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Cost of Heating Pump Systems in Russia

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ABSTRACT

Based on the average standardized energy cost over the entire lifetime of the project, the possibility of choosing a heat pump installation using low-potential heat as a source of heat for an individual consumer is shown. As an example, to assess the economic performance of a heat pump installation in the Chelyabinsk region 6 variants of heat supply systems are considered, taking into account the climatic characteristics of the region for four types of individual houses. The results of the study showed that the most expensive in the Chelyabinsk Region is 100% heat supply because of a heat pump installation. In terms of the average standardized energy cost, the most attractive is the project with 50% heat supply from the heat pump installation. Comparative analysis of the results of the study with the data of the international assessment of the heating systems and costs of EU energy shows the similarity of the nature of the changes in the given indicators.

Keywords: Renewable Energy, Aquatic Resources, Lower-grade Heat, Heat Supply System, Heat Pump Arrangement, Energy Saving
JEL Classifications: C30, D12, Q41, Q48

1. INTRODUCTION

The development of society is closely linked to the state of the energy sector. In these conditions, it is necessary to develop the energy sector itself, and at a faster pace. For the development of the energy sector it is necessary to introduce new innovative technologies aimed at energy saving, according to the Federal Law № 261 "On energy saving and energy efficiency" (An et al., 2019a). Reducing the consumption of fuel energy resources through innovative technologies is an urgent task.

In the energy supply system to increase its energy efficiency it is necessary to reduce energy losses during its transmission. Creation of economically effective and ecologically safe energy supply system is possible based on renewable energy sources (RES) (An et al., 2019b; An et al., 2019c).

The development of the RES market in Russia has been identified as a strategic goal of the state policy. A number of laws and regulations have been developed and adopted to promote RES in Russia (Ahmed et al., 2014; Amini et al., 2011; Bansal at al., 2013). Thus, the goal is to increase the share of RES in electricity generation to 2.5% by 2020, which will require the introduction of 5.87 GW of RES-based capacity. However, the use of RES faces with:

- High capital costs and low level of development of domestic technologies;
- The difficulty in predicting the generation of electricity from RES and the relatively low capacity utilization factor.

In these circumstances, studies are needed to assess the economic performance of renewable energy to design incentives for renewable energy development. This task is especially relevant for heat supply systems, where the share of RES is growing much slower than in the electricity sector (Bove and Lunghi, 2006).

The development of the heat power industry in Russia plays an important role. The long cold season, especially in the Urals, Siberia and the Far East, makes the heat supply system socially significant and quite costly. About 40% of the energy resources in the energy balance of the country are spent on heating, and more than half of these resources are used for domestic needs. Russia traditionally has two types of heat supply: centralized (43%) and decentralized (67%), of which about 18% are autonomous and individual sources. Organic fuel is traditionally used as an energy source (Cai et al., 2011; Tryndina et al., 2020; Lisin, 2020).

In the conditions of growing costs of traditional energy carriers, it is necessary to search for ways to reduce their use. One of the ways is to use RES (An et al., 2019b; An et al., 2019c; Chiemchaisri et al., 2012). At the same time, the use of not only solar and wind energy in the energy supply system is relevant (Denisova et al., 2019; Denisova, 2019; Gardner et al., 1993), but also the heat of the earth (Jaramillo et al., 2005; Mikhaylov, 2019; Nyangarika et al., 2019a).

In the absence of sufficient experience in the design and installation of heat generating plants, there is a simple transfer of foreign schemes, which is not always justified, and there is no single approach to the economic assessment of energy objects, due to the wide range of different performance indicators, it is difficult to determine the cost-effectiveness of heat supply systems using RES.

The purpose of the study is a technical and economic feasibility study of the possibility of using RES on the example of the heat supply system in the Chelyabinsk region.

2. LITERATURE REVIEW

At designing of systems of a heat supply it is necessary to consider temperature of the coldest 5-day security period of 92% and temperature which should be maintained indoors (Lopatin, 2019a; Lopatin, 2019b). For example, the Chelyabinsk Region is characterized by an air temperature of −34°C in the coldest 5-day period, with a security of 92%, an absolute minimum temperature of −48°C at an average annual temperature in the region - plus 2°C, and an average monthly temperature in January −15,8°C.

Based on these parameters and taking into account the materials from which the building will be built, the thermal balance of the building is calculated, the result of which will be the necessary (peak) power of the heat generating unit. In order to select a RES-based power plant, it is necessary to assess the potential of the RES.

Among the renewable sources, the most promising is the low potential heat of water resources, such as aboveground and underground waters, lakes and rivers. In the conditions of the Chelyabinsk region necessary researches on an estimation of a total potential of low-potential heat for region have been spent (Meynkhard, 2019a; Meynkhard, 2019b).

It has been established that the Chelyabinsk Region has no deep thermal water reserves and belongs to the zone of abnormally low heat flow (<30 mW/m^2), but it is possible to use near-surface low-temperature geothermal energy of shallow depths on its territory (Denisova, 2020; An et al., 2019d).

In the course of the study of the gross potential of groundwater thermal energy, the upper horizon of active water exchange of various security was considered. Hydrological calculations, based on observation materials at 35 locations on 21 rivers, taking into account the relief and geological structure, allowed to determine the value of underground runoff of 50% of security and to estimate its heat flow. The value of heat flow in the region ranges from 0.045 W/m^2 in the west to 0.015 W/m^2 in the east. The average long-term gross potential of ground water heat in the Chelyabinsk region is 12.2 billion kWh (Meynkhard, 2020; Nyangarika et al., 2019b).

The results of theoretical studies formed the basis for the project on the use of low-potential heat in the heat supply system in the Chelyabinsk region.

A steam-compression heat pump unit (STP) has been designed and installed in the "water-water" system, which uses the low-potential heat of groundwater. STP is installed for heating a production facility with a total area of 96 m2 (Lopatin, 2019b).

Characteristics of the heat pump installation:
- Installed capacity of STP is 8 kW;
- Consumption power of the compressor is 2 kW;
- Number of wells - one;
- Total length of the heat exchanger in the well - 240 m.

The unit includes devices for monitoring the operation of STP. The controller gives to switch on STP, when the temperature in the room is below 17°C.

The installation is valid for three heating seasons. There were no interruptions in its operation. During operation, the Coefficient of Performance (COP) conversion factor was determined, which averaged 3.8-4.7.

During the heating season 2017-2018, during 7 months, from September to April, the plant produced 13.6 Gcal or 15,805 kWh of heat energy. The compressor consumed 3,360 kWh of electricity. As can be seen, the STP conversion factor (STP) is 4.7.

Thus, it can be concluded that STP, which uses low-ground water heat potential, provides heat energy. However, the economic efficiency of the heat supply system and how competitive heat pumps are.

3. METHODS

For the economic evaluation of the heat supply system using low potential heat, known methods have been studied. Thus, two main approaches to the definition of economic efficiency in the energy sector have been developed in Russia so far:

The foundations of this approach were developed back in the last centuries and are still used by some economists today. The advantage of this approach is that the capital and current costs of the project are taken into account at the same time, which allows to make a choice on almost the same indicator. However, a number of disadvantages level out the positive aspects. Firstly, the regulatory efficiency factor is ambiguous, for example, the latest technologies have not yet developed their service life, as stated by the manufacturer, and this factor can only be calculated based on the manufacturer's calculations. In addition, the life cycle cost of the project, i.e. the time factor, is not taken into account in calculating these costs. Under market conditions, this may lead to an incorrect decision.

In the case of an investment approach, it is recommended to select technologies and projects on the basis of investment project efficiency indicators. To evaluate these indicators, cash flows are modeled taking into account changes in their value over time over the life cycle of the project or its implementation period.

The investment approach takes into account the disadvantages of the "comparative" approach by excluding from the calculation of the normative efficiency coefficient and taking into account the time factor by discounting. Therefore, this approach is widely applied (Nyangarika et al., 2018).

The investment approach is universal, which is its undoubted advantage. But in the energy sector, when it is necessary to choose between absolutely technologically different projects using different energy sources, more specific indicators characterizing this technology are needed for analysis (Dayong et al., 2020).

In the world practice, the indicator of standardized (average) cost of energy levelized cost of energy (LCOE), which was born more than 20 years ago, is widely used by investors to select projects as the main tool. There are various modifications of the LCoE formula. Thus, the definition of the standardized cost of electricity (Mikhaylov et al., 2018; Mikhaylov, 2018a; An et al., 2020) and the standardized cost of heat energy (LCOE) are widespread in the world (Mikhaylov, 2018b; Milbrabdt et al., 2014; An et al., 2019).

The following variant is offered for estimation of the rated cost of heat energy in (Milbrabdt et al., 2014):

$$LCOE_j = \frac{\sum_{t=1}^{n} \frac{TOC(t)_j + Capex(t)_j}{(1+WACC)^t}}{\sum_{t=1}^{n} \frac{SOR(t)_j}{(1+WACC)^t}} \quad (1)$$

where $TOC(t)$ - operating costs of the project in year t; $Capex(t)$ - investment costs of the project in year t; $SOR(t)$ - amount of heat produced in year t; $WACC$ - weighted average cost of capital; j - type of technology; n - life cycle of technology.

The normalized energy cost shows how much is spent on average over the entire lifetime of the project on the production of electricity or heat. This indicator combines the advantages of the two approaches described above and provides an opportunity to choose the source of energy for the individual consumer's power supply system. At definition of the rated cost of energy, it is necessary to establish accurately borders of system of power supply and structure of necessary expenses (Mikhaylov et al., 2019).

4. RESULTS

As an example, to assess the economic performance of STP in the Chelyabinsk region 6 variants of heat supply systems are considered, taking into account the climatic characteristics of the region for 4 types of individual houses with an area of 100, 150, 200, 250 m^2.

The limitations and characteristics for calculation of the rated cost of heat energy are accepted:

1. The installed capacity of heating systems was calculated for the temperature of the coldest 5-day period with the security of 92%, −34°C.
2. Six variants of heating systems: Gas heating; electric heating; STP with electric drive, which uses low-potential heat of ground water of "water-water" type and provides 100%, 75%, 50% and 25% heat demand. It is assumed that the missing capacity from the STP will be compensated by an electric peak heater
3. The service life of gas equipment is 7 years, electric equipment - 5 years, STP - 25 years
4. The investment costs include the costs of project preparation, purchase of boilers, compressors and other necessary elements of heat generating plants, installation of the system.
   Of heating. It is assumed that the necessary equipment will be purchased with own funds, especially since there are no state subsidies for residential houses in Russia
5. In this connection, individual houses were considered and energy resources (gas, electricity) and renovation and repair

Figure 1: Investment costs for heating system, Euro/kW

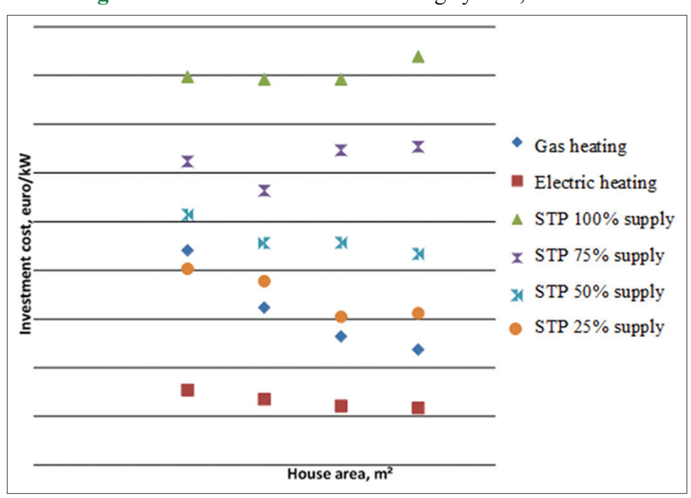


Table 1: Economic indicators of different heating systems

Heating system	Operational costs, euro/kWh	Investment costs, euro/kWh	LCOE, euro/kWh
Gas heating (Southern Ural)	264-630	0,0069-0,0114	0,037-0,082
Gas heating (European Union-28)	80-360	0,001-0,004	0,025-0,095
STP (Southern Ural)	305-885	0,0086-0,0139	0,055-0,088
STP (European Union -28)	737-1 560	0,017-0,035	0,070-0,175

LCOE: Levelized cost of energy

Figure 2: Operating costs per 1 kWh of heat, Euro/kW

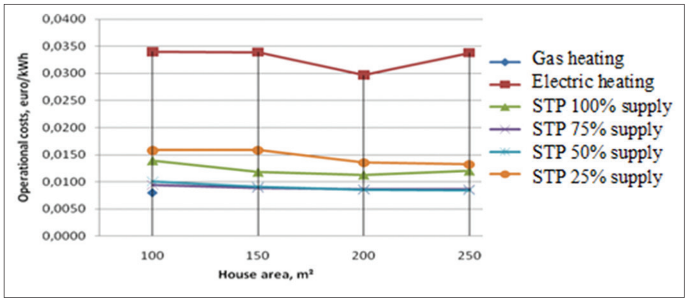


Figure 3: Levelized cost of energy (LCOE) (heat) for heat pump (LCOE), Euro/kW

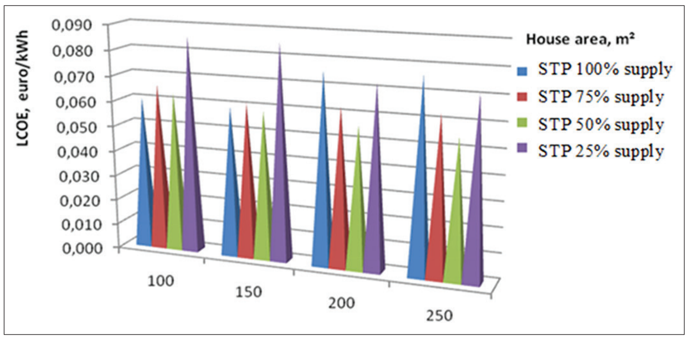
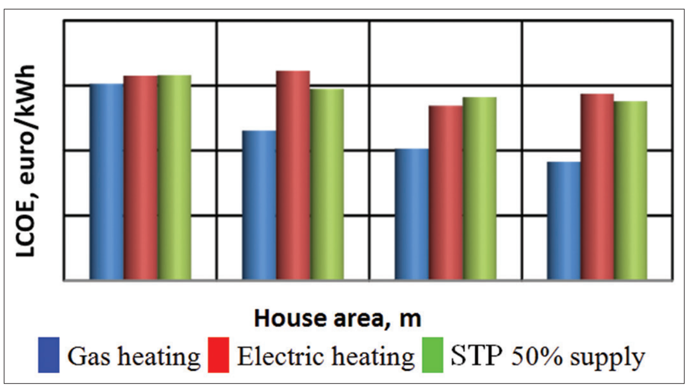


Figure 4: Levelized cost of energy (heat)



costs amounting to 1% of the total cost of the heating system were included in the operating costs. Depreciation and compensation of labor were not included (Morgan and Yang, 2001). The tariff for electricity is 2.12 rubles/kWh, the tariff for gas is 4,277 rubles/1,000 cubic meters. Tariffs are expected to increase by 10% per annum (Table 1).

6. The discount rate during the life cycle of projects did not change and amounted to 10%, as for high-risk investments in a constantly changing market environment without inflationary expectations, similar to the calculations of Projected Costs of Generating Electricity, 2015
7. The euro was adopted as at 14.10.2018. 1 euro - 76.4 rubles. For the various options under consideration, according to the above conditions, studies of the economic indicators of the heat supply system have been conducted. The results of the study of investment costs of the heat supply system in the Chelyabinsk Region are shown in Figures 1-3.

If we compare the average cost of heat production by heat pump systems (LCOE) is inferior in economic terms to the traditional heating systems and the systems that use the system with its high operating costs using STP with 50% security, the latter is not (Figure 4).

5. CONCLUSION AND DISCUSSION

RES can be used to supply consumers with energy. At the same time, they can work together with the traditional energy supply system, providing part of the energy consumed to reduce the cost of energy consumed. In the energy supply system, there are technical and economic opportunities to use RES.

The results of the study of heat supply systems based on RES show their efficiency. Under certain economic conditions and limitations (e.g., the electricity tariff is 2.12 rubles/kWh, which is valid for rural residents), RHWs with different degrees of heat demand satisfaction can be competitive in the heat supply system even without state support.

The use of low-potential ground water heat is relevant for heat supply. Thus, in the Southern Urals, with a gross potential of 12.2 billion kWh of ground water heat energy, projects based on heat pump installations are being successfully implemented, ensuring the efficiency of heat supply corresponding to the global level.

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