Journal of Environment and Earth Science
ISSN 2224-3216 (Paper) ISSN 2225-0948 (Online)
Vol.6, No.6, 2016

Underground Thermal Energy Storage Application in Erbil City Kurdistan, Region-Iraq (Case Study)

Abdulfattah Ahmad Amin
Department of Surveying, Erbil Technology Institute. Erbil Polytechnic University, Kurdistan, Iraq

Abstract
Energy storage technology is used to save energy. Different storage methods are used depending on the energy form. A borehole thermal energy storage system is an underground structure for large quantities of heat and cool energy in soil and rock. Earth energy design 2.0 PC-Program is used for borehole design. The test building consists of six class rooms. Total build area was about 1200m^2, height was 3m and the total volume was 3600m^3.The annual mean temperature was 20.95 °C. The degree hour method is used to calculate the energy demand above the base temperature 17 °C for heating and 20 °C for cooling. The required maximum power demand for heating is 158.4KW and the maximum power demand for cooling the building is 211.2KW. In the months of January, February, March, April and November and the total heating demand for the building is 254,52MWh. In the months of May, June, July, August and September, the total cooling demand for the building is 10MWh. Earth energy designer was applied for a proper hole system. Five attempts were applied by changing the seasonal performance factor and each attempt was divided in to two sections according to the assumed borehole spacing and details seasonal performance factor (SPF) is strongly correlated to the borehole depth and borehole spacing. To get a high SPF value, the borehole depth and spacing must be increased.
Keywords: Thermal energy, SPF, Kurdistan, Iraq.

1. Introduction

To justify searching for energy resources in Iraq is very difficult. For many years it was hard to convince the authorities and the people in one of the biggest oil producing countries in the world to think about alternative energy resources. Now after more than two decades of wars, neglect, poor management and violence, most of Iraq's infrastructure is destroyed. Oil producing facilities, electricity plants, and gas producing projects are seriously damaged; transportation of the oil products is not secure, also the electricity networks are under daily attack. For people in Iraq especially in Kurdistan it is difficult to get enough energy to manage ordinary life demands, and it is very expensive now compared with the prices. There is a good chance now to introduce renewable energy resources concepts and it may be accepted by the people and the authorities, even if it is still difficult to convince most of them due to the cost factor. By using renewable energy resources in this area it may help also in solving one of the modern world's problems which is the global climate change.

One of the most important available alternative energy sources are different solar energy systems, which provide an alternate source of energy in many developing and industrialized countries, and might have potential in Iraq's.

This project intends to perform a design of a Thermal Energy Storage system for Space Heating and Cooling in a school and to calculate the costs.

The available data was collected from the study area, generally in Erbil.

1.1 Underground thermal Energy storage

Energy storage technology is used to save energy, to be used later. Energy storage must be less expensive than producing the energy when it is needed; also it must be considered to be, friendly to the environment. Different energy storage methods are used depending on the energy form; Table 1 shows different methods of energy storage according to the energy form (Nordell, 1987).

Table1: Table showed the methods used to store different energy forms from (Nordell, 1987).

Energy form	*Storage method*
Kinetic	Balance wheel
Potential	Hydropower
Chemical	Salts
Pressure	Pressure accumulator
Electrical	Superconductor
Thermal	Thermos, heat storage, ground storage

Thermal energy storage systems may store heat in water or in the ground (soil, sand and gravel) or in water and ground together. Thermal energy storage systems can be constructed above ground or underground. The most common underground thermal energy storage methods are:

1.1.1 Rock- Cavern Thermal Energy Storage (CTES).

In this system heat is stored in form of hot water in underground rock cavities. Since it is possible to charge and discharge water rapidly, these systems can give and check a large effect (see figure 1a). Rock- Caverns must have a large volume; therefore they are not heat insulated (Nordell, 1987).

1.1.2 Aquifer Thermal Energy Storage (ATES).

Aquifer is an underground layer from which ground water is extracted. In this system the heat will be stored in groundwater and sand or in a gravel layer, which consists the aquifer (see figure 1b). This system can be used for heating in winter and cooling in summer by using ground- source heat pumps (Nordell, 1987).

1.1.3 Borehole Thermal Energy Storage (BTES).

In this system heat is stored in soil or rock during the charging phase and it is extracted during the cooling phase. The heat is transferred from/to the ground through pipes installed in holes (see figure 1c). During winter heat is extracted from the ground and converted to a higher temperature by the heat pump and the process will be reversed in summer as it will be extracted from the air and transferred to be stored in the ground (Nordell, 1987, EnerGuide, 2004 and Sanner, 2001).

1.1.4 Snow storage (PCM).

In this system snow is stored in rock cavities to be used as a source of cooling in hot seasons. It can be constructed both in small scale about 100m^3 and in big scale till 100,000m^3 (see figure 1d).

Figure 1: Figure shows the most common underground thermal energy storage systems.

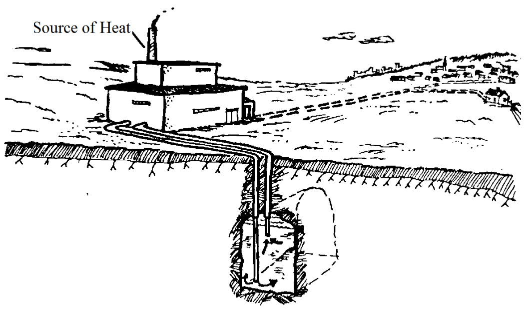


Figure 1a: Rock- Cavern Thermal Energy Storage (CTES) from (Nordell, 1987)

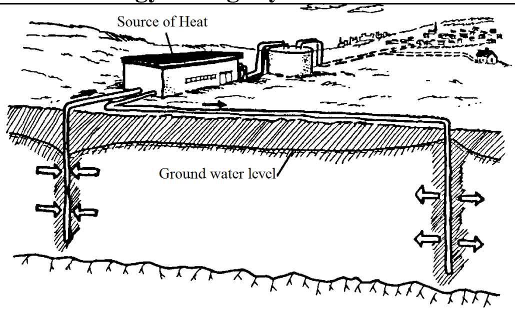


Figure 1b:Aquifer Thermal Energy Storage (ATES) from (Nordell, 1987)

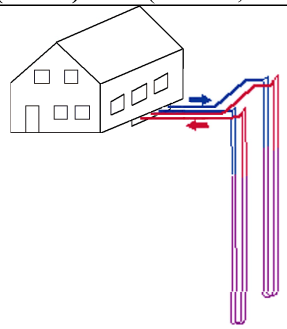


Figure 1c: Borehole Thermal Energy Storage (BTES) from (Sanner, 2001)

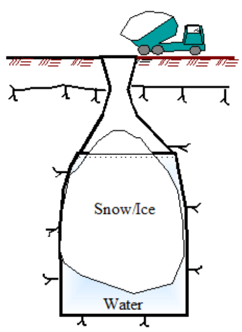


Figure 1d:Snow storage (PCM)

1.2 Borehole Thermal Energy Storage (BTES)

A BTES system is an underground structure for storing large quantities of heat and cool energy in soil and rock. It is basically a large, underground heat exchanger. A BTES consists of an array of boreholes, resembling standard drilled wells. There are two different types of borehole system: open and closed systems. In the open system the charging pipe's outlet will be placed close to the bottom of the hole, while the discharging pipe's inlet opening will be placed close to the top of the hole, but under the ground water table (see Figure 2a). Groundwater is used as a heat carrier, and is brought directly to the heat pump. In this system the circulating water will be in direct contact with the borehole wall.

In closed systems (see Figure 2b), pipes are installed in the ground. U-pipes are used in this system, the pipes are filled with a proper liquid, which absorbs heat from the ground and transfers it to the heat pump, and the heat carrier is pumped in a closed circuit. The U-pipes act as a heat exchanger between the heat/cold carrying medium and the surrounding rock. The closed system is more common in Sweden (Nordell, 1987, EnerGuide, 2004 and Sanner, 2001).

Figure 2 .Figure shows the types of borehole systems.

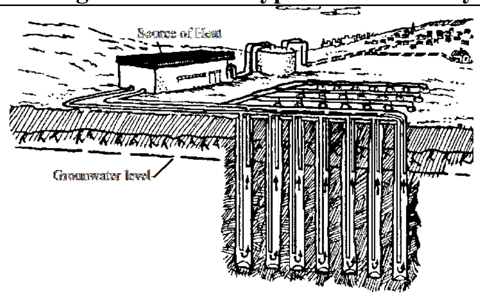


Figure 2a:Borehole, Open system
from (Nordell, 1987)

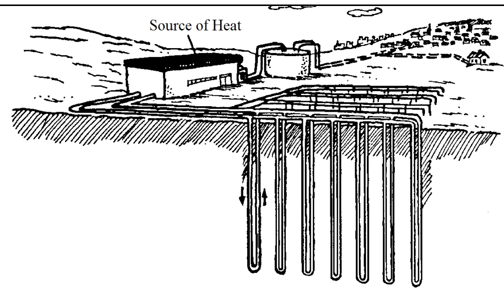
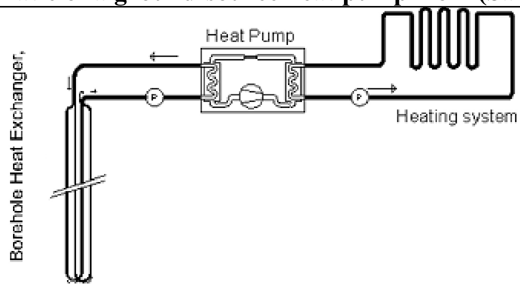


Figure 2b: Borehole, Closed system
from (Nordell, 1987)

In a borehole heat storage system, holes of around 100mm diameter are drilled to the depth of 50m- 100m or more. Plastic pipes with "U" bend at the bottom are installed inside the holes. The pipes are filled with a heat carrier liquid, which is circulated in the loops. In cold places antifreeze is mixed with the heat carrier liquid. The borehole is filled with water if the groundwater table is not low, or it will be filled with a high thermal conductivity grouting material such as sand, mortar, betonies or clay, to provide a thermal contact with the surrounding soil. The BTES systems performance depends on its design, filling material, spacers, and heat carrier flow rate. The liquid inside the pipes, which has extracted heat from the ground, will be brought to the heat pump inside the building see Figure 3. Waste hot and cold energy is stored in the rock during the summer and winter seasons for use in the following season.

Figure3: Figure showed Schematic of a ground-source heat pump from (Sanner, 2001).



During summer, heat is transferred by the liquid (heat carrier) into the centre of the BTES field through the U-pipe series. Heat is extracted by the surrounding soil and rock, and the water gradually cools as it reaches the outer edge and is used directly to cool the buildings. In that case, the heat pump operates as a cooling machine and stores condenser heat in the ground.

Conversely, in winter, heat is extracted by the liquid (heat carrier) that absorbing heat from the ground. This heat is used as heat source for the heat pump, which brings absorbed energy up to a useable temperature level.

2. Materials and Methods

Earth Energy Designer 2.0 (EED), which is a PC-program used for borehole design is used in this project. The annual temperature data of Erbil is available. The test building is a 6 classroom school building as shown in Figure 4 and 5.

Figure 4: Figure showed Primary School of 6 class rooms.

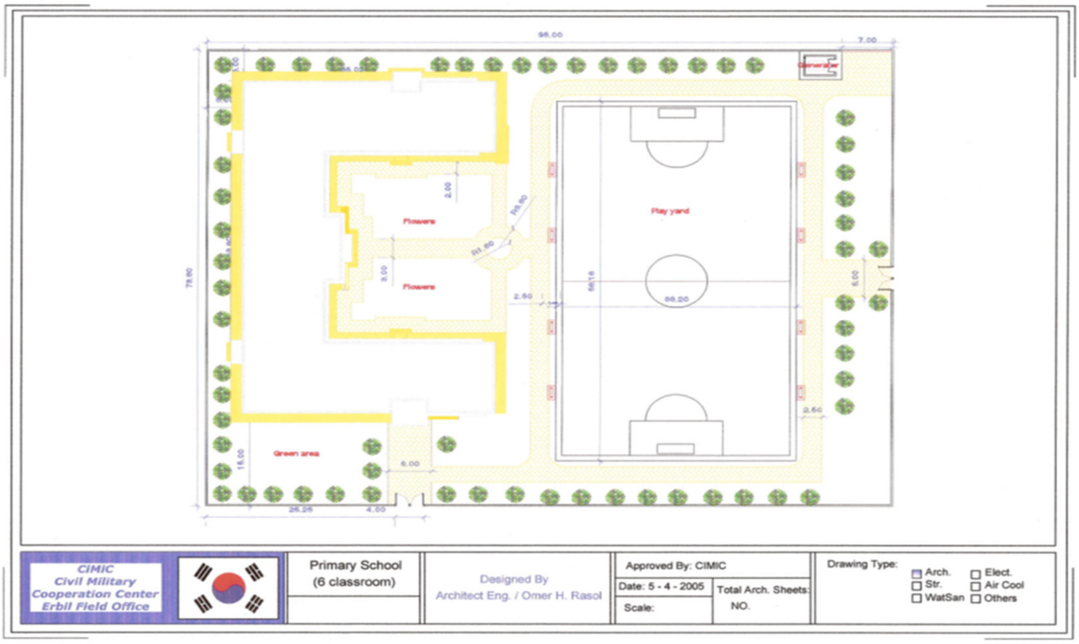
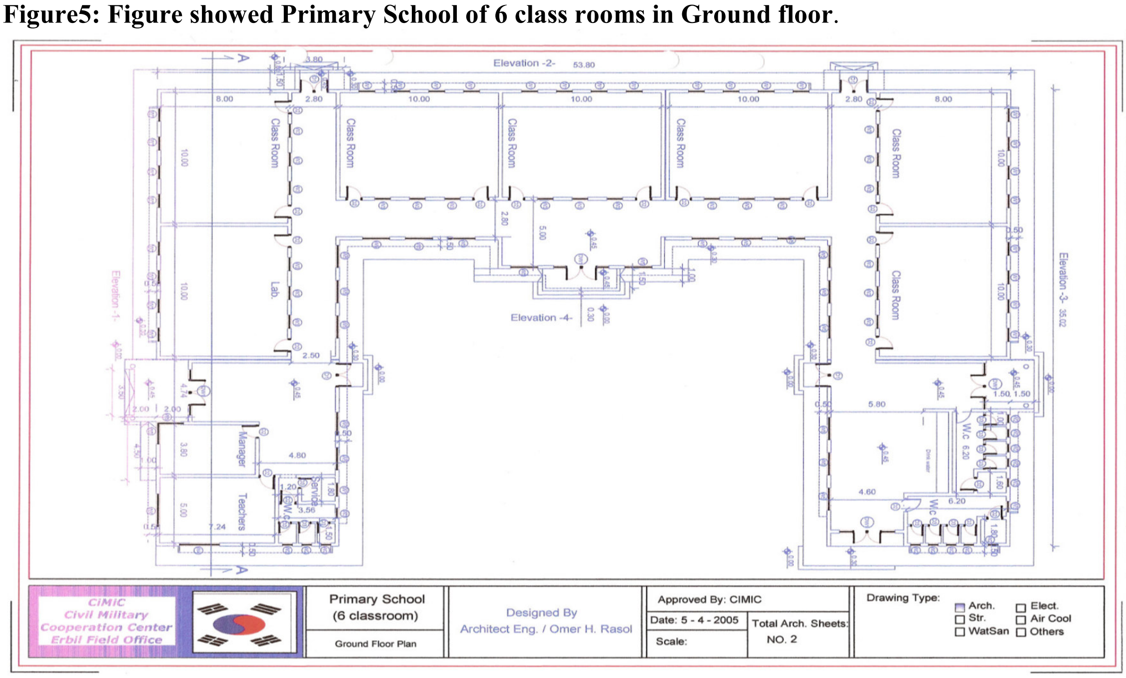


Figure5: Figure showed Primary School of 6 class rooms in Ground floor.



Total build area is about 1200 m^2, divided into 6 classrooms, two rooms for the teachers and the headmaster, a corridor, in addition to the toilets and other services. Since the height is 3m, the total volume will be about 3600m3.

Erbil is located in Northern Iraq it has cold winters and hot summers, dry and mostly sunshine. The warmest month is August with over 22 °C - 45 °C and the coldest month is January with temperatures below zero at times. The average precipitation in the area falls between October and May, and the period June to August has no rainfall.

The monthly mean air temperatures are presented in Table 5. According to the data provided by Erbil Weather Forecasting authorities, the annual mean air temperature is 20.95°C, and since the ground temperature is considered to be equal to the mean air temperature, the ground temperature is assumed to be 20.95°C. More detailed data on the annual temperature was obtained from the Swedish Meteorological and Hydrological Institute see table 6 that explored in Figure 6. The annual mean air temperature is 17.76°C.

Table 2: Monthly mean air temperatures in Erbil (annual mean temperature is 20,95ºC), According to the data provided by Erbil Weather Forecasting Authorities.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Mean temp.	8,36	9,32	13,18	18,02	26,44	30,50	34,27	33,67	29,05	23,59	15,18	9,77

Table 3: Monthly mean air temperatures in Erbil (annual mean temperature is 17,76 ºC), According to the data obtained from the Swedish Meteorological and Hydrological Institute.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Mean temp.	5,05	7,05	10,96	15,75	21,99	27,38	31,34	30,34	25,65	19,28	11,60	6,73

Figure 6: Monthly mean air temperatures in Erbil.

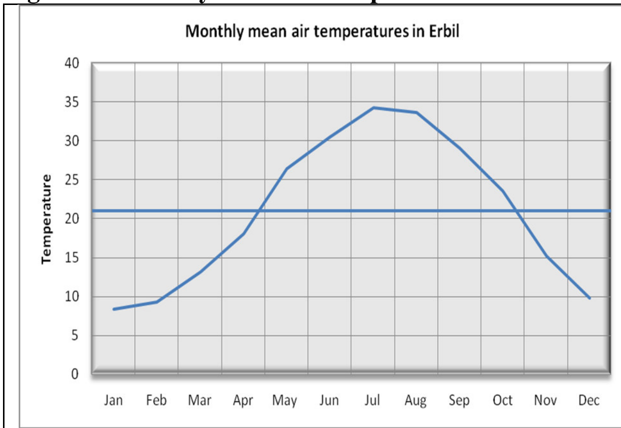


Figure 6a: Monthly mean air temperature in Erbil (data provided by Erbil Weather forecasting authorities)

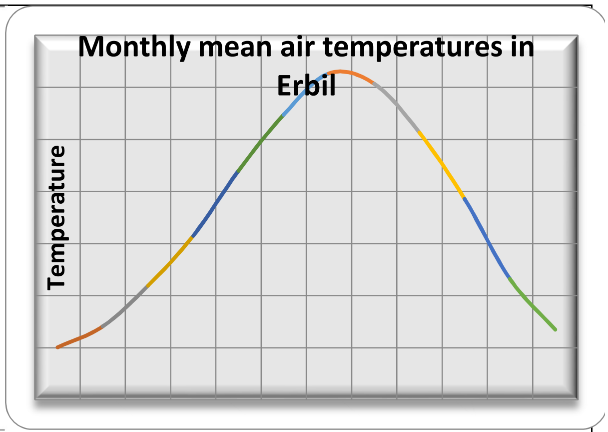
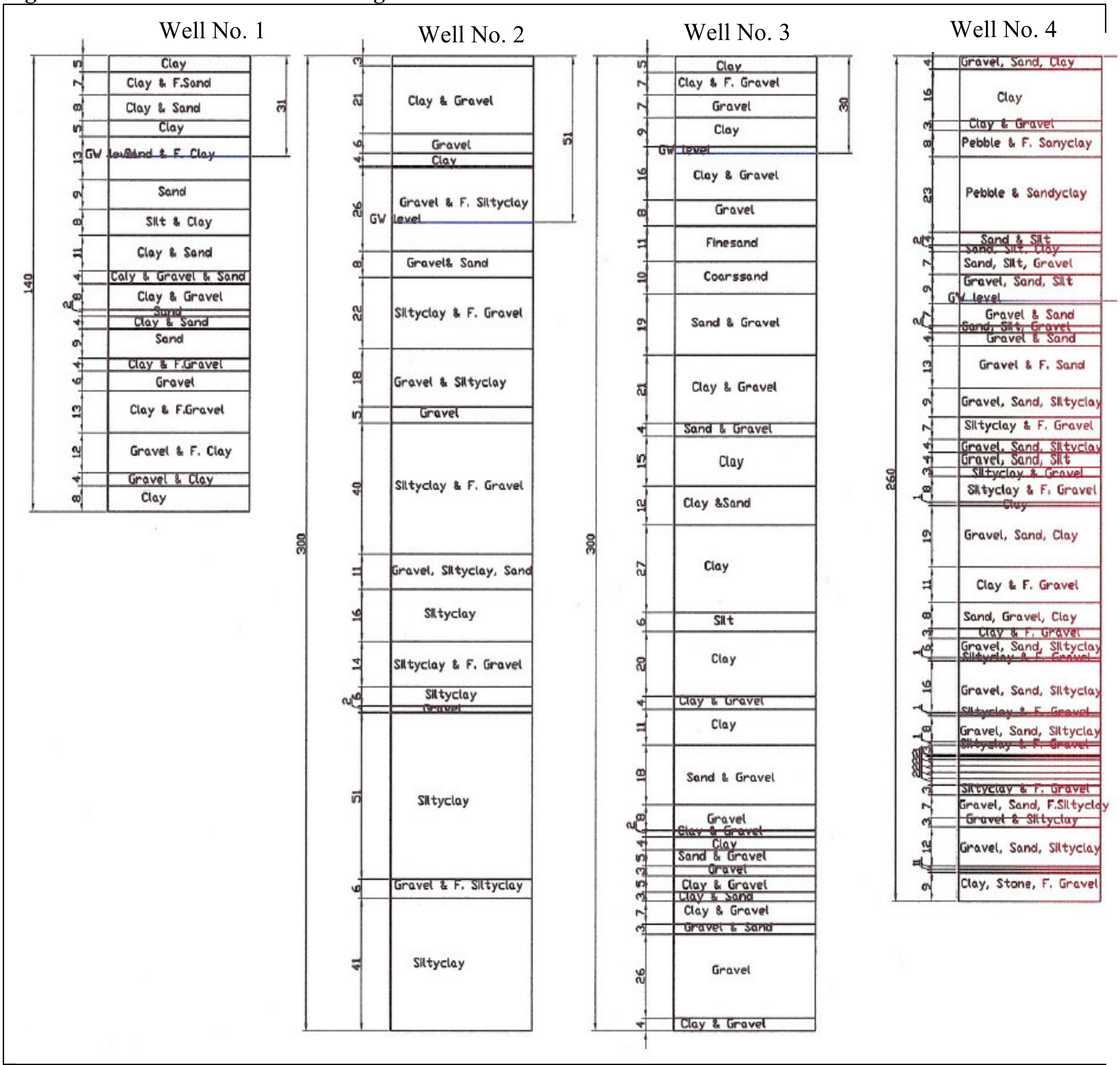


Figure 6b:Monthly mean air temperature in Erbil (data obtained from the Swedish Meteorological and Hydrological Institute)

2.1 Ground properties

According to the information provided by the Underground Water authorities in Erbil and the Geological Survey authorities, the bedrock in Erbil is limestone and it is at around a depth of 1000m. The soil in Erbil consists of gravel, clay, sand and silt in different fractions. Figure 7 shows the ground water levels and the soil profile around a number of wells in Erbil, which at different positions; south, **west,** northwest, and northeast.

Figure 7: Soil stratification and the groundwater level in a number of wells in Erbil.



The groundwater levels for each of the mentioned wells are shown below in table 7. Data was collected from different samples at different positions around the city.
In order to estimate the thermal conductivity, it is assumed that the soil in Erbil consists of 38% gravel, 30% clay, 16% sand and 16% silt.
According to the estimations:
Thermal conductivity will be; 0,38* 0,40+ 0,30* 0,40+ 0,16* 0,40+0,16* 0,40= 0,40 W/m, K.
The volumetric heat capacity is; 0,38*1,6+ 0,30* 1,5+ 0,16* 1,4+ 0,16*1,6= 1,53 MJ/m^3, K.
The ground water level is estimated to be around 45m.

Table 4: Table showed Ground water details.

	Name	Position	Depth	GW level	Capacity	Salinity
1	Adil	South	140 m	31 m	10 l/s	369 µg/ l
2	Park	West	170 m	28 m	14 l/s	
3	Einkawa 1	N- west 1	300 m	51 m	8 l/s	
4	Einkawa 2	N- west 2	300 m	58 m	22 l/s	
5	Centre	N- east	260 m	75 m	6 l/s	414 µg/ l

2.2 Heating and cooling demands

As the temperature data obtained from the Swedish Meteorological and Hydrological Institute is given in details, it was used to calculate the heating and cooling demands in Erbil by using the Degree hour method. The differences in the data provided by Erbil Weather forecasting authorities and the Swedish Meteorological and Hydrological

Institute was taken into consideration, when the base degrees for heating and cooling were estimated.

Degree hour method is a method used to calculate the energy demand based on the cumulative degrees above a base temperature for heating and under another base temperature for cooling. A base temperature of 17°C for heating, and 20°C for cooling, was assumed. The difference between the base temperature 17°C for heating and 20°C for cooling, and the average air temperature of the hour is calculated. If the average air temperature for the hour falls below 17°C the degree hour recorded as a heating degree. If it rises above 20°C, it is recorded as a cooling degree. The heating degree hours for a month are derived by adding the heating degree hours for that month, and the cooling degree hours for a month are derived by adding the cooling degree hours for that month.

According to experts in the city, they assume that 9Am are needed for heating 12m^2 and 12Am is needed for cooling the same area. To convert that into power they use the following equation:

$9\times220\times0.8=1.584$KW maximum power demand for heating 12m^2.

$1.584\div12=0.132$KW/m^{2}maximum power demand for heating 1m^2.

$12\times220\times0.8=2.11$KW maximum power demand for cooling 12m^2.

$2.112\div12=0.176$KW/m^2 maximum power demand for cooling 1m^2.

Then the maximum power demand for the building is calculated as following:

Maximum power demand for heating the building=$0.132\times12000=158.4$KW

Maximum power demand for cooling the building= $0.176\times12000=211.2$KW

The building needs heating for the period between November- April, and it needs cooling for the period May- September, and since the schools are closed in July and August cooling is needed for May, June, and September. Table 5 shows the monthly heating and cooling demands calculated according to the degree hour method as mentioned above. The heating demand is explored in figure 8a, while the cooling demand is explored in Figure 8b.

Table 5: Monthly heating and cooling energy demand for a school building in Erbil.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Heating MWh	66,44	50,00	34,65	15,74	4,18	0,26	0,00	0,00	0,33	6,85	30,62	57,07
Cooling MWh	0,00	0,00	0,21	4,81	25,19	50,80	78,04	71,25	25,01	6,28	0,00	0,00

Total heating demand for the building=254,52MWh, the months Jan, Feb, Mar, Apr, Nov, and December are included. Total cooling demand for the building=101MWh, the months May, Jun and September are included.

Figure 8: Monthly heating and cooling demand for a school building in Erbil.

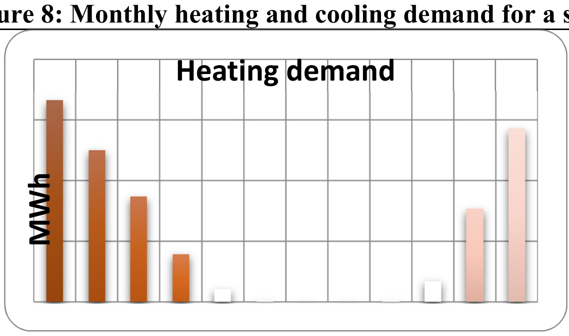


Figure 8a: Monthly heating energy demand for a school building in Erbil

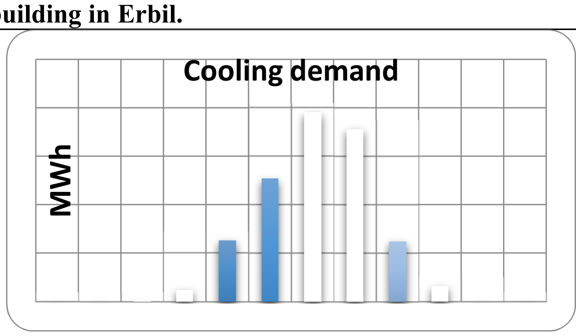


Figure 8b: Monthly cooling energy demand for a school building in Erbil

2.3 Earth Energy Design (EED) simulations

Using EED to design a proper borehole system for the reference building, the following input data were used:

- Ground properties,
- Thermal conductivity = 0,40 W/m,K.
- Volumetic heat capacity = 1,53MJ/m^3,K.
- Ground surface temperature= 17,76 °C.
- Borehole and heat exchanger,

The borehole type chosen is either single-U or double-U, depending on the situation. Double-U pipe is used to reduce the number of required boreholes. The following assumptions were made in this case:

- Borehole installation Double- U pipes.

U- pipe diameter 32mm, and U- pipe thickness 2mm.

- Since the ground water level is low, sand is used as a filling- grouting- material to enhance the thermal conductivity. As the ground water level is about 40m under the ground surface, it was assumed that the grouting will be 40% dry sand, and 60% moist sand. Thermal conductivity will be ($0.4\times0.4+0.6\times1=0.76$W/m,K).

- The heat carrier fluid is condensed to water at 20°C.

- Base load,
- Annual heating= 254,52MWh and Annual cooling= 101MWh.
- SPF (Seasonal Performance Factor) using heat pumps= 3, and SPF using direct cooling= 20.

Table 6: The annual base load is divided per months as in the table.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Heating (MWh)	66,44	50,00	34,65	15,74							30,62	57,07
Cooling (MWh)					25,19	50,80			25,01			

- Fluid temperature constraints are between
- Minimum fluid temperature= $5^{o}C$
- Maximum fluid temperature= $45^{o}C$

Five attempts were applied by changing the Seasonal Performance Factor SPF, and each attempt is divided into two sections according to the assumed Borehole Spacing with the details presented in Table7.

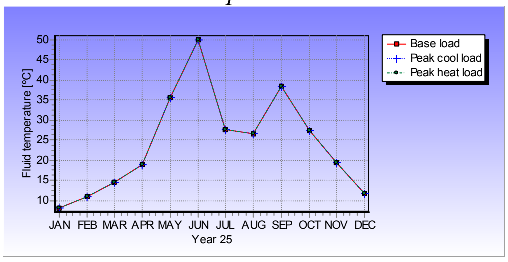
Table7: The following table shows, the results obtained from EEA module simulation. Four attempts were applied by changing the Seasonal Performance Factor SPF, and each attempt was divided into two sections according to the assumed Borehole Spacing.

	First attempt SPF Heating=3 SPF cooling=3		*Second attempt SPF Heating=3 SPF cooling=20*		*Third attempt SPF Heating=4 SPF cooling=4*		*Forth attempt SPF Heating=4 SPF cooling=20*		*Fifth attempt SPF Heating=20 SPF cooling=20*	
Thermal conductivity	0.40		0.40		0.40		0.40		0.40	
Volumetic heat capacity	1.53		1.53		1.53		1.53		1.53	
Ground surface temperature	17.76		17.76		17.76		17.76		17.76	
Borehole installation	Double- U		Double- U		Double- U		Double- U		Double- U	
Borehole diameter	0,114m		0,114m		0,114m		0,114m		0,114m	
U- pipe diameter	32mm		32mm		32mm		32mm		32mm	
Grouting material- sand	0.76		0.76		0.76		0.76		0.76	
Base load	Heating	Cooling	Heating	Cooling	Heating	Cooling	Heating	Cooling	Heating	Cooling
Jan	66.44		66.44		66.44		66.44		66.44	
Feb	50.00		50.00		50.00		50.00		50.00	
Mar	34.65		34.65		34.65		34.65		34.65	
Apr	15.74		15.74		15.74		15.74		15.74	25.19
May		25.19		25.19		25.19		25.19		50.80
Jun		50.80		50.80		50.80		50.80		
Jul										
Aug										25.01
Sep		25.01		25.01		25.01		25.01		
Oct										
Nov	30.62		30.62		30.62		30.62		30.62	
Dec	57.07		57.07		57.07		57.07		57.07	
Minimum fluid temperature	5	5	5	5	5	5	5	5	5	5
Maximum fluid temperature	50	50	43	40	38	43	40	38	38	35
Configuration	5*7	5*7	5*7	5*7	5*7	5*7	5*7	5*7	5*7	5*7
Borehole spacing	10m	7m	10m	7m	10m	7m	10m	7m	10m	7m
Borehole depth	140,13m	128,2m	137,03m	145,94m	145,53m	158m	153,41	165,38	185	205,25

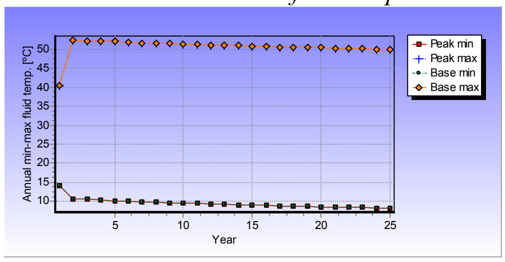
Figure9: The following charts represent, the results obtained from EEA module simulation. Four attempts were applied by changing the Seasonal Performance Factor SPF, and each attempt was divided into two sections according to the assumed Borehole Spacing.

First attempt, borehole spacing= 10m

Fluid temperature chart

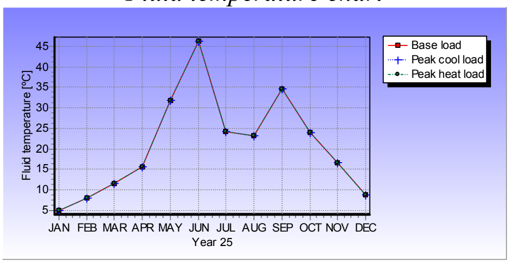


Minimum and maximum fluid temperature

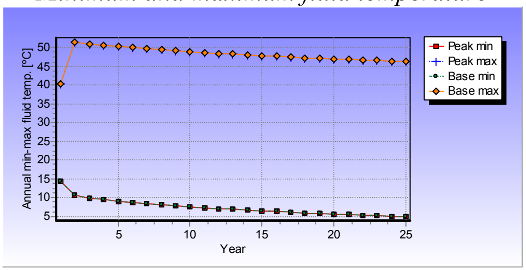


First attempt, borehole spacing= 7m

Fluid temperature chart

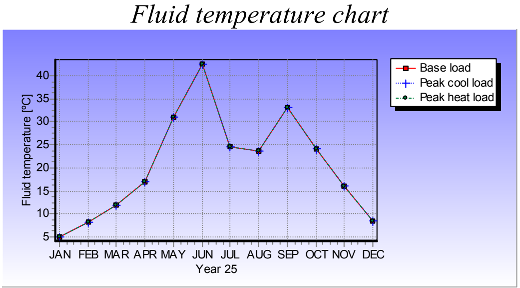


Minimum and maximum fluid temperature

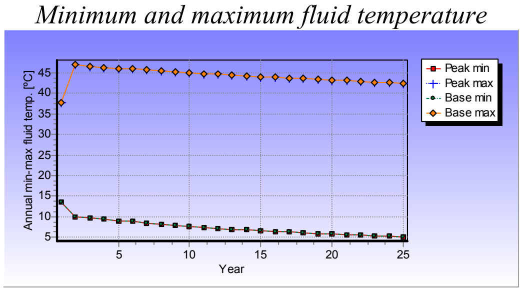


Second attempt, borehole spacing= 10m

Fluid temperature chart

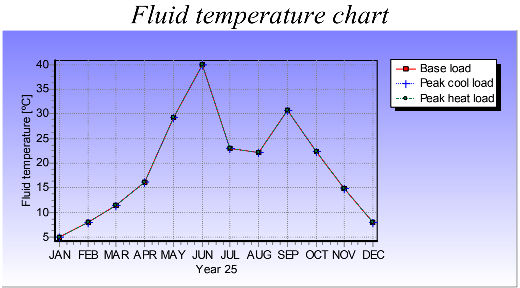


Minimum and maximum fluid temperature

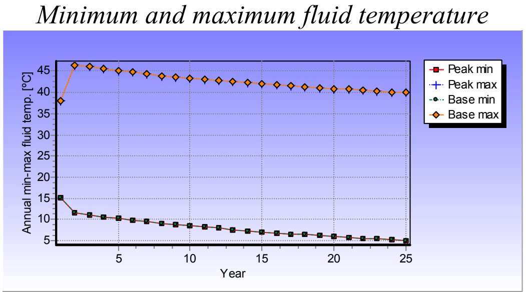


Second attempt, borehole spacing= 7m

Fluid temperature chart



Minimum and maximum fluid temperature



3. Results and Discussion

Following results obtained from EEA simulations after four attempts by changing the Seasonal Performance Factor SPF, and each attempt was divided into two sections according to the assumed Borehole Spacing (see table 7).

- First attempt, by using heat pumps for both heating and cooling SPF=3:
- Borehole installation Double- U pipes.
- Configuration 35: 5*7, rectangular.

The borehole depth will be 140,13m if Borehole spacing is 10m, and the borehole depth will be 128,20m if Borehole spacing is 7m.

- Second attempt, by using heat pumps for heating, SPF=3, and using free cooling SPF=20:

- Borehole installation Double- U pipes.
- Configuration 35: 5*7, rectangular.

The borehole depth will be 137,03m if Borehole spacing is 10m, and the borehole depth will be 145,95m if Borehole spacing is 7m.

• Third attempt, by using heat pumps for both heating and cooling SPF=4:
- Borehole installation Double- U pipes.
- Configuration 35: 5*7, rectangular.

The borehole depth will be 145,53m if Borehole spacing is 10m, and the borehole depth will be 158m if Borehole spacing is 7m.

• Fourth attempt, by using heat pumps for heating, SPF=4, and using free cooling SPF=20:
- Borehole installation Double- U pipes.
- Configuration 35: 5*7, rectangular.

The borehole depth will be 153,41m if Borehole spacing is 10m, and the borehole depth will be 165,38m if Borehole spacing is 7m.

• Fifth attempt, by using free heating and cooling systems SPF=20:
- Borehole installation Double- U pipes.
- Configuration 35: 5*7, rectangular.

The borehole depth will be 185m if Borehole spacing is 10m, and the borehole depth will be 205,25m if Borehole spacing is 7m.

• Costs

The electricity power is subsidized by the government in Erbil. Each 1KWh costs the costumer 0.05 USD, while it costs the government much more than the mentioned price. In addition to that, the available electricity does not cover the demand in Erbil.

- The annual heating demand for the reference building is 254,52MWh, and the annual cooling demand is 101, 00 MWh.
- The total annual heating and cooling cost is about 18000 USD, but it costs the government much more.
- A complete borehole system including borehole heat exchanger, installation and heat pumps in Europe costs around 2000 – 4000 USD per KW heating.
- Assuming that the required power for the building is around 150- 200KW. The total cost will be around 300000 USD to 800000. The payback time is around 16-45 years. In addition to the operation costs.

4. Conclusion

The Seasonal Performance Factor (SPF) is an indicator of the efficiency of a borehole system. It is calculated by dividing the sum of all kinds of useful output energy by the total power needed over a season. The exact calculation is obtained by using seasonal performance factor equation.

The results show that SPF is strongly correlated to the borehole depth and the Borehole spacing. To get a high SPF value, the Borehole depth and spacing must be increased. Since there is a lot of available space in the reference building, the Borehole spacing is not considered as an important factor in this study.

The Borehole depth is the most important factor between the alternatives, and the best available alternative in this case is the second attempt that is as follows:

- SPF=3 for heating, and SPF=20 for cooling by using free cooling method.
- Borehole installation Double- U pipes.
- Configuration 35: 5*7, rectangular.
- Borehole depth, 137,03m.
- Borehole spacing, 10m
- Borehole diameter= 0,114m as recommended by EED.
- U- Pipe diameter 32mm, and U- pipe thickness 2mm.

References

EnerGuide. (2004). Heating and Cooling with a Heat pump. Ottawa, Canada: Office of Energy Efficiency's EnerGuide programs.

Nordell, B. (1987). Solar Energy and Heat Storage. Luleå, Sweden: Luleå University of Technology.

Sanner, B. (2001). Shallow Geothermal Energy. Giessen, Germany: Justus-Liebig University.

Wemhöner, C., & Afjei, T. (2003). Esasonal Performance calculation for residential heat pumps with combined space heating and hot water production (FHBB Method). Basil: University of Applied Science Basel Institute of Energy.