DOKUZ EYLÜL UNIVERSITY
GRADUATE SCHOOL OF NATURAL AND APPLIED SCIENCES

# A CASE STUDY ON THE BALÇOVA-NARLIDERE GEOTHERMAL DISTRICT HEATING SYSTEM

by
**Hüseyin Mesut ÖZMEN**

July, 2010
İZMİR

# A CASE STUDY ON THE BALÇOVA-NARLIDERE GEOTHERMAL DISTRICT HEATING SYSTEM

**A Thesis Submitted to the**
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**In Partial Fulfillment of the Requirements for the Degree of Master of Science**
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**by**
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# M.Sc THESIS EXAMINATION RESULT FORM

We have read the thesis entitled **"A CASE STUDY ON THE BALÇOVA-NARLIDERE GEOTHERMAL DISTRICT HEATING SYSTEM"** completed by **HÜSEYİN MESUT ÖZMEN** under supervision of **PROF. DR. İSMAİL HAKKI TAVMAN** and we certify that in our opinion it is fully adequate, in scope and in quality, as a thesis for the degree of Master of Science.

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Hüseyin Mesut ÖZMEN

# A CASE STUDY ON THE BALÇOVA-NARLIDERE GEOTHERMAL DISTRICT HEATING SYSTEM

## ABSTRACT

Turkey is among the first five countries in abundance of geothermal resources around the world so geothermal energy is an important renewable energy resource in Turkey.

In this study, following a general information concerning geothermal energy, it is specified in tables that the direct and indirect utilization of the geothermal resorces in Turkey and its established capacities at the present day are given. Direct utilization of geothermal energy focuses on district heating system and is implemented in 21 geothermal field. The biggest and the most important of all is that of the one in the Balçova-Narlıdere geothermal field. Concerning the Balçova-Narlidere district heating system, the general evaluation of the geothermal field, its historical development, geothermal wells, the total residence capacity, an evaluation of the system, price comparison with the other fuels, and the environmental factors are all discussed.

Finally, the Narlıdere district heating system stage-3 project in Balçova-Narlıdere geothermal field is presented under the headings of geothermal loop, city loop and building loop. Each building situated in stage-3 is specified one by one and the total peak field and the total peak load are deducted and 3D design of the heating system is worked on.

**Keywords:** Geothermal District Heating Sysem, Geotermal Loop, City Loop, Building Loop, Balçova-Narlidere Geothermal Field.

# BALÇOVA-NARLIDERE JEOTERMAL BÖLGESEL ISITMA SİSTEMİ ÜZERİNE BİR ÖRNEK ARAŞTIRMASI

## ÖZ

Türkiye jeotermal kaynakların zenginliği bakımından dünyada ilk beş ülkeden biridir, bu yüzden jeotermal enerji Türkiye de önemli bir yenilenebilir enerji kaynağıdır.

Bu çalşımada jeotermal enerji ile ilgili genel bir bilgi verildikten sonra Türkiye'deki jeotermal kaynakların dolaylı ve doğrudan kullanımı tablolar halinde belirtilmiş ve günümüzdeki kurulu kapasiteleri verilmiştir. Doğrudan kullanım, bölgesel ısıtma sistemleri üzerine yoğunlaşmıştır ve 21 jeotermal alanda uygulanmaktadır. Bunlardan en önemlisi ve en büyüğü Balçova-Narlıdere jeotermal alanında bulunan bölgesel ısıtma sistemidir. Balçova-Narlıdere bölgesel ısıtma sistemi ile ilgili olarak; jeotermal alanın genel değerlendirmesi, tarihsel gelişimi, jeotermal kuyular, günümüzdeki toplam konut kapasitesi, sistemin incelenmesi , diğer yakıtlarla olan fiyat karşlaştırması, ve çevresel faktörleri tanımlanmıştır.

Son olarak Balçova-Narlıdere jeotermal alanındaki Narlıdere bölgesel ısıtma sistemi etap-3 projesi; jeotermal devre, şehir devresi bina devresi başlıkları altında sunulmuştur. Etap-3 de bulunan tüm binalar tek tek belirtilmiş toplam alan ve toplam yük çkartılmştır ve ısı merkezinin 3 boyutlu tasarımı yapılmıştır.

**Anahtar Sözcükler:** Jeotermal Bölgesel Isıtma Sistemi, Jeotermal Devre, Şehir Devresi, Bina Devresi, Balçova-Narlıdere Jeotermal Alanı.

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# CHAPTER ONE

# INTRODUCTION

Geothermal energy comes from the natural generation of heat primarily due to the decay of the naturally occurring radioactive isotopes of uranium, thorium and potassium in the earth. Because of the internal heat generation, the Earth's surface heat flow averages 82 $mW/m^2$ which amounts to a total heat loss of about 42 million megawatts. The estimated total thermal energy above mean surface temperature to a depth of 10 km is 1.3 x 1027 J, equivalent to burning 3.0 x 1017 barrels of oil. Since the global energy consumptions for all types of energy, is equivalent to use of about 100 million barrels of oil per day, the Earth's energy to a depth of 10 kilometers could theoretically supply all of mankind's energy needs for six million years (Wright,1998).

The utilization of geothermal resources can be divided into two very broad categories: (1) utilization for the production of electricity , and (2) direct utilization in industry, space conditioning, and agriculture and aquaculture. These two broad categories can be further broken down on the basis of temperature and the relative percentage of steam and water.

Utilization of geothermal resources is no different than the use of steam or hot water produced by burning oil , coal, wood, or through nuclear reaction. The main differences lie in problems of corrosion or scaling which result from the chemical composition of some geothermal resources, making material selection critical ; and the fact that geothermal resources must' be used within relatively short transmission distance of the source.

Turkey is one of the top five countries for geothermal direct applications (Lund, 2005). The present (2010) installed geothermal power generation capacity in Turkey is about 100 $MW_e$, while that of direct use installations is around 967.3 $MW_t$. Direct use of geothermal energy in Turkey has shown an impressive growth with considerable increases in district and greenhouse heating.

Geothermal District Heating is defined as the use of one or more production fields as sources of heat to supply thermal energy to a group of buildings. Services available from a district heating system are space heating, domestic water heating, space cooling, and industrial process heat. Geothermal district heating system applications exist in many countries especially in Iceland, France, Poland, Hungary, Turkey, Japan, Romania, China and the USA.

Geothermal district heating systems (GDHSs) are the main geothermal utilization in Turkey, which have an important meaning to the Turkish citizens who make use of this system; since, a clean environment and comfort has been provided to residences in an economic situation.

The district heating system applications were started with large-scale, city-based geothermal district heating systems in Turkey; whereas, the geothermal district heating center and distribution networks have been designed according to the geothermal district heating system parameters. This constitutes an important advantage of GDHS investments in Turkey in terms of the technical and economical aspects.

A GDHS comprises three major components. The first part includes production and injection wells and heating centre. There are some equipment like main heat exchangers, collectors, pumps and valves in the heating centre (Geothermal loop). The second part is the transmission/distribution system. It delivers the city water which is heated by geothermal energy to the consumers. In this system, hot water circulates between heating centre and buildings in the close loop (City loop). The third part includes costumer-building equipment. Building heat exchanger and in building equipments exist in this part of the system (Building loop).

In Turkey, initial studies on the exploitation and exploration of geothermal energy started in 1962 with the inventory of hot water springs. Then, in 1963, the first successful downhole heat exchanger was realized at the Balçova-Narlidere geothermal (BNG) field, and the real explorations and development of the geothermal energy potential of Turkey started. The first geothermal heating application in Turkey was applied to the Izmir–Balcova thermal facilities in 1983, where the first downhole heat exchanger was also used. As of April 2010, in the BNG field, the number of geothermal district heating system subscribers has reached 30,500 dwelling equivalence.

# CHAPTER TWO
# GEOTHERMAL ENERGY

Heat is a form of energy and *geothermal energy* is, literally, the heat contained within the Earth that generates geological phenomena on a planetary scale. ‘Geothermal energy’ is often used nowadays, however, to indicate that part of the Earth's heat that can, or could, be recovered and exploited by man, and it is in this sense that we will use the term from now on (Dickson & Fanelli, 2004).

## 2.1 Brief Geothermal History

Early humans probably used geothermal water that occurred in natural pools and hot springs for cooking, bathing and to keep warm. We have archeological evidence that the Indians of the Americas occupied sites around these geothermal resources for over 10,000 years to recuperate from battle and take refuge. Many of their oral legends describe these places and other volcanic phenomena. Recorded history shows uses by Romans, Japanese, Turks, Icelanders, Central Europeans and the Maori of New Zealand for bathing, cooking and space heating. Baths in the Roman Empire, the middle kingdom of the Chinese, and the Turkish baths of the Ottomans were some of the early uses of balneology; where, body health, hygiene and discussions were the social custom of the day. This custom has been extended to geothermal spas in Japan, Germany, Iceland, and countries of the former Austro-Hungarian Empire, the Americas and New Zealand. Early industrial applications include chemical extraction from the natural manifestations of steam, pools and mineral deposits in the Larderello region of Italy, with boric acid being extracted commercially starting in the early 1800s. At Chaudes-Aigues in the heart of France, the world’s first geothermal district heating system was started in the 14th century and is still going strong. The oldest geothermal district heating project in the United States is on Warm Springs Avenue in Boise, Idaho, going on line in 1892 and continues to provide space heating for up to 450 homes (Lund, 2005).

The first use of geothermal energy for electric power production was in Italy with experimental work by Prince Gionori Conti between 1904 and 1905. The first commercial power plant (250 $kW_e$) was commissioned in 1913 at Larderello, Italy. An experimental 35 $kW_e$ plant was installed in The Geyers in 1932, and provided power to the local resort. These developments were followed in New Zealand at Wairakei in 1958; an experimental plant at Pathe, Mexico in 1959; and the first commercial plant at The Geysers in the United States in 1960. Japan followed with 23 $MW_e$ at Matsukawa in 1966. All of these early plants used steam directly from the earth (dry steam fields), except for New Zealand, which was the first to use flashed or separated steam for running the turbines. The former USSR produced power from the first true binary power plant, 680 $kW_e$ using 81 ºC water at Paratunka on the Kamchatka peninsula – the lowest temperature, at that time. Iceland first produced power at Namafjall in northern Iceland, from a 3 $MW_e$ non-condensing turbine. These were followed by plants in El Salvador, China, Indonesia, Kenya, Turkey, Philippines, Portugal (Azores), Greece and Nicaragua in the 1970s and 80s. Later plants were installed in Thailand, Argentina, Taiwan, Australia, Costa Rica, Austria, Guatemala, Ethiopia, with the latest installations in Germany and Papua New Guinea (Lund 2007).

## 2.2 Nature and Distribution of Geothermal Energy

The terms that are basic to a discussion of the nature and distribution of geothermal energy are geothermal gradient, heat flow and geothermal anomaly. Geothermal gradient refers to the increase of temperature as the depth increases: the deeper into the earth, the higher the temperature. Normally the temperature increases 1°C in 33 m. However, the increase may exceed 5 °C in 33 m because geologic setting and rock types differ. Thermal energy moves toward the earth's surface by conduction of heat through solid rock, by movement of molten rock (magma), or by movement of water. The vertical movement of thermal energy by conduction is called heat flow.

Because of the difference in temperature between the different parts of the asthenosphere, convective movements and, possibly, convective cells were formed some tens of millions of years ago. Their extremely slow movement (a few centimetres per year) is maintained by the heat produced continually by the decay of the radioactive elements and the heat coming from the deepest parts of the Earth. Immense volumes of deep hotter rocks, less dense and lighter than the surrounding material, rise with these movements towards the surface, while the colder, denser and heavier rocks near the surface tend to sink, re-heat and rise to the surface once again, very similar to what happens to water boiling in a pot or kettle.

These phenomena lead to a simple observation: since there is apparently no increase in the Earth's surface with time, the formation of new lithosphere along the ridges and the spreading of the ocean beds must be accompanied by a comparable shrinkage of the lithosphere in other parts of the globe. This is indeed what happens in *subduction zones*, the largest of which are indicated by huge ocean trenches, such as those extending along the western margin of the Pacific Ocean and the western coast of South America. In the subduction zones the lithosphere folds downwards, plunges under the adjacent lithosphere and re-descends to the very hot deep zones, where it is "digested" by the mantle and the cycle begins all over again. Part of the lithospheric material returns to a molten state and may rise to the surface again through fractures in the crust. As a consequence, magmatic arcs with numerous volcanoes are formed parallel to the trenches, on the opposite side to that of the ridges. Where the trenches are located in the ocean, as in the Western Pacific, these magmatic arcs consist of chains of volcanic islands; where the trenches run along the margins of continents the arcs consist of chains of mountains with numerous volcanoes, such as the Andes. Figure 2.1 illustrates the phenomena that was just described by Dickson & Fanelli (2004).

Spreading ridges, transform faults and subduction zones form a vast network that divides our planet into six immense and several other smaller lithospheric areas or plates (Figure 2.2). Because of the huge tensions generated by the Earth's thermal engine and the asymmetry of the zones producing and consuming lithospheric material, these plates drift slowly up against one another, shifting position continually. The margins of the plates correspond to weak, densely fractured zones of the crust, characterised by an intense seismicity, by a large number of volcanoes and, because of the ascent of very hot materials towards the surface, by a high terrestrial heat flow. As shown in Figure 2.2, the most important geothermal areas are located around plate margins.

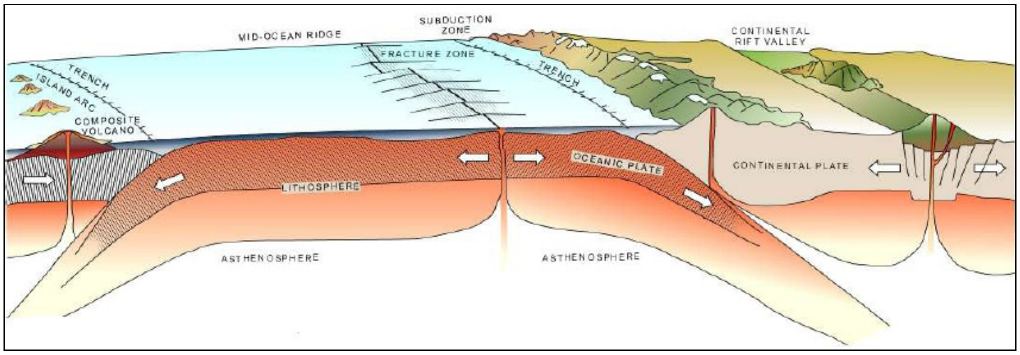

Figure 2.1 Schematic cross-section showing plate tectonic processes (Dickson & Fanelli, 2004).

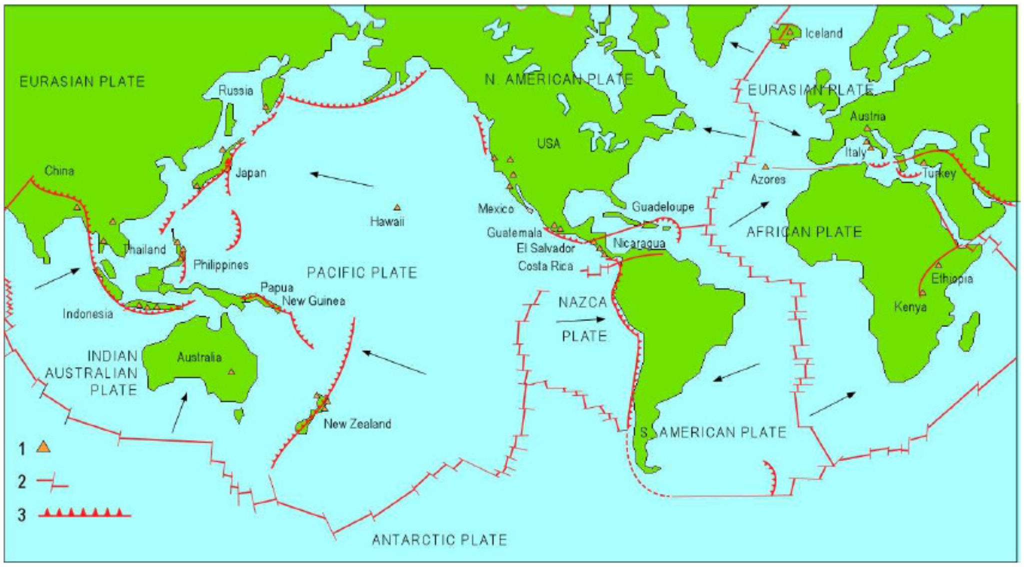

Figure 2.2 World pattern of plates, oceanic ridges, oceanic trenches, subduction zones, and geothermal fields. Arrows show the direction of movement of the plates towards the subduction zones. (1) Geothermal fields producing electricity; (2) mid-oceanic ridges crossed by transform faults (long transversal fractures); (3) subduction zones, where the subducting plate bends downwards and melts in the asthenosphere. (Dickson & Fanelli, 2004).

## 2.3 Geothermal Systems

Geothermal systems can therefore be found in regions with a normal or slightly above normal geothermal gradient, and especially in regions around plate margins where the geothermal gradients may be significantly higher than the average value. In the first case the systems will be characterized by low temperatures, usually no higher than 100 ºC at economic depths; in the second case the temperatures could cover a wide range from low to very high, and even above 400 °C. What is a *geothermal system* and what happens in such a system? It can be described schematically as "convecting water in the upper crust of the Earth, which, in a confined space, transfers heat from a heat source to a heat sink, usually the free surface" (Hochstein, 1990). A geothermal system is made up of three main elements: a *heat source*, a *reservoir* and a *fluid* , which is the carrier that transfers the heat. The heat source can be either a very high temperature (> 600 ºC) magmatic intrusion that has reached relatively shallow depths (5-10 km) or, as in certain low temperature systems, the Earth's normal temperature, which, as we explained earlier, increases with depth. The reservoir is a volume of hot permeable rocks from which the circulating fluids extract heat. The reservoir is generally overlain by a cover of impermeable rocks and connected to a surficial recharge area through which the meteoric waters can replace or partly replace the fluids that escape from the reservoir by natural means (through springs, for example) or are extracted by boreholes. The geothermal fluid is water, in the majority of cases meteoric water, in the liquid or vapour phase, depending on its temperature and pressure. This water often carries with it chemicals and gases such as $CO_2$, $H_2S$, etc. Figure 2.3 is a simple representation of an ideal geothermal system (Dickson & Fanelli, 2004).

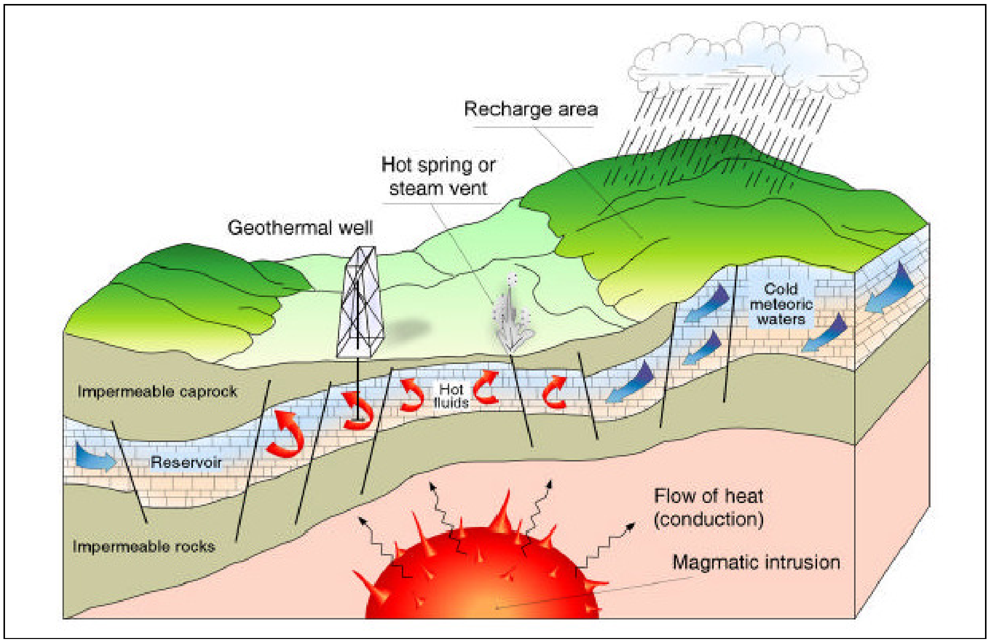

Figure 2.3 Schematic representation of an ideal geothermal system (Dickson & Fanelli, 2004).

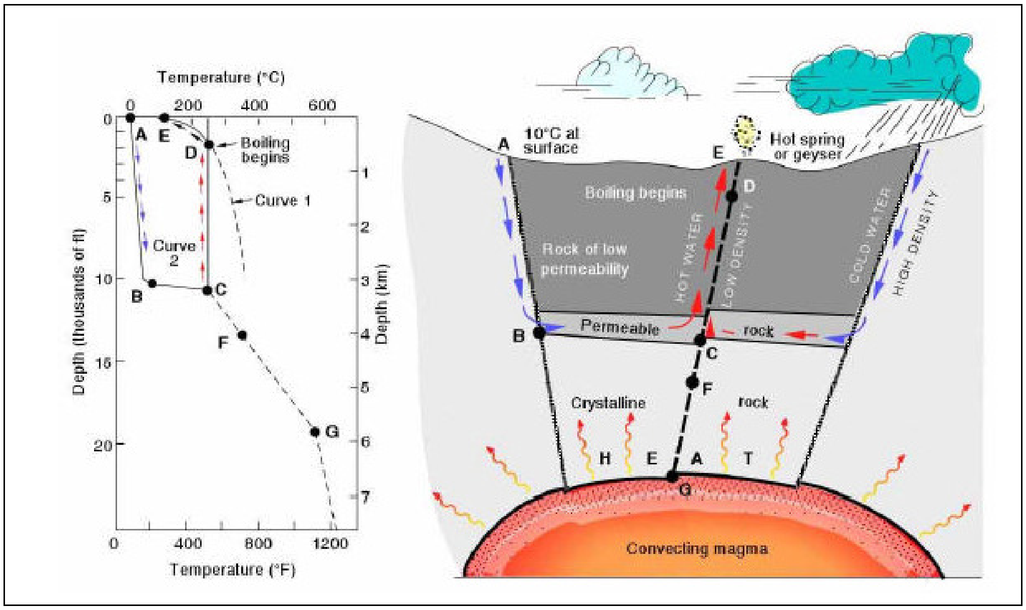

Figure 2.4 Model of a geothermal system. Curve 1 is the reference curve for the boiling point of pure water. Curve 2 shows the temperature profile along a typical circulation route from recharge at point A to discharge at point E. (White, Buffler & Truesdell, 1973).

The mechanism underlying geothermal systems is by and large governed by *fluid convection*. Figure 2.4 describes schematically the mechanism in the case of an intermediate temperature hydrothermal system. Convection occurs because of the heating and consequent thermal expansion of fluids in a gravity field; heat, which is supplied at the base of the circulation system, is the energy that drives the system. Heated fluid of lower density tends to rise and to be replaced by colder fluid of high density, coming from the margins of the system. Convection, by its nature, tends to increase temperatures in the upper part of a system as temperatures in the lower part decrease (White, Buffler & Truesdell, 1973).

### *2.3.1 Types of Geothermal Resources*

Geothermal resources are usually classified as shown in Table 2.1, modeled after (White & Williams, 1975). These geothermal resources range from the mean annual ambient temperature of around 20 °C to over 300 °C. Resources below 150°°C are usually used in direct-use projects for heating and cooling. Ambient temperatures in the 5 to 30 °C range can be used with geothermal (ground-source) heat pumps to provide both heating and cooling.

Table 2.1 Geothermal resource types

| **Resource Type** | **Temperature Range (˚C)** |
|---|---|
| Convective hydrothermal resources | |
| Vapor dominated | 240˚ |
| Hot-water dominated | 20 to 350˚+ |
| Other hydrothermal resources | |
| Sedimentary basin | 20 to 150˚ |
| Geopressured | 90 to 200˚ |
| Radiogenic | 30 to 150˚ |
| Hot rock resources | |
| Solidified (hot dry rock) | 90 to 650˚ |
| Part still molten (magma) | >600˚ |

*Convective hydrothermal resources* occur where the Earth's heat is carried upward by convective circulation of naturally occurring hot water or steam. Some hightemperature convective hydrothermal resources result from deep circulation of water along fractures.

*Vapor dominated* systems (Fig. 2.5) produce steam from boiling of deep, saline waters in low permeability rocks. These reservoirs are few in number, with The Geysers in northern California, Larderello in Italy and Matsukawa in Japan being ones where the steam is exploited to produce electric energy (Lund, 2007).

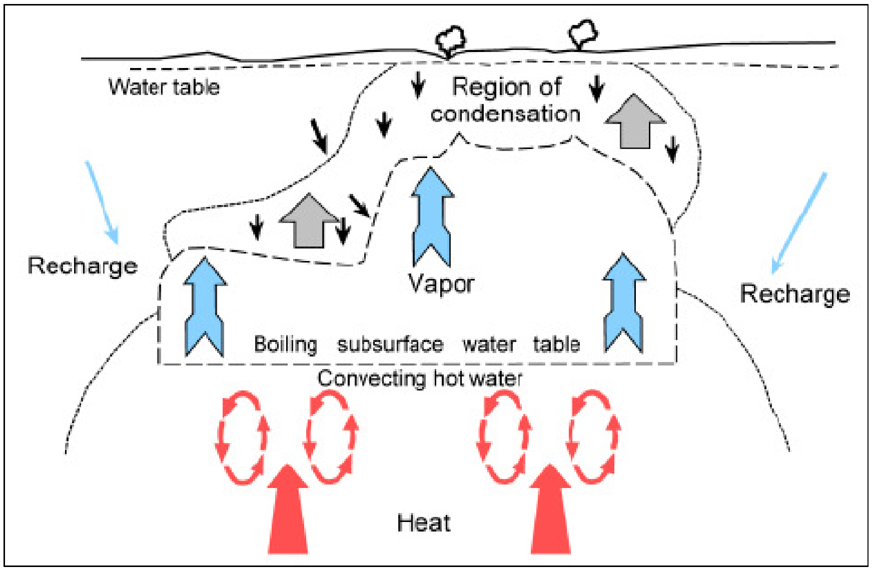

Figure 2.5 Vapor dominated geothermal system (White, Buffler & Truesdell, 1973).

*Hot dry rock resources* (Fig. 2.6) are defined as heat stored in rocks within about 10 km of the surface from which energy cannot be economically extracted by natural hot water or steam. These hot rocks have few pore space, or fractures, and therefore, contain little water and little or no interconnected permeability. In order to extract the heat, experimental projects have artificially fractured the rock by hydraulic pressure, followed by circulating cold water down one well to extract the heat from the rocks and then producing from a second well in a closed system. Early experimental projects were undertaken at Fenton Hill (Valdes Caldera) in northern New Mexico and on Cornwall in southwest England; however both of these projects have been abandoned due to lack of funds and poor results. Projects are currently underway in Soultz-sous-Forêt in the Rhine Graben on the French-German border, in Switzerland at Basil and Zurich, in Germany at Bad Urach, several locations in Japan, and in the Cooper Basin of Australia (Tenzer, 2001).

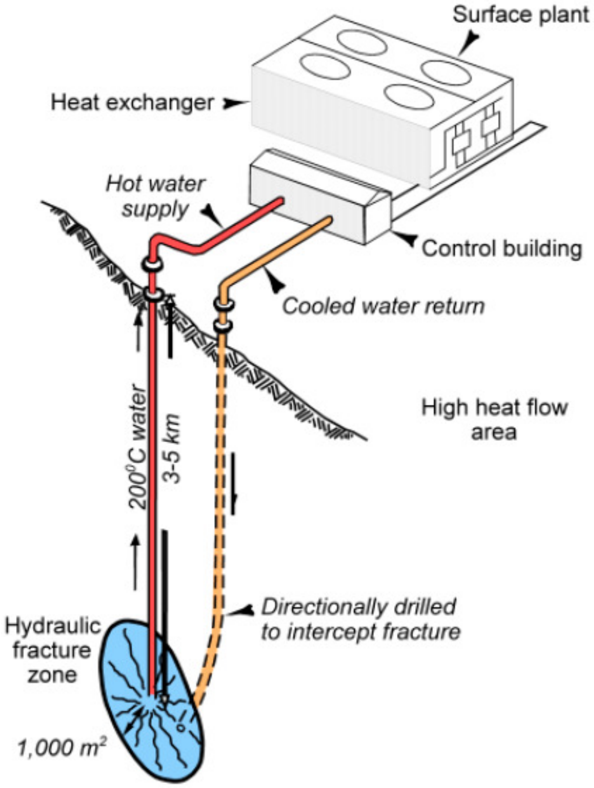

Figure 2.6 Hot dry rock exploitation (Tenzer 2001).

## 2.4 Utilization in World

The utilization of geothermal resources can be divided into two very broad categories: (1) utilization for the production of electricity , and (2) direct utilization in industry, space conditioning, and agriculture and aquaculture. These two broad categories can be further broken down on the basis of temperature and the relative percentage of steam and water.

Utilization of geothermal resources is no different than the use of steam or hot water produced by burning oil , coal, wood, or through nuclear reaction. The main differences lie in problems of corrosion or scaling which result from the chemical composition of some geothermal resources, making material selection critical ; and the fact that geothermal resources must' be used within relatively short transmission distance of the source.

Based on 68 country update papers submitted to the World Geothermal Congress 2005 (WGC 2005) held in Turkey, the following figures on worldwide geothermal electric and direct- use capacity, are reported. A total of 72 countries have reported some utilization from WGC 2000 and WGC 2005, either electric, direct-use or both (Lund & Freeston, 2001; Lund, et al., 2005a; Bertani, 2005a) (Table 2.2).

Table 2.2 Total geothermal use in 2005 (Bertani, 2005a)

| Use | İnstalled Power MW | Annual Energy Use GWh/yr | Capacity Factor | Countries Reporting |
|---|---|---|---|---|
| Electic Power | 8,933 | 56,786 | 0.73 | 24 |
| Direct Use | 28,268 | 75,943 | 0.31 | 72 |

The figures for electric power capacity ($MW_e$) appear to be fairly accurate; however, several of the country's annual generation values (GWh) had to be estimated which amounted to only 0.5% of the total. The direct-use figures are less reliable and probably are understated by as much as 20%. The author is also aware of at least five countries, which utilize geothermal energy for direct-heat applications, but did not submit reports to WGC 2005. The details of the present installed electric power capacity and generation, and direct-use of geothermal energy can be found in (Bertani 2005a). These data are summarized in Table 2.3.

A review of the above data shows that in electric power generation each major continent has approximately the same percentage share of the installed capacity and energy produced with North America and Asia having over 80% of the total. Whereas, with the direct-use figures, the percentages drop significantly from installed capacity to energy use for the Americas (32.3 to 16.7%) due to the high percentage of geothermal heat pumps with a low capacity factor for these units in the United States. On the other hand, the percentages increased for the remainder of the world due to a lesser reliance on geothermal heat pumps, and the greater number of operating hours per year for these units.

Table 2.3 Summary of regional geothermal use in 2005 (Bertani, 2005a)

| Region | Electric Power | | Direct Use | |
|---|---|---|---|---|
| | %MWe | %GWh/yr | %MWt | %GWh/yr |
| Africa | 1,5 | 1,9 | 0,7 | 1,1 |
| Americas | 43,9 | 47,0 | 32,3 | 16,7 |
| Asia | 37,2 | 33,8 | 20,9 | 29,4 |
| Europe | 12,4 | 12,4 | 44,6 | 49,0 |
| Oceania | 5 | 4,9 | 1,5 | 3,8 |

### *2.4.1 Electrical Generation*

The generation of electricity using geothermal resources began in Larderello, Italy in 1904. Worldwide generating capacity has been slow to develop and it has been only since the early 1960's that significant gains in total generating capacity have been achieved.

Electrical generation can be accomplished utilizing geothermal resources in a number of ways dependent upon the temperature and the relative percentage of steam and water. The four primary generating plant types include: (1) those utilizing dry steam, (2) flashed steam in either single or multiple flash units, ( 3) binary plants which utilize secondary working fluids where for some reason, the direct use of the geothermal resources is impossible or undesirable, and (4) plants utilizing a combination of flashed steam and binary technology. A fifth plant type is a hybrid where geothermal resources are used in conjunction with fossil fuels, solar energy, or biomass for electrical generation (Lund 2007).

### *2.4.2 Direct Use of Geothermal Energy*

Direct or non-electric utilization of geothermal energy refers to the immediate use of the heat energy rather than to its conversion to some other form such as electrical energy. The primary forms of direct use include swimming, bathing and balneology (therapeutic use), space heating and cooling including district heating, agriculture (mainly greenhouse heating, crop drying and some animal husbandry), aquaculture (mainly fish pond and raceway heating), industrial processes, and heat pumps (for both heating and cooling). In general, the geothermal fluid temperatures required for direct heat use are lower than those for economic electric power generation.

Most direct use applications use geothermal fluids in the low-to-moderate temperature range between 50 ºC and 150 ºC, and in general, the reservoir can be exploited by conventional water well drilling equipment. Low-temperature systems are also more widespread than high-temperature systems (above 150 ºC); so, they are more likely to be located near potential users. In the U.S., for example, of the 1350 known or identified geothermal systems, 5% are above 150 ºC, and 85% are below 90 ºC (Lund, 2007). In fact, almost every country in the world has some low temperature systems; while, only a few have accessible high-temperature systems.

Traditionally, direct use of geothermal energy has been on small scale by individuals. More recent developments involve large-scale projects, such as district heating, greenhouse complexes, or major industrial use. Heat exchangers are also becoming more efficient and better adapted to geothermal projects, allowing use of lower temperature water and highly saline fluids. Heat pumps utilizing very low-temperature fluids have extended geothermal developments into traditionally non-geothermal countries such as France, Switzerland and Sweden, as well as areas of the mid-western and eastern U.S. Most equipment used in these projects are of standard, off-the-shelf design and need only slight modifications to handle geothermal fluids (Gudmundsson & Lund, 1997).

The Lindal diagram (Gudmundsson, Freeston & Lienau, 1985), named for Baldur Lindal, the Icelandic engineer who first proposed it, indicates the temperature range suitable for various direct use activities (Fig. 2.7). Typically, the agricultural and aquacultural uses require the lowest temperatures, with values from 25 to 90 ºC. Space heating requires temperatures in the range of 50 to 100 ºC, with 40 ºC useful in some marginal cases and ground-source heat pumps extending the range down to 4 ºC. Cooling and industrial processing normally require temperatures over 100 ºC.

*District heating* involves the distribution of heat (hot water or steam) from a central location, through a network of pipes to individual houses or blocks of buildings. The distinction between district heating and space heating systems, is that space heating usually involves one geothermal well per structure. Chapter 3 provides information on equipment for geothermal district heating systems. An important consideration in district heating projects is the thermal load density, or the heat demand divided by the ground areas of the district . A high heat density is required to make district heating economically feasible, because the distribution network that transports the hot water to the consumers is expensive.

Geothermal district heating systems are capital intensive. The principal costs are initial investment costs for production and injection wells, downhole and circulation pums, heat exchangers, pipelines and distribution network, flowmeters, valves and control equipment, etc. Operating expenses, however are in comparison lower and consists of pumping.

Geothermal district heating systems are in operation in 17 countries, including large installations in Iceland, France, Poland, Hungary, Turkey, Japan, China, Romania and the U.S. The Warm Springs Avenue project in Boise, Idaho, dating back to 1892 and originally heating more than 400 homes, is the earliest formal project in the U.S (Rafferty, 1992).

*Space cooling* is a feasible option where absorption machines can be adapted to geothermal use. The absorption cycle is a process that utilises heat instead of electricity as the energy source. The refrigeration effect is obtained by utilising two fluids: a refrigerant, which circulates, evaporates and condenses, and a secondary fluid or absorbent. For applications above 0 °C (primarily in space and process conditioning), the cycle uses lithium bromide as the absorbent and water as the refrigerant. For applications below 0 °C an ammonia/water cycle is adopted, with ammonia as the refrigerant and water as the absorbent. Geothermal fluids provide the thermal energy to drive these machines, although their efficiency decreases with temperatures lower than 105 °C (Dickson & Fanelli, 2004).

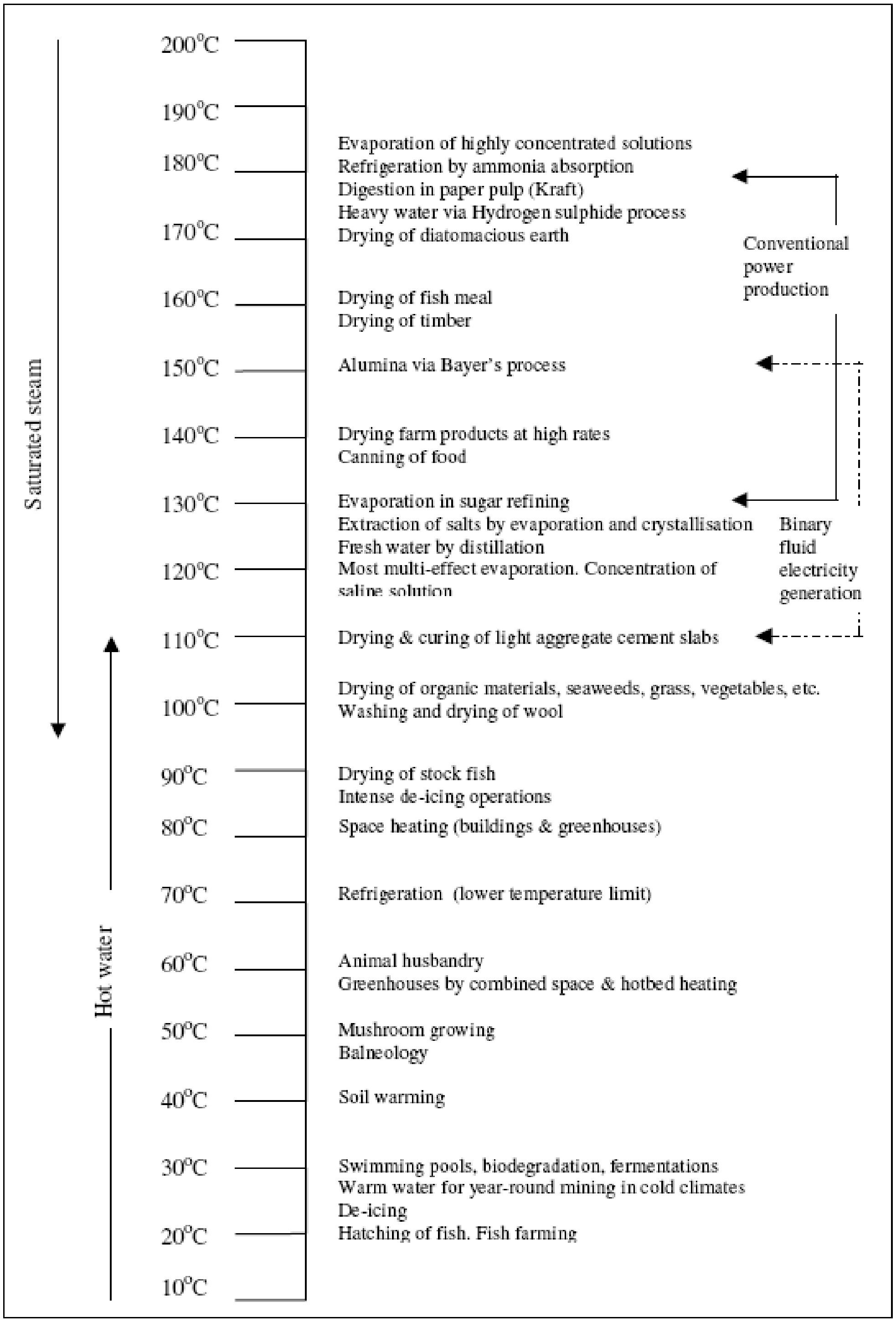

Figure 2.7 Lindal diagram (Gudmundsson, Freeston & Lienau, 1985).

Geothermal space conditioning (heating and cooling) has expanded considerably since the 1980s, following on the introduction and widespread use of *heat pumps*. The various systems of heat pumps available permit us to economically extract and utilise the heat content of low-temperature bodies, such as the ground and shallow aquifers, ponds, etc. (Sanner, 2003) (Figure 2.8 ).

As engineers already know, *heat pumps* are machines that move heat in a direction opposite to that in which it would tend to go naturally, i.e. from a cold space or body to a warmer one. A heat pump is effectively nothing more than a refrigeration unit (Rafferty, 1998). Any refrigeration device (window air conditioner, refrigerator, freezer, etc.) moves heat from a space (to keep it cool) and discharges that heat at higher 40 temperatures. The only difference between a heat pump and a refrigeration unit is the desired effect, cooling for the refrigeration unit and heating for the heat pump. A second distinguishing factor of many heat pumps is that they are reversible and can provide either heating or cooling in the space.

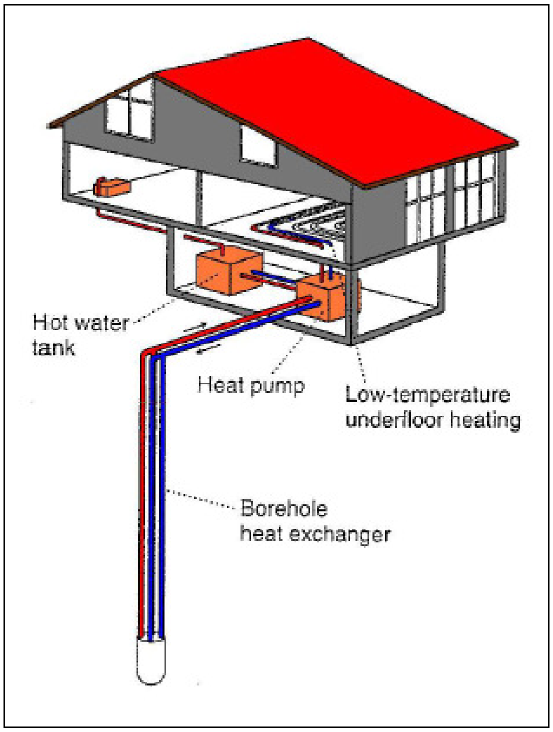

Figure 2.8 Typical application of ground-coupled heat pump system ( Sanner., 2003).

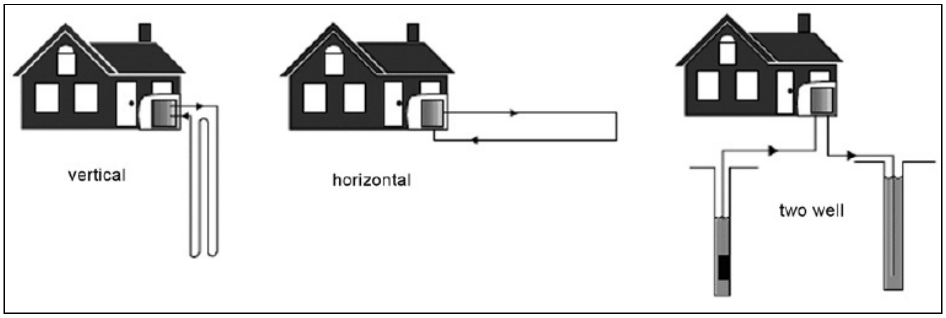

Figure 2.9 Examples of common geothermal heat pump installations.

A number of comnercial crops can be raised in *greenhouses*, making geothermal resources in cold climates particularly attractive. Crops include vegetables, flowers (potted and cut), house plants, and tree seedlings.

*Greenhouse heating* can be accomplished by several methods; finned pipe, unit heaters, finned coils, soil heating, plastic tubing, cascading, and a combination of these methods. The use of geothermal energy for heating can reduce operating costs and allows operation in colder climates where commercial greenhouses would not normally be economical. Economics of a geothermal greenhouse operation depend on many variables, such as the type of crop, climate, resource temperature, type of structure, etc. Greenhouses are one of the fastest growing applications in the direct use industry. A number of the existing greenhouse systems are expanding.

*Swimming, bathing and balneology;* Romans, Chinese, Ottomans, Japanese and central Europeans have bathed in geothermal waters for centuries. Today, more than 2200 hot springs resorts in Japan draw 100 million guests every year, and the "return-to-nature" movement in the U.S. has revitalized many hot spring resorts.

Depending on the chemical composition of the mineral waters and spring gas, availability of peat and sulfurous mud, and climatic conditions, each sanitarium is designated for the treatment of specific diseases. The therapeutic successes of these spas are based on centuries of healing tradition (balneology), systematically supplemented by the latest discoveries of modern medical science (Lund, 2007).

Figures for this use are difficult to collect and quantify. Almost every country has spas and resorts that have swimming pools (including balneology), but many allow the water to flow continuously, regardless of use. As a result, the actual usage and capacity figures may be high. Undeveloped natural hot springs have not been included in the data. A total of 60 countries have reported bathing and swimming pool use, amounting to a worldwide installed capacity of 5401 $MW_t$ and energy used of 83,018 TJ/yr (2,306 GWh/yr) based on data from country update papers from the World Geothermal Congress 2005 (WGC2005) in Turkey.

*Aquaculture* involves the raising of freshwater or marine organisms in a controlled environment to enhance production rates. The principal species raised are aquatic animals such as catfish, bass, tilapia , sturgeon, shrimp, and tropical fish. The application temperature in fish farming depends on the species involved. Typically, catfish grow in 4 to 6 month at 18 to 27 ºC, trout in 4 to 6 month at 13 to 18 ºC and prawns in 6 to 9 month at 30 to 37 ºC. The benefit of a controlled rearing temperature in aquaculture operations can increase growth rates by 50 to 100% and thus increase the number of harvests per year. Water quality and disease control are very important in fish farming.

The entire temperature range of geothermal fluids, whether steam or water, can be exploited in *industrial applications*, as shown in the Lindal diagram (Figure 2.7). The different possible forms of utilization include process heating, evaporation, drying, distillation, sterilisation, washing, de-icing, and salt extraction. Industrial process heat has applications in 19 countries (Lund & Freeston, 2001), where the installations tend to be large and energy consumption high. Examples also include concrete curing, bottling of water and carbonated drinks, paper and vehicle parts production, oil recovery, milk pasteurisation, leather industry, chemical extraction, $CO_2$ extraction, laundry use, diatomaceous earth drying, pulp and paper processing, and borate and boric acid production. There are also plans to utilise low-temperature geothermal fluids to deice runaways and disperse fog in some airports. A cottage industry has developed in Japan that utilises the bleaching properties of the $H_2S$ in geothermal waters to produce innovative and much admired textiles for ladies' clothing. In Japan they have also experimented a technique for manufacturing a lightweight 'geothermal wood' that is particularly suited to certain types of constructions. During treatment in the hot spring water the polysaccharides in the original wood hydrolise, rendering the material more porous and thus lighter.

## 2.5 Geothermal Energy in Turkey

Turkey is poor in fossil fuel resources but rich in renewable resources such as geothermal, solar, hydraulics, wind, and biomass. Geothermal energy is used for direct utilization and power generation. The wide spread hydrothermal occurrences due to tectonic activities and some young volcanism indicate significant existence of geothermal resources in Turkey. The first geothermal researches and investigations in Turkey started by MTA in 1960’s. Nearly 1500 thermal and mineral water springs and more than 170 geothermal fields with a temperature range up to 242 °C have been discovered in Turkey which is located on Mediterranean sector of Alpine-Himalaya belt. Figure 2.10 shows the locations of those 170 geothermal fields which can be useful at the economic scale and about 1500 hot and mineral water resources which have the temperatures ranged from 20-242 °C. Turkey is very active with earth crust movements, tectonic movements of the rock formations, and volcanic activities.

The geothermal resources in Turkey are mostly moderate and low-temperature ones. Some are distributed mostly at the central and western parts of the country, some at the central and eastern Anatolia volcanic regions, whereas high temperature geothermal resources capable of supporting direct use projects and power generation are discovered primarily in the graben structures of Western Anatolia.

The present (2010) installed geothermal power generation capacity in Turkey is about 100 $MW_e$, while that of direct use installations is around 967.3 $MW_t$. The distributions of proven geothermal potential according to the geographic regions are given at Figure 2.11.

Geological studies indicate that the most important geothermal systems of Turkey are located in the major grabens of the Menderes Metamorphic Massif, while those that are associated with local volcanism are more common in the central and eastern parts of the country (Fig.2.12).

Figure 2.10 Main neotectonic lines and hot spring distribution of Turkey (Serpen, 2004).

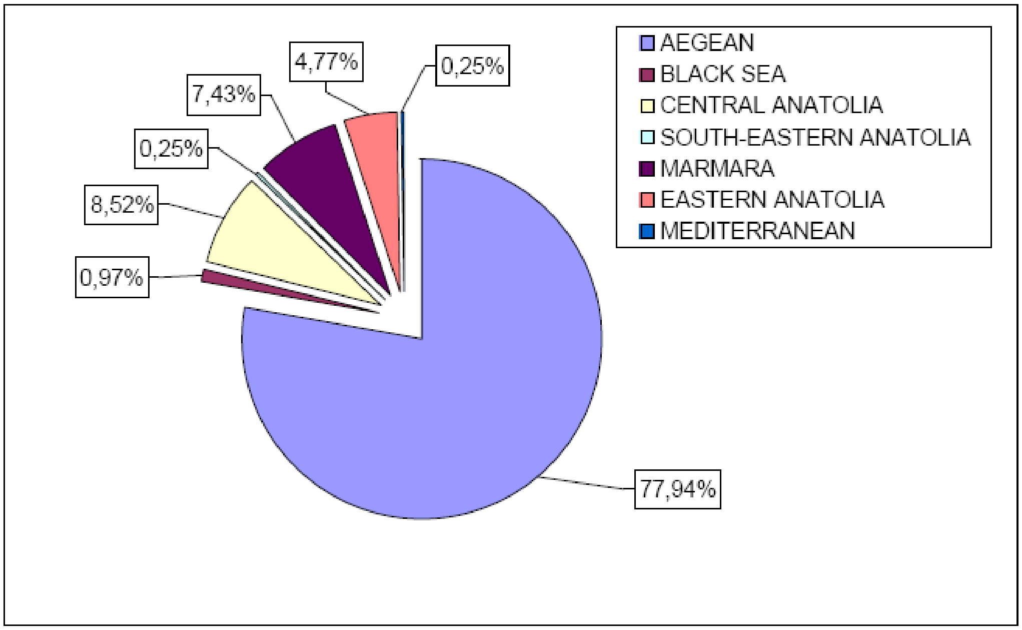

Figure 2.11 Proven geothermal potentials of regions in Turkey.

The geothermal systems in Turkey (Fig.2.12) are located mainly following recent and regional structural lines and are more frequent in regions of recent tectonism and Tertiary volcanism and/or metamorphism. However, while these systems differ radically between regions, substantial similarities tend to exist among systems of a given region. This zonation also defines the suitability of conditions for the existence of possible deep geothermal resources. Following division of some known geothermal fields and occurrences are made on the basis of both geographical distribution and some geoscientific aspects of those geothermal resources (Serpen, Aksoy, Ongur, & Korkmaz, 2009a).

*Aegean Coastal Belt:* Seferihisar, Cesme, Balcova, Aliaga, Dikili-Bademli, Edremit, Tuzla and Kestanbol.

*Menderes Metamorphic Massif and Western Anatolian grabens:* Germencik, Aydın Yılmazköy İmamköy, Serçeköy-Umurlu, Salavatlı-Sultanhisar, Pamukören, Kızıldere, Yenice, Gölemezli geothermal systems in Büyük Menderes Graben. Salihli- Kursunlu, Caferebeyli and Sart, Turgutlu-Urganlı and Alasehir-Kavaklıdere geothermal systems in Gediz Graben. Dikili-Kaynarca and Bergama geothermal systems in Dikili-Bergama Graben, and Simav, Saphane and Gediz-Abide geothermal systems in Simav Graben. These geothermal systems are all in the same geological environment (Serpen, Aksoy, Ongur, & Korkmaz, 2009a).

*Central Anatolian geothermal fields:* Afyon, Kapadokya, Kırsehir, Kozaklı, Kizıicahamam.

*Eastern Anatolian geothermal systems:* Nemrut Caldera, Ercis-Zilan ve Diyadin.

*Geothermal Fields Formed in the North Anatolian Fault Zone:* Erzincan, Cerkes, Bolu, Adapazari- Akyazi, Bursa Cekirge-Kukurtlu, Gonen

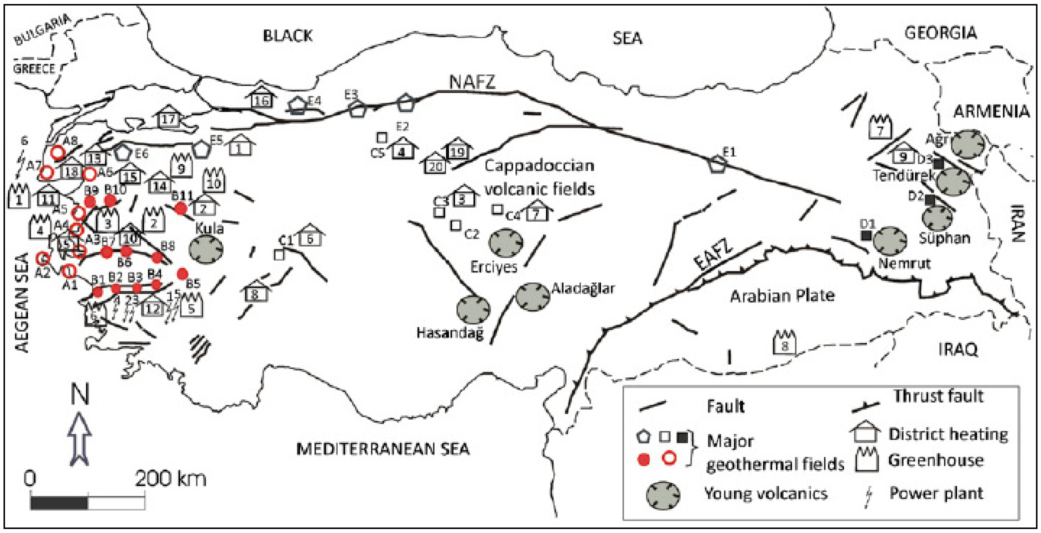

Figure 2.12. Location of major geothermal fields in Turkey. In the *Aegean Coastal Belt*: (A1) Seferihisar, (A2) Cesme, (A3) Balcova, (A4) Aliaga, (A5) Dikili-Bademli, (A6) Edremit, (A7) Tuzla, and (A8) Kestanbol; in the *Western Anatolian grabens*: (B1) Germencik, (B2) Aydin, (B3) Salavatli Sultanhisar, (B4) Kizıildere, and (B5) Denizli; (B6) Salihli-Kursunlu, Caferebeyli and Sart, (B7) Turgutlu-Urganlı, (B8) Alasehir-Kavaklidere, (B9) Dikili-Kaynarca, (B10) and Bergama and (B11) Simav; in *Central Anatolia*: (C1) Afyon, (C2) Cappadocia, (C3) Kirsehir, (C4) Kozakli, and (C5) Kizilcahamam; in *Eastern Anatolia*: (D1)Nemrut Caldera, (D2) Ercis-Zilan, and (D3) Diyadin; in the *North Anatolian Fault Zone*: (E1) Erzincan, (E2) Cerkes, (E3) Bolu, (E4) Duzce, (E5) Bursa and (E6) Gonen. NAFZ: North Anatolian Fault Zone; EAFZ: East Anatolian Fault Zone. *Geothermal district heating systems*: (1) Gonen-Balikesir, (2) Simav-Kütahya, (3) Kirsehir, (4) Kizilcahamam-Ankara, (5) Balçova-Izmir, (6) Afyon, (7) Kozaklı-Nevsehir, (8) Sandikli-Afyon, (9) Diyadin-Agri, (10) Salihli-Manisa, (11) Dikili-Izmir, 12 Saraykoy-Denizli, (13) Edremit-Canakkale, (14) Bigadic -Balikesir, (15) Bergama-Izmir, (16) Kuzuluk-Sakarya, (17) Armutlu-Yalova, (18) Güre-Balikesir, (19) Sorgun-Yozgat and (20) Yerkoy-Yozgat. *Geothermal greenhouses*: (1) Dikili-Izmir, (2) Salihli-Manisa, (3) Turgutlu-Manisa, (4) Balçova-Izmir, (5) Kizildere- Denizli, (6) Gumuskoy-Aydin, (7) Diyadin-Agri, (8) Karacaali-Urfa, (9) Sindirgi-Balikesir and (10) Simav-Kütahya. *Geothermal power plants*: (1) Kizildere-Denizli, (2 and 3) Dora-1 and Dora-2, Salavatli-Aydin, (4) Gurmat, Germencik-Aydin (5) Bereket, Kizildere-Denizli and (6) Tuzla-Canakkale (Serpen, Aksoy, Ongur, & Korkmaz, 2009a).

### *2.5.1 Fields for Direct Applications*

The direct utilization of geothermal energy includes space heating and district heating, the heating of pools, baths and spas, greenhouses, and industrial applications. Direct use of geothermal energy in Turkey has shown an impressive growth with considerable increases in district and greenhouse heating. Tables 2.4 and

2.5 give the direct use capacities of district and greenhouse heating systems, respectively.

Turkey is one of the top five countries for geothermal direct applications (Lund, 2005). Direct use of geothermal energy in Turkey has focused mainly on district heating. The first of these systems came on line at the low-temperature Gonen field in 1987. During 1991-2010 period other 20 district heating systems were installed.

### *2.5.1.1 District Heating*

As mentioned before district heating in Turkey started in 1987 heating 1500 households. Later the system was expanded to 2500 subscribers. As seen in Table 2.4, by 2010, Turkey had 21 district heating systems working with geothermal energy. Of these district heating systems, one in Saraykoy is heated by the waste heat coming from bottoming binary power plant in Kizildere. Table 2.4 shows that low temperature geothermal resources are mostly used in district heating with the exception of Balcova and Simav, which have medium grade resources that could also have been used for power generation purpose. About 6 million square meter space are heated by district heating with a capacity of 471.9 $MW_t$.

Unfortunately few district-heating systems in Turkey have been properly designed or installed. Because of inadequate corrosion protection some have serious water losses in their distribution loops (Toksoy & Serpen, 2001). Others because of improper hydraulic design are costly to operate. In district heating systems using low-enthalpy geothermal waters, such as Gonen, Edremit, Kizilcahamam, Bigadic¸ Sandıklı and Diyadin, the pumping costs needed to send the hot waters to the buildings and adequately distribute the heat in them, are excessive.

The most important problem with these district systems is that the hydraulic characteristics of the thermal resources have been completely ignored in their design. For example, in the towns of Salihli and Gönen the existing wells cannot supply sufficient volume of hot fluids to satisfy the needs of the system (Serpen, 2006). As a result the local government officials in the town of Sandıklı had to install a coal-fired boiler to send additional hot fluids to the existing geothermal district heating system. Similarly, in Bigadic¸ the temperature of the geothermal waters is raised by heating them using natural gas. These cases have been discussed by Toksoy & Serpen (2001) and Serpen (2006).

Table 2.4 shows the systems with their maximum flow rates, inlet and outlet temperatures of geothermal fluid in primary heat exchangers.

Table 2.4 Turkey's geothermal district heating (updated from Serpen, 2009a)

| Locality | Year Commissioned | $T_{in}$ (°C) | $T_{out}$ (°C) | $Q_{max}$ (kg/s) | Capacity ($MW_t$) | Equivalent Space ($x100m^2$) |
|---|---|---|---|---|---|---|
| Gonen-Balikesir | 1987 | 67 | 45 | 200 | 18.4 | 2,500 |
| Simav-Kutahya | 1991 | 100 | 50 | 175 | 36.6 | 6,000 |
| Kirsehir | 1994 | 54 | 49 | 270 | 5.6 | 1,800 |
| Kizilcahamam-Ank. | 1995 | 70 | 42 | 150 | 17.6 | 2,600 |
| Balçova-Izmir | 1996 | 118 | 60 | 320 | 156.0 | 30,500 |
| Omer-Gecek-Afyon | 1996 | 90 | 45 | 180 | 33.9 | 5,000 |
| Kozakli-Nevsehir | 1996 | 98 | 52 | 100 | 19.2 | 1,500 |
| Sandikli-Afyon | 1998 | 70 | 42 | 250 | 29.3 | 4,000 |
| Diyadin-Agri | 1998 | 65 | 55 | 200 | 8.4 | 400 |
| Salihli-Manisa | 2002 | 80 | 40 | 150 | 25.1 | 4,000 |
| Dikili-Izmir | 2008 | 120 | 60 | 40 | 10 | 150 |
| Saraykoy-Denizli | 2002 | 125 | 60 | 100 | 27.2 | 2,500 |
| Edremit-Canakkale | 2004 | 60 | 45 | 270 | 16.9 | 2,740 |
| Bigadic-Bakikesir | 2006 | 80 | 50 | 80 | 10.0 | 1,000 |
| Bergama-Izmir | 2006 | 62 | 40 | 100 | 10.0 | 200 |
| Kuzuklu-Sakarya | 1994 | 80 | 40 | 25 | 11.2 | 500 |
| Armutlu-Yalova | 2000 | 78 | 40 | 30 | 4.8 | 250 |
| Güre-Balikesir | 2006 | 62 | 52 | 200 | 8.5 | 300 |
| Sorgun-Yozgat | 2007 | 75 | 50 | 200 | 20.9 | 1,500 |
| Yerkoy-Yozgat | 2007 | 60 | 40 | 40 | 2.3 | 500 |
| TOTAL | | | | | 471.9 | 58,940 |

### *2.5.1.2 Greenhouse Heating*

Heating greenhouses with geothermal energy has recently become very popular in Turkey. This sort of heated greenhouse areas has substantially increased from 809 decare in 2006 (Serpen, 2006) to 2295 decare this year (2010) creating a threefold increment. Table 2.5 shows important greenhouse sites and areas heated by geothermal fluids, and their estimated capacities. Majority of these greenhouse areas are situated in Western Anatolia and their areas are expanding very fast.

Table 2.5 Greenhouse heating in Turkey (updated from Serpen, 2009a)

| Locality | Greenhouse Area Decare=$10^3 m^2$ | Estimated Capacity $MW_t$ |
|---|---|---|
| Dikili-Izmir | 775 | 83.7 |
| Salihli-Manisa | 350 | 22.6 |
| Turgutlu-Manisa | 110 | 15.4 |
| Simav-Kutahya | 100 | 17 |
| Gumusluk-Aydin | 50 | 2.5 |
| Edremit-Balikesir | 50 | 9.0 |
| Tuzla-Canakkale | 50 | 9.0 |
| Karacaali-Urfa | 170 | 25.0 |
| Balçova-Izmir | 80 | 14.0 |
| Sindirgi-Balikesir | 200 | 3.0 |
| Diyadin-Agri | 2.4 | 3.1 |
| Kizildere-Denizli | 357 | 40.0 |
| Seferhisar-Izmir | 6 | 1.1 |
| TOTAL | 2294.4 | 245.4 |

Geothermal resources with moderate and high enthalpy in our country have high $CO_2$ content (1-2.5% by weight of geothermal fluid) and this gas is also used to accelerate the growth of greenhouse produces. It is necessary to inject 1000-2000 ppm of $CO_2$ into greenhouse atmosphere and greenhouses consume 4000 ton/year $CO_2$ per hectare. In other words, $CO_2$ obtained from geothermal resources are used for greenhouses (Serpen, Aksoy, Ongur, & Korkmaz, 2009a).

Much larger projects could be on the way, especially considering that major greenhouse developers are already exporting their products. As seen in Table 2.5, 2294.4 decare greenhouse area are heated by geothermal energy with 245.4 $MW_t$ direct heat capacity.

### *2.5.1.3 Balneological Use*

Turkey has many natural balneological sites with thermal waters to treat different kinds of illnesses, and the health-spa business is thriving; about four million domestic visitors enjoy them every year. It was found that generally the facilities are not in good condition. If these sites were rebuilt and proper health services were provided, the spas could attract many foreign patients.

In Turkey, there are important healt-spa sites, such as Balçova, Afyon, Cesme, Gonen and Kizilcahamam, and besides, balneological services could also be provided for residences in Akyazi- Adapazari and Armutlu-Yalova. In Cesme 42 km long pipeline is installed to supply thermal (about 57 °C) waters for 18 major hotels. About 62 hotels with 10,000 beds capacity will be connected to this pipeline and then Cesme might become the most important balneological center in Turkey. For the time being, the total thermal capacity in Cesme is around 20.9 $MW_t$. Other popular Health Spa center is being developed in Afyon area, and nowadays three important thermal hotels with health therapy centers are being built. A 15 km long hot water pipeline is also being built in this region.

Table 2.6 Total direct use capacity in Turkey (updated from Serpen, 2009a)

| Type of direct use | Capacity ($MW_t$) |
|---|---|
| District heating | 471.9 |
| Greenhouse heating | 245.4 |
| Balneology | 250.0 |
| Total | 967.3 |

Direct use capacity for balneological utilization is estimated around 250 $MW_t$. Total Turkey's direct-use capacity (with district heating, greenhouse heating and balneological uses) is about 967.3 $MW_t$ (Table 2.6).

### *2.5.2 Fields for Power Generation*

Geothermal fields with field average temperatures higher than 140 °C are listed below. The first figure in the parenthesis represents the field average temperature and the second one the maximum temperature measured in the field. 1. Kizildere Field (217 $^{o}$C and $T_{max}$=242 °C, used for power generation), 2. Salavatli-Sultanhisar Field (157.5 $^{o}$C and $T_{max}$=171 °C, used for power generation), 3. Germencik-Omerbeyli Field (220 $^{o}$C and $T_{max}$=232 °C), 4. Tuzla Field (160 °C and $T_{max}$ =174 $^{o}$C, used for direct applications), 5. Simav Field ( 145 $^{o}$C and $T_{max}$ =162 $^{o}$C, used for direct applications), 6. Seferihisar Field (144 $^{o}$C, $T_{max}$ =153 $^{o}$C), 7. Yilmazkoy-Imamkoy Field (142 $^{o}$C), 8. Kavaklidere Field (215 $^{o}$C), 9. Caferbeyli Field (155 $^{o}$C).

Table 2.7 Geothermal Power Plants of Turkey (updated from Serpen et al., 2009a)

| Geothermal power plants | Year commisioned | Installed capacity ($MW_e$) | Resource temprature (°C) |
|---|---|---|---|
| Kizildere-Denizli | 1984 | 17.8 | 243 |
| Dora-I Salavatli-Aydin | 2006 | 7.35 | 172 |
| Bereket Energy Denizli | 2007 | 7.5 | 145 |
| Germencik-Aydin | 2009 | 47.4 | 232 |
| Tuzla-Canakkale | 2009 | 7.5 | 171 |
| Dora-II Salavatli-Aydin | 2010 | 11.1 | 174 |
| Total | | 98.65 | |

Total installed power generation capacity has reached to 100 $MW_e$ by the beginning of 2010. Among power plants indicated in Table 2.7, Dora II was commissioned in early February/2010. Next year another 17.5 $MW_e$ power plant in Hidirbeyli would be commissioned.

### *2.5.3 Geothermal Legislation in Turkey*

Turkey is used a geothermal energy resources law finally in June/2007, and the law was enacted a year later in June/2008.

After 2.5 years of implementation of highly criticized Geothermal Energy Resources Law and Regulations have created substantial chaotic circumstances in legal, administrative, economic and technical areas. After beginning of application of new geothermal legislation, numerous lawsuits at various categories have been brought at different levels of courts, and most of them are still going on (Serpen, Aksoy & Ongur, 2009b).

Three-headed administration (Local Government- Mining Authority and Mineral Research Institution) has created contradictions and disagreements between different administrative levels. Sometimes unlawful applications occur. Numerous geothermal fields are closed to exploration and development. A market for licenses has been created. The geothermal fields have dangerously been divided. There is no transparency in operations, and information gathering and distribution channels are not well functioning; and technical and state supports are nonexistent.

There are important problems in bidding preparation and management. License transfer contracts have caused some injustice and biased actions. Identification of blocked neighboring areas to geothermal fields has created injustice and illegal acts (Serpen, Aksoy & Ongur, 2009b).

Geothermal resource protection area reports for the surroundings geothermal fields have not being approved, and therefore, controls for the fields can not be implemented. Technical responsibility subject is blurred and there is a future uncertainty.

Resource is being damaged in the fields that are divided, uncontrolled, and responsibilities are not openly and correctly distributed. Pressures and temperatures of the reservoirs are declining and the sustainability of the resources is in grave danger.

# CHAPTER THREE
# GEOTHERMAL DISTRICT HEATING SYSTEM

## 3.1 District Heating Systems

District heating is a system, composed of many elements, building a chain from the resource over to the interior of the buildings which are heated. All elements in this chain are equally important, from the geothermal well over to the building radiators, and they have to be designed with utmost care (Valdimarsson, 2003).

District heating system (DHS) distributes thermal energy from a central source to residential, commercial, and/or industrial consumers for use in space heating, water heating, and/or process heating. The energy is distributed by steam or hot chilled water lines. Thus, thermal energy comes from a distribution medium rather than being generated on site at each facility (ASHRAE 2008).

Whether the system is a public utility or user owned, such as a multi-building campus, it has economic and environmental benefits depending somewhat on the particular application. Political feasibility must be considered, particularly if a municipality or governmental body is considering a DHC installation. Historically, successful district heating systems have had the political backing and support of the community.

District heating systems are best used in markets where the thermal load density is high and the annual load factor is high. A high load density is needed to cover the capital investment for the transmission and distribution system, which usually constitutes most of the capital cost for the overall system, often ranging from 50 to 75% of the total cost for district heating systems.

District heating systems consist of three primary components; the central plant, the distribution network, and the consumer systems. The central source or production plant may be any type of boiler, a refuse incinerator, a geothermal source, solar energy, or thermal energy developed as a by-product of electrical generation.

The second component is the distribution or piping network that conveys the energy. The piping is often the most expensive portion of a district heating or cooling system. The piping usually consists of a combination of preinsulated and field-fieldinsulated pipe in both concrete tunnel and direct burial applications. These networks require substantial permitting and coordinating with nonusers of the system for right ofway if not on the owner's property. Because the initial cost is high, it is important to optimize use.

The third component is the consumer system, which includes in-building equipment. When steam is supplied, it may be used directly for heating; it may be directed through a pressure-reducing station for use in low-pressure (0 to 100 kPa) steam space heating, service water heating, and absorption cooling; or it may be passed through a steam-to-water heat exchanger. When hot water or chilled water is supplied, it may be used directly by the building system or isolated by a heat exchanger.

## 3.2 Major Components of Geothermal District Heating System

Geothermal District Heating is defined as the use of one or more production fields as sources of heat to supply thermal energy to a group of buildings. Services available from a district heating system are space heating, domestic water heating, space cooling, and industrial process heat. Geothermal district heating system applications exist in many countries especially in Iceland, France, Poland, Hungary, Turkey, Japan, Romania, China and the USA. (Lund, 2007)

A geothermal district heating system comprises three major components.

The first part includes production and injection wells and heating centre. There are some equipment like main heat exchangers, collectors, pumps and valves in the heating centre (Geothermal loop).

The second part is the transmission/distribution system. It delivers the city water which is heated by geothermal energy to the consumers. In this system, hot water circulates between heating centre and buildings in the close loop (City loop).

The third part includes costumer-building equipment. Building heat exchanger and in building equipments exist in this part of the system (Building loop).

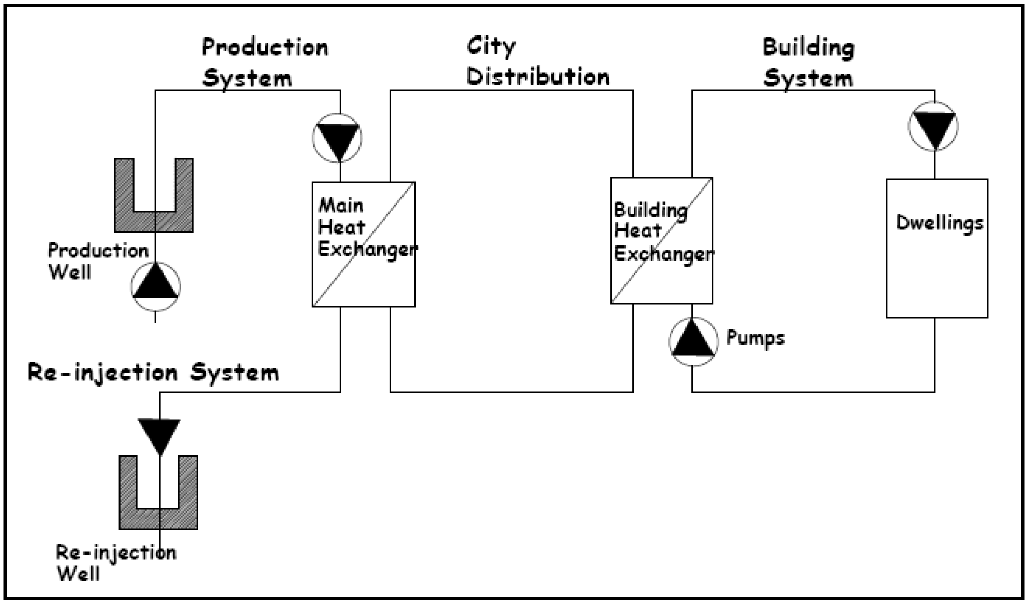

Figure 3.1. Typical Geothermal District Heating System scheme

## 3.3 Potential Advantages of Geothermal District Heating

Potential advantages of geothermal district heating:

- Reduced fossil fuel consumption. Geothermal district heating nearly eliminates the consumption of oil, coal, or natural gas traditionally used for space and domestic water heating.
- Reduced heating costs. Through the use of geothermal energy and increased efficiency, district heating systems often can offer thermal energy at lower prices than conventional heating systems.
- Improved air quality. Geothermal district heating systems eliminate noxious gases, greenhouse gases (such as $CO_2$) and particulate that occur in cities with conventional single-building heating systems.

- Continual Heating. Geothermal energy is available 24 hours a day.
- Cogeneration. Cities located near high-temperature (T>150°C) geothermal fields, in addition produce electric power, space heating, space cooling, greenhouse heating, domestic water heating and etc. are available using the disposal water with great efficiency.
- Reduced fire hazard in buildings. The fire hazard in buildings is reduced because no combustion with fossil fuel occurs within individual buildings.

### 3.4 Geothermal District Heating System Basic Equipments

Standard equipment is used in most direct-use projects, provided allowances are made for the nature of geothermal water and steam. Temperature is an important consideration, so is water quality. Corrosion and scaling caused by the sometimes unique chemistry of geothermal fluids, may lead to operating problems with equipment components exposed to flowing water and steam. In many instances, fluid problems can be designed out of the system. One such example concerns dissolved oxygen, which is absent in most geothermal waters, except perhaps the lowest temperature waters. Care should be taken to prevent atmospheric oxygen from entering district heating waters; for example, by proper design of storage tanks. The isolation of geothermal water by installing a heat exchanger may also solve this and similar water quality derived problems. In this case, a clean secondary fluid is then circulated through the used side of the system as shown in Figure 3.2. (Lund, 1998)

The primary components of most low-temperature direct-use systems are downhole and circulation pumps, transmission and distribution pipelines, peaking or back-up plants, and various forms of heat extraction equipment (Figure 3.2). Fluid disposal is either surface or subsurface (injection). A peaking system may be necessary to meet maximum load. This can be done by increasing the water temperature or by providing tank storage (such as done in most of the Icelandic district heating systems). Both options mean that fewer wells need to be drilled. When the geothermal water temperature is warm (below 50 $^{o}$C), heat pumps are often used. The equipment used in direct-use projects represents several units of operations. The major units will now be described in the same order as seen by geothermal waters produced for district heating (Lund, 1998).

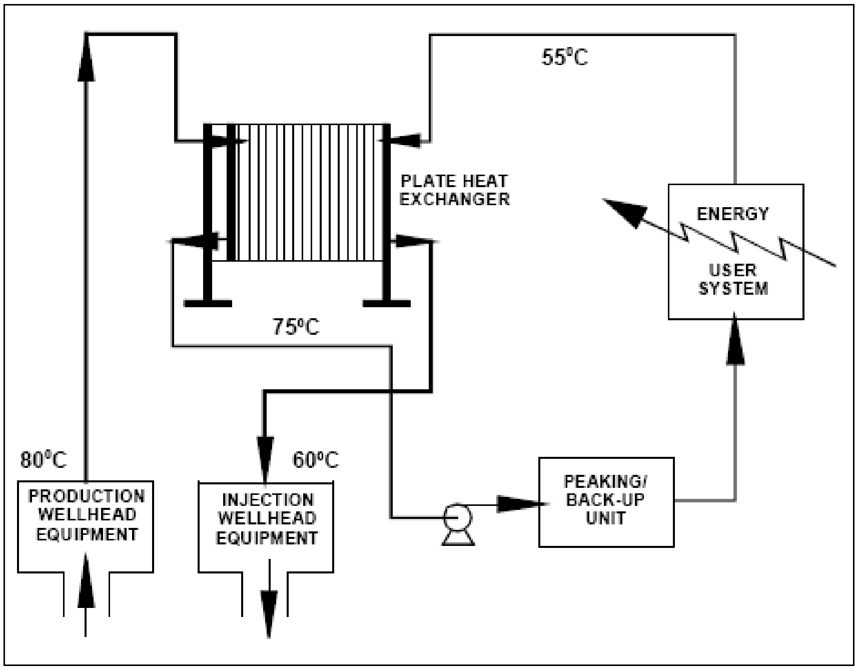

Figure 3.2 Geothermal direct-utilization system using a heat exchanger (Lund, 1998)

### *3.4.1 Well Pumps*

Pumping is often necessary in order to bring geothermal fluid to the surface. For direct-use applications, there are primarily two types of production well pumps; (a) lineshaft turbine pumps and (b) submersible pumps. The difference being the location of the driver. In a lineshaft pump, the driver, usually a vertical shaft electric motor, is mounted above the wellhead and drives the pump, which may be located as much as 610 m below the ground surface, by means of a lineshaft. In a submersible pump, the driver (a long, small diameter electric motor) is usually located below the pump itself and drives the pump through a relatively short shaft with a seal section to protect the motor from the well fluid. (Culver & Rafferty, 1998)

Lineshaft pumps have two definite limitations: (a) they must be installed in relatively straight wells and (b) they are economically limited to settings of <=610 m.

For direct heat applications, the economic setting depth limit is probably closer to 245 m. A general comparison of lineshaft and submersible pumps appears below in Table 3.1.

Table 3.1 Comparison of Lineshaft and Submersible Pumps (Culver & Rafferty, 1998)

| Lineshaft | Submersible |
|---|---|
| Pump stage efficiencies of 68 to 78%. Lower head/stage and flow/unit diameter. Higher motor efficiency. Little loss in power cable. Mechanical losses in shaft bearings. | Pump stage efficiencies of 68 to 78%. Generally, higher flow/ unit diameter. Lower motor efficiency--operates in oil at elevated temperature. Higher losses in power cable. Cable at least partially submerged and attached to hot tubing. |
| Motor, thrust bearing and seal accessible at surface. | Motor, thrust bearings, seal, and power cable in well--less accessible |
| Usually lower speed (1,750 rpm or less). Usually lower wear rate. | Usually higher speeds (3,600 rpm). Usually higher wear rate. |
| Higher temperature capability, up to 205 $^{o}$C+. | Lower temperature capability but sufficient for most direct heat and some binary power applications, assuming the use of special high-temperature motors. |
| Shallower settings, 610 m maximum. | Deeper settings. Up to 3660 m in oil wells. |
| Longer installation and pump pull time. | Less installation and pump pull time. |
| Well must be relatively straight or oversized to accommodate stiff pump and column. | Can be installed in crooked wells up to 4 degrees deviation per 30 m. Up to 75 degrees off vertical. If it can be cased, it can be pumped. |
| Impeller position must be adjusted at initial startup. | Impeller position set. |
| Generally lower purchase price at direct use temperatures and depths. | Generally higher purchase price at direct use temperatures and depths. |

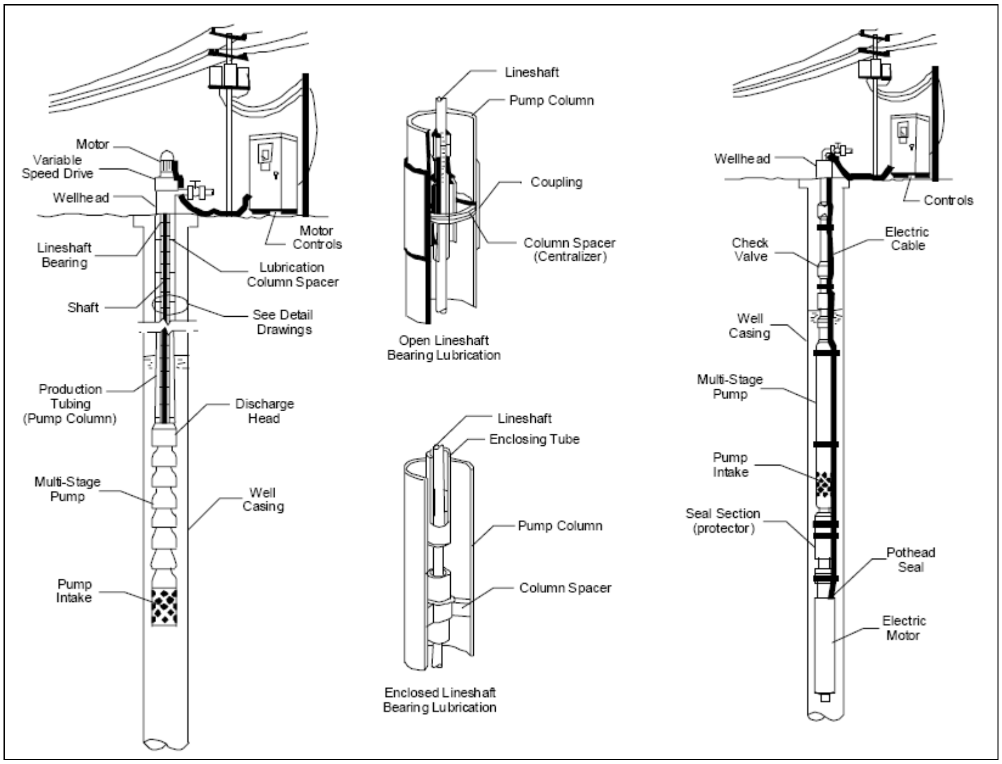

Figure 3.3 Lineshaft pump and submersible pump (Lund, 1998)

### *3.4.2 Piping*

The source of geothermal fluid for a direct use application is often located some distance away from the user. This requires a transmission pipeline to transport the geothermal fluid. Even in the absence of transmission line requirements, it is frequently advisable to employ other than standard piping materials for in-building or aboveground piping. Geothermal fluid for direct use applications is usually transported in the liquid phase and has some of the same design considerations as water distribution systems. Several factors including pipe material, dissolved chemical components, size, installation method, head loss and pumping requirements, temperature, insulation, pipe expansion and service taps should be considered before final specification (Rafferty, 1998).

Piping materials for geothermal heating systems have been of numerous types with great variation in cost and durability. Some of the materials which can be used in geothermal applications include: asbestos cement (AC), ductile iron (DI), slip-joint steel (STL-S), welded steel (STLW), gasketed polyvinyl chloride (PVC-G), solvent welded PVC (PVC-S), chlorinated polyvinyl chloride (CPVC), polyethylene (PE), cross-linked polyethylene (PEX), mechanical joint fiberglass reinforced plastic (FRP-M), FRP epoxy adhesive joint-military (FRP-EM), FRP epoxy adhesive joint (FRP-E), FRP gasketed joint (FRP-S), and threaded joint FRP (FRP-T). The temperature and chemical quality of the geothermal fluids, in addition to cost, usually determines the type of pipeline material used (Rafferty, 1998). Figures 3.4 and 3.5 introduce the temperature limitations and relative costs of the materials covered in this chapter. Generally, the various pipe materials are more expensive the higher the temperature rating. Figure 3.5 includes 15% overhead and profit (O&P) (Lund, Lienau & Lunis, 1998).

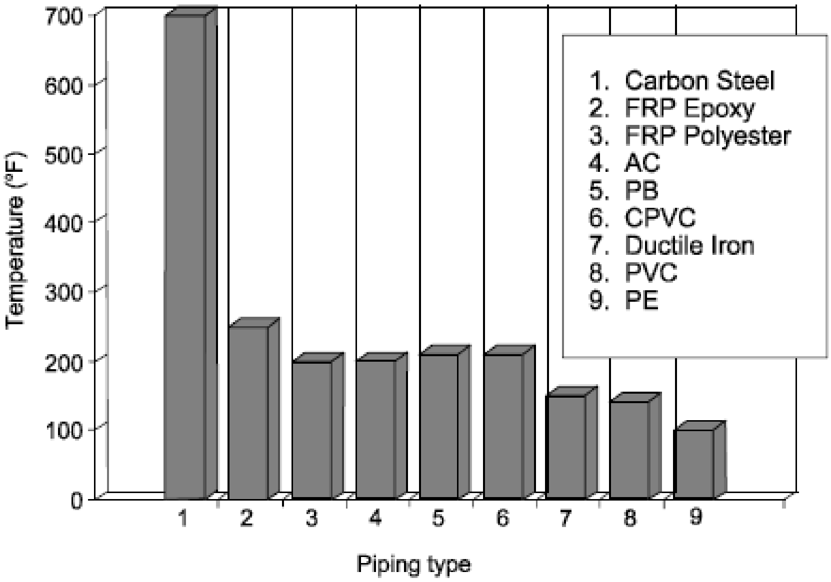

Figure 3.4 Maximum service temperature for pipe materials (Rafferty, 1998)

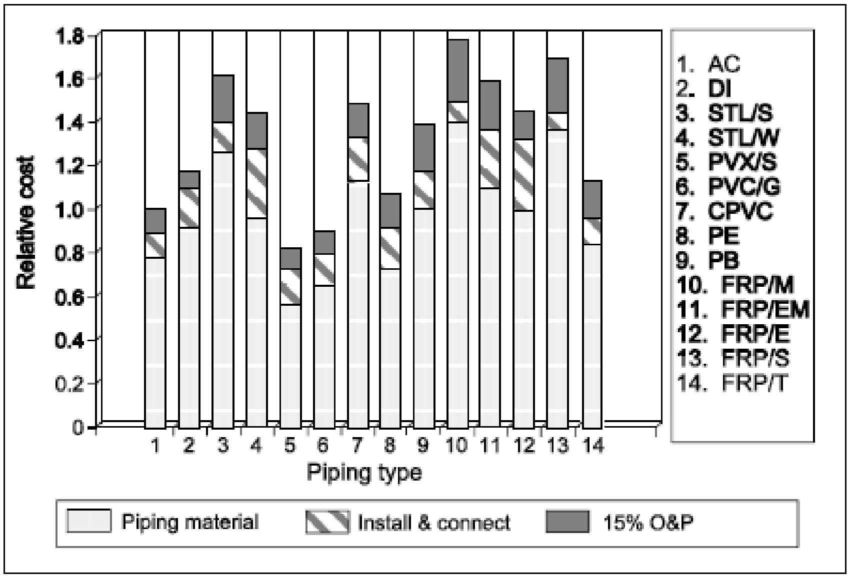

Figure 3.5 Relative cost of piping by type (Rafferty, 1998).

Carbon steel is now the most widely used material for geothermal transmission lines and distribution networks; especially if the fluid temperature is over 100 $^{o}$C. Other common types of piping material are fiberglass reinforced plastic (FRP) and asbestos cement (AC). The latter material, used widely in the past, cannot be used in many systems today due to environmental concerns; thus, it is no longer available in many locations. Polyvinyl chloride (PVC) piping is often used for the distribution network, and for uninsulated waste disposal lines where temperatures are well below 100 °C (Gudmundsson, 1988). Cross-linked polyethylen pipe (PEX) have become popular in recent years as they can tolerate temperatures up to 100 °C and still take pressures up to 550 kPa. However, PEX pipe is currently only available in sizes less than 5 cm in diameter. Conventional steel piping requires expansion provisions, either bellows arrangements or by loops. A typical piping installation would have fixed points and expansion points about every 100 m. In addition, the piping would have to be placed on rollers or slip plates between points. When hot water metallic pipelines are buried, they can be subjected to external corrosion from groundwater and electrolysis. They must be protected by coatings and wrappings. Concrete tunnels or trenches have been used to protect steel pipes in many geothermal district heating systems. Although expensive (generally over U.S.$300 per meter of length), tunnels and trenches have the advantage of easing future expansion, providing access for maintenance and a corridor for other utilities such as domestic water, waste water, electrical cables, phone lines, etc.

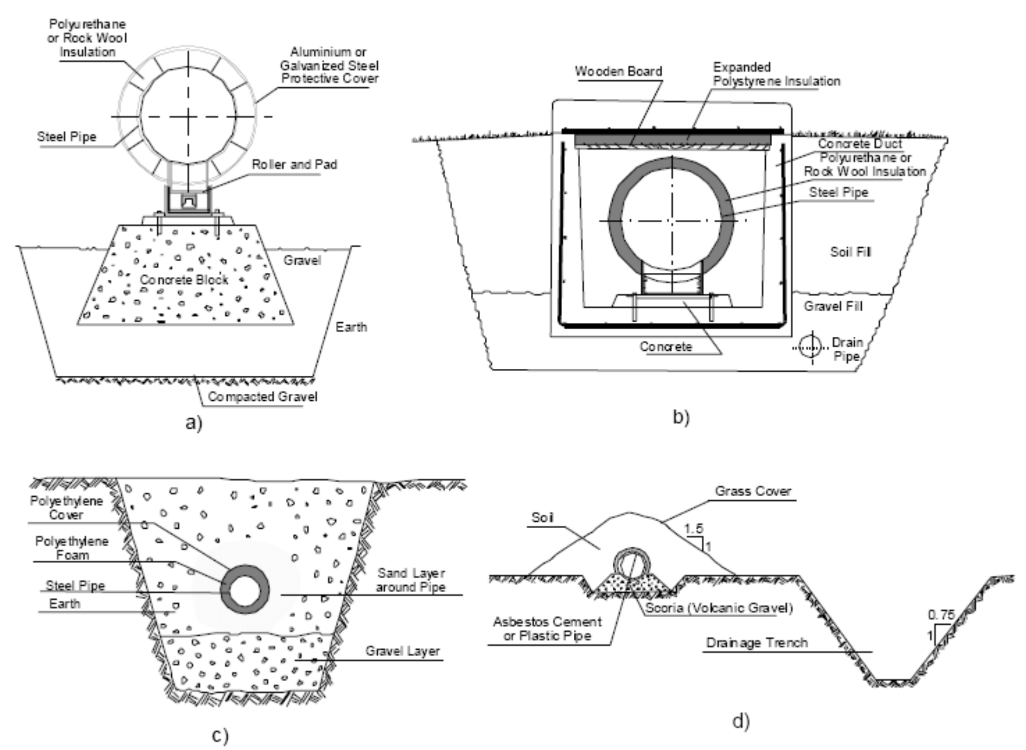

Figure 3.6 Examples of above and below ground pipelines: a) aboveground pipeline with sheet metal cover, b) steel pipe in concrete tunnels, c) steel pipe with polyurethane insulation and polyethylene cover and d) asbestos cement pipe with earth and grass cover (Lund, Lienau & Lunis, 1998)

District heating systems can be designed as "open" or "closed" distribution networks. In the open design, the geothermal fluid is delivered directly to the customer. Waste or cooled fluid is collected in the return piping for delivery to the disposal facility. Closed systems, on the other hand, employ central heat exchangers to isolate most of the district system from the geothermal fluid. Heat is delivered to the customer via a "closed loop" of clean treated water.

The characteristics of open and closed systems are quite different. For example, closed systems generally employ insulated piping for both the supply and return piping; whereas, open systems may use insulation only on the supply piping. More importantly, open systems expose all of the piping to the geothermal fluids and as a result, corrosion considerations are more critical to these designs. Finally, the cost of closed systems is generally much higher than open systems. This is the result of costs associated with the central plant and the more extensive use of insulated piping.

### *3.4.3 Heat Exchangers*

Most geothermal fluids, because of their elevated temperature, contain a variety of dissolved chemicals. These chemicals are frequently corrosive toward standard materials of construction. As a result, it is advisable in most cases to isolate the geothermal fluid from the process to which heat is being transferred. (Rafferty & Culver, 1998)

The task of heat transfer from the geothermal fluid to a closed process loop is most often handled by a plate heat exchanger. The two most common types used in geothermal applications are: bolted and brazed.

For smaller systems, in geothermal resource areas of a specific character, downhole heat exchangers (DHEs) provide a unique means of heat extraction. These devices eliminate the requirement for physical removal of fluid from the well. For this reason, DHE-based systems avoid entirely the environmental and practical problems associated with fluid disposal (Rafferty & Culver, 1998).

#### *3.4.3.1 Plate Heat Exchanger*

The plate heat exchanger is the most widely used configuration in geothermal systems of recent design. A number of characteristics particularly attractive to geothermal applications are responsible for this. Among these are:

1. Superior thermal performance.
2. Availability of a wide variety of corrosion resistant alloys.
3. Ease of maintenance.
4. Expandability and multiplex capability.
5. Compact design.

As shown in Figure 3.7, the plate heat exchanger is basically a series of individual plates pressed between two heavy end covers. The entire assembly is held together by the tie bolts. Individual plates are hung from the top carrying bar and are guided by the bottom carrying bar. For single-pass circuiting, hot and cold side fluid connections are usually located on the fixed end cover. Multi-pass circuiting results in fluid connections on both fixed and moveable end covers.

Figure 3.8 illustrates the nature of fluid flow through the plate heat exchanger. The primary and secondary fluids flow in opposite directions on either side of the plates. Water flow and circuiting are controlled by the placement of the plate gaskets. By varying the position of the gasket, water can be channeled over a plate or past it. Gaskets are installed in such a way that a gasket failure cannot result in a mixing of the fluids. In addition, the outer circumference of all gaskets is exposed to the atmosphere. As a result, should a leak occur, a visual indication is provided.

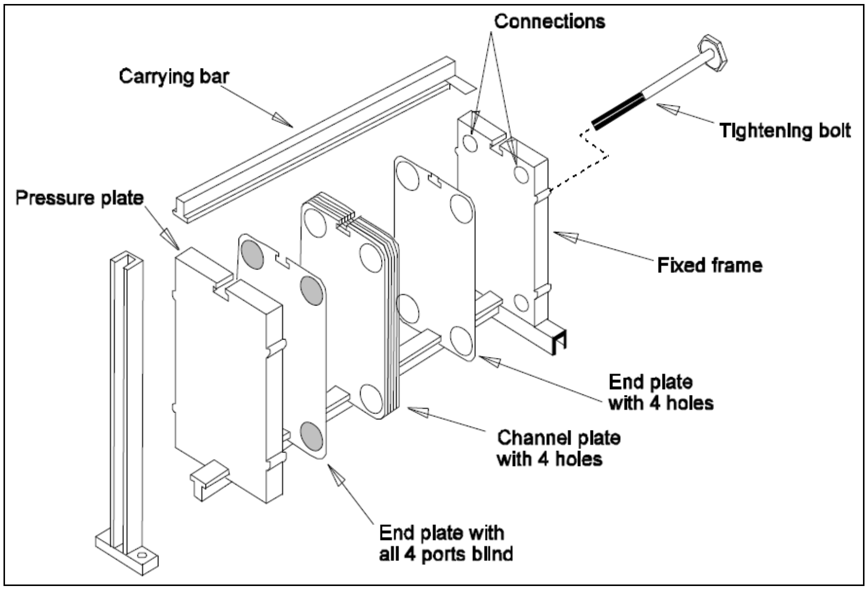

Figure 3.7 The plate heat exchanger.

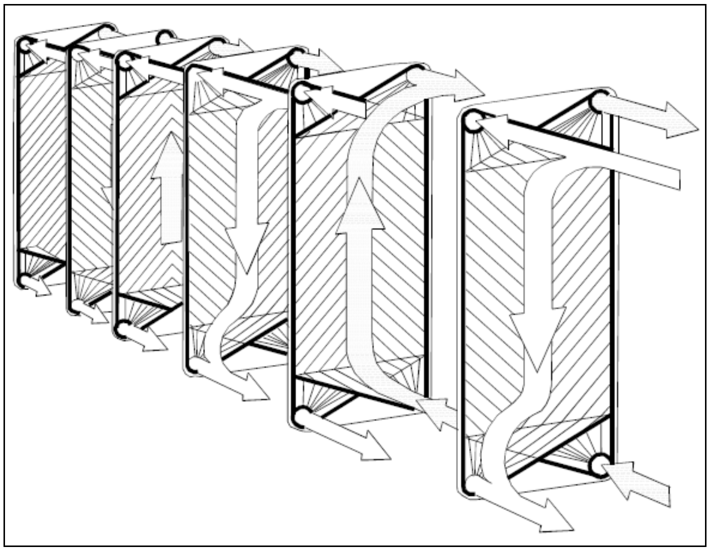

Figure 3.8 Nature of fluid flow through the plate heat exchanger.

### *3.4.3.2 Downhole Heat Exchangers*

The downhole heat exchanger (DHE) is of a design that eliminates the problems associated with disposal of geothermal water since only heat is taken from the well. These systems can offer significant savings over surface heat exchangers where available heat loads are low and geologic and ground water conditions permit their use.

The use of a DHE for domestic or commercial geothermal space and domestic water heating has several appealing features when compared to the alternative geothermal heat extraction techniques. It is essentially a passive means of exploiting the geothermal energy because, in marked contrast to the alternative techniques, no water is extracted or flows from the well. Environmental and institutional restrictions generally require geothermal water to be returned to the aquifer from which it was obtained. Therefore, techniques involving removal of water from a well require a second well to dispose of the water. This can be a costly addition to a small geothermal heating project. The cost of keeping a pump operating in the sometimes corrosive geothermal fluid is usually far greater than that involved with the maintenance of a DHE (Rafferty & Culver, 1998).

The principal disadvantage with the DHE technique is its dependence on the natural heat flow in the part of the hot aquifer penetrated by the well. A pumped well draws in hot water and the resultant heat output is normally many times the natural value. This limitation on the potential heat output of a DHE makes it most suitable for small to moderate-sized thermal applications.

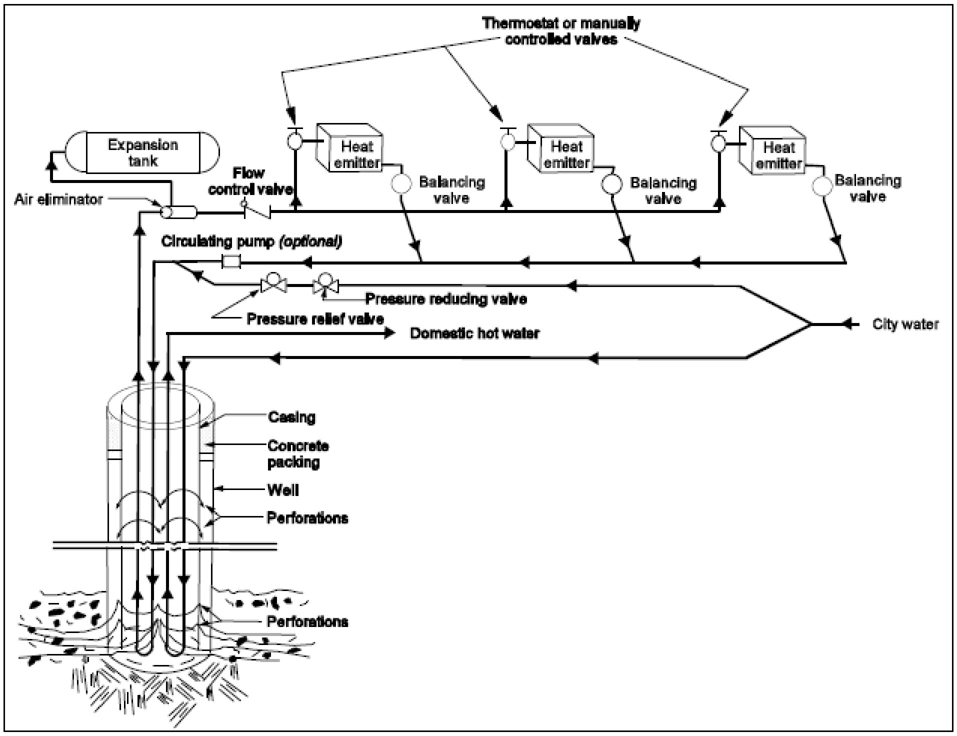

Figure 3.9 Typical hot-water distribution system using a downhole heat exchanger (Culver and Reistad, 1978).

## 3.5 Costs

### *3.5.1 Initial Cost*

Geothermal district heating systems are capital intensive projects. Investment costs are depend on the size of the project. Drilling costs, cost of pipelines (transmission and distribution networks) and connection equipments (used in pipelines, buildings and wellhead), and the cost of equipments used in the heating center are the components of initial investment.

Initial costs have the greatest impact on a feasibility of study. In order to make correct economic analysis for geothermal district heating systems, investment cost should be determined sensitively. Developer should make every effort to minimize the project cost without sacrificing quality and reliability. Plate type heat exchangers, well pumps, diameter and material of pipelines and other equipment should be choosen carefully by the specialists who have enough information and experience.

### *3.5.2 Operational Cost*

The maintenance cost of all equipment and pipelines, electricity consumption cost of pumps used in the system, personnel wages, cost of water losses in the city loop of the system (distribution network), expenses on research and development, cost of inhibitor used to solve scaling problems and other chemicals are the components of operational cost.

Hydrolic balancing should be well designed in the planning stage (design phase) of geothermal district heating systems. Especially in a system which has a lot of branches for distribution of water heated by geothermal fluid, well designed hydrolic balancing is required. Lack of hydrolic balancing causes working of pumps under non required loads. Water losses must be controlled periodically in the city loop of the system. If any losses in the distribution network is detected, should be immediately repaired. Heat demand of buildings changes with time. Therefore operational costs will be reduced by using automatic control systems.

# CHAPTER FOUR
# BALÇOVA – NARLIDERE GEOTHERMAL DISTRICT HEATING SYSTEM

## 4.1 Overwiew of the Field

Izmir geothermal district heating system is fed from Balçova Geothermal Field and is one of the important geothermal fields in Turkey. The Balçova Geothermal Field is located between Balçova and Narlıdere region, approximately 10 km west of Izmir city center. Having the first geothermal well in Turkey, Balçova Geothermal Field has a different importance in Turkish geothermal history. Also first downhole heat exchanger application was to be set in nine shallow wells in this field in Turkey.

The Balçova–Narlidere geothermal (BNG) field is located on the shore of the Aegean Sea within the limits of Izmir (Fig. 4.1), Turkey's third largest city. The population in the BNG area is about 100,000; many living in multi-story buildings. The field supplies hot fluids to the presently largest geothermal district heating system in the country.

As of April 2010, there were 18 wells in the BGF, with depths ranging from 48 to 1100 m. 15 wells are used for production and three as re-injection wells. Wellhead production tempratures vary from 95 to 140 °C, and the volumetric well flow rates from 70 to 300 $m^3/h$.

The geothermal district heating project at Izmir (Fig. 4.2) started in 1996; in 2000, 0.64 million $m^2$ of indoor space corresponding to 5489 houses, hotels, schools and a university hospital and campus were being heated with geothermal energy (Toksoy et al., 2003). By the end of 2005, the heated area had increased to 1.6 million $m^2$, and, in addition, the project supplied heat to 10 ha of greenhouses; the most important milestones of the BNG project are given in Table 4.1. In April 2010 the total heated area (excluding greenhouses) was 2.45 million $m^2$. The total heating capacity of the production wells has reached to 156 $MW_t$ in April 2010.

The BNG area is located in the extensively exposed Upper Cretaceus Izmir Flysch structure; the geothermal field is at the northern edge of the Seferihisar Horst. South of the geothermal field, talus breccias cover the northern flank of the horst, while more recent sediments infill the Izmir Bay further north (Fig. 4.1). The stratigraphic sequence of the area generally consists of Upper Cretaceous Izmir Flysch, Miocene sediments, Pliocene volcanics, Quaternary talus breccias and alluvium (Aksoy, Serpen & Filiz, 2008)

The Izmir Flysch, the most extensive outcropping formation of the region, is composed of a variety of rocks (i.e. sandstones, clayey schists, phyllites, limestones, limestone olistoliths, granodiorites, serpentinites and diabases). The wells in the BNG area are mainly completed in lightly metamorphosed sandstones, clays and siltstones of the Izmir Flysch sequence (Serpen, 2004).

The hot waters recharging the BNG system move through a major, about 2 km long, fracture zone associated with the Agamemnon fault (Fig.4.3). From this zone, the thermalwaters flowmainly into two permeable horizons, one in the alluvium located in the upper 100 m of the system, and the other in ill-defined, more permeable (i.e. fractured) layers of the Izmir Flysch formation between 300 and 1100 m depth. These two permeable zones correspond to the shallow (upper) and deep (lower) reservoirs of the BNG field.

## 4.2 History of the Balçova-Narlidere Geothermal Field

Balçova is one of the districts of İzmir City which is located at the western tip of Anatolia (Fig. 4.1). The history of Balçova geothermal field goes to ancient times. Balçova geothermal field or so called Agamemnon Spas have been attractive place for settlers over the ages. Agamemnon Spas were known in antiquity for the therapeutic qualities of the water. According to a legend, Agamemnon was advised by an oracle to bring soldiers who had been wounded during campaign against Troy to the sulphur-rich waters of these natural hot springs. The periods that Ionians passed to Aegean coasts, a part of Alexander the Great's army's injured soldiers were cured in these hot springs. It had a wide usage in that period, constructions were brought and progressed. Today, the ancient ruins are not seen in the area. Only information about the springs are available from the historical sources in 1763. After that period, Agamemnon Spas are reconstructed by a Frenchman called Elfont Meil with adding the staying units. (Gokcen, 2002)

In 1962 and 1963 the reconnaissance and exploration studies started with resistivity, thermal probing, and self potential surveys in Balçova. It was the first time that the geothermal area received a systematic, scientific delineation in Turkey. There was a single manifestation of hot water, a spring, had a temperature of 72 °C. At the begining three wells were drilled, including the first geothermal exploratory well in Turkey. The first well drilled produced a mixture of hot water and steam at 124 °C at a depth of 40 m. The survey revealed a fault zone delineated by low resistivity and huge temperature closures under 30-50 m thick alluvium. Because of high carbonate content and rapid scaling the geothermal utilization did not start until 1981-82. From 1981 to 1983, 16 wells, including 7 thermal gradient and 9 production wells (100-150 m) were drilled. Temperatures of 50 °C to 126 °C with a flow of 4-20 kg/s were encountered. Turkey's first downhole heat exchanger application was used to heat the healt centre and hotel. In 1983, geothermal heating for Dokuz Eylül University, Medical Facility Campus and Hospital Building (about 30,000 m$^2$) began operation. (Battocletti, 1999). For the next 27 years, geothermal energy utilization was put into use for certain facilities like swimming pools, health centres, hospital buildings, and district heating systems.

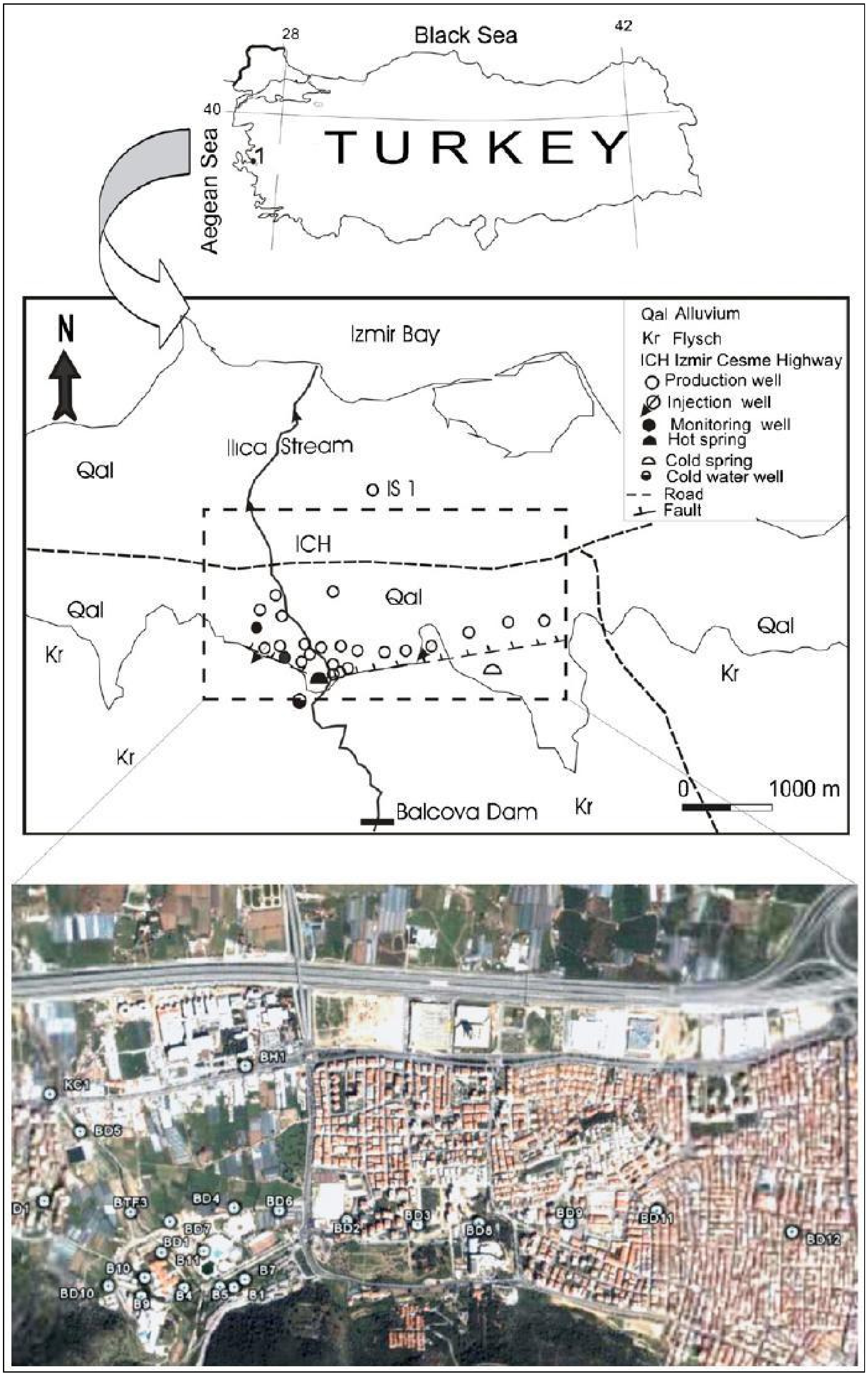

Figure 4.1 Location of the Balçova-Narlidere geothermal area, Turkey.

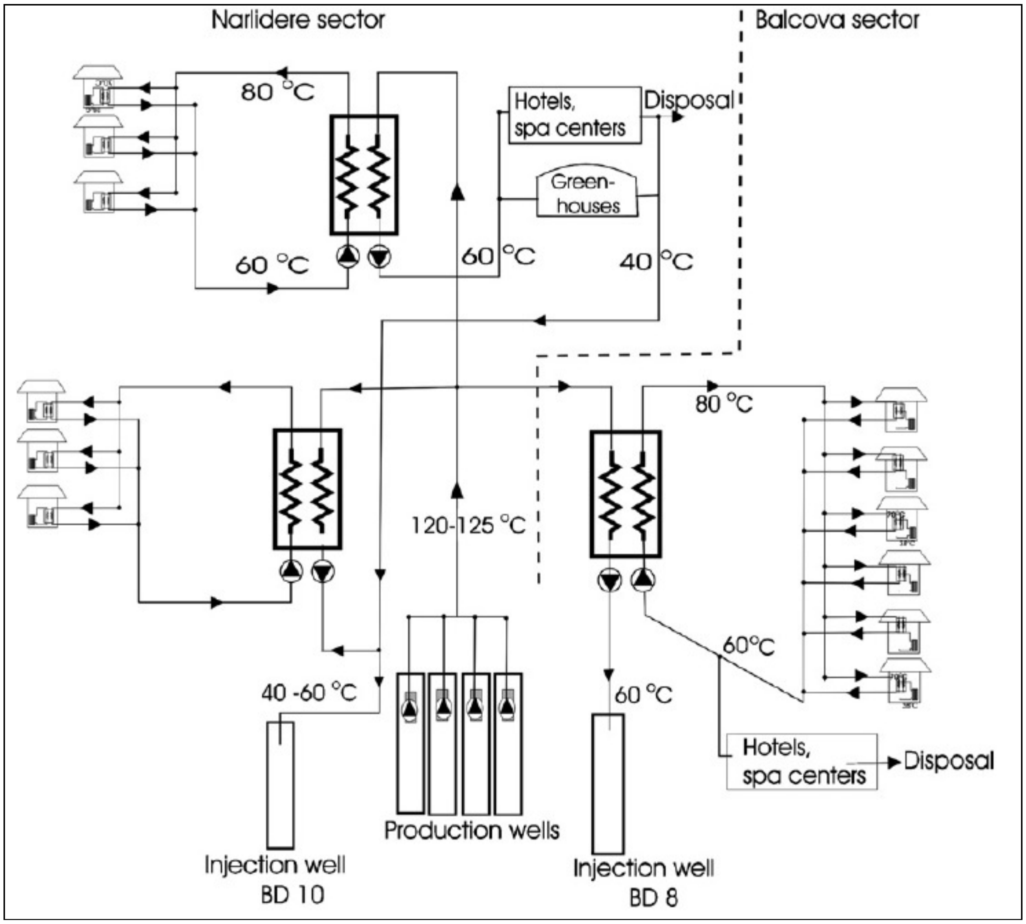

Figure 4.2 Schematic diagram of the Balçova-Narlidere geothermal district heating system (Aksoy, Sepen & Filiz, 2008)

## 4.3 Development of the Balçova-Narlidere Geothermal Field

Geothermal utilization in BNG field has a continuous improvement since 1963. The history of the development of the BNG field between 1963 and 2010 is summarized in Table 4.1.

Table 4.1. Development milestones for the Balçova -Narlıdere GDHS (IBGE Inc., 2010)

| Year | Improvement |
|---|---|
| 1963 | The first geothermal well was drilled in the field (S1) |
| 1983 | A down hole heat exchanger was used to heat Balçova Thermal Facilities |
| 1983 | A down hole heat exchanger was used to heat Dokuz Eylül University Medical Faculty |
| 1992 | Plate type heat exchanger usage was started in Dokuz Eylül University Medical Faculty |

Table 4.1. Continued

| | |
|---|---|
| 1994 | Geothermal heating of Princess Hotel was started |
| 1995 | Adjudication of the first stage geothermal heating and cooling works with 2500 and 500 dwellings, respectively |
| 1996 | Increasing the capacities from 2500 to 5000 dwellings for heating and 500 to 1000 dwellings for cooling |
| 1996 | Balçova Geothermal District Heating System was commissioned |
| 1996 | Re-injection was started |
| 1997 | Capacity was increased to 7680 dwellings |
| 1998 | Narlıdere Geothermal District Heating System was commissioned for 1500 dwellings |
| 2001 | Modernization and enlargement of Dokuz Eylül University Medical Faculty geothermal heating center |
| 2001 | Izmir University of Economics was connected to the Balçova Geothermal District Heating System |
| 2001 | Geothermal reservoir was modeled by ITU Petroleum and Natural Gas Engineering Department |
| 2002 | Energy economy and automation studies were started |
| 2002 | Feasibility studies for the geothermal heating of 5000 dwellings were started |
| 2002 | Re-injection to the shallow wells was stopped and re-injection to the deep wells was started |
| 2003 | Dokuz Eylül University Fine Arts Faculty has been connected to the system |
| 2003 | Özdilek Hotel and Shopping Center was connected to the system |
| 2003 | Inciraltı Dormitory of YURTKUR was connected to the system |
| 2004 | Salih Isgören housing estate was connected to the system |
| 2005 | Running of 1500 dwellings Yenikoy Project |
| 2006 | Running of Telefirik quarter geothermal district heating system |
| 2006 | Running of a calorimeter system for the first time |
| 2006 | Running of the first automatization system in Sahilevleri Pump Station |
| 2007 | Reaching the established capacity 24,500 dwellings by stepping in of Balçova District-2, Stage-2 Geothermal Heating System |
| 2008 | Commencing of the projects 3500 dwellings Balçova District-2 , Stage-3 and that of 2900 dwellings Narlıdere -3 |
| 2010 | As of April 2010, the number subscribers to the BGDHS had reached 30,500 equivalent dwellings. |
| 2010 | Heated space area reaches a total of 2.45 million $m^2$. |

### 4.4 Geothermal Wells in the Balçova-Narlidere Geothermal Field

Since the 1960s a total of 44 wells have been drilled in the BNG field; 13 are deep and 31 are shallow (i.e. depth less than 160 m). The wells presently being used for production, injection and reservoir monitoring are shown in Fig. 4.3.

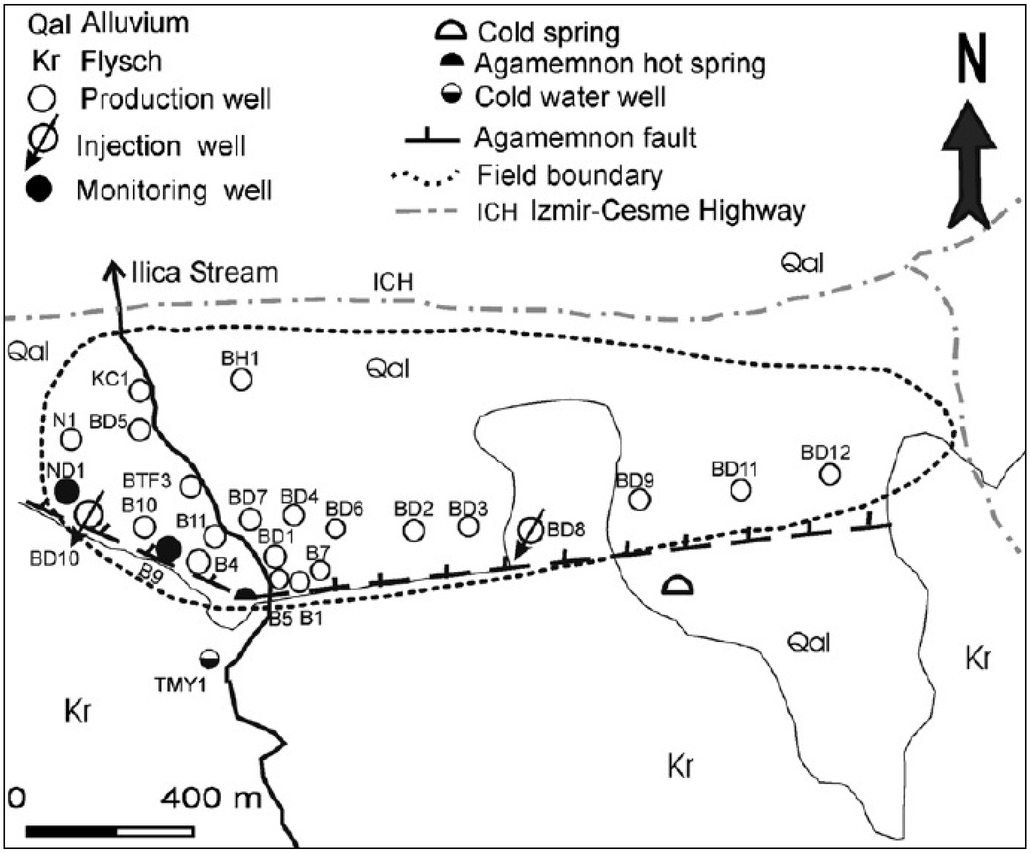

Figure 4.3 Map showing location of the production, injection, and monitoring wells in the Balçova-Narlidere geothermal field (Aksoy, Serpen & Filiz, 2008).

The first exploration well (S1) was drilled in 1963; 124 ºC geothermal waters were found at 125 m depth. This well quickly became clogged with mineral deposits, and because of this scaling problem no additional work was done in the field until 1983.

In 1983, 10 gradient wells, from 80 to 180 m deep, were drilled to determine the subsurface temperature distribution in the area. The data showed that the highest temperature and heat flow occurred at and around the Agamemnon hot spring, slowly decreasing toward the north. Also that year, nine shallow production wells (i.e. depth <160 m) were completed in this high heat flow region. To avoid future scaling problems, these wells were designed so as to allow the installation of downhole heat exchangers (DHEs). The location of production and injection wells in the BNG field is given in Fig. 4.3.

In 1994, the 564 m deep well BD1 was completed, showing a maximum temperature of 130 ºC and proving the existence of a deep geothermal production zone. Initially, the well had artesian flow; later, fluid production was maintained using an air compressor. Eventually, BD1 became blocked by mineral scales. BD2, the second deep (677 m) well, was drilled in 1995 and, just like BD1, it was also clogged by scale deposits after a short fluid production period. The use of chemical inhibitors did not prevent scaling in either well.

In the 750 m deep BD3 well, also drilled in 1995, a frequency-controlled downhole line shaft pump (LSP) was used for the first time. It was found that the inhibitors worked effectively when utilized together with LSPs, and that wellbore scaling was easier to control.

Five more deep wells (BD4, BD5, BD6, BD7 and ND1) were drilled by 1999. Although at that time a total of 26 production wells had been completed, the maximum rate of fluid extraction was only 140 kg/s. Most of the BNG wells were operating at low capacity or had been abandoned due to problems such as mineral scaling, casing collapse, or general deterioration.Wells ND1 and N1, which were drilled in the north-western portion of the field, showed that permeability decreases to the north of the Agamemnon fault.

During the years 2001 and 2002, IBGE Inc. made the field more productive by re-activating unused wells and changing the re-injection strategy. The total production capacity has been increased from 620 $m^3/h$ to 1250 $m^3/h$. Also, BD-6 well, which was cleaned and prepared to use again, and BD-9 well (static heat of BD-9 in Fig. 4.5), which was drilled in 2003 (Aksoy, 2005; IBGE Inc., 2009). Those two wells can produce 500 $m^3/h$ geothermal fluids according to tests.

In the year 2002, the re-injection strategy has been completely changed. It has been found that the re-injection to shallow wells causes decrease in the geothermal fluid temperature. After stopping re-injection to the shallow wells, geothermal fluid temperatures have been started to increase. After this event, all re-injection has been directed to the BD-8 well. The effects of re-injection to BD-8 to the reservoir are still being observed and until now, there is not any negative effect detected. BD-10 was used for re-injection. BD-10 (static heat and water loss of BD10 in Fig. 4.6) was drilled at 2004 summer. (Aksoy, 2005; IBGE Inc., 2009).

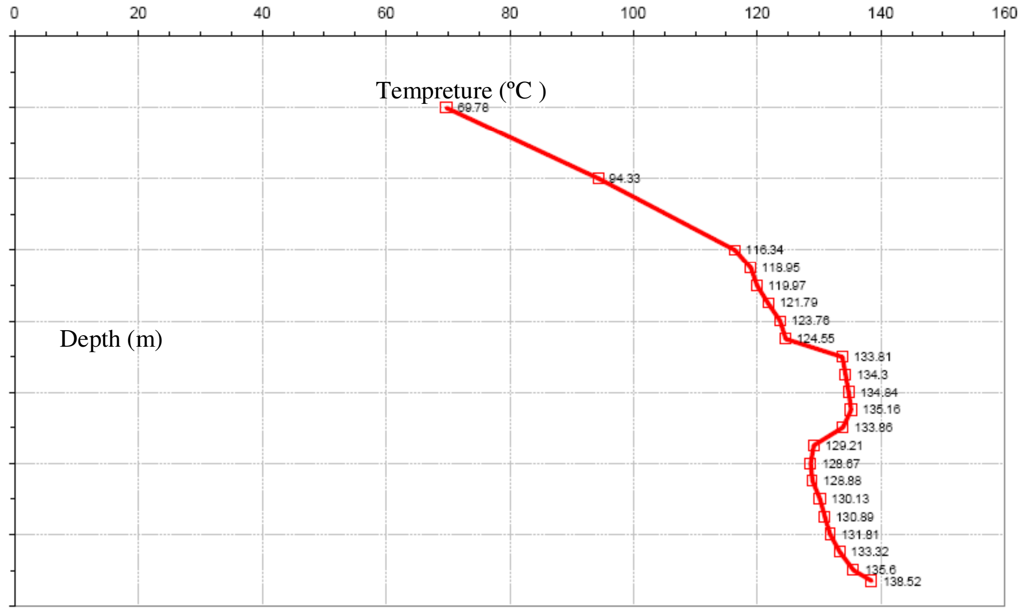

Figure 4.5 Static heat of BD9 (Aksoy, 2005; IBGE Inc.,2009).

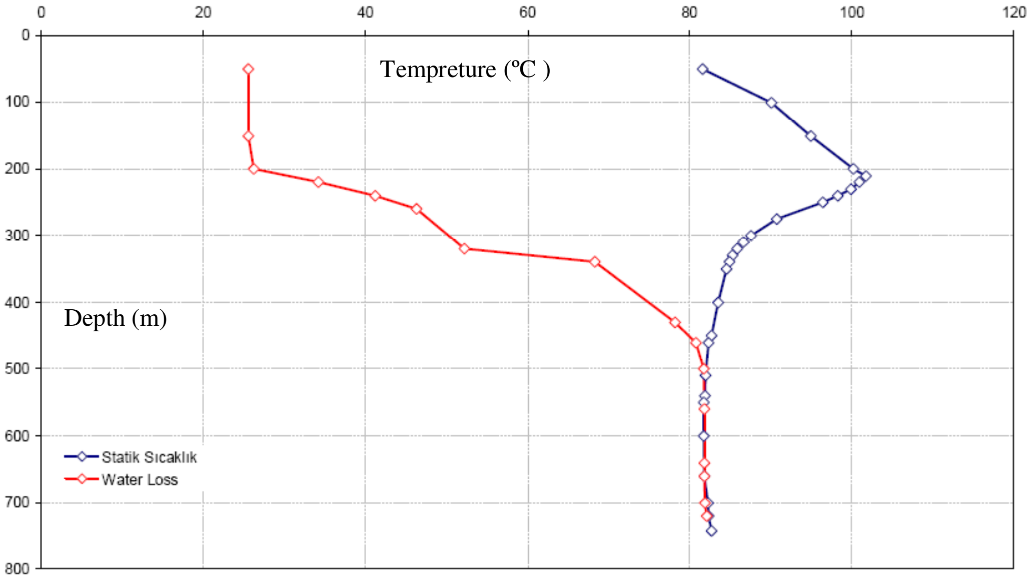

Figure 4.6 Water loss and static heat of BD10 (Aksoy, 2005; IBGE Inc.,2009).

As of April 2010, there were 18 wells in the BGF, with depths ranging from 125 to 1100 m. 15 wells are used for production and three as re-injection wells. Wellhead production tempratures vary from 95 to 140 °C, and the volumetric well flow rates from 70 to 300 $m^3/h$ (Table 4.2).

Table 4.2 Wells in Balçova – Narlıdere geothermal field (IBGE Inc., 2010)

| Well | Date | Lenght [m] | Temperature [$^oC$] | Flow Rate [$m^3/h$] | Role |
|---|---|---|---|---|---|
| BD-1 | 1994 | 677 | 120 | 70 | Production |
| BD-2 | 1995 | 564 | 135 | 165 | Production |
| BD-3 | 1996 | 750 | 131 | 115 | Production |
| BD-4 | 1998 | 624 | 137 | 195 | Production |
| BD-5 | 1999 | 1100 | 121 | 90 | Production |
| BD-6 | 1999 | 605 | 135 | 200 | No production |
| BD-7 | 1999 | 1100 | 120 | 85 | Production |
| BD-8 | 2002 | 630 | - | 2500 | Re-injection |
| BD-9 | 2004 | 776 | 139 | 300 | Production |
| BD-10 | 2004 | 750 | - | - | Re-injection |
| BD-11 | 2006 | 800 | 139 | 300 | Production |
| BD-12 | 2006 | 1000 | 135 | 290 | Production |
| BD-14 | 2007 | 650 | 129 | 154 | New |
| BD-15 | 2007 | | | | New |
| B-1 | 1982 | 104 | 103 | 100 | Production |
| B-2 | 1989 | 150 | 95 | - | No production |
| B-3 | 1983 | 160 | 110 | - | No production |
| B-4 | 1983 | 125 | 100 | 60 | Production |
| B-5 | 1983 | 109 | 106 | 125 | Production |
| B-6 | 1983 | 150 | - | - | Closed |
| B-7 | 1983 | 120 | 95 | 80 | Production |
| B-8 | 1983 | 250 | 95 | - | No production |
| B-9 | 1983 | 48 | 95 | - | No production |
| B-10 | 1989 | 125 | 100 | 180 | Production |
| B-11 | 1989 | 125 | 109 | - | No production |
| B-12 | 1998 | 160 | 95 | - | No production |
| ND-1 | 1996 | 800 | 115 | - | No production |
| N-1 | 1997 | 150 | 95 | - | No production |
| BTF-2 | 1989 | 100 | - | - | Closed |
| BTF-3 | 1989 | 100 | 100 | 30 | No production |
| BH-1 | 1998 | 300 | 80 | 15 | No production |

## 4.5 System Description

Figure 4.2 provides a schematic diagram of the Balçova GDHS which includes hotels and official buildings heated by geothermal energy. The Balcova-Narlidere GDHS consists mainly of three cycles: (a) an energy production cycle through a geothermal well loop and geothermal heating center loop, (b) an energy distribution cycle through a district heating distribution network, and (c) an energy consumption cycle through building substations. In the present district heating facility, there are two systems: the Izmir-Balçova geothermal district heating system (IBGDHS) and the Izmir-Narlidere geothermal district heating system (INGDHS). Both IBGDHS and INGDHS are investigated here under Balcova geothermal district heating system (BGDHS) (Ozgener, 2004).

As of April 2010, there were 18 wells ranging in depth from 48 to 1100 m in the BNG field. Of these, 15 wells (designated as BD1, BD2, BD3, BD4, BD5, BD7, BD9, BD11, BD12, B1, B4, B5, B7 and B10) and two well (BD8 and BD10) are production and reinjection wells, respectively. Here, BDs stand for deep wells and Bs stand for shallow wells. The temperatures of the production wells vary from 95 to 140 ºC, while the flow rates of the wells range from 70 to 300 $m^3/h$, respectively.

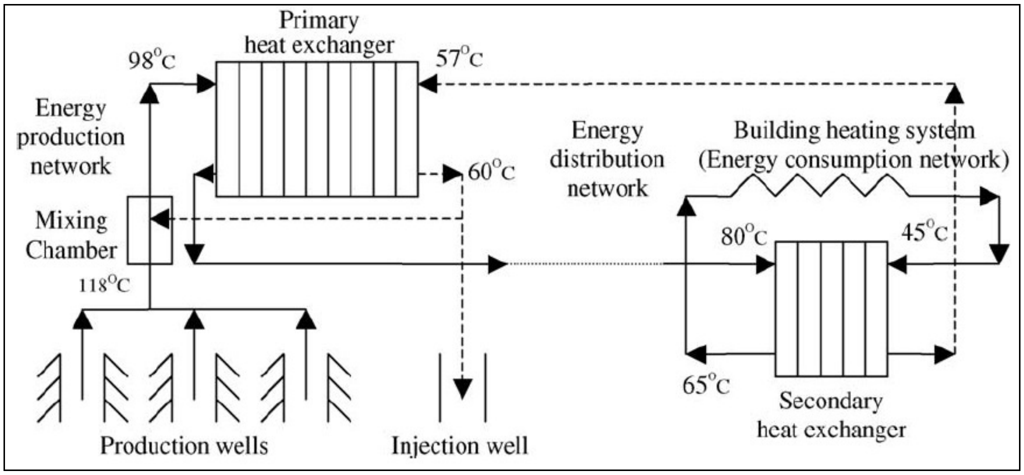

Figure 4.7 Schematic representation of networks in the Balçova-Narlidere geothermal district heating system (IBGE Inc.,2009).

The design heating capacity of BGDHS is equivalent to 22,600 residences. NGDHS was designed for 8600 residence equivalence and total 31,200 residence equivalence.

Table 4.3 Project name and total dwellings equivalent in the BNGDHS (IBGE Inc., 2010)

| Project name in the BNG field | Dwellings equivalent |
|---|---|
| Balçova System-1 | 7500 |
| Balçova System-2 Stage-1 | 3900 |
| Balçova System-2 Stage-2 | 4500 |
| Balçova System-2 Stage-3 | 3500 |
| Balçova System-2 Stage-4 | 3200 |
| Narlidere Stage-1 | 1500 |
| Narlidere Yenikoy Stage-1A | 1500 |
| Narlidere Faculty of Fine Arts Stage-2 | 1720 |
| Narlidere Stage-3 | 2900 |
| Sahilevleri | 980 |
| Total | 31,200 |

Balçova geothermal district heating system is composed of two main subsystems, the geothermal pipeline system and the city distribution loop. The geothermal pipeline system transfers the geothermal fluid from wellheads to the pumping stations. In the pumping stations, the energy of the geothermal fluid is transferred to clean water, with the help of plate type heat exchangers, and then circulated in the city distribution loop.

The geothermal pipeline system is connected to production and injection wells. Geothermal fluid produced from the production wells, is pumped into the geothermal pipeline system. After giving its energy, it is pumped into the injection wells from the geothermal pipeline system. Although the system is generally called Balçova district heating system, the geothermal pipeline system does not supply heat to only Balçova. It is also connected to several facilities (Pool, spa, hotels, hospitals), which take approximately 40% of the produced heat. Therefore, the geothermal pipeline system can also be treated as a distribution system supplying geothermal water to different stations.

The Balçova city distribution loop delivers hot water to the buildings connected to the system. Each building has its own heat exchanger in which energy of city distribution water is transferred to the building heating system. After giving its energy to the building heating system, the city circulation water returns to the pumping station.

### *4.5.1 Geothermal Pipeline System*

Geothermal pipeline system of Balçova – Narlıdere Geothermal District Heating System collects the geothermal fluid from the 15 production wells and distributes it to the 10 heat stations of each sub systems. After transferring its heat to the consumers, geothermal fluid is directed to re-injection well. Well head temperatures, maximum and average flows of wells that were in production in 2008 – 2009 heating season are shown in Table 4.4.

Table 4.4 Production wells in 2008 – 2009 heating season

| Well | Temprature [$^{o}$C] | Average Flow [m$^3$/h] | Maximum Flow [m$^3$/h] |
|---|---|---|---|
| BD-1 | 120 | 58 | 70 |
| BD-2 | 135 | 105 | 165 |
| BD-3 | 131 | 84 | 115 |
| BD-4 | 137 | 144 | 195 |
| BD-5 | 121 | 75 | 90 |
| BD-7 | 120 | 68 | 85 |
| BD-8 | 63 | -310 | -510 |
| BD-9 | 139 | 270 | 300 |
| BD-11 | 139 | 290 | 300 |
| BD-12 | 135 | 285 | 290 |
| B-1 | 103 | 72 | 100 |
| B-4 | 100 | 43 | 60 |
| B-5 | 106 | 97 | 125 |
| B-7 | 95 | 70 | 80 |
| B-10 | 100 | 100 | 180 |

A schematic presentation of the geothermal pipeline system is given in Figure 4.7. Heat exchanger stations and wells are not located in the same order in the field. The system is actually composed of two parallel pipeline systems. While the supply pipeline transmits the geothermal fluid to the stations, the return pipeline collects the geothermal fluid at the heat exchanger outlets and transmits it to the re-injection wells. The biggest portion of the energy produced by the wells is used by the Balcova district heating system (IBGE Inc., 2009; Sener, 2003)

Facilities directly connected to the geothermal pipeline system and their maximum static heat loads are shown in Table 4.5. Number of facilities and dwellings are directly related to the productions of the wells and their characteristics.

Figure 4.8 represents the recent situation of geothermal pipeline. Geothermal pipeline system consists of two parallel pipeline systems; supply and return. Supply part of the system collects the geothermal fluid from the wells and distributes it to the consumers. Return part collects the geothermal fluid from the consumers and transmits it to the re-injection well. Just supply part of geothermal pipeline system is represented in the Figure 4.8.

Table 4.5 Facilities directly connected to geothermal pipeline system

| Facility | Maximum Static Head Load [kW] |
|---|---|
| Balçova GDHS | 50365 |
| Narlıdere GDHS | 24000 |
| Balcova Thermal Hotel | 5175 |
| Princess Hotel | 3200 |
| Ozdilek (Crowne Plaza) | 4650 |
| Inciralti Dormitory of Yurtkur | 3375 |
| Salih Isgoren housing estate | 400 |
| 9 Eylül Hospital | 15700 |
| Total | 106,865 |

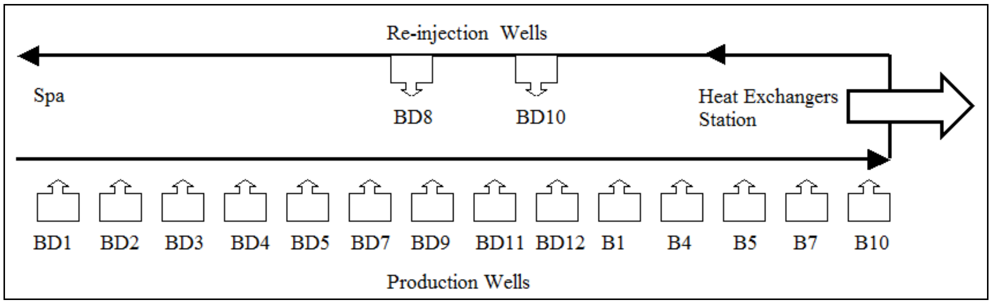

Figure 4.8 Scheme of geothermal pipeline system in the BNG field (updated from IBGE Inc.,2009)

Most of the pipes of main geothermal pipeline are 300 mm steel pipes, and some parts of 200 mm and some part of 250 mm steel pipes are used. Well branches are mostly 150 mm steel pipes. All pipes in the system have polyurethane foam insulation wrapped with insulating coat (fiberglass) to provide seal.

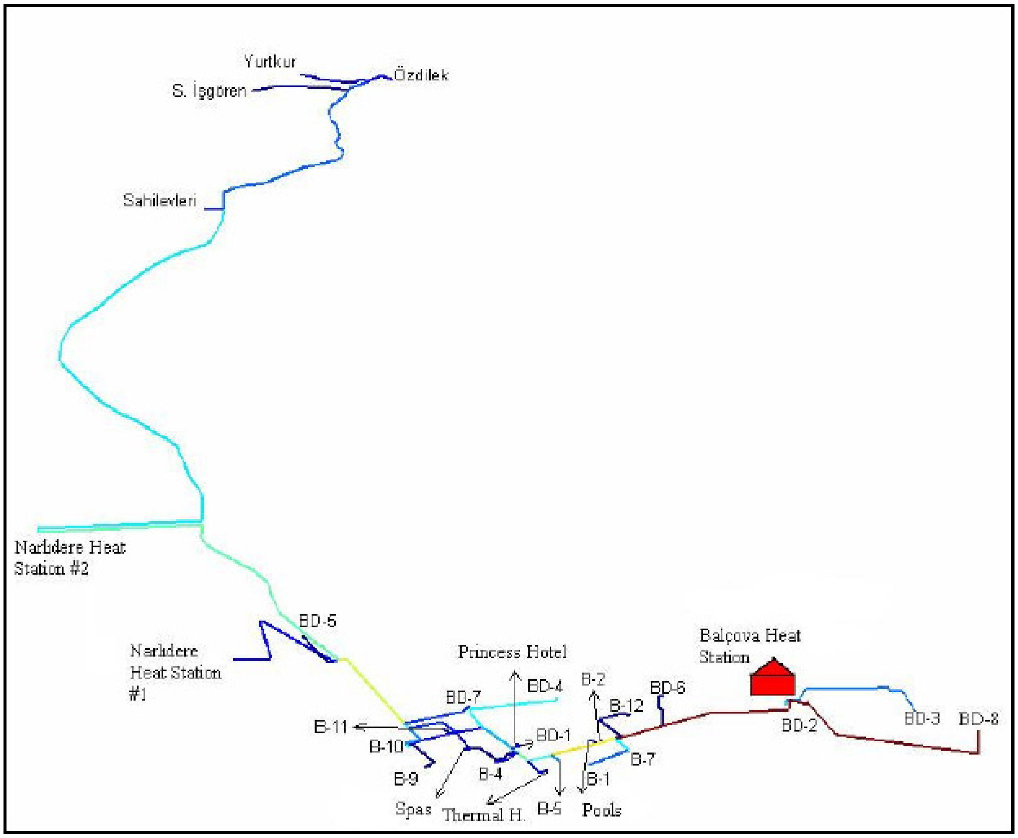

Figure 4.9 Balçova-Narlıdere Geothermal District Heating System, geothermal pipeline.

Geothermal fluids pumped from the wells which are connected different points of geothermal pipeline and mixed in the geothermal pipeline system. Because of the difference of geothermal fluids from each well, the temperature of the geothermal pipeline system is not constant and it changes according to the operation of wells. Because the geothermal pipeline system is quite complex network as shown in Figure 4.9, it is important to monitor and control the temperatures and pressures along the system. For the proper operation of system, thermodynamic and hydraulic balance of the pipeline system is very important. (IBGE Inc., 2009; Sener, 2003)

The geothermal fluids temperature changes according to operations of wells. Heat exchanger inlet temperatures vary between 105-115 °C and re-injection temperature is about 60 °C in the system.

Geothermal well pumps of the system are operated according to constant well head pressure strategy. Well head pressures are kept constant at 3 bars with the help of valves in the system. Pressure monitoring is available only at the well heads. To increase the inlet pressure of the heat exchangers at the Balçova and Narlıdere Heat Stations, booster pumps are used. The pressure of the geothermal fluid along the pipeline is about 1.5-2 bars. There is no monitoring or controlling device for the geothermal pipeline pressure (IBGE Inc., 2009; Sener, 2003).

Each of the production wells has a down-hole pump. These pumps are controlled with the help of frequency converters. Therefore, the flow of each well can be controlled from zero to a maximum value. For practical reasons, a certain minimum flow exists for each well.

Flow rates and flow directions are regulated with the help of valves installed into critical points of the system. There is not an automatic control system, and valves are controlled manually. Data acquisition and monitoring processes have also been done manually. But an automatic control system installation is planned and studies about this project are going on.

### *5.5.2 City Distribution System*

In Balçova, hot water at 85 °C is delivered to customers using the city distribution loop. The city distribution loop is a 80 km long pipeline system, which distributes hot water and collects warm return water. Each building has its own heat exchanger on the first floor. Heat is transferred to the building heating systems with the help of these heat exchangers. (IBGE Inc., 2009)

In Balçova, a constant tariff is applied for the heating service. There is no flow meter at the customer end of the system. Moreover types and sizes of buildings are very variable. For instance, five floor buildings, mosque, schools, and single houses are all connected to the distribution system. Therefore, heat load demands of customers are variable. Diameters of building connection pipes, sizes of heat exchangers and flow controller elements are set according to heat demand.

The basic control scheme of the city distribution loop is shown in Figure 4.10. Water is heated in the main heat exchanger, and pumped to the supply network. The supply network branches at each building connection. Pipes diameters in the main network vary from 350 to 40 mm, while building connection pipes vary from 25 to 50 mm in diameter. The duty of flow regulators is vital for the system. As can be seen from Figure 4.10, flow regulator valves are installed to outlets of building heat exchangers (city distribution site). Flow regulators are used to keep heat exchanger outlet temperature of city circulation water at a constant value (IBGE Inc., 2009; Sener, 2003)

When heat demand of a building decreases (outside temperature increases), the return temperature of city circulation water, coming from the building heat exchanger, increases. The temperature sensor of the flow regulator measures this temperature change. The cross-sectional area of flow is decreased by the regulator. Also, if heat demand increases, the flow regulator increases the cross sectional area of flow (Sener, 2003). These pressure changes are measured by system technicians at points 1 and 2 in Figure 4.10 and are recorded at the pumping station where the main heat exchanger and pumps are operated. According to pressure changes of the system, flow rates of the city circulation pumps are changed by frequency converters, which are adjusted manually. The main idea in using this kind of control is to decrease pumping cost by adjusting the flow rate of the hot water according to varying heat demand.

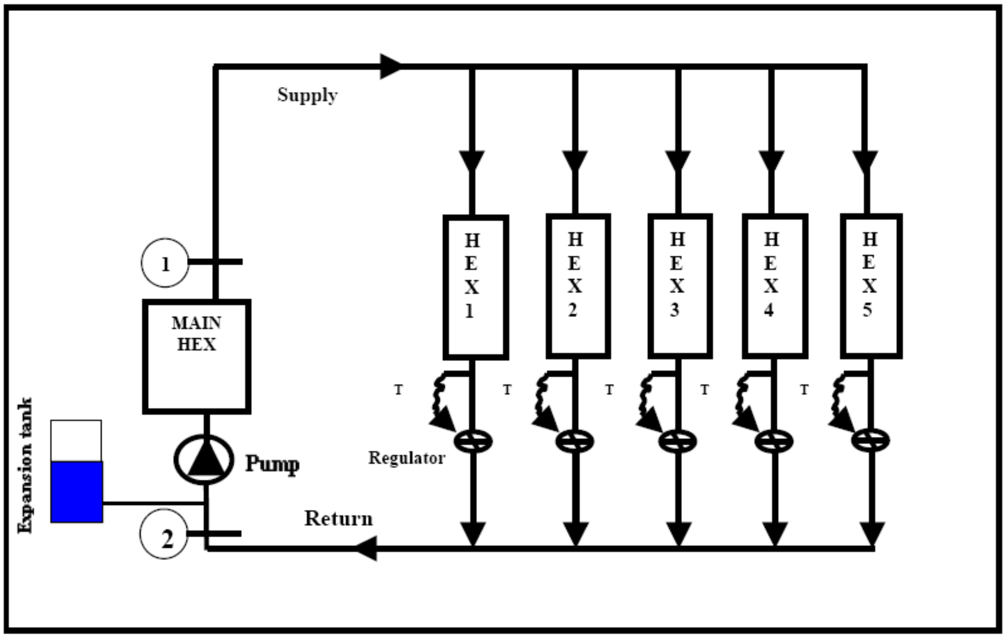

Figure 4.10 Basic control scheme of the city distribution network.

An expansion tank is used to compensate pressure fluctuations and supply stable suction head to the circulation pumps. It is also used to add water to the system, when there is leakage. For proper operation of the expansion tank, a minimum required pressure at point 2 is 20 m (2 bars).

### *4.5.3 Building Loop*

Includes costumer building equipment. Building heat exchanger and in building equipments (circulation pumps, expansion tank, ultrasonic compact heat meter, safety valve) exist in this part of the system (Fig. 4.11).

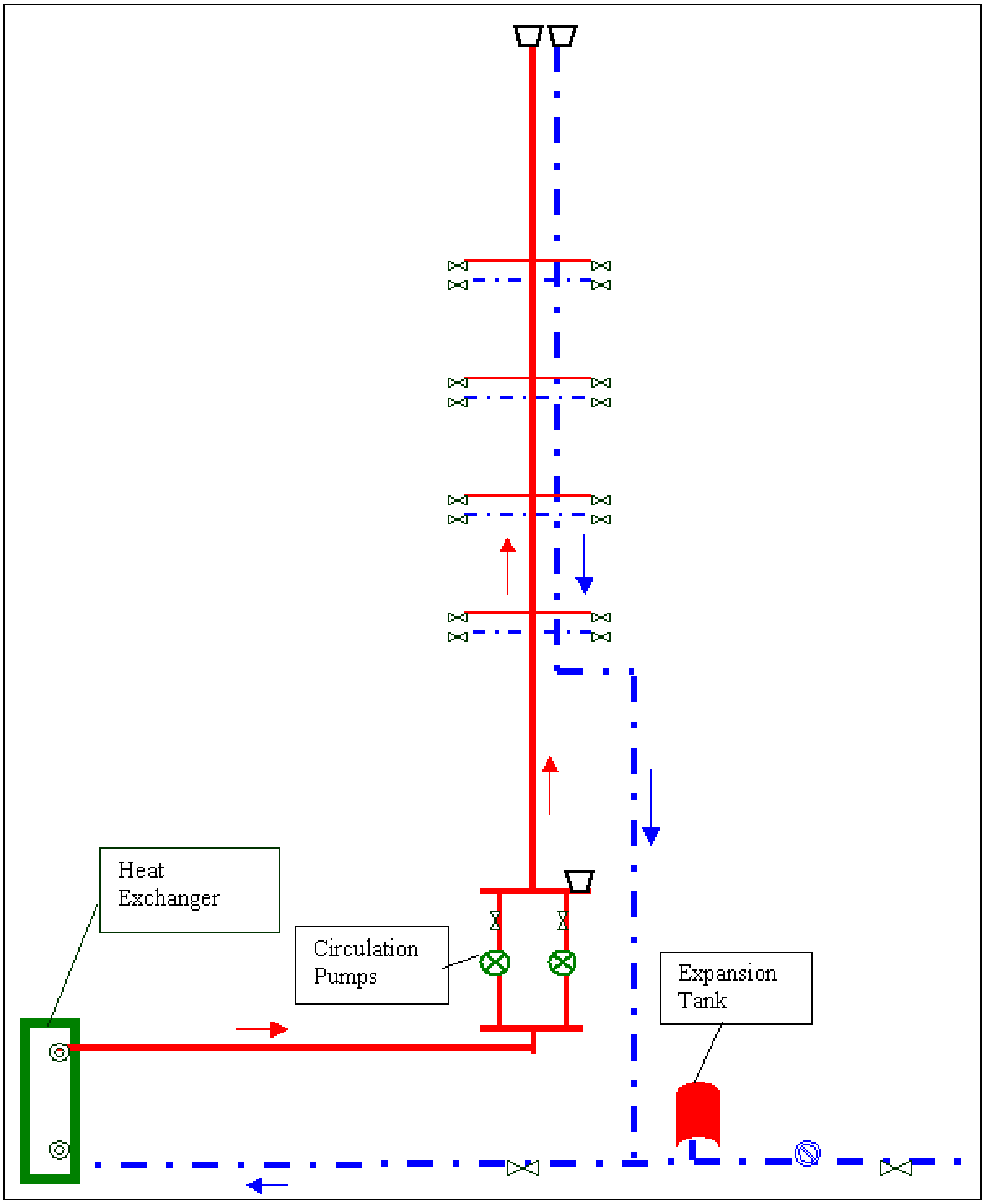

Figure 4.11 Example of a geothermal district heating system building loop (Izmir).

### *4.5.3.1 Ultrasonic Compact Heat Meter*

The apparatuses, which are called calorimeter and which we use in setting costs for the geothermal heating systems work by a calculation method of the energy that is lost, briefly by calculating the temprature diffrence between entrance and exit pipes and that of the flow that passes through the entrance pipe.

*4.5.3.1.1 Calculator.* The calculator contains all the necessary circuits for recording the flow rate and temperature and for calculating, logging and displaying the data. The calculator housing can be mounted directly on the flow sensor or on the wall. The heat meter can be conveniently read from a singleline 7-digit display with units and symbols. A push-button provides user-friendly control of the various display loops. All failures and faults are recorded automatically and shown on the LC display. To protect the reading data, all the relevant data are saved in a non-volatile memory. This memory saves the measured values, device parameters and types of error at regular intervals.

*4.5.3.1.2 Mounting.* Depending on the design, the heat meter is installed either in the supply or return line as indicated on the data plate. The heat meter is to be installed so that the direction of flow corresponds to the direction of the arrow on the flow sensor. Ensure that the flow sensor is always filled with liquid on completion of installation. Straight inlet/outlet pipes (calming sections) are not required for the flow sensor. The heat meter can be installed in both horizontal and vertical pipe sections, but every time so that air bubbles cannot collect in the flow sensor. For low flow we recommend to mount the flow sensor tilted 90 °C into the pipe.

Make sure the heat meter is installed sufficiently far away from possible sources of electromagnetic interference (switches, electric motors, fluorescent lamps, etc.). For cooling application and for medium temperatures more than 90 °C, the calculator must be mounted on the wall at a sufficient distance away from heat sources using the holder supplied. It is recommended that stop valves be fitted before and after the heat meter to simplify dismantling the heat meter. The heat meter should be installed in a convenient position for service and operating personnel.

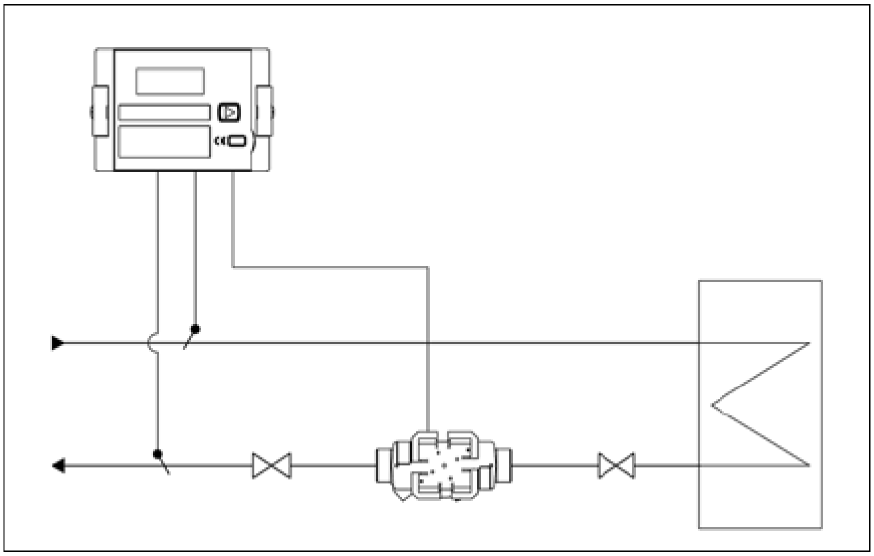

Figure 4.12 Application example.

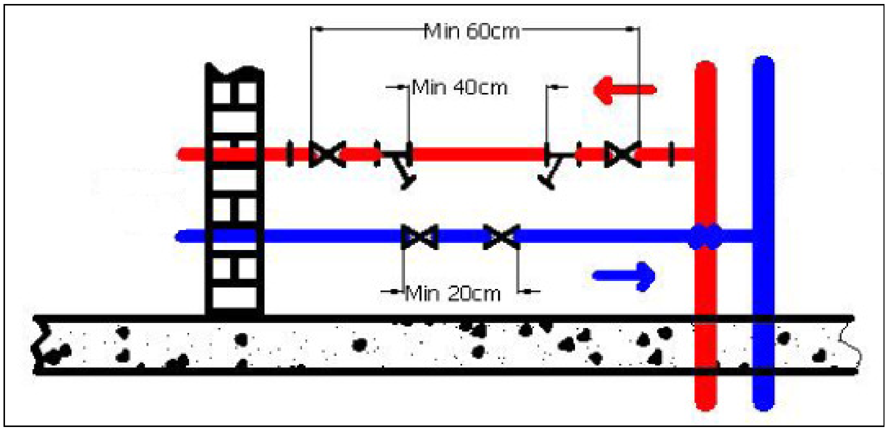

Figure 4.13 Horizantal mounting detail.

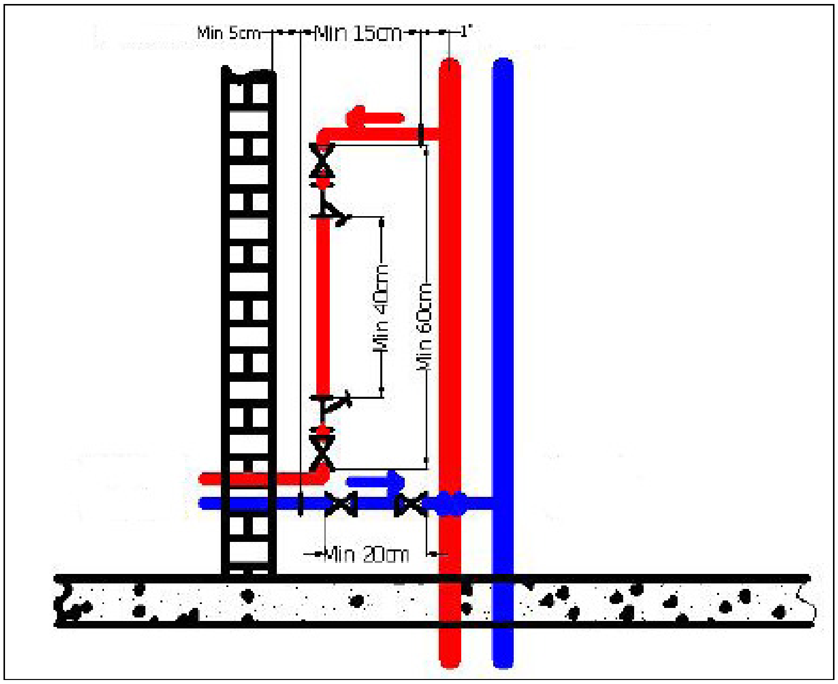

Figure 4.14 Vertical mounting detail.

Figure 4.15 Example of horizantal mounting.

## 4.6 Conceptual Model of the Field

A conceptual model of the BNG system was developed (Fig. 4.16) on the basis of well logs, water chemistry, isotope, tracer test and other field data (Aksoy, Serpen & Filiz, 2008).

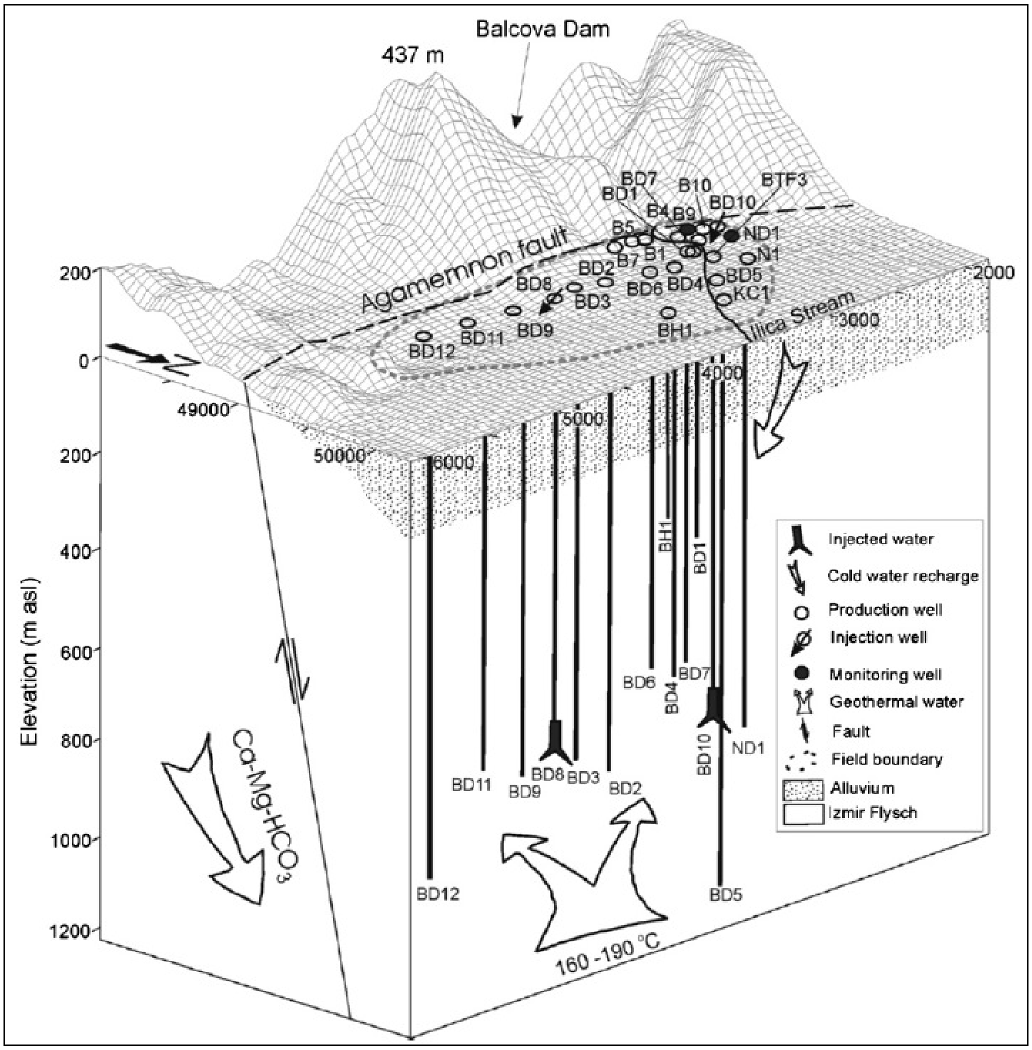

Figure 4.16 Conceptuel model of the Balçova-Narlidere geothermal field (Aksoy, Serpen & Filiz, 2008).

The geothermal system is fed by meteoric water that infiltrates over a 35 $km^2$ area south of the field (Serpen, 2004). The average elevation of the recharge area and the geothermal field is 900 and 100m above sea level, respectively. The meteoric waters penetrate deep into the system by flowing down a high-permeability fracture zone associated to the Agamemnon fault (Serpen, 2004). The temperature of the infiltrated waters increase as they pick up heat from the rocks; the terrestrial heat flow in the area is about 110 $mW/m^2$ (Serpen, 2004). Eventually, because of its lower density the heated water ascends and is found in a hot zone parallel to the Agamemnon fault (Fig. 4.3). As mentioned earlier, the largest sources of cold waters in the region are the Balçova Dam and the Ilica Stream, which recharge the shallow and deep geothermal reservoirs. As these waters move into the system they mix with the thermal fluids.

The 3D models of the field (Fig. 4.17) show that the temperature decreases rapidly toward the north, away from the Agamemnon fault, and increases toward the east, confirming results of geophysical surveys conducted in the north. Based on that temperature distribution, wells BD8, BD9, BD11 and BD12 were sited. These four wells are the hottest and most productive wells in the field at this time (November 2007) and confirmed that that the highest temperatures are in the eastern part of the field.

The 3D distribution of temperature in the BNG system, developed based on the static temperatures measured in the wells is given in Fig. 4.17. The volume of the geothermal system with temperatures equal above 80 ºC is about 4.5 km$^3$.

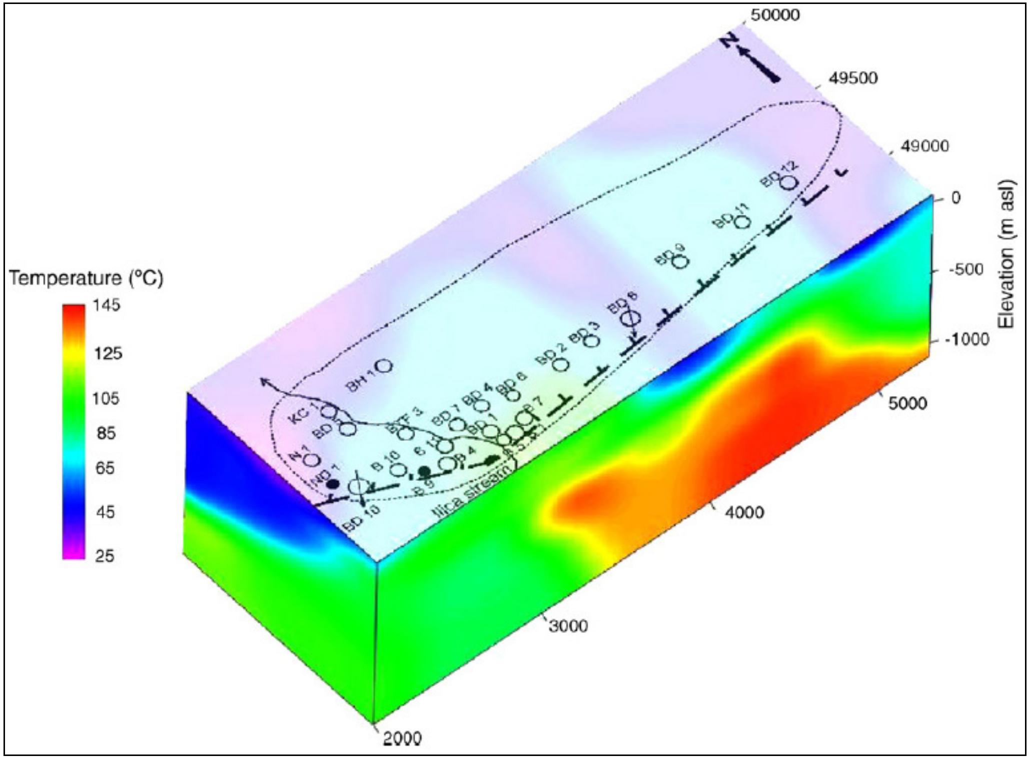

Figure 4.17 Temperature distribution in the Balçova-Narlidere geothermal field (dimension in m) (updated from Aksoy,Serpen & Filiz, 2008).

## 4.7 Benefits of the Balçova-Narlıdere Geothermal District Heating System

In order for district heating to become a serious alternative to existing or future individual heating and/or cooling systems, it must provide significant benefits to both the community in which it is operated and the consumer who purchases energy from the system. Further, it must provide major societal benefits if federal, state, or local governments are to offer the financial and/or institutional support that is required for successful development. In this regard,the benefits gained from the Balcova-Narlidere GDHS will be briefly described below from the view of the customer and environmental points, while they are discussed generally in detail elsewhere.

### *4.7.1 Fuel Cost Consideration*

The general equation for calculating fuel requirements for the heating season (*F*), using the degree-day procedure, is that given by Hepbasli & Canakci (2003):

$$F = \frac{24(DD)C_D \dot{q}}{\eta_h (T_i - T_o) H} \tag{4.1}$$

where *F* is the quantity of fuel required for the period desired (the units depend on *H*), *DD* is the degree days for the period desired in °C-day, $C_D$ is the interim correction factor for degree days based on various outdoor design temperatures (set at 0.8 to account for the values given by Lund and Lienau, 1997), the total calculated heat loss based on design conditions in W, $\eta_h$ is the average heating system efficiency in percent, *H* is the heating value of the fuel in kWh per unit volume or mass and $T_i$ and $T_o$ are the indoor and outdoor design temperatures in °C, respectively.

The amount of fuel required was obtained using Eq. (4.1), as explained below. The annual number of degree days (DD) for Izmir at a zero-load (base) temprature of 18 °C was taken to be 1223 by Uner and Ileri (2001). Based on design conditions, the head load was estimated to be 6.384 kW for an equivalent dwelling at the design tempratures of $T_i$ = 22 °C and $T_o$ = 0 °C (Toksoy and Canakci, 2001). The geothermal based heating fee was fixed to be 71 Turkish Lira (about 47.34 US$) per month for the heating season 2009-2010 by Izmir Balcova Geothermal Energy Inc. (2010).

Table 4.6. Cost comparisons for diffrent energy sources used to heat an equivalent Balçova dwelling over the heating season based on April 2010 prices

| Energy source used for space heating | Heating value (a) | Unit price[a], (b) | Average efficiency (c) % | Annual cost increase[b], (d) % | Fuel cost (e=[100b/ac]) (US$/kWh) | Fuel requirements for the heating season | Annual cost of fuel (g=bf) (US$/yr) | Average monthly cost of fuel (h=g/12) (US$/month) |
|---|---|---|---|---|---|---|---|---|
| Domestic coal | 5.41 kWh/kg | US$ 0.2266 $kg^{-1}$ | 60 | 0 | 0.0698 | 2099.18 kg | 475.67 | 39.64 |
| Natural gas | 9.59 $kWh/m^3$ | US$ 0.4886 $m^{-3}$ | 90 | -20 | 0.0566 | 789.47 $m^3$ | 385.74 | 32.15 |
| LPG | 12.79 kWh/kg | US$ 2.5853 $kg^{-1}$ | 90 | 30 | 0.2246 | 591.95 kg | 1530.37 | 127.53 |
| Furnace oil | 11.28 kWh/kg | US$ 1.3067 $kg^{-1}$ | 80 | 25 | 0.1448 | 755.09 kg | 986.68 | 82.22 |
| Electricity | 1 kJ/kWh | US$ 0.1889 $kWh^{-1}$ | 99 | 11 | 0.1908 | 6882.76 kWh | 1300.15 | 108.35 |
| Geothermal energy | | | | | | | 568 | 47.33 |

[a] Assuming 1US$ = 1.56 Turkish Lira (TL) (as of April 2010) (note that the table refers to April 2010 prices)

[b] Based on cost in TL

The cost per kJ (or kWh) of heating with conventional fuels and equipment must be determined to evaluate the relative attractiveness of district heating (Lund and Lienau, 1997). Table 4.6 shows typical fuel prices for various types of residential heating systems as of April, 2010. The prices for fuel are issued monthly in the Turkish Plumbing Magazine, which is very popular in the field of heating, ventilating, and air-conditioning (HVAC) in Turkey.

### *4.7.2 Environmental Consideration*

All heating projects have some impact on the environment, but the degree or extent will depend on the technology used (Rybach, 2003). The emission of air pollutants such as nitrogen oxides, sulfur dioxide and particulates, and carbon dioxide, will be greatly reduced if we manage to limit our consumption of fossil fuels.

The environmental benefits of exploiting the Balçova-Narlidere geothermal resources for district heating can be quantified by calculating the reduction in pollutant emissions compared to fossil fuels. We assumed the following parameters for the Balcova-Narlidere GDHS:

a) Total equivalent dwellings: 30,500, which includes hotels, public buildings, schools, tanneries and mosques.
b) The share of coal-fired heating systems (stoves and boilers) in the total dewelling heat load is 60% (i.e. 18,300 dwellings), followed by the systems using fuel oil at 40% (i.e. 12,200 dwellings).
c) The sulfur contents in coal and fuel oil are taken as 1.25 and 1.0wt%, repectively; the actual values for fuel oil range between 1.0 and 1.5%, and for coal between 1.25 and 4.0% (EIE, 1997). The chemical characteristics of the coal to be used in Izmir are regulated at the beginning of every winter period by the Local Environment Council to prevent utilisation of low grade coals. In this regard, the limiting values for sulfur in the coal should be a maximum of 0.9% and 1.1% for domestic and imported coals by mass, respectively (Hepbasli, 2001).
d) The sulfur is completely converted to sulfur dioxide with a value of 1.998 kg $SO_2$ per kg S, while C is completely converted to carbon dioxide with a figure of 3.664 kg $CO_2$ per kg C (EIE, 1997).
e) The carbon contents for coal, furnace oil, and diesel oil are, in percent by mass, 60, 85, and 86, respectively (EIE, 1997).

Using the values for heating systems burning coal, fuel oil and diesel oil over the heating season (Table 4.6), the local emissions of $SO_2$ and $CO_2$ have been reduced annually by about 1143.47 and 120,483.09 tonnes/year, respectively, when geothermal energy is used instead. This represents average values per equivalent dwelling of about 40 kg of $SO_2$ and 3950 kg of $CO_2$, respectively, as shown in Table 4.7.

Table 4.7. Distribution of values for local emissions of sulfur dioxide and carbon dioxide associated with the fuel combustion

| Type of heating system | Number of dwelling equivalence, (a) | Amount of fuel used over the heating season per dewelling (from Table 5.5.), (b) | Total amount of fuel used over the heating season (tons/year) (c=ab) | Contect of S in fuel (% by mass) (d) | Tons $SO_2$/ tons S, (e) | Tons $SO_2$/ year or tons $SO_2$/ heating season, (f=cde/100) | Contect of C in fuel (% by mass) (g) | Tons $CO_2$/ tons C, (h) | Tons $CO_2$/ year or tons $CO_2$/ heating season, (i=cgh/100) |
|---|---|---|---|---|---|---|---|---|---|
| Coal-fired heating systems | 18300 | 2099.18 | 38,414.99 | 1.25 | 1.998 | 959.41 | 65 | 3.664 | 91,489.15 |
| Furnace-oil fired sytems | 12200 | 755.09 | 9,212.10 | 1 | 1.998 | 184.06 | 85.9 | 3.664 | 28,993.94 |
| Total | | | | | | 1143.47 | | | 120,483.09 |
| Average (per dwelling) | | | | | | 0.04 | | | 3.95 |

# CHAPTER FIVE
# PROJECT OF THE NARLIDERE GEOTHERMAL DISTRICT HEATING SYSTEM STAGE- 3

## 5.1 Geothermal Loop

A necessary heating energy should be calculated considering the calculation of dwelling equivalent ( Dwelling Equivalent: 100 $m^2$ =1DE) which is to be heated in district heating system ( For Izmir Province 1 dwelling equivalent = 5091 kcal/h = 5.92 kW) (IBGE Inc., 2009).

The necessity of thermal flow should be determined considering the calculated heating load and the in and out heatings of geothermal loop.

Pipe material, which is to be used for transmission of geothermal line, should be selected at optimum level considering the working conditions, the chemical structure of the water and the cost (ST 37, Rustless 317, Dublex, CTP, PPRC, Pex-a, etc.).

The diameter calculation of the pipe line, which is to be used for the transmission of jeotermal flow, should be made considering the determined methods. Here the technical properties of the pipe, which is to be chosen, should be used. ( Relative Roughness Coefficient, Internal Diameter Area, etc.)

When the design of geothermal transmission line is actualized, it should be taken into consideration that the connection point of the current geothermal loop and the condition of the reinjection place.

In the condition that there occurs a problem in the circumvolution system of the geothermal loop because of its own pressure with the heat center losses according to the necessary calculations, geothermal pump should be chosen for the system.

## 5.2 City Loop

A necessary heating energy should be calculated considering the calculation of dwelling equivalent ( Dwelling Equivalent: 100 $m^2$ = 1 DE) which is to be heated in district heating system.

Pipe material, which is to be used for transmission of city loop line, should be selected at optimum level considering the working conditions, the chemical structure of the water and the cost. (ST 37, Rustless 317, Dublex, CTP, PPRC, Pex-a, etc.)

The diameter calculation of the pipe line, which is to be used for the transmission of city loop line, should be made considering the determined methods. Here the technical properties of the pipe, which is to be chosen, should be used. ( Relative Roughness Coefficient, Internal Diameter Area, etc.)

The designer should decide how many loops he/she is going to make in the system considering the density of buildings and the conditions of the streets in the city loop line.

The critical hydraulic loop balance should be installed for each loop considering the chosen calculation method.

The pump and the exchanger should be chosen considering the critical loop calculation.

The building loads should be determined considering the loadings of the closed heating areas of the buildings that are in the loop line. The branch duct diameters, exchangers, flow control gates, calorimeters, spheral gate contamination holders should be chosen considering the determined building loads.

## 5.3 Heating Central Design

The design should be actualized considering the assembly and disassembly conditions and placing of the pumps and exchangers to the selections in the geothermal loop and the city loop line within the administrative possession area.

The heating central collector diameters and loading diameters should be decided and the the pump and exchanger dimension informations should be got from the producers.

First, two dimensional heating central should be projected considering the flowing diagram and the working of the pipes should be blocked by actualizing three dimensional design, if possible.

## 5.4 Sample Project

### *5.4.1 Introduction to Stage-3*

After the labourings with Narlıdere Municipality Housing and Urban Development Administrative, the project load of the district from the current heated area to the edge of the highway is calculated approximately according to 1,5 peer.

It is thought that the project should be actualized from the single heating central. Is planned that the heating central should be somewhere in the middle of the project. The project is planned to be actualized in two-phase, initially as of 2500-3000 dwelling equivalance because of inadequacy of the geothermal resources. It is accepted that Sema Avenue be as the frontier considering the conditions of the residential area.

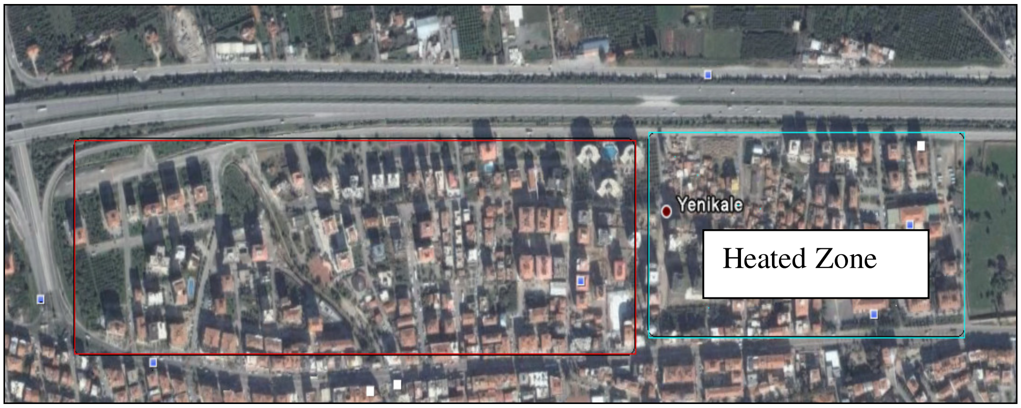

Figure 5.1 Heat center (Yenikale) of the NGDHS Stage-3 in the BNG field.

### *5.4.2 Geothermal Loop*

A branch duct is thought to be taken from Dokuz Eylül University Faculty of Fine Arts Heating Central which is the nearest geothermal transmission line.

#### *5.4.2.1 Total Peak*

1014 dwelling equivalent of the project, which is 6500 dwelling equivalent in total, is thought of to be supported by natural gas.

Table 5.1 Dwelling equivalent and total peak

| Dwelling equivalent | Total peak ( kcal/h) | Total peak (MW$_t$) |
|---|---|---|
| 5486 | 27,929,226 | 32.48 |

#### *5.4.2.2 Geothermal Flow Rate*

A necessary geothermal flow can be calculated for the total load. Q = 27,929,727 kcal/h, $\rho_{su}$ =1000 kg/m$^3$, $\Delta t$ = (120-55) = 65 $^oC$, so Flow Rate = 429, 69 m$^3$/h.

#### *5.4.2.3 Pipe Choice*

When the chemical structure of the water and a pipe choice considering the cost is evaluated, it is thought to be appropriate to use ST37 steel pipe in TSE253 standarts.

A diameter choice is done by calculating the length between GSF Heating Central and that of the new one that is to be constructed.

### 5.4.2.4 Geothermal Pump

A geothermal pump is chosen considering the transmission of the total flow to the accumulation pool that is the nearest reinjection point. As the system is planned in two-phase, the calculation is done by taking the half size of the total flow as 2 basic pumps. After determining the system characteristic (Figure 5.2) according to the changing outdoor temperatures (Table 5.3), the most efficient pumps are chosen from the manufacturer catalogues.

The general equation for calculating requirements for the pump power (*P*) is described as:

$$P = \frac{1}{\eta_g} * \gamma * Q * H_m \tag{5.1}$$

where $\eta_g$ is the overall efficiency (70%), $\gamma$ is the specific weight ($\gamma = \rho g = 1000 * 9.81 = 9810$ N/m$^3$), $Q$ is the flow rate (215 m$^3$/h), $H_m$ is the head loss (79.1 mSS), so that:

$$P = \frac{1}{0.7} * 9810 * \frac{215}{3600} * 79.1 = 66{,}203.875 \text{ W} = 66.2 \text{ kW}$$

Table 5.2 Total $H_m$ for geothermal pump

| Pipe (a) (mmSS) | Fittings (b) (mmSS) | Reinjection (c) (mmSS) | Heat center (d) (mmSS) | Coefficient of safety (e) | Total $H_m$ f=[(a+b+c+d)*e] /1000 |
|---|---|---|---|---|---|
| 12,740 | 2548 | 50,000 | 10,000 | 1.1 | 82.81 mSS |

Table 5.3 System characteristics with changing outdoor temperature

| Outdoor Temprature | T | $^{o}C$ | 14 | 12 | 10 | 8 | 6 | 4 | 2 | 1,6 |
|---|---|---|---|---|---|---|---|---|---|---|
| Head loos | $H_m$ | mss | 10 | 16 | 24 | 32 | 42 | 53 | 65 | 79 |
| Flow Rate | $Q$ | $m^3/h$ | 78 | 98 | 117 | 137 | 156 | 176 | 195 | 215 |

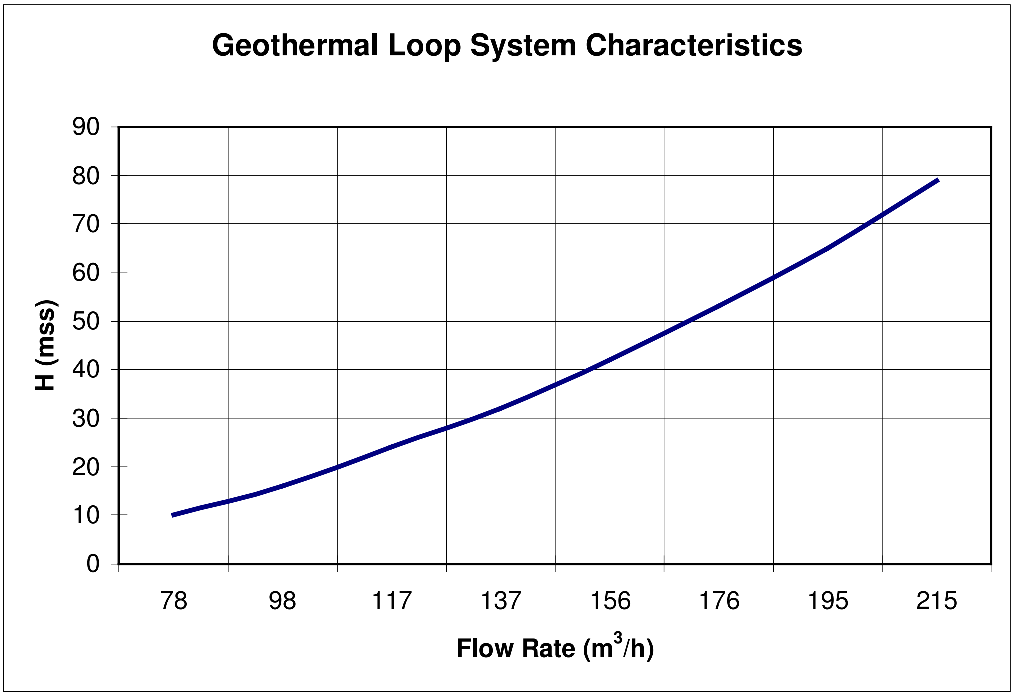

Figure 5.2 System characteristics of the geothermal pump

### *5.4.3 City Loop*

#### *5.4.3.1 Dwelling Areas*

The building loads are calculated by considering the heights and fields of the buildings that are within the first phase frontiers.

Table 5.4 Dwelling areas

| No | Node | Building Name | Building No | Area ($m^2$) | Stories | Total Area ($m^2$) | Total Peak Demand (kcal/h) | Loop |
|---|---|---|---|---|---|---|---|---|
| 1 | | | | | | | | |
| | 101 | Taninmis | 73/A | | | | | |

Table 5.4 Continued

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 102 | Taninmis | 73/B | | | | | |
| | 103 | Taninmis | 73/C | 1404 | 9 | 12636 | 643264 | K-2 |
| 2 | | | | | | | | |
| | 201 | Idea A Blok | 19-17 | 240 | 9 | 2160 | 109960 | K-2 |
| | 202 | Idea A Blok | 15-13 | 240 | 9 | 2160 | 109960 | K-2 |
| | 203 | Sevkibey | 42 | 237 | 9 | 2133 | 108585 | K-2 |
| | 204 | Bravo | 40 | 215 | 9 | 1935 | 98506 | K-2 |
| 3 | | | | | | | | |
| | 301 | Ata | 30 | 168 | 7 | 1176 | 59867 | K-2 |
| | 302 | Celik-2 | 28 | 212 | 7 | 1484 | 75546 | K-2 |
| 4 | | | | | | | | |
| | 401 | Park | | | | | | |
| 5 | | | | | | | | |
| | 501 | Hanim Sultan | 12 | 170 | 8 | 1360 | 69234 | K-2 |
| | 502 | Mustafa Bey | 10 | 213 | 8 | 1704 | 86746 | K-2 |
| | 503 | Celik-3 | 8 | 200 | 8 | 1600 | 81452 | K-2 |
| 6 | | | | | | | | |
| | 601 | Canbek | 5 | 233 | 8 | 1864 | 94891 | K-2 |
| | 602 | Cengiz | 11 | 151 | 8 | 1208 | 61496 | K-2 |
| | 603 | | | 90 | 8 | 720 | 36653 | K-2 |
| 7 | | | | | | | | |
| | 701 | Lena | 6 | 253 | 7 | 1771 | 90157 | K-2 |
| | 702 | Brova | 7 | 435 | 7 | 3045 | 155013 | K-2 |
| | 703 | Kaplan | | 275 | 7 | 1925 | 97997 | K-2 |
| | 704 | | 5 | 234 | 7 | 1638 | 83386 | K-2 |
| 8 | | | | | | | | |
| | 801 | | | 228 | 7 | 1596 | 81248 | K-2 |
| | 802 | | 158 | 114 | 5 | 570 | 29017 | K-2 |
| | 803 | | 1 | 100 | 3 | 300 | 15272 | K-2 |
| | 804 | | 3 | 100 | 2 | 200 | 10181 | K-2 |
| | 805 | | 7 | 100 | 2 | 200 | 10181 | K-2 |
| 9 | | | | | | | | |
| | 901 | | 150 | 379 | 7 | 2653 | 135057 | K-2 |
| | 902 | | 16 | 104 | 4 | 416 | 21177 | K-2 |
| | 903 | | 146 | 114 | 4 | 456 | 23214 | K-2 |
| | 904 | | 146 | 152 | 4 | 608 | 30952 | K-2 |
| | 905 | Merkez Cami | | 185 | 4 | 740 | 37671 | K-2 |
| 10 | | | | | | | | |
| | 1001 | | 142 | 207 | 6 | 1242 | 63227 | K-2 |
| | 1002 | Yilmaz | 140 | 122 | 5 | 610 | 31053 | K-2 |

Table 5.4 Continued

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 1003 | | 136 | 149 | 6 | 894 | 45511 | K-2 |
| | 1004 | Cetinkilinc | 134 | 164 | 5 | 820 | 41744 | K-2 |
| | 1005 | | 132 | 232 | 4 | 928 | 47242 | K-2 |
| | 1006 | | 128 | 97 | 4 | 388 | 19752 | K-2 |
| | 1007 | | 126 | 235 | 3 | 705 | 35890 | K-2 |
| | 1008 | | 34 | 141 | 6 | 846 | 43068 | K-2 |
| | 1009 | | 5 | 99 | 6 | 594 | 30239 | K-2 |
| | 1010 | | 3 | 85 | 6 | 510 | 25963 | K-2 |
| | 1011 | | 7 | 110 | 4 | 440 | 22399 | K-2 |
| | 1012 | | 11 | 178 | 6 | 1068 | 54369 | K-2 |
| | 1013 | | 13 | 184 | 6 | 1104 | 56202 | K-2 |
| | 1014 | | 15 | 85 | 4 | 340 | 17308 | K-2 |
| | 1015 | | | 100 | 5 | 500 | 25454 | K-2 |
| | 1016 | | 138 | 122 | 6 | 732 | 37264 | K-2 |
| | 1017 | | | 100 | 5 | 500 | 25454 | K-2 |
| | 1018 | | 120 | 70 | 2 | 140 | 7217 | K-2 |
| 11 | | | | | | | | |
| | 1101 | Park | | | | | | |
| 12 | | | | | | | | |
| | 1201 | | 41/A | 372 | 7 | 2604 | 132563 | K-2 |
| | 1202 | | 41/B | 189 | 7 | 1323 | 67350 | K-2 |
| | 1203 | | 41/C | 378 | 7 | 2646 | 134701 | K-2 |
| 13 | | | | | | | | |
| | 1301 | Sefa | 36 | 196 | 8 | 1568 | 79823 | K-2 |
| | 1302 | Naciye Hanım | 34 | 227 | 8 | 1816 | 92448 | K-2 |
| 14 | | | | | | | | |
| | 1401 | Idea B Blok | 9 | 200 | 9 | 1800 | 91633 | K-1 |
| | 1402 | Idea B Blok | 7 | 189 | 9 | 1701 | 86593 | K-1 |
| 15 | | | | | | | | |
| | 1501 | Idea E Blok | | 830 | 9 | 7470 | 380277 | K-1 |
| 16 | | | | | | | | |
| | 1601 | Idea C Blok | C-5 | 445 | 9 | 4005 | 203884 | K-1 |
| | 1602 | Idea C Blok | C-6 | 445 | 9 | 4005 | 203884 | K-1 |
| 17 | | | | | | | | |
| | 1701 | Idea C Blok | C-1 | 445 | 9 | 4005 | 203884 | K-1 |
| | 1702 | Idea C Blok | C-2 | 445 | 9 | 4005 | 203884 | K-1 |
| | 1703 | Idea C Blok | C-3 | 445 | 9 | 4005 | 203884 | K-1 |
| | 1704 | Idea C Blok | C-4 | 445 | 9 | 4005 | 203884 | K-1 |
| 18 | | | | | | | | |
| | 1801 | Park | | | | | | |
| 19 | | | | | | | | |

Table 5.4 Continued

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 1901 | Haksever | 39-13 | 235 | 5 | 1175 | 59816 | K-1 |
| | 1902 | Pot Bina | | 235 | 5 | 1175 | 59816 | K-1 |
| | 1903 | | 11 | 235 | 3 | 705 | 35890 | K-1 |
| 20 | | | | | | | | |
| | 2001 | Idea D Blok | | 400 | 10 | 4000 | 203629 | K-1 |
| | 2002 | Idea D Blok | | 560 | 10 | 5600 | 285081 | K-1 |
| 21 | | | | | | | | |
| | 2101 | Cetin Sevindi | 43 | 309 | 8 | 2472 | 125843 | K-1 |
| | 2102 | Kılıc | 41 | 212 | 9 | 1908 | 97131 | K-1 |
| | 2103 | Pot Bina | | 235 | 8 | 1880 | 95706 | K-1 |
| | 2104 | Pot Bina | | 235 | 8 | 1880 | 95706 | K-1 |
| | 2105 | Pot Bina | | 235 | 8 | 1880 | 95706 | K-1 |
| | 2106 | Pot Bina | | 235 | 8 | 1880 | 95706 | K-1 |
| 22 | | | | | | | | |
| | 2201 | Park | | | | | | |
| 23 | | | | | | | | |
| | 2301 | Idea F Blok | | 1146 | 9 | 10314 | 525058 | K-2 |
| 24 | | | | | | | | |
| | 2401 | Idea G Blok | | 300 | 10 | 3000 | 152722 | K-2 |
| | 2402 | Idea G Blok | | 480 | 10 | 4800 | 244355 | K-2 |
| 25 | | | | | | | | |
| | 2501 | | 7 | 375 | 6 | 2250 | 114541 | K-2 |
| | 2502 | | 3 | 186 | 6 | 1116 | 56813 | K-2 |
| | 2503 | Melek | 114 | 81 | 5 | 405 | 20617 | K-2 |
| | 2504 | Cuneyt | 112 | 207 | 6 | 1242 | 63227 | K-2 |
| | 2505 | Cetin Sevindi | 110 | 120 | 6 | 720 | 36653 | K-2 |
| | 2506 | Pot Bina | 116 | 120 | 6 | 720 | 36653 | K-2 |
| 26 | | | | | | | | |
| | 2601 | | 108 | 174 | 6 | 1044 | 53147 | K-2 |
| | 2602 | Gulduren | 106 | 107 | 6 | 642 | 32682 | K-2 |
| | 2603 | | 3 | 484 | 6 | 2904 | 147835 | K-2 |
| | 2604 | Ahu | 11 | 165 | 6 | 990 | 50398 | K-2 |
| | 2605 | | 12 | 119 | 6 | 714 | 3648 | K-2 |
| 27 | | | | | | | | |
| | 2701 | Aksoy | 104 | 110 | 6 | 660 | 33599 | K-2 |
| | 2702 | Necipbey | 10 | 206 | 6 | 1236 | 62921 | K-2 |
| | 2703 | | 4 | 100 | 6 | 600 | 30544 | K-2 |
| | 2704 | Koroglu | 8 | 100 | 6 | 600 | 30544 | K-2 |
| | 2705 | Pot Bina | | 120 | 6 | 720 | 36653 | |
| 28 | | | | | | | | |

Table 5.4 Continued

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 2801 | M.Seyfi Eraltay | | | | 0 | | |
| | 2802 | M.Seyfi Eraltay | | | | 0 | | |
| | 2803 | M.Seyfi Eraltay | | 401.3 | 15 | 6019.5 | 306436 | K-2 |
| 29 | | | | | | | | |
| | 2901 | Birlik | 18 | 241 | 7 | 1687 | 85881 | K-2 |
| | 2902 | Koroglu | 1 | 330 | 7 | 2310 | 117596 | K-1 |
| | 2903 | Deniz | 3 | 178 | 7 | 1246 | 63430 | K-1 |
| | 2904 | Pot Bina | | 180 | 7 | 1260 | 64143 | K-1 |
| 30 | | | | | | | | |
| | 3001 | Pınar | 2 | 278 | 7 | 1946 | 99066 | K-1 |
| | 3002 | Aksaray | 12 | 311 | 6 | 1866 | 94993 | K-2 |
| | 3003 | Derya | 4 | 195 | 8 | 1560 | 79415 | K-1 |
| | 3004 | Ozener-1 | 1 | 317 | 6 | 1902 | 96826 | K-1 |
| 31 | | | | | | | | |
| | 3101 | Erdem | 12 | 312 | 6 | 1872 | 95298 | K-1 |
| | 3102 | Kutlu | 4 | 246 | 9 | 2214 | 112709 | K-1 |
| | 3103 | Ozener-2 | 6 | 315 | 5 | 1575 | 80179 | K-1 |
| 32 | | | | | | | | |
| | 3201 | Derya | 18 | 238 | 5 | 1190 | 60580 | K-1 |
| | 3202 | Sahin | 37 | 492 | 7 | 3444 | 175325 | K-1 |
| | 3203 | Akgul | 14 | 174 | 8 | 1392 | 70863 | K-1 |
| | 3204 | Elif | 35 | 335 | 7 | 2345 | 119378 | K-1 |
| 33 | | | | | | | | |
| | 3301 | Aşık | 1 | 333 | 6 | 1998 | 101713 | K-1 |
| | 3302 | Kınacı | 3 | 342 | 9 | 3078 | 156683 | K-1 |
| | 3303 | Alp | 1 | | 8 | 0 | 0 | |
| | 3304 | Eren | 3 | 560 | 8 | 4480 | 228065 | K-1 |
| 34 | | | | | | | | |
| | | Takev | | 1965 | 3 | 5895 | 300098 | K-1 |
| 35 | | | | | | | | |
| | 3501 | Cetaş F Blok | 19 | 449 | 7 | 3143 | 160002 | K-2 |
| | 3502 | Cetaş A Blok | 1 | 392 | 6 | 2352 | 119734 | K-2 |
| | 3503 | Cetaş B Blok | 3 | 392 | 6 | 2352 | 119734 | K-2 |
| 36 | | | | | | | | |
| | 3601 | Cetaş E Blok | 15 | 367 | 8 | 2936 | 149464 | K-2 |
| | 3602 | Cetaş C Blok | 1 | 390 | 6 | 2340 | 119123 | K-2 |
| | 3603 | Cetaş D Blok | 3 | 390 | 6 | 2340 | 119123 | K-2 |
| 37 | | | | | | | | |
| | 3701 | Folkart Part-3 | | 1199.4 | 10 | 11994 | 610600 | K-1 |
| 38 | | | | | | | | |

Table 5.4 Continued

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 3801 | Folkart Part-4 | | 1013.6 | 10 | 10136 | 516000 | K-1 |
| 39 | | | | | | | | |
| | 3901 | Folkart Part-2 | | 1207.8 | 10 | 12078 | 614,890 | K-1 |
| 40 | | | | | | | | |
| | 4001 | Folkart Part-1 | | 2027.1 | 10 | 20271 | 1,032,000 | K-1 |
| | | | | | | | | |
| Total | | | | | | 284,030.5 | 14,426,718 | |

### *5.4.3.2 Hydraulic Considerations*

Is decided that the hydraulic balance will be installed as a two loop considering the building dispersion and load density. Two outputs ( blue and magenta ) from the heating central is decided to be actualized in the method that is shown in digital map.

The buildings are added to the balance calculation page beginning from the end of line for each critical loop and the critical loop hydraulic calculation is done.

Table 5.5 Total area and total peak for each loop

| Loop | Number of apartment | Total area ($m^2$) | Total peak (kcal/h) | Total peak ($MW_t$) |
|---|---|---|---|---|
| K-1 | 41 | 153,742.0 | 7,826,694 | 9.10 |
| K-2 | 77 | 130,288.5 | 6,600,024 | 7.68 |
| Total | 118 | 284,030.5 | 14,426,718 | 16.78 |

Figure 5.3 City loop line of the NGDHS Stage-3 (IBGE Inc.,2009).

### *5.4.3.3 Circulation Pumps*

After pressure lost calculation is done for each critical loop, closed loop circulation pump selection is done.

*5.4.3.3.1 K-1 Loop.* After determining the system characteristic (Figure 5.4) according to the changing outdoor temperatures (Table 5.7), the most efficient pumps are chosen from the manufacturer catalogues. Pump power is calculated using equal (5.1), so that:

$$P = \frac{1}{0.7} * 9810 * \frac{237}{3600} * 55 = 50{,}743.393 \text{ W} = 50.7 \text{ kW}$$

*5.4.3.3.2 K-2 Loop.* After determining the system characteristic (Figure 5.5) according to the changing outdoor temperatures (Table 5.9), the most efficient pumps are chosen from the manufacturer catalogues. Pump power is calculated using equal (5.1), so that:

$$P = \frac{1}{0.7} * 9810 * \frac{202}{3600} * 51 = 40{,}104.214 \text{ W} = 40.1 \text{ kW}$$

Table 5.6 Total $H_m$ for circulation pump of K- 1 loop

| Pipe (a) (mmSS) | Fittings (b) (mmSS) | Reinjection (c) (mmSS) | Heat center (d) (mmSS) | Coefficient of safety (e) | Total f=[(a+b+c+d)*e] /1000 |
|---|---|---|---|---|---|
| 21,000 | 4000 | 5000 | 20,000 | 1.1 | 55 mSS |

Table 5.7 System characteristics with changing outdoor temperature

| Outdoor Temprature | T | $^{o}$C | 14 | 12 | 10 | 8 | 6 | 4 | 2 | 1,6 |
|---|---|---|---|---|---|---|---|---|---|---|
| Head loos | Hm | mss | 10 | 14 | 19 | 25 | 31 | 37 | 45 | 55 |
| Flow Rate | Q | $m^3$/h | 86 | 108 | 129 | 151 | 172 | 194 | 215 | 237 |

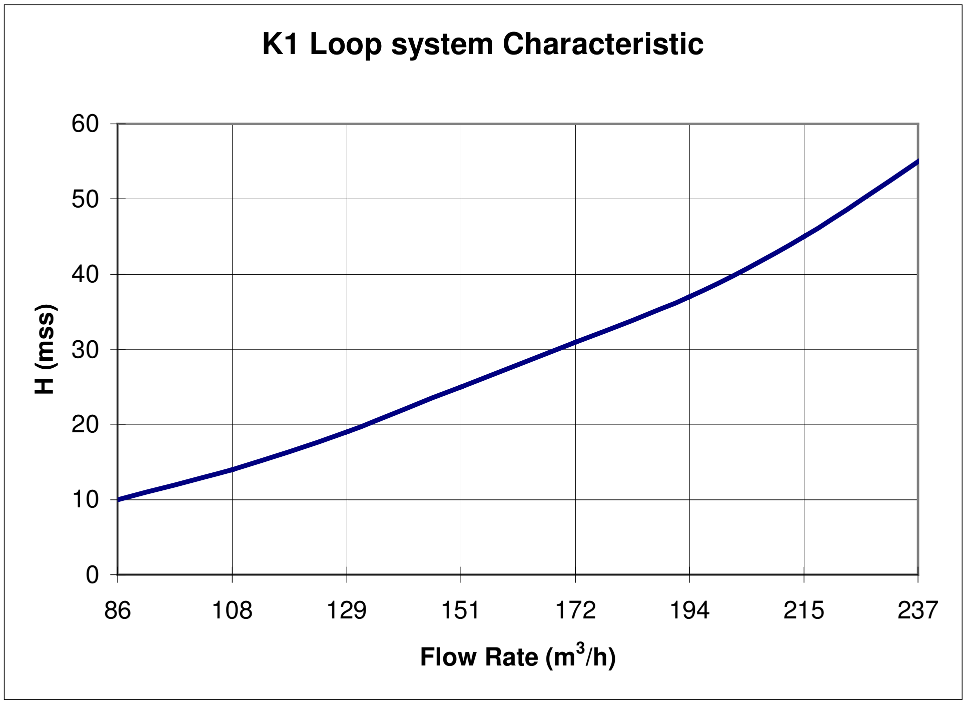

Figure 5.4 System Characteristics of the circulation pump in the pumping station (K-1 loop)

Table 5.8 Total $H_m$ for circulation pump of K- 2 loop

| Pipe (a) (mmSS) | Fittings (b) (mmSS) | Building loop (c) (mmSS) | Heat center (d) (mmSS) | Coefficient of safety (e) | Total f=[(a+b+c+d)*e] /1000 |
|---|---|---|---|---|---|
| 17,790 | 3558 | 5000 | 20,000 | 1.1 | 51 mSS |

Table 5.9 System characteristics with changing outdoor temperature

| Outdoor Temprature | T | °C | 14 | 12 | 10 | 8 | 6 | 4 | 2 | 1,6 |
|---|---|---|---|---|---|---|---|---|---|---|
| Head loos | Hm | mss | 7 | 11 | 15 | 21 | 27 | 34 | 42 | 51 |
| Flow Rate | Q | $m^3/h$ | 73 | 92 | 110 | 128 | 147 | 165 | 183 | 202 |

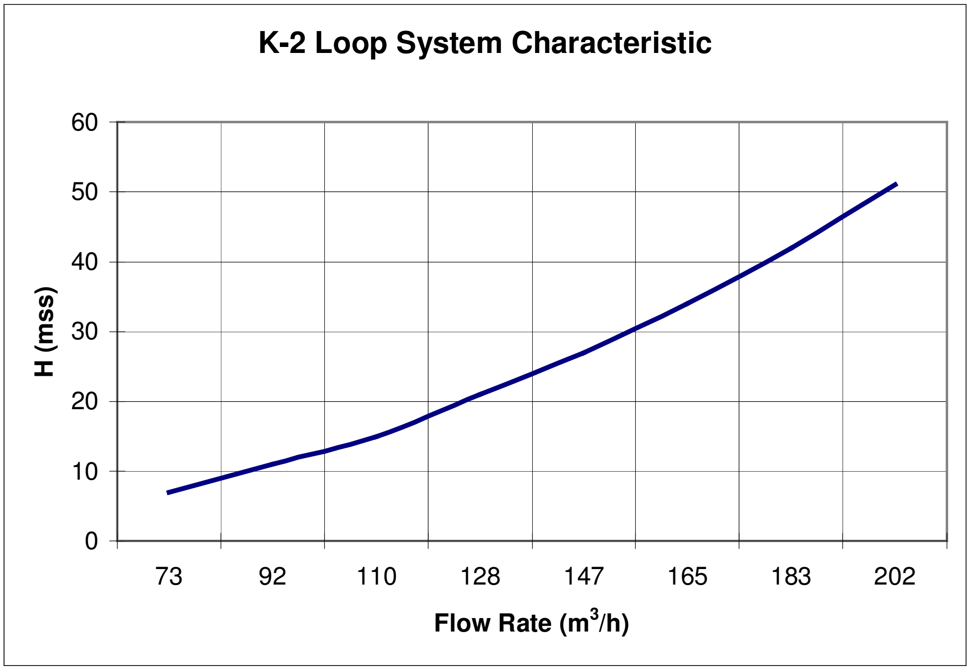

Figure 5.5 System Characteristics of the circulation pump in the pumping station (K-2 loop).

### *5.4.3.4 Expansion Tanks*

An expansion tank selection is done for each critical loop. The general equation for expansion tank for the system ($V_n$) is described as:

$$V_n = (V_e + V_v)\frac{P_e + 1}{P_e - P_o} \tag{5.3}$$

where $V_n$ is the volume of expansion tank , $V_e$ is the volume by which water contents expands (2061 lt), $V_v$ is the total water volume in the installation (358.73 lt), $P_e$ is the max. absolute pressure that can be applied to the system (4.5 bar), $P_o$ is the absolute static pressure of the water in installation ( 1 bar), so that:

$$V_n = (2061 + 358.73)\frac{5.5}{3.5} = 3802.43 \text{ lt}$$

The closer tank volume bigger than this value and expansion tank is chosen capacity of 5000 lt.

### *5.4.3.5 Heat Exchangers*

Plate heat exchangers (PHEs) are an important part of a geothermal heating system.

*5.4.3.5.1 Overall Heat Transfer Coefficient.* The overall heat transfer coefficient is:

$$K = \left( \frac{1}{\alpha_1} + R_{s1} + \frac{\delta}{\lambda} + R_{s2} + \frac{1}{\alpha_2} \right)^{-1} \tag{5.4}$$

where $\alpha_1$ is the heat transfer coefficient between the warm medium and the heat transfer surface in W / m$^2$ ºC, $\alpha_2$ is the heat transfer coefficient between the heat transfer surface and the cold medium in W / m$^2$ ºC, $R_{s1}$ and $R_{s2}$ is the fouling factor in m$^2$ ºC / W, $\lambda$ is the thermal conductivity of the unit PHE in W / m ºC, and $\delta$ is the thickness of the unit PHE in m. In geothermal heating systems , K is in practice always about 2900-4650 (m$^2$ ºC / W).

*5.4.3.5.2 Heat Transfer Equation.* The heat transfer equation is described as :

$$Q = \mathrm{K} * \mathrm{A} * \Delta t_m \tag{5.5}$$

For a single phase fluid: $Q = q_m * C_p * (t_{in} - t_{out})$, where A is area of heat transfer (m$^2$), $\Delta t_m$ is the Logarithmic Mean Temperature Difference LMTD (ºC), $q_m$ is flow rate (kg/s), $C_p$ is specific heat (kJ/kgºC), $t_{in}$ is inlet flow temperature, and $t_{out}$ is outlet flow temperature.

The LMTD is the effective driving force in the heat exchangers. The LMTD relates to the flow and temperature parameters. These parameters influence the cost of equipment. LMTD in practice a is always taken as 1.1-1.3 in geothermal heating systems (Zhu & Zhang, 2004).

*5.4.3.5.3 Calculation of Pressure Drop.* According to the relation Eu = $b\mathrm{Re}^d\, m$ and Eu = $\Delta p/(\rho w^2)$, the pressure drop when the heated fluid passes through the system can be calculated as:

$$\Delta p = b\mathrm{Re}^d\, m\rho w^2 \tag{5.6}$$

where Eu is the Euler number, $w$ is fluid velocity (m/s), $m$ is the flow path, $\rho$ is fluid density (kg/m$^3$), Re is the Reynold's number, and $b$ and $d$ are constants associated with the model of PHEs and can be found in the product manuel (Zhu & Zhang, 2004).

*5.4.3.5.4 Materials Selection.* Titanium has a very low rate of corrosion in high chloride concentrations. It is selected as the ideal material for extending the lifespan of the system despite it being so expensive for heat exchangers (IBGE Inc, 2009).

*5.4.3.5.5 Plate Arrangements.* There are two arrangements of plates, lambdoidal and straight. The operating pressure of the lambdoidal ararngement can exceed 1.0 MPa (Yang, 1995), and that of the straight model is about 1.0 MPa. In addition, the heat coefficient and pressure drop of the lambdoidal arrangement are higher than that of the straight model. The lambdoidal arrangement is often used in geothermal heating systems (Zhu & Zhang, 2004).

*5.4.3.5.6 Plate Size.* The holes in the plate are related to plate size. In order to attain a high efficiency, the flow velocity in the holes is generally set at about 6 m/s. However, if this is too small, the number of flow paths should be increased so that the pressure drop increases. On the other hand, if they are too big, the flow velocity in the holes is unable to reach the required value, and the heat transfer coefficient will be too low. Taking into account factors such as flow rate, flow velocity and pressure drop, there are several plate sizes suited to a geothermal heating system only, through optimization, such as 0.5, 0.8, 1.0 m$^2$; these will depend on heat demand, utilization requirements, and economic factors.

*5.4.3.5.7 Flow Velocity.* Flow velocity may influence both heat transfer efficiency and pressure drop. A high flow velocity can produce too high a heat transfer coefficient and pressure drop. This occurs with a velocity range of 0.2-0.8 m/s in the system.

*5.4.3.5.8. Flow Paths.* If the flow rates on the hot and cold sides are approximately equal, the PHEs should be designed as symmetrical exchangers. In a geothermal heating system, equivalent flow path PHEs are always used, because this produces a counter-current flow.

*5.4.3.5.9 Other Parameters.* Based on the dimensions of the heat exchangers and its other parameters, the heat transfer area ($A_e$) and the number of heat exchangers ($T$) can be estimated as:

$$A_e = \frac{Q}{K_i * \Delta t_m} \tag{5.7}$$

where $K_i$ is the experimental value for the overall heat transfer coefficient (2900-4650 W/m$^2$ °C).

$$T = \frac{A_e}{A_0 * N} \tag{5.8}$$

where $A_0$ is a single plate size (m$^2$) and $N$ is the number of plates per heat exchangers.

By applying $A_e$ and $T$, the placement, flow path ($m$) and channels ($n$) of each flow path can be determined. So the flow velocity ($w$) and the heat transfer coefficient ($\alpha$) can be given as:

$$w = \frac{q_m}{N_z * A_s * \rho * n} \tag{5.9}$$

where $N_z$ represents the number of paralel connection groups, $A_s$ is flow crossection (m$^2$) and $n$ is the number of flow channels.

$$\alpha = \frac{Nu * \lambda}{d_e} \tag{5.10}$$

where $\lambda$ is the thermal conductivity of metal, $d_e$ is equivalent diameter (m), and $Nu$ is the Nusselt number.

Then, considering the fouling factor and contact resistance, the overall heat transfer coefficient ($K$) and the heat load of the exchanger ($Q_1$) can be calculated. Comparing $Q$ and $Q_1$, if heat requirements are satisfactory, we can examine the pressure drop. Through Eq. (5.11):

$$\Delta p = N_t * m * Eu * w^2 * \rho \tag{5.11}$$

where $N_t$ is the number of exchaangers in each group.

If the pressure drop is within the permitted range, then this step in the design has been completed. In This conditions, two heat exchangers, which each critical loop total load is 8,000,000 kcal/h (9.3 MW$_t$) for 14,426,718 kcal/h (16.78 MW$_t$) (Table 5.5), are chosen (IBGE Inc., 2010).

### *5.4.3.6 Materials Selection*

The estimate is developed by ascertaining the pipe size calculated in consequence of critical loop balance, the exchanger diameter, the line holders that are placed appropriately, the branch duct gates, the external pressured compensators, the numbers of sub-building equipments, the excursion amount in accordance with pipe lengths, the sand, stabilized equipments, and those of the numbers of other equipments. The prosperity unit prices and the proposals from the manufacturing companies are used when transmitting from estimate amount to that of the approximate cost.

### *5.4.4 Heating Central Design*

A flow diagram is done taking the selected pump and exchangers into consideration and figuring out also that of the second phase -6500 DE, a residential and architectural project work is actualized considering the electricity room, the operator room, the dressing room and the toilets.

A residential plan is developed by placing equipments equipments on the architectural work.

3 dimensional residential work is developed considering the residential work.

The estimate is completed and the project is developed to be actualized by an electricity need list and the construction estimate lengths to be added to the approximate cost.

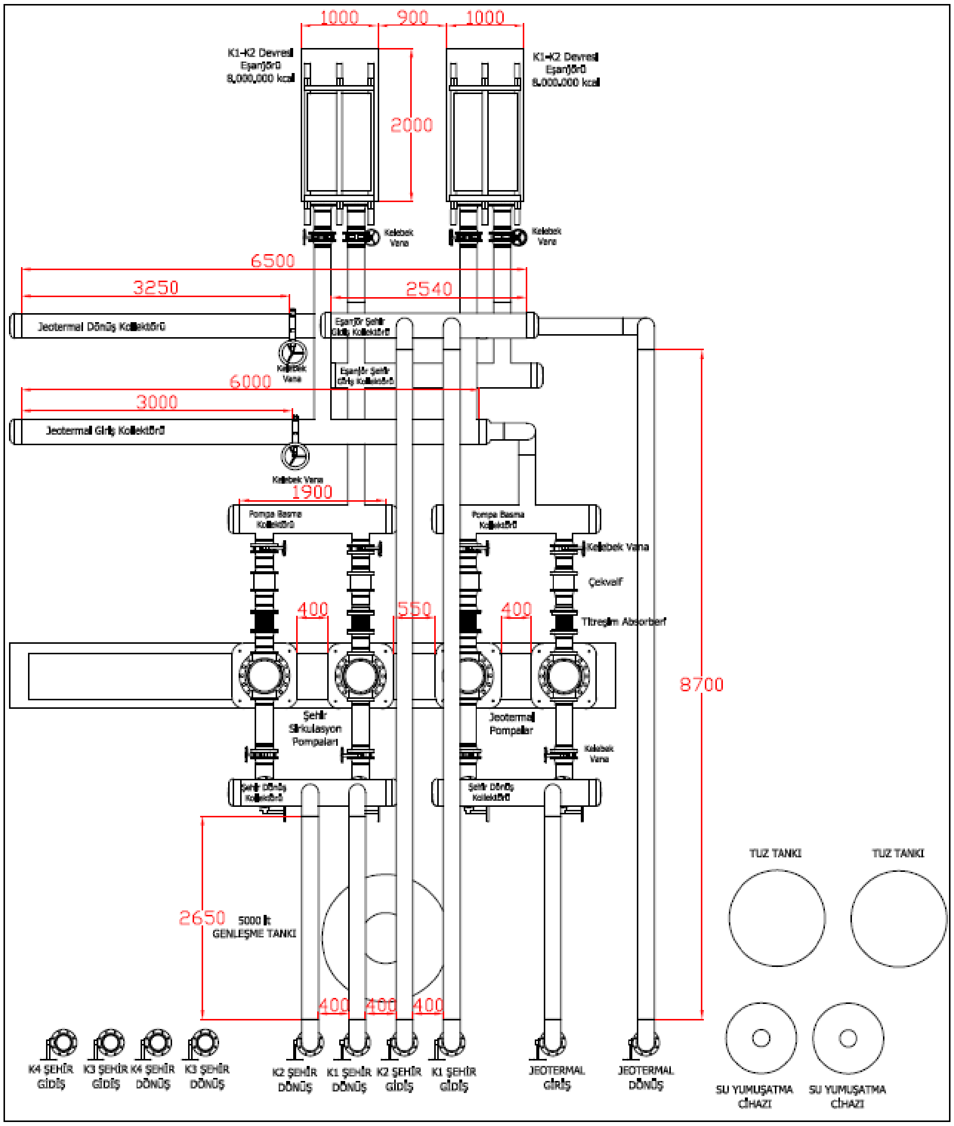

Figure 5.9 Residential plan of Yenikale heat center (IBGE Inc., 2009).

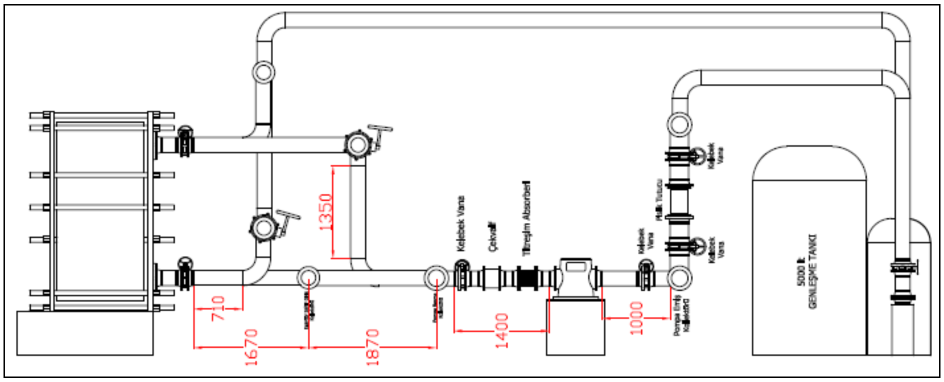

Figure 5.10 Residential plan of Yenikale heat center (IBGE Inc., 2009).

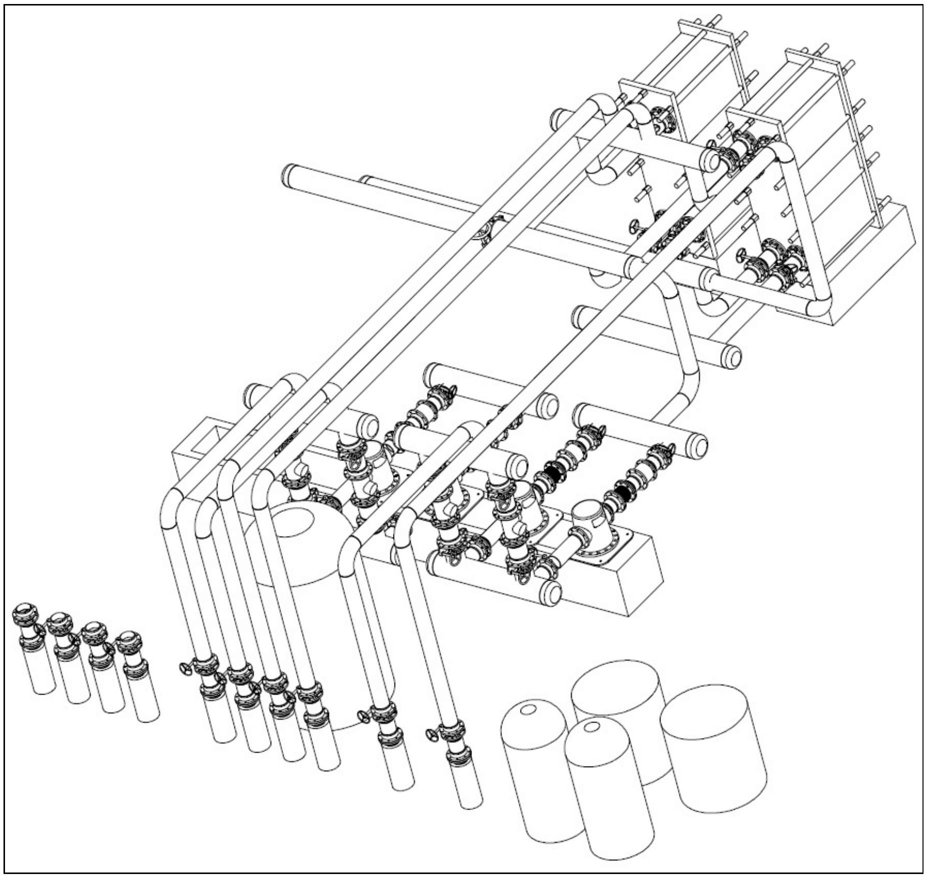

Figure 5.11 Yenikale heat cenral design in the BNG field (IBGE Inc., 2009)

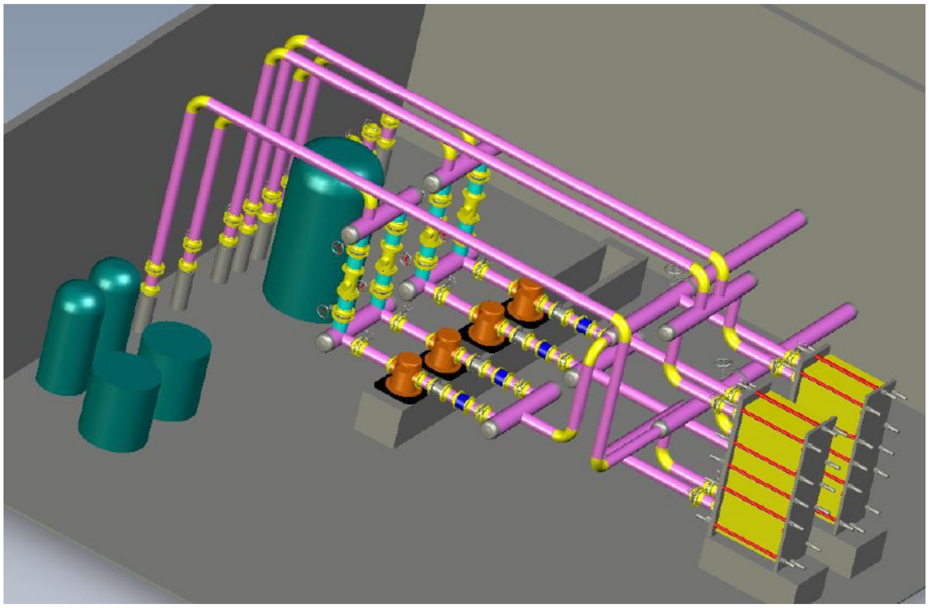

Figure 5.12 Yenikale heat central design (3D) of NGDHS Stage-3 (IBGE Inc., 2009).

# CHAPTER SIX
# CONCLUSIONS

Results about geothermal energy in Turkey;

- The present (2010) installed geothermal power generation capacity in Turkey is about 100 $MW_e$, while that of direct use installations is around 967.3 $MW_t$.

- Heating greenhouses using geothermal fluids has grown very fast during the last decade. Much larger projects could be on the way, especially considering that major greenhouse developers are already exporting their products.

- Turkey is used a geothermal energy resources law finally in June/2007, and the law was enacted a year later in June/2008.

Results about the Balçova-Narlidere geothemal field;

- As of April 2010, the number subscribers to the BGDHS had reached 30,500 equivalent dwellings and heated space area reaches a total of 2.45 million $m^2$.

- As of April 2010, there were 18 wells ranging in depth from 48 to 1100 m in the BNG field. Of these, 15 wells (designated as BD1, BD2, BD3, BD4, BD5, BD7, BD9, BD11, BD12, B1, B4, B5, B7 and B10) and two well (BD8 and BD10) are production and reinjection wells, respectively. Here, BDs stand for deep wells and Bs stand for shallow wells. The temperatures of the production wells vary from 95 to 140 ºC, while the flow rates of the wells range from 70 to 300 $m^3/h$, respectively.

- The area is heavily populated, all activities related to drilling are done under very difficult conditions. In 2007, blowouts occurred while wells BD11 and BD12 were being drilled, but neither the nearby houses nor their inhabitants were hurt.

- The 3D models of the field (Fig. 4.17) show that the temperature decreases rapidly toward the north, away from the Agamemnon fault, and increases toward the east, confirming results of geophysical surveys conducted in the north. Based on that temperature distribution, wells BD8, BD9, BD11 and BD12 were sited. These four wells are the hottest and most productive wells in the field at this time (November 2007) and confirmed that that the highest temperatures are in the eastern part of the field.

- An automatic control system is seriously updated for the Balçova-Narlıdere District Heating System. If this can not be setup due to any reason, at least according to the changing outdoor temperature, an operational control strategy should be developed and applied in the earliest heating season.

- Geothermal district heating systems require relatively high initial investments, but their operation and maintenance costs are low compared to fossil fuel-driven systems (Table 4.6). The geothermal based heating fee was fixed to be 71 Turkish Lira (about 47.34 US$) per month for the heating season 2009-2010 by Izmir Balçova Geothermal Energy Inc. (2010). To reduce GDHS costs, remote-controlled energy or flowmeters should be installed at every dwelling. These meters could be monitored using real-time data acquisition systems. The information that is collected could be used to study the operation of the GDHS, and to reduce the number of personnel needed to monitor the system, bill customers, update databases, etc.

- Until recently, the U.S. 2000-3000 $ collected from each subscriber was used to finance part of the geothermal district heating projects; additional monies came fromlocal government subsidies. The situation has changed completely and nowfroman economical point of viewthere is no reason to subscribe to a geothermal district heating system; it is cheaper to use natural gas. Moreover, the distribution network in a geothermal district heating systemis much more complex, bothersome and costly that a natural gas distribution network. A liberalized market resulted in competitive natural gas prices for industrial uses and for heating. It is very cheap to connect gas to houses. At the beginning the connection chargewas only U.S. 180 $.

- The local emissions of $SO_2$ and $CO_2$ have been reduced annually by about 1143.47 and 120,483.09 tonnes/year, respectively, when geothermal energy is used instead. This represents average values per equivalent dwelling of about 40 kg of $SO_2$ and 3950 kg of $CO_2$, respectively, as shown in Table 4.7.

- The district heating system at Balçova-Narlidere geothermal feild shows that geothermal energy is not only cheaper, but also cleaner than fossil fuels. A countrywide database for Turkey should be set up to monitor the advantages of geothermal district heating systems in the long-term. The number of geothermal direct applications is expected to increase significantly in Turkey once geothermal laws and regulations have been ratified.

- District heating projects has been stalled for the following reasons: (1) no geothermal resource close to towns available anymore, (2) hard competition from natural gas industry despite high natural gas costs, (3) disappointments with geothermal district heating systems because of lack of heat supply in some of them and (4) weak economics of such projects due to high heating costs.

Results about project of the NGDHS Stage-3;

- NGDHS Stage-3 which has a dwelling area of 14,426,718 $m^2$ and total peak demand need for this system design is 16.78 $MW_t$.

- It is thought that the project should be actualized from the single heating central. Is planned that the heating central should be somewhere in the middle of the project. The project is planned to be actualized in two-phase, initially as of 2500-3000 Dwelling Equivalance because of inadequacy of the geothermal resources. It is accepted that Sema Avenue be as the frontier considering the conditions of the residential area.

- A branch duct is thought to be taken from Dokuz Eylül University Faculty of Fine Arts Heating Central which is the nearest geothermal transmission line. 1014 dwelling equivalent of the project, which is 6500 dwelling equivalent in total, is thought of to be supported by natural gas.

- Each building situated in stage-3 is specified one by one and the total peak field and the total peak load are deducted and 3D design of the heating system is worked on (Table 5.4).

- Titanium has a very low rate of corrosion in high chloride concentrations. It is selected as the ideal material for extending the lifespan of the system despite it being so expensive for heat exchangers.

- NGDHS Stage-3 was connected to the system in 2008-2009 winter season.

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