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Energetic Efficiency Evaluation by Using Ground-Water Heat Pumps

Romania has significant energy potential from renewable sources, but the potential used is much lower due to technical and functional disadvantages, to economic efficiency, the cost elements and environmental limitations. However, efforts are being made to integrate renewable energy in the national energy system. To promote and encourage private investments for renewable energy utilization, programs have been created in order to access funds needed to implement these technologies. Assessment of such investments was carried out from technical and economical point of view, by analyzing a heat pump using as heat source the solar energy from the ground.

***Keywords**: heat pump, renewable energy, energetic potential, heating, horizontal collectors, efficiency*

1. Sustainable development strategies for reducing energy consumption

The sustainable development prerogatives in construction in terms of rapid depletion of the conventional resources aim to establish the necessary measures to ensure energy resources. The construction field in terms of buildings and their utilities recorded the highest specific energy consumption and therefore sustainable development strategies are setting out analysis lines to reduce the energy consumption while performances are increasing.

In this regard are noted as analysis directions the following considerations:

- The performance improvement of building outer cover by using thermo insulation and building materials with phase change, insulated windows, structural and geometric configurations optimization;
- Enhancing systems integration of renewable energy;
- The accomplishment of more efficient whole system of production, transport and energy distribution by applying the integrated management of resources,

systems regulation and automatization, through rehabilitation, reorganization and modernization.

Measures required to avoid the effects it would have the depletion of energy resources is based on providing more energetic efficiency of buildings by reducing the energy consumption from production to exploitation, development and optimization of renewable energy sources utilization and research of those unexplored yet.

It requires that the goals of sustainable development on the high comfort level to overlap with measures on the energy consumption reduction.

The gradual depletion, but undoubtedly, of the conventional fuel reserves in correlation with the obligation to protect the environment, requires the green energy sources utilization. In this regard, in terms of heating systems, heat pumps (PDC) equipment is clean, safe, efficient and innovative and has the advantage of economic operation.

2. Considerations regarding the heat source selection

At present, the heat sources diversity, make very difficult the choice of heating solution for new buildings. Regarding the tertiary sector, the more common heating solution is or central heating system or individual heating with thermal power stations on gas, liquid or solid fuels. By using the renewable energy for heating has experienced a significant evolution, which on the one hand, requires considerable investment costs, and on the other hand, the payback period can exceed the system life.

In other words, not all renewable energy sources can be used with efficient heating systems. In this regard, solar heat stored in the ground, air and water is effective in providing the heat required for heating. Wind energy and biomass presents high efficiency in electricity generation and the solar energy has a high efficiency in domestic hot water production [1].

Although the sun is everywhere, is free and easy to capture, classical systems of solar power (solar panels) used for heating spaces is a concept without a logical justification. Due to low thermal inertia of solar panels, low temperatures in cold periods, short period of solar radiation in summer, solar collectors heating systems are inefficient, but can be used as heat supply in combination with other heating systems. On the other hand, high investment and operating costs are not justified by systems efficiency.

In choosing the renewable energy solution in order to provide heat for a building are competing several factors which can be individually or globally analyzed. Among the most important are economic factors, thermal comfort, the system efficiency, environmental protection, conventional energy reserves conservation, etc.

From the overall analysis of these factors one can say that a combined heat pump and solar panels can be the most favorable solution. Thus, in the summer

(June-September) solar panels provide high efficiency for hot water preparation and can contribute to heat supply in winter (from October to April). Regarding the heat pump, it shall be sized to provide full heat demand for heating and hot water and during warm periods can be used for air conditioning.

On the other hand, choosing a heating system based on heat source type depends on the size, insulation and destination of the building, the degree of comfort, the existence of restrictions on renewable energy source, the existence and availability of conventional energy sources close to the building, facilities by government programs for certain types of energy.

3. The dimensioning of heating system with ground-water heat pump

To reduce the energy consumption at national level, an important role is the measures consumption for providing the energy efficiency in public and tertiary sector.

For new buildings is recommended to encourage by subsidies to users, the renewable heating systems implementation. Thus, heat pumps prove their efficiency if their dimensioning is correct.

Heat pump sizing shall be based on the capacity on the evaluation of the natural heat source (the ground, air, water) thermal capacity, the heat required for heating and/or cooling and/or domestic hot water production, but also on the electrical power required for pump to transfer energy from the environment to indoor.

The heating capacity of the soil is determined by the temperature variation which is influenced by the soil properties, climate conditions related to season and climate, geological conditions depending on altitude and latitude, but also on the collectors layout. In this respect, the choice of ground - water heat pumps, for the building design depends on the land surface and the heat requirement. In cases where the heat can be provided by the heat pump the system will be combined with a classic equipment to compensate the difference in thermal load.

3.1. Determination of the heat required and heat pump selection

It was analyzed a heating system for a new building with good insulation, with a surface area S = 150 m^2. The heat pump installation dimensioning was carried out by computing the heat required, based on standards [2], [3], [4]. Therefore, for the considered construction a specific consumption of 50W/m^2 is estimated.

The heat required is:

$$\dot{Q}_{req} = q_{estimated} \cdot S = 50 \cdot 150 = 7500 \ [W] \tag{1}$$

Where:

The heat required computation was made for an outdoor temperature of 15°C and in order to ensure the indoor temperature of 24°C. Maximum temperature of the pump delivery circuit is of 55°C. According to current standards methodology, the heat required for the building was determined; equal to 7.5kW it is known that the soil throughout the year has a temperature between 8°C and 12°C at a depth of 180cm. This means less energy consumption because the energy extraction is performed at moderate temperatures.

It is considered that the soil in which shall be placed the pipes circuit, represents a land sufficient wetted with a high mineral content, which gives it storage capacity and thermal conductivity corresponding to its use in heat pump heating systems. The values of specific extraction power Q_E for the soil are presented in the literature. The surface soil should be determined according to the cooling capacity of the heat pump Q_0. The heat pump cooling capacity Q_K is calculated as the difference between its thermal power Q_P and the power consumption P_P [5], [6]:

$$\dot{Q}_K = \dot{Q}_P - P_P = 7.5 - 1.82 = 5.6kW \quad (2)$$

The ground - water heat pump Vitocal 300-G Type BW108 is chosen. At a constant water temperature of 10°C, the heat pump provides a cooling power of 6.6kW heat output of 8.4kW, power consumption of 1,82kW and a coefficient of performance (COP) of 4.6.

The ground-water heat pump, Vitocal 300-G Type BW108, is electrically operated and can feed 3 heating circuits and a domestic hot water circuit and during summer, by using proper equipment can be used for cooling. The heat pump operating mode is monovalent.

For the heat pump sizing was taken into account the cooling capacity at the operating point (the salt water input temperature of 0°C and the output temperature of 55°C) The characteristic data are presented in Table1, Table 2 and Table 3.

Table 1. Characteristic data for the cooling circuit and the admissible working pressure of Vitocal 300-G Type BW108

Cooling circuit			Admissible working pressure for heating [bar]		Tap	
Working fluid	Filling quantity [kg]	Compressor	Primary circuit	Secondary circuit	Primary flow/ return	Secondary flow/ return
R407	2,3	Scroll with complete hermetic sealing	3	3	11/4″	1″

Table 2. Characteristic data of the primary thermal agent

Capacity [l]	Minimum volumetric flow [l/h]	Flowing resistance [mbar]	Maximum inlet temperature [°C]	Maximum outlet temperature [°C]
2,8	1224	75	25	-5

Table 3. Characteristic data of the secondary thermal agent

Capacity [l]	Minimum volumetric flow [l/h]	Flowing resistance [mbar]	Maximum flowing temperature [°C]
4,5	723	20	60

The verification was performed by using the power chart for the ground-water heat pump [6].

3.2. Dimensioning of required soil surface and the collector placed in the ground

According to [1], by placing collectors horizontally, the energy that can be extracted from the soil depends on the soil quality. Therefore, for the wet soil, the distance between the collectors is of 0.5m, the specific power extraction Q_E=20-30W/m^2 and collector surface between 36 m^2/kWh and 24 m^2/kWh.

The soil surface depending on the power extraction required Q_E, is given by:

$$S_E = \frac{\dot{Q}_K}{\dot{q}_E} \; [m^2] \tag{3}$$

$$S_E = \frac{6600}{25} = 264 \, [m^2 \, sol]$$

In order to extract heat from this surface, several plastic tubes circuits (PE PN10) shall be placed in the soil. The length of each plastic tube circuit has the same size and is provided with available connections and links. Installation is performed with pipe slope towards the building exterior.

For circuits consisting of plastic tubes is generally used a length of 100m.

Solar collectors are placed alongside the ground at a depth of 1.2 m, for the distance between circuits of about. 0.5 m, so that for each m^2 of absorber area to be mounted about 1.43m tube. Therefore, for the designed installation at the soil surface of 264m^2 it results a tube length which is calculated as product between surface SE and density of tubes per m^2.

The number of tubes circuits X (tube DN 25 x 2.3) of 100m length results from equation (4) [5], [6]:

$$X = \frac{S_E \cdot 1{,}43}{100} \quad (4)$$

$$X = \frac{264m^2 \ soil x \ 1{,}43 \ m \ tube/m^2}{100m} = 3{,}77 \ tubes$$

For X = 3.77 tubes, a number of 4 tube circuits were determined. Each circuit is of 100m length. The tubes have the nominal diameter of 25mm x 2.3 mm.

The distributor and collector are mounted outside the building, in a place that is accessible for service or further revisions and are made of PE 32 x 2.9 tubes. The layout distance of PE DN 32 x 3 tubes is around 0.7 m (1.5 m tube/m^2).

Each tube circuit will be blocked separately, at least on the flow direction, in order to fill and vent the collector.

For the heat pump BW108, the required number of tube sections and distributors located in the soil for primary fluid - water heat pump, for power extraction of 25W/m^2, is determined according to Table 4.

Table 4. Distributors characteristic data for primary thermal fluid –water heat pump

Cooling power [kW]	Soil surface required [m^2]	Number of tubes sections required PE 32 x 2,9 with length of 100m	Step pipe laying PE 32 x 2,9 [m]
6,6	265	4	0,7(1,5m tub/m^{2}soil)

Accurate dimensioning is done depending on soil properties and may take place only on site. Tube length does not exceed 100m, thus the pressure losses are covered and therefore the pump power is the one analytically calculated. The supply pipe was sized to a value higher than the circuit tubes, the recommended one being DN 40 - DN60.

The feed pipe has the total length L = 10m that means two tubes, each one 5m length with DN 32 x 2.9 mm diameter.

The supply amount is determined with the following relation:

$$V = circuits \ number \cdot 100m \cdot V_{cond} + L \cdot V_{col} \ \ [l] \quad (5)$$

Where:

L [m]-The supply pipe length;

V_{cond} [l] – The water volume inside the pipe;

V_{col} [l] – The water volume inside the collector, including the salt water amount of the heat pump;

$$V = 4 \cdot 100 \cdot 0{,}327 + 10 \cdot 0{,}521 = 136{,}01\ [l]$$

It is chosen 140l amount of water supply.

3.3. The pressure loss calculation of the collector placed in the ground

The pressure loss was calculated for the collector placed in the ground considering Tyfocor as thermal fluid. From the heat pump data sheet is determined the pump capacity of 1224l/h.

The flow rate on the tube circuits is determined with relation:

$$\dot{V}_{pipe\,circuits} = \frac{\dot{V}_{heat\ pump}}{circuits\ number}\ [l/h] \tag{6}$$

$$\dot{V}_{pipe\ circuits} = \frac{1224}{4} = 306\ l/h/circuit$$

The collector pressure loss Δp is determined by combining the pressure loss on tube circuit (7), pressure loss in the supply pipe (8) and pressure loss into the heat pump (9), computed with the relation (10). The unitary pressure loss R [Pa/m tube] is selected depending on the supply pipe diameters for the determined pump capacity.

Therefore, for pipelines with diameter DN 25 x 2.3 mm, at flow rate in circuits of 723l/h is selected R = 420Pa/m [5] and, for pipes with diameter DN 32 x 3.0 mm, at pump flow of 1224l/h is selected R = 333.3 Pa/m [5].

It is considered a heat pump unitary pressure loss R = 9000Pa.

$$\Delta p_{tube\ circuits} = R \cdot L_{tube\ circuits}\ [Pa] \tag{7}$$

$$\Delta p_{tube\ circuits} = 420 \cdot 100 = 42000\ Pa$$

$$\Delta p_{sup\,ply\ pipe} = R \cdot L_{sup\,ply\ pipe}\ [Pa] \tag{8}$$

$$\Delta p_{sup\,ply\ pipe} = 333{,}3 \cdot 10 = 3333{,}0\ \ Pa$$

$$\Delta p_{heat\ pump} = R \cdot L_{heat\ pump}\ [Pa] \tag{9}$$

$$\Delta p_{heat\ pump} = 9000\ [Pa]$$

$$\Delta p = \Delta p_{tube\ circuits} + \Delta p_{sup\,ply\ pipe} + \Delta p_{heat\ pump}\ [Pa] \tag{10}$$

$$\Delta p = 42000 + 3333{,}0 + 9000 = 54333{,}3 Pa = 543{,}85 mbar$$

3.4. The heat pump efficiency analysis

The theoretical sizing was achieved for an interruption period of 3x2 hours.

For Vitocal BW108 ground-water heat pump, the calculation is performed to assess the electricity demand with [7].

$$\dot{q} = \frac{n_i \, \dot{Q}_{req}}{t_i - t_e} \text{ [kW/h day]} \tag{11}$$

Where:

$\dot{q}$ [kW/h day] - electricity demand;

n_i [h] - number of hours of uninterrupted operating;

$\dot{Q}_{req}$ [kW] - the heat required;

t_i [°C] - indoor temperature;

t_e [° C] – outdoor temperature.

$$\dot{q} = \frac{18 \times 7.5}{24 + 15} = 3.37 \text{ [kW/h day]}$$

Whether a lifetime N_c = 2430h is considered for the entire heating season (4.5 months x 30 days / month x 18 hours operation / day), and the heat pump efficiency of 96%, it can be calculated the power consumption for the considered season with the relation:

$$P_e = \frac{1}{\eta} \cdot q \cdot N_c \text{ [kW]} \tag{12}$$

$$P_e = \frac{1}{0{,}96} \cdot 1{,}87 \cdot 2430 = 4733{,}43 \text{ kW}$$

The price for 1kWh power to consumers for consumption between 2kWh day-3kWh day is 0.53Lei/kWh.

Since the pump has a consumption of 1.82 kWh/day, it will be calculate the fuel cost for the entire winter season by taking into account the value of 0.53Lei/kWh.

4733,43kW·0,53/kWh= 2508,72 Lei

Fuel costs throughout the cold season are of 2509Lei, which represents a cost of 557.5 Lei/month for domestic hot water and heating the analyzed building. A comparative analysis of the heating solution, classical system with central heating versus heat pump for the considered building, is essential in order to choose the heating system, by taking into account the advantages and disadvantages of the two solutions. Therefore, it is known that heat pumps consume 1 kW to drive the compressor and gives 3 kW heat.

Knowing that for the residential customers, the cost of 1kW of electricity is of 0.53USD/kW, and the price for the $1Nm^3/h$ of methane is of 1.26 $Lei/Nm^3/h$ by performing a simple calculation, we obtain:

-The 1kW thermal energy cost with heat pump:

0,53 Lei/kW·1/3=0,176 Lei

- The 1kW thermal energy cost with condensing boiler powered with natural gas (the calorific power of methane is considered 8.8 $kW/Nm^3/h$):

1kW 1,26$Lei/Nm^3/h$·/8,8kW/ Nm^3/h =0,143Lei

Whether is taken into account the cost of the produced thermal energy with heat pump versus condensing boilers, in the same time with the investment costs to achieve the two systems, it is found that the heat pumps utilization is clearly disadvantageous. But if we take into account electricity generation from renewable sources (photovoltaic, wind, etc.) required driving the heat pump, the situation would reverse and it can be said that heat pumps have a significantly higher advantage. Moreover, conventional resource depletion issues, the benefit of emissions significantly reduction and the possibility of using heat pumps as cooling systems in warm seasons, are recommending them as solution in order to ensure the buildings heat/cooling required.

4. Conclusions

The significant difference between the conventional heating systems and heat pumps, is that by capturing heat stored in the ground it is not necessary to produce energy, therefore no chemical combustion emissions. Heat pumps are designed to concentrate the heat soil and distribute it as heat in cold periods, respectively, to extract heat from a building but since the end of summer can be used for hot water or send it into the soil.

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