*Proceedings World Geothermal Congress 2000*
*Kyushu - Tohoku, Japan, May 28 - June 10, 2000*

# A STUDY ON THE UTILIZATION OF GEOTHERMAL HEAT PUMPS IN TURKEY

Arif Hepbasli and Huseyin Gunerhan
Solar Energy Institute, Ege University, 35100 Bornova, Izmir, Turkey

**Key Words:**geothermal, heat pumps, geothermal heat pumps, ground-source heat pumps

**ABSTRACT**

Turkey is located on the Alpine-Himalayan Orogenic Belt and is among the top 7 countries around the world for the abundance of geothermal resources. However, only 2% of its potential is used. This means that considerable studies on geothermal energy could be conducted in order to increase the energy supply and to reduce atmospheric pollution in Turkey. There are 140 geothermal fields containing geofluid with a wellhead temperature above 40 °C in Turkey. The concept of ground-source (or geothermal) heat pumps (GSHPs), commonly known as 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 are well documented. In addition, relatively few data are available for systematically assessing the systems installed in Turkey because GSHPs have started to appear on the Turkish market in the domestic sector in limited quantities. This study analyzes the current situation of GSHPs in Turkey and indicates future directions. Based on a value from the GSHP retailers, total investment costs can be considered to be 3,000 US$ per ton of cooling capacity and 30 US$ per $m^2$ of floor area. The simple payback time for a residential system GSHP is just under four years in Turkey. Well-prepared pilot projects that demonstrate the advantages of GSHPs are also very important for the future of GSHP development. Case studies show that GSHPs are widely used in two or three-storey houses having a floor area in the range from 230 $m^2$ to 1100 $m^2$. This infers that GSHPs are preferred by high income earners.

## 1. INTRODUCTION

Turkey has been evolving from a purely agricultural country to an industrialized nation for several decades. Since 1950, Turkey's rural population has dropped from 86% to 47%. This trend will continue, and it is estimated that the rural population will account for only about one-third of the total in the year 2010 (Kaygusuz, 1997). From 1960 to 1994 the gross domestic product (GDP), which indicates the economic development of a country, increased from $14.63 billion to $80 billion (based on 1985 prices). In 1994 net per capita electricity consumption was 956 kWh (Dincer, 1997; Kaygusuz, 1997).

Turkey is located on the Alpine-Himalian Orogenic Belt and has a place among the world's first 7 countries with respect to the abundance of its geothermal resources (Mertoglu *et al*, 1993). However, only 2% of its potential is used (Eltez, 1997). Studies on exploitation and exploration were started in the 1960's, and approximately 140 geothermal fields, with a wellhead temperature above 40 °C, were explored (Mertoglu and Basarir, 1995; Simsek, 1997). Using these fields, almost 35% of Turkey's settlement region could be heated economically (Mertoglu, 1997 a). 135 of these fields are mostly suitable for geothermal heating and integrated geothermal applications. 87% of geothermal energy consumption in Turkey is from heating (Mertoglu and Basarir, 1995).

The Turkish commercial HVAC market is served with a wide range of products, including packaged chillers, unitary air conditioners and heat pumps, packaged terminal air conditioners and heat pumps, and room air conditioners and heat pumps. Currently in Turkey, the heat pump unit most widely used is the packaged air-to-air system. Nowadays, water-loop heat pump (WLHP) systems, which are an important option for space conditioning of commercial buildings and provide the opportunity of saving energy through heat recovery (Kush, 1990), are available on the market. Further, GSHPs have been in use since 1998 for residential space heating and cooling in Turkey.

GSHP is used as an all-inclusive term for a variety of systems that use the ground, groundwater, and surface water as a heat source and sink. GSHPs, often referred to as geothermal heat pumps (GHPs) (Kavanaugh and Rafferty, 1997), are known by a variety of names. These names include ground-coupled heat pumps, earth-coupled heat pumps, earth energy systems, ground-source systems, ground-water source heat pumps, well water heat pumps, and a few other variations. Some names are used to describe more accurately the specific application. The concept of GSHPs (or GHPs), in general heat pumps, is not new in Turkey. However, the use of GSHPs in residential buildings is new in Turkey, although GSHPs have been used for years in developed countries. For example, interest in earth-coupled heat pump technology first surfaced in the late 1940s and early 1950s in the United States. The technology was limited by unsuitable pipe materials, and interest waned with the advent of inexpensive natural gas. The technology re-emerged in Sweden during the 1973 oil embargo, and a few years later, a research program began at Oklahoma State University, USA (Hughes *et al*., 1985). Parallel to this development of GSHPs, there were 134,000 earth-energy installations in 1988 in Sweden (Sulatisky and van der Kamp, 1991) and around 400,000 GSHPs were also operating in the United States at the end of 1997 (GRC, 1998). In this regard, there are a few Turkish firms importing GHPs from abroad and making efforts to put them into the Turkish market at an increasing rate. But in reality, interest in GSHPs is growing very slowly. In other words, the Turkish GSHP industry is relatively young.

There are many terms used in the heating, air-conditioning, and refrigeration industry that convey performance and efficiency (Hepbasli, 1999 a). Among these, four terms, namely COP (Coefficient of Performance), EER (Energy Efficiency Ratio), SEER (Seasonal Energy Efficiency Ratio) and HSPF (Heating Seasonal Performance Factor) are widely used for these purposes in the United States and rated by the American Refrigeration Institute (ARI). However, the last three terms are new in Turkey for consumers and not taken into consideration as one of the key components such as size or cooling capacity, efficiency and price of heat pump, air conditioner or geothermal unit.

Considering the potential of geothermal energy in Turkey, numerous advantages of GSHPs technology and the fact that, still, GSHPs are not readily available commercially, raises the question of which factors are important for its dissemination in Turkey. One of the major aims in conducting the present study is to analyze these factors for Turkish conditions. The other aims are (i) to compare as many types of like case studies taken from as many sources as possible throughout the country, (ii) to compare GSHPs with conventional heating and cooling systems, and (iii) to discuss how studies (strategies for expanding direct uses of geothermal resources and applications of GSHPs) should be implemented in both the residential and commercial sectors in Turkey.

## 2. ENERGY USAGE AND PRICES IN TURKEY

Since energy consumption plays an important role in indicating the life style or quality, there are many indicators to compare life styles in various countries. A definition of energy intensity (energy consumption per gross domestic product) is an useful tool which can be used for this purpose. In order to compare Turkey's energy intensity with that of some developed countries in TOE per million dollars, the followings can be given. Turkey's energy intensity was 349.8 TOE/m$ compared to U.S.A.'s 338.1, Japan's 155.4 and OECD (Organisation for Economic Cooperation and Development) Countries's 248.7. This shows the increase in energy intensity for Turkey, while a decline for Japan, U.S.A. and OECD Countries. Turkey is on the very low side as far as energy/capita is concerned. This means that Turkey consumes about one fourth the energy consumed by OECD Countries (Hepbasli and Eltez, 1999).

Before the energy prices in Turkey are given, it is very important to discuss what energy is. In this regard, based on the questionnaire filled out by 150 engineers and students during energy management courses in Turkey, most energy definitions were described as "the ability to do work" (Hepbasli, 1999 b). However, from the viewpoints of energy efficiency, energy is cash and cash needs safeguarding and managing (EEO, 1993). On the other hand, in the words of Naoto Shinkawa (1998) who has received three awards in the field of energy conservation in Japan, "energy is money to buy comfortable and convenient livelihood". This clearly demonstrates that developed countries deal with "cash or money" while developing countries with "the ability to do work". Taking into account that energy is money, geothermal heat pumps (in general geothermal energy) can be defined as "cash or money machines".

Table 1 shows typical fuel prices which apply to the Turkish residential sector at the time of publication. The prices for fuel are issued monthly in the Turkish Plumbing Magazine (TY, 1999) 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 with the help of the Turkish Heating, Refrigeration, and Air-Conditioning Manufacturers' Association (abbreviated to 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). In order to compare on a common basis, the prices (tariffs) were converted from Turkish Liras (T.L) to U.S.$ ( 1 U.S. $ was equal to 425,000 T.L of that time) and also to calculate the 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 basis of cents/kWh (per unit energy) is electricity, which is about four times the cost 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 1 can be used for comparison on the basis of fuel costs.

## 3. GEOTHERMAL ENERGY UTILIZATION IN TURKEY

The General Directorate of Mineral Research and Exploitation (MTA) has carried out geothermal energy exploration in Turkey. The inventory and chemical analyses of the hot springs and mineral waters started in 1962. The existence of more than 600 hot springs indicate that Turkey has an important geothermal energy potential (see Baytorun and Aksu, 1997). Only a very small fraction of this potential has so far been utilized.

Taking into consideration the current development of geothermal energy in Turkey, it is estimated that in the year 2000, about 2,520 $MW_{th}$ will be installed in district heating together with a generating capacity of 125 $MW_e$. By the year 2010, these figures should be increase to 6,500 $MW_{th}$ and 258 $MW_e$, respectively. Thus, Turkey is likely to be the leading country in the world at the beginning of the 21$^{st}$ century, regarding geothermal district heating schemes (Mertoglu, 1997 b).

Direct uses of geothermal heat have increased at a relatively slower rate. The main geothermal heating systems installed in $MW_{th}$ are illustrated elsewhere (Gunerhan, 1999). The installed capacity for heating is equal to 349.3 $MW_{th}$. Taking into account greenhouses and other space heating systems of 78.9 $MW_{th}$ and balneology (therapeutic baths) of 285 $MW_{th}$, the total installed capacity is found to be about 634 $MW_{th}$ .

Heat pumps can be used in low temperature geothermal heating schemes to generally boost the heat output of the fluid, but their particular role in any specific scheme will depend upon the temperature of the fluids which are being used. Thus, for moderate temperature fluids ranging from 40 ºC to 70 ºC the heat extraction will be dominated by the primary heat exchanger and the heat pumps will usually be connected in a way which extracts additional heat from the geothermal fluid. However, with fluid temperatures of less than 40 ºC, direct heat exchange becomes almost impossible and the heat pump is connected so that it accomplishes all of the heat transfer (Harrison *et al.,*1990). Beside these explanations, Kelvin and Rafferty (1991) reported that when geothermal resource temperatures fall below the 100 (37.8) to 120 (48.9 ºC) ºF range, it is frequently impractical to use the fluid directly for most applications. Under these conditions, the water source heat pump can provide the necessary temperature boost to concentrate the heat from a very low temperature resource. This is particularly true in areas which are characterised by geothermal resources, moderate climate and low electrical rates. Taking into consideration the temperature limits for the use of GSHPs mentioned above, the temperature of geothermal fluid used for space heating in Turkey is as low as 43 ºC without heat pump utilization. For example, two mosques in Haymana are heated with a geothermal water of 43 ºC, Sivas Sicak Cermik Spa with 46 ºC, Rize Ayber Thermal Curing Center and Havza Spa with 54 ºC and Kirsehir Geothermal District Heating System with 54 to 57 ºC (Mertoglu, 1997 a).

## 4. STUDIES ON GSHPs IN TURKEY

The energy performance of a GSHP system can be influenced by three primary factors: (i) the heat pump machine, (ii) the circulating pump or well pump, and (iii) the ground-coupling or groundwater well. As a result, it is necessary when evaluating a GSHP system to consider the efficiency of the machine used, the adequacy of the ground coupling, and the nature of the pumping design, to fully understand the efficiency of the system (Lienau, 1997). It is relatively easy to rate the GSHP itself since it is a simple packaged unit (Kavanaugh, 1992 b) and the data of ground heat exchangers including pumps are imported from abroad. The most important factor for efficient and proper operation of GSHPs in Turkey consists of the successful design of the system by the HVAC engineer. As well, correct installation of the system is also necessary.

In the literature, there are numerous studies on the design (Kavanaugh and Rafferty, 1997; Oerder and Meyer, 1998; Spilker, 1998; Fleming, 1998), performance ( Healy and Ugursal, 1997; Lineau, 1997; Phetteplace and Sullivan, 1998) and economic analysis (Catan and Baxter, 1985; Martin, 1990) of GSHPs. Case studies (Hughes *et al*., 1985; Franck and Berntsson, 1985; Sulatisky and van der Kamp, 1991; Hatten, 1992; Kavanaugh, 1992 a), handbooks and standards (Bose *et al*., *1985;* Kavanaugh, 1992 b) are also available that discuss installation procedures for GSHPs. Studies on GSHPs are very limited in Turkey although the temperature of the soil is stable in most areas and suitable for GSHPs applications. Figure 1 shows the average ground temperatures in ºC at 1 meter in depth throughout Turkey. This map was drawn using values obtained from the State Meteorological Service on the basis of an average of ten year's measurement (SMS, 1974).

Various organisations are involved with the GSHP industry in developed countries. They include utility companies, electric co-operatives, contractors, design engineers and hydrogeological consultants, manufacturers of equipment, universities and research organisations, and government. However, in Turkey the number of similar organisations is very limited. There are no Turkish GSHP manufacturers yet. Currently, there are three companies, one of which one deals with water-loop pump systems, who are trying to introduce GSHPs into the Turkish market. The studies performed in Turkey can be divided into three groups; a) university studies, b) case studies (heat pump industry), and c) standardization studies.

### 4.1 University Studies

Turkish universities, societies, and research organisations can provide innovative techniques and testing of procedures and equipment to determine the effectiveness of GSHPs. However, up to date GSHPs' contractors in Turkey have carried out their own work without cooperation from Turkish universities. That is, they install GSHPs with the limited knowledge obtained from the GSHPs' manufacturers.

In Turkey, most of the studies on heat pumps are generally focused on the air-to-air units (Kaygusuz, 1994; Kent, 1996), while limited studies are performed on GSHPs. University studies on GSHPs can be classified into two categories: theoretical and experimental. In recent years, various theoretical studies have been reported on GSHPs. Kilkis (1981) has investigated methods of utilization of soil heat by using heat pumps. Hepbasli (1985) and Ataman (1991) have studied the design of GSHPs and heating of homes by using GSHPs. Beside these, only two experimental studies were carried out by Babur (1986) and Kara (1999). Babur (1986) designed a single-pipe horizontal coupled heat pump system operating with the refrigerant R-12 on ground to air basis and constructed by using the available equipment in the Mechanical Engineering Department, Middle East Technical University (METU). He performed 44 experimental runs during the 1985-86 heating season under varying climatic conditions to determine the Coefficient of Performance (COP) and change in soil temperatures. Approximately 10 m of ground coil was installed at 1.5 m depth with a spacing of 0.6 m. The COP for heating was found to vary from 1.1 to 1.3.

Kara (1999) investigated both theoretically and experimentally the utilisation of low temperature resources for space heating of a health resort centre in Erzurum by using GSHPs coupled to geothermal wells at Pasinler. For example, at Pasinler, there are two wells at 40 ºC temperature, 200 m depth and 75 to 95 l/s flow rates. Another well was also available in Ilica at 39 ºC, and 605 m depth. The wells are used just for health care and the temperature of the waste water from the baths is around 30 to 35 ºC. Considering these temperature limits, Kara (1999) designed a water-to-water geothermal heat pump system running with R-22 to evaluate the wells mentioned above for space heating and developed a computer simulation for the system. The system produced water at 45 ºC temperature for a floor heating system by using the geothermal resource at 35 ºC. The COP for heating was 2.8 and results from the computer simulations were in good agreement with those from experiments. A comparison was made among R-22, R-502 and R-500 alternatively, the last giving the highest COP. On the other hand, it was concluded that, as an environmentally safe gas, R-134a would give as good results as R-500.

### 4.2 Case Studies (Heat Pump Industry)

GSHP systems installed so far in Turkey are few in number. In order to determine the number of GSHPs installed, information from 16 case studies was collected on residential and commercial systems from three Turkish GSHP sellers contractors throughout Turkey. The firm names are given below (see Acknowledgements) designated as Firm A, Firm B and Firm C, respectively. Based on the limited information given by firms, "Firm A" installed in 1998 a water-loop heat pump system (WLHPS) at Kaya Building consisting of 12 storeys in 1998 which is the biggest one in Turkey. Six projects have been implemented by "Firm B" 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 are still in progress. To date, "Firm C" have installed 9 GSHPs in two-storey houses with an air-conditioned floor area varying from 230 $m^2$ to 460 $m^2$. Five houses were designed for heating only and the remaining for both heating and cooling. The heating load was approximately 94 $W/m^2$, while the cooling load was 130 $W/m^2$. For six houses, where the outdoor design temperature was -3 $^0C$, heat is obtained from vertical bore holes with depths of 120 m to 170 m, while the remaining houses utilised a horizontal ground loop. The diameter of U-bend tubes was 1¼ inches for both applications. Based on the data of "Firm C", the calculated COP for heating and cooling was in the range of 3.4 to 3.9 and 4.1 to 4.2, respectively.

### 4.3 Standardisation Studies

Considering governments may provide standards and regulation of the industry and/or equipment, the Turkish Standards Institution, TSI (called TSE in Turkey) is responsible for preparing all national standards. There are numerous standards issued by TSI in Turkey and they are contained in numerical form in a catalogue consisting of two volumes (TSI, 1998 a,b). In the catalogue, the standards are classified according to the "International Classification for Standards (ICS)" system which is prepared by International Standards Organisation (ISO) and adopted by ISO member bodies.

Turkish standards relating to heat pumps are few in number. Up to 20 April 1998, 14 standards were issued on heat pumps by TSI, of which only two contained the water to water type heat pumps (TS 10055, 1992; TS prEN 255-3, 1996). This means that standardisation studies are also new in Turkey.

### 4.4 Economic Analysis

The main objective of the economic analysis was to compare the cost of all GSHP systems installed in Turkey with the cost of conventional systems. However, this objective has not been achieved yet because too few data have been available for systematic assessment of complete, installed systems. However, some values are given from "Firm B" and "Firm C" for comparison purposes. Based on the figures of these firms, total investment costs can be considered to be 3,000 US$ per ton of cooling capacity and 30 US$ per $m^2$ of floor area, respectively. In addition, both firms reported that a simple payback for GSHPs in Turkey was just under four years.

## CONCLUSIONS

The main conclusions that can be drawn from the present study on the utilization of GSHPs in Turkey are listed below. Most of these conclusions are generally valid for geothermal energy, as reported by Sigurdsson (1997) and the Geothermal Resources Council (1998).

a) Up-to-date information on GSHPs installations could not be easily found. Further documented information on the operating experience obtained from various locations in Turkey is needed. In addition, good documented systems for GSHPs should be established.

b) The number of GSHPs installed in Turkey is very few in number and estimated to be 16 based on the data gathered from Turkish firms selling GSHPs. There are no GSHP manufacturers in Turkey yet. This means that the GSHP industry is very young in Turkey.

c) Residential case studies show that GSHPs are mostly used in two or three-storey houses having a floor area ranging from 230 $m^2$ to 1100 $m^2$. This means GSHPs are preferred by the high income people as well as and also in commercial and community buildings, such as at Izmit Archaeology Museum, with a floor area of 3500 $m^2$.

d) Based on the information of GSHP retailers, total investment costs can be taken to be 3,000 US$ per ton of cooling capacity and 30 US$ per $m^2$ of floor area, respectively. A residential building simple payback for GSHPs is just under four years in Turkey.

e) The primary barrier to marketing GSHP systems in Turkey is the incremental cost of installing ground heat exchangers which makes the total investment higher. Beside this, Turkish heating systems differ in many respects from US ones. Stoves are widely used in single-family houses and also apartments. Furthermore, both single-family and multi-family houses are heated by using hydronic piping systems and terminal units. For these reasons, there is customer resistance to GSHP technology.

f) Well-prepared pilot projects that will demonstrate the advantages of GSHPs are very important for the future of GSHP development.

g) New financing mechanisms are needed to promote investment in energy efficiency and renewable energy which will support the development of GSHPs.

h) There is lack of effective dissemination campaigns in the field of GSHPs.

i) Education and training schemes would be necessary for the creation of specialised personnel.

j) In order to encourage the installation of GSHPs, incentive packages designed by utilities in developed countries would need to be supplied.

## ACKNOWLEDGEMENTS

The authors would like to thank Turkish GSHPs firms, namely FORM INC. (in Istanbul), ENTA AVRASYA LTD (in Izmit), and YESIL CIZGI LTD. (in Istanbul) for their assistance in collecting the limited data.

## REFERENCES

Ataman, H. (1991). *Design of GSHPs* (in Turkish). M.Sc. Thesis, Technical University of Istanbul, Mechanical Engineering Dept., Istanbul, Turkey, 151 pp.

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

Baytorun, C. and Aksu, L. (1997). Technologies for geothermal energy use for heating greenhouses in Turkey. In: *Proceedings of the International Workshop on Strategy of Geothermal Development in Agriculture in Europe at the End of XXth Century*. K. Popovski, O., Mertoglu, and K. Dimitrov (Eds)., 218 pp.

Bose, J. E., Parker, J. D., and McQuiston, F. C. (1985). *Design/data manual for closed-loop ground-coupled heat pump systems*. ASHRAE, Atlanta.

Catan, M. A. and Baxter, V. D. (1985). An optimized ground-coupled heat pump system design for northern climate applications. *ASHRAE Trans.,* Vol. 91 (2B), pp. 1185-1203.

Dincer, I. (1997). Energy and GDP analysis of OECD Countries. *Energy Convers. Mgmt*, Vol. 38(7), pp. 685-696.

Eltez, M. (1997). *Geothermal Energy Report*, prepared for the Scientific and Technical Research Council of Turkey, TUBITAK (in Turkish), 55 pp.

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

EEO, Energy Efficiency Office. (1993). *Energy, Environment and Profits, Making a Corporate Commitment.* Department of the Environment, England, 24 pp.

Fleming, W. S. (1998). Ground-source heat pump design and operation-experience within an Asian country. *ASHRAE Trans.* Vol. 104 (1B), pp. 771-774.

Franck, P. And Berntsson, T. (1985). Ground-coupled heat pumps: some Swedish experiences. *ASHRAE Trans.* Vol. 91(2B), pp. 1285-1296.

GRC, Geothermal Resources Council. (1998). A vision for the future. *Geothermal Bulletin*, Vol. 27(8), pp. 171-178.

Gunerhan, G.G. (1999). *Theoretical and Experimental Investigations on Condensation/Boiling Modelled Heat Exchangers Designed for Removal of Noncondensable Gases from Geothermal Steam* (in Turkish). Ph. D. Thesis, Natural Sciences Institute, Izmir, Turkey, 252 pp (in press).

Harrison, R., Mortimer, N. D. And Smarason, O. B. (1990). *Geothermal heating: handbook of engineering economics.* Pergamon Press, 558 pp.

Hatten, P. E. (1992). Groundwater heat pumping: lessons learned in 43 years at one building. *ASHRAE Trans.,*Vol. 98 (1), 1031-1037.

Healy, P. F. and Ugursal, V. I. (1997). Performance and economic feasibility of ground-source heat pumps in cold climate. *Int. J. Energy Research,* Vol. 21, pp. 857-870.

Hepbasli, A. (1985). *Heat Pumps Systems and a Storey-House Heating* (in Turkish). MSc. Thesis, Technical University of Istanbul, Turkey, 134 pp.

Hepbasli, A. (1999 a). Performance and efficiency definitions in HVAC systems: Part I and II (in Turkish). *Jnl. HVAC and Plumbing*, Branch Office of Istanbul, Chamber of Mechanical Engineers, Vol. 50 and 51, pp. 24-48 and 24-42..

Hepbasli, A.. (1999 b). *How an Energy Efficiency Consultant* (in Turkish). 18th Energy Conservation Week, National Energy Efficiency Congress, Ankara, Turkey, 203 pp.

Hepbasli, A. and Eltez, M. (1999). *A Survey on Building Energy Management Systems at Turkish Universities*, TIEES 98, Energy and the Environment Proceedings of the Second Trabzon International Energy and Environment Symposium (July 26-29, 1998), Begell House, Inc., 585 pp.

Hughes, P. E., Loomis, L., O'Neil, P. E., and Rizzuto, J. (1985). Results of the residential earth-coupled heat pump demonstration in Upstate New York. *ASHRAE Trans.* Vol 91(2B), pp. 1307-1325.

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.

Kavanaugh, S. P. (1992 a). Field test of a vertical ground-coupled heat pump in Alabama. *ASHRAE Trans.,* Vol. 98 (2), pp. 607-616.

Kavanaugh, S. P. (1992 b). Using existing standards to compare energy consumption of ground-source heat pumps with conventional equipment. *ASHRAE Trans.,* Vol. 98 (2), pp. 599-606.

Kavanaugh, S. P. and Rafferty, K. (1997). *Ground-Source Heat Pumps: Design of Geothermal Systems for Commercial and Institutional Buildings*. *ASHRAE*, 167 pp.

Kaygusuz, K. (1994). Performance of an air-to-air heat pump under frosting and defrosting conditions. *Applied Energy,* Vol. 48, pp. 225-241.

Kaygusuz, K. (1997). Energy, water, and environment in Turkey. *Energy Sources*, Vol. 19, pp. 917-930.

Kelvin, D. and Rafferty, P. E. (1991). Heat pumps. In: *Geothermal Direct Use Engineering and Design Guidebook*, P. J. Lienau and C. Ben (Eds)., Geo-Heat Center, 2nd ed. The United States Department of Energy (USDOE), Idaho, pp. 283-294.

Kent, F. E. (1996). Performance evaluation of a compact air-to-air heat pump. *Energy Convers. Mgmt.,* Vol. 38(4), pp. 341-345.

Kilkis, B. (1981). Methods of utilization of soil heat by using heat pumps in residential areas built outside urban (in Turkish)**,** Vol. 4 (1), pp. 21-25.

Kush, E. A. (1990). Detailed field study of a water-loop heat pump system. *ASHRAE Trans.* Vol. 96(1), pp. 1048-1063.

Lienau, P. J. (1997). Geothermal heat pump performance and utility programs in the United States. *Energy Sources*, Vol.19, pp. 1-8.

Martin, P. E. (1990). A design and economic sensitivity study of single-pipe horizontal ground-coupled heat pump systems. *ASHRAE Trans.,* Vol. 96 (1), pp. 634-642.

MFAAH, Ministry of Food, Agriculture and Animal Husbandary. (1974). *Mean and Extreme Meteorological Bulletin* (in Turkish). State Meteorological Service, Ankara, Turkey, 676 pp.

Mertoglu, O. (1997 a). Performance of low temperature geothermal district heating systems. In: *Geothermal District Heating Sheme,*. K. Dimitrou (Ed)., International Summer School on Direct Application of Geothermal Energy, Skopje (Republic of Macedonia), 36 chapters.

Mertoglu, O. (1997 b). Geothermal district heating schemes in Turkey. In: *Proceedings of the International Workshop on Strategy of Geothermal Development in Agriculture in Europe at the End of XXth Century*. K. Popovski, O., Mertoglu, and K. Dimitrov (Eds)., 218 pp.

Mertoglu, O. and Basarir, N. (1995). Geothermal utilization and applications in Turkey. *Proceedings of the World Geothermal Congress,* Florence, Italy, Vol. 1, pp. 345-349.

Mertoglu,O., Mertoglu, F. M., and Basarir, N. (1993). Direct use of heating applications in Turkey. *Geothermal Resources Council Transactions.* 1993 Annual Meeting, California, Vol. 17, pp. 19-22.

Oerder, S. and Meyer, J. P. (1998). Effectiveness of a municipial ground-coupled reversible heat pump system compared to an air-source system. *ASHRAE Trans.* Vol. 104 (1A), pp. 540-549.

Phetteplace, G. and Sullivan, W. (1998). Performance of a hybrid ground-coupled heat pump system. *ASHRAE Trans.* Vol. 104 (1B), pp. 763-770.

Shinkawa, N. (1998). *An Outlook for Energy in Energy Conservation Point of View.* Energy Conservation and Management Course, Kyushu International Center, Japan, 36 pp.

Sigurdsson, J. (1997). Geothermal development in Central and

Eastern Europe: transfer of technology and financial resources. *Energy Sources*, Vol. 19, pp. 79-88.

Simsek, S. (1997). Geothermal education studies in Turkey (in Turkish). *Turkish Geothermal Association Bulletin*. Vol. 1, pp. 19-20.

Spilker, E. H. (1998). Ground-coupled heat pump loop design using thermal conductivity testing and the effect of different backfill materials on vertical bore length. *ASHRAE Trans*. Vol. 104 (1B), pp. 775-779.

Sulatisky, M. T. and van der Kamp, G. (1991). Ground-source heat pumps in the Canadian prairies. *ASHRAE Trans.*, Vol. 97 (1), pp. 374-385.

TS 10005. (31 March 1992). Heat pumps: mechanically driven-water to water type (in Turkish), 14 pp.

TS prEN 255-3. (04 April 1996). Heat pumps: heat pump units with electrically driven compressors for heating or for heating and for cooling-part 3: water/water and brine/water air/water heat pump units, testing and requirements for marking (in Turkish), 9 pp.

TSI, Turkish Standards Institution. (1998 a). Turkish Standards Catalogue (in Turkish), Vol. 1, 1076 pp.

TSI, Turkish Standards Institution. (1998 b). Turkish Standards Catalogue (in Turkish), Vol. 2, 688 pp.

TY, Teknik Yayincilik Inc. (1999). Energy cost comparisons of different fuels used in Turkey (in Turkish). *Plumbing Magazine.* Vol. 42, pp. 56-60.

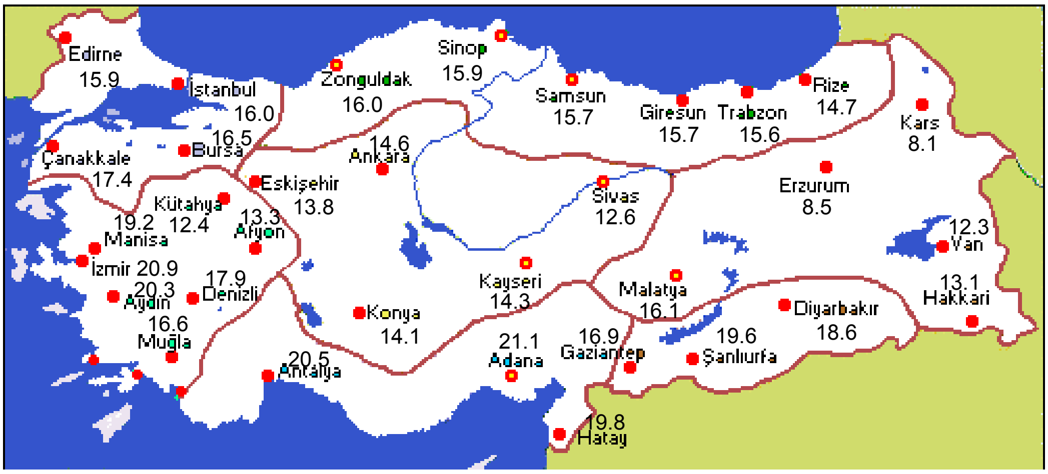

Figure 1. Ground Temperatures at 1 m in depth (Numbers on the map indicate degrees Celsius).

Table 1. Energy cost comparisons of different fuels used in Turkey (based on prices of June 1999).

| Energy Type | Heating Value | Unit Price | Average Eff. (%) | Increase in Ann. Cost (%) | Energy Cost (cents/kWh) |
|---|---|---|---|---|---|
| Natural gas (Bursa City) | 9.59 kWh/m$^3$ | 18.9 cents/m$^3$ | 90 | 49 | 2.19 |
| Domestic Soma coal (Istanbul City) | 6.40 kWh/kg | 9.65 cents/kg | 60 | 28 | 2.51 |
| Furnace oil | 11.28 kWh/kg | 27.44 cents/kg | 80 | 85 | 3.04 |
| Wood (Istanbul City) | 2.91 kWh/kg | 6.12 cents/kg | 60 | 44 | 3.51 |
| LPG of 12 kg (in a container) | 12.79kWh/kg | 55.39 cents/kg | 88 | 96 | 4.92 |
| Light fuel oil | 11.86kWh/kg | 59.23 cents/kg | 84 | 91 | 5.94 |
| Gas oil | 12.09 kWh/kg | 61.85 cents/kg | 84 | 73 | 6.09 |
| Electricity | 3600 kJ/ kWh | 7.84 cents/kWh | 99 | 65 | 7.92 |