Ground source heat pump systems efficiency in Russia – economical estimations and territory zoning

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Abstract
The subject of research is an efficiency assessment of low-potential ground source heat in heat pump systems under climatic conditions in Russia with regard to energy rates.

As a result of the study, zoning of the Russian Federation territory has been presented, with zones classified according to: a) electric and heat energy rates, heat energy rates for domestic hot water supplies, as well as according to electric and heat energy rates ratio; b) ground source heat pump systems efficiency, considering actual climatic conditions of regions and ground temperatures changes over multiannual operation.

Furthermore, comprehensive assessment of ground source heat pump systems efficiency has been made, based upon prices of heat energy generated by such systems with account of an actual coefficient of performance, and heat energy from a conventional heat supply source. Corresponding maps have been attached.

1. Introduction
The housing and public utility sector is one of the primary industries of the Russian economy, upon which welfare and development of the country and its citizens are based. According to experts’ evaluations, the turnover of the Russian housing and public utility sector is equal to 4.2 trillion rubles a year (67.7 billion USD) to make 5.7% of Russia’s GDP. The sector employs more than 2 000 000 people. An important feature of the sector in Russia is its large scale. For instance, the total length of heat and water supply networks is about 900 000 km, with residential areas to come to 3.5 billion sq. m. [4]. Currently, there exists an acute and pressing problem – quick growth of utility rates.

With increase of rates another problem is related, which is a high level of non-payments in the sector: debts to suppliers as of the end of 2017 are over 1 trillion rubles (16.1 billion USD). Public services and utilities require extensive improvements together with significant investment, and aimed at lower costs. As branch experts believe, planned growth of utility rates must, though partially, provide for amounts of financing needed [6]. However, in spite of brisk rise in prices, the measures are not effective, because, up to now, the utility rates have not been brought in line with cost of production of these services.

Rise of the utility rates depends upon a number of factors. The most significant one is the price of energy resources. Calculations of expenses for CHPP (main suppliers of heat and electric energy in the majority of large cities in Russia) show that by 2020 the highest share of expenses will be related to fuel (70%) [5].
Moreover, there are some other reasons pacing the rise of the utility rates to include as follows:

- critical rate of wear of public utilities, with a national average to make 65%; but in some regions this rate has already reached a warning level of 95%;
- steady increase of accident rates and, correspondingly, expenses for accident handling and emergency treatment operations;
- huge losses of resources (to reach 40% of water and 50% of heat) on their way to consumers.
Dynamics of energy rates and costs of their production, as well as estimated values, are presented in Figures 2-3 to cover a period through 2025 [7].

The result is that the costs for energy production are higher than existing and estimated electric and heat energy rates to make the most energy suppliers and public utility companies “planned loss-making” ones [8-10]. A solution to the problem is in conduction of energy saving policy. Basic energy saving measures in housing may be divided into 2 groups: those aimed at improvements of heat insulation of building envelopes and those oriented to higher efficiency of utility systems and equipment used. A greater part of proposed energy saving measures to cover residential areas refers to the first group. However, renovation of utility systems in residential buildings may turn out to be a more efficient tool to reach the energy saving effect than further heat insulation.

One of solutions to the problem may be introduction of heat pump systems which seem the most prospective ones in the field of energy saving.

Introduction of heat pump systems will enable to:

- save energy resources;
- reduce volumes of fossil fuel to be combusted;
- improve environmental sustainability in cities and towns;
- provide for independent operation of residential buildings heat supplies;
- reduce expenses for heating networks;
- reduce construction time;
- free up municipal areas occupied by utility facilities.

To evaluate economic feasibility and energy efficiency of use of heat pump systems in Russia, its territories have been zoned as further presented in this paper.

2. Objective

Applicability of the heat pump systems in the housing and public utility sector is to a great extent determined by current economic conditions in a region under review. The objective of the present study is to analyze current heat energy rates to be applied to space heating and domestic hot water
supplies, as well as electric energy rates in each region and find out regions with a ratio of rates to be the most advantageous one for the use of heat pumps.

Russia is the largest country in the world by area. It stands to reason that climatic conditions of various regions may be very much different which would have an effect on operation efficiency of both air and ground source heat pump systems. Taking this into account is one of the problems to be solved in this paper.

3. Energy rates
Let us consider electric and heat energy rates in all the regions of Russia and derive a ratio between these two values. Our calculations will be based upon official rates for population to come into force since 01.01.2017 [11-12].

Fig. 4 shows a map of electric energy rates. Here, the rates are shown, applying to population living in homes with electric stoves.

![Electric energy rates map, rubles/kWh.](image)

Figure 4.- Electric energy rates map, rubles/kWh.

Space heating heat energy and domestic hot water supplies heat energy (separately) maps are in Figures 5 and 6, correspondingly.

Figure 7 presents changes to a ratio between electric energy rates for population living in homes with electric stoves and heat energy rates. As heat pump systems consume electric energy to generate heat energy, this ratio will be very indicative: the lower it is the more efficient is the use of heat pumps for space heating in apartment buildings. At that, to secure economic feasibility of heat pump-based systems, one has to attain a COP higher than the ratio between the rates shown.

As a result of the analysis, we have obtained that the lowest ratio between electric and heat energy rates is observed in the regions as follows: Kerch (0.44), Yalta (0.56), Primorsky Krai (0.6), Murmansk (0.62), Magadan region (0.88). The highest ratio between electric and heat energy rates is in Naryan-Mar (2.9) and Kurgan region (2.73).
**Figure 5.** – Map of heat energy rates for population

**Figure 6.** – Map of hot water supplies heat energy rates
4. **Energy efficiency of ground source heat pump systems**

As it has been noted earlier, the COP is one of the key factors to determine economic feasibility of use of GSHPs. Let us consider energy efficiency of their operation in each region. As an evaluation criterion, COP will be used to zone the territory of Russia by efficiency of use of ground source heat pump systems for space heating.

Zoning is carried out on the basis of results of numerical study consisting in modelling of ground source heat pump systems under climatic conditions of various regions of Russia. Numerical study have been carried out by the example of a double-stories family cottage with 200 sq. m to be heated, equipped with a ground source heat pump system. The thermal modelling has been conducted using developed INSOLAR.GSHP.12 software, submitted in articles [13, 14 and 15].

Subjects of the numerical experiment have been as follows:
- a horizontal ground heat exchanger made of PE pipes with diameter of 0.05 m and length of 400 m;
- a vertical ground heat exchanger - single coaxial BHE with outer diameter of 0.16 m and length of 40 m.

Natural state ground temperatures have been taken from data available [3].

It is important to emphasize that consumption of heat energy from soil by the end of a heating season causes decrease of ground temperatures close to ground heat exchanger pipes that, under geological and climate conditions in the greater part of Russia, cannot be compensated in summer time. So, at the beginning of the next heating season soils have a lower temperature. This effect is of a long lasting nature, however, by the fifth year of operation ground temperature changes become very similar to periodic one, and further significant temperature decrease does not occur anymore [1, 2]. To take this into consideration for zoning procedures, in further calculations as ground temperature was used the temperature value, estimated by the fifth year of operation of ground source heat pump system. Therefore, as the final assessment criterion of efficiency of ground source heat pump systems we have taken an average value of COP within the fifth year of operation.

Russia’s territory zoning results by efficiency of ground source heat use are presented in Figures 8 and 9.
**Figure 8.** Efficiency of ground heat energy use by means of ground source heat pump systems with horizontal ground-coupled heat exchangers (contour lines in the map mean values of COP, unit fractions).

**Figure 9.** Efficiency of ground heat energy use by means of ground source heat pump systems with vertical ground-coupled heat exchangers (contour lines in the map mean values of COP, unit fractions).
As seen from Figures 8 and 9, maximum COP values to make 4.24 (horizontal systems) and 4.14 (vertical ones) can be expected in the South of Russia, and minimum ones, 2.87 and 2.73, correspondingly, in its northern areas. In the central part of Russia, COP values for horizontal systems range from 3.4 to 3.6 and those for vertical ones range from 3.2 to 3.4. It is worth noting, that rather high COPs can be found in the Far East (3.2 – 3.5), where fuel supply conditions are traditionally complicated. Considering this, the Far East can be regarded as a region, where ground source heat pump systems should be introduced on a priority basis.

5. Economic effect of GSHPs

As defined before, GSHPs applicability depends upon a ratio between heat and electric energy rates in a region under review, as well as upon COP, taking into account climatic conditions of this region. Now, let us make a comprehensive assessment of economic effect of GSHPs use, for which we are going to examine a ratio between costs of heat energy generated by a GSHPs and heat energy from a conventional heat supply source.

As a GSHPs generated heat energy rate we take an electric energy rate that population, living in homes with electric stoves, has to pay, divided by a COP for the fifth year of operation of a ground source heat pump system with vertical ground-coupled heat exchangers, as defined in the previous chapter. Figure 10 shows a map to present economic effect of use of GSHPs.

**Figure 10.** Ratio between heat energy costs from a GSHPs and a “conventional” heat source, unit fractions.

As seen from the data presented, use of GSHPs for heat supplies turns out to be economically feasible and viable in the greater part of Russia, with the exception of some areas in Eastern Siberia and Kurgan region.
Conclusions
On average, a Russian family spends 16.6% of its monthly income for public utility services, while families in Europe, America and Canada, on average, spend only 13.5%, 12.9% and 11.8%, correspondingly. And this is despite the fact that quality of public utility services there often is considerably higher as compared to that in Russia [11]. Up to date, 60% of Russians (data provided by the “ROMIR” holding social scientists) are not satisfied with policy in the housing and public utility sector: the rates are rising, with no improvements of services quality - on contrary, number of accidents also increases. To make the problem less acute and pressing, one can take a range of measures aimed at energy saving, in particular, use heat pumps. This paper is dedicated to zoning of the territory of Russia by GSHPs use efficiency. The maps presented can be used for preliminary assessments of applicability of ground source heat pump systems in various regions of Russia with due consideration of their climate pattern and energy rates. As a result of works performed, it has been found that the lowest ratio between electric and heat energy rates are in Kerch (0.44), Yalta (0.56), Primorsky Krai (0.6), Murmansk (0.62), Magadan region (0.88). In these areas the use of heat pump systems will be the most effective in economic terms. The highest ratio between electric and heat energy rates is observed in Naryan-Mar (2.9) and Kurgan region (2.73). Here, expenses for electric energy consumed by GSHPs may turn out to be even higher than income from the heat generated.

In the context of a relative value of heat energy generated by GSHPs, the most promising regions are the Far East, Murmansk region and Crimea. The most interesting and promising in this respect is the Far East as a region, where fuel supplies are traditionally complicated and energy rates are very high, including those that apply for population.

In addition to the data presented in this paper, it would be useful to note that in Russia, with its current level of energy rates, heat pump systems turn out to be not competitive as compared to gas-based heat supply systems in most cases, where a facility is already supplied with gas: ratios between electric energy and gas rates range from 3.97 (Republic of Bashkortostan) to 11.45 (Moscow). The costs for heat generated by heat pumps with due consideration of an actual COP will turn out to be higher than those for gas generated heat. However, if gas networks must be routed, heat pumps can sometimes require smaller capital investments. But even in that case gas combustion heat supplies, in pure form, will be cheaper, from a standpoint of operating costs. The only exception is a case, where a facility requires both heat and cold supplies. Then, the use of heat pumps can be advantageous both at the stages of capital investments and operation.

References
[1] Vasilyev G P, Peskov N V, Gornov V F, Kolesova M V 2016 The effectiveness of low-grade geothermal heat usage under conditions of the Russian climate Geothermics Vol 62 pp 93-102
[2] Vasilyev G P 2007 Geothermal heat pump heating systems and its operating efficiency in climate conditions of Russia AVOK. No 5 pp 58-68
[3] Climatic Atlas of the USSR. H 1.2. -M., 1960-1962
[4] Vasilyev G P, Gornov V F, Peskov N V, Kolesova M V, Burmistrov A A, Timofeev N A, Leskova V A, Yurchenko I A 2014 Accounting for “Zero Curtain” Effect in GSHP Simulation. Applied Mechanics and Materials Vol 664 pp 243-249
[5] Vasilyev G P 2006 Heating and cooling supplies buildings and structures using low-grade thermal energy of the surface layers of the Earth (Monograph). Publishing house “Granite”. M., “Red star”, 220 P
[6] Man Y., Yang H., Wang J. and Fang Z. 2012 In situ operation performance test of ground coupled heat pump system for cooling and heating provision in temperate zone. Applied Energy Vol 97 pp 913-920
[7] Vasilyev G P, Peskov N V, Gornov V F, Kolesova M V, Yurchenko I A 2015 Zoning of the Territory of Russia According to the Efficiency of the Use of Low-Grade Ground Heat for Heating. MATEC Web of conferences Vol 30

[8] http://www.expert.energosovet.ru/stati.html “About some conditions of return of investments into new energy sources”. Gasho E.G., PhD in Technical Sciences; Repetskaya E.V., Ph.D. in Economics.

[9] https://informatio.ru/news/society/tarify/tarify_na_zhkhh_v_2017_godu/

[10] http://www.expert.energosovet.ru/pages/files/69o_nekotoryiy_usloviyay_okupaemosti_invest_siy_v_novyie_energoistochniki.doc

[11] http://expert.ru/2016/11/15/rost-tarifov-v-grazhdanskom-zhkh---nezbezhen-v-voennom---zhiznennno-neobhodim/

[12] https://energo-24.ru/tariffs/electro/2017/12327.html

[13] Vasilyev G P 2006 Heating and Cooling of Buildings and Structures Using Low-Grade Thermal Energy of the Surface Layers of the Earth Monograph (Publishing house “Granitca”. M., “Red star”) p 220

[14] Vasilyev G P, Peskov N V, Lichman V A, Gornov V F, Kolesova M V 2015a Simulating the thermal operating conditions in the thermal wells of groundsource heat pump heat supply systems. Part I accounting the porous moisturefreezing processes in soil. Thermal Engineering Vol 62 No8 pp 547–552

[15] Vasilyev G P, Peskov N V, Lichman V A, Gornov V F, Kolesova M V 2015b Simulating the thermal operating conditions in the thermal wells of groundsource heat pump heat supply systems. Part II: consideration of porous moisture phase transitions in soil. Thermal Engineering Vol 62 No10 pp 1021–1026