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ANALYSIS OF THE USE OF GEOTHERMAL HEAT PUMPS FOR HEATING AND COOLING OF INDIVIDUAL RESIDENTIAL BUILDINGS

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Abstract. Today, humanity is beginning to realize the problem of the growing shortage of natural energy sources. The prices of these sources are rising uncontrollably and will continue to rise in the future. As the Republic of Moldova does not have its own fossil fuels fields and is totally dependent on foreign imports, the implementation of renewable energy sources technologies becomes vital. In this sense, the usage of closed type geothermal heat pumps with direct heat exchange in new and reconstructed residential buildings to replace traditional heating boilers is beneficial. They can be especially effective in areas where there are no gas supply pipelines. The purpose of the paper is to determine the perspectives of geothermal heat pumps using in residential buildings in the Republic of Moldova climatic conditions. Examples with implemented geothermal heat pumps and project solutions for heating/cooling and hot water supply systems for three individual residential buildings in the southern region of the Republic of Moldova were analyzed for task implementation. During the 2020-2021 heating season, it was not necessary to use the additional reserve heat source for the examined objects.

Keywords: Heating *system, warm floor, direct heat exchange, alternative energy source.*

Rezumat. Astăzi omenirea începe să conștientizeze problema deficitului tot mai mare de surse de energie naturale. Prețurile pentru acestea cresc necontrolat și vor continua să crească în viitor. Deoarece R. Moldova nu dispune de zăcăminte proprii de combustibili fosili şi totalmente depinde de importurile din exterior, implementarea tehnologiilor cu utilizarea surselor de energie regenerabile devine vitală. În acest sens este benefică, utilizarea pompelor de căldură geotermale tip închis cu schimb direct de căldură, în locuințe noi și reconstruite pentru a înlocui cazanele tradiționale de încălzire. Acestea pot fi deosebit de eficiente din punct de vedere al costurilor în zonele în care rețelele cu gaze naturale nu sunt disponibile. Scopul lucrării este de a determina perspectivele utilizării pompelor de căldură geotermale în clădirile rezidențiale în condițiile climatice ale R. Moldova. Pentru realizarea scopului propus au fost analizate exemple cu pompe de căldură geotermale implementate şi soluțiile de proiect de sisteme pentru încălzire/răcire şi alimentarea cu apă caldă pentru trei clădiri individuale de locuit din regiunea de sud a R. Moldova. Pe perioada sezonului de încălzire 2020-2021, la obiectele examinate nu a fost necesară utilizarea sursei de căldură de rezervă adițională.

Cuvinte cheie: *Sistem de încălzire, podea caldă, schimb direct de căldură, sursă alternativă de energie.*

1. Introduction

According to statistics [1], the annual increase in the construction of individual residential houses was 30% in the period 2017-2019 in the Republic of Moldova. In 2021 it increased by 18 % compared to 2020 and amounted to 288.9 thousand m^2 (about 2 thousand of houses). But, despite the increase in the volume of construction of individual housing, the designers of engineering systems pay little attention to the provision of a comfort microclimate of a residential house using energy-efficient technologies, limiting themselves to classic solutions. The Republic of Moldova does not have energy resources. And after the gas crisis in the fall of 2021-2022, it became even more clear that it is necessary to implement alternative energy sources. In this sense, heat pumps that work on electricity and are safe, automated and reliable equipment offer great hope [2-7].

The purpose of this work is to analyze the already operational geothermal heat pumps (GHPs) in residential individual houses to understand the feasibility of using them in the conditions of the Republic of Moldova since the experience of using heat pumps in our country is very little. In this regard, for the analysis of the effectiveness of the use of GHPs, three residential houses in the southern regions of the Republic of Moldova were selected, in which the geothermal heat pumps were installed and used for heating, cooling, and supplying the house with hot water.

GHPs use the relatively constant temperature of the earth as the exchange medium. Some models of geothermal systems are available with two-speed compressors and variable fans for more comfort and energy savings. Compared to air-source heat pumps, they are quieter, last longer, need little maintenance, and do not depend on the temperature of the outside air [8].

The biggest benefit of GHPs is that they use 25 %–50 % less electricity than conventional heating or cooling systems. According to the Environmental Protection Agency, geothermal heat pumps can reduce energy consumption and corresponding emissions by up to 44 % compared to air-source heat pumps and up to 72 % compared to electric resistance heating with standard air-conditioning equipment [9].

2. Examples of practical solutions for the use of geothermal heat pumps in the conditions of the Republic of Moldova

2.1 General information

In this paper, closed-type GHPs with direct heat exchange (DX - "direct exchange"). Unlike other types of heat pumps, the refrigerant takes heat directly from the ground, without the use of intermediate heat exchangers and thermal agents, copper pipes are used as probes through which refrigerant R 407C circulates, taking heat from the soil. One of the benefits of the DX geothermal system is the copper ground loop, which is a more effective means of transferring heat than the plastic ground loop [10].

Among the advantages of this technology, a higher temperature difference can be noted, which increases heat transfer, this advantage is partially neutralized by a smaller area of contact with the ground. A significant advantage of this technology is the small diameter of wells during drilling, which significantly reduces the cost of installation work. At the same time, they require more refrigerant and their piping systems are more expensive.

The ground loop system can be installed in several different configurations: vertical, diagonal, and horizontal. In the examples considered, diagonal systems are used, which usually take up very little space, the probes are located at an angle of 45 degrees (figure 1).

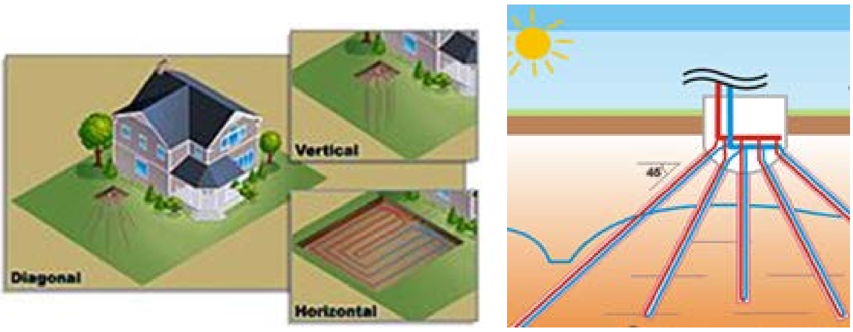

Figure 1. Configurations of the ground loop system and geothermal heat pumps with direct heat exchange [11].

High energy efficiency is ensured by combining a heat pump with a radiant floor heating system ("warm floor"). Low-temperature radiant floor heating system "warm floor" allows getting a heat flow of 50-150 W/m^2, at a heat transfer fluid temperature of 35-55 °C. At the same time, there are restrictions imposed on interior elements, in the general case, the maximum area for laying a "warm floor" is 60-70 % of the heated area [12].

2.2 Application of a geothermal heat pump in a residential building located in the village of Cania, Cantemir district

The main indicators of objects and heat pumps are presented in (table 1). Calculation of heat losses for this building was made for two boundary conditions of outdoor temperature -16 °C and 3 °C and at an indoor air temperature of 22 °C [13, 14]. The -16 °C/22 °C mode is selected to determine the heat pump capacity, the 3 °C/22 °C mode is selected to estimate the amount of heat required for the entire heating season to maintain the set indoor temperature.

Figure 2. Geothermal circuit of the heat pump in the village of Cania.
(*SRL "Climatehnic" photo*)

The temperature of 3 °C corresponds to the average temperature of the 2020-2021 heating season for Cantemir, calculated according to the data of the State hydro meteorological service [15], the duration of the heating period is 164 days [13, 14].

Estimated heat loss in -16°C/22°C mode is 4.2 kW and, respectively, in 3 °C/22 °C mode, 2.4 kW. A geothermal heat pump used for heating and cooling the house was installed by SRL "Climatehnic" in November 2018. The heat pump is built using direct evaporation technology. The geothermal circuit is made in the form of 5 probes with a total length of 120 m installed at an angle of 45 degrees, structurally the probes are made in the form of a single U-shaped connection of two copper pipes with a diameter of ¼ and ½ inch. Distribution collectors are located in the ground below the freezing depth (figure 2).

During the installation of the geothermal circuit and the analysis of the groundwater level, it was determined that approximately 60 % of the total length of the probes was located in water-saturated soil, which positively affects the performance of the system. Periodic monitoring of heat pump operation (figure 3), showed that the average boiling point of refrigerant (freon) at this facility during operation changed from -7 °C in the first year of operation (2018-2019) to -3 °C for the period (2020-2021). The measurements were carried out during periods of cooling in the second half of winter, while the continuous operation time of the compressor was at least 60 minutes. A digital manifold TESTO 550 was used as a measuring device. The increase in the average boiling point during the heating season can be associated with the degree of soil compaction around the walls of the probe, the complete shrinkage of which occurs over several years, and stabilizes, based on observations of objects, in the third year heat pump operation.

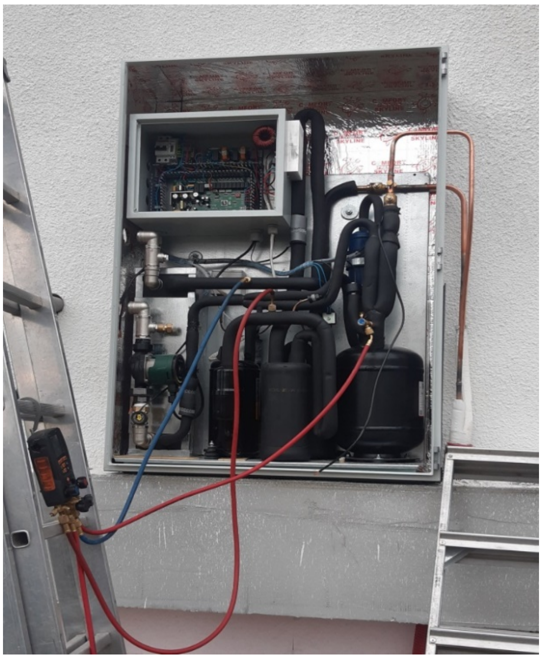

Figure 3. A heat pump implemented in the village of Cania.
(*SRL "Climatehnic" photo*)

This heat pump has a compressor, Copeland, Emerson Climate, the main parameters of the refrigeration circuit (boiling point of Freon R407C -3 °C, Freon condensation temperature 35 °C) in the selection program from the manufacturer, the compressor capacity is 5.07 kW (*Qc*), [16].

The operation of a heat pump is characterized by the performance coefficient (*COP*), defined as the ratio between the useful effect produced (thermal energy supplied, *Qc*) and the energy consumed to obtain it (actuation energy, *Qp*). To find out the heat pump coefficient performance (*COP*), the *Qc* is divided by the electric power consumption of the compressor, control unit, and circulation pump (*Qp*).

$$COP = \frac{Qc}{Qp} \tag{1}$$

$$COP = \frac{5.07}{1.11 + 0.045 + 0.03} = 4.2$$

The cooling of this residential building is also carried out by floors. The temperature of the heat carrier at the inlet to the HP heat exchanger, due to the limitations of the controller used, cannot be set above 18 °C, which turned out to be too low in practice, therefore, to solve this problem, a room thermostat was installed that turns off the cooling when the set room temperature is reached. In this mode, according to the results of several measurements, over the summer temperature of the refrigerant, it was: boiling point t_o=8 °C, condensation temperature t_c=30 °C.

The demand for maintaining the indoor temperature all year round and covering the housing supply with domestic hot water is on average 4700 kW per year (a separate meter is installed to measure the electricity consumption of the heat pump).

2.3. Application of a geothermal heat pump in a residential building and a dental clinic in one separate building in the city of Comrat

The special feature of this object is that it is divided into 2 parts, one half of the building is a residential area, and the second is a dental clinic. The building size and thermal characteristics are presented in (table 1).

The estimated heat losses of the building in the -16°C/22°C mode are 15.1 kW, and in the average temperature mode for the heating season 2020-2021 3°C/22°C, they are 7.6 kW. For heating and cooling a house with an area of about 600 m^2, a heat pump with a rated capacity of 18 kW is used, taking into account the expansion of the area. This heat pump was manufactured and installed by SRL "Climatehnic" in April 2020. The heat pump is also built based on direct evaporation technology, compressor control is the inverter, and the total length of geothermal probes is 320 m (figure 4).

Figure 4. Geothermal circuit of the heat pump in the city of Comrat.
(*SRL "Climatehnic" photo*)

The GHPs are the main source for heating and cooling the building. A condensate gas boiler with a capacity of 35 kW is used as a backup (reserve) for heating and hot water supply. Radiant underfloor heating is used as a heat distribution system, to increase the efficiency of passive cooling, heat carrier pipes are also laid above the floor slab of the second floor under thermal insulation. The building has a supply and exhaust ventilation system with heat recovery.

The hot water supply at this facility is implemented according to the scheme: two indirect heating are used as storage tanks, the storage tanks of which are connected in series, the first boiler is heated directly from the heat pump, the second boiler heat exchanger is connected to a gas boiler. In case of insufficient heating of the water in the first boiler and to ensure a stable temperature in the hot water supply system the second boiler is an auxiliary source of energy to maintain the required hot water temperature (figure 5).

Figure 5. Gas boiler and hot water boilers.
(*SRL "Climatehnic" photo*)

In the heating mode, floor heating is used, and the heating working fluid is also supplied to the heating coils installed in the ventilation unit.

In the premises of the dental clinic, cooling in the warm season is hybrid, the ceiling of the second floor is used as a cooling panel, and fan coil units and a water cooler section are used in the supply ventilation system. It should be noted that in the first year of operation, the cooling of the building, except the water cooler of the supply ventilation system, was performed only using cooling panels (floors and the ceiling of the second floor). Analysis of the data obtained during this observation period allows us to draw the following conclusions:

- panel cooling system uses cold water at 14/18 °C temperature, higher than air type cooling system, 7/12 °C mode for fan coil units. Panel cooling is a very good alternative to standard air cooling systems;
- in the part of the building where the dental clinic is located, there was a problem with high relative humidity. The client required that the room temperature should not exceed 22°C. The optimum indoor air temperature is within 25-26 °C, when the indoor air temperature drops to 22 °C, the relative humidity in the room rises to 70 % at an outside air temperature of 35 °C and a relative humidity of 32 %, the operation of the ventilation system does not reduce the humidity. The indoor air humidity rises to 70 % because at least 15 people are constantly in the room, after each patient the rooms are processed, and wet cleaning is carried out at least 4 times per working day. All this led to the transition to fan coil cooling. It should be noted that the panel cooling system coped with maintaining the set temperature, but the high relative humidity (70-80 %) prompted a switch to a hybrid cooling system Due to the different requirements for the water temperature in the cooling circuits, the heat pump supply temperature is maintained in the range of 4 -7 °C, and water is supplied to the ceiling circuit using a mixing unit with a temperature of at least 14 °C.

The temperature of the coolant at the outlet of the heat exchanger for the heating season 2020-2021, was in the range of 32-37 °C, the boiling point of Freon was in the range of (-3 °C) – (-5 °C), the temperature difference in the heat exchanger of the heating circuit was about 3K, thus the average operating mode of the compressor was -4/38 °C. According to the manufacturer's data sheet for the compressor Mitsubishi LNB42FSAM [16] installed in this heat pump and after some extrapolation, the average calculated heat pump COP for the heating season was 4.6. In cooling mode, the average operating mode is 2/35 °C, respectively, EER, according to [16], will be 5.18. During the past heating season, there was no need to connect a backup heat source.

2.4. Application of a geothermal heat pump in a residential building located in the city of Cahul

The building size and thermal characteristics are presented in (table 1). The estimated heat loss of a residential building in the city of Cahul in the -16 °C / 22 °C mode is 5.8 kW, in the average temperature mode for the heating season, 2020-2021 is 3.5 °C/22 °C they are 3.4 kW. The facility has a geothermal heat pump with a rated capacity of 12.5 kW. This heat pump was manufactured and installed by SRL "Climatehnic" in November 2020.

Heating and cooling of the building take place with the help of pipes embedded in the floor structure, as well as in the walls. In the building under consideration, the Multilevel^{tm} technology proposed by the Swedish company Thermotech was applied. This technology is described in [17]. In this building, the floor heating on the first floor is made according to standard technology, with insulation under the pipe, to avoid heat loss to the ground, on the second floor, the floor heating piping is located directly on the floor slab. The thermal calculation of the heating system was performed using the Valtec calculation program. The power of the warm floor was insufficient, therefore, pipes with a heat carrier were additionally installed in the wall panels placed under the windows of the first floor (figure 6).

Figure 6. Location of pipes with coolant in the walls.
(*SRL "Climatehnic" photo*)

Operation during 2020-2021 showed a high level of comfort in both heating and cooling modes. A gas condensate boiler was installed as a backup heat source, but it was not used during the heating season 2020-2021.

This heat pump is equipped with a Mitsubishi LNB42FSAMC compressor. The main parameters of the refrigeration circuit as of December 15, 2021 were: pressure in the circuit 6.14 Bar; boiling point of the Freon R410C -3.4 °C; Freon condensation temperature 33.6 ºC; outdoor air temperature 1.3 °C, compressor frequency 30 Hz. Under these conditions, the compressor capacity was 5.5 kW. Taking into account the consumption of the compressor, circulation pump, and control unit, the calculated *COP* of the heat pump is:

$$COP = \frac{5.5}{(1.2+0.045+0.035)} = 4.23 \quad (2)$$

Table 1

Main indicators of objects

Indicators of objects	Residential building in the village of Cania	Residential building and a dental clinic in the city of Comrat	Residential building in the city of
Number of levels	1	3	2
Surface, m^2	118 $м^2$	600 $м^2$	250 $м^2$
Exterior walls Ceiling	400 mm limestone 200 mm clay	400 mm limestone, 160 mm reinforced concrete	400 mm limestone, 160 mm reinforced concrete
Thermal insulation [18]: - exterior walls - ceiling - floors	100 mm foam 100 mm mineral wool 50 mm polystyrene	100 mm mineral wool basalt 300 mm foam 50 mm polystyrene	100 mm mineral wool basalt 150 mm mineral wool 30 mm PIR panels
Heat pump capacity	5 kW	18 kW	12.5 кW
Heat pump technology	GHPs with direct heat exchange	GHPs with direct heat exchange	GHPs with direct heat exchange
Total probe length	120 m	300 m	250 m
Technology geothermal circuit	Diagonal loop pipe material - copper	Diagonal loop pipe material - copper	Diagonal loop pipe material - copper
Soil	Clayey water-saturated	Clayey water-saturated	Clayey water-saturated
Backup heat generator	Wood burning stove	Gas condensing boiler	Gas condensing boiler
Heating/cooling system	Warm floor	Warm floor, fan coil units	Warm floor, wall panels
Ventilation system	Natural	Mechanical supply and exhaust with heat recovery	Natural
Hot water supply	Indirect heating boiler 150 L	2 consecutive indirect heating boilers of 200 L each	Indirect heating boiler 200 L
Calculated average COP* of a heat pump for heating	4.28	4.6	4.23
Initial investment**, EUR	3225	6550	5200
Electricity consumption for the heating season, kWh	2463	7256	3146

Note. *- calculated COP of the system, based on the actual, operational, parameters of the heat pump; **- as an initial investment for heat pumps, we take the cost of a heat pump together with a geothermal circuit.

3. Conclusions and Recommendations

Having considered practical examples of the implementation of geothermal heat pumps, the following **conclusions** can be made:

- heating f residential individual buildings using gas boilers is by far the most common option, but more and more factors are forcing us to find out alternative, reliable, and sustainable energy sources. These factors are: the depletion of world hydrocarbon resources, the rising price of natural gas, the unpredictability of natural gas supplies; the lack of widespread gasification; and the need for air-conditioning housing in the warm season;
- the use of heat pumps in residential buildings is in many cases an energy-efficient and economically justified solution, leading both to saving of non-renewable energy resources and to protecting the environment by reducing CO_2 and other harmful greenhouse gas emissions into the atmosphere;
- operating experience of geothermal heat pumps shows that they can act as an efficient generator of heat and cold in the conditions of the Republic of Moldova and are most efficient when used in both heating, cooling, and hot water modes;
- in the conditions of Moldova, where clay soils prevail, it is reasonable to install a vertical heat exchanger for a geothermal heat pump;
- the use of a geothermal heat pump and radiant heating/cooling system (walls, floor, ceiling) ensures indoor comfort throughout the year;
- considering that the envelope of the examined buildings was thermally insulated and the real average outdoor air temperature for the heating period is 2-3 °C, no auxiliary heating source was needed.

Recommendations for the use of heat pumps:

- considering the rather high building density in the Republic of Moldova and the relatively small areas of land for individual buildings, it is usually difficult to allocate space for the location of the geothermal circuit, one of the solutions to this problem is to use the diagonal loop method of installing geothermal probes, the essence of which is drilling probes from one receiver at an angle, this allows you to cover a large amount of soil without occupying a large area and without carrying out bulk earthworks, which reduces the cost of developing of the circuit (loop);
- taking into account the growth in electricity and gas tariffs and the rate of inflation in the Republic of Moldova, the demand for the installation of heat pumps for heating residential buildings will increase.

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