Geothermal Energy Use in Western Siberia and Prospects for Its Innovative Application in Construction

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Abstract. The article gives an overview of the use of low-temperature geothermal energy sources for heat and cold supply of buildings in areas of Western Siberia. The experience of using geothermal heat pumps shows their economic efficiency and environmental friendliness. An innovative application of the low-temperature energy of the shallow subsurface soil layers is the double use of the underground foundation of a building or another structure as energy active elements of the heat-pumping system. The paper analyzes the problems why green technologies are not developing as dynamically as indicated in the Energy Program of Russia and barriers that prevent the wider use of heat pumps and systems in the heat and cold supply of buildings in the Siberian region. These include considerable regulatory and investment barriers, as well as lack of awareness about renewable energy and energy efficiency. Further, market entry remains challenging in Russia that has not fully liberalised its energy market. Furthermore, entrenched interests in conventional energy resources represent a significant barrier to effective legislation and policy implementation. Thus, huge conventional resources of oil, gas and coal in Siberia region, neighboring to Novosibirsk, Omsk and Altay districts are other obstacles to the introduction of renewable green technologies. Some examples on the limitation of barriers to geothermal heat pumps systems application in building construction are given.

1. Introduction
According to the long-term energy policy of Russia, 2020 is designated as the final year in the formation of a qualitatively new state of the fuel and energy complex. The “Energy Strategy of Russia” clause 6.8, states that the inexhaustibility and environmental cleanliness of renewable energy resources necessitate their intensive use.

Space heating and cooling (hereinafter SHC) is the world's largest energy sector, for instance, it accounts for 50% of the final energy consumption of Europe [1]. In Russia about 45% of the generated heat and electricity are also used for these purposes [2]. For Siberia and the Far East, which occupy more than half of the country's territory and are characterized by a cold and arctic climate, the proportion will be even higher.

This share of the energy sector is mainly based on the use of hydrocarbon and solid fuel raw materials, which significantly pollutes the atmosphere and contributes to the greenhouse effect, which negatively affects the environment. A significant improvement in the economic and environmental characteristics of the production of thermal energy can be achieved with the help of heat pumps (hereinafter - HP) and heat pump systems that use the low-potential heat of renewable, in particular,
geothermal energy resources for the purposes of SHC of buildings. In Russia, according to some estimates, geothermal heat can provide up to 30% of the energy requirements of SHC and hot water supply (the so-called direct use of low-potential renewable heat resources) [2].

2. Materials and Methods

2.2. Experience of using HP for SHC of public and commercial sector buildings in Western Siberia (Siberian Federal District)

We analyze only the use of HPs and HP systems, that are powerful enough for SHC and hot water supply of public and commercial buildings, such as schools, kindergartens, hospitals, shopping malls, etc in this paper. In Siberia, the research on their for SHC was started by a team of scientists and designers led by Yu.M. Petin. They established the Energyia Company in 1986. Over the next 10 years, CJSC Energyia produced and launched about 70 HPs with a total thermal capacity of more than 40 MW, which were installed at various facilities in Russia and abroad [3].

The authors don’t have any reliable information on the statistic of use HP on the territory of the whole Siberian Federal District as for the first decade of the XXI century. As of 01.01.2003, in the region 10 HPs and HP systems were operating in 6 rural communities, using the hydrothermal resources of the Cretaceous aquifer complex (Pokur Formation) of the West Siberian artesian basin from depths of 800 - 1000 m. Most of the HP systems used the existing fresh water supply wells. The total power of all HPs was about 4 MW. Unfortunately, the imperfection of the equipment produced at that time, the disinterest of local energy supplying organizations in saving energy consumed, and the lack of significant attention of officials to the environmental problems of the settlements in which the HPs functioned, did not allow their use for present.

Let us analyze the efficiency of using one of the above mentioned HP system with a total capacity of 1.4 MW, produced and installed by Energyia company in Karasuk city, Novosibirsk Region, in 1992, for SHC and hot water supply of a school building with an area of 6,000 sq.m. According to Shevchenko, et al (2019), groundwater of the Pokur Formation from a well with a temperature of 24 °C (at the mouth) was used as a heat source [4]. The HP system consisted of two NKT-300 HPs with a total heat output of 700 kW. The cost of the building’s SHC and hot water supply using geothermal heat made up about 40% of the cost of boiler house heat in this region, the payback period was 13 months. At the same time, the emission of ash and greenhouse gases into the atmosphere was significantly reduced. That HP system had been functioning for 12 years and, after running out its resource, was dismantled and the SHC of building was provided with a traditional coal boiler.

An interesting recent case study was the transfer of a secondary school with a total area of 1960 sq.m in Novosibirsk city to a low-temperature source of fractured water from a rocky granite massif. Some preliminary information about the project was given earlier when the work on the site was just beginning [4]. The need to change the source of SHC of the building arose due to the deterioration of the old boiler equipment and the very expensive connection to the central heating supply due to the remote location of the school. The project envisaged the drilling of 43 wells up to 75 m deep and the installation of 3 HP with a total capacity of 180 kW. Despite the difficult geological and drilling conditions, all the wells were drilled at designed depths and equipped with heat transfer systems (Figure 1).

Next to the school building, a geothermal module was mounted (Figure 2). The heating season for the autumn-winter period 2019-2020 showed the success of the project. Observation of the change in groundwater temperature at the wellhead over this period of time showed that its maximum values were in early autumn (+ 6 °C), and the minimum in February (+ 2 °C). However, even such a low-temperature geothermal energy source made it possible to successfully maintain a temperature of at least 21 °C in the school building, as well as provide hot water supply.
The successful application of HP systems using hydrothermal low-temperature sources for SHC of socially significant objects has been carried out in several other regional cities of the Siberian Federal District - Tomsk (the project parameters have been described by Shevchenko, et al, [4]) and Barnaul. Unfortunately, projects using thermal and low-thermal groundwater resources both in Russia as a whole and in the south of Western Siberia are implemented in very limited quantities.
3. Possibilities of innovative application of HP systems in the heat and cold supply of buildings and structures

Technological equipment producing HP for heat and cold supply of buildings is constantly being improved, which leads to a decrease in the cost of its production and an increase in the efficiency of its use. An innovative approach to solving the SHC problem of a building is to use an underground part of an engineering structure as a heat exchange element. These can be piles, diaphragm walls foundation slabs and other structural foundation elements, tunnel lining, etc. [5, 6, 7]. In this case, they got to their name the prefix thermo- or energy, for example, thermopiles, or energy piles. In fact, a new direction in the construction industry is currently being created - thermal geotechnics [7].

![Figure 3](image3.png)

**Figure 3.** A cross-section view of a 5-meter energy pile section. Absorber pipes fitted to the reinforcement cage of a large-diameter bored energy pile. The connecting ends are protected by a tube at the pile head [7]

![Figure 4](image4.png)

**Figure 4.** Reinforcement with attached absorber pipes inserted within casing of an auger pile; ready for casting concrete [7].

Austria and Switzerland (world leaders in the per capita use of geothermal energy) became pioneers in this field, in which, in the early 1980s, research began in the field of energy-active foundation structures and their practical use in SHC of buildings.

Piles are widely used in construction practice in the south of Western Siberia as structures for creating artificial foundations with high load-bearing capacity, creating retaining and sheet pile walls, piling enclosures, constructing anti-filter curtains, erecting seasonal cooling units and solving a number of other tasks. Piles are made of various materials - concrete, reinforced concrete, steel, wood.
Such structures, immersed in the soil in various ways, can reach depths of hundreds of meters, while cutting through soil layers with various physical, mechanical and thermal properties. In almost all cases (except for the use of high depth permafrost soils as the base), the pile body will come into contact with soils having more or less constant positive temperatures (“unfrozen” soils). Due to the high thermal conductivity and heat capacity of the pile material (reinforced concrete, steel), the temperature regime of the soil will be quickly transmitted and held by the pile. Of course, such properties of piles can be used as a heat exchanger in solving the problem of heat supply to buildings (structures). Moreover, according to RF State Standard SP 25.13330.2012. Foundations and foundations on permafrost soils (2012) the use of piles for artificial cooling (freezing) of soils in the North (solving the inverse problem) is well known. When equipping a pile shaft with a heat exchanger pipe system, this design turns into a thermal well, capable of solving the main problem - ensuring the stability and reliability of the construction object, and another - creating a system for efficient power supply of the building (structure). Figure 3 shows a cross-section of a 5-meter section of a thermopile with the placement of heat-exchange (absorber) pipes inside its reinforcing shell, and Figure 4 – view of the structure, buried in the ground and ready for filling with concrete [7].

The use of thermo active foundation structures significantly reduces the cost of the use of geothermal energy, as expenses for drilling geothermal wells and installation of additional equipment are not required.

Despite the large number of studies in the field of application of thermo active foundation structures published recently by foreign researchers, there are still many unresolved issues in this area, such as the influence of structural features of the building on the choice of thermo active foundation elements, impact of thermal piles on the underground temperature regime, including seasoning and climatic factors, the efficiency of obtaining geothermal energy from various soil media, role of soil saturation and some others [8, 9].

The segment of development of thermo active foundation structures, has not yet received practical application Russia, but it is very promising.

4. Barriers to Geothermal HP and HP systems wider application in the region

An analysis of the reasons that impede the widespread use of green technologies, including geothermal low-temperature energy of the subsurface layers of the earth, is given in a large number of foreign and Russian reviews and articles.

Despite the “Energy Strategy of Russia for the Period Until 2020”, adopted back in 2003, indicating the importance of developing and using renewable energy sources, the use of hydrocarbon resources, coal, and renewable sources still prevail in the country's fuel and energy complex sources - hydropower. Entrenched interests in conventional energy resources represent a significant barrier to effective legislation and policy implementation. In the legislative field, in order to support initiatives to develop energy programs using environmentally friendly and cost-effective technologies in the country, there is a great need for liberalization of the heat and energy supply market, greater transparency of legislative acts for large-scale investments of non-state energy companies and the implementation of state-owned programs and private partnership. Major regional programs reviewed by Shiganova, Shevchenko (2017). One of the most successful of those was “Omsk Region Heat and Water Resources Development Program for 2005-2010” with elements of public-private partnership in the Omsk region. Its developers were RF Ministry of Natural Resources and Ecology, research institutes VSEGINGEO (Moscow district), SNIIGGiMS (Novosibirsk). The measures included in the Program were funded both from the federal budget (1.3 million rubles) and from subsoil users (2.4 million rubles) [10].

Unfortunately, for a number of reasons, such programs are not developed any more, despite the task, given to the RF Ministry of Natural Resources and Ecology by the Committee of the State Duma of the Russian Federation to initiate the development of federal programs for the use of geothermal energy [14].

There is an interesting example of promoting renewable energy by a local government in the Russian regional market. According to Shevchenko, Shiganova (2018) the effectiveness of the use of HP systems can be shown by the example of the Chuvash Republic (situated at the east of European part of Russia), where favorable conditions for the application of HP were created [11]. So, the Cabinet of Ministers of the Chuvash Republic, for the first time in Russia, on March 4, 2002, introduced a tariff for electricity for SHC and hot water supply with HP systems for industrial, commercial and resident buildings, which was lower than the tariff used for calculating the consumed electricity for existing heat supply systems by 2.15 times at average. The difference in tariffs was covered by the power system, which did not lead to a drop in the profitability of electricity production, because conventional fuel consumption in the power system for the production of electric energy for HP by more than 70% was compensated by fuel savings for SHC supply in the same power system [12]. This example shows the ability of the regional administration to advance energy efficiency in the building SHC sector.

5. Conclusion

The analysis of the efficiency of using heat pumps in Western Siberia showed that at all facilities where they were installed, even with a very low geothermal potential of the energy sources, the tasks of the SHC and hot water supply were successfully implemented.

The environmental safety of the functioning of geothermal equipment, the autonomy and reliability of the HP are additional arguments for the widespread use of these systems.

Nevertheless, renewable and energy efficient green technologies have advanced slowly in Russia over the past decade, and there is significant room for improvement. Russia is not the only country, where regulatory policies to advance energy efficiency have been enacted. The regional international review of the most post-Soviet and some South East European countries (17 at all) says that all of them except Turkmenistan have enacted regulatory policies to advance energy efficiency – most commonly in the building sector and most have established efficiency targets [13]. Despite the great diversity in population size and economic, social and political characteristics, the energy systems of these countries all were developed in a similar manner, and renewable and energy efficiency face some common challenges across the region. These include considerable regulatory and investment barriers, as well as lack of awareness about renewable energy and energy efficiency. Further, market entry remains challenging in countries that have not fully liberalised their energy markets. These are the reasons why the market for renewable energy resources is not developing as dynamically as indicated in the Energy Program of Russia. Furthermore, entrenched interests in conventional energy resources represent a significant barrier to effective legislation and policy implementation. Thus, huge petroleum resources in Siberia region, coal deposits in the Kuzbass region neighboring to Novosibirsk, Omsk and Altay districts are other obstacles to the introduction of HP technologies, despite the proven energy and economic efficiency of their operation, while maintaining a fairly low cost of the conventional resources. Recent shocks in the global hydrocarbon resources market should push the authorities to alternative approaches to the functioning of the country's fuel and energy complex.

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