Proceedings of the 3rd IASME/WSEAS Int. Conf. on HEAT TRANSFER, THERMAL ENGINEERING AND ENVIRONMENT, Corfu, Greece, August 20-22, 2005 (pp344-348)

Economic Analysis of Heating Systems using Geothermal Heat Pump

E. TORHAC, L.C. LIPUS[1], J. KROPE[2], D. GORICANEC[2], A. SALJNIKOV[3], R. STIPIC[3], Đ. KOZIC[3]
Nafta-Geoterm d.o.o.
Mlinska ulica 5, 9220 Lendava
[1]Faculty of Mechanical Engineering
[2]Faculty of Chemistry and Chemical Engineering
University of Maribor
Smetanova 17, 2000 Maribor
SLOVENIA
[3] Faculty of Mechanical Engineering
University of Belgrade
Kraljice Marije 16, 11120 Belgrade
SERBIA AND MONTE NEGRO
evgen.torhac@nafta-geoterm.si, lucija.lipus@guest.arnes.si, jurij.krope@uni-mb.si, darko.goricanec@uni-mb.si, asaljnikov@mas.bg.ac.yu, dkozic@mas.bg.ac.yu

Abstract: This paper presents profitability evaluation of geothermal heat pumps as an alternative, non-polluting solution for heating of modern buildings and well-insulated houses. The investment into geothermal heat pump is much higher than for heating stations with fossil fuels, more than four times as for earth gas and more than three times than for light fuel oil, but the operating costs are very low, as much as five times lower than for light fuel oil. Taking into account Slovenian market prices at the end of 2004, a credit with 7% discount rate and ten-year payback for the investments, the total price (comprising investment, maintenance and operating costs) for heating energy yield by geothermal heat pump is comparable to the prices of the majority of conventional heat sources.

Key Words: Geothermal heat pump, renewable energy, heating system, economic analysis

1 Introduction

Since the 1990s global environment concerns have been increasing. In particular, world attention has been focused on global warming caused by greenhouse gases such as carbon dioxide (see Table 1). At the United Nations' conferences about the environment protection in Rio de Janeiro (1991) and Kyoto (1997), Europe accepted the task to reduce the emission of these gases by 8% of the emission in 1990. This has lead to a diminution of fossil fuels consumption and to exploitation of renewable energy sources such as ambient (earth, water, air), wind and solar energy.

Most of the countries which due to their climatic conditions use an essential share of energy for heating of buildings [1-2], depend heavily on imported fossil fuels, but have a good potential to use renewable energies. Although no source is unlimited, since wind and hydro-potentials are limited and geothermic fields do not exist in every place and even solar energy is available only during sunny days, partial reliance on own sources in combination with appropriate energy storage systems would contribute not only to the environment protection but also to security of the energy supply.

Therefore, there are several reasons to expect that renewable sources are going to play a major role in the 21st century.

Table 1: CO_2 emission [3]

Fuel	kg CO_2 per kWh of heating energy
Earth gas	0.202
Light fuel oil	0.267
Black coal	0.355
Lignite	0.378

2 Heat pumps

Ambient energy can be exploited for heating of buildings by heat pumps (Fig. 1). Heat pump transmits heat from the ground, terrestrial water or surrounding air into heating installation of the building. Because the temperature of the heat source is lower than the temperature of the heating installation, some electric energy is consumed by the pump, precisely, by compressor.

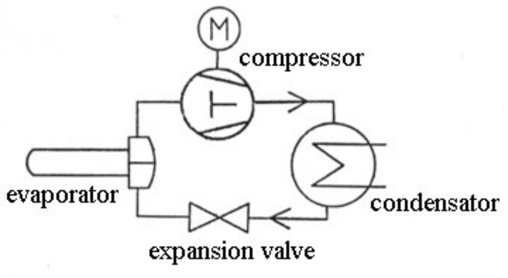

Fig. 1: Principle of the heat pump

Heating coefficient, defined as the ratio of yielded heating energy and consumed electric energy, strongly depends on the characteristics of energy sources and achieves the best values at low-temperature heating installations (from 35 to 45°C), such as floor heating.

Exploitation of the air heat requires the highest investment, but in this case, the heat coefficient varies strongly with the weather in the range between 2 and 3.5 [4].

Such heat pumps operate efficiently under 0°C. Therefore, in Central Europe climate, an installation of such heat pump is suitable as replenishment to an already existing heating station with furnace or in coast areas as solitary heating system. Although the temperature of the source decreases as the need for heating is rising, heat pump operates efficiently about two months and a half at the beginning and two months and a half at the end of seven-month long heating season (in average for years 1989/90 – 1997/98) for well insulated houses [4].

Exploitation of ground water or geothermal energy has advantages the temperature of the source is higher and remains constant all heating season providing higher heating coefficient. This enables us to use solitary heat pump system with constant heat flux available throughout a year.

Ground water has temperatures from 8 to 10°C at about 10 m of depth yielding heating coefficient sometimes higher than 4.

Earth crust is theoretically an unlimited energy source: the upper, 10 km thick continental layer contains more than $5 \cdot 10^{27}$ J of heat available for the utilization. Temperature in the few-meters thin layer below the surface varies with climatic conditions, while in lower layers it is constant and increases with depth for about 1 K per 33 meters [5].

Heating coefficient depends on constructional and geological characteristics: local geothermal gradient, type and porosity of rocks and on presence of water (thermal capacity and conductivity).

Geothermal heat pumps with horizontally installed pipes 1.5 m below the surface and 0.5 m apart give from 10 to 30 W per m^2 of surface, depending on the type of the soil. The best type is wet loam. Heating coefficient varies through the year in the range between 2.5 and 3.5.

The installation of horizontal pipe network is not as expensive as vertical boreholes are, but the horizontal system gives lower heating coefficient and requires a big surface, from 200 to 300 m^2 for a small, insulated house.

Heat pumps with U-bend pipes, vertically inserted into boreholes (borehole heat exchanger, BHE [6], Fig. 2) 40-150 m deep, with diameter 0.15 m and at least 0.1 m apart, give about 50 W per m of borehole [7]. Heat coefficient can even exceed 5.

More than 20 years of research and development focusing on geothermal heat pump systems have resulted in well established technology with proper sound design and installation criteria [8-10]. Practical realization of heat pumps is now the question of economic, social and ecologic aspects [11].

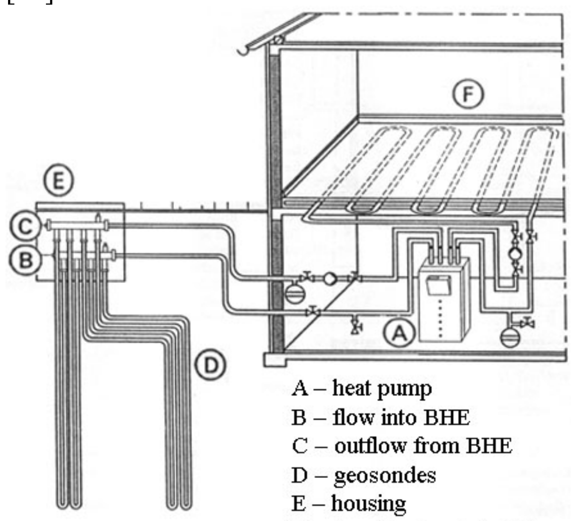

Fig. 2: Geothermal heat pumps with vertically installed pipes [6].

BHE systems require expensive drillings and installation. However, there are many deep boreholes that have been drilled for oil, gas or even made for geothermal prospecting purposes that are now abandoned. These wells could be either liquidated, which is expensive, or used for BHEs, which may turn out to be profitable and many distinct-heating systems could be supplied this way [12].

3 Economic analysis of a geothermal heat pump system

An economic analysis of building heating by BHE was made in comparison to the conventional heat sources: earth gas, liquidized naphtha gas, light fuel oil and grid electricity. It was made for a well insulated one-family house (150 m^2 of living space, 18000 kWh of heat consumption per half-year long heating season) with low-temperature heating installation (35°C).

When we have to decide among different heating sources, we consider all costs in the lifetime of the particular heating system: investment, operational and maintenance costs. Investment costs were considered to be covered by a credit with 7% discount rate and paid off in 10 years.

In a life span of a geothermal heat pump, the compressor is the most expensive component of the pump and exposed to the highest wear. Its life time is about 40000 operational hours, which for common 1400 operating hours per year means 30 years. Additional factor influencing on its life span is the number of starts. To insure an at least 20-minute long continuous operating of the heat pump, 200 L heat accumulator is recommended. This assures 15 to 20 years of operation without any maintenance costs. Therefore, chosen payback time is much shorter than the lifetime of the equipment.

Table 2 presents the investment, maintenance costs and prices of heat sources, taken from Slovenian market at the end of 2004. Investment was evaluated as annuity (paid at the end of every year in 10 years) by following formula:

$$a = \frac{Ip(1+p)^n}{(1+p)^n - 1} \qquad (1)$$

Parameters are:
I - investment costs,
p - discount rate (0.07) and
n - number of payback years (10).

Prices of heating energy were calculated from the market price of a source, yearly maintenance costs and annuity, both derived by 18000 kWh of annual heating energy consumption.

For instance, the heating station for oil requires a room, a furnace, 2000 l reservoir, a chimney and a proper pipeline installation, which together cost about 3800 EUR. Annuity is than 3800 EUR·0.1424 = 540 EUR. Light fuel oil with 10.06 kWh/l of heating value has the market price of 0.495 EUR/l and the efficiency of the furnace is assumed to be 80%. The maintenance costs of furnace costs 140 EUR per year. The total price of heating energy from oil is than 0.1 EUR/l.

Table 2: Total prices of heating energy from different sources

	Light fuel oil	Earth gas	Liquidized naphtha gas	Grid electricity	Geothermal heat pump
Investment (EUR)	3800	3000	1800	1900	13800
Annuity (EUR/a)	541	427	256	271	1965
Market price	0.495 EUR/l	0.417 EUR/m^3	0.815 EUR/kg	(MP) 0.085 EUR/kWh	(MP) 0.085 EUR/kWh (LP) 0.059 EUR/kWh
Heating value	10.06 kWh/l	10.42 kWh/m^3	12.60 kWh/kg		(heating coefficient) 4.2
Furnace efficiency	80%	90%	90%	~ 100%	
Energy price (EUR/kWh)	0.062	0.044	0.072	0.085	(MP) 0.020 (LP) 0.014
Maintenance (EUR/a)	140	90	190	___	___
Total energy price (EUR/kWh)	0.100	0.073	0.097	0.100	(MP) 0.129 (LP) 0.123 (MP + sub.) 0.113 (LP + sub.) 0.106
15% raise of energy price (EUR/kWh)	0.109	0.079	0.108	0.113	(LP + sub.) 0.109

In the case of liquidized naphtha gas, a rent for 2000 l reservoir is included in maintenance costs.

In the case of BHE, drilling and pipe insertion are as expensive as the heat pump, but high investment can be compensated by low energy costs as the price of electricity is reduced by heating coefficient. For one-family house, one borehole about 100 m deep is commonly enough, because Slovenian ground is wet and heat flux 60 W/m and heating coefficient 4.2 can be taken in the calculation. Heat accumulator is included into investment costs. Maintenance costs are negligible in the payback period. Calculations were made for middle-price electricity (MP), lower-price electricity (LP) and for state subvention (2080 EUR for a private house). One of advantages of floor heating system is that it can accumulate heat and the heat pump can operate during the nights, when electricity is cheaper.

The results show that the price of heating energy from BHE is comparable to the prices of fossil fuels (with exception of earth gas, which is the cheapest). Practical values of heating coefficient are even higher, but the rise from 4.2 to 5 doesn't influence much on the result (from 0.106 to 0.105 EUR/kWh).

4 Conclusion

Utilization of geothermal energy is an attractive way of building heating from several reasons. This heat is permanently available and cheap after payback period is accomplished, and it is much less polluting.

If we assume that the electricity consumed by heat pumps is covered by hydro- or nuclear-potentials, then emission of CO_2 is zero.

If in the worst case, state covers it only by thermo-plants by coal, than the emission is less than 0.1 kg CO_2 per kWh of heating energy. Comparing to heating by oil (about 0.27 kg CO_2/kWh), this means more than 60% lower pollution. Slovenia covers electricity by hydro- nuclear- and thermo-plants in approximately the same shares. The emission by heat pump is than 0.03 kg CO_2/kWh in average.

Our calculations on the basis of Slovenian market prices of energy and heating equipment have shown that total price of heating energy from geothermal heat pumps is comparable to the conventional ways of heating when electricity is consumed mostly at nights and investment is discharged partially by state subvention.

According to prognoses of increase of fuel prices, heat pumps could become the cheapest way of heating even for small houses.

In our calculations, conventional heating systems were evaluated without any air-cooling system, which would raise the investment costs and electricity consumption essentially. While in the case of geothermal heat pump, heating pipe-network can be installed also into walls enabling passive cooling during hot days – simply by circulation of fluid through BHE and walls at switched off heat pump. From this point of view, the investment into a geothermal heat pump is surely financially justified.

Furthermore, the evaluation was made for small houses, while the results for bigger houses and buildings are even better. Additionally, our state promotes heat pumps in public buildings even more intensively, offering a subvention of 40% of all investment costs.

References:

[1] Garbai L., Szánthó Z.: Optimal operational parameters of district heating systems. *Proceedings of second conference on mechanical engineering*, Technical University of Budapest, May 2000, pp.25-26

[2] Garbai L., Barna L.: Description of the gas and service water consumption process by means of probability calculation. *Periodica Politechnica, Mechanical Engineering* 44/2, 2000.

[3] http://www.uradnilist.si/1/objava.jsp?urlid=200291&stevilka=4530

[4] Marcic M.: Long-term performance of central heat pumps in Slovenia homes, *Energy and Buildings*, Vol. 36, 2004, pp. 185-193.

[5] Holmes A.: *Principles of Physical Geology*, 2nd Ed., Nelson, 1972, London.

[6] VIESSMANN catalogues and prospects, Viessmann d.o.o., Cesta 14. divizije 116a, Maribor, Slovenia.

[7] Sanner B., M. Reuss, E. Mands and J. Müller: Thermal Response Test – Experiences in Germany, TERRASTOCK 2000:8th International Conference on Thermal Energy Storage, Germany.

[8] Sanner B., C. Karytsas, D. Mendrinos, L. Rybach: Current status of ground source heat pumps and underground thermal energy storage in Europe, *Geothermics*, Vol. 32, 2003, pp. 579-588.

[9] Smolen S.:''Earth coupled'' heat pump with direct evaporation – thermodynamic analysis,

heat transfer and some economical aspects, WSEAS conference: Heat and mass transfer 2005, Italy.

[10] Kohl T., R. Brenni, W. Eugste: System performance of a deep borehole heat exchanger, *Geothermics*, Vol. 31, 2002, pp. 687-708.

[11] Vuataz F.D., H.L. Gorhan, M. Geissmann: Promotion of geothermal energy in Switzerland: a recent program for a long-term task, *Geothermics*, Vol. 32, 2003, pp. 789-797.

[12] Sliwa T., J. Kotyza: Application of existing wells as ground heat source for heat pumps in Poland, *Applied Energy*, Vol. 74, 2003, pp.3-8.