Assessment of economic efficiency of unconventional renewable energy sources utilization for energy supply of individual residential houses

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Abstract. Practical topics of evaluation of efficiency of heat pumps usage for individual residential houses heating with comparing of different technical options and solutions. Power of the heating system on the basis of geothermal heat pump on the example of specific building investigated. The role of heat insulation in heat losses and influence on the required power of heating system assessed, economical aspects evaluated. Comparison with alternative heating on the basis of main (pipelined) gas made in order to get objective picture of competitiveness of renewable energy sources with traditional ones in the existing regulatory and energy market conditions.

1. Introduction
Individual housing construction (IHC) has a large development potential in Russian Federation. For instance, in the Moscow region more than 24 thousand individual houses with total square more than 4 million square meters were built in 2019.

According to the data of Federal State Statistic Service (Figure 1), IHC share at the last reported year is 45.9% of total volume residential buildings. The federal program to support IHC in Russian Federation planned for 2020. It's planned that by 2024 the total volume of IHC building will reach 40 million square meters per year.

It’s offered to involve resource supplying companies for building of utilities infrastructure under investment programs. If required funds from local budgets as well as federal subsidies may be used under existing procedures already applied using for multi apartment residential buildings construction.

Increase of individual housing construction volume requires solving of corresponding technical and technological issues with energy and utility supply of the houses. At the one hand this is higher requirements to life quality and on the other hand it means significant building area which leads to

1Official web site of the Moscow region government https://mosreg.ru/sobytiya/novosti/organy/ministerstvo-zhilishnoi-politiki-moskovskoi-oblasti
2https://erzrf.ru/news/rosstat-vvod-zhilya-v-2019-godu-prevyssil-80-mln-kv-m-spasibo-izhs
3Official web site of Ministry of construction, housing and communal services of Russian Federation https://minstroyrf.gov.ru/press/
longer utility networks and in some cases to change of energy supply technology. There may be
different options like electricity, wood fuel pellets or natural gas for heating as well as unconventional
renewable energy sources like heat pumps for buildings heating or wind generators for electricity
supply. Choose of one technology or another depends on its technical data, equipment accessibility as
well as on the building environment.

![Figure 1. Dynamics of residential building by individuals and
companies, millions of square meters (MAH – multi apartment
residential houses).](image)

Essential factors making influence on technology choice and specific technical solution are
regulation in the field of energy saving and economic incentives. As an example in Germany one of
the parameters making influence on long term (more than 10 years) mortgage interest rate for house
building is energy consumption of the house per square meter.

Individual houses with electrical heating considered as promising consumer segment for energy
sales companies especially taking into account potential federal program of IHC support and activity
in gradual cancellation of cross subsidization in energy industry.

In its turn opportunity to save electricity for house heating by using unconventional renewable
energy sources (URES) may become an additional incentive
for implementation “Housing and urban
environment” program since it doesn’t require additional investments in gasification and building of
long heat supply networks.

2. General project information

Individual residential houses have to correspond to the building code SP 55.13330.2016 including
requirements to the heating system in according with code SP 50.13330.2012 (heat protection of the
buildings).

On the basis of data about the values of the average daily outdoor temperature and its duration during a year and indoor temperature +20°C the required amount of the heat energy for the building defines. In accordance with the building code the building envelope at the value of degree-day heating period (DDHP) 4000-6000 (°C·day/year) has to have following values of heat transfer resistance $R_0^{TR}$ (m²·°C/W):

- walls – 2.8-3.5;
- attic floor, ceilings over unheated basements – 3.7-4.6;
- translucent enclosing structures (windows, glass doors, etc.) – 0.63–0.73.

For Moscow region DDHP is in the range from 4800 to 5200°C·day/year. On the assumption of average value of DDHP the heat transfer resistance ($R_0^{TR}$) is taken as corresponding to the standard if it’s 3.16 m²·°C/W for walls, 0.54 m²·°C/W for windows and balcony doors, 4.16 m²·°C/W for ground floor overlap.

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4In SP 131.13330.2012 «Building climatology. Updated edition of SNiP 23-01-99*» average values for the period 1996-2010 indicated depends on the region of building.
The article considered a private individual house made of structured insulated panels (SIP) consisting of three layers: heat insulation (expanded polystyrene, 150 or 200 mm thickness) and two outer cement bonded particle boards (CBPB) on both sides of insulation. CBPB is a composite sheet building material consisting of water (8.25%), portland cement as binder (65%), wood shavings (24%), hydration supplements (2.5%). Use of these materials provides heat transfer resistance through walls $3.2 \, \text{m}^2\text{K}/\text{W}$ that corresponds to the values for Moscow region in the building code.

Heat losses of the building calculated for minimal temperature of January (-27°C) and for average temperature (-3.2°C) per heating period for total building square as 250 square meters (Table 1). The biggest amount of heat loosing through walls and overlaps since the glazing area has been selected as standard regarding square of building walls. Also translucent enclosing structures (windows, glass doors, etc.) with increased heat transfer resistance value 1.06 selected.

| Table 1. Building heat losses at $R=3.2$. |
|------------------------------------------|
| **Outdoor temperature/Losses, W** | **-3.2, °C** | **-27, °C** | **Structure of heat losses** |
| Walls | 1349.86 | 2624.74 | 27.45% |
| Windows | 875.73 | 1702.81 | 17.81% |
| Doors | 112.21 | 218.19 | 2.28% |
| Overlaps | 2580.48 | 5017.62 | 52.47% |
| Total | 4918.28 | 9563.34 | 1 |

3. Economic assessment of the use of a geothermal heat pump for heating

A heating system on the basis of geothermal heat pump was developed in the project. As a criterion for economical evaluation the total cost of life cycle (total discounted costs) for minimal life time of the equipment (10 years) has been selected [1]. The authors consider that this criterion has to be used for technical solutions selection since there is no cash inflow for individual house building. Thus methodology for assessing economic efficiency in terms of net present value and payback period is not applicable for such evaluations [2].

For the object in question with the level of maximal heat losses 9563.34 W and adding heat losses due to natural ventilation and air infiltration the heat pump with rated power 13 kW was offered. The cost of the equipment including geothermal probes and drilling works in accordance with manufacturer’s information is 830 thousand Rubles (c.a. 11-12 thousand USD depends on exchange ratio). Let's estimate the life cycle cost (LCC) at a discount rate of 10% by electricity consumption for heating period with coefficient of performance (COP) of the heat pump 4.82 in accordance with the manufacturer’s data. To do this, calculate the electricity consumed by the heat pump based on the average value of the outdoor air temperature (Table 2).

| Table 2. Heat pump electricity consumption for heating at the averaged temperature. |
|------------------------------------------|
| **at -3.2 °C** | **Power consumption, kW** | **Electricity consumption kWh/year** |
| R=3.2 | 4918.28 | 1.02 | 5118.276 |
| R=6.3 | 3840.68 | 0.80 | 3996.862 |

It should be noted that it will be more accurate to calculate electricity consumption by the values of average daily temperature of outdoor air and its duration. For 13 kW heat pump the electricity consumption is 7543.7 kWh/year. At the price of electricity for individual houses in the Moscow region 3.89 Ruble/kWh the lifecycle of the heating system with heat pump calculated as 1.108 million Rubles (c.a. 15-16 thousand USD, depends on exchange ratio).
The task was to reduce the cost of the life cycle of the heating system. In order to solve the task it was offered to reduce heat losses of the by insulating the enclosing structures with mineral wool with a layer thickness of 100 mm. Extra costs evaluated as 84.5 thousand rubles (c.a. 1200 USD, depends on exchange ratio). The value of heat transfer resistance coefficient has changed to 6.3 that corresponds lower heat losses of the building (Table 3). The structure of heat losses is also changed: the biggest share of losses now goes through overlaps and windows.

| Outdoor temperature/Losses, W | -3.2, °C | -27, °C | Structure of heat losses |
|-----------------------------|----------|---------|-------------------------|
| Walls                       | 682.40   | 1326.88 | 17.77%                  |
| Windows                     | 875.73   | 1702.81 | 22.80%                  |
| Doors                       | 112.21   | 218.19  | 2.92%                   |
| Overlaps                    | 2170.35  | 4220.12 | 56.51%                  |
| Total                       | 3840.68  | 7468.00 | 1                      |

At the level of heat losses 7468 W with taking into account losses for ventilation and air infiltration the power of heat pump reduced to 10 kW and price decreases to 700 thousand Rubles. Also electricity consumption for heating period becomes less (Table 2).

Table 4 shows the cost of the life cycle of the heating system of the considered building according to the averaged temperature and its duration at different heat transfer coefficients. Also annual maintenance cost of the equipment has been accounted as 20 thousand Rubles (c.a. 270-290 USD, depends on exchange ratio) per year.

| R=3.2, T=-3.2   | 830  | 5118.28 | 19.91 | 1050.16 |
| R=3.2, T- average daily | 830  | 7543.70 | 29.34 | 1108.13 |
| R=6.3, T=-3.2   | 700  | 3996.86 | 15.55 | 985.27  |
| R=6.3, T- average daily | 700  | 5802   | 22.57 | 1028.42 |

Annual heating costs are reduced by 23%, cost of equipment and drilling decreased by 15% and lifecycle cost is less by 7%. Lifecycle cost reduced less due to the discounting effect when costs of future periods are lower at the moment of making decision about investing.

Thus change of building parameters has essential value for selection of heating system equipment on the basis of unconventional renewable energy sources.

4. Comparison of heating technologies at individual housing construction
Let’s compare lifecycle cost of heating system with heat pump and heating system on the pipelined natural gas for the same building. The gas equipment is cheaper than heat pump equipment by 3-4 times. Also there is no drilling works in case of gas heating. However the gas equipment requires special approval and regular maintenance and inspection by authorities. In the Moscow region cost of
connection to the gas pipeline calculates by standardized rates. In accordance with the order of Committee for prices and tariffs of Moscow region payment for connection to the gas distribution system of regional gas supply operator “Mosoblgas” JV with following conditions:

- equipment has maximal gas consumption up to 15 cubic meters per hour;
- the distance from the equipment using gas to the gas distribution network with project working pressure up to 0.3 MPa, measured by direct line (minimal distance) is not more than 200 meters;
- construction works are limited by building supplying/entering parts of pipelines only (no gas pressure reduction stations, no trenchless pipeline laying) in accordance with gas supply layout of the specific area is 65 thousand Rubles, VAT 20% included (c.a. USD 920-930 depends on exchange ratio).

This price doesn’t include any costs for works required for gas connection on the land of the specific household i.e. the gas pipeline for the above mentioned price will be located at the border of the land of the household. Without taking into account these costs the lifecycle cost of the heating system on the basis of gas equipment is 543 thousand Rubles (c.a. 7700-7800 USD depends on exchange ratio).

Note that the conditions for preferential connection to the gas network can’t be always executed easily for the individual house located even within settlement with the existing gas supply network. For instance often individual houses located on the distance longer than indicated in the conditions above. For the settlements located relatively far from gas pipeline the distance condition fulfillment is often quite difficult.

Thus, the equal cost of the life cycle of heating systems based on heat pump and pipelined gas for the building under consideration has technical solutions implemented with connection to gas network and the amount of financing as 582 thousand Rubles (c.a. 8200-8300 USD depends on exchange ratio).

5. Conclusion

So, heating systems based on unconventional renewable energy sources, in particular heat pumps can have equal economic efficiency with traditional power supply systems.

These unconventional systems can effectively participate in the interfuel competition "gas-electricity". In increasing number of buildings heating by electricity energy sales companies may be interested. Electricity consumption of such buildings is much higher since heating consumes significantly more power than conventional household needs.

At the same time, technical solutions based on heat pumps reduce electricity consumption by 3-5 times (depending on COP, temperature modes) comparing to the heating directly by electric boilers that makes them attractive for individual houses.

Centralized heating of individual houses is difficult due to lower density of population and consequently high cost of construction and maintenance of heat supply networks. However, the share of individual housing construction in the programs for providing population with the housing will increase that shows the importance of solving the problems of economical energy supply of such facilities, including through the supply of various types of energy from unconventional renewable energy sources.

References

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