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Geothermal Heat Pump Systems Efficiency in Russia

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ABSTRACT

In the article the survey of the current development of geothermal heat pump systems in Russia is represented. The basic negative and determent factors of their application are indicated.

The construction of an effective borehole heat exchanger is described and its fundamental characteristics are given.

The phase transitions of pore moisture in the soil are considered and the determination of design characteristics of ground heat exchangers is examined.

The description of the developed program product for heat pump systems design is given.

The results of the Russian Federation territory zoning by running efficiency of geothermal heat pump systems are given.

1. INTRODUCTION

At present in Russia, geothermal heat pump systems have only just begun to penetrate the market and to attract the attention of the customers -- until now they have been seen as a kind of an exotic object, not a reasonable alternative to traditional heat sources. In the majority of the cases the user simply does not understand what it is, hence the fault is in a deficiency of information. However, this concerns not only geothermal systems, but heat pump systems as a whole.

Recently this situation began to change; people became more interested in questions of energy-economy, including the geothermal heat pumps as energy-saving equipment.

The main determent factor, which impedes the widespread introduction of heat pump systems, is the presence of significant reserves of organic fuel in our country, and also their relatively low cost. In this case one should establish that from the point of view of energy-effectiveness and ecology, the natural resources are not universally good, but on the contrary, they play here a negative role.

Nevertheless, today in the Russian market a sufficiently large number of companies is represented - the producers of heat pump equipment, mostly European, but there are also North American and Chinese. Russian enterprises also began to produce heat pumps both on the foreign license and of their own construction.

The majority of foreign companies come to the Russian market with finished technological solutions and standard equipment, designed for the operating conditions often differing strongly from the real geoclimatic conditions of Russia. Maybe the distributors are forced, or maybe they do it on the private venture, when they use the standard solutions from the foreign catalogs, even without making an attempt to rethink them on the basis of the actual operating conditions. But there are very serious differences.

In Russia, the heating period is considerably longer than in Europe, for example. For the geothermal systems this means that more heat is extracted from the ground. Compared to Europe, in Russia winter temperatures are remarkably lower. This means that the heat of the soil is consumed more intensively. All this leads to the fact that temperatures of the soil toward the end of the heating season are lower, and the period of time for the restoration of thermal condition in the ground are shorter. This aspect is rarely considered during the design process and impacts extremely negatively the following process of operation.

In the most cases, toward the end of the heating season the ground heat exchangers appear to work with the temperatures below zero. It sounds like there is no problem, but here should be considered one of the Russian special features. The fact is that all, or almost all, ground heat exchangers are made from the polyethylene pipes, but in Russia there are no standards that regulate the properties of polymeric pipes at negative temperatures. Accordingly, the corresponding tests are not conducted, and this means that no one is responsible for the fitness of pipes for work under the conditions of minus temperatures and no one guarantees it, but indeed the reliability of the operation of the ground heat exchangers determines the reliability of entire heating system.

Russia is a northern country, and very serious requirements on reliability and safety are imposed, when the heating systems are on the agenda. Sometimes one attempts to relate to a heat pump system just as to a cooling system, which is absolutely unacceptable. Failure of a cooling system does not entail any serious consequences - it will just become hot in the room - while failure of a heating system can lead the house to freeze, which will cause considerable expense. Moreover, this can create a situation when the question will not only be the health, but even the survival of people.

Another determent factor is the absence of qualified personnel, properly trained to operate and maintain the geothermal heat pump systems.

However, in spite of all these and a lot of other difficulties, we are looking to the future with great optimism and attempting to solve the problems confronting us. Below some of our achievements are represented.

2. EFFECTIVE BOREHOLE HEAT EXCHANGER

We have developed and applied practically a coaxial type of vertical ground heat exchanger. It consists of an external metal tube and internal pipe made of polyethylene. Along the internal pipe the heat-transfer agent (ethylene glycol) goes down to the bottom of the heat exchanger, after that it gets into the intertube space, and, rising through it, extracts heat from the surrounding ground. In spite of the fact that in the given construction a polyethylene part also is present, its leak-tightness does not play an important role in the functioning of the heat exchanger. This pipe fulfills only a transport function and, to a certain degree, the function of the heat insulation (it blocks heat transfer from the heated liquid in the intertube channel to the cold liquid inside the pipe).

Despite its simplicity, this heat exchanger has a number of advantages over its traditional analogs.

First, this heat exchanger evidently has a heat transfer surface exceeding the surface of usual U-shaped heat exchangers, since the external diameter of the steel tube used is 133 to 168 mm in comparison with 25 to 50 mm for U-shaped ones.

In the second place, metal possesses larger thermal conductivity than polyethylene, which also gives gain in the effectiveness.

The results of calculations showed, and so did the operating experience, that the effectiveness of this heat exchanger is from 150 to 200 Watt from each meter of its length, and in the case of greatly watered soils it can reach up to 250 W/m, which exceeds by several times the analogous indices for plastic heat exchangers.

This, in turn, makes it possible to reduce the number and depth of ground heat exchangers considerably, which is essential to decrease expenditure for drilling operations, thus making the geothermal heat pump systems more affordable to customers.

3. THE PHASE TRANSITIONS OF PORE MOISTURE IN THE SOIL AND ASSOCIATED EFFECTS, VASSILIEV, (2003)

During the operation of geothermal heat pump system, the ground massif, which is located within the limits of the zone of the thermal influence of ground heat exchangers, as a result of seasonal changes in the parameters of external climate, and also under the action of operating loads on the system, as a rule, undergoes repeated cycles of freezing and thawing. In this case, evidently, phase transitions of moisture take place in the pores of soil and in the general case, all the phases -- liquid, solid and vapor -- occur simultaneously.

The ground massif is a complex three-phase system, whose skeleton is formed by a great quantity of solid particles of various shape and size and can be both rigid and mobile, depending on how tightly the particles are connected, or how they are isolated from each other by substance in the mobile phase. The spaces between the solid particles can be filled with the mineralized moisture, gas, vapor and ice, or with a combination of them simultaneously. In other words, the medium, which fills the pore space of solid skeleton, can be found in different states.

In the capillary-porous systems, such as the ground massif, the presence of moisture in the pore space has a noticeable effect on the process of heat transfer. The correct calculation of this influence is associated nowadays with the serious difficulties, which are, first of all, connected with the absence of clear ideas about the nature of the distribution of the solid, liquid and vapor phases of moisture in different ground structures. Until now the nature of forces, binding the moisture with the particles of skeleton is not precisely explained, and so is the mechanism of moisture transport in the pore space. However, use of "effective" characteristics of heat and mass transfer during the construction of mathematical models makes it possible to consider the influence of the humidity of the ground massif on the thermal processes taking place within it, with a sufficient degree of accuracy for practical purposes.

The phase transitions of pore moisture during the operation of the ground heat exchanger in a general case have two consequences: with the spreading of the freezing boundary, the latent heat of phase transition starts to affect the process of heat transfer and the thermophysical characteristics of soil change.

While designing the geothermal heat pump system, the procedure of calculation, dealing with the phase transitions of moisture in the pore space of the ground massif, is based on the new concept of "equivalent" thermal conductivity of soil. Thus, we substitute the scheme, in which takes place the change in the phase state of moisture, accompanied by the liberation of the latent heat of phase transition, and the motion of the boundary of freezing, to the scheme, in which we deal with the stationary thermal condition of the ground massif, whose temperature field coincides with the temperature field of the original one, but in which the liberation of the latent heat of phase transitions does not occur. Soil in this case is considered as a quasi-homogeneous body, to which the usual equation of thermal conductivity is applicable and its thermophysical and mechanical characteristics can change both in time and along the spatial coordinates.

One can anticipate that "equivalent" thermal conductivity of soil depends on the radius of the pipes of the ground heat exchanger, "working" temperature of the heat-transfer agent, humidity of soil and duration of the period of thermal energy consumption from the ground – the heating period.

The analysis of the calculations conducted made it possible to make the following conclusions:

- the "equivalent" thermal conductivity of ground massif depends only slightly on the duration of the period of thermal energy consumption from the ground, and with an increase in this period the "equivalent" thermal conductivity of soil diminishes;

- the "equivalent" thermal conductivity of ground massif depends slightly on the temperature of the heat-transfer agent, circulating in the borehole heat exchanger, and with a decrease in this temperature the "equivalent" thermal conductivity of soil diminishes.

There are several different classifications of soils. To the larger degree we are interested in the classification of soils based on their thermal conductivity. In Table 1 the data of well-known reference book ASHRAE is represented, ASHRAE Handbook, (1999).

Employing the procedure, described above, for the vertical systems of low-potential ground heat collection as for most promising under the climatic conditions of Russia, the "equivalent" thermal conductivity of soils was determined according to ASHRAE classification. The results of calculations are presented in Table 2.

The analysis of the values of "equivalent" thermal conductivity of soils, which considers the latent heat of the phase transition of pore moisture, shows that the influence of the phase transition effects are very significant and they must be considered during the design process of geothermal heat pump systems, operated in minus temperatures.

Table 1. ASHRAE soils classification.

Class of the soil	λ, W/(м.*°C)	Type of the soil
Very low thermal conductivity	<1	Light clay (15% humidity)
Low thermal conductivity	<1,5	Heavy clay (5% humidity)
Normal thermal conductivity	<2	Heavy clay (5% humidity) Light sand (15% humidity)
High thermal conductivity	<2,5	Heavy sand (5% humidity)
Very high thermal conductivity	>2.5	Heavy sand (15% humidity)

Table 2. "Equivalent" thermal conductivity of soils, considering the latent heat of the phase transition of pore moisture (soils according to ASHRAE classification)

Class of the soil	λ, W/(м.*°C)	Type of the soil
Very low thermal conductivity	<2,2	Light clay (15% humidity)
Low thermal conductivity	<3,2	Heavy clay (5% humidity)
Normal thermal conductivity	<4,3	Heavy clay (5% humidity) Light sand (15% humidity)
High thermal conductivity	<5,4	Heavy sand (5% humidity)
Very high thermal conductivity	>5,4	Heavy sand (15% humidity)

4. PROGRAM PRODUCT FOR HEAT PUMP SYSTEMS DESIGN, VASSILIEV, (2003)

A computer program product was developed to conduct the calculations to determine the optimum parameters of the ground heat collection system in accordance with the geoclimatic conditions of the application site, heatproof qualities of building, operating characteristics of heat pump equipment, circulation pumps, heaters of the heating system, and also the routine of their operation. This program is based on the method of the mathematical simulation of the thermal behavior of the ground heat collection system, which made it possible to avoid the difficulties, concerned with the informative uncertainty of existing models and approximations of external acting factors due to the use in the program of the experimentally obtained information about the natural thermal condition of ground. This made it possible to partially consider the entire complex of the factors (such as the presence of ground water, its velocity and thermal conditions, structure and the arrangement of the ground layers, atmospheric precipitations, the phase transitions of moisture in the pore space and other), most essential for the formation of the thermal condition of ground heat exchangers system and joint consideration of which is practically impossible in a strict formulation of the problem today.

The program actually allows us to carry out a multi-parameter optimization of a geothermal heat pump system for a specific building in a specific region. The objective of the optimization is the minimum of annual power expenditures for system operation, and the optimization criteria are ground heat exchanger diameter and its depth (length and depth for a horizontal one). The program makes it possible to consider in design process and calculations the parameters of ground heat exchangers and the thermal condition of the ground, which will be achieved in the fifth year of system's operation, since it was discovered, that after a lapse of five years the ground reaches its new temperature conditions, which afterwards changes very little. Beside this, the program allows to perform the calculations of the ground heat use in combination with other sources, such as ventilation exhaust air heat or heat of waste water.

5. RUSSIAN FEDERATION TERRITORY ZONING BY RUNNING EFFICIENCY OF GEOTHERMAL HEAT PUMP SYSTEMS, VASSILIEV, (2003)

For the estimation of running efficiency of geothermal heat pump systems of heat supply under the climatic conditions of Russia, its territory zoning was performed. This zoning was carried out on the basis of the results of numerical experiments on the simulation of operating parameters of geothermal heat pump system under the geoclimatic conditions of different regions of the Russian Federation. Numerical experiments were conducted based on the example of a hypothetical two-story cottage with a heated area of 200 square meters, equipped with a geothermal heat pump system. The external enclosing structure of the house in question has the following resistances to the heat transfer (according to Building regulations and rules 23-02-2003, (2003)):

- external walls– 3,2 m2*h*˚C/W;

-doors and windows - 0,6 m2*h*˚C/W;

- roof and floor – 4,2 m2*h*˚C/W.

In the calculation, only the load for the heating is considered (ventilation and hot water supply are not examined).

The coefficient of performance was accepted as a criterion of effectiveness, which includes expenditures of energy not only for operation of heat pump itself, but also all of the support systems and devices (peak heater, circulation pumps, etc).

While conducting the numerical experiments, two systems of ground heat exchangers were taken into consideration:

- the ground heat collection system with low density of energy consumption - horizontal ground heat exchanger from polyethylene pipes with a diameter of 50 mm and with a length of 400 m.

- the ground heat collection system with high density of energy consumption - vertical (borehole) ground heat exchanger with a diameter of 160 mm and with a length of 40 m.

The results of numerical experiments and the Russian Federation territory zoning by running efficiency of geothermal heat pump systems are represented in Figures 1 and 2.

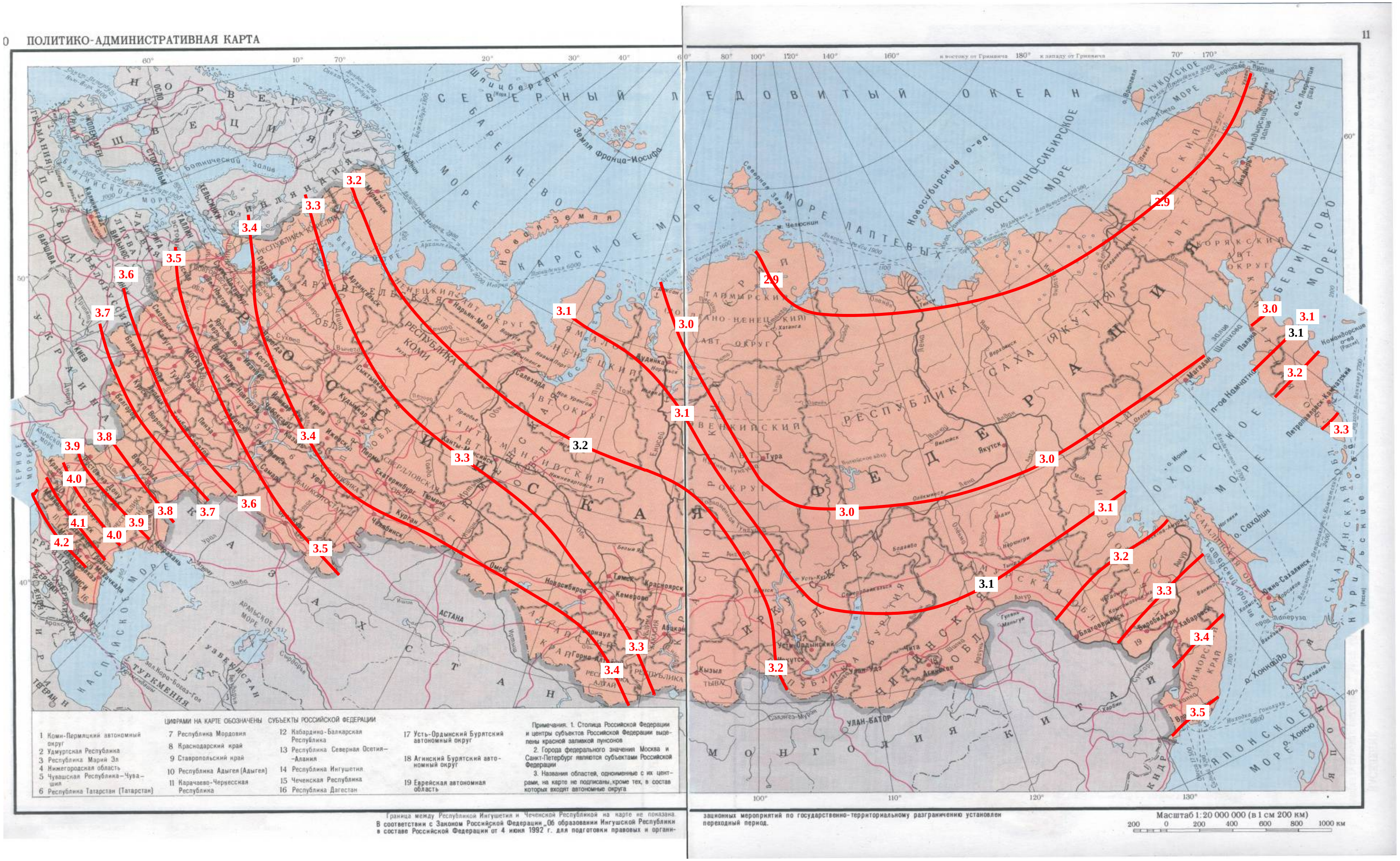

Figure 1. COP of the geothermal heat pump systems of heat supply, equipped with the horizontal ground heat exchangers.

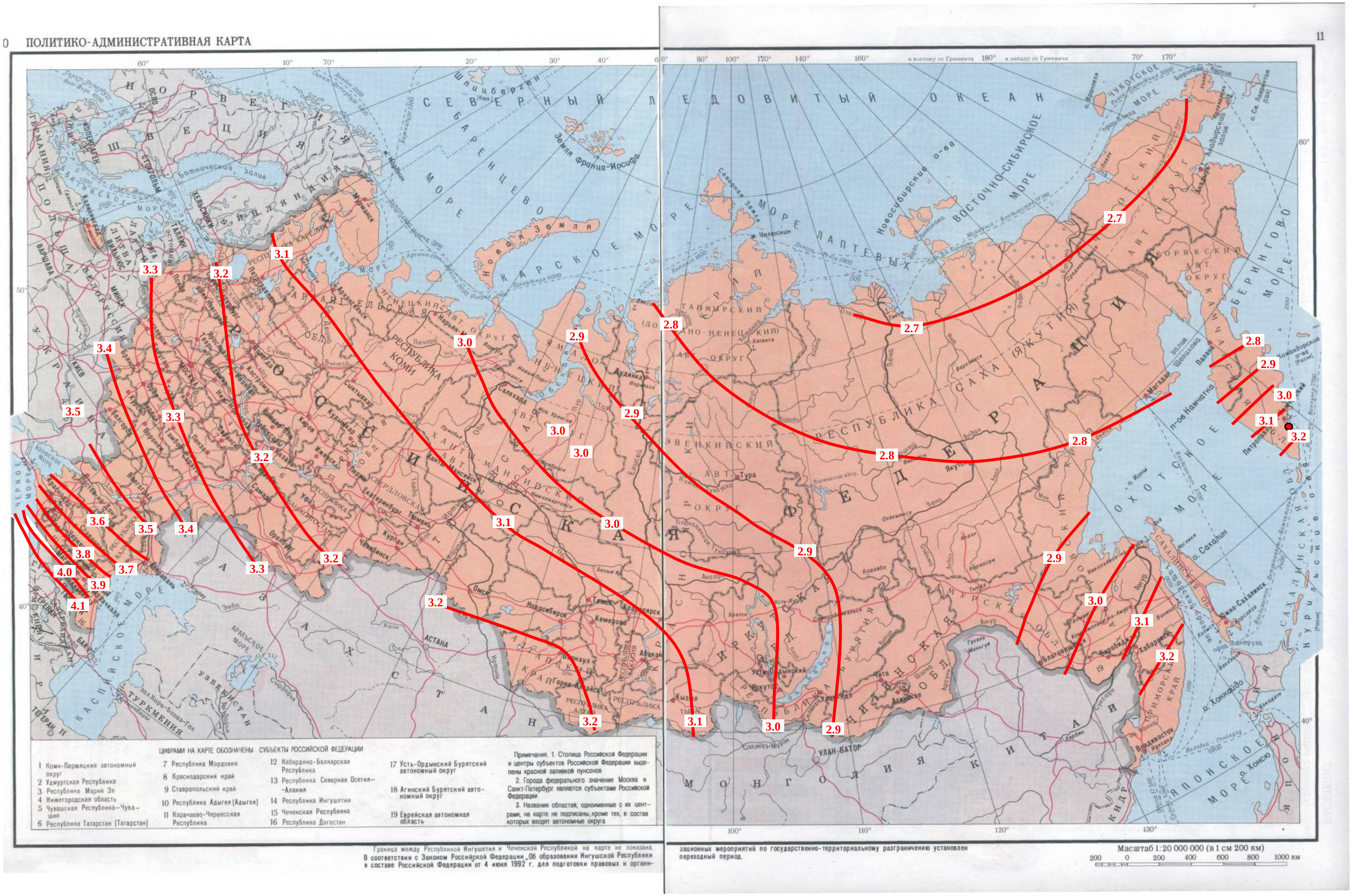

Figure 2. COP of the geothermal heat pump systems of heat supply, equipped with the effective vertical ground heat exchangers.

Figure 1 depicts values and contour lines of the coefficient of performance of the geothermal heat pump systems of heat supply, equipped with the horizontal systems of heat collection, while Figure 2 shows the same characteristics for the systems with the vertical ground heat exchangers.

As can be seen from figures, the maximum values of COP – 4.24 for the horizontal systems and 4.14 for the vertical ones - is possible to expect in the south regions of Russia, and the minimum values of, correspondingly, 2.87 and 2.73 on the north. It is worthwhile to note that the use of ground heat in the northern regions provides us an opportunity to supply heat to the houses, and, at the same time, to solve the problem of the degradation of permafrost, which is extremely urgent for these regions.

For the middle part of Russia the values of COP for the horizontal systems of heat collection are within the limits of 3.4 to 3.6, while for the vertical systems the limits are 3.2 to 3.4.

One can notice the sufficiently high values of COP (3.2 to 3.5) for the regions of the Far East, the regions with traditional difficulties of fuel supply. Apparently, the Far East is the region of priority introduction of geothermal heat pump systems.

CONCLUSION

Within this one article all existing aspects of geothermal heat pump systems application cannot be examined. A lot of them, including those which are completely positive, remain unmentioned.

But one of the positive aspects nevertheless should be mentioned. At present both the federal government and the government of Moscow more and more frequently announce the initiatives, aimed toward an increase in the energy effectiveness of the economy, and it lets us hope that in the very near future the mechanisms will be created for the correct evaluation of the ecological damage, caused by the use of fossil fuels, which would be a great support for a wider implementation of non-traditional energy sources, and, on the whole, conditions for the honest competition of heat pump systems with the systems of traditional heat supply will appear.

REFERENCES

1999 ASHRAE Handbook. HVAC Application. Chapter 31. Energy Resources, American Society of Heating, Refrigeration, and Air-Conditioning Engineers, Inc.

Building regulations and rules 23-02-2003. Thermal protection of buildings, State Building Corporation of Russian Federation, Moscow, (2003).

Vassiliev, G., Heat and Cold Supply for the Buildings with Use of Low Potential Heat Energy of the Upper Layers of Ground, Moscow, (2006).