

Efficiency of use of waste heat energy on the example of Chelyabinsk

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Abstract. We consider the possibility of improving the existing heat-supplying system in Chelyabinsk through the introduction of heat pump technology for the disposal of waste low-grade heat. Sources of information concerning the ways of utilization of waste thermal energy, the principles of work of heat pumps, classification of city sources of waste heat are analyzed. The technique directed to assess the effectiveness of applying heat pumps for each category of city sources of waste thermal energy is designed. The calculated assessment showed that the utilization of waste heat in the conditions of Chelyabinsk will reduce the annual energy of fuel consumption by 2.2 million tons of conventional fuel (24.9%). At the same time, thermal pollution will decrease by 1.5 million tons of equivalent fuel. This effect is possible with the use of heat pumps with a total heat output of 1,145 MW.

1 Introduction

The heat supply system is one of the key sectors of the fuel and energy complex of Russia. It is significant not only as a saving energy, but economically and socially [1]. This is primarily due to the climatic features of Russia. Most of the territory of Russia is located in moderately and sharply continental climatic zones characterized by long and cold winters, which, in turn, causes to meet the needs for significant heating over long periods [2].

The provision of heat to consumers located in large Russian cities largely occurs due to the outdated centralized heat supply system of the Soviet times. Such an irrational policy has risen the problems associated with sources of thermal energy (combined heat and power plants (CHPP) and boiler houses) and the systems of delivery and distribution of heat produced by them (heat networks) [3]. One of the ways to solve these problems can be the utilization of waste heat energy. Such an approach makes it possible to meet the part of the heat demand at the expense of energy, which in the ordinary case is simply discharged into the environment. In addition, heat recovery contributes to the reduction of thermal pollution, which in some cases is a significant factor of anthropogenic impact on the biosphere [4].

2 Methods

In order to classify urban facilities as sources of waste heat, it should be taken into account that these include those facilities that produce (CHPP, boiler houses) and

transport heat (heat networks) [5]. These types of objects belong to the energy category. In the non-energy category there are all those objects that are not involved in the direct production, transportation or distribution of electricity. Such objects include residential, public and industrial subcategories [6]. Thus, the general classification of urban sources of low potential waste energy is presented in Figure 1.

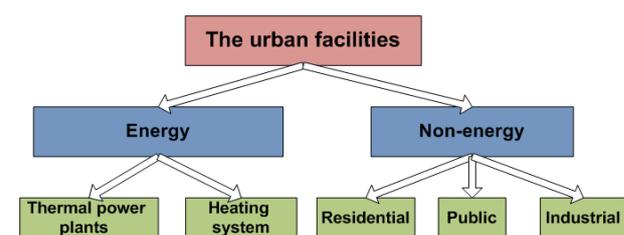


Fig. 1. Types of city sources of waste heat

First of all, combined heat and power plants (CHPPs) are sources of waste heat, which during the generation of electricity are forced to produce side heat [7]. Some of this heat is unsuitable for direct use in heating systems, so it must be discharged through cooling towers or sprinkler basins. This can be avoided with the help of heat pumps that can convert such heat into useful heat [8].

The CHPP efficiency increases with decreasing return water temperature compared with the value given by the temperature schedule. It follows that an increase in the efficiency of the operation of heat networks with

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the help of heat pumps can be based on a decrease in the temperature of the return network water [9].

Finally, improving the efficiency of heat supply may consist not only in improving CHPPs and the network, but also in the way in which the generated and delivered heat is consumed. Thus, the use of heat pumps is advisable not only in terms of improving the efficiency of energy facilities, but also in order to increase the efficiency of heat consuming facilities.

Virtually every urban facility (production, residential and public categories) is a source of waste heat. Typically, this heat is contained in the water discharged into sewage or directly into the reservoir, as well as in the exhaust air [10, 11].

3 Results and Discussion

The basis of this study is the development of a calculation method to evaluate the efficiency of waste heat utilization when introducing heat pumps into the existing centralized heat supply system, consisting of a source (CHPP), a transporter (heat networks) and heat consumers (non-energy facilities).

For the developed calculation method, the conventional combined heat and power plant (CHPP) was chosen, the electrical and thermal capacity of which was assumed to be 100 MW and 150 MW (129.1 Gcal/h), respectively. In accordance with these capacities, consumers were supplied with the conventional combined heat and power plant. These data formed the basis for further calculations to estimate the annual dynamics of changes in the total required heat output.

These calculations are based on the fact that all consumers of thermal energy can be divided into three categories: residential, public and industrial. Moreover, each of these categories needs heating and requires hot water supply. In addition, the needs of industrial consumers are also to be met (Fig. 2).

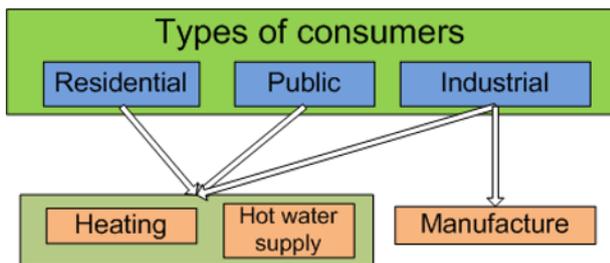


Fig. 2. Classification for consumers of thermal energy

Then, the assumption was made according to which the average monthly values of heat capacity necessary for meeting production needs and supplying hot water are constant over the year, whereas the average monthly values of heating needs vary according to the 150/70 regulation schedule [12], i.e. dependent on outdoor temperature. The values of this temperature for each month are assumed to be equal to the average monthly air temperature in Chelyabinsk [13].

For the conventional CHPP, it was assumed that it supplies heat to the district, the main territory of which is

occupied by residential areas with public buildings and industrial facilities. According to these conditions, as well as the above assumptions, the dynamics of changes in the required heat output for each category of CHPP consumers was calculated over the year. It made possible to find the annual dynamics of the total required heat output (Fig. 3).

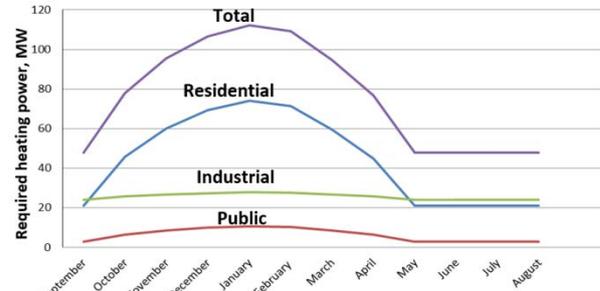


Fig. 3. Annual schedule of required powers of consumers

The resulting dynamics served as the basis for the research calculations of the CHPP itself. This study was also based on some assumptions. First, it was assumed that the average monthly electric power generated by the conventional CHPP is unchanged over the year. Secondly, these calculations were based on tentative coefficients estimating the CHPP primary energy parameters without taking into account a number of its physical and technical aspects. In addition, these calculations imply a simplified description of the operation of the absorption heat pump system. According to the accepted simplification, the heat pump system extracts heat from the waste water of the CHPP, and the peak boiler house supplies it with thermal energy (the costs of electrical energy necessary for the operation of the heat pump system were assumed to be insignificant). In this case, the conversion coefficient of the heat pump (HP) is assumed to be constant, independent on the operation mode of the heat pump system. Finally, the CHPP efficiency increases due to the fact that the heat pump is able to generate partially the energy that peak boilers have to produce during the heating period.

Thus, according to the accepted assumptions, a comparative graph was obtained (Fig. 4) to show the dynamics of changes in the capacity of the CHPP fuel combustion with and without using the heat pump system.

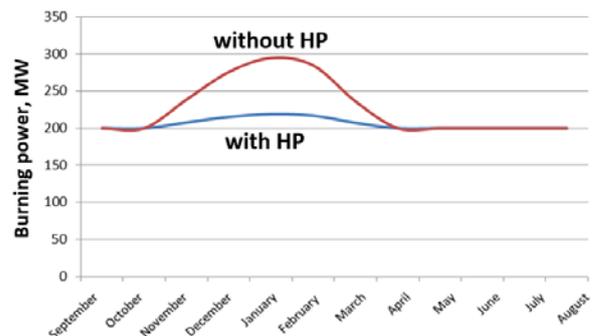


Fig. 4. Annual schedule changes of capacity of fuel consumption

When integrating this graph, the results were obtained, according to which, with the constant amount of total annual energy demand, the HP use for the utilization of waste heat at the CHPP reduces the annual energy of burning fuel from 7164.5 TJ to 6479 TJ. Such savings are equivalent to 23.4 thousand tons of standard fuel, or 9.6%.

The next step in the computational survey was to assess the effectiveness of the HP use on heat networks that distribute the heat produced by the CHPP to its customers. To carry out calculations at this stage, it was assumed that the increase in the efficiency of the heating network when using a HP is achieved by reducing the water temperature on the return lines. As in the previous calculations, a simplified description of the absorption heat pump is adopted here. Only, the heat is not taken from waste water, but from the heat losses of the network, and the drive energy is produced by using heating elements, which, in turn, receive electricity from the CHPP. Taking into account the above assumptions, the average monthly values of temperatures on the return lines of the CHPP heat supply network were obtained when using the HP on it [14].

Then we accept that, the energy taken by the HP due to utilizing heat loss, is able to meet some of the thermal needs of consumers. This, in turn, leads to a reduction in power, which should generate the CHPP to meet the needs of consumers [15, 16]. Thus, a graph of the change in thermal power of the CHPP was drawn up with and without the HP use on heat networks (Fig. 5)

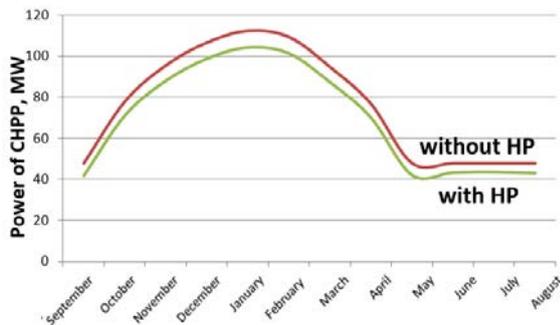


Fig. 5. Annual schedule changes of thermal power

Thus, the utilization of heat losses on the heat supply network using a heat pump system allows us to reduce the total annual thermal energy of the CHPP from 2330.6 to 2192.3 TJ. Such savings are equivalent to 6.9 thousand tons of standard fuel, or 8.5%.

The next item of the computational research was an assessment of the energy that can be extracted by disposing of the heat discharged by non-energy facilities (the CHPP consumers).

Residential, public and industrial categories of urban facilities can be not only consumers of thermal energy produced by the thermal power plant, but also act as sources of low-potential thermal energy (Fig. 6).

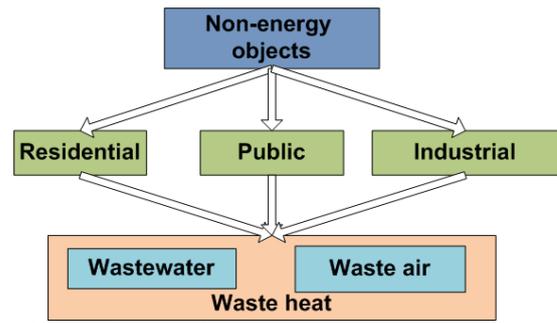


Fig. 6. Classification of non-energy sources of waste heat

So, the accepted assumptions allowed us to calculate the average monthly values of thermal power that can be obtained with the help of the HP by utilizing the waste heat of non-energy facilities heated by the CHPP. It is worth noting that, since the accepted assumptions do not take into account seasonal changes in the amount of wastewater and exhaust air, the total average monthly capacity of all categories of non-energy facilities was unchanged throughout the year [17, 18]. This power, in turn, can be used to meet the thermal needs of the same facilities (Fig. 7).

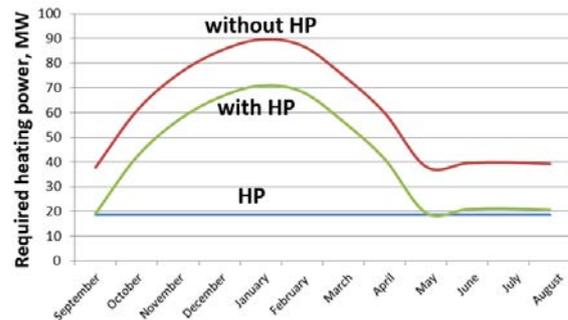


Fig. 7. Annual schedule changes required by power consumers

Thus, the utilization of waste heat of non-energy urban facilities supplied with heat from the CHPP allows one to reduce the annual required heat energy of the same facilities from 1906.7 to 1318 TJ. Such savings are equivalent to 20.1 thousand tons of standard fuel, or 30.9%

The final stage of the research calculations was a return calculation, the essence of which is to repeat the earlier calculations for the CHPP and its heat network when some initial parameters change (Fig. 8).

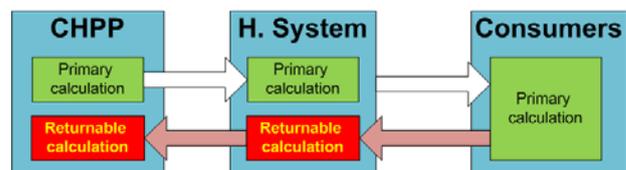


Fig. 8. Return calculation scheme

The calculations of the efficiency of using heat pumps in order to utilize the waste heat of urban facilities are for the most part isolated from each other. In other words, they do not take into account the direct relationship between them. Such isolation does not allow to fully assess the efficiency of heat utilization of urban facilities, since [19] this assessment should take into

account the heating scheme as a whole, including all three levels: the source (a CHPP), transportation (heat networks) and consumers (non-energy facilities). Hence, the final calculation, which makes it possible to fully assess the efficiency of using the waste heat of urban facilities with the help of the HP unit for heating purposes, is a return calculation [20,21]. As noted above, the calculations carried out do not take into account changes in the initial parameters of the calculation of the heating network and the CHPP. Therefore, the return calculation will apply only to these categories of objects (Figure 1)

In fact, the return calculation of the combined heat and power plant is the final stage, leading to the final result on how efficient the HP application will create in the district heating system. This is explained by the fact that in these calculations, the primary source of thermal energy in any case is the heat and power plant. That is, the heat pump cannot completely replace the CHPP, it only increases the efficiency of its operation and the operation of the heat supply system as a whole. At the same time, all the savings with an increase in the efficiency of heat supply ultimately boil down to a decrease in the amount of fuel burned at CHPPs.

So, the CHPP return calculation led to the following results: annual fuel combustion when using the HP decreases from 7164.5 TJ to 5922.9 TJ, which is equivalent to 42.4 thousand tons of conventional fuel or 17.3%.

Conducted theoretical studies allowed us to obtain a calculation method that allows us to estimate the efficiency of using low-potential waste energy in the heating system with varying initial parameters of the heat and power plant, network and consumers [22]. In other words, this method is suitable for evaluating the effectiveness of introduced heat pumps into any centralized heat supply system, including the heat supply system in Chelyabinsk.

As in the case of CHPP, the initial data of the calculations are the installed electrical and thermal capacities of Chelyabinsk combined heat and power plants. Each Chelyabinsk CHPP supplies thermal energy to a certain number of consumers in one category or another [23, 24]. The amount of energy that is to meet the heating needs of residential, public and industrial categories of consumers was estimated due to the population, the availability of public facilities and industrial enterprises in the territory located in the coverage area of a certain CHPP. Such an approach made it possible to estimate the annual dynamics of changes in thermal power required to meet the heat needs of consumers who receive energy from each of CHPPs.

Further, taking into account the peculiarities of the main heating networks of Chelyabinsk, the amount of heat losses during transportation of energy from Chelyabinsk CHPPs to their consumers, as well as the effect of utilization of these losses by means of HPs, was estimated using the same method.

Finally, the previously taken into account peculiarities of consumers of Chelyabinsk CHPPs made it possible to estimate how much energy can be extracted

when disposing of the waste body, the source of which is non-energy facilities of Chelyabinsk [25].

The final stage of this assessment was the return calculation, which showed how efficient the utilization of low-grade waste heat in Chelyabinsk was. Figure 9 presents a graph illustrating the results obtained.

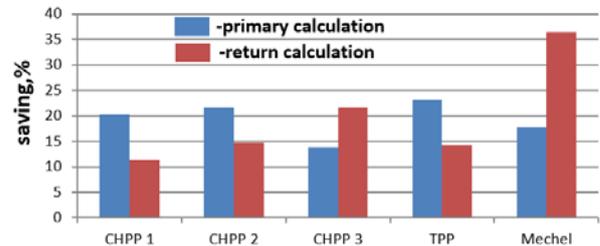


Fig. 9. Return calculation results

Thus, the calculated assessment showed that the utilization of waste heat in the conditions of Chelyabinsk will reduce the annual energy of fuel consumption by 2.2 million tons of conventional fuel (24.9%). At the same time, thermal pollution will decrease by 1.5 million tons of equivalent fuel. This effect is possible with the use of heat pumps with a total heat output of 1,145 MW.

To assess the efficiency of heat pumps can be used indicator «levelized cost of energy». The levelized cost of energy shows how much money is spent on average for the entire lifetime of the project to produce a unit of energy [26].

4 Conclusions

The results obtained in this assessment indicate the feasibility of applying the utilization of low-potential waste energy due to using heat pumps to increase the efficiency of district heating in Chelyabinsk. The use of heat pumps helps to increase the efficiency of heat supply both at the level of production (CHPPs) and thermal energy transportation, and at the level of consumers, which in this case are a non-energy category of urban sources and low-potential waste energy.

The use of heat pumps at Chelyabinsk CHPPs makes it possible to reduce the power of peak boiler houses, which, as a result, leads to a decrease in the power of used fuel. The use of heat pumps in heat networks reduces the temperature of the return water. This leads not only to a reduction in losses, but also to a decrease in the heat load on combined heat and power plants. Finally, the utilization of heat from waste water and exhaust air from non-energy facilities in Chelyabinsk makes it possible to generate a substantial part of the energy required to meet the heat needs of the same facilities.

With all this, it should be noted that the utilization of waste energy in Chelyabinsk will create a more significant effect in the case of an integrated approach aimed at improving the heating system in the city. So the increase in electrical efficiency at combined heat and power plants will allow the use of heat pumps of higher power. Improving the system of regulation on heat

networks will also make it possible to get great benefits when using heat pumps.

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