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Technical and Economic Assessment for using Ground-Source Heat Pumps in Commercial and Institutional Buildings

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ABSTRACT

One of the most important methods proposed for reduction of consumed energy in facility and ventilation systems in a building is application of ground source heat pumps (GSHPs). With regard to the enhanced use of such pumps in providing heat and cold demands in homes, commercial centers, institutions and industrial buildings analysis of their performance as well as their benefits and deficiencies compared to common ventilation systems have gained interest of many researchers. Such systems apply ground as a thermal well in summer and as a heat source in winter. They can be used in various climatic conditions in different regions. They have no combustion and they only transfer heat. In the present article first, performance conditions of ground source heat pumps (in two modes of heating and cooling) are analyzed. Then in order to assess the performance of proposed model economically, its application in Iran will be studied. Finally after introducing the proposed plan and by concluding the overall results the return time for investment will be estimated. The obtained results from graph analysis would indicate the superiority of proposed model over other plans and also it provides an appropriate general context for the researchers for a better understanding and examining this system in comparison to other systems.

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1. INTRODUCTION

Most designers use independent thermal systems to provide desirable temperature; this matter needs only fossil fuels or electrical energy and one of the ways for generating electrical energy is generating thermal through fossil fuels. It is notable that earth absorbs 46% of sun’s energy (Figure 1). Sun energy is the basis for keeping a fixed earth internal temperature during the year. It is concluded that, earth is among a lot of energy resources available and it can be said that the it is one of the valuable resources in geothermal domain [1].

One of the most important parts to which engineers pay too much attention while designing a building is designing of air conditioning systems. Reduction of fossil fuel resources on the one hand and ever increasing use of such resources in ventilation systems needed by human beings on the other hand motivated researchers to design ventilation systems independent of fossil fuel resources.

Ground source heat pumps (GSHPs) provide a new and clean method of heating buildings in the world. They make use of renewable energy stored in the ground, providing one of the most energy efficient ways of heating buildings. They are suitable for a wide variety of building types and are particularly appropriate for low environmental impact projects. They do not require hot rocks (geothermal energy) and can be installed in most of the world regions, using a borehole or shallow trenches or, less commonly, by extracting heat from a pond or lake. Heat collecting pipes in a closed loop, containing water (with a little antifreeze) are used to extract this stored energy, which can then be used to provide space heating and domestic hot water. In some applications, the pump can be reversed in summer to provide cooling [2].

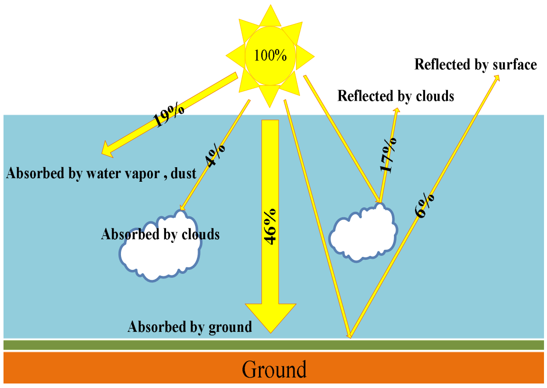


Figure 1. Distributing sun energy

Due to applied features of ground source heat systems they attracted too many researchers. The superiority of such systems over other common ventilation systems is use of ground as a thermal well in summer and as a heat source in winter. The critical point in using these systems is their application in different climatic condition in different regions. In these systems contrary to current common ventilation systems (in which fossil fuel is combusted and produces heat) no combustion is produced and such systems only transfer heat from ground.

The only energy used by GSHP systems is electricity to power the pumps. Typically, a GSHP will deliver three or four times as much thermal energy (heat) as is used in electrical energy to drive the system. For a particularly environmental solution, green electricity can be purchased. GSHP systems have been widely used in other parts of the world, including North America and Europe, for many years. Typically they cost more to install than conventional systems; however, they have very low maintenance costs and can be expected to provide reliable and environmentally friendly heating for in excess of 20 years. As such, they make an ideal partner for under floor heating systems. Heat pumps offer the most energy efficient way to provide heating and cooling in many applications, as they can use renewable heat sources in our surroundings. Even at temperatures we consider to be cold, air, ground and water contain useful heat that is continuously replenished by the sun.

By applying a little more energy, a heat pump can raise the temperature of this heat energy to the level needed. Similarly, heat pumps can also use waste heat sources such as from industrial processes, cooling equipment or ventilation air extracted from buildings. Geothermal heating can be more efficient than electric resistance heating. These systems are also typically more efficient than gas or oil fired heating systems. They are more energy efficient than air-source heat pumps because they draw heat from, or release heat to, the earth, which has moderate temperatures year round, rather than to the air (which is generally colder in winter and warmer in summer than the earth, resulting in less effective heat transfer). It is argued that heat pumps are highly energy efficient, and therefore environmentally benign [3].

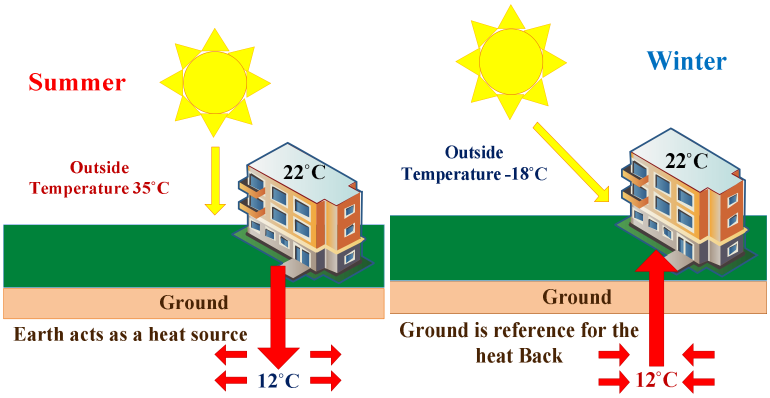
In the present work first, performance design of ground source heat pumps is explained in the second section. In the third section, different constituents of ground source heat pumps are described and internal structure of theses pumps is briefly reviewed. In the fourth section, these systems are examined in the light of economy in order to envisage the advantageous effects of the proposed system. Finally in the fifth part of this article as an applied investigation on a practical network the application possibility of ground source heat pumps in Iran will be evaluated and the subsequent results will be provided.

2. PERFORMANCE PRACTICES OF GROUND SOURCE HEAT PUMPS

To assess and analyze performance of ground source heat pumps first, studying the performance of such pumps is crucial.

Ground temperature, unlike the ambient air, is almost constant. Ground heat pumps, of ground or ground water or both, as the heat source in winter and as thermal wells in the summer use. The ground heat pumps, also known as geothermal energy systems. The temperature of the earth, to help the fluid such as ground water, or a solution of water and antifreeze, and by the heat pump, is transferred to the air inside the house. In summer, the reverse process occurs, this means, the temperature taken of the air inside and by ground water or a solution of water and antifreeze, is transmitted to the ground.

In geothermal heat pumps, the air conditionings systems are dual purpose are used for the cooling in summer and heating in winter. Heat pumps work between two cold and warm source, so that energy consumption in the compressor can transfer heat from warm to cold environments. These pumps use the earth as a heat source (Figure. 2) [4].



(a) (b)

Figure 2. Ground source heat pump performance in the summer and winter

The most common type of heat pump used with GSHP systems is a “water-to-air” type. The water-to-air designation indicates that the fluid carrying heat to and from the earth connection is water or a water/antifreeze mix and that the heat distribution system inside the building relies on hot or cold air. The heat pump may be an extended range unit, allowing lower entering fluid temperatures in heating mode and higher entering fluid temperatures in cooling mode. All the components of this type of heat pump are in one enclosure: the compressor, an earth connection to refrigerant heat exchanger, controls, and an air distribution system containing the air handler, duct fan, filter, refrigerant to air heat exchanger, and condensate removal system for air conditioning.

For residential applications and small commercial systems, a single heat pump unit will suffice. For larger commercial, institutional or industrial systems, multiple heat pump units are typically used in a distributed network connected to a common fluid loop. The heat pump operates using the same cycle as a refrigerator. The heat pump uses compression and expansion of a refrigerant to drive heat flows between the inside of the building and the earth connection. As the Second Law of Thermodynamics, heat will flow only from hotter to colder matter, but a heat pump will draw heat from the ground temperature to warm a building to 22C. At certain times of the year, the temperature of the ground will be such that heat would flow in the desired direction anyway. The heat pump may still need to operate, however, in order to ensure that the rate of heat flow is sufficient. This rate is related to the temperature difference between the heat pump and the earth connection: during cooling, the higher the temperature of the building, the better the rate of transfer with the earth connection would be [5].

In heating mode, the heat pump works as follows: heat from the earth connection arrives at an earth connection to refrigerant heat exchanger called the evaporator. On the other side of the heat exchanger is cold refrigerant in a mostly liquid state. The refrigerant is colder than the temperature of the heat transfer fluid from the earth connection, so heat flows into the refrigerant. This heat causes the liquid refrigerant to evaporate; its temperature doesn’t increase much. This gaseous, low pressure and low temperature refrigerant then passes into a compressor. This raises the refrigerant’s pressure and, as a consequence, its temperature. The high temperature, high pressure, gaseous output of the compressor is fed into a second heat exchanger, called the condenser. In water to air heat pumps, a fan blows air to be heated through this “air coil”. In water to water heat pumps, water which will heat the building flows through the condenser. Since the refrigerant is hotter than the air or water, it transfers heat to it. As it loses heat, the refrigerant’s temperature drops somewhat and it condenses.

This high temperature liquid refrigerant then passes through an expansion valve. The valve reduces the pressure of the refrigerant, and as a consequence, its temperature drops significantly. Now, this low temperature liquid flow to the evaporator and the cycle starts again. In this way, the heat from the water or other heat transfer fluid in the earth connection is transferred to the air or water in the building: hence the name “water-to-air heat pump” or “water-to-water heat pump” [6].

Performance process of Ground source heat pumps can be explained as follows:

One significant difference between a ground source heat pump and a refrigerator is that the ground source heat pump is meant to run in both directions. When in cooling mode, the earth connection to refrigerant heat exchanger becomes the condenser, and the refrigerant to air heat exchanger becomes the evaporator. This is accomplished through a reversing valve inside the heat pump.

A desuperheater provides domestic hot water when the compressor is operating. The desuperheater is a small auxiliary heat exchanger at the compressor outlet. It transfers excess heat from the compressed gas to water that circulates to a hot water tank. During the cooling season, when air-conditioning runs frequently, a de super heater may provide all the hot water needed in a residential application. Some residential heat pumps are designed to provide hot water year round in quantities sufficient to meet a household's needs [7].

Ground sourced heat pumps simply move energy from one place to another Figure 3. The process of which is explained on the image below:

1. An Evaporator (ground loop heat exchanger) transfers the heat from the ground into the fluid circulating in the loop.
2. At this point the energy in the ground loop transfers through the evaporator within the heat pump and into a CFC free refrigerant.
3. A compressor increases the pressure of the working fluid, which causes the temperature to rise.
4. This energy is transferred over the condenser and into the distribution circuits, where hot water is circulated through the under floor circuits and in turn heating the property.
5. The refrigerant now passes through an expansion valve and the process starts again.

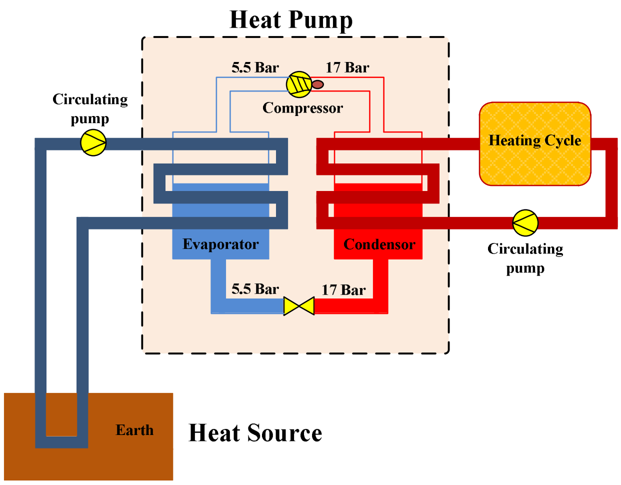


Figure 3. Geothermal heat pump's performance and its structural components.

3. COMPONENTS OF GEOTHERMAL PUMPS

Ground heat pumps have two main parts. A circuit of underground piping outside the building, And a heat pump is placed inside the building. The tubes are also divided into two parts including pipes inside buildings and outside buildings the fact that the inner tube had been within the main devices and are responsible for preparing the air and hot water supply and air, also prepared by the canal will be distributed in buildings.

The outer tubes of the inner tubes are of greatest importance. The Piping systems outside can be an open or a closed loop [8].

Ground source heat pumps can be categorized as having closed or open loops, and those loops can be installed in three ways: horizontally, vertically, or in a pond/lake. The type chosen depends on the available land areas and the soil and rock type at the installation site. These factors will help determine the most economical choice for installation of the ground loop.

For closed loop systems, water or antifreeze solution is circulated through plastic pipes buried beneath the earth's surface. During the winter, the fluid collects heat from the earth and carries it through the system and into the building. During the summer, the system reverses itself to cool the building by pulling heat from the building, carrying it through the system and placing it in the ground. This process creates free hot water in the summer and delivers substantial hot water savings in the winter [9].

A. Closed vertical loop

The ideal choice when available land surface is limited. Drilling equipment is used to bore small-diameter holes from 50m to 150m deep.

B. Horizontal loop

Often considered when adequate land surface is available. Pipes are place in trenches in length that range from 30m to 120m.

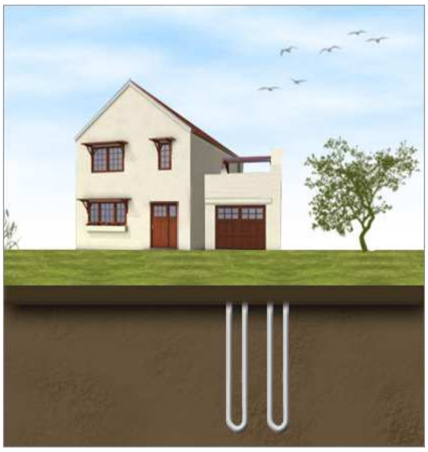


Figure 4. Closed Vertical Loop system

Figure 5.Closed Horizontal loop system

C. Pond (lake) loops

These are very economical to install when a body of water is available because excavation costs are virtually eliminated. Coils of pipe are simply placed on the bottom of the pond or lake.

Open loop systems operate on the same principle as closed loop systems and can be installed where an adequate supply of suitable water is available and open discharge is feasible. Benefits similar to the closed loop system are obtained.

Figure 6. Closed Pond (lake) loops system

Figure7.Open loop system

Open loop systems utilize ground water as a direct energy source. In ideal conditions, an open loop application can be the most economical type of geothermal system.

4. ECONOMIC EVALUATION OF GEOTHERMAL HEAT PUMPS

Geothermal heat pumps require an initial investment cost is relatively high compared to other conventional systems. However, due to lower maintenance costs and lower electrical energy consumption, the initial additional investment cost can be covered in little time [10].

Given that geothermal coil tube, pass through the basement, the costs of drilling and filling the channel, circulation pump, antifreeze fluid is added to the cost of Heat pump. Major part of the investment cost of heat pumps for geothermal drilling costs related to the terrestrial channels, is cost of installation and polyethylene pipe. The cost of installing underground pipes for open loop systems , with a capacity of 3, 4 and 5 tons respectively about 405, 506 and 675 $/ton and for horizontal closed system, about 904 $/ton for vertical systems, is about 1028 $/ton. Installation costs of domestic no underground piping, with The canal and without the canal, for small household units, with a power of 3, 4 and 5 tons respectively are about (4700 - 5900) , (5550 - 7000) and (6000 - 8100) Dollar .The total cost for installing of air heat pump system with a capacity of 3 tons , is approximately 440$, open loop systems is 6900$, horizontal closed system is 8100$, slinky closed system is 8600$, and for vertical closed system , is about 9000$. Figure.5 show the percentage of the cost components of the vertical closed system. Operating costs of a geothermal pump due to savings in fuel is relatively low compared to other heating systems. because ground source heat pumps are used less fuel and more production electricity , Savings relative, dependent on electricity and fuel prices in the region. If the heat pump in an area where electricity prices are expensive, operating costs increase.

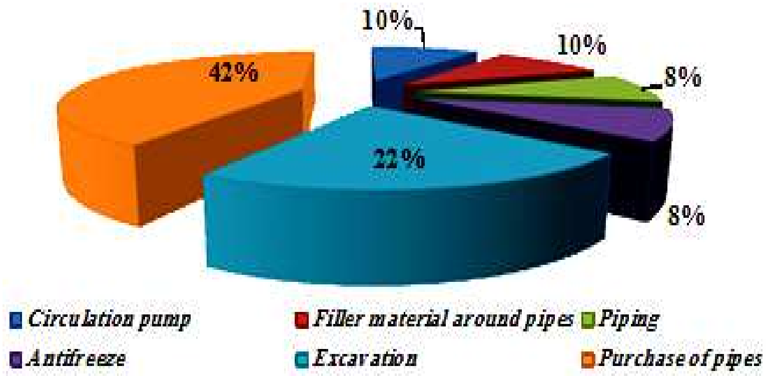


Figure 8. percentage of the cost components of the vertical closed system

Ground heat pumps are available with different efficiencies. Open loop Ground heat pumps, coefficient of performance (COP) Heating, at between 3 and 4 and the cooling coefficient of performance, range 3.5 is to 6. Closed loop Ground heat pumps, coefficient of performance (COP) Heating, at between 2.5 and 4 and the cooling coefficient of performance, range 3 is to 7. In recent years, been achieved large improvements in the efficiency of heat pumps. Today, with technology development of compressors construction, motors and appropriate controls, ground source heat pumps have increased efficiency. The average coefficient of performance in ground source heat pumps is 3.5 and in air source heat pump with 12.5 to be considered.

Economic analysis of projects for the time required for return of capital that time is needed, the annual benefit from the project, to offset the initial investment cost. In fact, after a period time the project reaches the stage of profitability.

5. ECONOMIC CALCULATIONS FOR A TYPICAL BUILDING (A SPORT COMPLEX BUILDING IN ISFAHAN MUSEUM PARK)

Compared to conventional systems for heating and cooling with geothermal heat pumps a sport complex building in Isfahan Museum Park with of underpinning 3562 square meters and consider with heating load 1600 GJ/year , Cooling load 900 GJ/year And hot water 550 GJ/year. A maximum and average value of heating and cooling load is in accordance with Table 1 [11]. Pay the cost of fuel for heating consumption in buildings the per Every one million B.T.U Based on the price of fossil fuels and electricity consumed, can be calculated Heating value of fuel and equipment efficiency (Tables 2 & 3).

Table 1. Maximum and average values of heating and cooling load on KW

Variable	Value
The maximum cooling load for a very hot sunny day	200
cooling load for an average	190
Maximum thermal load for a very cold day	280
thermal load for an average	240

Table 2. Heatingvalueandpriceofenergy carriers

	Heatingvalue offuel	Fuelpriceswith subsidies	Fuelpriceswithoutsubsidies
Kerosene and Diesel	36500 B.T.U/Lit	0.18 $/Lit	0.4 $/Lit
Natural Gas	36500 B.T.U/m^3	0.13 $/m^3	0.4 $/m^3
Electricity	3413 B.T.U/Kwh	0.17 $/Kwh	0.7 $/Kwh

Table 3. the cost of useful energy in a million B.T.U

	Type ofSystem	*The cost of thermal energy (with subsidies) $/Million B.T.U*	*The cost of thermal energy (withoutsubsidies) $/Million B.T.U*
$\frac{\text{Fuel prices} * 1000000}{\text{Heating value of fuel} * \text{Efficiency}}$	*Kerosene and Diesel*	*5.1*	*106.7*
	Natura lGas	*3.7*	*121.8*
	Electricity	*39.1*	*190.5*
	Air source heat pumps	*18.2*	*88.4*
	GSHPs	*11.2*	*54.3*

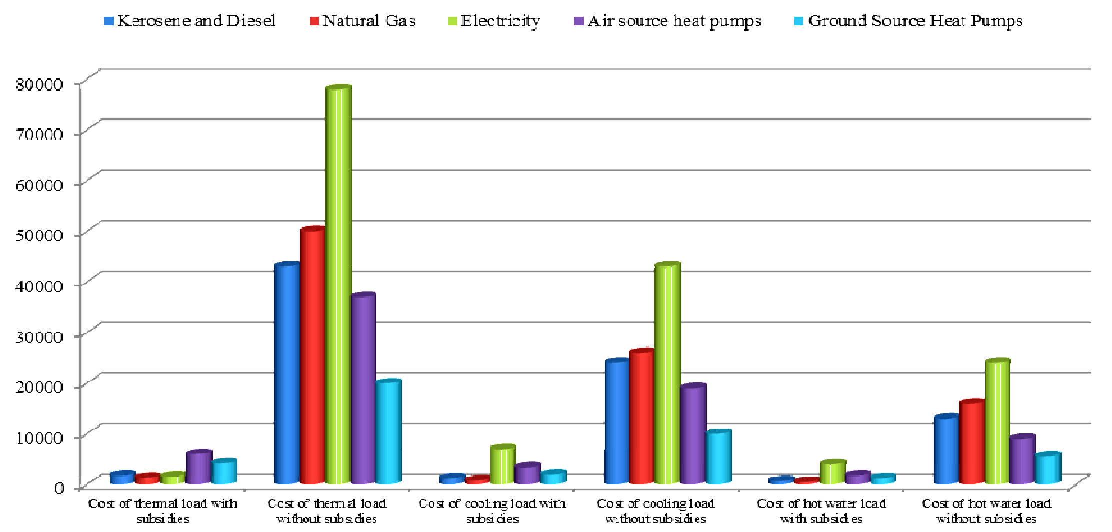


Figure 9. Compare the cost of building energy consumption by different methods

Efficiency of conventional heating systems using fossil fuels, oil and gasoline and natural gas is 65% to 85% in this study assumed that 75% and coefficient of performance Air source heat pump 2.15 and coefficient of performance ground source heat pumps 3.5 has been considered. Given these values, Formulas and high-cost assumptions for each one million joules of useful thermal energy consumption will be in accordance with Table 2.

In the conventional heating and cooling equipment consider the most critical conditions, but in choosing heat pump, generally the pump selection criteria consider between the maximum and intermediate load. For example we can consider the 70 kW thermal also provides the cooling load [12].

When the heat pump alone cannot provide for thermal load of the building Get help electric elements in an heat pump. Of course there are other options the heat pump is according to the maximum thermal load of the building. With this mode selected initial investment costs are more but there still exists the possibility of using standby electric elements. In heat pumps, that the task supply air and hot water at home are responsible simultaneously Due to limitations in the cold of winter, it is possible the heat pump fails to duly both do a decent work to do. In this mode electrical elements are entered.

The annual cost use of types systems for a sport complex building in Isfahan Museum Park, The Figure 9 would be show prices with the subsidized and without subsidies. Can be seen, without the elimination subsidies of energy carriers the method is not economically justified.

Economic evaluation of geothermal heat pump system instead of conventional systems based on the real price of energy carriers Study and its results are included in Table 4. As can be seen, use geothermal heat pump systems instead of using conventional system In addition to significant savings in energy consumption, relatively high initial investment in a period of approximately 3 years to be compensated.

Table 4. Economic evaluation results using geothermal heat pumps instead of conventional systems

	Ground Source Heat Pumps	Air source heat pumps	Electricity	Natural Gas	Kerosene and Diesel
The annual cost of heating energy	2320	3775	8112	5194	4544
The annual cost of cooling energy	1290	2097	4507	2885	2524
The annual cost of hot water	772	1258	2704	1731	1515
Total annual energy cost	4382	7130	15323	9810	8583
Additional cost of initial investment	8333	---	---	---	---
Value of annual savings	---	2748	10941	5428	4201
Rate of return on investment Per year	---	3.03	0.76	1.53	1.98

6. CONCLUSIONS

As air conditioning systems are among the fundamental parts of a building, and also because they play an important role in energy consumption thus they are always one of the concerns of researchers. Currently one of the key equipment proposed for use in air conditioning systems of buildings is heat pumps which result in prominent reduction in energy consumption. Heat pumps are of different types .by conducting research studies the present work has shown that by using heat pumps while using ground as heat source with fix temperature the best performance is obtained. By economical analysis It was proved that using such pumps in the present conditions in Iran is not economically reasonable, but by omitting of subsides of energy transferors, this method would be one of the effective ways to save energy. However as a practical sample the building of sport complex of Museum Park in Isfahan was economically analyzed and it was concluded that the invested money will be returned in this project within 3years.

REFERENCES

[1] J.E.Bose,“Closed-loop/Ground source heat pump systems”, International Gorund-Source, Heat Pump Association. Stillwater, Oklahoma State University, 1988.

[2] S.P. Kavanaugh, “Ground and Water Source Heat Pumps”, IGSHPA. Stillwater, Oklahoma State University, 1992.

[3] J.W. Lund, “Geothermal (Ground-Source) Heat Pumps – A World Overview”, edited and updated version of the article from Renewable EnergyWorld, Vol. 6, No. 4, July-Aug 2003.

[4] Lund. J, et al. 2004. *Geothermal (Ground-Source) Heat Pumps—A World Overview*. Geo-Heat Center Bulletin, September.

[5] Ball, D.A., R.D. Fischer, and D.L. Hodgett. 1983. Design methods for ground-source heat pumps. *ASHRAE Transactions* 89(2):416-440.

[6] Pahud, D., and G. Hellström. 1996. The new duct ground heat model for TRNSYS. *Eurotherm Seminar No. 49*, Eindhoven, The Netherlands, pp. 127-136.

[7] Yavuzturk, C., and J.D. Spitler. 1999. A short time step response factor model for vertical ground loop heat exchangers. *ASHRAE Transactions* 105(2):475-485.

[8] Yavuzturk, C., and J.D. Spitler. 2000. Comparative study to investigate operating and control strategies for hybrid ground source heat pump systems using a short time-step simulation model. *ASHRAE Transactions* 106(2):192-209.
[9] Yavuzturk, C., and J.D. Spitler. 2000. Comparative study to investigate operating and control strategies for hybrid ground source heat pump systems using a short time-step simulation model. *ASHRAE Transactions* 106(2):192-209.
[10] Yavuzturk, C., and J.D. Spitler. 2000. Comparative study to investigate operating and control strategies for hybrid ground source heat pump systems using a short time-step simulation model. *ASHRAE Transactions* 106(2):192-209.
[11] Largest Geothermal System in Ohio goes to high school", Engineered System, Mars 2001, Vol.18.lssue3.

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