# FIRST THERMAL RESPONSE TEST IN SYRIA

Mohamad Kharseh[1], Bo Nordell[2]
Dept. of Civil and Environmental Engineering, Luleå University of Technology
SE-97187 Luleå, Sweden
[1]khamoh@ltu.se; [2]bon@ltu.se

## ABSTRACT

Ground source heat pumps (GSHPs) mean attractive heating and cooling systems. The injection/extraction of thermal energy is obtained by borehole heat exchangers (BHE). Since the GSHP operates at a relatively stable temperature, the coefficient of performance of such systems is higher than that of air source heat pumps. BHEs are drilled to a depth <300 m with a diameter of 0.10-0.15 m. The proper BHE design requires knowledge of ground thermal properties. Thermal response testing (TRT) is used primarily for in situ determination of design data for BHEs. In current study, which was the first TRT in Syria, the purpose was to determine the effective ground thermal conductivity. Measured data were evaluated by the line source model. Used method and performed evaluation are presented for a borehole drilled in clay, silt and sand. The resulting effective ground thermal conductivity was 2.011 W/m.K and the borehole thermal resistance was 0.111 K /(W/m).

## 1. INTRODUCTION

The current global energy consumption is $14 \cdot 10^{10}$ MWh/year (2007), partly covered by a daily oil consumption of 86 Mbbl(EIA, 2008), fig (1). The $CO_2$ emission, which is supposed to play a leading role in global warming, is about 2.94 ton-$CO_2$/$m^3$ of oil (Boyle, 2004 and Genchi et al., 2002). This means that oil alone results in an annual emission of $1.47 \cdot 10^{10}$ tons of $CO_2$. Space heating/cooling systems consume 30-50% of the global energy consumption (Seyboth et al., 2008 and Ala-Juusela, 2007) i.e. ~$5.6 \cdot 10^{10}$ MWh/year, which corresponds to $1.41 \cdot 10^{10}$ tons $CO_2$/year, considering that 70 kg of $CO_2$ is emitted per GJ (Boyle, 2004). Foreseen environmental problems require actions for sustainable development. In this regard, more efficient use of energy and increased use of renewable energy (RE) appears to be the most efficient and effective solutions (Hepbasli, 2008). The main problem facing RE is varying power supply of renewable energy. Fig 2 shows that solar energy is available when heating demand is very low. In climates with seasonal temperature variations, there is a potential to use the underground as heat source (low heat reservoir) during the cold season and as heat sink (high heat reservoir) during the hot season (Nordell et al., 2007 and Ozgener et al., 2007). Extracted thermal energy is renewable since the seasonal temperature variation restores the temperature from the ground surface. According to the second law of thermodynamics, the Coefficient of Performance (COP) of a heat pump is mainly affected by

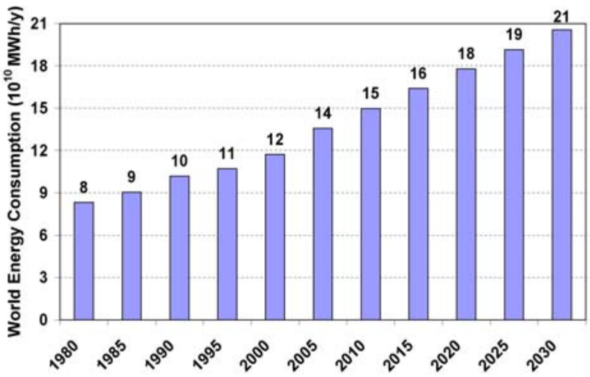

Fig. 1. Global Energy Consumption

the operating conditions. The highest COP is obtained when the cycle is reversible i.e. operating at the Carnot limit, figure (3). In this case, the COP is a function of the temperature of high heat reservoir (HHR) and low heat reservoir (LHR):

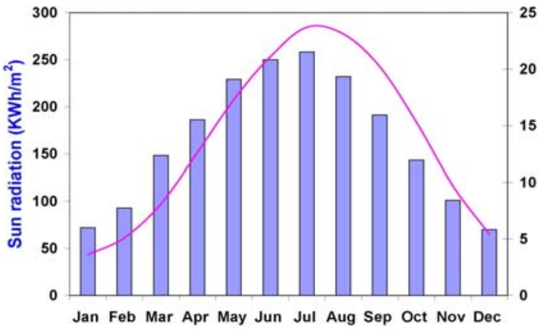

Fig. 2. Annual available solar energy and average air temperature in Hama, Syria

During the winter (heating machine) the COP is:

$$COP_h = \frac{T_{high}}{T_{high} - T_{low}}$$

Here, $T_{high}$ represents the condensation temperature, while $T_{low}$ represents the evaporation temperature. As seen, $COP_h$ will increase if the $T_{low}$ increases.

During the summer (cooling machine) the $COP_c$ is:

$$COP_c = \frac{T_{low}}{T_{high} - T_{low}}$$

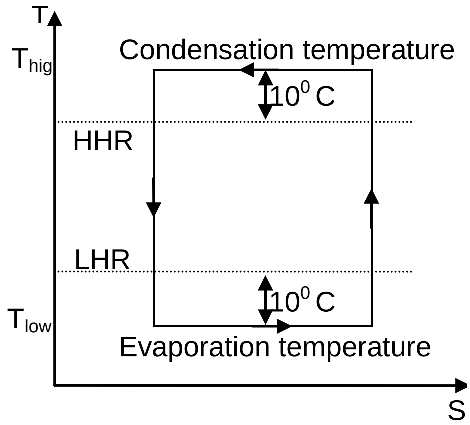

Fig. 3. Carnot Cycle of heat pump

Here, $T_{low}$ and $T_{high}$ is proportional of the evaporation condensation temperature, respectively. Figure (4) shows the theoretical COP for heating and cooling machines as a function of temperature of low and high reservoirs, respectively. Ground coupled heating/cooling systems depend on the fact that the ground temperature equals the annual mean air temperature at a certain depth below ground surface (Nordell et al., 2000 and Omer, 2008). Figure (5) shows the underground temperature as function of the depth at different time during a year, which can be expressed as (Nordell et al., 2000 and Al-Ajmi et al., 2006)

$$T(x,t) = T_0 - A \cdot e^{-(x \cdot \sqrt{\frac{C \cdot \pi}{\lambda \cdot t_0}})} \cdot \cos(\frac{2\pi}{t_0} t - x \cdot \sqrt{\frac{C \cdot \pi}{\lambda \cdot t_0}})$$

Where is

| | |
|---|---|
| $T(x,t)$ | ground temperature at depth x and time t. |
| $T_0$ | annual mean ground temperature ($^oC$) |
| A | annual surface temperature amplitude ($^oC$) |
| $t_0$ | variation period (s). |
| C | volumetric heat capacity of the ground ($J/m^3$) |
| $\lambda$ | thermal conductivity of the ground /W/m,K). |

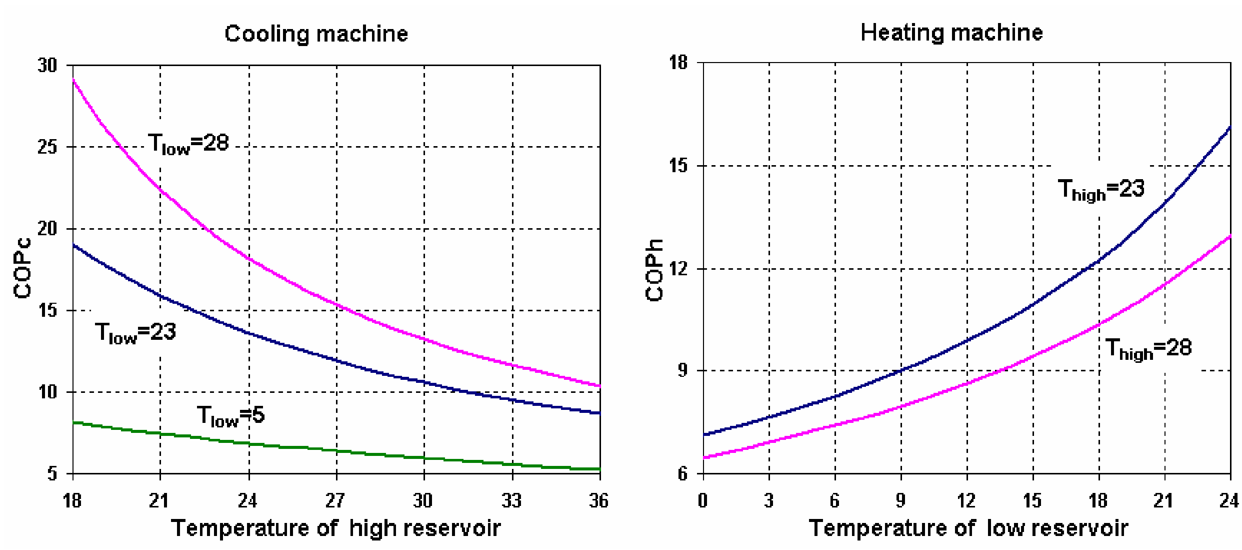


Fig.4. COP as a function of low/high reservoir temperature, assumed that $T_{high}$ is 10°C higher than HHR, while $T_{low}$ is 10°C lower than LHR

The seasonal air temperature change means that the ground is lower than the air temperature during the summer and warmer during the winter. Therefore, ground source heat pump (GSHP) systems are inherently more efficient than an air source heat pump (ASHP) system (Genchi et al., 2002, Ozgener et al., 2007, Diao et al., 2004 and Kharseh et al., 2008 ). As an example the COP of GSHP heating systems in Syria will be 190% greater than that of ASHP systems.

Proper design of GSHP requires knowledge of thermal properties ground at the site, such as heat conductivity of the ground and thermal resistance of the ground heat exchanger (GHE), as well as, undisturbed ground temperature. The aim of this study is to determine the thermal properties of the ground that will be used in future to install GSHP system in Hama in Syria.

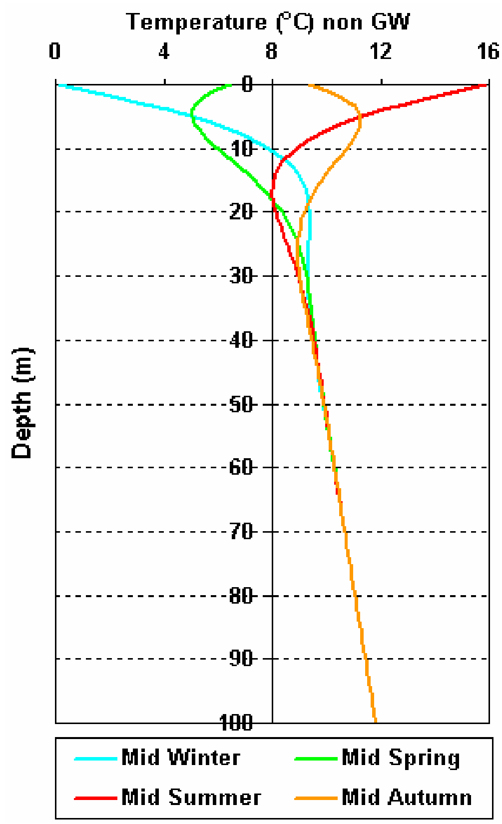


Fig. 5. Temperature profile through the ground

## 2. Theoretical Background of Thermal Response Test theory

There is no direct way to measure the ground thermal conductivity and the borehole thermal resistance (Mattsson et al., 2008). The thermal response test (TRT), is considered as simplest and most exact way to determine the thermal properties (Gehlin, 2002). The idea of measuring in-situ the thermal response of boreholes thermal energy storage (BTES) was first presented by Mogensen (1983) at a conference in Stockholm, in June 1983. He suggested a simple arrangement with a circulation pump, a chiller or heater with constant power rate, and continuous logging of the inlet and outlet temperatures of the duct. The thermal response data (i.e. temperature development in the borehole at a certain energy injection/extraction) allow estimation of the effective thermal conductivity of the ground and the thermal resistance of the ground heat exchanger. Basically, in order to fulfill the TRT experiment the following recommendations should be taken into account (Gehlin, 2002 and Sanner et al., 2005):

• use a power load as steady as possible,

• record the development of the inlet and outlet temperature of the GHE,

• do this for a minimum time of ca. 50 h. In particular in the USA a recommendation for a minimum of 50 h was given

• evaluate according to rules set in this paper.

First of all the undisturbed ground temperature is required, so to determine the undisturbed ground temperature, the heat carrier is circulated through the system without heating during a 20-30 minutes. The mean fluid temperature corresponds to the undisturbed ground temperature. The next steep is to switch on the heater and the measurement is proceeding for 60-72 hours.

During the test, the heat transfer into the ground surrounding the borehole is essentially radial and relatively constant along the borehole. The solution for a thermal line source, which is based on Fourier's law of heat conduction, states the mean borehole temperature $T_b(t)$ as function of the time t:

$$T_b(t) = \frac{q}{4\pi \cdot \lambda} \cdot \left[ \ln\left( \frac{4 \cdot \alpha \cdot t}{r_b^2} \right) - \gamma \right] + T_g \quad \text{provided that} \quad t > \frac{5 \cdot r_b^2}{\alpha} \tag{1}$$

The mean fluid temperature is evaluated by taking the line source temperature at the borehole radius ($r = r_b$) and adding the effect of the borehole thermal resistance ($R_b$) between the fluid and the borehole wall as follows (Gehlin, 2002 and Florides et al., 2008):

$$T_f(t) - T_b(t) = R_b \cdot q$$

$$\Rightarrow \quad T_f(t) = \frac{q}{4\pi \cdot \lambda} \cdot \left[ \ln\left( \frac{4 \cdot \alpha \cdot t}{r_b^2} \right) - \gamma \right] + T_g + R_b \cdot q \tag{2}$$

Where:
$\alpha$ is thermal diffusivity of the ground ($m^2/s$)
$\lambda$ is thermal conductivity of the ground (W/m,K)
$r_b$ is borehole radius (m)
$T_g$ is undisturbed initial temperature of the ground (K)
t is time from start (s)
q is heat injection rate per unit borehole length (W/m)
$R_b$ is thermal resistance (K,m/W)
$\gamma$ is Euler's number (0.5772)
$T_f(t)$ represents the arithmetic mean of the inlet fluid temperature ($T_{fin}$) and outlet fluid temperature ($T_{fout}$) of the borehole heat exchanger at time t

$$T_f(t) = \frac{T_{fin} + T_{fout}}{2} \tag{3}$$

Eq. (2) can be rearranged in a linear form as:

$$T_f(t) = \frac{q}{4\pi \cdot \lambda} \cdot \ln(t) + q \cdot \left[ \frac{1}{4\pi \cdot \lambda} \left( \ln\left( \frac{4 \cdot \alpha}{r_b^2} \right) - \gamma \right) + R_b \right] + T_g \quad (4)$$

Eq.(4) can be written more simply as;

$$T_f(t) = k \cdot \ln(t) + m \quad (5)$$

Fig 6 shows the theoretical mean fluid temperature as function of the time. Hence, thermal conductivity can be determined from the slope of the line "k" resulting by plotting the mean fluid temperature against ln(t), figure (7).

$$k = \frac{\Delta Y}{\Delta X} \quad \Rightarrow \quad \lambda = \frac{q}{4\pi \cdot k} \quad (6)$$

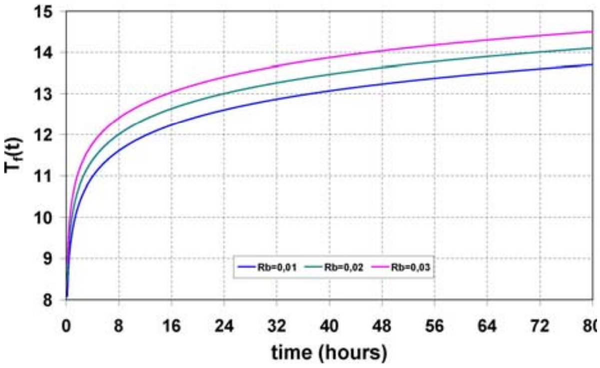


Fig.6. Theoretical mean fluid temperature circulated through borehole, Eq. 4 with λ=3.5 W/m,K and q=40 W/m.

Once the effective ground thermal conductivity is known, the borehole thermal resistance (the thermal resistance between the heat carrier fluid and the borehole wall, $R_b$ [K/(W/m)]) is then assessed on the basis of Eq (2)

$$R_b = \frac{T_f(t) - T_g}{q} - \frac{1}{4\pi \cdot \lambda} \cdot \left[ \ln\left( \frac{4 \cdot \alpha \cdot t}{r_b^2} \right) - \gamma \right] \quad (7)$$

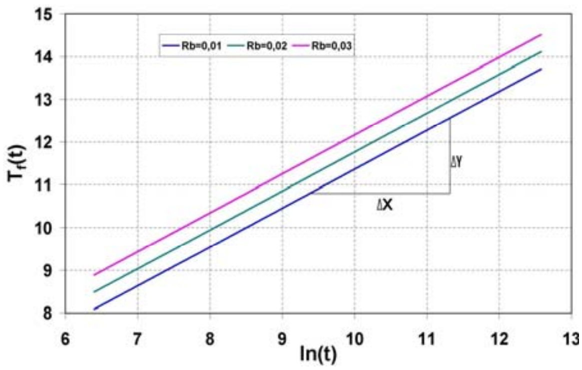


Fig. 7. Theoretical mean fluid temperature circulated through borehole, Eq.5 with λ=3.5 W/m,K & q=40 W/m

Eq (7) gives that in order to calculate $R_b$ the undisturbed ground temperature must be known, which is obtained in the beginning of the test by circulating the fluid before switching on the heating and measuring the temperature. The ground volumetric heat capacity must also be known. Since this is relatively constant for various types of rocks it can be assumed from geological information of the site. However, convective heat flow in the groundwater will depend on temperatures in the borehole. A higher temperature results in a lower borehole resistance due to a higher flow rate in the groundwater as a result of the larger density difference for water at different temperature.

## 3. Thermal Response Test Measurements

There are no studies carried out on ground heat exchanger systems in Syria. It was therefore of interest to examine such systems in this environment, in order to estimate the ground properties that will be used in future work. Thus, current study is the first TRT in Syria. For this purpose, a vertical borehole was installed in 57 m deep of 320 mm diameter, single U polyethylene pipe, with 32 mm outer diameter and wall thickness of 3 mm. Since the ground water table depth is 26 m at the site, normal soil was used to refilling the well as seen in fig 8. To determine undisturbed ground temperature the experiment was running for 40 min without heating or cooling.

Fig. 8. The equipments used for TRT before it was thermally insulated.

The test itself was conducted by injecting heat at constant power of 3.25 kW for approximately 72 h. Inlet and outlet temperatures to/from the borehole were recorded at 30 min intervals with the thermal response. The electrical heater and circulation pump were installed as indicated in Figure (8).

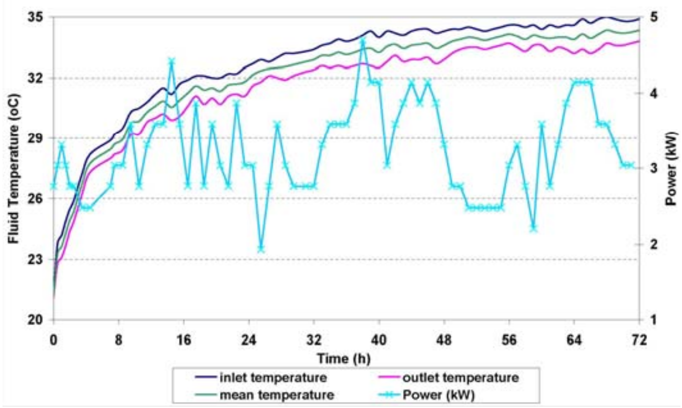


Fig. 9. Fluid temperatures and input power during the experiment

## 4. Response analysis

The undisturbed mean fluid temperature (undisturbed ground temperature) was found to be 21.2 $^{o}$C. After that, the heater was switched on and the test was carried out for 72h. During the test, the flow of the pump remained nearly constant at 39.7 l/min. The recorded fluid temperatures and input power to the system are indicated in figure (9).

To evaluate the thermal conductivity of the ground the previously explained theory was used. Using Eq. (5) and the linear mean temperature shown in Fig (10), we have found that k=2.2611. The thermal conductivity can then be calculated by using Eq (6):

$$\lambda = \frac{q}{4\pi \cdot k} = \frac{3250/57}{4\pi \cdot 2.2611} = 2.011\ \text{W/m.K}$$

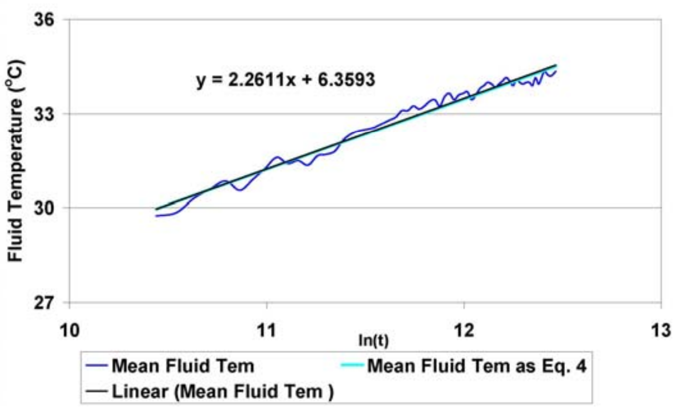


Fig. 10. Mean fluid temperature and during the experiment

To determine the borehole thermal resistance, the mean fluid temperature and Eq (2) were drawn versus time in the same diagram. The volumetric heat capacity of the ground was assumed 2 MJ/m$^3$K. Trying different values of $R_b$ to get the best-fitted graph with mean fluid temperature, the thermal resistance was found $R_b$=0.111 K/(W/m), as indicated in Fig (11). Using this value, we can calculate the temperature drop between the heat carrier inside the pipe and the borehole wall.

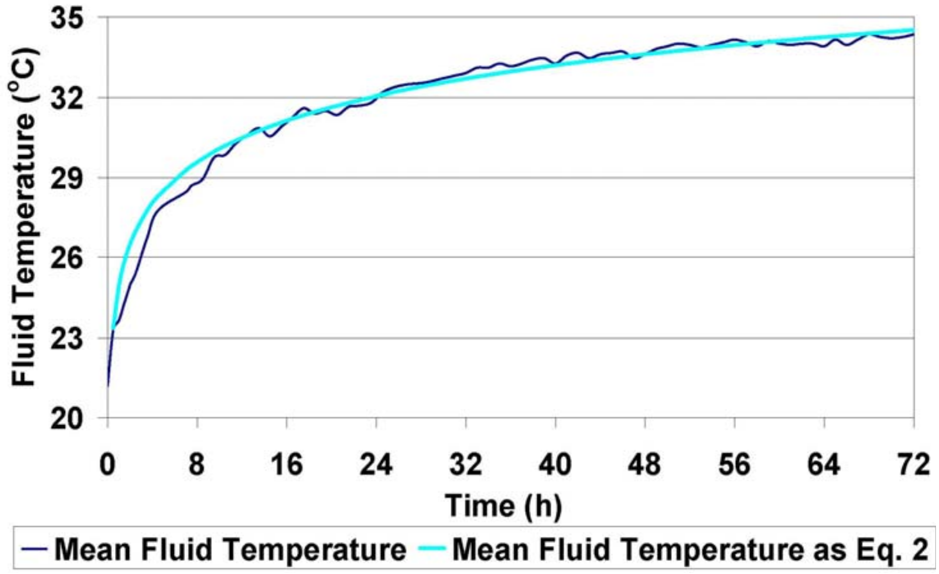


Fig. 11. Mean fluid temperature during the experiment, and Eq (2). Assumed Rb=0,111 and C=2MJ/m$^3$K

It is also possible to calculate the borehole thermal resistance by using the program EED (Hellström et al., 1997); in this case the result is founded to be Rb=0.114 K/(W/m).

## 5. Conclusions

From the results detailed above, the following conclusions can be drawn:

- For the borehole under test the effective ground thermal conductivity (λ) was found to be 2.011W/m.K and the borehole thermal resistance (Rb) to be 0.111 K/(W/m). This is in accordance with values for similar types of ground layers.
- The experiment was carried out immediately after refilling the well, which means the soil density through the well was quite little comparing with the well wall, as well as, measured undisturbed ground temperature was higher that normal; this reason may be explain the low value of effective ground thermal conductivity
- The classical line source model can be used as a fast and reliable tool and it is an easy method of evaluating the characteristics of the borehole
- The thermal response test can easily be made, as it was done with this test.

## 6. REFERENCES


Al-Ajmi, F., Loveday, D.L., Hanby, V.I. (2006). The Cooling Potential Of Earth–Air Heat Exchangers For Domestic Buildings In A Desert Climate. Building and Environment, 41, 235–244

Ala-Juusela, M. (2007). Heating and Cooling With Focus on Increased Energy Efficiency and Improved Comfort. Guidebook to IEA ECBCS Annex 37

Boyle, G. (2004). Renewable Energy, second edition

Diao, N., Li, Q., Fang, Z. (2004). Heat Transfer In Ground Heat Exchangers With Groundwater Advection. International Journal of Thermal Sciences, 43,1203–1211

Energy Information Administration. (2008): www.eia.doe.gov/ipm/demand.html

Florides, G., Kalogirou, S. (2008). First in situ determination of the thermal performance of a U-pipe borehole heat exchanger, in Cyprus. Applied Thermal Engineering, 28,157-163

Gehlin, S. (2002). Thermal Response Test—Method Development And Evaluation, Ph.D. Thesis, Department of Environmental Engineering, Luleå University of Technology, Sweden

Genchi, Y., Kikegawa, Y., Inaba, A. (2002). CO2 Payback–Time Assessment Of A Regional-Scale Heating And Cooling System Using A Ground Source Heat–Pump In A High Energy–Consumption Area In Tokyo. Applied Energy, 71, 147-160

Hellström, G., Sanner, B., Klugescheid, M., Gonka, T. and Mårtensoon, S. (1997). Experience With The Borehole Heat Exchanger Software EED. Proc. MEGASTOCK 97, 247-252, Sapporo.

Hepbasli, A. (2008). A Key Review On Exergetic Analysis And Assessment Of Renewable Energy Resources For A Sustainable Future. Renewable and Sustainable Energy Reviews, 12, 593–661

Kharseh, M., Nordell, B. (2008). Sustainable H/C Systems For Chicken Farms In Syria. Global Conference On Global Warming, Istanbul, Turkey.

Mattsson, N., Steinmann, G., Laloui, L. (2008). Advanced Compact Device For The In Situ Determination Of Geothermal Characteristics Of Soils. Energy and Buildings, 40, 1344-1352

Nordell, B., Söderlund, M. (2000). Solar Energy and Heat Storage. Luleå University of Technology

Nordell, B., Grein, M., Kharseh, M. (2007). Large-scale Utilization of Renewable Energy Requires Energy Storage. International Conference for Renewable Energies and Sustainable Development. Université Abou Bekr BELKAID – TLEMCEN, Algeria

Omer, A.M. (2008). Ground-Source Heat Pumps Systems And Applications. Renewable and Sustainable Energy Reviews, 12, 344-371

Ozgener, O., Hepbasli, A. (2007). Modelling And Performance Evaluation Of Ground Source (Geothermal) Heat Pump Systems. Energy and Buildings, 39, 66-75

Sanner, B., Hellström, G., Spitler, J., Gehlin, S. (2005). Thermal Response Test–Current Status And World-Wide Application. Proceedings World Geothermal Congress April 24–29, 2005 Antalya, Turkey

Seyboth, K., Beurskens, L., Langniss, O., Sims, R.E.H. (2008). Recognising the Potential For Renewable Energy Heating And Cooling. Energy Policy, 36, 2460-2463