Utilization of geothermal heat pumps in residential buildings for GHGs emission reduction

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Abstract: This study aims to reduce energy consumption by application of geothermal heat pumps in residential buildings and reduction of Greenhouse Gases (GHGs) emissions under Clean Development Mechanism (CDM) project. In this approach, the required thermal load of a typical four-floor 12-units residential building located in Tehran city has been considered and calculated separately based on the actual operational data. According to the thermal properties of soil and the annual average temperature of the area, the appropriate geothermal heat pump system has been taken into consideration. Subsequently, three scenarios based on transaction of Certified Emission Reductions (CERs) as Primary, Secondary and Unilateral types of CDM projects were created considering the primary costs of purchase and installment of geothermal heat pump system and its electricity consumption. Technical, economical and environmental feasibility study of this project has been assessed through using Proform software in three different scenarios based on global carbon credit market.

The results show that in the optimum scenario in case of replacing the boiler system with vertical geothermal heat pump system in the residential building, could conserve 67,000 GJ of natural gas during the project implementation period and 3,759 tons of CO_2 equivalent emissions would be reduced. Results demonstrate also the favorable economic and environmental impacts that can be achieved by CDM.

***Keywords**: Geothermal Heat Pump, GHGs Emission, Residential Building, Carbon Credit*

1. Introduction

Geothermal energy use avoids the problem of acid rain, and it generally reduces greenhouse gas emissions and other forms of air pollution. A continuing strong market for geothermal heat pumps is anticipated as a result of the increasing interest in controlling atmospheric pollution because of the spreading concern about global warming and because of their reliability, high level of comfort, low demand, and low operating costs. Ground source heat pumps (GSHPs), also known as geothermal heat pumps (GHPs), are attractive alternatives for both conventional heating and cooling systems because of their higher energy efficiencies. However, GSHP systems have recently been applied to many residential and a few commercial buildings for heating/cooling purposes [1,2]. These systems have had the largest growth since 1995, almost 59 or 9.7% annually in the United States and Europe. The installed capacity is 6850 MW and annual energy use is 23,214 TJ/year in 26 countries. The actual number of installed units was around 500,000 in 2000. It is also estimated that there are over a million today (e.g. [3,4-9]).

GSHPs have several advantages over air source heat pumps, as given by Lund and Freeston [10]: (a) they consume less energy to operate; (b) they tap the earth or groundwater, a more stable energy source than air; (c) they do not require supplemental heat during extreme low outside temperature; (d) they use less refrigerant; (e) they have a simpler design and consequently less maintenance; and (f) they do not require the unit to be located where it is exposed to weathering. The main disadvantage is the higher initial capital cost, being about 30-50% more expensive than air source units. This is due to the extra expense for burying heat exchangers in the earth or providing a well for the energy sources. However, once installed, the annual cost is less over the life of the system, resulting in a net savings. In a comprehensive study conducted by Lund et al. [11], it is reported that GSHPs have the largest energy use and installed capacity according to the 2005 data, accounting for 54.4% and 32.0% of the worldwide capacity and use. The installed capacity is 15,384 MW_t and the annual energy use is 87,503 TJ/year, with a capacity factor of 0.18 (in the heating mode) [12].

The concept of GHP is not new. However, the utilization of GHPs in residential buildings is very new in Iran, although they have been in use for years in developed countries and the performance of the components is well documented. Worldwide GSHPs account for 12% of the geothermal energy used for direct applications, amounting to approximately 16,500 TJ (4580 GWh) annually. Present estimates indicate that there are over 150,000 groundwater and 250,000 ground coupled (55% vertical) heat pump installations in the USA [13]. According to the Kyoto Protocol, industrialized countries have agreed to reduce their overall emission of greenhouse gases (GHGs) by at least 5 percent below 1990 levels in the commitment period 2008–2012 (United Nations, 1998). In order to minimize the compliance cost, three flexible mechanisms are defined: the Clean Development Mechanism (CDM), Joint Implementation (JI), and Emission Trading (ET). CDM is the only mechanism applicable to the developing countries. Certified Emission Reductions (CERs) is a unit of GHGs reductions issued pursuant to the Clean Development Mechanism of the Kyoto Protocol, and measured in metric tons of carbon dioxide equivalent. One CER represents a reduction in greenhouse gas emissions of one metric ton of carbon dioxide equivalent. Primary CDM is the transaction of CERs between the original owner of the carbon asset and a buyer in the market. Depending on the amount of risks taken by the buyer and the seller, the price of CERs is agreed upon, which is lower than the secondary CDM prices. Secondary CDM is the transaction where the seller is not the original owner of the carbon asset. Usually, the seller and the buyer of secondary CDM are Annex I countries. Secondary CERs have higher prices than primary CERs due to its minimal risks imposed on the buyer. Unilateral CDM is the type of CDM project that an Annex I country is not involved and the developing country accepts all the risks and expenses in order to sell the CERs with higher prices in the market [14]. However, the developing country requires past experience in development and marketing of CDM projects. The present study deals with technical, economical and environmental feasibility assessment of a four-floor 12-units residential building, located at east of Tehran city, capital of Iran in which a boiler system is replaced by vertical ground source heat pump system under Primary, Secondary and Unilateral CDM projects.

2. Methodology

The residential building under study is a 12-unit complex located at east of Tehran city with four floors and the area of $565m^2$ at each floor. The required heating and cooling loads of the building was calculated based on number of residents. Then considering the geographical position, thermal properties of the soil and the climate conditions, for supply of air and water heating, a vertical GSHP system was introduced to replace the present boiler. The reasoning for choosing the vertical type was land limitation, the necessity of keeping the private boundaries of the neighbors and also having the possibility of penetration into depth under ground in order to achieve a rather stable temperature all throughout the year. Then based on the global carbon market, by using Proform software, three scenarios based on Primary, Secondary and Unilateral types of CDM projects were created considering the primary costs of purchase and installment of GSHP system to replace the boiler system. Table (1) shows the specifications of the present heating system of the building.

Table 1. Specifications of the present heating system (boiler)

System Type	Efficiency (%)	Fuel Type	Annual Gas Consumption (GJ/y)
Boiler	75	Natural Gas	16750

For replacing the boiler system by GSHP system and in order to supply the required heating loads in the residential building, some required information and specifications are shown in Table (2).

Table 2. Required information and specifications for choosing proper geothermal heat pump for the desired building

Isentropic Compressor Efficiency (%)	75	Heating load(kW)	220
Electrical Compressor Efficiency (%)	80	Cooling l(kW)	184.4
Pump Efficiency (%)	80	total time of heating operation mode (h/y)	2880
Pump motor Efficiency (%)	80	System function of time for full time(h/y)	1350
Condenser internal diameter (m)	0.0318	System lifetime (year)	10
Condenser external diameter (m)	0.0348	Interest rate (%)	10
Thermal conductivity coefficient of condenser tube (kW/m°C)	0.398	Coefficient of thermal conductivity of soil (W/m°C)	4.2
Inner diameter tube evaporator(m)	0.0318	Earth temperature (°C)	16
Outer diameter tube evaporator (m)	0.0348	Overall heat transfer coefficient in soil (W/m2°C)	12
Heat pipe thermal conductivity coefficient (W/m°C)	0.3979	Thermal conductivity coefficient of evaporator tubes (kW/m°C)	0.398

According to Table (2) and the specifications provided by the manufacturer of different types of geothermal heat pumps [15], and by applying the correlations offered in the reference No.16, the vertical GSHP system with the specifications given at Table(3) was chosen for supplying the required air and water heating.

Table3. Technical specifications and costs of the chosen GSHP system in the building under study

Vertical pipe length converter (m)	9000	Compressor power consumption (kW)	3900
Type of pipe	polyethylene	Power pump (kW)	5.5
The initial investment cost (US$)*	28073.67	Deep wells (m)	111.8
Electricity consumption (MWh/y)	60	Coefficient of performance(COP)**	4.94

*Cost of initial investment is: cost of pump + cost of compressor + cost of operator + cost of condenser + cost of excavation + cost of piping + cost of vertical land converter + cost of installation and launching.

**The temperature dependence of the efficiency has been neglected.

2.1. Technical, Economical and Environmental Assessment of GSHP System

Technical, economical and environmental feasibility study of the chosen GSHP system in the residential building has been implemented by Proform software. Some required information about the present boiler system and new system (GSHP) are offered at Tables (4) and (5). Based on the international carbon credit market, three scenarios were created according to the data on Table (6) and compared by Proform software.

Table 4. Technical data provided as input for Proform software

Depreciation period (Years)	GSHP Capacity (kW)	Coefficient of performance (%) GSHP	Life time GSHP (Years)	GSHP energy consumption (MWh/y)	Boiler efficiency (%)	Type of fuel consumed by the boiler	Old system energy consumption (boiler) (MWh/y)
10	220	4.95	10	60.053	75	Natural gas	465.2

Table 5. Financial and economical data provided as input for Proform software

Discount rate (%)	Income tax rate (%)	Initial investment cost of the GSHP system (US$)	Inflation rate* (%)	Annual interest rate of electricity price (%)	Annual interest rate of natural gas price (%)	Natural gas consumption ** (US$/Gj)	Electricity price (US$/kWh)
16	15	28073.67	20.2	21	5.6	0.271	0.011

*Annual inflation rate based on the report of Central Bank of Islamic Republic of Iran, General Director of Economic Statistics, May 2009.
** Energy Balance, 2008, each m^3 of natural gas GJ 0.03726 and price of natural gas [17].

Table 6. Scenario Analysis based on carbon credit defined by World Bank

Scenarios	Value of carbon credits reduction CO_2 (US$/ton CO)	Price Growth Rate (%)	Sales income tax (%)
Scenario A	10	15	0
Scenario B	15	15	0
Scenario C	20	20	0

As shown in Table (6), carbon credit in scenario A (Primary CDM) is US$ 10/tonCO_2, in scenario B (Secondary CDM) is US$ 15/tonCO_2 and in scenario C (Unilateral CDM) is US$ 20/tonCO_2. In case of taking no action for sale of carbon credit, the results of such case was also compared with the scenario analysis results. The depreciation rate considered in accordance with statistics of balance sheet in the year 2008 is equivalent to 16%. Also income tax rate was considered to be 15%, but the income generated by sales of carbon credit is free from any tax.

3. Results and Discussions

Replacing the boiler system by GSHP system could conserve 67,000 GJ of natural gas (601 MWh/10yr electricity). In Table (7), the amounts of GSHP electricity consumption and decrease in fossil fuel consumption caused by implementation of the project have been shown.

Table7. Amounts of electricity consumption and decrease in fuel consumption over the life of the GSHP system

	Power consumption by GSHP (MWh)	Natural gas consumption rate (GJ000)
Average Annual	60.053	7
Total Project (10 yr)	601	67

As shown in Table (8), in scenario A, taking all the initial investment costs as well as the installment and operation costs fro replacing the boiler by GSHP system into account , the pay back period is 3.9 years. Moreover, net present value (NPV) without tax is estimated to be about US $ 17,000 and the internal rate of return (IRR) is about 27.45%. In case of tax being included, NPV is US$ 15,000, the IRR is 25.88%. In scenario B, the pay back period is 3.1 years. Taking tax into account, the NPV is US$ 30,000 and IRR is 34.66%, however without considering tax, NPV is US $ 33,000 and IRR is 36.11%. In scenario C, before tax, NPV is US $ 62,000 and the pay back period is in 2.6 years and the IRR is 47.66%. In case of considering tax, NPV is US $ 59,000 and IRR is 46.38%. Since the IRR is more than the interest rate (16%), the project is proven to be cost-effective in this case. In case of taking no action for sale of carbon credit, the results show minus profit.

Table 8. Economic assessment of different scenarios A, B, C

Scenarios	Before tax			After Tax	
	Simple pay back (year)	Net present value (NPV) (US$)	Internal rate of return (IRR) (%)	Net present value (NPV) (US$)	Internal rate of return (IRR) (%)
Scenario A	3.9	17000	27.45	15000	25.88
Scenario B	3.1	33000	36.11	30000	34.66
Scenario C	2.6	62000	47.66	59000	46.38
Without considering the sale of carbon credit	8.8	-14000	2.74	-16000	-

Net present values in different scenarios before and after tax have been compared over the life of the GSHP system (10 years) and according to Fig. (1) The scenario C in comparison to other scenarios has higher profit making.

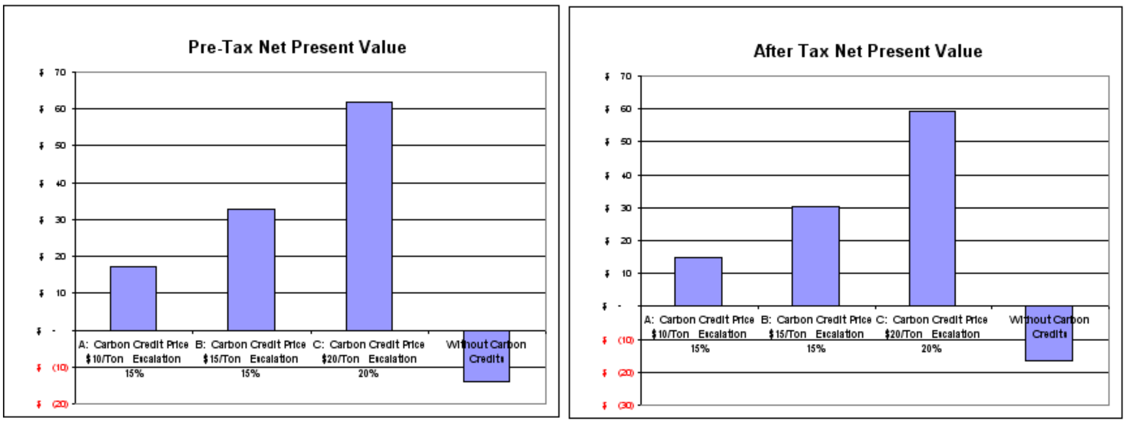

Fig.1. Comparing net present values in different scenarios before and after tax

Table (9) shows the annual income gained by sales of carbon credit in the three scenarios, so that if in the first year (year 0) the amount of US $ 30,000 is invested in the project, the amount of profit during the next year (year 1) in scenario A will be US $ 7,000, in scenario B will be US $ 9,000 and in scenario C will be US $ 10,000. While, in case of non selling of carbon credit, only US $ 3,000 profit in one year will be gained which makes the implementation of the whole project economically non feasible and non profitable. Furthermore, in the next coming years over the life of the project (10 years) the annual cash flow is compared and shown in the Table(9).

Table 9. Annual profit gained by sale of carbon credit in three scenarios during 10 years

Annual Cash Flow (US$000) Before Taxes

	Without sale of Carbon Credit	Carbon Credit (Scenario A)	Carbon Credit (Scenario B)	Carbon Credit (Scenario C)
Year 0	-30	-30	-30	-30
Year 1	3	7	9	10
Year 2	3	7	10	12
Year 3	3	8	11	14
Year 4	3	9	12	16
Year 5	3	10	13	19
Year 6	4	11	15	22
Year 7	5	12	17	26
Year 8	5	14	19	31
Year 9	5	16	21	36
Year 10	6	17	24	43

Results of Proform software show that the elimination of natural gas consumption in the building reduces green house gases emission by 658 tons of CO_2 equivalent per year and by 3759 tons of CO_2 equivalent during the whole period of implementing the project. As shown in Fig. (2), the rate of CO_2 emission reduction is going up over the time.

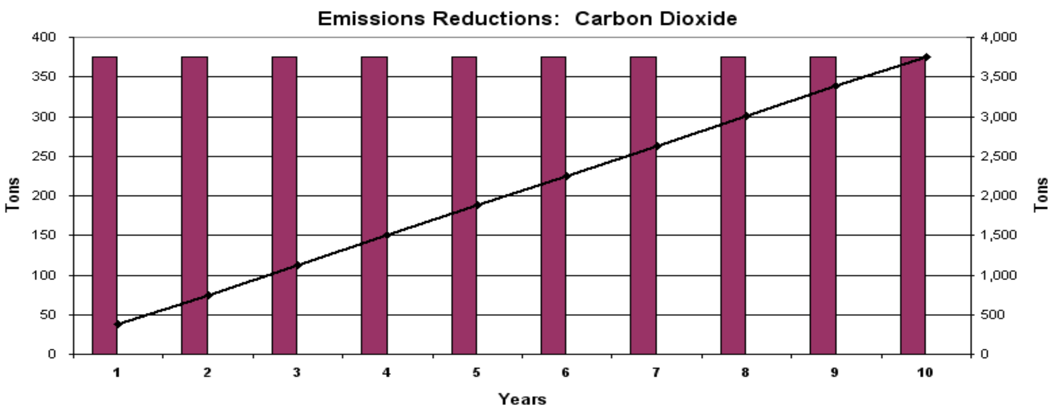

Fig. 2. CO_2 emission reduction during different years of the project implementation

4. Conclusion

In the present study a four-floor 12 unit residential building located at east of Tehran was assessed in the case of replacing the present boiler system by a vertical geothermal heat pump system. Based on the global carbon credit market, by using Proform software, three scenarios were considered on the basis of the primary costs of purchase and installment of GSHP system to replace the boiler system. In scenario A considering all the investment expenses as well as the installment and operation costs of the geothermal heat pump and replacing boiler with it, the pay back period is 3.9 years. Moreover, considering tax, NPV is estimated to be US $ 15,000 and the internal rate of return (IRR) is about 25.88%. In scenario B the pay back period is 3.1 year. Considering tax, NPV is US $ 30,000 and IRR is 34.66%. In case of implementing scenario C, the NPV is US $ 59,000 and the pay back period is 2.6 years. Furthermore, IRR is 46.38%. Therefore, it is suggested that this project be implemented according to scenario C in which IRR is more than the other two scenarios. The results show that in the optimum scenario in case of replacing the boiler system by vertical geothermal heat pump system under the CDM project in the residential building could conserve 67,000 GJ of natural gas during the project implementation period (10 years) and 3,759 tons of CO_2 equivalent emissions would be reduced. Thus, the results clearly demonstrate that increasing geothermal utilization results to GHG emission reduction while helping to meet increasing power demand. It demonstrates also the favorable economic and environmental impacts that that can be achieved by CDM. The message is that the utilization of GSHP without carbon credit is economically not feasible. However, significant opportunities for GSHP CDM projects are likely to extend into future decades.

References

[1] Kavanaugh SP. Field test of vertical ground-coupled heat pump in Alabama. ASHRAE Transactions, 1992,98:60716.

[2] Hepbasli A, Akdemir O. Energy and exergy analysis of a ground source (geothermal) heat pump system. Energy Conversion and Management 2004,45:73753.

[3] Lund J.W. Ground source (Geothermal) heat pumps. Course on heating with geothermal energy: conventional and new schemes, Convener Paul J Lienau, WGC 2000 Short Courses Kazuno, Thoku District, Japan 810 June, 2000, p. 20936.

[4] Lund J. W. Geothermal heat pumps-trends and comparisons. Geo-Heat Center Q Bull 1989,12(1):16.

[5] Lund JW, Freeston DH. World-wide direct uses of geothermal energy 2000. Proceedings world geothermal 587 congress 2000, Kyushu-Tohoku, Japan, May28 - June 10, 2000, p. 121.

[6] Lund JW, Freeston DH. World-wide direct uses of geothermal energy 2000. Geothermics, 2000,30:2968.

[7] Lund JW. Direct use of geothermal energy in the USA. Appl Energy 2003,74:3342.

[8] Lund JW. Geothermal heat pump utilization in the United States. Geo-Heat Center Q Bull 1988,11(1):507.

[9] Lienau PJ, Lund JW. Geothermal direct use. Testimony presented at the house subcommittee on environment, July 30. Geo-Heat Center, Klamath Falls, OR; 1992.

[10] Lund JW, Freeston DH. World-wide direct uses of geothermal energy 2000. Proceedings world geothermal congress 2000. Kyushu-Tohoku, Japan, May 28June 10, 2000. p. 121.

[11] Lund JW, Freeston DH, Boyd TL. Direct application of geothermal energy: 2005 worldwide review. Geothermics 2005,34(6):691727.

[12] Akpinar E. .K , Hepbasli A., A comparative study on exergetic assessment of two ground-source (geothermal) heat pump systems for residential applications, Building and Environment, 2007, 42 :20042013

[13] Lund JW. Geothermal heat pump utilization in the United States. Geo-Heat Center Q Bull 1988,11(1):507.

[14] United Nations Development Program (UNDP), Human & Income/Poverty in Developing Countries, 2008.

[15] http://www.fhp-mfg.com/aecinfo/1/company/09/09/81/company_1.html

[16] Sanaye S., Niroomand B., "Thermal economic modeling & optimization of vertical ground coupled heat pump", Energy Conversion & Management, 2000, 50, 1136 - 1147.

[17] Ministry of Energy, Energy Balance, Iran Energy optimization Organization, 2008.