CONSIDERATIONS ABOUT EFFICIENT USE OF GEOTHERMAL HEAT PUMPS

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REZUMAT.. Pompele de căldură sunt văzute ca nişte soluţii raţionale, durabile de valorificare a cantităţilor de căldură preluate din mediul ambiant, cu un consum redus de energie şi în condiţii de poluare minime. Lucrarea studiază patru cazuri distincte, diferenţiate de temperatura aerului exterior, caracteristică fiecăreia dintre cele 4 zone climatice în care este împărţită România. Se determină eficienţa energetică şi economică a utilizării pompelor de căldură pentru încălzirea unei locuinţe unifamiliale în fiecare dintre cele patru cazuri analizate.

Cuvinte cheie: pompe de căldură geotermale, coeficient de performanţă la încălzire, valoarea investiției.

ABSTRACT. Heat pumps are seen as some sustainable and rational solutions to use the heat taken from the environment, with low electricity consumption and in minimal pollution conditions. This paper studies four different cases, differentiated by outdoor air temperature characteristic each of the four climate areas where is divided Romania. Thus are determined the energy efficiency and economic use of heat pumps for heating for a house in each of the four analyzed cases.

Keywords: geothermal heat pumps, heating seasonal performance factor, investment value.

1. INTRODUCTION

The purpose of this paper is to underline the importance of efficient use of heat pumps in current international energy context. In the last decade all official EU documents are focused on increasing energy efficiency, using of renewable energy technologies and reduce greenhouse gas emissions [1]. Heat pumps are seen as some sustainable and rational solutions to use the heat taken from the environment, with low electricity consumption and in minimal pollution conditions. Ground source heat pumps (GSHP) are very important because source of the energy is renewable energy source and thus the emissions of greenhouse gases are reduced.

In this paper is studied the efficiency of geothermal heat pumps used for residential heating. Geothermal heat pumps which are also called ground source heat pumps uses earth as heat source. Earth can be considered a good source of heat, given its constant temperature at acceptable levels and possibilities of accumulation over time and space, as is shown in fig. 1 [2].

The most important factors that characterize the ground from thermal point of view are thermal conductivity, density, specific heat, and moisture content. It is known that the evolution of ground temperature is practically constant at about 15 m depth and is equal to the average annual temperature of the exterior air. The temperature of the earth is bigger than the air temperature in winter and smaller than the air temperature in summer. It is also important to note that ground temperature does not depend on outside air temperature variation.

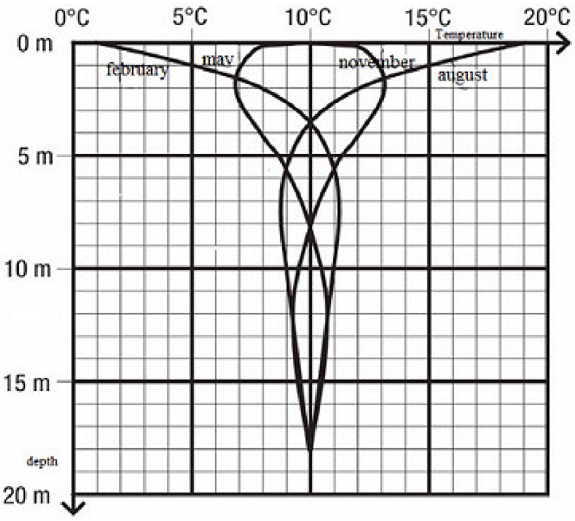

Fig.1. Variation of the temperature in the upper earth crust

Geothermal heat pumps consumes about 25% less electricity for heating than heat pumps that use air as the heat source, and in the same time these have low-cost maintenance and are reliable. Finally, ground source heat pumps are very environmentally clean systems with reduced carbon footprint. Like disadvantage it can be mentioned the installation cost.

2. THE CONSIDERED DWELLING BUILDING FOR PRESENT STUDY

A new individual dwelling building with ground and one floor (G+1Fl) is studied. The house is placed in urban environment. The front facade of the building is South- directed and the opposite facade, North-directed, covers the secondary entrance in the building. The perimetral opaque building elements, the exterior walls, are made from 30 cm brick masonry and are covered with thermal insulation – expanded polystyrene by thickness of 5 cm. The windows are double glazed windows with PVC panels and are improved with low-E glass and Argon gas filling. The PVC panels are with five interior chambers. The inside structural walls of the building are made of brick masonry of 25 cm thickness and the inside non-structural walls are made of 10 cm thick BCA masonry. The roof is made of wood elements with mineral wool insulation and a metal sheet envelope. The attic is unheated. The house has a natural ventilation system. The areas of the rooms of studied dwelling building are shown in table 1.

Table 1

Areas and temperatures of the rooms

Room	Temperature θ_j [^{0}C]	Area, A_j [m^2]	Height, [m]
Ground Floor			
Kitchen	18,00	16,00	2,60
Living room	20,00	20,00	2,60
Batthroom 1	22,00	5,16	2,60
Pantry	18,00	4,20	2,60
Hall1	18,00	16,69	2,60
Entrance Hall	18,00	8,19	2,60
Stairwell	18,00	5,52	5,35
First Floor			
Master Bedroom	20,00	20,00	2,60
Second Bedroom	20,00	16,00	2,60
Third Bedroom	20,00	16,69	2,60
Bathroom 2	22,00	9,80	2,60
Hall1	18,00	7,86	2,60

The heated area is 146,10 m^2 and the internal volume is 395,05 m^3. Average internal temperature of the building is calculated with formula 1.

$$\theta_i = \frac{\sum_{j=1}^{n} \theta_j \times V_j}{\sum_{j=1}^{n} V_j}, \text{ [}^o\text{C]} \quad (1)$$

Where V_j , [m^3] – volume of room j. θ_i =19,35 ^{o}C. The temperatures of each room are chosen in accord cu national standard SR 1907-2 [3].

Table 2 introduces the thermal features of the elements of the building envelope: areas of building envelope components S_k, [m^2], and adjusted thermal resistances R_k', [m^2*K/W], where k- component of the building envelope. The adjusted thermal resistance is calculated considering the effect of thermal bridges.

Table2

Thermal features of the elements of the building envelope

Element of building envelope	S_k [m^2]	R_k' [m^2*K/W]
Exterior Walls	182,83	2,48
Windows and Exterior Doors	23,15	0,96
Attic Flooring	80,50	2,88
Ground Flooring	80,50	2,87

3. THE INFLUENCE OF THE OUTDOOR TEMPERATURE ON THE HEAT REQUIREMENT OF THE BUILDING AND ON ITS ENERGY CONSUMPTION

This paper studies four different cases, differentiated by dimensioning outdoor temperature, characteristic each of the four climate areas where is divided Romania. Architectural features, construction and orientation of the dwelling building are the same for each case. Determination of the heat requirements of the building is realized in accordance with national standard SR 1907-1, calculating the heat losses [4].

Heat load of a building is determinate by the rates of heat transfer between the interior and exterior under extreme conditions. Heat demand for domestic hot water for the analyzed building is calculated, too.

The computation of the annual energy needs for space heating is based on the energy balance of the building. Energy balance of a building refers to the sum of the heat losses (e.g., heat going through the roofs, external walls and windows) being equal to the sum of the heat gains (e.g., passive solar gains, internal gains and active heating).

According with national regulation Mc 001 and with SR EN ISO 13790 is necessary to know [5], [6]:

- Transmission and ventilation properties;
- Heat gains from internal heat sources, solar properties;
- Climate and wind data;

- Inside temperatures and ventilation rate.

For all four considerate cases, ventilation rate is n_a=0,5 h^{-1}. Length of heating season for all four cases is determinate using the national standard SR 4839 [7]. Constanta, Bucuresti, Bacau and Brasov are the four chosen cities like characteristic for the four climatic zones. Table 3 shows the climatic data and the calculated number of degree-days for each city. Number of degree-days is computed according with thermal inertia of the building and with solar heat gains.

Table 3

Climatic data and number of degree-days

City	Climatic zone	Wind zone	θ_e, [°C]	θ_{eo}, [°C]	*HDD*, [degree.days]
Constanta	1	2	-12	12	2900
Bucuresti	2	2	-15	12	3223
Bacau	3	3	-18	12	3648
Brasov	4	4	-21	12	4011

ϑ_e - Dimensioning Outdoor Temperature, ϑ_{eo} - Temperature at which heating needs stop, *HDD* - Number of degree-days.

The dimensioning outdoor temperatures from SR 4839 have very closely with the calculated values with METEONORM software. The variation of daily values of exterior air temperature in Bucuresti is given in fig. 2 [8].

Fig.2. Daily values of exterior air temperature in Bucuresti

The numerical results for buiding heat load, annual energy needs for space heating (SH), annual energy needs for domestic hot water (DHW) for all four cases are presented in table 4.

Table 4

Numerical results: heat load, annual energy needs for SH and DHW

City	P_{SH} [kW]	P_{DHW} [kW]	Q_{SH} [kWh/yr]	Q_{DSH} [kWh/yr]
Constanta	7,96	4,39	8885,59	5729,59
Bucuresti	8,63	4,39	10516,36	5729,59
Bacau	9,21	4,39	12337,07	5729,59
Brasov	9,92	4,39	13520,42	5729,59

P_{SH} - heat load, P_{DHW} – requirement heat for domestic hot water, Q_{SH} – annual energy needs for space heating, Q_{DSH} – annual energy needs for domestic hot water.

4. THE CHOOSING OF REQUIRED HEAT PUMP

The objective of this paper is to study energy and economic efficiency of a ground source heat pump. So, this type of heat pump will be chosen.

Ground source heat pump (GSHP) transforms the energy of earth into necessary energy to heat a building and energy for preparing hot water domestic. The work principle is the same like from refrigerators, based on a reverse thermodynamic cycle. The operating regime is the monovalent regime. The heat pump has an additional energy source - an electrical resistance heater. Fig.3 shows the scheme of the ground source heat pump which is used for heating a dwelling building and for hot water domestic.

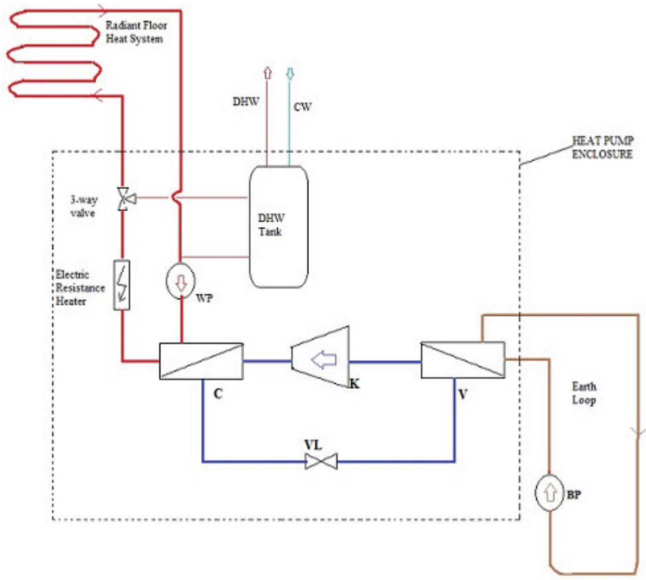

Fig.3 Scheme of the ground source heat pump
V- evaporator; K- compressor; C- condensator, VL- expansion valve; DHW Tank- boiler for domestic hot water, WP- water circulation pump; BP- brine circulation pump.

In evaporator, which is a heat exchanger, the refrigerant fluid absorbs heat from brine from ground loop and evaporates. The compressor serves two main purposes: to circulate the refrigerant fluid through the circuit like a pump and to compress and raise the pressure and temperature of the refrigerant gas. In condensator, compressed refrigerant gas is condensed to a liquid and the heat is absorbed by the circulating water in heating system. The high temperature liquid refrigerant passes through expansion valve. Here the pressure and temperature of the refrigerant drops significantly and then liquid flows to the evaporator. The cycle starts again [9].

The GSHP system has three important components:

- ✓ a heat pump;

- ✓ an earth connection;
- ✓ Heating distribution system.

The studied dwelling building is placed in the urban environment. So, it is almost impossible to use horizontal collectors to retrieve the energy from earth, due to the required large space.

Therefore like earth connection will be used vertical collectors which are, in fact, heat exchangers which draw and transport the energy from the earth, using an antifreeze mixture (ethylene glycol, in this case) which circulates in a ground loop. Vertical collectors have the advantage of a reduced surface, but have the disadvantage of high cost for drilling. The cost of drilling is variable depending on soil type and depth of drilling. The ground loop consists of several lengths of polyethylene or polypropylene pipe buried in vertical holes with U-bend or double U-bend at the bottom. The remaining room in the hole is filled with bentonite or sand- bentonite mixture. Each borehole is 0,1÷0,5 m in diameter and distance between vertical collectors is minim 6m. Thus the collectors have little influence on each other, ensuring good regeneration in summer. In this paper are used polyetylene U-pipes, consisting of a pair of straight pipes like in fig. 4.

The required loop length is calculated in function of heat load, soil type, and conductivity of soil. VDI 4640-2 reccomands in the case of small systems with a heat pump heating capacity of up to 30 kW the using of specific heat extraction values from table 5 [10].

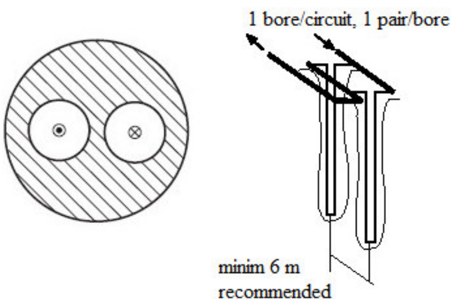

Fig.4. Example of a borehole with U-pipe

Building's heating system is under floor heating with the flow temperature 35 °C.

A monoenergetic regime means that maximum power cannot be covered only heat pump, but must be supplemented by an auxiliary electric heater. It is important that the percentage of direct electricity to be as small. It takes into account the coverage of 75% of compressor power.

Logatherm heat pumps are chosen for the 4 different houses situated in 4 different cities, as Table 6. The pipes of vertical collectors are from polyethylene (32 mmPE) [11].

Table 5

Specific heat extraction values of the underground

Underground	Specific heat extraction values [W/m]	
	For 1800 h	For 2400 h
Gravel, Sand, dry	<25	<20
Gravel, Sand, water-saturated	65-80	55-65
The strong flow of groundwater in the gravel, sand	80-100	80-100
Clay, silt wet	35-50	30-40
Chalk (massive)	55-70	45-60
Cemented sand	65-80	55-65
Acid igneous	65-85	55-70
Alkaline igneous	40-65	35-55
Gneiss	70-85	60-70

Logatherm heat pumps are chosen for the 4 different houses situated in 4 different cities, as Table 6. The pipes of vertical collectors are from polyethylene (32 mmPE) [11].

The evaporator power is calculated with the next relation:

$$P_V = \frac{(P_{SH} + P_{DHW}) \times (HSFP - 1)}{HSFP}, \text{ [kW]} \quad (2)$$

Where P_v – evaporator power, *HSFP* - heating seasonal performance factor. *HSFP* is defined as the ratio of the heat delivered and the total energy supplied over the season.

The length of pipe is calculated as a ratio between power of evaporator and specific heat extraction value. This value is chosen from the table 5, considering soil type – wet clay for all the four cases.

Annual running time of the heat pump is calculated for simultaneously operation for heat production for space heating and domestic hot water.

5. INITIAL INVESTMENT COSTS, ANNUAL ENERGY COSTS, PAYBACK PERIOD

The initial investment costs C_t are calculated with following relation:

$$C_t = C_e + C_i - S \quad , \quad \text{[lei]} \quad (3)$$

Where C_e - equipments costs, [lei]; C_i – installation costs, [lei], S – subvention from „Green House Program". In the costs of equipments are included the costs with heat pump, the cost of all pipes, the cost of refrigerant, the cost of brine, the cost of circulation pumps and others costs with included equipments. The cost with automation part is included in heat pump price. The installation costs consist of the drilling cost in principal and the labor cost.

Table 6

Characteristics of selected heat pumps

Characteristics	U.M.	Constan□a	Bucuresti	Bacau	Brasov
Heat pump type		WPS6K	WPS6K	WPS6K	WPS7K
Heat Output* (0/35)	kW	5,9 (14,9)	5,9 (14,9)	5,9 (14,9)	7,3(16,3)
Refrigerant fluid for compressor		R407c	R407c	R407c	R407c
COP** - technical data		4	4	4	4
DHW- tank integrated	l	185	185	185	185
Compressor type - electric		Mitsubishi Scroll	Mitsubishi Scroll	Mitsubishi Scroll	Mitsubishi Scroll
Emitted energy from heat pump	kWh/yr	14615,18	16245,95	18066,66	19250,01
Energy required to run heat pump	kWh/yr	4460	4860	5320	5670
Additional heat source	kWh/yr	0	20	140	10
Annual running time of the heat pump	h/yr	2500	2770	3100	2750
SFP		3,28	3,35	3,42	3,40
Evaporator power	kW	9,44	10,04	10,59	11,10
soil type		wet clay	wet clay	wet clay	wet clay
Specific heat extraction values	W/m	40	40	40	40
total collectors pipe length	m	236	251	265	278
Number of boreholes		3	3	3	3
Length of one borehole	m	79	84	88	93

- * Considering the electric resistance heater. The energy required to run the heat pump is the energy volume required to run the heat pump's compressor and circulation pumps.
- ** COP – is the coefficient of performance and is defined like the ratio of heat output to the amount of energy input of a heat pump.

Annual energy costs C_w cover the costs with energy required to run heat pump (for compressor and for circulation pumps) and for electric resistance heater:

$$C_W = (W_K + W_{BP} + W_{WP} + W_{EHR}) \times p_e \text{, [lei/yr]} \quad (4)$$

Where W_K - electricity consumed for compressor, [kWh/year], W_{BP} - electricity consumed for brine pumps, [kWh/year], W_{WP} - electricity consumed for water pump, [kWh/year], W_K - electricity consumed for compressor, [kWh/year], W_{EHR}- electricity consumed for electric heat resistance, [kWh/year], p_e – price of electricity, [lei/kWh].

If it is used for heating and domestic hot water a direct heating electric boiler the cost of the energy consumed in a year C_E would be:

$$C_E = W_e \times p_e \text{, [lei/yr]} \quad (5)$$

Where $W_e = Q_{SH} + Q_{DHW}$, [kWh/yr].
Yearly savings E_t is determinate with relation 6:

$$E_t = C_E - C_W \quad \text{[lei/yr]} \quad (6)$$

Payback period T_{rec} is evaluated with next relation:

$$T_{rec} = \frac{C_t}{E_t} \quad \text{[yr]} \quad (7)$$

6. CONCLUSIONS

As shown from calculations, the geothermal heat pumps are a viable alternative for heating and domestic hot water for dwelling buildings in Romania, for any climate zone. Payback period is acceptable, given that the average life time of a heat pump is of 20 years, and the price of electricity and natural gas is continuously increasing.

Very important in making a decision is the cost of drilling. The study has considered a cost of 130 lei / ml drilling. This differs greatly, as well as heat pump performance by the soil type. A great influence on the heat pump operation and on the payback period has the thermal insulation of the building, too.

Table 7

Economical indicators

Indicators	U.M.	Constan□a	Bucuresti	Bacau	Bra□ov
P_e	lei/kWh	0,465	0,465	0,465	0,465
S	lei	8000	8000	8000	8000
Cost of heat pump	lei	23822	23822	23822	25542
Drilling cost	lei	30573	32508	34056	35991
Cost of pipes, refrigerant, etc.	lei	3000	3000	3000	3000
Labor work	lei	5955,5	5955,5	5955,5	6385,5
Initial investment costs	lei	52351	54286	55834	59919
Annual energy costs	lei/yr	2074	2269	2539	2641
Cost of energy consumed in one year for a direct heating electric boiler	lei/yr	6796,058	7554,37	8401	8951,25
Yearly savings	lei/yr	4722	5285	5862	6310
Payback period	yr	11,08	10,27	9,52	9,50

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