for the development of municipalities heat supply schemes. In most of the developed heat supply schemes, the effective heat supply radius is determined in accordance with the empirical methodology outlined in this article. The paper considers new approaches to the centralized heat supply zones definition, as well as empirical relationships developed by E.Ya. Sokolov.

According to this technique, the effective heat supply radius should be determined based on a given heat energy losses level of through the insulation of heat networks. However, this technique task is the absent of calculations binding to the existing heat energy cost structure in heat supply systems, as well as the absent of calculations binding to the capital costs amount required to connect thermal energy prospective consumers.

Thus, at present, the methodology of the effective heat supply radius calculations has not been developed by existing scientific and technical organizations, and, therefore, has not been approved by the federal executive bodies in the field of heat supply.

1. The results of modern research

Russian scientists have studied and deduced the main dependencies that allow to determine the efficiency of centralized heat supply based on individual characteristic indicators. Most of the heat supply schemes of municipal formations contain in their composition calculations of effective heat supply radius constructed on the empirical dependencies basis.

Currently, in the Republic of Tatarstan, as in many regions of the Russian Federation, the requirements for solving energy saving and energy efficiency issues are increasing, and the problems of the optimal functioning of heat supply systems are becoming especially topical. Kazan, like many other large cities in Russia, is characterized by a combination of heat supply different types: centralized heat supply from sources with combined and non-combined production, individual heat supply. The effective heat supply radius of each heat source must be an instrument that determines the technical and economic expedience of new consumers connecting to existing district heating systems or the individual source construction, the choice between several heat sources operating in the same zone. With centralized heat supply to a significant number of consumers, questions arise about the heat supply scope and on the selection of indicators performance that determine the centralization of city heat supply.

One of the methods proposed in [6] for the effective heat supply radius determining is to estimate the production costs change while providing final consumers with thermal energy by considering heat supply two types:
1) heat supply based on existing district heating systems (expansion of the coverage of existing heat sources);

2) heat supply to consumers by alternative boiler house building.

An alternative boiler house is thermal energy local source, which consumers can replace the heat supply service from existing district heating systems. The alternative boiler house model is calculated on the use of modern efficient and economical technologies.

For the heat source the heat energy equipment optimal load (maximizing of the installed capacity use) is understood to exclude the payment for excess capacity [7-9].

In [6], a methodology of thermal energy cost calculation from an alternative boiler house is presented. The basic technical and economic performance of the boiler house adopted for calculation is applicable to the conditions of the Republic of Tatarstan. The heat energy resulting cost from an alternative boiler house can be used to calculate the effective heat supply radius of thermal energy sources in the Kazan city.

When developing the scheme of heat supply in the Kazan city, we made calculations of the thermal energy cost from thermal energy sources of JSC «Tatenergo» (mainly combined output), JSC «Kazenergo» (non-combined production). The results of calculations and comparison of the results with the heat cost produced by the alternative boiler house are shown in figure 1.

![Figure 1](image-url)

**Figure 1.** Calculated values of the thermal energy cost from various sources, rubles / Gcal

The above analysis of the heat supply efficiency based on a comparison of the heat cost produced in a district heating system and an alternative boiler house allows us to draw the following conclusions.

In recent years, there has been a trend of «boiler-building» and the withdrawal of consumers from large CHP. Of course, the tariff for combined heat and electric energy generation should be lower, but in some cases, the boiler house construction is a more optimal option, for example, with remote consumer distances. The thermal energy cost price produced by alternative boiler, taking into account
the return on its construction for 10 years is higher than the cost of thermal energy produced in the
district heating system by 12%.

We carried out research to find the optimal coverage area from sources and identified areas within
the boundaries with technological consumer connection were identified. The zones of heat mains from
Kazan CHP-1, CHP-2, CHP-3, district boiler-houses «Azino», «Gorki» and «Savinovo» action are
shown in figure 2, and their numerical values are given in table 1.

Figure 2. Effective heat supply radius in Kazan
КТЭЦ-3 - CHP-3; КТЭЦ-2 - CHP-2; РК Савино - «Savinovo»; КТЭЦ-1 - CHP-1;
РК Азино - «Azino»; РК Горки - «Gorki»

| Heat supply source | Effective heat supply radius, km |
|--------------------|--------------------------------|
| CHP-1              | 14.47                          |
| CHP-2              | 13.6                           |
| CHP-3              | 12.2                           |
| «Azino», «Gorki»   | 10.5                           |
| «Savinovo»         | 13.9                           |

However, these results do not allow us to assess the feasibility of connecting the consumer to one
of the thermal energy sources in the zones where they cross their action. The received indicator does
not carry information on the degree of connection efficiency to a definite heat supply system.

Thus, at present, it is actual to develop analytical expressions for assessing the efficiency of district
heating depending on the range of heat transfer. It is proposed in [6] to calculate the radius of effective
heat supply based on a comparative analysis of the thermal energy cost at the discharge points and a
comparison of the capital costs for the connection.
### 2. Development of a new method

When conducting an energy audit of a heat supply enterprise operating several boilers located not far from each other, it is advisable to evaluate the degree of heat supply efficiency to consumers from a particular boiler house, the possibility to reduce energy consumption in the enterprise as a whole by switching consumers to a more efficient source and to close inefficient boilers.

In 2014 V.N. Papushkin, S.O. Poliantsev, A.P. Shcherbakov and AA Khrapov proposed a method for calculating the effective heat supply radius, which allows to take into account the whole complex of factors affecting the radius value and solve the problems:

- determination of the actual (established) heat supply radius in the zone of the heat power source action and comparison it with the effective heat supply radius;
- determination of the possibility of the thermal power source coverage area expansion, in order to provide new consumers planned for construction outside the existing area of the source;
- the effects that arise when making a decision to redistribute the heat load between sources, with suppressing (or nested) zones of action.

The disadvantage of this technique is its labor intensity, the need to collect a large amount of raw data and to conduct a large number of computational work. When conducting an energy audit of a heat supply enterprise operating a large number of thermal energy sources, an express estimate of the effective heat supply radius is required. Taking into account the specifics of the conduct and tasks of the energy survey, the method for the effective heat supply radius, calculation proposed for use in the energy audit performance, should be based on the data available from the heat supply organization in the finished form, minimized labor and time costs, but the result should be in line with the results obtained by other methods.

The algorithm for the effective heat supply radius calculation by the proposed method is shown in figure 3.

![Figure 3](image)

**Figure 3.** Block diagram of the program for calculation effective heat supply of radius

- $T$ - thermal energy tariff, rubles / Gcal;
- $C_{\text{tarf}}$ - the share of the thermal energy cost price of attributable to generation, rubles / Gcal;
- $C_{\text{tarf}}^{y}$ - electricity unit costs in the heat energy cost, attributable to its transfer;
- $C_{\text{tarf}}^{y}$ - the specific costs for heat carrier losses and heat energy in the heat energy cost, attributable to its transfer.
\( C_{\text{ac}} \) - the share of the thermal energy cost attributable to generation from thermal energy sources, rubles / Gcal;
\( C_{\text{sup}} \) - the share of the thermal energy cost price attributable to the heat energy generation, rubles / Gcal.

The developed methodology is aimed at simplifying and reducing the complexity of the effective heat supply radius calculation. It is designed for rapid assessment of the efficiency of consumers connection and of effective heat supply radius obtention.

Therefore, the actual task is to compare the results of calculations on the proposed and existing methods, assess the reliability and applicability of the new, simplified scheme of calculations.

3. Results of calculation
Table 2 - the results of calculations of the effective heat supply radius from three Kazan CHP according to E.Ya. Sokolova, V.N. Papushkin (when connecting the consumer load 20 Gcal / h) and the methodology proposed in this paper.

Table 2. The results of calculation of effective heat supply radius (EHSR) from Kazan CHP using three methods

| A heat supply source | EHSR calculation by Sokolov’s method, km | EHSR calculation by Papushkin’s method, km | EHSR calculation according to the proposed method, m |
|---------------------|----------------------------------------|-------------------------------------------|----------------------------------------------------|
| CHP -1              | 14.47                                  | 3.1                                       | 3 508.68                                           |
| CHP -2              | 13.6                                   | 5.8                                       | 4 588.28                                           |
| CHP -3              | 12.2                                   | 6.4                                       | 7 611.14                                           |

For the express methodology, the following initial data was accepted (fact of 2014) (Table 3).

Table 3. Initial data for the EHSR calculation of sources with combined energy production

|                        |                                             |
|------------------------|---------------------------------------------|
| Useful heat output, Gcal | 5 046 540.23                                |
| The share in the cost price, coming on generation and constant expenses at transfer, ths. rubles. | 5 028 574.59                             |
| Thermal energy loss in heat networks, Gcal | 1 221 098.00                             |
| Heat loss in the heat networks, ths. rubles | 804 715.79                             |
| Electricity transmission costs, ths. rubles. | 306 577.98                             |
| The heat tariff, rubles / Gcal | 1 115.31                                    |
| The distance to the most remote consumer (according to the Heat Supply Scheme in Kazan) (example for CHP-1) | 6 500.00                                  |

Analysis of the results shows that the effective heat supply radius, calculated by the Sokolov’s method. Significantly exceeds the values obtained by the other two methods. It should be noted that these results differ significantly from the actual situation in the city heat supply. Thus, the zone of operation of CHP-2 almost completely «covers» the entire territory of the city, which is practically impracticable.
The results of calculations by the Papushkin’s method and the proposed express method are quite close to each other. The new methodology application is fully justified if it is necessary to quickly assess the heat supply efficiency, especially when it is necessary an energy survey to conduct.

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