Tomislav Kurevija

ISSN 0350-350X
GOMABN 47, 5, 355-390
Prethodno priopćenje/Preliminary communication
UDK 550.367 : 621.577.003.1.001.24 : 697.1 : 697.94

ANALYSIS OF POTENTIALS OF SHALLOW GEOTHERMAL RESOURCES IN HEAT PUMP SYSTEMS IN THE CITY OF ZAGREB

Abstract
The values of geothermal gradient and heat flow in the northern Croatia are above the European average which is the principal precondition and the indicator of the potentials of shallow geothermal resources. Still, at the time being they are not adequately used nor valorised in the Republic of Croatia, while in the EU this technology has almost exponential annual increase in the installed capacities. The fact is that Croatia uses two to three times more energy per unit of gross national product than the most of the EU member states, which results in the redundant import of mineral raw materials, higher costs, problems of product competitiveness and services in the European and global market, as well as its negative impact on the environment. Croatia has the technical/technological and distributed infrastructure necessary for the development and implementation of geothermal heat pump technology, but there are not adequate legal regulations, ecological regulations and security requirements which refer to the construction of borehole heat exchangers. The latter is considered to be the most important limiting factor. By means of the RETScreen program this paper presents a technoeconomic analysis of the cost effectiveness of the geothermal heat pump installation when compared to the conventional heating and cooling system on the example of a newly built business building.

1. Introduction

Geothermal heat pumps (GHPs) use the temperature of the geothermal fluid or the earth's soil 5–35 °C, when the direct heating or cooling systems with geothermal energy are not economically effective. Installing the geothermal heat pumps in the EU increases significantly in the last decade, by 20 % a year. The individual GHPs systems can range from 5 kW_t for house heating to larger systems with more than 150 MW. GHP systems are usually used for the heating purposes and the capacity factor ranges from 2000 to 6000 hours a year, depending on the purpose of heating and/or cooling.

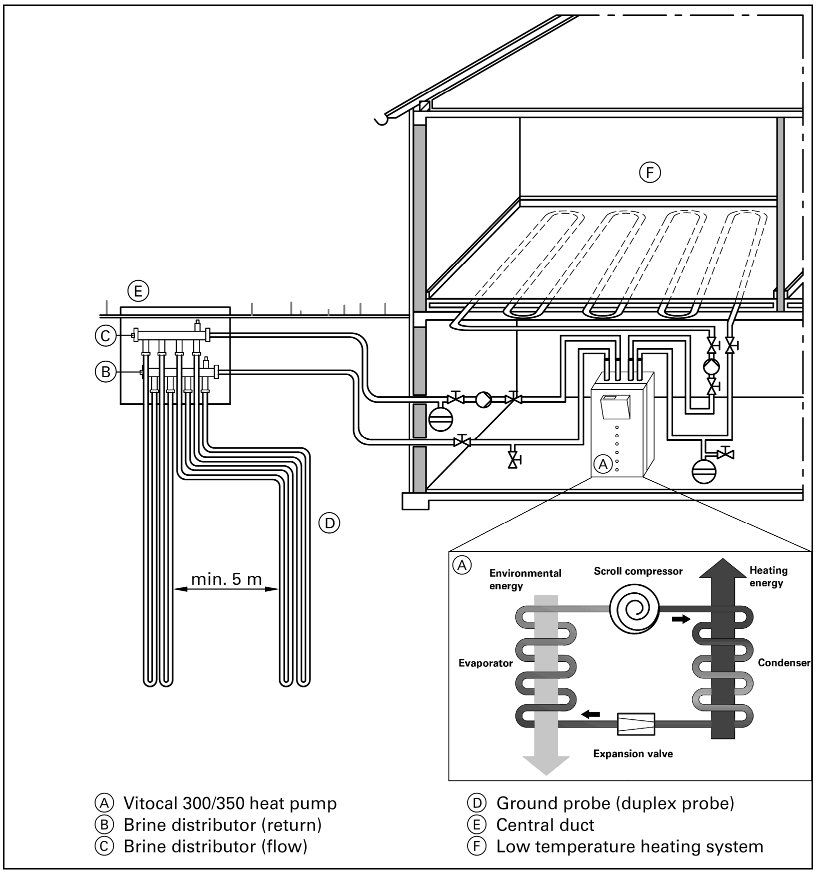
Table 1-1: Increase of the installed power of geothermal heat pumps in the EU [12]

Year	**2003**		**2004**		**2005**		**2006**	
Country	**Number**	**Capacity MWt**	**Number**	**Capacity MWt**	**Number**	**Capacity MWt**	**Number**	**Capacity MWt**
Sweden	146 172	1 334,0	185 531	1 700,0	230 094	2 070,8	270 111	2 431,0
Germany	39 069	507,9	48 662	632,6	61 912	681,0	90 517	995,7
France	38 250	420,8	49 950	549,5	63 830	702,1	83 856	922,4
Denmark	6 700	80,4	6 700	80,4	43 252	821,2	43 252	821,2
Finland	27 100	271,0	30 000	300,0	29 106	624,3	33 612	721,9
Austria	26 373	527,5	30 614	611,5	32 916	570,2	40 151	664,5
Netherlands	1 600	253,5	1 600	253,5	1 600	253,5	1 600	253,5
Italy	6 000	120,0	6 000	120,0	6 000	120,0	7 500	150,0
Poland	8 000	103,6	8 000	103,6	8 100	104,6	8 300	106,6
Czech Republic	2 100	36,0	2 700	47,0	3 727	61,0	5 173	83,0
Belgium	5 000	60,0	5 000	60,0	6 000	64,5	7 000	69,0
Estonia	1 035	10,7	2 190	20,7	3 500	34,0	5 000	49,0
Ireland	1 500	19,6	1 500	19,6	1 500	19,6	1 500	19,6
Hungary	400	4,0	400	4,0	230	6,5	350	15,0
United Kingdom	550	10,2	550	10,2	550	10,2	550	10,2
Others	504	23	537	21,7	919	14,5	1 039	15,7
TotalEU25	**310 353**	**3 782,0**	**379 684**	**4 535,0**	**493 236**	**6 158,0**	**599 511**	**7 328,3**
Switzerland	28620	572,4	33000	660,0				

2. Operating principle of geothermal heat pumps

The basic components of a heat pump are a scroll compressor, a check valve, an expansion valve and two heat exchangers (a condenser and an evaporator). An additional heat exchanger (preheater) can be added due to heating of hot water used. R-407C or R-410A usually serve as the coolants, which do not have the negative effect on the ozone as opposed to freon 12 (CF_2Cl_2) which was initially used.

Figure 2-1: Scheme of a geothermal heat pump [10]



In the cooling cycle the coolant enters the compressor intake throttles in the form of vapour of low temperature and pressure. The compression process increases the pressure and the temperature, and in this part a preheater for the used hot water can be added. When exiting the compressor the vapour is directed towards the heat exchanger (the condenser) by a check valve in the contact with the environment (the borehole heat exchanger). With the vapour under the higher temperature, the heat spreads on the brine in the borehole heat exchanger and the surrounding rocks. The lowering of the temperature results in vapour condensation and due to a small pressure drop in the condenser, the coolant leaves it in the form of a liquid with the temperature insignificantly higher than the environment. Subsequently the liquid enters the expansion valve where a sudden pressure drop occures. Then coolant enters the evaporator where significant temperature drop occures due to evaporation following heat transfer from surrounding air. The recuperator with the forced convection provides the distribution of the cooled air within the interior. The increased temperature leads to the evaporation of the coolant, and then the vapour reenters the compressor through the check valve which ends one cooling cycle.

In the heating process the check valve directs the high temperature vapour when exiting the compressor and entering the heat exchanger (the condenser) in the contact with the interior. In the recuperator the vapour transmits the heat onto the cooler surrounding air, which leads to the condensation, and then the liquid enters the expansion valve where the pressure and the temperature are reduced. Then the liquid enters the evaporator where the heat is transmitted onto the coolant from the borehole heat exchanger which leads to the vaporization. The check valve directs vapour towards the compressor intake throttle where the temperature and the pressure are increased and that means the end of the heating cycle.

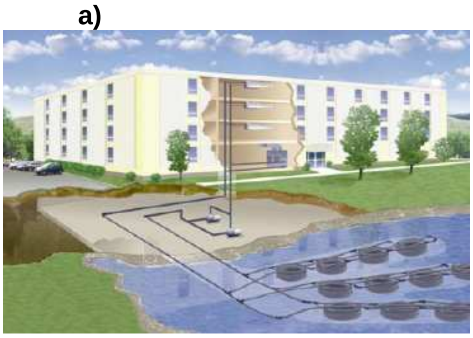
There are two basic types of geothermal heat pump systems: GHPs with closed and open loop systems. These two types can be divided into the following subsystems:

1) Closed loop system: a) vertical boreholes
b) horizontal trenches
c) closed system with surface water
2) Open loop system: d) two boreholes (production and injection wells)

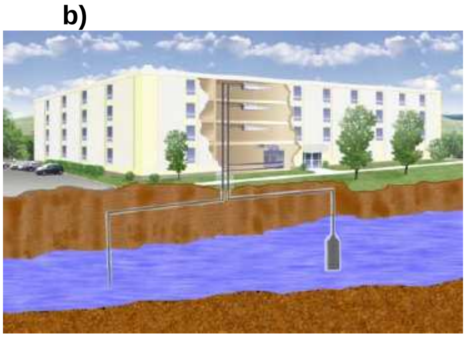
Figure 2-3: Basic geothermal heat pump systems

a)

b)



c)

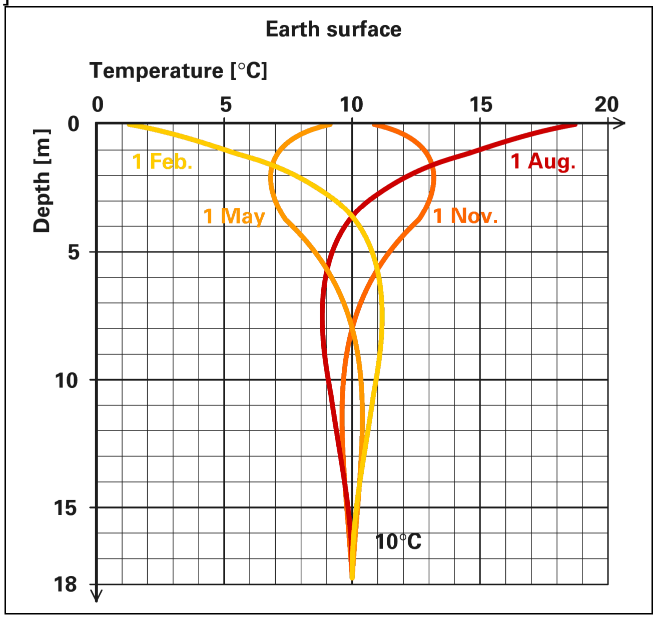


d)

2.1 Geothermal heat pumps with closed loop system

GHP with closed loop system does not exploit the heat of geothermal fluid, but it uses the shallow geothermal energy of the surrounding rocks for the heating of the buried pipes (usually made of plastic) through which operating fluid or brine flow. Liquids of lower freezing point, for example antifreeze blends or methanol, are most frequently used. Shallow geothermal resources are those under 15-200 m where there is no oscillation in temperature caused by the solar radiation, and the temperature increase by the depth functions as the temperature gradient, and the characteristics of rocks. The needed pipe length depends on climate conditions, soil characteristics and heating requirements.

Figure 2-4: Temperature increase by depth and solar radiation influence on the soil temperature [9]



3. Technoeconomic analyis of heating and cooling business building with a geothermal heat pump

For example, a newly built business building in Zagreb has 2000 m^2 of office area with 4 floors and daytime occupancy. As opposed to the conventional heating system with a gas boiler and cooling system with an air conditioner, the borehole heat exchanger system, or in other words the monovalent geothermal heat pump (100% sized for heating), is to be installed. Due to the maximum thermodynamic effectiveness, the building will have the floor heating system (low temperature heating) and the forced convection system for the purposes of cooling.

Based on the chosen equipment, the climatology conditions in Zagreb and the energy requirements of the building, the GHP system is to be compared to the conventional system. The technoeconomic analysis will be used in order to prove the possible effectiveness of the installation. The Viessmann Co. has been selected since this company has been present on the market for years; it has a supply chain network and a repair and install services, and the author had a relevant data for calculations. The euro price is shown for the purposes of easier comparison between the Croatian and global markets of heat pumps. On the basis of the technical-technological data given by the manufacturer of the equipment, the thermodynamic analysis will be done for the Vitocal BW226 brine/water heat pump according to the actual operating regime.

For the complete technoeconomic analysis RETScreen program has been chosen, which originates from the Canadian institution *National Resources of Canada* and which provides the comprehensive global database on the manufacturers of heat pumps and the climatology parameters. It consists of two parts: the technological part, which presents the borehole heat exchanger depending on the characteristics of the location, the equipment, the heating requirements and the saving analysis of greenhouse gasses emissions; and the economic part, which provides the most cost-effective installation model and the exploitation of the shallow geothermal resources with heat pumps by influencing the great part of input parameters.

3.1. Thermodynamic analysis of the heat pump in the loop borehole heat exchanger

Heating load

For the chosen business building of 2 000 m^2 and 4 floors, peak consumption is determined to be f_{og} = 35,3 W/m^2 or 70,6 kW_t peak load (medium thermal insulation).

Coefficient values of the heat flow for the chosen medium thermal insulation are: walls= 0,50 W/m^2°C, roof = 0,33 W/m^2°C, basement = 0,50 W/m^2°C, air exchange rate per hour = 0,50. Window area of the building has been considered as standard (15% of the walls area) and the type of windows in the model were clear insulated double glazed windows with a shading coefficient of 0,81 and a heat transfer coefficient of 3 W/m² °C.

Cooling load

Commercial buildings are characterised by much higher internal heat gains than residential ones. The sources of these internal gains can be very numerous but lighting and office equipment, also called plug loads, usually amount for the majority of internal heat gains in commercial buildings. In the energy model selected heat gains in combination with the type of occupancy have been used to evaluate the total daily internal heat gains.

Required peak cooling load for the peak consumption was calculated as f_{oh} = 49,1 W/m^2 or 98,2 kW peak load (medium thermal insulation). This value included climate conditions load factor and additional value of cooling load which depends on the equipment heat emission within the building such are lightening, technical equipment (~200 W_t/personal computer) and the number of personnel (~140 W_t/person) [11].

Because it was needed to take into consideration the heat losses of each wall and room, calculations of heating and cooling loads were done with software package Rhvac 8.01 with presumed indoor temperature of 20℃ for heating, 26℃ for cooling, as well as existing air humidity of 70% at the location.

Figure 3-2: Technical data for Viessmann Vitocal 300-BW226 heat pump related to the brine temperature (the heat exchanger exit) and the heating temperature [9]

Vitocal 300, type BW 226 and WW 226 (two-stage)

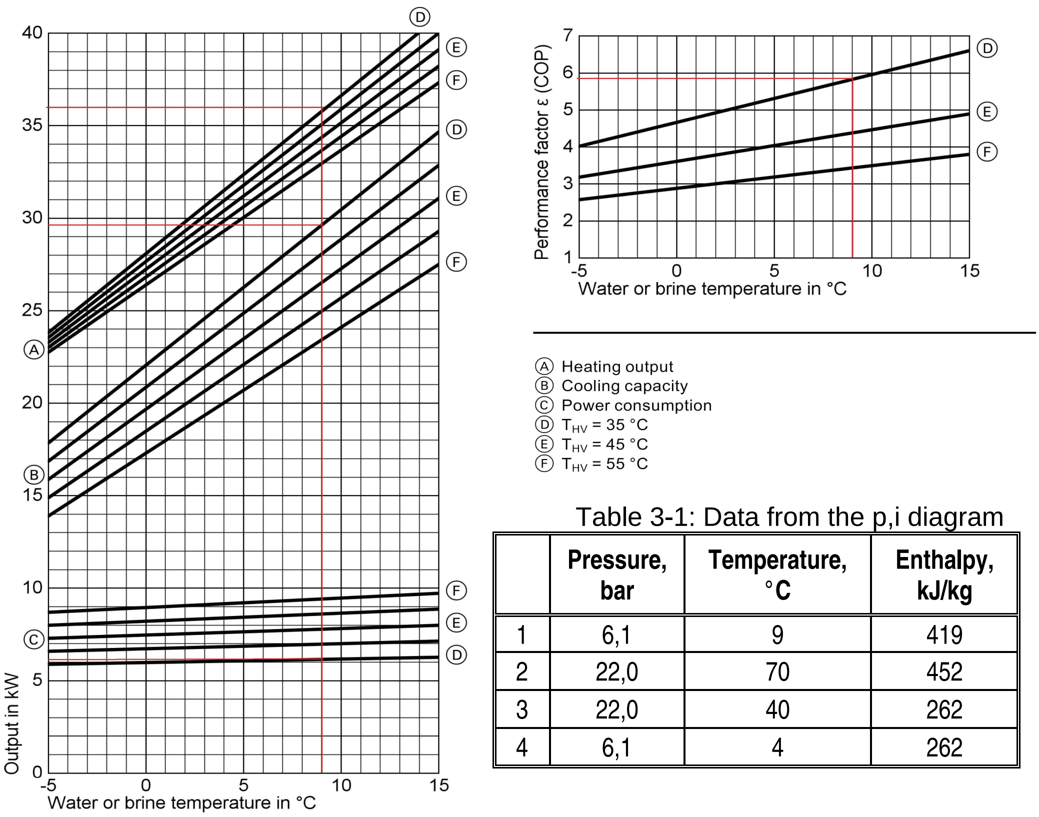


Table 3-1: Data from the p,i diagram

	Pressure, bar	Temperature, °C	Enthalpy, kJ/kg
1	6,1	9	419
2	22,0	70	452
3	22,0	40	262
4	6,1	4	262

Input data necessary for the thermodynamic analysis:

- effective space of the building for heating and cooling : 2000 m^2
- brine temperature when entering the heat exchanger of the heat pump (at the exit from the borehole heat exchanger): t_{gu} ~ 12 °C
- brine temperature when exiting the heat exchanger of the heat pump: t_{gi} = 5 °C (at the entry of the borehole heat exchanger)

- input temperature of the coolant R-407C into the compressor : t_1 = 9 °C
- temperature after the compression: t_2 = 70°C
- condensation temperature: t_3 = 40 °C
- evaporator temperature: t_4 = 4 °C

- floor heating temperature (input): t_{ru}=35 °C
- floor heating temperature (output): t_{ri} =20 °C

Operating cycle of geothermal heat pump

(A) Heat loss

1) The business building area A_z = 2000 m^2 (two geothermal heat pumps in the system, unit surface per heat pump = 1000 m^2)

2) Heat power needed for space heating:

$$Q^* = f_o \cdot A_z = 0{,}0353 \cdot 1000 = 35{,}3\ kW_t = 127{,}08\ MJ/h$$

(B) Unit size

3) Evaporator (1-4):

$$q_o = i_4 - i_1 = 419 - 262 = 157\ kJ/kg$$

4) Compressor work (1-2):

$$e = i_2 - i_1 = 452 - 419 = 33\ kJ/kg$$

5) Condenser (2-3):

$$q_* = i_2 - i_3 = 452 - 262 = 190\ kJ/kg$$

(C) Total values

6) The needed supply of freon R-407C:

$$D_{407C} = \frac{Q^*}{q_*} = \frac{127{,}08 \times 10^3}{190} = 668{,}8\ kg/h$$

7) Water supply in the floor heating system:

$$D_{H2O} = \frac{Q^*}{c_p \cdot \Delta t_{pod}} = \frac{127{,}08 \times 10^3}{4{,}187 \cdot 15} = 2023{,}4\ kg/h$$

8) Vaporization heat, equivalent to the cooling effect in the cooling cycle:

$$Qo = D_{407C} \cdot q_o = 668 \cdot 157 = 104{,}88\ MJ/h = 29{,}1\ kW_f$$

9) Supply of antifreeze blend/brine (50% water/50% ethylenglycol):

$$D_{ras} = \frac{Qo}{c_p \cdot \Delta t_{ras}} = \frac{104{,}88 \times 10^3}{3{,}284 \cdot 7} = 4\,562{,}4\, kg/h$$

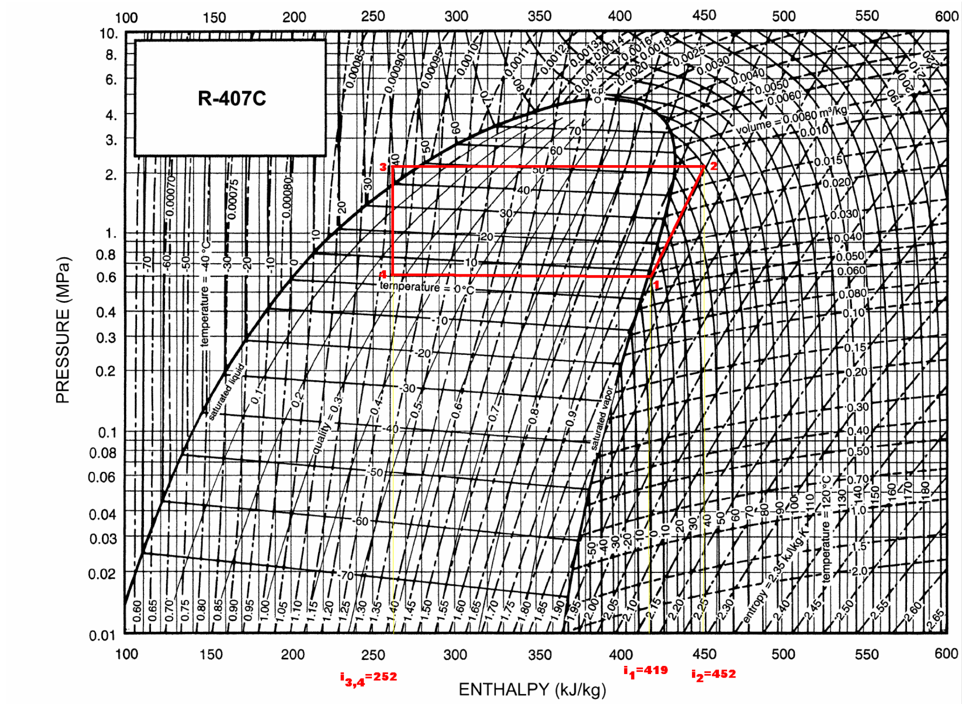
10) Compressor work and power:

$$E = e \cdot D_{407C} = 33 \cdot 668{,}8 = 22\,070\, kJ/h = 6{,}1\ kW_e$$

11) Coefficient of performance:

$$\eta_{COP} = \frac{q_*}{e} = \frac{190}{33} = 5{,}76$$

Figure 3-4: Operating cycle of the heat pump in the pressure-enthalpy diagram of R-407C



This means that 1 kW of electric energy of the compressor mechanical work provides 5,76 kW of useful heat energy. This calculated value matches the nominal value of the COP of the Vitocal BW226 heat pump, from the manufacturer's technical documentation, for the characteristic input data. Such a high COP is possible only when low temperature heating is being used because of low temperature difference between source temperature (temperature of the brine entering heat pump) and delivered temperature (floor heating temperature).

3.2. The results of the technological analysis of a GHP project in comparison to the conventional gas system

For the climatology conditions of the city of Zagreb the values of heating and cooling degree days have been calculated (at the nominal temperature value of 15℃) [1]. Based on data about the soil type, thermal characteristics, the geothermal gradient and peak load in a heating cycle, the depth needed for the borehole heat exchanger has been calculated.

Table 3-2: Geographical and climatology characteristics of the location

Zagreb	Unit	Climate data
Latitude	˚N	45,8
Longitude	˚E	16,0
Altitude	m	123
Designed outdoor temperature (heating)	°C	-13,7
Designed outdoor temperature (cooling)	°C	26,7
Annual amplitude of soil temperature	°C	24,3
Heat transfer of compact soil - damp	W/m	~60
Heating degree day (< 15°C)	°C-d	2 138
Cooling degree day (> 15°C)	°C-d	420
Heavy soil-damp (clay, sand, loam) - Heat Capacity	kJ/kg °C	0,96
Heavy soil-damp (clay, sand, loam) - Conductivity	W/m °C	1,3

Table 3-4: Overview of technological and economical parameters for the given heating and cooling project of the business building with the replaced conventional system (natural gas + air conditioner)

Replaced conventional heating system	Business building – heating project	
Heated floor area for building	m^2	2 000
Fuel type	m^3	Natural gas
Seasonal efficiency	%	75
Heating load for building	W/m^2	35,3
Peak heating load	kW_t	70,6
Domestic hot water heating base demand	%	10
Total heating	***MWh_t***	***104,0***
Annual fuel consumption	m^3	14 682
Fuel cost (GP Zagreb)	€/m^3	0,345 (2,50 kn/m^3)
Total annual fuel price	***€***	***5 065***

Replaced conventional cooling system	**Business building – cooling project**	
Fuel type	kWh_e	Electric energy AC
Seasonal efficiency	%	250
Cooling load for building	W/m²	49,1
Peak cooling load	kW_t	98,2
Total cooling	MWh_t	86
Annual fuel consumption	***MWh_t***	***37***
Fuel unit price (HEP); Orange tariff- for bussiness	€/kWh_e	0,141 (1,02 kn/kWh_e)
Total annual fuel price	***€***	***5 166***

Table 3-6: Overview of the technological and economic parameters of the heating and cooling project for the business centre with the geothermal heat pump

Proposed heating system of the heat pump with the borehole heat exchanger			
Needed space surrounding the building	m²	292	
Total needed depth of the heat exchanger	m	1 098 (6 boreholes×183 m)	
Circulation pump power	kW_e	1,8	
Brine volume in the heat exchanger	m³	0,19	
Needed length of polyethylene pipes for heat exchangers	m	2 196	
Heat pump manufacturer and model	Viessmann Gmbh, Vitocal300 BW226 (2 units)		
Heating capacity of the chosen heat pump model	kW_t	72,0	102 % of peak load
Heating delivered	MWh_t	104	100 % total annual energy needed
Annual electrical energy consumption of a compressor	***MWh_e***	***18,0***	
COP of the heat pump/heating	5,8		
Proposed cooling system of the heat pump with the borehore heat exchanger			
Cooling capacity of the chosen heat pump model	kW_t	59,6	60,7% of peak load provided
COP of the heat pump/cooling	4,80		
Cooling delivered	MWh_f	86	94,0% total annual energy needed
Annual electrical energy consumption of a compressor	***MWh_e***	***18,0***	
Back-up cooling system: Air-source heat pump, COP=3,0 with capacity of 39,6 kW (39,3% of peak load)	MWh_f	6,0	6,0 % total annual energy needed
Annual electric consumption of back-up cooling system	***MWh_e***	**2,0**	

3.3. Economic parameters of the heating and cooling project with the geothermal heat pump

While doing the economic analysis of the project and due to the specifications of an each location, wide range of possible costs should be considered. In the following Table 3-8, the economic analysis shows the most common costs, unavoidable in this project, and many different costs which may appear in any stage of the project. These additional costs primarily depend on the location specifications, legislation, subventions etc. The conventional system of heating with natural gas and cooling with the air conditioner has been compared to this project.

The investment costs are presented as the difference when related to the conventional system and the period of the investment return is presented not as the return of the total capital investments in the project, but as the return of the difference of investing into the system of the geothermal heat pumps.

The financial structure of the difference between these two systems is closed by taking a commercial credit. The values in italic in the table are subtracted from the total costs because these costs are also unavoidable in the conventional heating and cooling system. Since this project will last for several years, the natural gas price of 2,50 kn is taken (this being the necessary and unavoidable price increase when related to the current 2,08 kn). It has been planned that the project will last for 30 years (durability of the PE pipes installed in the ground), and for this period the analysis included the inflation rate and the energy price. The reduction of greenhouse gasses emissions by using this new system has also been considered as well as the potential subventions by the local community or the state in a form of a tax return (following the model of some EU member countries), accordingly to the promotion of the exploitation of renewable energy sources.

Table 3-8: Analysis of the capital and annual costs for each development stage of the heating and cooling project with the geothermal heat pump (difference from natural gas system)

INITIAL COSTS	UNIT	UNIT COST	TOTAL COST	PERCENT OF COSTS
Project development				
Permits and approvals	15h	65 €/h	975 €	
Site survey & land rights	15h	65 €/h	975 €	
Sub-total			**1 950 €**	**3,2 %**
Engineering				
Site & building design	20h	50 €/h	1 000 €	
Tenders & contracting	20h	50 €/h	1 000 €	
Construction supervision	20h	50 €/h	1 000 €	
Credit for gas			*(-3 000 €)*	
Sub-total			**-**	**0,0 %**

Heating system				
Base load–heat pumps Vitocal300BW226	72 kW_t	359 €/kW_t	25 848 €	
Gas boiler Vitogas100/Vitotronic300GW2	75 kW_t		*(-5 088 €)*	
Sub-total			**20 760 €**	**34,0 %**
Cooling system				
Base load–heat pumps Vitocal300BW226	59,6 kW_f		**-**	
Peak load-ASHP Climate Master	38,6 kW_f	130 €/kW_f	5 018 €	
Air conditioner Climate Master	98 kW_f	130 €/kW_f	*(-12 740 €)*	
Sub-total			**(-7 722 €)**	**-12,6 %**
Balance of system & miscellaneous				
Specific project costs	Ground heat exchanger			
Circulation pumps	1,8 kW	850 €/kW	1 535 €	
Circulation fluid	0,19 m^3	2 600 €/m^3	505 €	
Drilling and grouting	1 098 m	35 €/m	38 432 €	
Loop pipes 32mm polyethylene Series160	2 196 m	2 €/m	4 392 €	
Fittings & valves	98,2 kW	15 €/kW	1 470 €	
Building & yard construction			12 000 €	
Credit for gas engineering			*(-12 000 €)*	
Sub-total			**46 334 €**	**75,6 %**
TOTAL INITIAL COSTS			**61 322 €**	**100,0 %**
ANNUAL COSTS				
Operating and maintenance costs O&M				
Parts and labour	196 MWh	1 €/MWh	196 €	
Credit for gas parts and labour	196 MWh	3 €/MWh	*(- 588€)*	
Total			***(- 392 €)***	
Fuel price – proposed geothermal heat pump project				
Electricity HEP - Orange tariff business	38 MWh	140,70 €/MWh	5 361 €	
Total			**5 361 €**	
ANNUAL SAVINGS				
Fuel price –conventional system				
Natural gas GP Zagreb (+20% increment)	14 682 m^3	0,345 €/m^3	5 065 €	
Electricity HEP-Orange tariff for bussiness	37 MWh	140,70 €/MWh	5 166 €	
Total			**12 560 €**	
PERIODIC COSTS				
Replacement of gas boiler	15 years		*(- 5 088 €)*	
AC replacement	20 years		*(-12 740 €)*	
Replacement of heat pump compressor	20 years		12 740 €|	

Table 3-9: Analysis of GHG emission reduction by the use of the GHP system as opposed to the conventional system with natural gas and electrical energy

GHG EMISSION FACTOR DURING THE PRODUCTION OF ELECTRICAL ENERGY IN THE REPUBLIC OF CROATIA							
Croatia	***Fuel portion in electricity production***	***CO2 emission factor***	***CH4 emission factor***	***N2O emission factor***	***Production effectiveness of electrical energy***	***Transport and distribution losses***	***GHG emission factor***
Fuel type	*%*	*kg/GJ*	*kg/GJ*	*kg/GJ*	*%*	*%*	*tCO2/MWh*
Natural gas	15,0	54,5	0,0040	0,0010	45,0	17,0	0,529
Coal	5,0	95,8	0,0150	0,0030	35,0	17,0	1,203
Water power	52,0	0,0	0,0000	0,0000	100,0	17,0	0,000
Nuclear energy	8,0	0,0	0,0000	0,0000	30,0	17,0	0,000
Fuel oil	20,0	73,3	0,0020	0,0020	35,0	17,0	0,917
Electricity mix.	**100,0**	**88,9**	**0,0056**	**0,0023**		**17,0**	**0,323**

CONVENTIONAL HEATING AND COOLING SYSTEM (NATURAL GAS+AC) - GHG EMISSION							
	Fuel portion	***CO2 emission factor***	***CH4 emission factor***	***N2O emission factor***	***Fuel consumption***	***GHG emission factor***	***GHG emission***
Fuel type	*%*	*kg/GJ*	*kg/GJ*	*kg/GJ*	*MWh*	*tCO2/MWh*	*tCO2*
Natural gas	79,1	54,5	0,0040	0,0010	139	0,197	27
Electrical energy	20,9	88,9	0,0056	0,0023	37	0,323	12
Total	**100,0**	**58,3**	**0,0042**	**0,0011**	**175**	**0,224**	**39**

PROPOSED HEATING AND COOLING SYSTEM WITH GEOTHERMAL HEAT PUMP - GHG EMISSION							
	Fuel portion	***CO2 emission factor***	***CH4 emission factor***	***N2O emission factor***	***Fuel consumption***	***GHG emission factor***	***GHG emission***
Fuel type	*%*	*kg/GJ*	*kg/GJ*	*kg/GJ*	*MWh*	*tCO2/MWh*	*tCO2*
Electrical energy	100,0%	88,9	0,0056	0,0023	38	0,323	12
Total	**100,0%**	**88,9**	**0,0056**	**0,0023**	**38**	**0,323**	**12**

GHG EMISSION REDUCTION BY USAGE OF GHP SYSTEM				
Combined heating and cooling system	***Conventional system emissions***	***Emissions of the proposed GHP system***	***Annual GHG emission reduction***	**The annual reduction of 27 tCO2 is equivalent of:** consumption of 10 938 litres of motor petrol or, 55 barrels of crude oil not consumed, or 9,3 hectares of forest absorbing carbon.
	tCO2	*tCO2*	*tCO2*	
	39	12	**27**	

Table 3-10: Short overview of the financial structure of the heating and cooling project with the GHPs system

FINANCIAL STRUCTURE OF THE PROJECT		
Basic macroeconomic indicators and financing conditions		
Fuel cost escalation rate	%/year	3,5
Inflation	%/year	4,0
Discount rate	%	8,0
Duration of project	years	30
Incentives and grants (possible, according to EU case)	€	0
Debt	€	61 322
Equity	€	0
Debt interest rate	%	8,00
Debt term	years	30
Debt payments	€/year	5 447

PROJECT COSTS AND SAVINGS/INCOME SUMMARY		
Initial costs		
Development (3,2%)	€	1 950
Heating system (33,9%)	€	20 760
Cooling system (-12,6%)	€	*(-7 722)*
Balance of systems & miscellaneous (75,6%)	€	46 334
Total difference of initial costs in relation to the conventional system	€	61 322
Annual costs and debt payments		
Operating and maintenance costs	€	*(-392)*
Fuel costs – proposed case	€	5 361
Debt payments - 30 years	€	5 447
Total annual costs	**€**	**10 416**
Periodic costs		
Gas boiler replacement (15 years)	€	*(-5 088)*
Air conditioner replacement (20 years) equal to replacement of compressors in the heat pumps	€	0
Annual savings and income		
Annual fuel price – conventional system (gas boiler + AC)	€	10 231
Total annual savings and benefits	€	**10 231**

Figure 3-5: Review of borehole U-tubes heat exchangers field installation and interior heat pump

Table 3-11: Annual cash flow in the project period

ANNUAL CASH FLOW					
Year	After tax	Cumulative	Year	After tax	Cumulative
	€	€		€	€
0	0	0	16	3 732	36 621
1	2	2	17	4 057	40 679
2	194	196	18	4 394	45 072
3	394	590	19	4 742	49 815
4	600	1 190	20	5 103	54 918
5	814	2 005	21	5 477	60 394
6	1 036	3 041	22	5 863	66 258
7	1 265	4 306	23	6 264	72 522
8	1 503	5 809	24	6 679	79 200
9	1 749	7 558	25	7 108	86 308
10	2 003	9 561	26	7 553	93 861
11	2 267	11 828	27	8 013	101 874
12	2 540	14 368	28	8 490	110 364
13	2 823	17 191	29	8 984	119 348
14	3 116	20 307	30	25 997	145 345
15	12 582	32 889			

Technoeconomic analysis shown that effectiveness of geothermal heat pump installation in new building exist over conventional systems of natural gas+AC, if the low temperature heating is utilised, because of maximization of COP. By financing investment cost difference between this two technologies with credit equal to project life, it is possible to have positive cash flow immediately in the first year of the system operation, regarding greater annual savings in energy then annual debt term (Table 3-11). In addition, government subvention for CO2 reduction could be subjoin in annual savings after model in most of EU Member States, as well as tax rebates and subventions for highly efficient technologies which are not included in this paper because in Croatia there are still no concrete system of incentives. However, in the future these elements could significantly accelerate further development and implementation of heat pumps.

4. Conclusion

In the Republic of Croatia there is no significant commercial or private use of the heating and cooling technology of the heat pumps with shallow geothermal resources as a heat source. Since the use of geothermal heat pumps in the EU is constantly increasing by nearly 20% during this decade, there is a need to start a pilot project financed by the state or the local communities which is related to the imperative of using the renewable energy sources. Firstly, the law has to be enacted, following the German or Swedish model, on a drilling depth limit and the security procedures taken during installation which is the biggest problem and an obstacle to the significant development of this technology. There are a number of mining and geotechnical companies in the Republic of Croatia which are willing to include drilling for installing the heat exchangers as one of their activities.

This paper presented the technoeconomic analysis of the potential heating and cooling project within the business building. In order to provide as equable and precise data as possible (for drilling and cementing, for example), the possible costs of the project stages have been observed, as well as foreign literature and pilot projects have been studied. Cost effectiveness is done for the city of Zagreb based on the substituting the natural gas, as the primary energy-generating product, for geothermal heat pumps. Modelling the current and the future cost ratio of energy-generating products by macroeconomic indicators, capital and operative costs, as well as the proposed financial structure of project crediting, is showing that this project is economically competitive to the conventional technologies only if debt term is 30 years which is not realistic, taking into account that banks are financing commercial project up to 15 years (like Croatian Bank for Reconstruction and Development - HBOR). If debt term is lowered to this period, project becomes economically unviable because of high capital investments (prior heat pump), as well as small difference in prices between natural gas and electricity in Croatia, even if future price of 2,50 HRK for natural gas is considered (2009.) In EU, gas prices are relatively higher in comparison to electricity and state subventions and grants program are highly developed which is not considered for Croatia case. Therefore, further competitiveness and implementation could be accomplished if the government initiate incentives and grants for installing heat pumps, as well as subvention for lower emissions of carbon dioxide, like in the EU members countries.

References

1. Air Conditioning and Refrigeration Institute - ARI: *Ground Source Closed-loop Heat Pumps Standard 330*, 1998, Arlington, SAD, p.p.11
2. Climate Master Inc.: *Ghp Engineering Design Guide*, Oklahoma City, SAD, 2005, p.p.64
3. State hydrometerological institute of the Republic of Croatia – internal data
4. Institute de recherche Laboratoire des technologies de l'énergie (LTE): *North American Test Procedures and Calculations for Residential Heat Pumps with Combined Space and Domestic Hot Water Heating*, IEA HPP Annex 28 N 62, Quebec, Canada, p.p.52
5. McQuay International: *Geothermal Heat Pump Design Manual*, AG 31-008, Staunton, SAD, p.p. 70
6. Swedish Heat pump Association SVEP: *Heat Pumps Technology And Environmental Impact,* Mid-Sweden -University, 2005*,* p.p.120
7. Turner, W.; Doty, S.: *Energy Management Handbook Sixth Edition*, ISBN: 0-88173-542-6, The Fairmont Press, Lilburn, SAD, p.p. 924
8. Krieder, J: *Handbook of Heating, Ventilation, and Air Conditioning*, ISBN 0-8493-9584-4, CRC Press, 2001, New York, SAD
9. Viessmann Gmbh.: *Datasheet Vitocal 300WW-BW*, technical documentation taken from www.viessmann.com, p.p.12
10. Viessmann Gmbh.: *Installation Service Vitocal 300WW-BW*, technical documentation taken from www.viessmann.com, p.p. 95
11. The American Society of Heating, Refrigerating and Air-Conditioning Engineers: ASHRAE 1997-00 Handbook, Englewood, Colorado, USA
12. http://epp.eurostat.ec.europa.eu European Commission - Eurostat Home page

UDK	ključne riječi	key words
550.367	geotermalni izvori energije	geothermal power resources
621.577	toplinska pumpa	heat pump
.003.1	gledište ostvarivosti	feasibility viewpoint
.001.24	gledište tehničkog proračuna	technical calculation viewpoint
697.1	grijanje zgrada	house heating
697.94	klimatizacija zgrada	house aiconditioning

Author

Tomislav Kurevija, grad.eng., e-mail: tomislav.kurevija@rgn.hr
Faculty of Mining, Geology and Petroleum Engineering, University of Zagreb,Croatia

Received

25.8.2008.