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Optimal planning of heat supply systems in urban areas

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ABSTRACT

The need to solve problems of planning and justification of the rational level of centralization and concentration of sources' heat capacity was noted in the law "About a Heat Supply". For the solution of these tasks, the complex methodology was developed; it allows us to define locations of heat sources and the border of their action at the predesign level of heat supply schemes' development of settlements. In presented complex methodology, standard values of heat load density per unit of the area (heat load density) and per unit of the pipelines' length (linear heat density) are criteria of scales restriction of the systems. The important task is to find their standard values. Authors offer dependences for determination of standard values of heat density indicators for carrying out a predesign analysis of heat supply systems. The analysis carried out showed that heat supply from chosen heat source of part of consumers isn't economically feasible if values of heat density indicators are less than their standard values. The less value of heat density in the system, the higher specific costs for generation, distribution and transmission of heat energy.

1. Introduction

In Russia, a large number of DH (district heating) systems with one or several heat sources working separately from each other (except for peak sources), and complex distributed heat networks were developed and they are operated now. The heat power of some large CHP (combined heat and power) plants can be 5000 MW and their electricity installed capacity is more than 1000 MW, the heat power of the heat-only boilers reaches 900 MW and more. Heat supply radiuses (distance from a heat source to the most remote consumer) exceed 30 km (Moscow, Yekaterinburg, Novosibirsk, etc.), the total length of networks in one heat supply system can be up to several hundred kilometers, the diameters of the transmission pipes amount to 1200–1400 mm.

The share of DH based on heat sources with installed heat power capacity more than 23 MW is about 80% in some cities, and it is about 72% in the whole country. Total production of heat energy in 2012 amounted to 2200 TWh in Russia, and systems based on CHP plants provided about 32% of total heat.

Large heat supply systems were also created in other countries, for example in the Scandinavian countries where energy planning is developed. In Copenhagen, Helsinki and Stockholm the heat power of operational heat supply systems can reach 3500 MW. Approximately 60% of all households are heated with district heat from district-heating plants and co-generation plants. These systems have extensive heat networks, but at the same time, they have a very high efficiency. In particular, heat losses in them don't exceed 7%.

In Russia, the development of heat supply was historically focused on creation of large DH systems. For a number of reasons their design, construction and development were followed by decrease in capital investments and application of simplified decisions which aren't corresponding to their scales and complexity. As a result, existing systems don't meet requirements for reliability, efficiency and ecology imposed on them today. Besides, they can't make use of the advantage of centralization and cogeneration fully. Development of the market of available, effective equipment and technologies promotes growth of competitiveness of decentralized systems. At the same time DH and, first of all, cogeneration objectively retains technical and economic advantages despite obtained negative features and they are most prepared for modernization and technical upgrade. In this regard, the relevance of problems of rational areas' definition for implementation of different heat supply types and scales of systems development increases.

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In 2003 new standards of requirements to thermal protection of the buildings CNiP 23-02-2003 "THERMAL PERFORMANCE OF THE BUILDINGS" came into force. Specific heat consumption levels of buildings, which were built after 2000, must be reduced by 50% according to these standards. Values of standardized specific heat energy consumption for heating in five large cities of Russia are presented in the Table 1.

Differentiation on energy efficiency classes is entered for existing and new buildings. Classes of buildings energy efficiency are presented in Table 2. Houses that were built before 2000 belong to classes D – lower level, E – the lowest. They would have to be reconstructed for increasing their energy efficiency class to level C – normal.

Implementation of innovative energy-efficient technologies in construction will reduce the heat consumption. This will inevitably lead to changes in the heat density map and the energy plan of the city.

The relevance of problems of energy zoning, determination of rational scales of systems and optimum levels of centralization of heat supply have increased in connection with new challenges and existing negative tendencies of DH systems' efficiency decrease and the unorganized development of individual heating sector. At the same time, a designer has to solve problems of energy planning at the initial phase of working out of settlements' detailed planning projects. There are two main objectives, they are:

- Territory zoning. It is territory division into zones of the district and individual heating.
- Justification of optimum levels of DH and concentration of heat sources capacities.

In practice, the territory zoning by type of heat supply is still not widespread in Russia, for example, it is customary for the Nordic countries. At the same time, the need to meet this requirement is legislated and regulated by requirements for the development of DH schemes [1,2]. Research work in the field of justification of optimum levels of DH have been carried out for more than 70 years [3,4] and in recent years these objectives are widely discussed in Russian publications [5–12]. However, these publications are devoted to the solution of individual tasks and significantly separated in the technique.

In this work it's proposed to combine two objectives and to carry out their simultaneous optimization by means of the complex methodology. It allows planning the placement of heat energy sources and an amount of consumers connected to it at the prelevel. The criterion for territory division into zones of DH and individual heating is the annual heat supply cost. The standard value of criterion of heat load density per area unit allows us to restrict different zones of heat supply.

Since the beginning of heat supply development a number of tasks such as choice of heat sources structure and parameters, development of main equipment types for CHP plant, differentiation of scopes of combined and separate energy supply schemes, choice of parameters of heat carrier, schemes and operating modes of heat networks, raises the question of optimum levels of DH and concentration of heat sources capacities [13–15]. At that time it was raised as a problem of choosing the optimal heat power of a CHP plant. To solve the problem analytical dependence was received. It's valid for created small and simple systems. It allowed the determination of the cost effective locale of a CHP plant under a given heat load density [3,4,13,14]. On the basis of such approach on condition of the fixed heat source location it was possible to find the approximate radius limit of heat supply, and the rational level of centralization of heat supply in case of one source.

In Europe, energy planning has developed after the 1973 energy crisis. The Scandinavian countries, Denmark and Sweden, become the leading countries in the field of increase of heat supply efficiency [16]. To overcome the crisis the Danish government was forced to develop methods of fuel economy to protect the interests of society and to reduce heat costs for consumers. They placed emphasis on energy planning.

The first Heat Supply Law of 1979 has been an important factor for creation of a new public planning process at the level of municipalities that rationalized heat supply. The main objectives of the Heat supply Law of 1979 are: providing the population with a gas supply system to cover 15% of the heat load and increasing the market share of DH. The central authorities have developed guidelines to supervision of planning and approved plans, the municipalities carried out planning in collaboration with energy companies and consultants. The most economical territory zoning on DH and decentralized heating (heating by natural gas) zones and determination of rational scales of DH systems based on CHP plants and waste incineration plants became the main results of planning. The study [17] shows a basic division of tasks between the central and the local level within such a strategic energy planning system.

Since then, the energy map of a number of the European countries has changed significantly and active research work began in the field of targeting an increase of heat supply efficiency and creation of DH systems [18–20]. If energy efficiency of DH systems increased, their area has extended and the number of DH sources have increased significantly. The main criterion for territory zoning is a thermal stress or density of heat consumption per unit area of the territory. On the basis of this criterion, heat load density maps are formed, the territory zoning is carried out, zones of DH, the centralized gas supply and individual heating are determined. The standard value of heat density has changed in over time, in connection with introduction of new technologies in heat supply [21,22].

Despite the fundamental differences in the organization of DH systems in Russia and the European countries, DH systems in these countries are the basis for the development of advanced integrated intelligent energy systems [23,24].

To solve the problem of definition of rational scale of DH systems in Europe the technique developed by authors of publications [25,26] is widely used. In the Scandinavian countries, the study on justification of DH for customers located in areas with low heat density is carried out [27]. In these works the indicator of linear heat density for determination of DH systems efficiency is used, the

Table 1
Values of standardized specific heat energy consumption for heating an apartment in five large cities of Russia, Wh/(m^2·degree-day).

City	Buildings constructed before the year 2000				Buildings constructed after the year 2000			
	1–2 fl.	3–4 fl.	5–9 fl.	>9 fl.	1–2 fl.	3–4 fl.	5–9 fl.	>9 fl.
Moscow (−28 °C)	58.9	36.1	30.1	28.8	20.6	17.1	15.4	14.1
Novosibirsk (−39 °C)	50.7	31.8	27.5	26.2	19.9	16.9	15.5	14.1
Irkutsk (−36 °C)	52.3	32.7	28.5	27.3	19.9	16.9	15.4	14.2
Yakutsk (−54 °C)	46.6	28.8	25.6	24.5	20.1	17.1	15.7	14.3
Vladivostok (−24 °C)	63.3	38.5	31.9	30.7	19.7	16.9	15.0	14.2

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