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TECHNICAL AND ECONOMIC ANALYSIS OF AN UNCONVENTIONAL ENERGY SYSTEM USING GEOTHERMAL HEAT PUMP

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Abstract: *In order to assess energy and economic performances of the climate systems in buildings powered with renewable energies, it is proposed a simulation conducted on the basis of economic indicators: initial costs, operating and performance costs, internal rate of return, payback period, net present value, cost benefit by using an analysis program for renewable energy projects RETScreen International.*

Key words: *analysis, indicators, unconventional energy, heat pump.*

1. Introduction

The study takes into account the energy and economic analysis carried out on a target – social and administrative building – for which has been proposed the replacement of equipments for producing energy for air conditioning (appointed during the study- reference system) with equipments using solar energy embedded in the ground - geothermal heat pumps.

Therefore, the comparison of a reference case - usually conventional technology, and the proposed case - technology to exploit renewable energy is a key element of the structure of the program [1,5].

The comparative analysis was performed for three different systems by type heat exchanger, which equips the cold source:

1. Vertical probe – Dn =150 mm, L= 70m with closed loop ϕ 32 x 3 mm (13 pieces);
2. Horizontal closed loop L= 100 m cu 32x3 mm (L total= 4200 m);
3. Geo exchanger modular type B – Dn=450 mm, L = 50 m (4 pieces).

The building is located in the climatic zone II, on a vacant land that can be used for installation of geothermal heat exchangers related to heat pumps - Fig. 1.

The construction, destined for social administrative center has a floor area of 450 square meters, height regime is ground floor.

The envelope of the building consists of the following elements:

- External walls thermal insulated with expanded polystyrene with 10 cm, R = 3.091 mp K/W thickness
- Triple glazed surfaces with 2 selective coatings and wood joinery R= 0.77 mp K/W;
- Flat roof thermal insulated with mineral wool with 20 cm, R= 4.39

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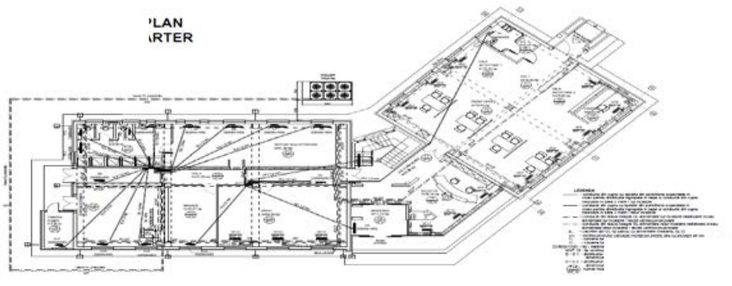

Fig. 1. *Ground floor plan of the building*

- mp K/W thicknes

Plate on the ground thermal insulated with extruded polystyrene10 cm, R= 2.834 mp K/W.

The heat demand for heating and cooling was calculated according to SR 1907/1997 for each of the rooms of the building. The summary on thermal loads (heating /cooling) related to the studied building is presented in Table 1:

Summary on thermal loads (heating /cooling) related to the studied building Table 1

No.	Room cooled / heated	Surface cooled / heated	Ceiling height cooled / heated	Volume cooled / heated	Required heat	Required cold
		m²	m	m³	W	W
P1	Hall 1					
P2	Waiting room 1					
P3	Waiting room 2	130.89	2.60	340.31	9523	9432
P4	Front office					
P5	Toilet 1	8.12	2.60	21.11	-	591
P6	cashier	9.70	2.60	25.22	820	757
P7	Hall + Staircase	31.35	3.00	94.05	-	2351
P8	Reception	32.18	3.00	96.54	3015	2896
P9	Windfang	11.70	3.00	35.10	-	878
P10	Hall 2	31.28	3.00	93.84	-	2346
P11	Electricians locker	51.29	3.00	153.87	-	3847
P12	Toilet 2	26.68	3.00	80.04	-	2001
P13	Office	54.34	2.60	141.28	4386	4239
P14	Storage room	20.37	3.00	61.11	-	1100
P15	Central heating	36.90	3.00	110.70	-	1993
P16	Pump room	7.20	3.00	21.60	-	389
	Total cold / heat required (W)				17744	32820

2. Reference System

The heat flow for heating / cooling the space is provided through fan casing wall or through static radiators - convectoradiators panel of sheet steel - for premises that do not require air conditioning (bathrooms, hallways) [2].

Originally, the building was filled with heating water - hot water - prepared in a condensing boiler gas fuel capacity of 35 kW.

The fluid is cold water (7/12 C^0) produced by the chiller proposed with a capacity of 25 kW that is placed outside the building.

All the abovementioned can be integrated in the "reference system" (outlining the first step in the program RETScreen) accounted for preparing heat for heating (the boiler running on natural gas fuel) and preparation of coolant (in chiller cooled air) [3,4].

A – Reference system – boiler 35 kW; chiller cooled with air 25 kW

3. Proposed System

Even though the solutions which propose classical equipments for the air conditioning of the buildings usually require, lower investment costs, the operating expenses are - most often - quite large.

The solution proposed is the equipment of the building with heat pumps to provide full cooling of the building (without using, in parallel, a

Heat production system - Reference Case Table 2

Heat production system - Reference Case		
Surface of the heated building	m²	450
Fuel flow		Natural gas - kWh
Seasonal efficiency	%	92%
Heat load calculation		
The thermal load of the building	W/m²	50
Required total heat	MWh	64
Total peak heat load	kW	31.5
Fuel consumption - annually	kWh	79.401
Fuel tariff	RON/kWh	0,112
Fuel price	RON	8.893

Cooling production system - Reference case Table 3

Cooling production system - Reference case		
Building cooling surface	m²	450
Fuel flow		Electric energy
Seasonal efficiency		2.9
Building cooling load	W/m²	50
Required total cold	MWh	37
Total peak cold load	kW	22.5
Fuel consumption - annually	MWh	13
Fuel tariff	RON/kWh	0,650
Fuel price	RON	5.206

device that works on the basis of conventional fuels).

It was opted for an air conditioning system in which cold and heat are produced by geothermal heat pump ground-water.

Thus, the thermal energy required to heat / cooling the analyzed space is soil-borne, from which is extracted / injected by means of a heat transfer fluid (ethylene glycol 25% -water).

The heat pump proposed is a pump ground-water with a capacity of 35 kW - REHAU GEO - 37 BC Heating / Cooling and refrigerant R 407C.

The unit of the heat pump has the thermal heating capacity of 34.8 kW at a temperature of the working fluid in the heat exchanger of 0^0 C and 35^0 C in the circuit of heating. Pump coefficient of performance (COP), in these circumstances, is 4.1.

The cooling capacity in the temperature of the working fluid in the heat exchanger 15^0 C and 18^0 C and in the cooling circuit is 46 kW. Energy efficiency (EER) in these conditions is 5 (Fig. 2.)

Fig. 2. *REHAU GEO 37BC Heat Pump*

To highlight energy and economic effects of the implementation of equipment that exploit unconventional energies were analyzed three separate situations in which "key element" was REHAU GEO geothermal heat pump 37 BC.

Heat pump - Heating Table 4

Heating producing system - proposed case			
Technology	Heat pump with mechanical vapor compression		
Fuel	Electric energy		
Fuel cost	RON/MWh	650,000	
Heat pump			
Capacity	kW	35	111.1%
Delivered heat	MWh	64	100%
Sesonal efficiency	%	410%	
Necessary fuel	GJ/hour	0.1	

Heat pump - Cooling Tabel 5

Technology	Heat pump with mechanical vapor compression		
Fuel	Electric energy		
Fuel tariff	RON/MWh	650,000	
Capacity	kW	25	111.1%
EER		6.4	
Delivered coolant	MWh	32	100%

Conditions of the proposed system - Case I Table 6

Heat pump	Unit	Heat	Cooling
Capacity	kW	35.0	25.0
Average load	kW	32	20
Soil type		Moist soil	
Soil temperature	°C	10.2	
The amplitude of soil temperature	°C	22.1	
Ground heat exchanger			
Type	Vertical closed loop		
The design criterion		heat	Cooling
Land surface	m²	150	
Configuration		Standard	
Drilling length	m	875	

It was therefore proposed to replace the existing system of producing energy for cooling of the building (the reference system) with a system - done in several ways - quantified as a case study.

By entering these data on the proposed energy model, the program gives us the opportunity to determine the work strategy, aspect which directly affects the system performance and cost analysis.

The correct evaluation of technical and economic efficiency for a system that capitalizes clean energy is difficult to quantify because in all stages - from design to execution of a project –one can meet so many factors that can not be identified right from the beginning of the work.

To highlight the complexity of such an action it should be specified that a system can be structured in various ways, each with more technological options, and - obviously - different economic implications.

Each case includes information on proposed implementation period, cost, resources required, and the required quality. For choosing the best options in such situations, or can be used certain techniques for analyzing economic performance.

These techniques take into account a number of performance indicators which are determined on the basis of selection criteria, indicators that bring forward information about the variants studied in qualitative and quantitative terms.

To perform this analysis there were taken into account, the following economic and financial indices:

- The price of natural gas in Romania: 1 kWh natural gas= 0.112 lei
- The price of kWh electric energy in Romania: 1 kWh = 0.65 lei
- The value of inflation in Romania 3 %
- The boiler efficiency reference case 80%
- COP split air conditioner reference case: 2.9
- lifetime of the project: 20 years

The cost of implementing a ground-water heat pump system with vertical collectors in moist soil is 166250 RON (Table 7).

The savings from using the system are 19131 RON / year which generates a payback period of approximately nine years, A rate of return of about 10% and a benefit cost ratio of 2.3. The total savings are made up of revenues from the production of renewable energy / clean

(EC) through the capitalization of green certificates and the difference between the energy consumption.The cost of implementing a ground-water heat pump with horizontal collectors in moist soil (sandy wet) is 332500 RON (Table 9).

The savings from using the system are 19131 RON / year which generates a payback period of about 17.4 years. A rate of return of about 2% and a cost benefit ratio of 1.15.The total savings are made up of revenue from the production of renewable energy / clean (EC) through the capitalization of green certificates and the difference between the energy consumption

Financial Analysis Case I Table 7

The costs of the project and the cost savings generated by the project			
Initial costs			
Heating and cooling system	100%	RON	166.250
Total initial costs	100%	RON	166.250
Fuel cost – reference case		RON	13.825
Total annual costs		RON	13.825
Fuel cost – reference case		RON	17.179
Revenue from the production of EC - 20 years		RON	15.777
Total annual savings and revenue		RON	32.956
Financial viability			
RIR after tax -		%	9.7%
Simple payback period		year	8.7
Net present value (NPV)		RON	216,368
Annual savings in lifetime		RON/year	10,818
Cost-benefit ratio (C-B)			2,30

Proposed system conditions - Case II Table 8

Heat pump	Unit	Heat	Cooling
Capacity	kW	35	25
Average load	kW	32	20
Soil type		Wet soil (wet sand)	
Soil temperature	°C	10.2	10.2
The amplitude of soil temperature	°C	22.1	22.1
Ground heat exchanger			
Type	Horizontal closed loop		
Design criterion		Heating	
Land area	m²	1400	
Configuration		Standard	
Loop length	m	4200	

Financial analysis of income from the production of renewable energy - Case II Table 9

The costs of the project and the cost savings generated by the project			
Inital costs			
Heating and cooling system	100%	RON	332,500
Total initial costs	100%	RON	332,500
Fuel cost-reference case		RON	13,825
Total annual costs		RON	13,825
Fuel cost-reference case		RON	17,179
Revenue from the production of EC - 20 years		RON	15,777
Total annual savings and revenue		RON	32,956
Financial viability			
RIR after tax		%	1.4%
Simple payback period		year	17.4
Net present value (NPV)		RON	50,118
Annual savings in lifetime		RON/year	2,506
Cost-benefit ratio (C-B)			1.15

Proposed system conditions - Case III Tabel 10

Heat pump	Unit	Heat	Cooling
Capacity	kW	35	25
Averege load	kW	32	20
Soil type		Wet soil	
Soil temperature	°C	10.2	
The amplitude of soil temperature	°C	22.1	
Ground heat exchanger			
Type	Variable geometry geo modular exchanger		
Design criterion	Heat		
Land area	38 m²		
Configuration	Standard		
Drilling length	20 m		

The cost of implementing a heat pump ground-water heat exchangers modular variable geometry in moist soil (sandy wet) is 123.500 RON (Table 11). The savings from using the system are 19.131 RON / year which generates a payback period of approximately 6.5 years, A rate of return of approximately 14.4% and a cost-benefit ratio of 3.1. Total savings are made up of revenue from the production of renewable energy (EC) by exploiting the difference between green certificates and energy consumption

3. Conclusions

The economic and energy performance simulation for the three cases was conducted through the proposed economic performance indicators (internal rate of the

Financial analysis of income from the production of renewable energy - Case III Table11

The costs of the project and the cost savings generated by the project			
Initial costs			
Heating and cooling system	100,0%	RON	123,500
Total initial costs	100,0%	RON	123,500
Fuel cost – reference case		RON	13,825
Total annual costs		RON	13,825
Fuel cost – reference case		RON	17,179
Revenue from the production of EC - 20 years		RON	15,777
Total annual savings and revenue		RON	32,956
Financial viability			
RIR after tax		%	14.4%
Simple payback period		year	6.5
Net present value (VAN)		RON	259,118
Annual savings in lifetime		RON/year	12,956
Cost-benefit ratio (C-B)			3,.10

return, payback period, NPV, cost benefit) and the resulting conclusions are as follows

▪ The study of the projects by considering the RIR factor involves RIR ≥ 5%. The internal rate of return for geothermal exchanger is 14% compared to vertical collectors (9.7%) and 1.4% - horizontal collectors.

▪ Analyzing the three cases by using the factor abovementioned, the payback period, do the case I is 8.7 years, for the case II a payback period of 17.4 years and for those with a payback III 6 ,5 years.

▪ The cost - benefit is a performance indicator that requires a value greater than 1. Therefore all systems used comply with this condition. For if in case I the cost-benefit ratio is 2.3, for the case II, the cost-benefit ratio is 1.15 and the pump modular geothermal heat exchanger this ratio has a value of 3.1.

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