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CURRENT STATUS AND FUTURE DIRECTIONS OF GEOTHERMAL HEAT PUMPS IN TURKEY

A. Hepbasli[1], M. Eltez[2] and H. Duran[2]

[1]Ege University
[1]Mechanical Engineering Department, Engineering Faculty, 35100 Bornova, Izmir, Turkey
[2]Dogan Geothermal Co. Inc.,
Ceyhun Atif Kansu Avenue 9. Street No. 3, 06520, Balgat, Ankara, Turkey
e-mail: hepbasli@bornova.ege.edu.tr, meltez@doganjeotermal.com, hduran@doganjeotermal.com
[1]http://bornova.ege.edu.tr/~hepbasli, [2]http://www.doganjeotermal.com

ABSTRACT

Ground-source or geothermal heat pumps (GHPs) are attractive alternative to conventional heating and cooling systems owing to their higher energy utilization efficiency. In this regard, GHPs have had the largest growth since 1995, almost 59% or 9.7 annually in the United States and Europe. The installed capacity is 6,850 MW_t and annual energy use is 23,214 TJ/yr in 26 countries. The actual number of installed units is around 500,000. The utilization of GHPs in residential buildings is new in Turkey, although they have been in use for years in developed countries. In other words, GHPs have been put on the Turkish market for about three years. There are no Turkish GHPs' manufacturers yet. It is estimated that 43 units are presently installed in Turkey, representing a total capacity of 527 kW. Considering the ongoing installations, the total installed capacity will reach 3,763 kW in this year, with a total of 282 units. The majority of the installations are in the Marmara region of Turkey (in Istanbul). High-income earners also prefer these systems. In the present study, first, energy outlook of Turkey is presented. Next, the weather data for the country are given. The current status of GHPs in Turkey is then treated. In this regard, the two case studies are described, of which the first one relates to the University of Ege, Izmir, Turkey while the second one includes a commercial application, which replaced a furnace. Finally, the results are discussed.

1. INTRODUCTION

Turkey, with a population of about 63 million, is located between 35°50' and 42°06' north latitudes and 25°40' and 44°48' east longitudes (Tasdemiroglu, 1993). Most of Turkey is in Asia. The far northwestern part of the country is in Europe, and is separated from the rest of the country by the Dardanelles and Bosperus straits, and the Sea of Marmara. Some basic socioeconomic data for the country is shown in Table 1 (MENR 2000; SIS, 2000; WECTNC, 2000). Urban population as a percentage of the total population has sharply increased from 34% in 1965 to 65.03% in 1997, representing with an average urbanization growth of about 2% annually.

Table 1. Some basic socioeconomic data of Turkey (MENR 2000; SIS, 2000; WECTNC, 2000).

Description	Value
Population (in 1997)	62,865,754
Population growth (1990-97)	1.5%
Urbanization ratio (in 1997)	65.03%
Urbanization growth (1990-97)	2.82%
Area (km^2)	774,815
GNP per capita (in 2000)	US$2,880
GNP growth (1999-2000)	6.9%
Commercial energy use per capita (kpe* in 1997)	1,048
Growth in commercial energy use (1970-97)	6.0%
Electricity consumption per capita (kWh in 1997 and 1999)	1,303 and 1,417

*kpe: kilogram petroleum equivalent

Lund and Freeston (2000,2001) have reviewed the worldwide application of geothermal energy for direct utilization. They concluded that GHPs have had the largest growth since 1995 almost 59%, representing 9.7% annually. All this growth occurred almost in the United States and Europe. The installed capacity is 6,850 MW_t, representing an annual energy use of 23,214 TJ/yr in 26 countries. It is estimated that the actual number of installed units are around 500,000 while the equivalent number of 12 kW units installed is slightly over 570,000. The 12 kW equivalent units installed are used as typical of homes in the US and some western European countries.

Turkey has been in the forefront of direct use application and development in recent years (Lund and Freeston, 2000,2001). The main uses of geothermal energy in the country are mostly moderate and low temperature applications such as space heating and domestic hot water supply, greenhouse heating, swimming and balneology, industrial processes, heat pumps and electricity generation. The data accumulated since 1962 show that the estimated geothermal power and direct use potential are about 4,500 MW_e and 31,500 MW_t, respectively (WECTNC, 2000; Gunerhan *et al*., 2000). At present, only 2-3% of total geothermal potential in Turkey is used. Since 1990, space heating and greenhouse developments have exhibited a significant progress. A geothermal power plant with a capacity of 20.4 MW_e and a CO_2 factory with a capacity 40,000 ton/year have been operated in the Denizli-Kizildere field since 1984 and 1986, respectively. Ground source heat pumps have been used in residential buildings for heating and cooling for approximately three years. Present applications have shown that geothermal energy in Turkey is clean and much cheaper compared to the other energy sources like fossil fuels and therefore is a promising alternative. As public recognizes the projects, the progress will continue.

2. ENERGY OUTLOOK OF TURKEY

Turkish energy consumption has risen dramatically over the past 20 years due to the combined demands of industrialization and urbanization. From 32 mtoe (million tons of oil equivalent) in 1980, Turkey's primary energy consumption has reached up to 74 mtoe in 1998. According to the planning studies, Turkey's final consumption of primary energy is estimated to occur 87 mtoe in 2000, 130 mtoe in 2005, 171 mtoe in 2010 and 298 mtoe in 2020. In other words, in 1999 the domestic energy production met 36% of the total primary energy demand, and will probably meet, with a decreasing rate, 28% in 2010 and 24% in 2020 (WECTNC, 2000; Mendilcioglu, 2000).

Although the level of Turkey's energy consumption is still low relative to similar-sized countries such as France and Germany with a gross inland consumption of 235 and 339 mtoe in 1995, and with an estimated value of 290 and 350 mtoe in 2020, respectively (EC, 1999), Turkey's upward trend may mean it will surpass these countries in the future. Energy use per capita of 1213 kpe in 1999 will continue to increase and this is estimated to reach 2312 kpe by 2000 and 3649 by 2020 (WECTNC, 2000; Mendilcioglu, 2000).

In 1998, of Turkey's final energy consumption, 38% was used by the industrial sector, followed by residential at 34%, transportation at 19%, the agricultural sector at 5%, and the non-energy use at 3%. The share of the industrial sector in this consumption is expected to continue to grow, at approximately 9% per year, and to reach 49% and 59% in 2010 and 2020, respectively. As Turkey's economy has expanded in recent years, the consumption of oil has increased. This growth in consumption is expected to continue up to the year 2020, at a rate of about 4.5% per year. The proportion of oil is expected to decrease somewhat as natural gas usage increases. In this regard, oil accounted for 46% of this consumption, with coal at 20 % and natural gas at 8% in 1998. It is projected that these figures will be %29 for oil, 35% for coal, and 11% for natural gas by 2020 (WECTNC, 2000; Mendilcioglu, 2000).

As for renewable energy sources, in 1998, the production and consumption of Turkey was 11 mtoe. Renewable energy sources production is the second biggest production source after total coal production. Two thirds of the need of the renewable energy sources is met by biomass, while the remaining is mainly met by hydroelectric energy. In 1998, 38% of the total electricity production was provided by hydroelectric energy (Hepbasli *et al*., 2000; Gunerhan *et al*., 2000).

3. WEATHER DATA

In estimating energy use in buildings, three methods are commonly used: (i) the degree-day method, (ii) the bin or modified method, and (iii) more detailed simulation approach. Among these three methods, the second one is useful when heating-system performance is directly affected by the outdoor temperature, such as with air-to-air heat pumps. Design temperatures and degree-days for some meteorological stations in Turkey are available, but there are significant deficiencies in some other data. In Turkey, meteorological measurements are taken and State Meteorological Service (DMI) keeps the related records. For nearly 250 meteorological stations throughout Turkey, measured values of parameters are recorded (Uner and Ileri, 2000).

In this context, Uner and Ileri (2000) obtained typical hourly weather data for the selected 23 provinces that represent demographic and climatic conditions of Turkey by using actual recordings. Based on their sample typical-year simulations it may be concluded that energy savings of about 11% and 16%could be expected in Ankara by 3 and 5 K night-setback, respectively.

Table 2. Degree-days of three main cities calculated for several base temperatures in Turkey (Uner and Ileri, 2000)

Months	Base temp. (^{o}C)	Ankara	Istanbul	Izmir
Jan	14	449	252	181
	16	511	313	242
	18	573	375	304
Feb	14	398	251	144
	16	454	307	195
	18	510	362	249
Mar	14	262	201	112
	16	323	262	169
	18	384	323	229
Apr	14	121	46	15
	16	176	88	41
	18	234	141	84
May	14	19	10	1
	16	45	26	4
	18	85	56	12
June	14	2	0	0
	16	7	0	0
	18	23	3	0
Jul	14	0	0	0
	16	0	0	0
	18	0	0	0
Aug	14	0	0	0
	16	0	0	0
	18	0	0	0
Sep	14	1	2	0
	16	8	6	0
	18	24	20	1
Oct	14	28	32	0
	16	59	58	1
	18	103	94	4
Nov	14	257	104	25
	16	316	158	60
	18	375	216	111
Dec	14	428	197	72
	16	490	258	128
	18	552	320	189
Annual	14	1,965	1,095	550
	16	2390	1,477	840
	18	2,865	1,911	1,183

Monthly degree-days calculated for 14, 16 and 18 ^{o}C base are given for three main cities, namely Ankara, Istanbul and Izmir in Table 2, while monthly heating and cooling degree-days (HDD and CDD) of three main cities for a base temperature of 18 ^{o}C and 22 ^{o}C are tabulated in Table 3. For three main cities, HDD are dominant.

Table 3. Monthly heating and cooling degree-days (HDD and CDD) of three main cities in Turkey for a base temperature of 18 ^{o}C and 22 ^{o}C (Uner and Ileri, 2000)

Months	Ankara		Istanbul		Izmir	
	HDD	CDD	HDD	CDD	HDD	CDD
J	574	0	375	0	304	0
F	509	0	362	0	248	0
M	384	0	323	0	191	0
A	233	0	197	0	85	0
M	84	0	55	3	15	26
J	22	11	0	19	0	107
Jy	0	63	0	53	0	196
A	0	46	0	49	0	166
S	23	10	5	10	0	56
O	93	0	81	0	0	25
N	375	0	214	0	146	0
D	553	0	320	0	275	0
An	2,851	129	1,933	135	1,264	577

Number of hours of occurrences for 3 ^{o}C bins for three main cities on the base of daily total is illustrated in Table 4. In the modified bin energy calculations, coincident maximum, minimum and

Table 4. Dry bulb temperature bins for three main cities in Turkey (Uner and Ileri, 2000)

Temp.(^{o}C)	Ankara	Istanbul	Izmir
-18	0		0
-15	5		0
-12	39		0
-9	88		0
-6	196	0	0
-3	572	77	11
0	836	106	79
3	906	671	300
6	790	1,245	659
9	700	1,193	837
12	744	874	1,151
15	802	905	966
18	899	1,038	872
21	793	1,215	955
24	599	823	1,070
27	432	480	902
30	242	128	580
33	111	5	318
36	6	0	60
39	0	0	0

average wet bulb temperatures are also given elsewhere (For more detail, see Uner and Ileri, 2000). In sizing ground loop systems, especially for calculating the run factors, which represent the percent of the time the unit can be expected to operate to handle the heating load during the coldest month and the warmest month, the bin method is used (Miles, 1994).

4. ENERGY PRICES

The prices for fuel are issued monthly in the Turkish Plumbing Magazine (TY, 2000) which is very popular in the field of HVAC in Turkey. In addition, costs of energy consumption for heat pumps depending on the outdoor temperature are prepared by the help of Turkish Heating, Refrigeration, and Air-Conditioning Manufacturers' Association (shortly called ISKID in Turkey) and also included in this magazine. The prices are tabulated in the units in which they are normally sold (e.g. cents/kWh for electricity). For right comparison purposes, the prices (tariffs) were converted from Turkish Liras (T.L) to U.S.$ (market exchange rate; US$1= 676,000 TL) and also to cost per unit energy taking into account average efficiency. At this stage, it is sufficient to say that a variety of tariffs are available in Turkey. Furthermore, the most expensive one on the base of cents/kWh (per unit energy) is electricity, which is about four times that of natural gas. Fuel costs are a major factor in calculating the running costs of schemes and the viability of proposed schemes (Eastop and Craft, 1996). For this reason, the prices given in Table 5 can be used for comparison on the basis of fuel costs.

5. GHPs APPLICATIONS IN TURKEY

In Turkey, the concept of the ground-source (or geothermal) heat pumps (GSHPs), in general heat pumps, is not new. However, the utilization of GSHPs in residential buildings is new in Turkey, although they have been in use for years in developed countries and the performance of the components is well documented. The first residential geothermal heat pump system in the country was installed in a villa with a floor area of 276 m^2 in Istanbul, in 1998 (Firm D, 2001) while the first experimental study was carried out in the Mechanical Engineering Department, METU (Middle East Technical University) in Ankara, in 1986 (for more detail see Babur, 1986; Hepbasli and Gunerhan, 2000). The residential system consisted of a heating-only heat pump with a scroll compressor (15.6 kW heating) coupled to a 160-m (525-ft) vertical 1 ¼ inch U-bend ground coupling. The representative firm of Swedish GSHPs' manufacturer imported the heat pump itself and its relevant ground coupling materials and this system has been successfully operated since its installation.

In this context, the studies carried out on GHPs in Turkey can be divided into three groups (for more detail, see Hepbasli and Gunerhan, 2000); a) university studies, b) case studies (heat pump industry), and c) standardization studies.

5.1 University Studies

University studies on GSHPs can be classified into two categories: theoretical and experimental. Up to date, only three experimental studies were carried out

Table 5. Energy cost comparisons of different fuels for Turkish industry (TY, 2000)

Energy Type	Heating Value	Unit Price[a,b]	Average Efficiency (%)	Increase in Annual Cost (%)[c]	Energy Cost (cents/kWh)
Natural gas (Istanbul City)	9.59 kWh/m^3	17.06 cents/m^3	92	36	1.93
Fuel-oil no. 6	10.70 kWh/kg	18.00 cents/kg	82	30	2.05
Domestic Soma coal (Istanbul City)	6.40 kWh/kg	8.93 cents/kg	65	28	2.15
LPG (mixed)	12.79 kWh/kg	36.30 cents/kg	90	41	3.15
Wood (Istanbul City)	2.91 kWh/kg	5.75 cents/kg	60	29	3.29
Light fuel oil	11.86 kWh/kg	66.48 cents/kg	84	34	6.67
Electricity	3,600 kJ/ kWh	6.90 cents/kWh	99	32	7.92

[a]1 US$ = 676,000 TL (Turkish Lira); based on the prices of December 2000
[b]The increasing rate in the value of the US$ occurred in average as 48% in the last year ([c]On the base of TL)

by Babur (1986), Kara (1999) or Kara and Yuksel (2000) and Hepbasli (2000). Table 6 shows the main characteristics of GHP systems installed at the three different universities. The theoretical studies performed were described elsewhere (Hepbasli and Gunerhan, 2000).

Table 6. Main characteristics of GHPs installed at the Turkish Universities as of January 2001 (Babur, 1986; Kara, 1999, 2000; Hepbasli 2000)

Name of University	Year built	System type	HP cap. kW
Middle East Technical University (Ankara)	1986	A single pipe-horizontal heat pump system for the heating only with R-12; 10 m of ground coil at 1.5 m depth with a spacing of 0.6 m; COP: 1.1 to 1.3.	0.95
Ataturk University (Erzurum)	1999	A water-to-water geothermal heat pump system for the heating only with R-22; an actual COP value of 2.8; Geothermal water inlet/outlet temp. 35/30 ^{o}C at a flow rate of 1,100 L/h	7.02
Ege University (Izmir)	2000	A GSHP system for both heating and cooling with a vertical-single U-bend heat exchanger; 4 ½ inch of a bore diameter with a boring depth of 50 m	5.2

5.2 Heat Pump Industry (Market)

GSHP systems installed so far in Turkey are few in numbers. There are not any Turkish GSHPs' manufacturers yet. Currently, there are three companies, of which one is the pioneer of GSHPs in Turkey (Firm D, 2001) and has installed many systems. The remainder deals with water-loop heat pump systems imported from the USA (Firm A, 1999; Firm C, 1999), excluding one (Firm B, 1999). Besides these, the others are trying to introduce GSHPs into the Turkish market nowadays. In order to determine the number of GSHPs installed, information from 16 case studies was collected on residential and commercial systems from Turkish GSHP sellers (and also contractors) throughout Turkey. "Firm A" installed in 1998 a water-loop heat pump system (WLHPS) at Kaya Building consisting of 12 storeys in 1998 which was the biggest one in Turkey and is still active. Based on the data given by the "Firm B", six projects have been implemented for building heating ranging from an air-conditioned floor area of 650 m^2 to 24,900 m^2 by means of GSHPs. Two of them were completed in 1999 and the remaining is in progress. In fact, no reliable data were obtained from "Firm B" and it is heard that this firm went bankrupt. Besides these, no data could get from "Firm C". Therefore, only data given by the "Firm D", which is at present the single one in the installation of GSHPs in Turkey, were taken into account. The distribution of GHP systems installed by "Firm D" so far is illustrated in Tables 7and 8. In 1998 when the first installation was began, two GHP systems with a total capacity of 26 kW were completed, representing a total floor area of 596 m^2. These systems have had the largest growth since the beginning of the year 2000. Today, the installed capacity is 527 kW while the number of installed units is 23, totaling 43 units with the equivalent number of 12 kW. The 12 kW equivalent is used as typical of homes in the United States and some western European countries (Lund and Freeston, 2000). The size of individual units is in the range 9 to 46 kW and 38 to 46 for residential and commercial uses, respectively. Considering the ongoing installations, the total installed capacity will be 3,763 kW, with a total of 282 units ranging from 7.3 to 46.2 kW for both residential and commercial uses. In addition, by taking into account the new works, which are at the design stage, with a total 130 villas ranging from 120 to 310 m^2 of floor areas, it is estimated that the installed capacity will reach about 5 MW. Of the GHP systems installed up to date, 80% were vertical ground-coupled GHP systems while about half was designed for both heating and cooling. The diameter of U-bend tubes was 1 ¼ inches for the both applications. The heating and cooling loads were approximately 80 and 95 W/m^2, respectively. The majority of the installations are in the Marmara region (in the province of Istanbul).

5.3 Standardization Studies

Turkish standards relating to heat pumps are few in numbers. Up to date, 14 standards were issued on heat pumps by TSI (Turkish Standards Institution), of which only two contained the water to water type heat pumps (Hepbasli and Gunerhan, 2000). This means that standardization studies are also new in Turkey.

Table 7. GHPs installations with vertical-single U-bend heat exchanger in Turkey as of January 2001 (Firm D, 2001; Hepbasli et al., 2001)

Situation of application		City and region[1]	Build. Type/ no. of build.	Total floor area (m²)	Floor area range (m²)	No. of HP units (type[2])	Total boring depth (no. of borings) (m)	Boring depth range (m)	Tot. HP cap. (kW)	HP cap. range (kW)	Equiv. no. of 12 kW units
Completed	R[4]	Istanbul/ Marmara	Villa / 13	4,828	276-535	13 (5 HC 8 H)	2,466 (21)	100-180	226.2	10.2-38	19
		Izmit/ Marmara	Villa / 1	230	230	1 (H)	90 (2)	45	9.0	9	
	Subtotal 1		Villa/ 14	5,058	230-535	14 (5 HC 9 H)	2,556 (23)	45-180	235.2	9-38	19
	C[5]	Diyarbakir/ Southeastern Anatolian	Show room / 1	1,200	1,200	3 (HC)	1,600 (10)	160	122.4	38-46	10
		Izmir/[7] Ege	Office build./ 1	49 offices		1 (HC)[6]	625 (5)	125	46.0	46	4
	Subtotal 2		2	1,200 +49 offices		4 (HC)	2,225 (15)	125-160	169.0	38-46	14
Grand total 1			16	6,258 +49 offices		18 (9 HC 9 H)	4,781 (38)	45-180	404.2	9-46	33
In progress		Istanbul/ Marmara	Villa / 40	13,200	330	40 (H)[3]	6,400 (40)	160	624.0	15.6	52
		Istanbul (Kumkoy Residence Project)/ Marmara	Villa/ 36	7,416	206	36 (HC)	13,500 (108)	125	561.6	15.6	47
			Villa/ 28	6,328	226	28 (HC)	10,500 (84)		436.8		36
			Villa/ 20	5,640	282	20 (HC)	7,500 (60)		312.0		26
			Villa/ 16	4,944	309	16 (HC)	4,800 (32)	150	163.2	10.2	14
			Villa/ 10	3,160	316	10 (HC)	3,000 (20)	150	102.0		8
			Villa/ 21	3,948	188	21 (HC)	6,300 (42)	150	214.2		18
			Villa/ 88	11,968	136	88 (HC)	11,880 (88)	135	642.4	7.3	54
		Subtotal 3	259	56,604	136-330	259 (219 HC 40 H)	63,880 (474)	125-160	3,056	7.3-15.6	255
GRAND TOTAL			275	62,862 + 49 offices	136-1,200	277 (228 HC 49 H)	68,661 (512)	45-180	3,460	7.3-46	85

[1]In Turkey, there are seven regions.
[2]the heating only: H
[2]both heating and cooling : HC;
[3]active cooling
[4]R : Residential; [5]C : Commercial
[6]In fact, two units are required. Therefore, the second unit will be installed later.
[7]The brand name of the unit is same, but the designer is different.

Table 8. GHPs installations with conventional horizontal ground loop in Turkey as of January 2001(Firm D, 2001)

Situation of application	City and region[1]	Building type/ no. of buildings	Total floor area (m^2)	No. of HP units (type[2])	Total Pipe length (m)	HP capacity (kW)	Total HP capacity (kW)	Total equiv. number of 12 kW units
Completed	Istanbul/ Marmara	Villa / 2	1,400 +400 = 1,800/	2 / (HC)	1,690 + 600 = 2,290	38 and 15	53.0	10
	Ankara/ Central Anatolian	Villa/ 1	525	1 / (H)	850	46.2	46.2	
	Bolu/ Black Sea	Bungalow / 1	240	1 / (H)	420	9.0	9.0	
	Mersin/ Mediterrean	Villa/ 1	435	1/ (H)	600	15.0	15.0	
TOTAL		5	3,000	5/ (2 HC 3 H)	4,160		123.2	

6. CASE STUDIES

In the following, the two case studies will be described. Of these, the first one relates to the University of Ege, Izmir, Turkey while the second one includes a commercial application, which replaced a furnace.

6.1. Case Study 1: Ege University

The water (ground)-to-water type heat pump (GSHP) system (Table 6) was connected to a 64-m^2 classroom of the Solar Energy Institute Building (SEIB) at the University of Ege, Izmir, Turkey (Ersoz, 2000; Hepbasli, 2000). The building constructed in 1986 uses passive solar techniques and hence it was well insulated. It has three floors and a total floor area of 3,000 m^2 (Akdeniz, 1989). The GSHP system mainly consisted of three separate circuits, which are called the ground coupling circuit (brine circuit or water-antifreeze solution circuit), the refrigerant circuit (or a reversible vapor compression cycle) and fan-coil circuit (water circuit). The system was commissioned in July 2000. Performance tests still continue. From the measurements, the specific heat extraction rate was found to be 84.4 W per meter of borehole length, while the COP for cooling was about 3.1.

6.2. Case Study 2: Office Building

The building, located in Izmir, has 49 offices. The heating and cooling loads of the structure are 259 and 294 kW, respectively. The building was formerly designed for the heating only and hence heated by a 406-kW oil-fired hot water generator through fan-coils. The GSHP system replaced this hot water generator in June 2000 (for more detail of the system, see Izmir City in Table 6) and has operated since that time. It was designed for both heating and cooling. No performance data were obtained from the installer. The measurement devices were missing in order to monitor the performance of the system.

7. CONCLUSIONS

The importance of energy as an essential ingredient in economic growth as well as in any strategy for improving the quality of life human beings is well established. In this context, energy, which can be defined as money and even cash from the viewpoint of energy efficiency, is the mainstay of the modern society. So, GHPs are attractive alternative to conventional heating and cooling systems. GSHPs are receiving increasing interest in Turkey. The technology is well established with over 500,000 units installed worldwide. The soil type and moisture content on the performance of GSHP have recently been reported by some investigators (Morino and Oka, 1994; Leong *et al.*, 1998; Allan, 2000). However, in Turkey, this cost reduction factor, which can be achieved by decreasing the necessary ground loop length with the optimal selection of the backfill material, is not taken into account in the design. Besides these, for the successful development of GHPs in Turkey, the other issues given elsewhere (Hepbasli and Gunerhan, 2000) should be taken into account.

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REFERENCES

Akdeniz, A. (1989), *Economic Analysis of Alternative Decisions in the Selection of the optimal Building Heating System* (in Turkish), M.S Thesis, Solar Energy Institute, Ege University, Bornova, Izmir, Turkey, 173 pp.

Allan, M. L. (2000), "Materials Characterization of Superplasticized Cement-Sand Grout," *Cement and Concrete Research*, **30**, 937-942.

Babur, N. (1986), *Design and Construction of an Earth Source Heat Pump.* M.Sc. Thesis in Mechanical Engineering, Middle East Technical University, 119 pp.

Eastop, T. D. and Craft, D. R. (1996), *Energy Efficiency for Engineers and Technologists.* Longman Group UK Limited, 385 pp.

EC. European Commission. (1999), *Energy in Europe: European Union Energy Outlook to 2020*, ISBN 92-828-7533-4, Special Issue, 217 pp.

Ersoz, I. (2000), *Cooling a Room by using a Ground Source Heat Pump* (in Turkish), M.S. Thesis in Mechanical Engineering (Supervisor: Hepbasli, A), Ege University, Izmir, Turkey, 333 pp.

Firm A, Form Inc. (1999), Documents, Istanbul, Turkey.

Firm B, Ente Avrasya Inc. (1999), Documents, Izmit, Turkey.

Firm C, TEBA Inc. (1999), Documents, Izmir, Turkey.

Firm D, Yesil Cizgi Inc. (2001), Documents, Istanbul, Turkey.

Gunerhan, G., Kocar, G. and Hepbasli, A. (2000), "Geothermal Turkey: Year-end Developments Status 1999," *Geothermal Bulletin*, **29(5)**, 179-183.

Hepbasli, A. (2000), *Both Heating and Cooling a Room by using a Vertical Ground-Coupled GSHP* (in Turkish), Research Fund Project of Ege University (not published).

Hepbasli, A., Ozdamar, A. and Ozalp, N. (2000), "Present Status and Potential of Renewable Energy Sources in Turkey," *Energy Sources* (to be published).

Hepbasli, A., Hancioglu, E. and Hosgor, R. (2001), "Feasibility of GHPs in our Country (in Turkish)", *Symposium on Alternative Energy Sources, Izmir, Turkey*, January 18-21, 53-60.

Kara, Y. A. (1999), *Utilization of Low Temperature Geothermal Resources for Space Heating by Using GHPs* (in Turkish), Ph.D. Thesis, Ataturk University, Erzurum, Turkey, 130 pp.

Kara, Y. and Yuksel, B. (2000), "Evaluation of Low Temperature Geothermal Energy through the Use of Heat Pump," *Energy Conservation and Management*, **42**, 773-781.

Leong, W. H., Tarnawski, V. R. and Aittomaki, A. (1998), "Effect of Soil Type and Moisture content on Ground Heat pump Performance," *Int. J. Refrig.*, **21(8)**, 595-606.

Lund, J. W. and Freeston, D.H. (2000), "World-Wide Direct Uses of Geothermal Energy 2000," *Proceedings World Geothermal Congress 2000*, Kyushu-Tohoku, Japan, May 28-June 10, 1-21, 2000.

Lund, J. W. and Freeston, D. H. (2001). "World-Wide Direct Uses of Geothermal Energy 2000,"*Geothermics*, **30**, 29-68.

Mendilcioglu, M. (2000), "Restructuring the Turkish Electricity Market (in Turkish)," *Proceedings of the Turkish Eighth Energy Congress* (Opening Talks, Invited Papers and Panels). World Energy Council Turkish National Committee. Ankara, Turkey, 169-176.

MENR. Turkey's Ministry of Energy and Natural Sources. 2000. http://www.enerji.gov.tr (in Turkish).

Miles, L. (1994), *Heat Pumps: Theory and Service*, Delmar Publishers Inc., 397 pp.

Morino, K. and Oka, T. (1994), "Study on Heat Exchanged in Soil by Circulating Water in a Steel Pile," *Energy and Buildings*, **21,** 65-78.

SIS. State Institute of Statistics, Turkey. (2000), http://www.die.gov.tr (in Turkish).

Tasdemiroglu, E. (1993), "Energy Portrait of Turkey: Achievable Savings through Renewable Energies and Conservation Technologies," *Energy Sources*, **15**, 561-585.

TY, Teknik Yayincilik Inc. (2000), "Energy Cost Comparisons of Different Fuels used in Turkey (in Turkish)," *Plumbing Magazine*, **.59**, 200-201.

Uner, M. and Ileri, A. (2000), "Typical Weather Data of Main Turkish Cities for Energy Applications," *Int. J. Energy Res.*, **24**, 727-748.

WECTNC. World Energy Council Turkish National Committee. (2000), "Energy Statistics 1998 (in Turkish)," *Proceedings of the Turkish Eighth Energy Congress*, Ankara, Turkey, 62-273.